

## BACHELORS DEGREE ASSIGNMENT SPECIFICATION

|                   |                                           |                                                |             |
|-------------------|-------------------------------------------|------------------------------------------------|-------------|
| Student name:     | STUBBINGS                                 | Student P number:                              |             |
| Programme:        | BEng Automotive and Manufacturing streams |                                                |             |
| Module:           | Advanced Stress Analysis & FEA            | Module Level (4, 5, 6):                        | 6           |
| Module code:      | M6X00420                                  | Contribution to Overall Module Assessment (%): | 50 %        |
| Lecturer:         | Kelvin Lake                               | Internal Verifier:                             | Rob Goodson |
| Assignment Title: | Can FEA replace physical testing?         | Assignment No (x of x):                        | 1 OF 1      |
| Hand Out Date:    | 25/02/2020                                | Submission deadline:                           | 29/03/2020  |

|                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                         |       |     |
|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------|-----|
| Referencing:                                                                                                                                                                                                                                                                                                                                                                             | In the main body of your submission you must give credit to authors on whose research your work is based. Append to your submission a reference list that indicates the books, articles, etc. that you have read or quoted in order to complete this assignment (e.g. for books: surname of author and initials, year of publication, <u>title of book</u> , edition, publisher: place of publication). |       |     |
| Disclosure:                                                                                                                                                                                                                                                                                                                                                                              | I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people. All references have been duly cited.                                                                                                                                                                                                         |       |     |
| Student's Signature:                                                                                                                                                                                                                                                                                                                                                                     | Assignments will not be accepted without a signature here                                                                                                                                                                                                                                                                                                                                               | Date: |     |
| Turnitin: Lecturer to tick to indicate if an electronic version of the assignment must be submitted to Turnitin. Note: the Turnitin version is the primary submission and acts as a receipt for the student. Penalties for late submission: Up to four weeks late, maximum mark of 40%. Over four weeks late, Refer. Only Year Tutors and the Programme Director may grant an extension. |                                                                                                                                                                                                                                                                                                                                                                                                         |       | YES |
|                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                         |       | ✓   |
|                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                         |       | NO  |
|                                                                                                                                                                                                                                                                                                                                                                                          |                                                                                                                                                                                                                                                                                                                                                                                                         |       |     |

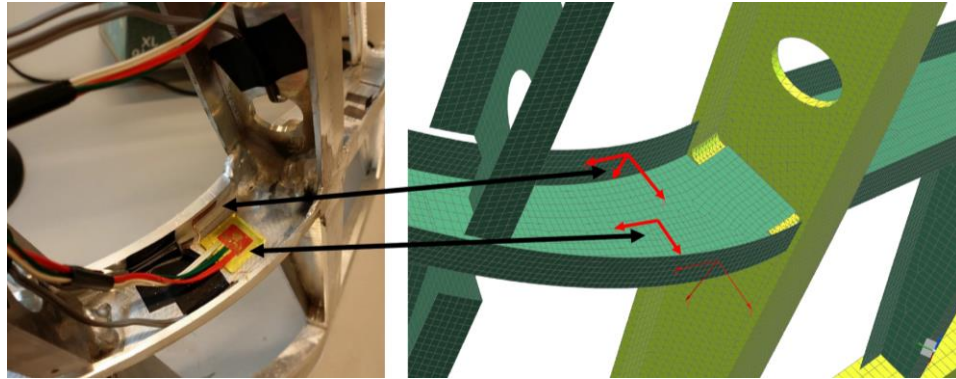
| Learning Outcomes tested (from module syllabus)                                                              | Assessment Criteria To achieve each outcome a student must demonstrate the ability to: |
|--------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles. |                                                                                        |

- DO NOT put this form into Turnitin or it will match many similarities with other students' submissions.

## TASK DESCRIPTION

This assignment explores FEA and the role that it plays in product development. It is expected that the student will research this topic (referencing any sources used, using Harvard or Vancouver).

## GUIDANCE FOR STUDENTS IN THE COMPLETION OF TASKS



The above image shows a component undergoing physical testing and the corresponding FE model. Your task for this assignment is to discuss the following;

1. Why companies typically carryout FE analysis alongside physical testing.
2. How a physical test may be correlated to an FE model.
3. If you think that FE analysis can (or should) ever replace physical testing.

In order to do this, you should consider a case study and use this to discuss the above tasks.

This report should be 3000 words long and should be submitted via moodle

## STRUCTURAL SECTION MARKING CRITERIA AND STUDENT FEEDBACK

This section details the assessment criteria. The *extent* to which these are demonstrated by you determines your mark. The marks available for each criterion are shown. Lecturers will use the space provided to comment on the achievement of the task(s), including those areas in which you have performed well and areas that would benefit from development/improvement.

