

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	WARD	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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	19.8
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	18.9
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	19.2
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	6.5

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)		64.4 %
	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			

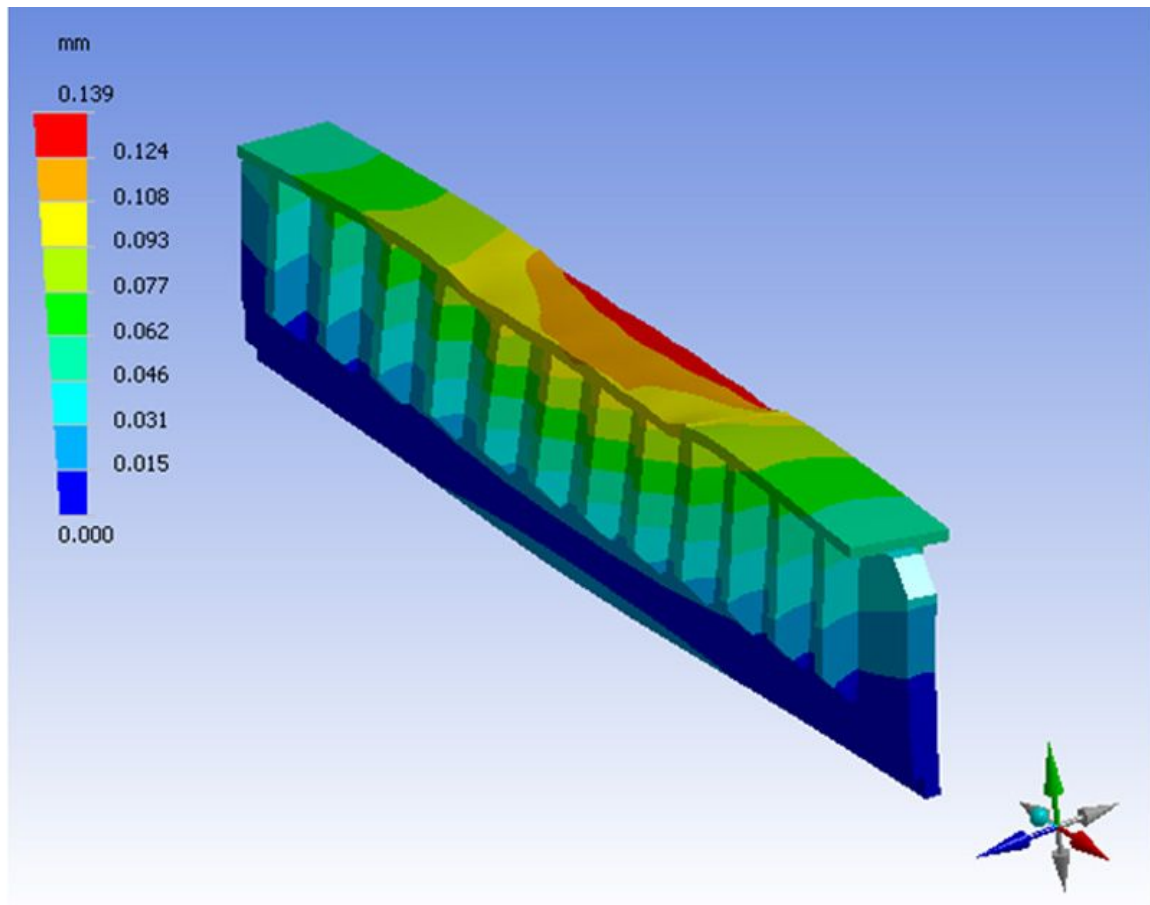


Figure 1 (Mechanical Engineering Portfolio and Samples - cadamen.com, n.d.)

Can FEA replace physical testing?

FEA

Milo Ward | Motorcycle Engineering | March 2020

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Introduction

The task for this following report has been split into three separate sections, firstly looking into and analysing the reasons why companies use Finite Element Analysis (FEA) testing alongside physical testing and the positives and negatives of this approach. The second section will be seeing how a physical test has been correlated to a FEA model, looking into why it used for this model and how similar the results were. The final section will be expressing the authors opinion on whether FEA analysis should/can replace physical testing in the future.

Hand Calculations

In modern day, FEA is mostly completed by computers and using software, this is due to its accuracy and the speed when compared to the other method. By using multiple equations and then putting these into matrices, it is possible to calculate basic stresses and loads that the elements would be under. The greatest problem with this is the complexity that is required when more elements are added, each time a new element is calculated, the matrices grows and gets more and more complicated. This means by using hand calculations it is incredibly difficult get accurate results, although it may be able to produce results that are close assumptions.

