

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	THOMAS	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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
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	17.1
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	19.5
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	20.1
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	6.6

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)		63.3 %
	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			

University of Wales Trinity Saint
David
School of Engineering

Can FEA Replace Physical Testing?
Advanced Stress Analysis & FEA
M6X00420

Nicholas David Thomas
1702567
29/03/2020

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1 Introduction

Finite element analysis or FEA is the simulation of a physical phenomenon acting on or around an object using the finite element method (Simscale, 2020). It is used to design and optimise ~~the~~ structures so that they are not only strong enough to withstand the loads but also not too strong to add extra weight so they can be faster or save on material costs. Moreover, it is also used to analyse the objects to see their characteristics. It can also be used to verify existing products (Caliber Design, 2020). The way this is all calculated is that the object is split into finite elements which are then each calculated in an iterative process using differential equations. The elements come in different shapes which are suited for each case such as tetrahedra (triangles) polyhedral (polygons) etc. They also come in different dimensions depending the complexity of the part e.g. 0D, 1D, 2D and 3D. Another part of the mesh which differs is the number of nodes in the elements themselves. The more nodes there are the more accurate the model but there is an increase in computing time as each node needs to be calculated.

Often in FEA the geometry in FEA is simplified. This could be taking of a fillet from a louvre or removing a hole which has no effect on the stress concentrations. This could be done for a number of reasons. One is that simplifying the mesh may make the model run quicker as there is no need for so many elements. It can also improve the quality of the mesh by reducing the number of skewed elements (elements that have deviated from the proper shape e.g. equilateral triangle to a misshapen triangle). In some cases, simplification can go as far as running a half model if the body and loading is symmetrical. This could mean that the mesh could be made even finer for the same amount of run time as the model is half as big. However, there maybe errors introduced by simplifying the model which need to be considered along with a reduction in accuracy.

2 Why use FEA

Why companies typically carryout FEA alongside Physical Testing?

FEA is used for a number of different reasons one of which is noise vibration and harshness (NVH). This is the study of the vibrations within things such as engines and cars which cause noise (X.Wang, 2010). FEA can be used to calculate where the vibrations are coming from, so that they can be dampened therefore the vehicle does not shake itself apart (Panda, 2015) such as a bridge. This is used on monocoques of cars as they need to make sure that vibrations are not resonated through the monocoque into the car disturbing or giving discomfort to the driver. FEA can also be used for stress analysis. This is used to test that when a load is applied then it can show where the stress concentrations are on the part(s) and if they will break. An example this could be on a race car monocoque (Kamble, et al., 2019). A load is applied and then this gives a location of where stress concentrations are so they can be strengthened in that area or weakened in areas where there are no stress concentrations. Although for a monocoque this is generally used to see if the part will break under certain load as it is a safety device. It can also be used to find the stiffness as this can affect the handling of the vehicle.

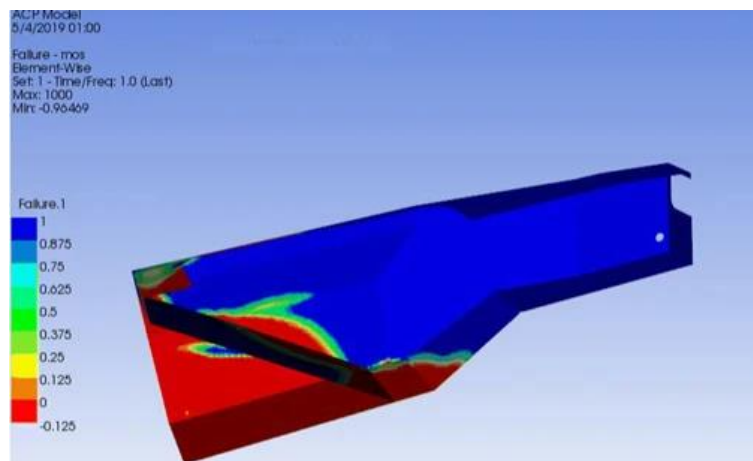


Figure 1-Monocoque undertaking Stress Analysis in FEA (Kamble, et al., 2019)

FEA can also be used for fatigue analysis which is often found to be the most common cause of breakage. This is where a component is put through a simulation of how it will react after it has been cycled through stresses a number of times (Abbey, 2013). Depending on the situation the number of cycles may be different. An example of a shorter-term analysis could be the first gear of an F1 car which only needs to be used for a very small amount of time. An example of a long-term use could be a bridge. This can be important as you want to make sure that the part will last long enough for its intended use but not too strong that it wastes material and mass. This can be done in a number of different ways such as linear (where the material

does not go into the elastic region), non-linear (the material goes into the elastic limit) and dynamic (the loads vary with time).