| Common Assessment Criteria Applied                                                                                                                                                                     | Marks available | Marks awarded |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------------|
| <b>1. Research-informed Literature</b><br>Extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions.                                    |                 |               |
| (Assessed in point 1)                                                                                                                                                                                  | 30              | 20.4          |
| <b>2. Knowledge and Understanding of Subject</b><br>Extent of knowledge and understanding of concepts and underlying principles associated with the discipline.                                        |                 |               |
| (Assessed in point 2)                                                                                                                                                                                  | 30              | 19.5          |
| <b>3. Analysis</b><br>Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence                                                     |                 |               |
| (N/A)                                                                                                                                                                                                  | 0               |               |
| <b>4. Practical Application and Deployment</b><br>Deployment of methods, materials, tools and techniques; application of concepts; formulation of innovative and creative solutions to solve problems. |                 |               |
| (Assessed in point 3)                                                                                                                                                                                  | 30              | 20.1          |
| <b>5. Skills for Professional Practice</b><br>Attributes in professional practice: individual and collaborative working; deployment of appropriate media; presentation and organisation.               |                 |               |
| (Assessed in report presentation and structure)                                                                                                                                                        | 10              | 6.8           |

|                                                                                                                                                                                                                   |                                                        |  |        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|--|--------|
| <b>Assignment Mark Overall</b> (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.) | <b>Late Submission Penalties (tick if appropriate)</b> |  | 66.8 % |
|                                                                                                                                                                                                                   | Up to one-week late                                    |  |        |
|                                                                                                                                                                                                                   | Over one week late                                     |  |        |

# COMMON ASSESSMENT AND MARKING CRITERIA

|                                                                                                                                                                                                                                                                                                              | OUTRIGHT FAIL                                                                                                                                                                                    | UNSATISFACTORY                                                                                                                                                                                                         | SATISFACTORY                                                                                                                                                                                                                                                   | GOOD                                                                                                                                                                                                                                                                                     | VERY GOOD                                                                                                                                                                                                                                                                                                      | EXCELLENT                                                                                                                                                                                                                                                                                            | EXCEPTIONAL                                                                                                                                                                                                                                                                    |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Assessment Criteria                                                                                                                                                                                                                                                                                          | 0-29%                                                                                                                                                                                            | 30-39%*                                                                                                                                                                                                                | 40-49%                                                                                                                                                                                                                                                         | 50-59%                                                                                                                                                                                                                                                                                   | 60-69%                                                                                                                                                                                                                                                                                                         | 70-79%                                                                                                                                                                                                                                                                                               | 80-100%                                                                                                                                                                                                                                                                        |
| <b>1. Research-informed Literature</b><br>Extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions                                                                                                                                           | Little or no evidence of reading. Views and findings unsupported and non-authoritative. Referencing conventions largely ignored.                                                                 | Poor evidence of reading and/or of reliance on inappropriate sources, and/or indiscriminate use of sources. Referencing conventions used inconsistently.                                                               | References to a limited range of mostly relevant sources. Some omissions and minor errors. Referencing conventions evident though not always applied consistently.                                                                                             | Inclusion of a range of research-informed literature, including sources retrieved independently. Referencing conventions mostly consistently applied.                                                                                                                                    | Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied.                                                                                              | A comprehensive range of research informed literature embedded in the work. Excellent selection of relevant and credible sources. High-level referencing skills, consistently applied.                                                                                                               | Outstanding knowledge of research-informed literature embedded in the work. Outstanding selection of relevant and credible sources. High-level referencing skills consistently and professionally applied.                                                                     |
| <b>2. Knowledge and Understanding of Subject</b><br>Extent of knowledge and understanding of concepts and underlying principles associated with the discipline.                                                                                                                                              | Major gaps in knowledge and understanding of material at this level. Substantial inaccuracies.                                                                                                   | Gaps in knowledge, with only superficial understanding. Some significant inaccuracies.                                                                                                                                 | Evidence of basic knowledge and understanding of the relevant concepts and underlying principles.                                                                                                                                                              | Knowledge is accurate with a good understanding of the field of study.                                                                                                                                                                                                                   | Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.                                                                                                                                                                                                                  | Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.                                                                                                                           | Highly detailed knowledge and understanding of the main theories/concepts, and a critical awareness of the ambiguities and limitations of knowledge.                                                                                                                           |
| <b>3. Analysis</b><br>Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence                                                                                                                                                           | Unsubstantiated generalisations, made without use of any credible evidence. Lack of logic, leading to unsupportable/missing conclusions. Lack of any attempt to analyse, synthesise or evaluate. | Some evidence of analytical intellectual skills, but for the most part descriptive. Ideas/findings sometimes illogical and contradictory. Generalised statements made with scant evidence. Conclusions lack relevance. | Evidence of some logical, analytical thinking and some attempts to synthesise, albeit with some weaknesses. Some evidence to support findings/ views, but evidence not consistently interpreted. Some relevant conclusions and recommendations, where relevant | Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances and ability to use evidence to support the argument. Valid conclusions and recommendations, where relevant | Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity & significance of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions / recommendations. | Thoroughly logical work, supported by evaluated evidence. High quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions, justifiable recommendations. | Exceptional work; judiciously selected and evaluated evidence. Very high quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Highly persuasive conclusions |
| <b>4. Practical Application and Deployment</b><br>Effective deployment of appropriate methods, materials, tools and techniques; extent of skill demonstrated in the application of concepts to a variety of processes and/or contexts; formulation of innovative and creative solutions to solve problems.   | Limited or no use of methods, materials, tools and/or techniques. Little or no appreciation of the context of the application.                                                                   | Rudimentary application of methods, materials, tools and/or techniques but without consideration and competence. Flawed appreciation of the context of the application.                                                | An adequate awareness and mostly appropriate application of well established methods, materials, tools and/or techniques. Basic appreciation of the context of the application.                                                                                | A good and appropriate application of standard methods, materials, tools and/or techniques. Good appreciation of the context of the application, with some use of examples, where relevant.                                                                                              | A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.                                                                     | An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, with extensive use of relevant examples. Application and deployment extend beyond established conventions. Innovation and creativity evident throughout.       | Outstanding levels of application and deployment skills. Assimilation and development of cutting edge processes and techniques.                                                                                                                                                |
| <b>5. Skills for Professional Practice</b><br>Demonstrates attributes expected in professional practice including: individual initiative and collaborative working; deployment of appropriate media to communicate (including written and oral); clarity and effectiveness in presentation and organisation. | Communication media is inappropriate or misapplied. Little or no evidence of autonomy in the completion of tasks. Work is poorly structured and/or largely incoherent.                           | Media is poorly designed and/or not suitable for the audience. Poor independent or collaborative initiative. Work lacks structure, organisation, and/or coherence                                                      | Can communicate in a suitable format but with some room for improvement. Can work as part of a team, but with limited involvement in group activities. Work lacks coherence in places and could be better structured.                                          | Can communicate effectively in a suitable format, but may have minor errors. Can work effectively as part of a team, with clear contribution to group activities. Mostly coherent work and is in a suitable structure.                                                                   | Can communicate well, confidently and consistently in a suitable format. Can work very well as part of a team, with very good contribution to group activities. Work is coherent and fluent and is well structured and organised.                                                                              | Can communicate professionally and, confidently in a suitable format. Can work professionally within a team, showing leadership skills as appropriate, managing conflict and meeting obligations. Work is coherent, very fluent and is presented professionally.                                     | Can communicate with an exceptionally high level of professionalism. Can work exceptionally well and professionally within a team, showing advanced leadership skills. Work is exceptionally coherent, very fluent and is presented professionally.                            |

