

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	SLADE	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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:	<i>Assignments will not be accepted without a signature here</i>	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	

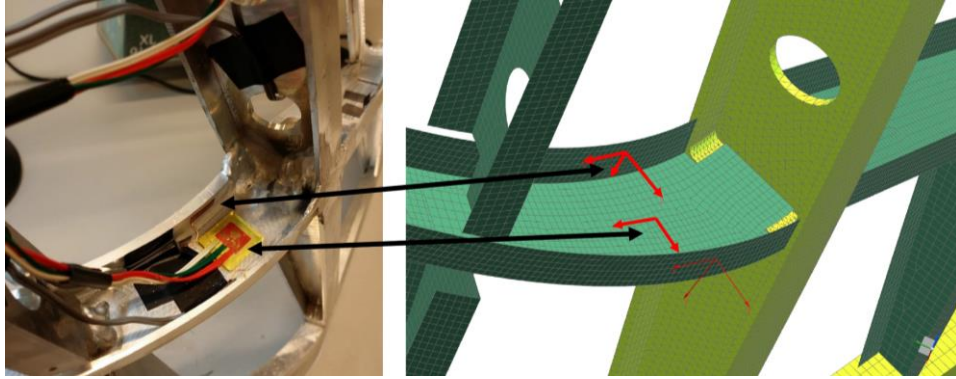
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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
1. Research-informed Literature Extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions.		
(Assessed in point 1)	30	15.6
2. Knowledge and Understanding of Subject Extent of knowledge and understanding of concepts and underlying principles associated with the discipline.		
(Assessed in point 2)	30	13.5
3. Analysis Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence		
(N/A)	0	
4. Practical Application and Deployment Deployment of methods, materials, tools and techniques; application of concepts; formulation of innovative and creative solutions to solve problems.		
(Assessed in point 3)	30	15
5. Skills for Professional Practice Attributes in professional practice: individual and collaborative working; deployment of appropriate media; presentation and organisation.		
(Assessed in report presentation and structure)	10	6.2

Assignment Mark Overall (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.)	Late Submission Penalties (tick if appropriate)		59 %
	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%
1. Research-informed Literature 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.
2. Knowledge and Understanding of Subject 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.
3. Analysis 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
4. Practical Application and Deployment 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.
5. Skills for Professional Practice 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 rd	2:2	2:1	1 st	1 st
	OUTRIGHT FAIL	UNSATISFACTORY	SATISFACTORY	GOOD	VERY GOOD	EXCELLENT	EXCEPTIONAL
1. Research-informed Literature	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
2. Knowledge and Understanding of Subject	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
3. Analysis	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
4. Practical Application and Deployment	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
5. Skills for Professional Practice	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐

PLEASE COMMENT ON AREAS IN WHICH YOU FEEL THAT YOU HAVE PERFORMED WELL	PLEASE COMMENT ON AREAS YOU FEEL THAT YOU NEED TO DEVELOP

Student's Name		Date	
Student's Signature			

Title Page

University of Wales Trinity Saint David

School of Engineering

Title of the coursework: Can FEA replace physical testing?

Your Name: Loaghan Slade

Your Student Number: P151151

Date: 05/03/2020

Module Name and Code: Advanced stress analysis & FEA

Lecturer's name: Kelvin Lake

Abstract

This report sets out to cover the connection and correlation between predictive FEA models and physical test results. Finally, using personal judgement, assess the possibility of FEA replacing the need for physical testing and whether or not it should.

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CORRELATED

1 Introduction

In this report research will be done into the importance of FEA in product development and testing. This will be done by assessing 3 points; why FEA is carried out in combination with physical testing, how the physical test results can be connected to the FEA model, and, finally, if FEA is likely to replace physical testing completely in the future.

2 What is FEA?

FEA or Finite Element Analysis is the numerical analysis of physical changes using the finite element method to reduce the total amount of prototypes that need to be made in developing a new product or part. (Simscale, 2020)

2.1 How can FEA be carried out?

FEA is a computerised simulation process used to aid the design process by completing many kinds of analysis, these include stress, thermal, vibration, seismic, impact, and crash analysis. While in the past FEA had to be completed in a dedicated program taking long periods of time for a model with limited detail, it has since been adopted into most CAD suites such as Solidworks where a change to the 3D model is automatically applied to the analysis that has been carried out. However dedicated FEA packages are still widely used, the most recognisable of these being ANSYS. REALLY? PROOF?

Implementation of FEA has a number of benefits; it can improve the design and aid in early testing of important design aspects, it has introduced virtual prototyping, thus speeding up the design process and reducing the need for physical prototypes, which in turn leads to a cheaper, more efficient design process. FEA also produces reports which can be used for quality control. (PES-Performance, 2020)

3 Why is FEA carried out as well as physical testing?

FEA is still carried out in combination with physical testing due to the uncertainty that comes from predictive data. This uncertainty comes in two main ways, these being physical and numerical uncertainty.