FEA also is used for crash analysis. This is the modelling of an object of when it is being crashed into. A big use of this is in the motorsport and automotive sector where strict regulations are put on the vehicle to make sure that the inhabitants are safe in an event of a collision (Advanced Engineering Solutions INC, n.d.). An example could again be the monocoque which has parts built in to crumple in an event of an accident to slow down the impact. Therefore, reducing the effect of the crash by reducing the forces acting on the passengers.

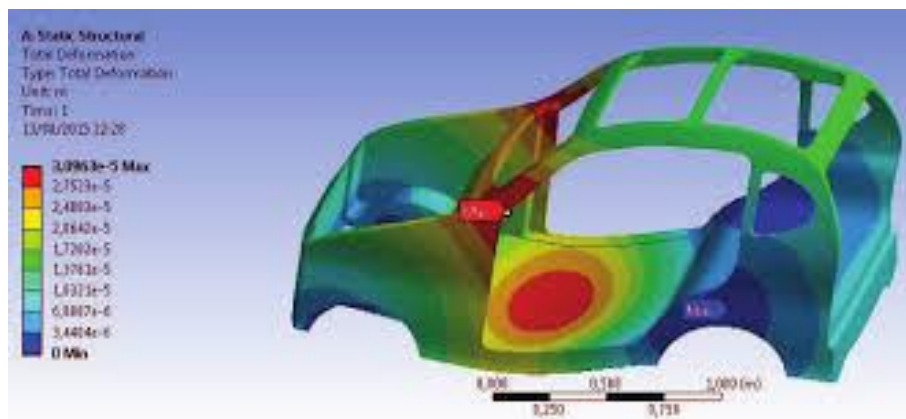


Figure 2-Monocoque Undertaking Crash Analysis (Makhrojan, et al., 2015)

There is also buckling analysis, which is analysing the stress acting on usually beams when under compression. This is used in cases such as conrods in compression to see if they will be able to withstand the loads. It can also be used to see the deformation of a beam so if the part was meant to deform to see if it deforms enough (Kurowski, et al., 2011). This comes in two varieties of linear and non-linear. Linear is when the load is applied in one step rather than with non-linear where it is gradually added on. Non-linear is a lot more complicated because as the load is added at each step the deformation changes and therefore the parts stiffness changes (Ellobody, et al., 2014).

There is also fluid and thermal dynamics. This is the modelling of the transfer of a fluid which could be air or water (Fu, et al., 2018) and the propagation of heat (Sun, et al., 2010) respectively. These can be used to design the bodywork of a race car or the transfer of heat across a heat sink. These can also be used in conjunction to model the heat transfer say through a car radiator (Sathyan, 2016). This still uses the same process of meshing and then solving. However, using the finite volume method rather than the finite element method. Another way which combines multiple analysis types is brake analysis. This uses thermal

transfer, fluid flow and stress analysis to see whether a brake disk won't break under load. It is also used for NVH to make sure it does not groan or squeal under stress (Abbey, 2014).

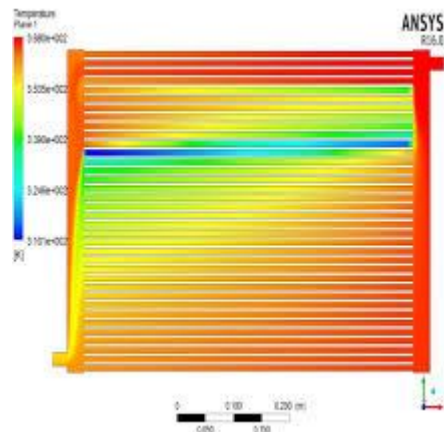


Figure 3-Car Radiator Having A Heat Transfer Analysis (Sathyan, 2016)

The benefits of using FEA is that using the analysis type above they can be combined to optimise a product. This means that a part can be strengthened in areas that needs it and weakened in others that do not (Bhardwaj, et al., 2018). This means that the material is in the area that is needed so that the mass is as low as possible. In turn this could save material costs. Not only in the final product but also in the prototype stage as less prototypes need to be made. There is also a time saving as the prototype does not need to be machined. The aging process can also be accelerated so instead of weeks to go through cycles the process can only take a few minutes to a day depending on the complexity of the model. Another benefit is that it is better for the environment as material does not need to be wasted to make prototypes which are just going to get destroyed straight away. It also means that the test conditions are consistent so that any changes in environment can be negated. Therefore, the results are more repeatable. FEA has the advantage of having the structures of the results rather than just data points. This could be the flow structure from the wake of fluid flow or could also be the structure of the stress concentrations.