# Student Self Evaluation Form

|                   |  |                   |  |
|-------------------|--|-------------------|--|
| Student name:     |  | Student P number: |  |
| Programme:        |  | Year of programme |  |
| Assignment Title: |  |                   |  |

This section repeats in brief the common assessment criteria detailed on previous pages. The *extent* to which these are demonstrated by you determines your mark. Using these criteria, tick the box that best indicates the level of achievement you feel you have achieved with regard to each of them.

| Common Assessment Criteria Applied        | Level of Achievement              |                                    |                                    |                                    |                                    |                                    |                                     |
|-------------------------------------------|-----------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|-------------------------------------|
|                                           | REFER                             |                                    | 3 <sup>rd</sup>                    | 2:2                                | 2:1                                | 1 <sup>st</sup>                    | 1 <sup>st</sup>                     |
|                                           | OUTRIGHT FAIL                     | UNSATISFACTORY                     | SATISFACTORY                       | GOOD                               | VERY GOOD                          | EXCELLENT                          | EXCEPTIONAL                         |
| 1. Research-informed Literature           | 0-29%<br><input type="checkbox"/> | 30-39%<br><input type="checkbox"/> | 40-49%<br><input type="checkbox"/> | 50-59%<br><input type="checkbox"/> | 60-69%<br><input type="checkbox"/> | 70-79%<br><input type="checkbox"/> | 80-100%<br><input type="checkbox"/> |
| 2. Knowledge and Understanding of Subject | 0-29%<br><input type="checkbox"/> | 30-39%<br><input type="checkbox"/> | 40-49%<br><input type="checkbox"/> | 50-59%<br><input type="checkbox"/> | 60-69%<br><input type="checkbox"/> | 70-79%<br><input type="checkbox"/> | 80-100%<br><input type="checkbox"/> |
| 3. Analysis                               | 0-29%<br><input type="checkbox"/> | 30-39%<br><input type="checkbox"/> | 40-49%<br><input type="checkbox"/> | 50-59%<br><input type="checkbox"/> | 60-69%<br><input type="checkbox"/> | 70-79%<br><input type="checkbox"/> | 80-100%<br><input type="checkbox"/> |
| 4. Practical Application and Deployment   | 0-29%<br><input type="checkbox"/> | 30-39%<br><input type="checkbox"/> | 40-49%<br><input type="checkbox"/> | 50-59%<br><input type="checkbox"/> | 60-69%<br><input type="checkbox"/> | 70-79%<br><input type="checkbox"/> | 80-100%<br><input type="checkbox"/> |
| 5. Skills for Professional Practice       | 0-29%<br><input type="checkbox"/> | 30-39%<br><input type="checkbox"/> | 40-49%<br><input type="checkbox"/> | 50-59%<br><input type="checkbox"/> | 60-69%<br><input type="checkbox"/> | 70-79%<br><input type="checkbox"/> | 80-100%<br><input type="checkbox"/> |

| PLEASE COMMENT ON AREAS IN WHICH YOU FEEL THAT YOU HAVE PERFORMED WELL | PLEASE COMMENT ON AREAS YOU FEEL THAT YOU NEED TO DEVELOP |
|------------------------------------------------------------------------|-----------------------------------------------------------|
| <br><br><br><br><br><br><br><br><br><br>                               | <br><br><br><br><br><br><br><br><br><br>                  |

|                     |  |      |  |
|---------------------|--|------|--|
| Student's Name      |  | Date |  |
| Student's Signature |  |      |  |

University of Wales Trinity Saint David, School of Engineering

# Can FEA Replace Physical Testing?

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Advanced Stress Analysis and FEA – M6X00420

Bryn Stubbings, 1702064

26/04/2020

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## 1 Abstract

This assignment looks into the utilisation of FEA in design projects by companies. It will explore the use of FEA and why it is used alongside physical testing. In addition, through the consideration of a case study, the correlation between FEA and physical testing will be explored. The use of FEA alongside physical testing instead of as a direct replacement is also discussed.

