

## BACHELORS DEGREE ASSIGNMENT SPECIFICATION

|                   |                                           |                                                |             |
|-------------------|-------------------------------------------|------------------------------------------------|-------------|
| Student name:     | LORD                                      | 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              | 21.3          |
| <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              | 22.5          |
| <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              | 20.4          |
| <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              | 6.9           |

|                                                                                                                                                                                                                   |                                                        |  |        |
|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------|--|--------|
| <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> |  | 71.1 % |
|                                                                                                                                                                                                                   | 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.

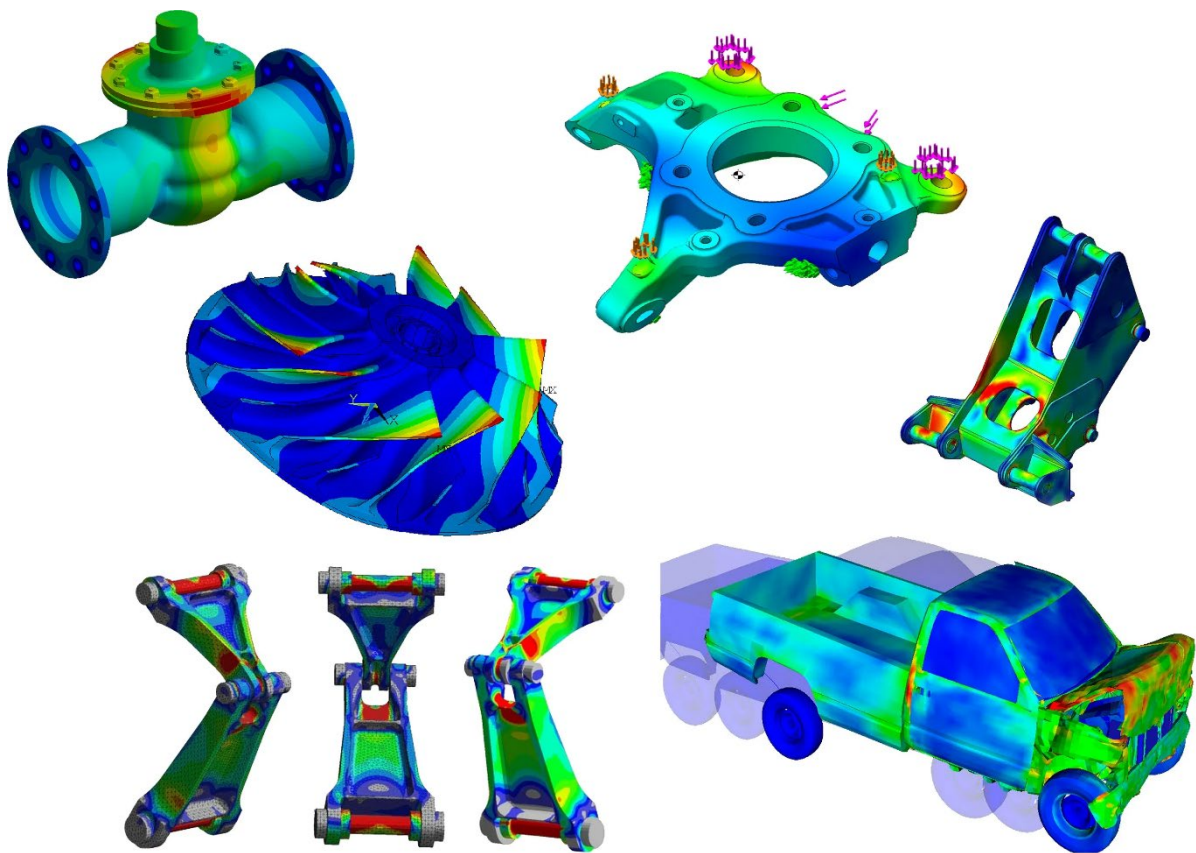
| Common Assessment Criteria Applied        | Level of Achievement              |                                    |                                    |                                    |                                    |                                    |                                     |
|-------------------------------------------|-----------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|------------------------------------|-------------------------------------|
|                                           | 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 |  |      |  |

# CAN FEA REPLACE PHYSICAL TESTING?

Advanced Stress Analysis & FEA (M6X00420)



University of Wales Trinity Saint David, School of Engineering  
BEng Motorcycle Engineering (4 Year Course)

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## 1 Introduction to Finite Element Method

The Finite Element Method of analysis is the scrutinization of material/component behaviour under loading through the application of simple mathematical relationships to an intricate structure of divisions of a component, known as a “mesh”. The individual divisions are known as “elements”, these elements can be 1<sup>st</sup>, 2<sup>nd</sup> or 3<sup>rd</sup> dimensional and can be split into various “orders” by way of the placement of manipulation points along their edges (known as “nodes”) to increase accuracy of mathematical approximation of component/material behaviour.