IT IS NOT CLEAR - YOU LIST MANY
WHAT THESE ARE - THINGS

Physical uncertainty comes from 4 main factors; boundary, and initial conditions, which can be defined by impact velocity and angle, mass, and characteristics of boundaries, loading, which can occur from environmental factors and changes such as earthquakes, wind, and waves. The properties and geometry of the component being analysed will also generate a

level of uncertainty. The yield stress, strain, and density, as well as the physical dimensions and manufacturing characteristics can vary between each unit, especially with the addition of other factors such as temperature and vibrational frequencies. Numerical uncertainties call into question the accuracy of the mathematical modelling; a lack of data on the physical characteristics, rounding errors, as well as the human error in choices of mesh type, size, and density. (Liliana G. May, 2012).

In order to mitigate the physical and numerical uncertainty, more testing is required. With the increase in complexity of components being analysed, experimental data is still required to validate any simulated results found. FEA alone can have up to 95% accuracy, the final 5% is where the continued need for physical testing comes from. With the continued collection of physical data, the need for physical testing may decrease over time. (Dascotte, 2004)

HOW IS
THIS
MEASURED
?
95% OF
WHAT?

So why do companies continue to perform both FEA and physical testing? In short, companies continue to do both forms of analysis because they need as much information as they can get for their products or components they are testing. It is unlikely that physical testing will be done away with completely as data validation still plays a vital role in testing. (Ahmad Ivan Karayan, 2012)

Physical testing provides the numerical basis necessary for FEA uses; key factors such as the Young's modulus and Poisson's ratio were found through physical testing. Without it, the predictive testing carried out in the process of finite element analysis cannot be accurately completed. The main way of finding accurate representations for these in new materials is to physically test them.

Young's modulus is used to describe the elastic properties of a material under compression or tension, it is defined as the longitudinal stress divided by the strain.

Poisson's ratio is longitudinal strain, defined by the ratio of lateral strain to the longitudinal strain. (Britannica, 2020)

Those companies seeking to eliminate the need for physical testing would need to invest considerable resources in order to compile a complete and accurate database of material properties, manufacturing tolerances, and their effect on the components being tested. Attention would also need to be paid to the effects of external influences such as weather, corrosion, and impact loading. It will also be necessary to find a way to eliminate any human error from their testing, and, finally, find a way to mitigate any uncertainty about the results they have gathered both physically and numerically, and to validate the results effectively. This would be a monumental undertaking, consuming large amounts of time and money, likely taking several years or even decades to complete. Until computer simulation

technology is advanced enough to provide 100% accurate results 100% of the time, companies and developers will continue to physically test their products in combination with completing FEA to gain numerical insight into the physical results they have gathered.

(Thornton, 2011) *FURTHER DETAILS ON THE IMPACT ON THE DESIGN PROBLEMS WOULD HAVE ADDED TO THIS SECTION*

4 How are physical tests correlated to FEA models?

Test analysis correlation is a critical step in minimising the differences in test results from the predictions made by the finite element model. This can include altering the mass and stiffness of the object being tested using FEA to more closely match the real-world testing. Correlating test results for both static and dynamic loads can be more easily validated when compared to the physical outcome.

There are many different types of correlation that can be used in a finite element model, these include; modal correlation, which is used to verify predicted frequencies, they are also used to estimate damping forces present or required. Design correlation is used to predict the stress distribution and fatigue factors found through design analysis. This form of testing can also be used to accurately predict any structural changes that may occur during the component's life cycle when analysed statically. The dynamic loading must be validated in order to properly create an accurate predictive model. (Engineering, 2020)

Another method for obtaining accurate and correct representation of an FEA model is to create a model of an existing system and then use measurements and data gathered from the existing system to correlate the two. When applied to dynamic linear systems, correlation helps to find equilibrium points between internal and external inertia and loading forces. (Francois M. Hemez, 2020)

Other correlation methods can be used when analysing components that have had experimental procedures already carried out on them. The application of virtual strain gauges allows the person running the study to place the gauges in pre-defined reference directions to correlate simulated strain data with the data collected from experiments. These can be used to analyse multiaxial loads at the correct position and directions to gather the "virtual strain" information. With virtual strain gauges and a properly constructed and meshed FE model, the predicted values can be quantified by comparing them to the real values.

In the same way virtual strain gauges can be used to correlate strain data predicted by an FE model to experimental data, virtual sensors can also be used. Virtual sensors can be positioned on the model at exact points to collect the displacement at those points, the data collected can then be compared to the measured displacements to help reduce the divergence between the two data sets. (Prenscia, 2020)

A further method for correlating FE models with physical data is to split the parts being tested into key areas. For example, when studying a hypoid gear set, the gears are split into separate studies; these are teeth strain, contact between the teeth, and the gear rim. The same is done to include a ring gear and a pinion. As gears are cyclically loaded, they experience several fatigue factors such as bending, pitting, wear, and scratching, the most common of which being bending fatigue. Bending fatigue is most commonly started at the base of a gear's tooth; the method for gathering this is to perform an EPG α test. These can be carried out on an FE model to measure displacements at the base of a gear's tooth and, as a result, calculate the bending stress present at that area but are unique to the specific torque at which they are completed. As such, they are typically completed across a range of torques.