## 2 Introduction

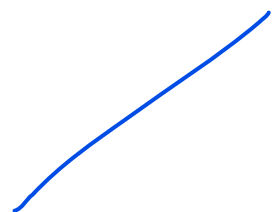
Finite Element Analysis (FEA) is part of the Finite Element Method (FEM), used for testing how different materials and structures behave under predetermined conditions such as stresses and strains. This method is simulation based and works from a 1, 2 or 3-dimensional model or representation of a physical component.

The FE Method comprises of three standard processes: Modelling/Pre-processing, Solution/Analysis, and Visualization/Post-processing.

Modelling/Pre-processing involves the importation of a Computer Aided Design (CAD) model into FEA Software (some packages offer an integrated version of both) and the organisation of the model to make it appropriate for analysing. One of the key factors of using FEA is its time saving quality; as the most time consuming part of the process can be the solving of the model, this is appropriately limited to fit with the time constraints of the project. This is done by simplifying the geometry of the model such as by removing a dimension or removing features not integral to the function of the component. The shape and size of the meshing can also be altered and is most effectively used when variable sizes are utilized over the entire component with a less dense mesh being used in parts of the component that are not significantly affected by the conditions. In addition, more information is attributed to the model to increase accuracy of the analyser this includes: the material and its properties, and component constraints.

Solution/Analysis is verifying the data acquired from the analysis and evaluating it against real data and expectations. To understand if your simulation is accurate and reliable, comparisons with similar component studies or data from a physical test of your component can be used. Inaccuracies can lead back to pre-processing and modelling to make alterations to the simulation thus improving results, this is where an efficient solving time has real advantages.

Once the analysis is deemed to provide an adequate amount of data within an acceptable degree of accuracy, the results can be visualized using contour plots and 2D / 3D graphs.



### 3 Why is FEA used?

Whilst there is no particular individual who invented the Finite Element Method, the current everyday use of it could be attributed to one man: M.J. Turner, who worked for Boeing during the 50's and beginning of the 60's, perfecting the direct stiffness method (or matrix stiffness method). This method, using 'the members' stiffness relations' is particularly suited for automated computer analysis of complex structures. (Indian Institute of Technology Kanpur, n.d.). M.J. Turner also published a paper in the Journal of the Aeronautical Sciences in 1956 along with R.W Clough, H.C. Martin and L.J. Topp centred on the "Stiffness and deflection of complex structures". (Turner, 1956). The objective for the method was to "yield structural data of sufficient accuracy to be adequate for subsequent dynamic and aeroelastic analyses" and was said that it could be "performed by non-engineering trained personnel". This indicates the method could be set up using a computer to be intuitive and user friendly, which is advantageous for companies as they do not require multiple engineering personnel to conduct multiple tests. Whilst having an experienced engineer to oversee analysis other people can be trained explicitly on FEA software allowing for the majority of the team to be paid less than fully trained engineers; saving money for the project and the company.

Before FEA ideas were sketched up, prototypes were developed, manufactured, and then physically tested. After testing it was then found that key parameters had possibly been overlooked. Ideas would then have to go back to the drawing board, go through redesign, and remanufactured for the testing to be repeated. This repetition of phases increases costs and time, featuring an element of trial and error. Since 1956 the FEA process has increased in accuracy and enhanced design. Using FEA maintains the design and material parameters throughout design and analysis negating the possibility for oversight in initial designs. A designer can also design an entire system instead of separate components, allowing the analysis of how stresses within a singular part will affect materials in other separate but connected components. (Manor Tool and Manufacturing Company, 2019)

The prototyping phase can be largely replaced by virtual prototyping which can go through multiple iterations without the vast expense of building physical prototypes. These are often hand built and very time intensive and often not as high quality as the intended end product. Initial virtual prototyping will reduce the physical prototypes down to only one or two iterations. Ultimately FEA is used as a way of saving money and reducing the timescale of a design project.

## 4 Correlating FE and Physical Testing

A case study undertaken by B. Smith and F. Kienhöfer saw the design of a lighter but characteristically similar motorcycle swing arm designed to be built from carbon fibre (B. Smith, 2014). In this case study, Smith and Kienhöfer detail their use of physical testing and FEA. Comparisons were drawn between the two methods to test the accuracy of the computer model analysis using several swing arms of varying metallic constructions.

The physical tests were conducted using a purpose-built jig and a series of strain gauges to accurately measure the torsional and lateral stiffness of the swing arms. The swing arms were then modelled and analysed using FEA software.

The FEA process had several limitations that affected its final data accuracy. The material data for the carbon fibre was not explicitly known and therefore the properties used for both unidirectional and woven plies were assumed.

In addition, due to over-complexity in the modelling of the laminar (ply) overlap it was omitted from the model. This was done to save time by simplifying the design of the model. Smith and Kienhöfer stated in the results section of their report that there were a 5% difference in vertical deflection and a 28% difference in the torsional deflections between the FE and physical analysis.

When physical testing the metal swing arms occurs, there is likely to be a deviance away from the general trend that the properties of the material possess. In an ideal world all materials would have exact material properties such as young's modulus, UTS and Endurance limit. However, to a certain degree two near identical components will always have a slight deviance away from their standard property figures. This difference can be further increased when a component is in a 'used' condition as it will have experienced different stresses, strains and impacts over its lifetime. (EPI Inc., 2014)

### 4.1 Linear vs Nonlinear

There are several parts to linear and nonlinear FEA however, for the purpose of relating to the carbon fibre swing arm case study, discussing linear and nonlinear relations between

stress and strain in a material is needed. When a material undergoes physical testing, its stress and strain results act in a nonlinear fashion.