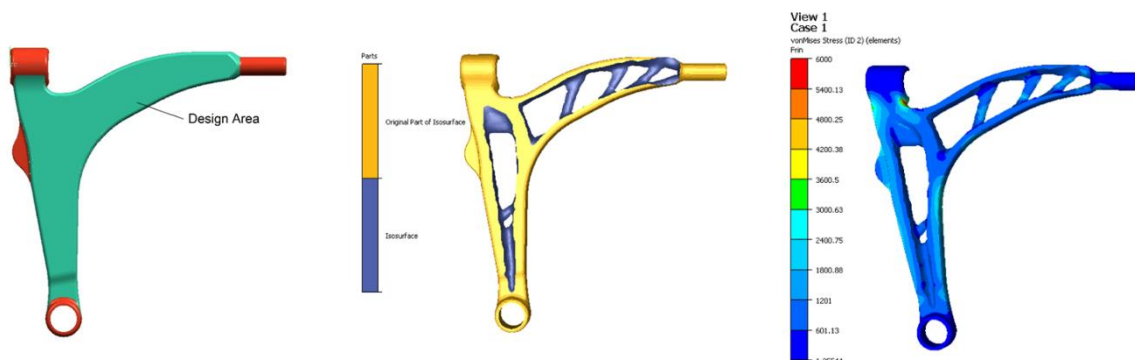


Figure 4-Part Being Optimised in FEA (Broekaart, 2019)

THIS LOOKS LIKE AN
INTERESTING STUDY. BUT WHY
IS THIS FIGURE HERE?
REFER TO IT IN THE TEXT!

However there is still need for FEA to be used with physical testing as the results of the FEA may not be correct so they need to be correlated with real life (Davis, et al., 2011). Nonetheless, once correlated any changes made to the geometry can be fairly sure that the same thing will happen in real life. In some cases, the actual value does not matter so much but rather the trends are, but the value should be fairly close. Such as in fluid dynamics it's the change in the lift and drag value matters more than the actual value itself when comparing to track and wind tunnel data. To add to that having FEA and physical testing just validates each other so that you are sure that in a real-world situation that the part will perform in the way it was designed. An example could be shaker rigs used to put loads on a car which can then be validated with the FEA (Campbell-Brennan, 2020).

ALSO, REGS MAY REQUIRE
THIS.

FURTHER DETAILS OF
FEA ON THE DESIGN PROCESS
IN TERMS OF COST & TIME
WOULD HAVE ADDED TO THIS
SECTION.

3 Correlation

How a physical test may be correlated to an FEA model

FEA can be correlated in a number of ways. One of which is using a multitude of different sensors whilst carrying out a physical test. An example of these is a PVDF film sensor which collects data on frequency and modal parameters (Wang, et al., 2006). Sensors can be as simple as a DTI gauge to measure the deflection of the material which is put under a certain load. This can be taken further on with equipment such as (Dantec Dynamics, 2020) which uses 3D imaging to find the strain acting in the part such as a human jaw (Groning, et al., 2009). In some case temperatures sensors are also used to measure the heat transfer across an object. This could be as simple as temperature strips which measure the temperature that a damper gets too around a track or it could be an infrared camera measuring the tyre temperature around a track. Slow motion cameras are also used in crash analysis to see how the vehicle deforms along with accelerometers to see the forces acting through the vehicle and passengers on impact.

Along with using these sensors there a number of tests that are used to also validate the results. This could be a day on a racetrack or a shaker rig. To add to that on individual parts a fracture test could be used to find what force it takes to fracture a part (Plummer, 2014). To add to that there are several compressive testing methods such as using a hydraulic press, used to measure the deflection of say a tyre (Hart & May, 2019). Tests are also used on torsional stiffness to make sure that monocoques are stiff enough so that it does not upset the handling of a vehicle (Marabini, 2005). There biaxial and uniaxial tension and compressive experiments which is essentially material being stressed in two directions for biaxial and uniaxial is a load acting in one direction (Zillmann, et al., 2015). This can be often used with composite testing as different layups can give strength in different directions.