The contact pattern between the teeth is verified by comparing it to a real-world contact pattern test, and a probe is used to measure how the surfaces of the gear differ from their 3D model being used in the FEA. The previously gathered EPG α test values are added to bring the FE model closer to the physical model. Inclusion of the gear rim in the study helps to eliminate any variation between the physical and FE models. (Gregefors, 2016)

*OTHER SENSORS SUCH AS ACCELEROMETERS
SHOULD HAVE BEEN DISCUSSED HERE*

5 Can or should Finite Element Models replace physical testing?

As opposed to assessing both questions in one answer, it is better to split the question into its two parts, answering first if FEA can replace physical testing with current technology, then answering if it should.

5.1 Can FEA replace physical testing?

Computerised simulations provide results by solving mathematical equations used to give definition to a physical system that is being studied. This being the case, the output of an FEA model relies completely on what is put in by the person creating the model. In order to create a fully accurate model and gain usable results, a tremendous amount of knowledge and experience is required.

There is, however, a wide variety of physical attributes that can be calculated accurately purely using equations, the most basic of which being linear and angular motion. These are then applied by the creator of the model in an attempt to validate results gathered from the simulation. Any number of small changes to the input or boundary conditions can alter the results obtained from the simulation, leading to the model needing validation again. Should

the simulation fail or be inaccurate, the best way to discover the reason is to study the system experimentally. An approach that uses experimental results to refine simulated results will increase its accuracy with each repetition. Models made using repeated real-world validation may be able to remove the need for physical testing all together.

However, as advancements are constantly being made in materials, which are then tested to replace existing ones, predicting their behaviour under varying boundary and loading conditions becomes challenging. This is because there isn't enough information available about them to accurately predict their behaviour. The reliability of simulations is based heavily on a computer's capability to handle the load it is put under, if the complexity of the design increases so too does the required computational ability to complete the simulation. Solving time will increase exponentially with the increase in complexity. (Vyas, 2015)

For a purely simulated or predictive process to replace physical, experimental, processes all uncertainty about the results gained from them must be removed. This entails the elimination of human error, mathematical uncertainty, and physical uncertainty. Even if all uncertainty is removed, simulated processes cannot yet replace physical validation, due to the speed at which new materials are developed. These new materials are constantly being analysed and tested for their ability to improve or replace the existing materials. It is an almost endless cycle of new technology being introduced with new and different processes in manufacturing. As such, there isn't an abundance of opportunity to fully explore materials short-comings or their full potential for design. (Schmitz, 2016)

5.2 Should FEA replace physical testing?

There are many advantages to using FEA, these include producing a complete set of results, including those that may have been ignored or impractical to gather during a physical test. Computer simulation is a completely safe approach to completing tests that may have otherwise been dangerous, or even impossible. Simulated tests can offer a wide range of results, including several failure points, and even physical factors that would not have been available from the standard experimental procedure, and reduce costs for completing tests. Due to these advantages it would be ideal for purely computational testing to replace physical testing. The versatility, speed, and low costs associated with FEA could lead to critical advancements in materials and critical testing for new products. (Pre Technologies, 2020)

*OFTEN REGULATIONS MEAN
THAT A PHYSICAL TEST IS REQUIRED.*

5.3 Final thoughts

Due to the inherent uncertainties with current FEA models, both mathematical and physical, as well as the limitations imposed by computing ability, it is unlikely that a purely FEA approach will replace physical testing in the foreseeable future. The need for experience and

existing expertise in setting up effective and accurate FEA models further adds to the difficulty in eliminating physical testing altogether. There will undoubtedly be an industry-wide push for more qualified and experienced FEA engineers in the future, as advancements are made in the technology required to complete these tests to increase efficiency and lower costs in product development and testing. There is no doubt that the industry will push for a decrease in physical testing as simulated testing improves in speed and accuracy, though it will never be fully eradicated while the need for data validation is still present.

In summary, can FEA currently replace physical testing? No, not with current technology and the rapid advancement of material properties. Should FEA replace physical testing? While data requires validation, no, FEA should not replace physical testing. Defects and tolerances in the manufacturing processes leads to a level of unpredictability that even the greatest FEA engineers cannot account for.

A reasoned approach utilising both FEA and physical testing to their fullest is still the best approach to an accurate, valid test of any material or component being manufactured and tested.

6 Recommended further work

Further examination of a variety of case studies would offer a more in-depth assessment of the need for physical testing in FEA. An alternative to a purely research-based assessment of FEA could be to perform both a simulated and a physical experiment to gain experience and thus a better understanding of the methods used to correlate FEA results to ones obtained through experimentation.

DIAGRAMS WOULD HAVE
ADDED TO YOUR WORK.

CASE STUDY?

7 Bibliography

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