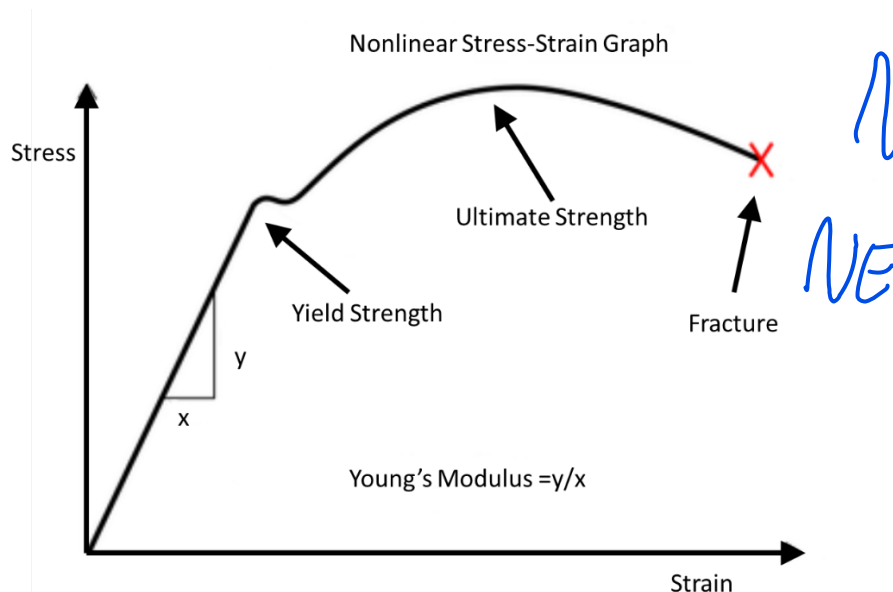


Figure 1 Nonlinear stress strain graph

However, in order to keep FEA models as simple as possible, a material's stress and strain characteristics are assumed to be linear. A component will be considered to fail or permanently distort if the results of the analysis go beyond the yield strength of the material used.

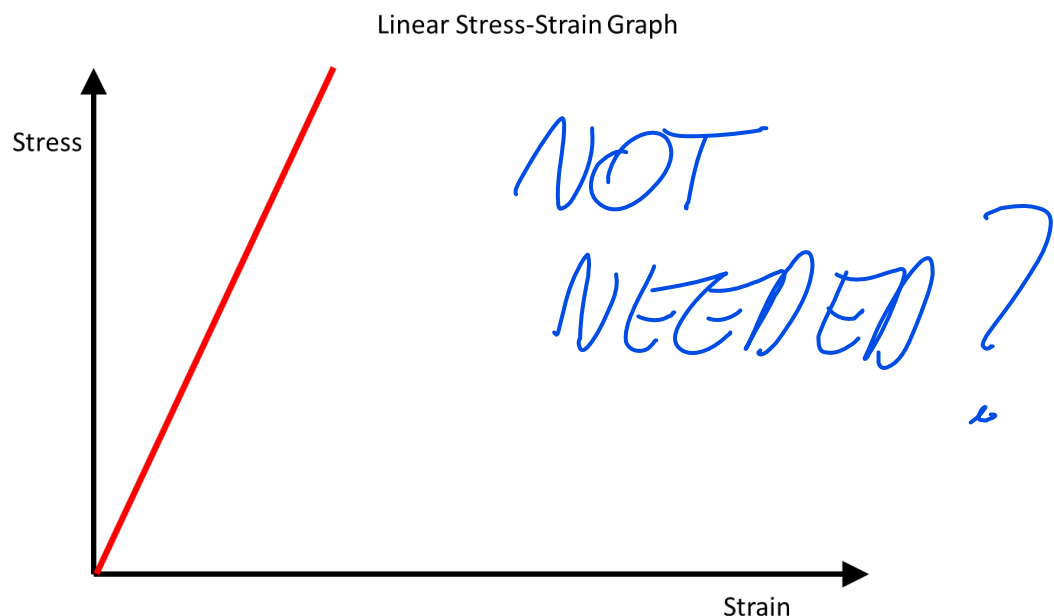


Figure 2 Linear stress-strain graph

Linear FEA is more commonly used for its lack of complexity being more time efficient and requiring fewer computing resources. This means the modelling only tends to be accurate

below the yield strength of the material. When stress concentrations occur above the yield strength, the simulated material does not fail in the same way it would in real life. However, R. Pienner, when analysing the limitations of linear FEA for company use, he found from his own recorded data that there was an allowable size of stress concentration that will not affect the overall strength of the component, and that the plastic zone in ductile metals is a very good buffer at redistributing stress in structural components. (Pienner, 2020)

## 4.2 Physical Testing

The goal of the experimental testing was to measure deflections and strains under various loads. This was for the purpose of determining stiffness characteristics, the strain distribution, and to validate the FE model of the swingarm. The measurements were conducted while applying vertical and torsional loads to the swing arm. The aim was not to study the load on the swing arm until failure, but to obtain stiffness and strain curves.