Using hand calculations can be useful, this along with using the 'slide ruler' is the basis to the mathematics for the rocket/lunar lander that managed to put man on the moon. Although the true detail and accuracy cannot be calculated, it is capable of reasonable results.

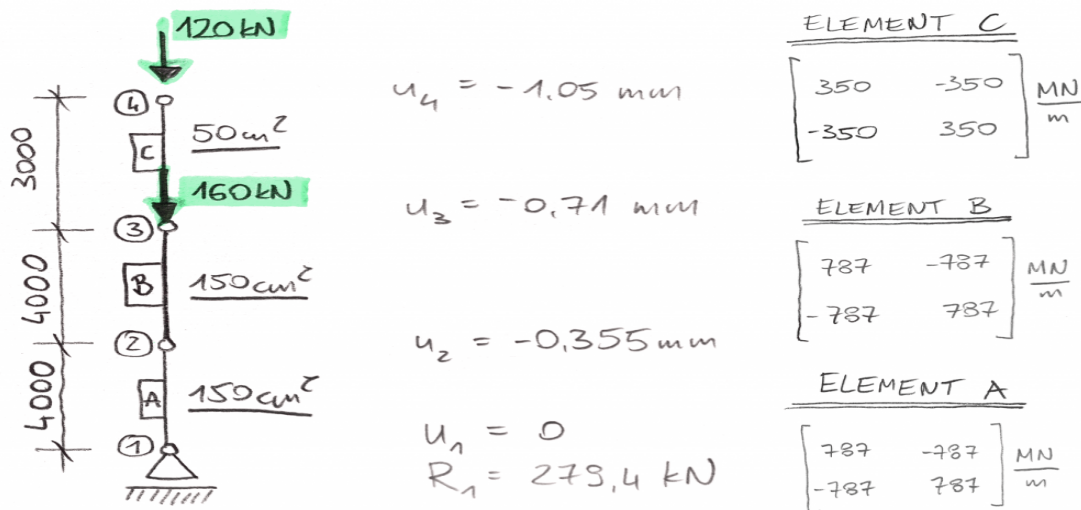


Figure 2 Example of hand calculations (Can You do Finite Element Analysis by Hand? | Enterfea, n.d.)

The key to remember when doing hand calculations for FEA is that the number of equations is equal to the number of unknown degrees of freedom. With each nodal point, three degrees of freedom is added, for more accurate results more nodal points are created. Constantly increasing the complexity of the mathematical equations.

THIS DEPENDS ON YOUR ELEMENT CHOICE, IT COULD BE 6.
WHAT IS FEA?

Finite Element Analysis is the simulation of a part under certain conditions that the part/assembly may be under in real conditions. This is done by using specialist software (such as Solidworks/ANSYS) where the software can use complex mathematical differential equations to analyse how the part will react to certain scenarios. By using a

mesh and splitting the part down into potentially hundreds of thousands/millions of smaller elements that can be calculated and then put together at the end. One thing that is worth noting is that these calculations are only assumptions, albeit incredibly accurate assumptions. Interpolation and polynomials are used, which means that at certain points the information is known, these are called nodal points and sit at the end ends of the elements. The middle of these are then the calculated estimations. (*What is FEA | Finite Element Analysis? — SimScale Documentation*, n.d.) Once the calculations for all elements are completed, a model can be produced like below:

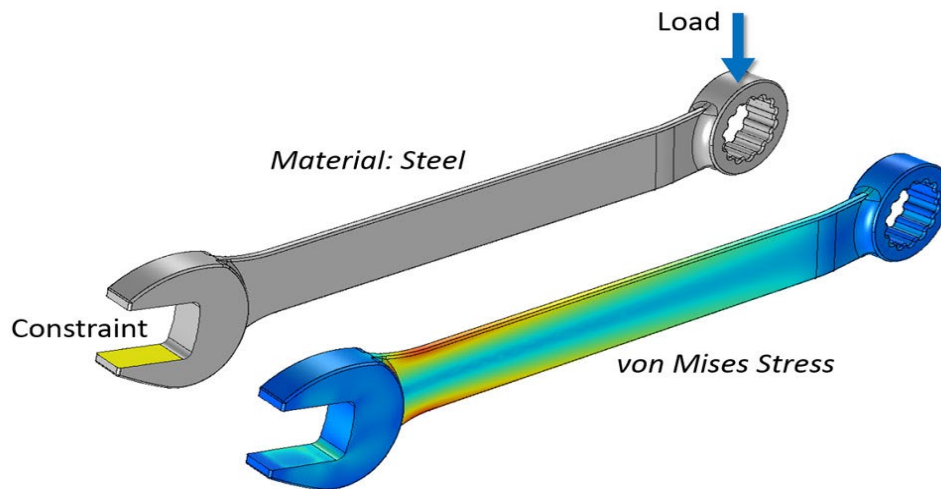


Figure 3 Showing the load and the resultant von Mises stress (Finite Element Mesh Refinement Definition and Techniques, n.d.)