This is carried out by utilising matrix algebra to apply these relationships across the elemental structure of this “mesh”. This mathematical model is known as a “stiffness matrix” (particularly in mechanical loading) and defines the properties of the component that will be subjected to the loading cases defined by the user. This matrix has to be defined in terms of a local or global coordinate structure to provide easily interpretable results for the user and this is carried through a transformation matrix to transform the loading and change seen in either local or global system into the most readily interpretable system.

Through these matrices a set of boundary conditions and loading cases are applied mathematically to predict behaviour at each of these elements and through extensive computational calculation a picture is developed of the behaviour of the component in that specified case. This can then be scrutinised in different ways to provide information of how the component or material would react in the case specified.

### 1 “Why do companies typically carry out FE analysis alongside physical testing?”

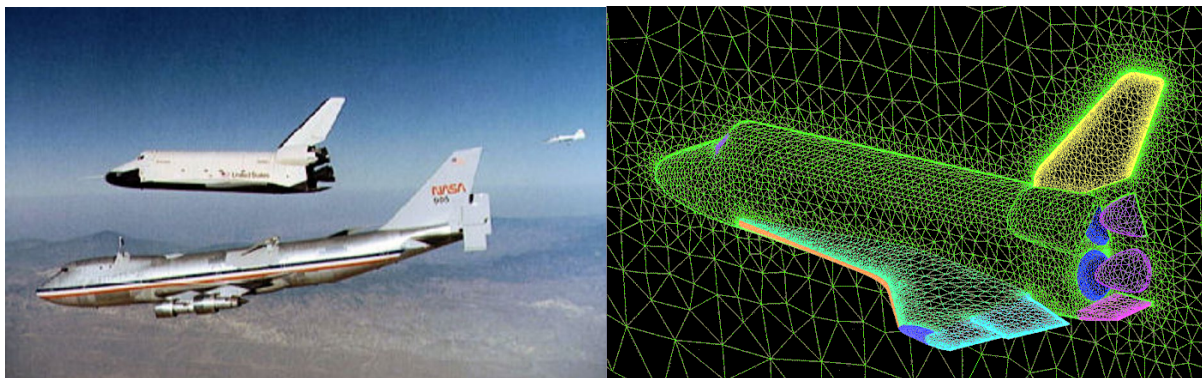


*Figure 1: The NASA “Space Shuttle” was developed and manufactured using a combination of physical testing methods and NASA’s own FEM package “NASTRAN” (National Aeronautics and Space Administration, 2008)*

Some primary reasons for using Finite Element Method alongside physical testing in modern engineering industries are as follows (PES Performance, 2020):

Prior design evaluation before costly prototypes and physical tests need to be constructed. Multiples of a specific design architecture can be created with small differences to determine the best “start-point” for physical testing.

Reduction in the number of physical tests required as multiple scenarios can be carried out virtually to determine most pertinent physical testing required. Results from initial physical testing can be applied to an FE model to refine the physical test in a virtual sense and then once a more accurately defined problem has been established the testing can return to the physical for final testing to reduce the overall number of physical tests.

Greater degree of safety and design-for-purpose can be obtained with correct FE/Physical Test method. If FE method is used correctly (correlation/validation) alongside physical testing it can provide a much more “user friendly” method of analysis with very visual results to highlight areas of note that may not be able to be easily identified during physical testing. For instance, secondary potential failure areas where a destructive physical test may only highlight the “worst” failure, running FE alongside will highlight “all” potential failure areas.