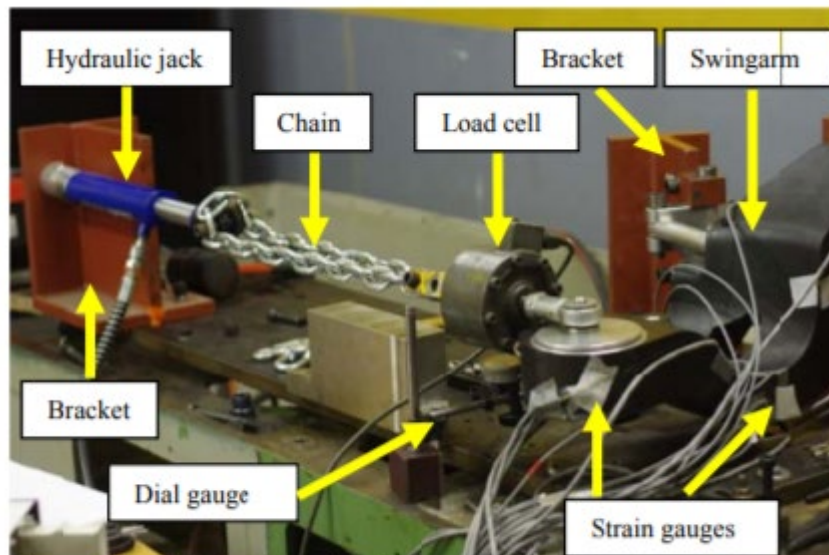


Figure 5: Test rig showing various components used during testing

Figure 3 Test rig showing various components

Figure 3 shows the test setup with the swing arm in the jig ready for vertical load testing. It also depicts the strain gauges, and the dial gauge used for measuring strain and deflection. Loads were applied to the swingarm from 0N to 8000N in increments of 1000N via a hydraulic jack.

### 4.2.1 Strain Gauges

Invented in 1938 by Edward E. Simmonds and Arthur C. Ruge, a strain gauge is a type of electrical sensor used to measure a force or strain. It measures using a variance in resistance which changes as an object is put under strain. Strain gauges can only measure strain effectively in one direction so multiple gauges were used to evaluate strain in several directions; rosette being the term for an arrangement of two or more strain gauges. (HBM, 2020) (Encardio Rite , 2019)

### 4.3 FEA Testing

Within the carbon fibre swingarm design case study, several correlations were made between the FE model and the physical testing results. The following section is a comparison of the FEA and physical testing at position 5 (Figure 4) in a longitudinal and transverse direction.

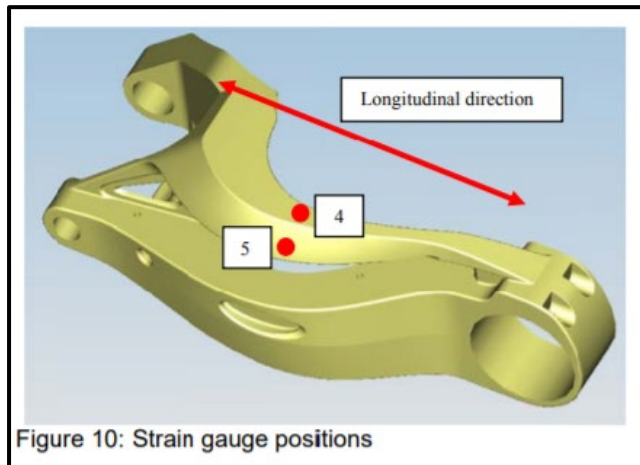


Figure 4 Position 5 Location

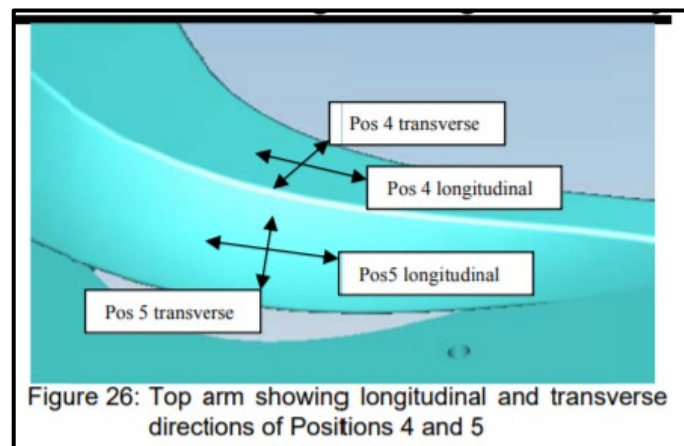


Figure 5 transverse and longitudinal direction of position 5

Figure 6 shows the longitudinal strain under a vertical load of 8000N. The strain is visualised using a colour scale that highlights

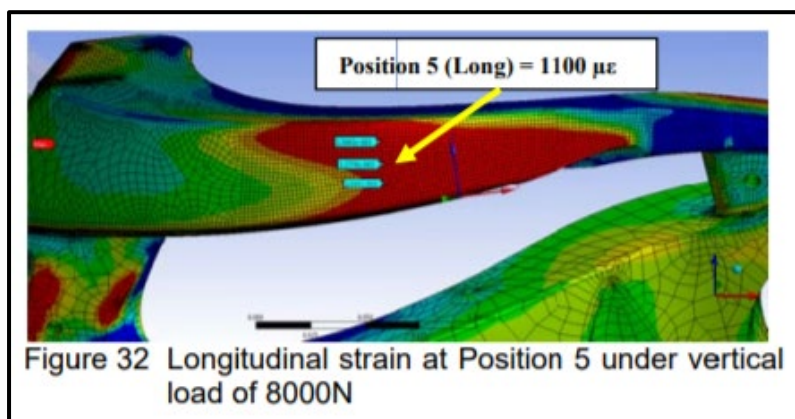


Figure 6 Longitudinal strain at position 5

the strain concentration points on the swingarm model. From this picture two other points can be immediately identified as being under a high amount of strain from the applied load.