FEA can produce multiple stresses for the results, these include von Mises stress, displacement, and static stress among many others.

How to produce a reliable FEA model

The key to producing a reliable and accurate FEA model is in the preparation of the model and being able to simulate the forces as close to a physical test as possible. This is done through various ways, the first aspect that must be correct is where the load is on the part and the amount of load that will be occurring at each point(s). If this is done incorrectly the part may deform unexpectedly, it is necessary to fully understand how the load would affect the part before applying the load.

Another important part of the model that needs to be correct is that the material is the right one, with different materials having a variety of characteristics. Although a material may be similar, the stiffness, elasticity or how it deals with heat could be different from the physical material and this could have a large impact on the results of the FEA.

Once the load is in the correct place and the material is correct, how the part is restrained and loaded in another crucial part to avoid problems and incorrect results. If the part is over/under restrained it will be unable to perform as it would in real conditions, giving unreliable results. This could be that the results show the part would easily perform the desired tasks, however when physically tested the part would break due to the real forces being loaded into the part in its real conditions. (Donnelly, 2016)

Why do companies carry out FEA alongside physical testing?

FEA is an incredibly useful tool for manufactures of parts, it allows a middle stage of production when compared to not using it. It allows the initial concept to be viewed in 3D and 'tested' without having to produce the part in the real world and that additional costs that come with that. Although designers try to get the design right first time for the job that is being required, sometimes other aspects have not been accounted for that could cause the part to fail. If FEA was not completed, to know about this failure the part must first be produced and then tested under the conditions that this part must be under. If the part were to then fail, the time and money put into this part has been wasted, not considering the potential for injuries while testing the part. The designer will then go back to redesigning the part to make sure this issue does not occur again. The process will then be repeated.

Whereas, if FEA was being used alongside this, the failure could have been spotted before the expense was paid for the prototype. By using FEA, the conditions that the part would have been under could have been replicated, for example. When designing a connecting rod in an engine, the part can first be created on CAD and then a FEA study can be conducted on the part. By using cylinder pressure data that the part would be under, this load can be put onto the part to attempt to replicate how the part would perform and the resultant forces that would occur on the rod. Once the part can perform in the FEA model, a prototype can be produced from these designed and the physical testing can begin on the part. It is worth noting that many manufactures will continue with the CAD and FEA to continually make improvements on the part so that it can perform better and possibly reduce the material (for weight or cost saving) while physical testing is occurring. Aiming for the results in the physical testing to replicate the results in FEA software's. FEA software can see stress, thermal conductivity, vibrations, and many other situations that parts may be under while in use. By being able to replicate this before physical testing allows for potential cost saving in the reduction of prototypes that need to be made. (*Why Use FEA?*, n.d.)

The best option for a company/engineer is to coincide the FEA and the real world prototyping, first starting with the FEA with the design, making sure it is capable of dealing with the desired situation, seeing where the potential weak spots and issues may be. Once the real world prototyping has been completed for the first part, the FEA can

then be revisited to adjust for any issues that occurred during the real world testing and seeing if any modifications can be made to the part to improve it more. After this the real-world testing can be completed again, this process can be repeated until the product/part is performing as desired. Moving from older 2D Design to 3D design and FEA saved Joseph Rhodes Limited £114,000 while producing rubber dye presses and knuckle point presses. (Ramakrishnan, n.d.) Supporting the suggestions that using FEA can save a company money over time, while increasing accuracy and the speed.

How a physical test may be correlated to an FEA model.

If done correctly, a FEA model can produce a fair representation of a physical test, for example an ISO Tanker used to transport liquids are required to pass stringent testing. The tanker had failed on the dynamic testing, where the tanker is subject to a 5G crash, it can permanently deform by 3mm, whereas this tanker failed, permanently deforming by 5mm. (Tiernan & Fahy, 2002)

To resolve this a FEA model of the tank crashing was completed and a variety of modifications were made to the tank to make sure that it is capable of passing the test. A redesign was completed on CAD, this required 8mm hexagonal plates and 8mm stiffeners at the bottom of the tank. Although other options were first considered, one option was to just up the 5mm stiffeners to 15mm, however when this was tested, the tank still permanently deformed to 5mm. The next option that was tried 8mm hexagonal plate, under the test conditions this deformed around 1.5mm.