Another reason to carryout an FE study alongside a physical test is the ease of modification to the style of testing undertaken, once an initial test has been undertaken the study can be modified extremely easily to accommodate a different loading case or a small change in the parts geometry whereas a real world test may take hours or even days to alter the part or testing procedure to garner the same analysis.

Also, the current trend of assimilation of FEA solvers into CAD/CAE software means that a complex FE tests can be readily carried out alongside a simplified physical test. This can be done when elaborating on the physical test may prove uneconomical or complex, in essence to alleviate the limiting factors of the physical testing by virtually providing more complex scenarios.

Additionally, to a lesser extent, the following is true of carrying out Finite Element Method analysis alongside physical testing:

The possibility for better material selection and optimisation as multiple material/material grade options can be explored to narrow down choices before physical manufacture for testing. There can be a reduction in the overall cost of the design cycle through reduced prototyping and testing costs when compared to a more traditional “non-FE” design cycle. And there is the possibility for providing alternate testing scenarios where a physical test would difficult or not economically viable to carry out.

## 2 How can a physical test be correlated to an FE model?"

### 2.1 How do you correlate?

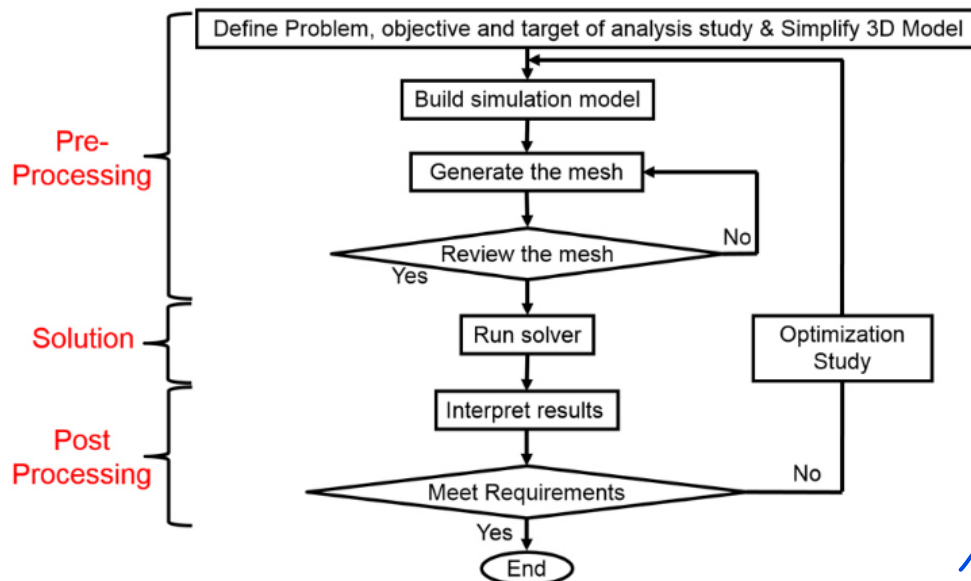


Figure 2: An example of a typical processing loop for FEM, BEM, FDM etc (Test Tooling Solutions Group, 2020)

There are a multitude of considerations for correlating an FE model with a physical test. These considerations form a negative feedback loop that aims to converge the FE results with the physical test results through means of logical scrutiny of incorrect method and output results until the virtual work is within a margin of the real-world results (Lake, 2020) (Dassault Systemes, 2018-2020).

The first and most obvious method is using normal engineering common-sense questions to properly define the problem and work out limitations, boundary conditions, loading scenarios and such to their closest possible numerical parameters to mimic the real-world test (de Weck & Kim, 2004):

- Are the loads of the correct magnitude, type (Thermal loading, Mechanical Loading, Fatigue cases etc) and applied in the correct planes and directions?
- Is the material correct for the test, does it match the real-world material, are any heat treatments or property modifiers accurately represented?
- Are any connections and jointing methods accurately represented, bolted connections, bonded connections, welds etc?
- In the case of thermal or pressure testing are the ambient conditions correct to those seen in the physical test (humidity and ambient airflow for convective analysis or barometric pressure for pressure vessel testing)?

The second set of questions is the more refined FE-specific criteria that must be considered:

- Is the mesh representative of the real-world test? Have local refinements been applied at areas of interest?
- Has the geometry and mesh been optimised for FE study, have sliver faces and erroneous or unimportant geometry conditions been eliminated?