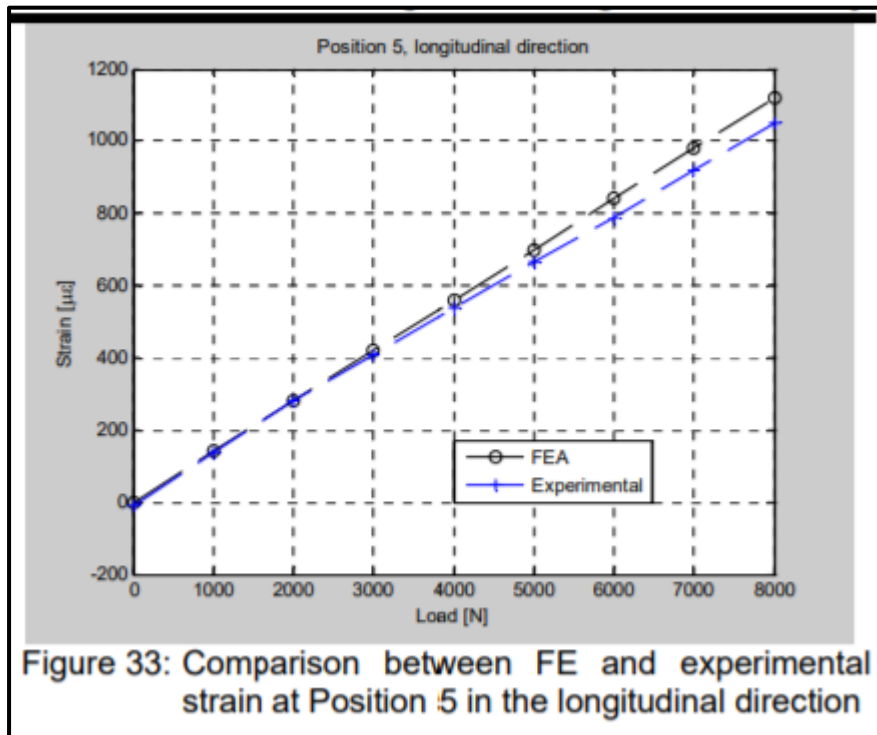


Figure 7 Strain graph in the longitudinal direction

the difference being only 5%.

Figure 6 is the strain experienced at position 5 over an increasing load up to 8000N depicted in graph form. This clearly shows the differing results of the FE model and the physical testing. Smith and Kienhöfer state that this showed a good correlation, the physical test resulted in a strain  $1050\mu\epsilon$  compared with the FE strain of  $1100\mu\epsilon$ , with

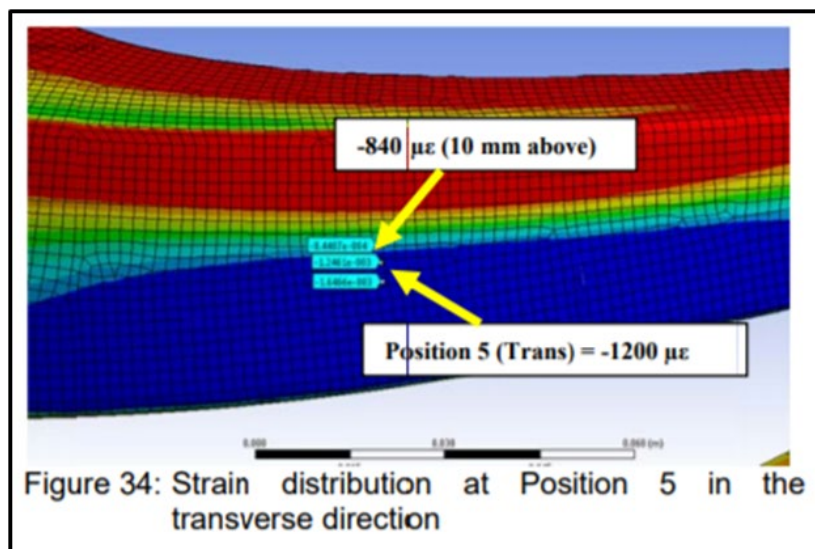


Figure 8 Transverse strain distribution at position 5

However, Smith and Kienhöfer go on to say in their report that if the results are viewed approximately 10mm above position 5, the strain experienced is a closer  $-840\mu\epsilon$ .

Figure 8 and Figure 9 show the strain distribution in the transverse direction at position 5. The strain at position 5 was  $-1200\mu\epsilon$  which as shown in Figure 8 is very different from the physical test result of  $-870\mu\epsilon$ . This 38% error clearly shows that the model was too inaccurate in this case to be considered a useable result.