The test was first completed on the FEA model with the new design to see if it was capable to passing, it was predicted and shown through the FEA model that the permanent deformation would be around 1mm compared to the original 5mm. Theoretically passing the inspection and becoming ISO approved. (Tiernan & Fahy, 2002)

Running FEA alongside physical testing also allows errors to be found and this allows errors to be rectified, this was experienced by GKN while testing tooth root stresses on hypoid gears. It was noticed that physical testing differed drastically compared to the FEA projections. These FEA test were rerun followed, followed by rerunning the physical testing, when running this it was noted that a sensor that was being used to measure stress in the physical testing had an issue, this was due to the sensor not being in the correct place. This meant that it did not pick up on the peak stress that the gears were undergoing, whereas on the FEA model it was able to pick up on the highest stress and this is where the largest discrepancies were. (Gregfors, n.d.)

Can FEA ever replace physical testing?

Finite Element Analysis is an incredibly useful tool when designing and manufacturing a part, being able to reduce the number of prototypes that need to be produced and tested cuts down on cost and time. However, this begs the questions on whether physical testing can be completely cut out and using only the FEA results to produce a product.

In a purely theoretical way, FEA could take over from physical testing. In a perfect world if the FEA modelling on the part has been done correctly, including the correct material, correct restraints and loading on the piece, this would show how the part will perform in a physical conditions and as long as the part is perfect and no other forces occur in the part. This would require perfect material that has no cracks or areas of fatigue and is perfectly able to replicate the theoretical model that was produced on CAD for the FEA. There can then be no stress concentrations on the part either as these could break when they did not occur on the FEA model. When loaded into the desired job, it would have to be under the same initial loading and strain that the FEA model was under as well to be able to perform as the FEA did. Although some FEA software's do allow for fatigue over time and this would be factored into the part and the model. It does not consider corrosion, dirt, and minor damage that some parts may receive, apart from FEA may work straight away for a period of time but could potentially fail at another point.

In the real world, this is impossible to achieve, especially on a mass production level, physical test need to be completed to see how the part would react under the real loading conditions and the potentially imperfect material that may have been used to create the part. One of the potential ways around this is to use nondestructive testing alongside FEA, although a more costly route due to needing to produce the test parts and run the testing as well as the time and cost of running the FEA side. However, by using FEA to find the max stress/load that the part can withstand before failure will allow a part to be produced that has that load well within reach. Then an FEA model can be run where the part would be under normal loading conditions, this data can then be used as a comparison to the nondestructive testing that can be completed with this part.

This manufacture model was used when proposing a new manufacturing technique for part of a fuselage on a small private plane. Previously the part had been made out of multiple sections, due to 'Joining and assembly accounting for up to 30% of a product's total manufacturing cost and up to 50% of its total manufacturing time' (I. Mendoza-Muñoz, 2015) it was decided that producing the part as one piece could potentially save money and time for the company.

Using FEA and nondestructive testing together, it was concluded that the new design was able to deal with the stress better, therefore suggesting that the stiffness of the new one piece part is greater than the original multiple piece that has to be joined together. The nondestructive testing required sensors being put into place, these were rectangular rosette strain gauges. These measured $0.5156\text{m}\epsilon @ 46.44\text{N}$ for the physical test for the new

piece and $0.7012\text{m}\epsilon @ 46.44\text{N}$ for the original multiple piece design. The FEA design supports the nondestructive testing, with the new design getting 0.4796 using FEA, and the original multiple piece design getting 0.7793 using FEA. These results are close in regards of the FEA vs physical testing and they both follow a similar drop in strain measured from the original to the one-piece design.

With this FEA modelling and the physical testing, it can be suggested that this new design is better than the original design that was used on the plane and if it was possible; the new design should be accepted and used on the plane in the future.

Conclusion

In conclusion, finite element analysis is an incredibly useful tool that when implemented into a product at the right stage can be used to reduce cost and time on real world prototyping and testing, potentially even making the process safer for the people testing the components. However, due to FEA considering all parts to be perfectly made to that specification, it does not take into account circumstances that the company may have no control over, such as material that maybe isn't perfect or dents/knocks that may occur in transport that would inflict stress concentrations in the piece. Meaning that when the product is tested, although it worked perfectly on the computer, with these extra stress concentrations that part has failed. Although the FEA software is always improving and changing to take more of these errors into account so that the FEA can be as close to the real thing.

Overall, FEA is an incredibly important tool when designing and producing various parts/products, however in the real world it currently can not replace real world testing of the product. It can certainly reduce prototypes and give indications of the problems that will occur before the product is produced so that these errors can be changed before the product is made, ,but a part/product should still not go from FEA modelling to mass production in case errors that can not be known to the software occur and the part does fail. For the best results, FEA and real-world testing should be used together to make a inferior product/part in a shorter and most cost effective time frame.

References

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THIS IS A REASONABLE REPORT, ALTHOUGH IS OVERLY SUBJECTIVE IN PLACES.