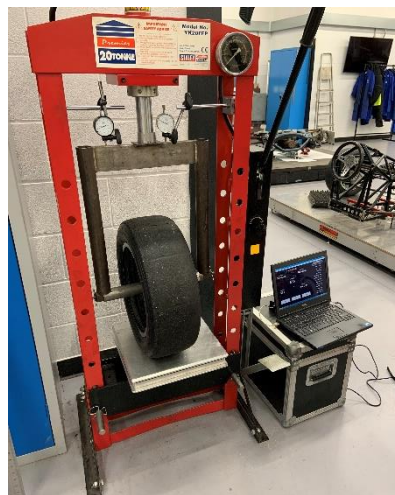


Figure 5-Tyre Stiffness Test (Hart & May, 2019)

However, if the physical test and the FEA do not correlate then it may be the model itself that is incorrect. It could be perhaps that the number of elements is not enough to pick up the finer details. There is a trade-off though, as the more elements there are the longer the computational time is. So, there is a limit on is it worth running a simulation for a week rather than an hour or so for an extra bit of accuracy. This can be solved by making the detail around areas where there are large changes in stress or pressure. On the flip side, areas with not much going on, the elements can be made bigger to reduce run time. To add to that the actual location of where the loads are taking place could be slightly different to a physical, more over it could be the solver being used. There are different solvers which are better suited for different situation such as an iterative solver which can be split into the Jacobi method, Gauss-Seidel method, SOR and JOR Method and a basic CG solver. Then there are non-iterative solvers such as the Cholesky Solver and direct solver (Rieg, et al., 2014) Each have their merits with trading off accuracy for iteration time. All of the solvers can be boiled down to two types, explicit and implicit. Explicit is more complicated but it introduces less errors between each iteration. Implicit is simpler so it can iterate quicker but it introduces errors at each iteration so this reduces the accuracy of the model (Harish, 2019). But it could be just be as simple as the loads have not been input correctly, a unit is incorrect, or a material has a different Young's modulus to what you are trying to model.

Another way in which FEA and physical testing can be correlated is with sweeps. An example could be that different variations of a design can be run in an FEA package and then the same tests can be performed in real life. The trends of these results can then be compared. If they both have the same trends they can be classed as correlated but has a percentage difference. As long as the engineers know that percentage difference can be factored in into the final design.

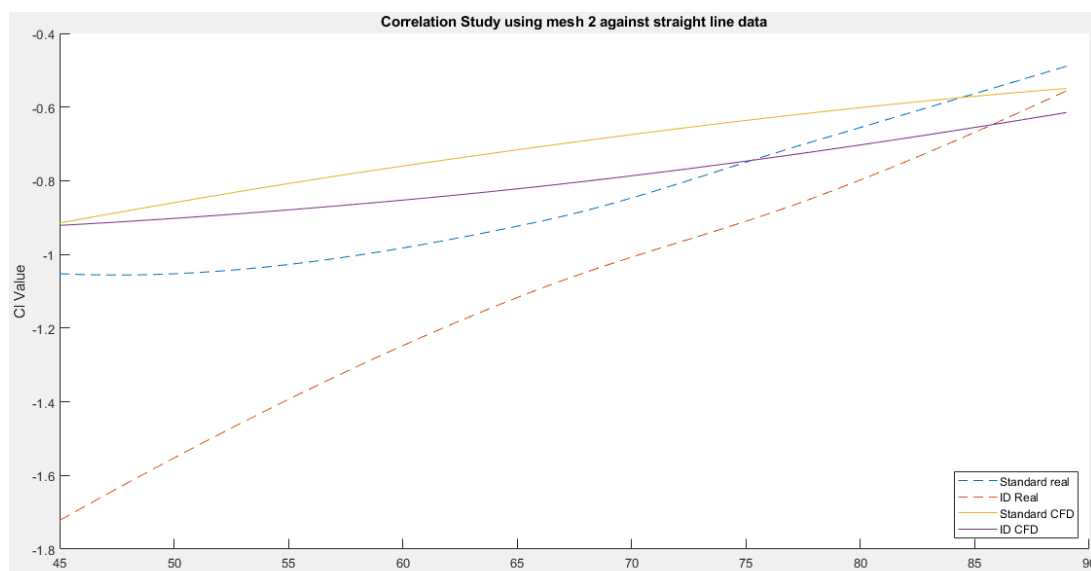


Figure 6-Example of Correlation Sweep (Thomas, 2019)

There are many different analysis methods which can also be used to compare the results. An example is spatial correlation which compares a point on the model to see how they compare from physical and FEA. To add to that there's different types of shape correlation so checking that the shape of the deformed object matches. Moreover, there is frequency response comparisons to analyse that the resultant frequencies are the same (FEMtools, 2020).