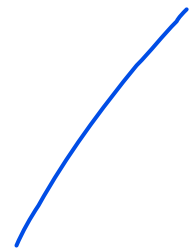
- Is the order of the elements being used the most pertinent to the results that are trying to be correlated?
- Are the type of elements correct for the study being undertaken? Triangular/tetrahedral elements, square/cuboid elements etc?
- Are there enough degrees of freedom to accurately describe the scenario under scrutiny?
- Have areas been simplified when they shouldn't, should the "coarseness" of the mesh be reduced despite the increase in computation/solve time?

Once these questions have been answered and the simulation has been run the results must then be scrutinised to determine the issues causing inaccuracies and differences between the physical and virtual results.

- Is the maximum reported value seen at a fixture of infinite stiffness (the end of a bar under static loading fixed to a wall for instance), could a margin of elements around this point be disregarded to more accurately portray the real-world scenario?
- Is the correct type of stress being scrutinised? Von Mises, Guest-Tresca etc? Are the stresses overall general stresses or stresses normal to an axis or direction? Are the normal stresses to the correct axis in the correct coordinate system?
- In a multiple case study are the correct cases being compared or is a later case the greatest stress and therefor most comparable to the real-world experiment?

An important consideration at this point in the correlation is, "how accurate does this need to be to real life?", obviously all engineers strive for the greatest accuracy possibly but if the correlation displays a very fine margin of error across multiple cases/datapoints is it really economical and reasonable to strive for the extra 0.001% or is it a reasonable enough assumption to use the information as a useful model going forward?

And a final and overarching question that should always be asked, is FEM the correct method of solve? Would, for instance, boundary element, finite difference or finite volume be a better method of solution for the particular problem defined in the physical test?



## 2.2 A Case Study

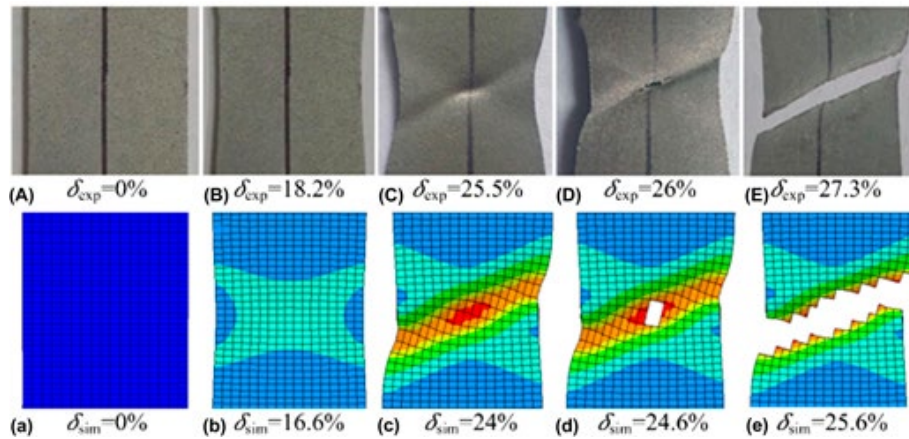


Figure 3: Example of FEM alongside physical testing in tensile tests of ductile sheet metal samples (Chong, Daxin, & Ning, 2016)

As can be seen above, FEM and physical testing can show very promising correlated results when properly developed and validated (Chong, Daxin, & Ning, 2016).

In the case above there are several methods of correlation that can be observed visually. The initial visual “tells” of failure can be identified in both the physical reality and virtual reality, “necking” and an “X” shaped deformation pattern beginning to develop in cases “B,b” and “C,c”, then further in cases “D,d” and “E,e” initial crack propagation can be observed in the centre of the test piece and finally component failure can be observed across the same fracture growth pathway as predicted by the FE analysis. Despite the correlation shown above several issues can be noted.

Firstly, it can be observed that the percentage deformation seen in the physical and the virtual tests differ by approximately 1% per “timestep” of tensile test. Secondly, the deformation and failure appear to be much exaggerated in the FE model than in the physical test piece.

In the case of the second point here there is the possibility that, at case “d” due to the two-dimensional nature of scrutinising the results (commonly referred to as a “Cut”, “Section” or “Cut Plot”) the FE analysis is highlighting a greater internal fracture that cannot be seen entirely at the surface in the image of the physical case “D”, an internal fracture “pocket” if you will.