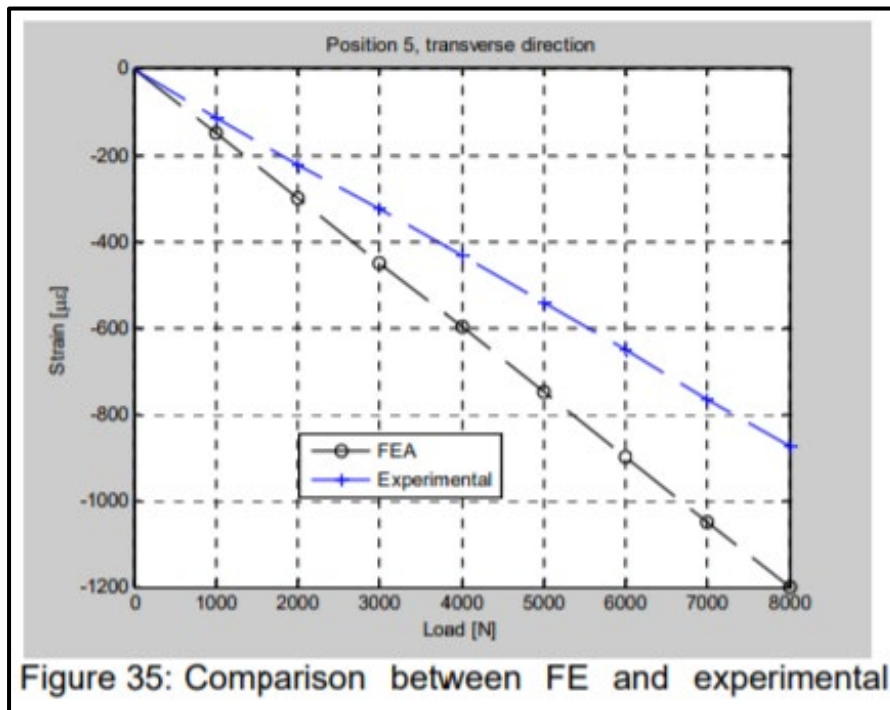


Figure 9 Strain graph in the transverse direction

They stated in their report that “This shows that the simulated load paths are slightly different to the actual load path” and that this was due to different rigidity in the transverse direction. A similar situation was found at a different position on the swingarm where approximately 10mm above the position saw a fall in error from 110% to within 2%. In this situation, the model was improved by adding the ply overlap in this area which brought the error to within 2% at the original position.

Evidently, the omission of some features while reducing the complexity and overall solve time can have a detrimental effect on results to the point where they are not useable. However, with comparison of the physical tests, appropriate adjustments can be made to increase accuracy and validity. The inclusion of ply overlap in a specific area would not have increased the solve time as much as if all ply overlaps had been added but was enough to validate an important section of results.

## 5 Can FEA Replace Physical Testing?

The advantages of FEA make it an invaluable resource to have at any companies' disposal that wants to reduce time and cost to their design process. FEA shifts the peak costs of a design project from the end to the beginning and often decreases the size of the peak substantially. FEA gives further insight into the strains experienced on a component, not just the specific points that are identified and measured in physical testing. Shigeaki Kinoshita, the FEA simulation Applications Engineer at CADspace describes several benefits to FEA including being able to 'fine tune' a design at the simulation stage, reducing production and testing of prototypes (Hingston, 2014). Prototyping is very expensive and time intensive as just a handful or a singular prototype is made; so does not benefit from the large discounts associated with mass quantity manufacturing. In addition, multiple iterations are produced over time as part of a trial and error basis. Allowing the product designer and engineer to improve the design in the early stages decreases the need for trial and error later on in the project.

Kinoshita also states that there are other benefits that sit outside of the designing itself. He presents the example benefit as when having to "present their concepts to non-engineering stakeholders such as to corporate executives, investors or marketing and sales personnel" (Hingston, 2014). FEA is a highly visual and can be used as a way of proving a design to the aforementioned personnel, it can be used to demonstrate performance capabilities and verify the integrity of a product.

Despite the great benefits of FEA, it still has to be utilized well to be of any worth; FEA is only as good as the person using it. It is important for the company utilizing FEA to ensure that the appropriate software is used and the people conducting FEA have professional training and high-quality equipment to use. Despite FEA's cost saving aspect it still requires a high initial investment that may not pay off if the engineers and designers do not know how to use it accurately and effectively. Kinoshita mentions that converting real life problems into FEA models requires understanding of the problem and good engineering judgement.

Validation of an FEA model is also key when conducting any simulation analysis: it increases confidence in the outputted data. Validation can come from previous work of a similar case or from physical testing of a final design that reinforces key figures and features.

## 6 Conclusion

In conclusion, FEA is a proven method the world over and has huge advantages, and when utilized appropriately and effectively, it can not only improve efficiency of the design process but cut costs that can be forwarded on to the customer. In an increasingly competitive age, getting products to market before competitors provides the edge needed to compete effectively and intensively. FEA is a vast improvement from old techniques that rely solely on experience required over decades of engineering and a reasonable amount of trial and error. This allows new smaller 'up and coming' businesses to compete more effectively with larger more well-established companies.

From the comparisons shown in the carbon fibre swingarm study, it can conclusively be thought that results from modelling can accurately represent real world testing. However, due to the nature of FEA mainly using simplified versions of products for better time management and real-life situations being far more chaotic than its simulated counterpart, I do not believe FEA can or should fully replace physical testing.

Furthermore, discrepancies in FEA from real world testing could result in misleading results such as shown by A. Hickey and S. Xiao in a report on "Finite Element Modelling and Simulation of Car Crash". This suggests discrepancies in FEA vs real world testing with smaller and larger cars will result due to varying masses of the vehicles simulated and the vehicles physically tested as simplified versions were used for the FE Model for the purpose of 'time saving' and additional variable mass such as passengers and luggage. (Hickey, 2017)

This all indicates that FEA should replace a large portion of the physical testing phase, but physical testing will always have its place for validation and confirmation of FEA results.

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