4 Future of FEA

If you think that FE analysis can (or should) ever replace physical

In some ways the author believes that it is perhaps possible to replace physical testing with FEA. Computers are becoming ever more powerful with computing power doubling every year proven by Moore's law (Encyclopaedia Britannica, 2019). This means that the calculations a computer can carry out are becoming ever more complex meaning that the accuracy can increase. (Harish, 2018) believes that the accuracy of CFD and FEA is always increasing with the algorithms becoming more accurate. There is even the possibility of quantum computing bringing an infinitely greater computing power than what is currently possible which would make it possible to run highly complex problems.

The meshing of the part, which is often the most difficult part, is ever becoming more accurate. A mesh is the geometric representation of the object being studied using small elements. Generally, the smaller the element the closer representation to the actual object and therefore the model is more accurate (Nguyen, et al., 2015). However, as each element is calculated the more elements are introduced the longer the solve will take. A new field of study called isogeometric analysis is making this more accurate. This means that ever more complex shapes can be modelled fully without the need for simplification. Isogeometric analysis uses splines to represent the geometry rather than straight lines which also means that a higher order degree of continuity is achieved (Borst, 2016).

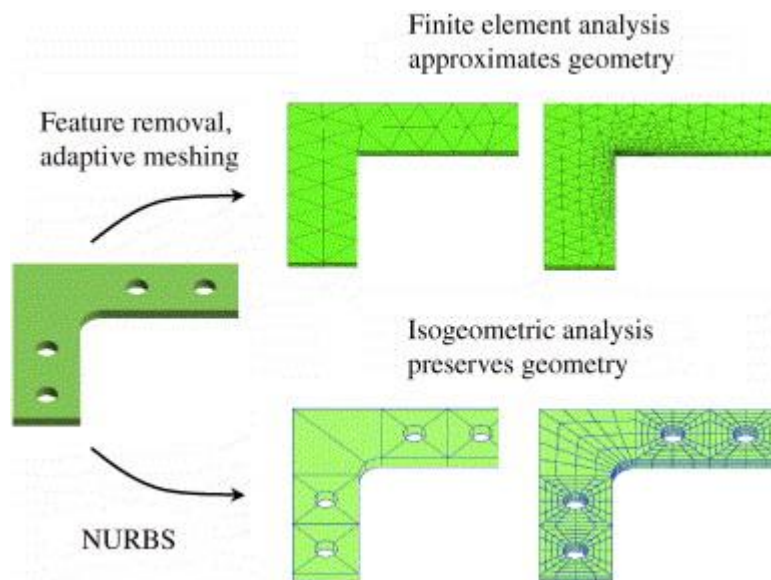


Figure 7-Example of Isogeometric Analysis (Cottrell, et al., 2006)

There is also a number of benefits to only using FEA. The time it takes to analyse a part is significantly less using FEA. The reason for this is that instead of having to go through a large amount of red tape such as risk assessments and then prepare the whole physical test you can

set up FEA in a matter of minutes depending on the complexity of the problem and get an answer. Along with this there is also a time saving with the manufacturing as a monocoque may take a few weeks to layup in carbon fibre but the CAD to analyse is there ready. These all together can save weeks to perhaps months of a product which can reduce the costs of the project significantly. There is also a cost benefit as instead of having to pay for material and the time of someone to machine said part(s).



Figure 8-Example of Monocoque Crash Testing (Grand Prix Insights- Monocoque (Including Spectacular Crash Test), 2012)

There are however some drawbacks to using just FEA. As there is no physical test to correlate a designer can never really be 100% sure that their model is correct. As there is so many different ways of setting up a model, without physical testing then there is no way to find out if the answer given is fully reliable. To add to that there is also errors in the calculations that the software uses. So, until computers are powerful enough to calculate to the nth degree there is always going to be errors in the FEA (Murad, 2019) from the assumptions in the calculations. But without physical testing there is no way of finding out how much that error is. Moreover, physical tests will always be needed to find out the strength of new materials. It could be that a new form of steel is made but without physical tests there is no real way of finding out how the material behaves when put under a change in condition.

In conclusion the author believes that FEA will replace more physical testing in the future. However, there will always be need for physical testing to validate the answers given and the need to test new materials to put the data into the analysis.

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