The more likely reason for this disparity between physical and virtual is the mesh size used for the FE analysis. As can be observed the initial fracture seen in the “d” case is the size of approximately 4 of the elements seen around it, from this it can be concluded that the reason for the fracture being so large is that this particular solver deletes the entire element when the stress exceeds the materials failure point and the stress drops to zero, therefore with a smaller element size this large failure visualisation could be more realistically portrayed by using a smaller element size.

For this particular case as the study is relatively small this piece it could be feasible to increase the mesh resolution as a whole but a better practice for the sake of expediency to reduce computing time either local meshing condition could be applied to the suspected site of failure, or, a more automated approach would be to define a function/command to refine the mesh when a certain level of stress of deformation is seen in an element, an automatic mesh refinement.

### 3 “Can (or should) FE analysis ever replace physical testing?”

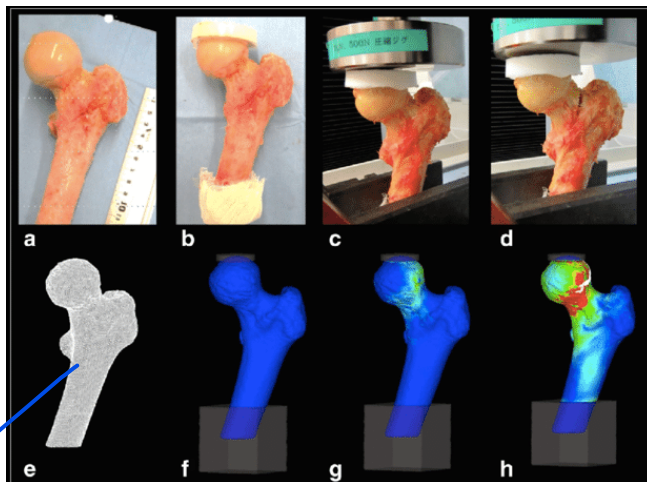


Figure 4: Example of physical tests alongside FEM for prediction of failure in bone structures (Miura, et al., 2017)

In the authors opinion, “No, Finite Element Method shouldn’t fully replace physical testing in its entirety, that being said it can definitely be more widely utilised.” The reasoning for this is as follows:

Firstly, there is no realistic method at current to accurately predict every possible

anomalous result discovered in a physical test, for instance a reasonably accurate FE test could be performed for a material that has previously undergone a weathering or damage scenario but every permutation and combination of these scenarios cannot be simulated without a degree of work that would prove nonsensical. A greater deal of these scenarios can be recreated in a physical sense than a virtual (albeit still not being able to cover all bases). Perhaps with the current advent of Artificial Intelligence and exponential increase in computing capability FE methods can take the fore in this “random-real-world-scenario” testing (Javdi, Mehravar, Faramarzi, & Ahangar-Asr, 2009) (Blanco, 1990).

Secondly, an extremely important point is that FE simulations are computational solvers meaning regardless of your inputs they will apply their commands and logic to the absolute, meaning if you apply incorrect inputs and parameters it will supply output parameters based on those inputs, the commonly used phrase is “Garbage In equals Garbage Out”. Whilst this is true for physical testing also, it can be much easier to see problems/incorrect method in a physical experiment than a complex FE simulation (Enterfea, 2020) (Lake, 2020).

Another key consideration with FEM is that even at its best it is still a mathematical approximation and while, with a great enough degree of refinement and a high enough resolution of calculation, it can be extremely accurate it is up to the user to define the accuracy of the study (Ghionea, 2007). For instance, to be able to accommodate cavitation seen in a badly designed casting process the areas of porosity must first be defined with in the FE model either by designing a further study to mimic the fluid behaviour of the casting pour causing cavitation and translating those results into the FE model or by manually designating areas of porosity found in the part after the casting process. As is obvious, this can be lengthy, complex, and expensive process. A destructive physical test of a component can be much easier to design to highlight this type of issue as the part can then be sectioned to view the internal geometry rather easily. Again, potentially with increased use of AI and greater computing power this will bring FE further to the fore in this regard but at current this style of investigation is reserved the pinnacle of engineering establishments.

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