

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	HAU	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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	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	16.2
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	15.9
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	5.8

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)		53.5 %
	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:			

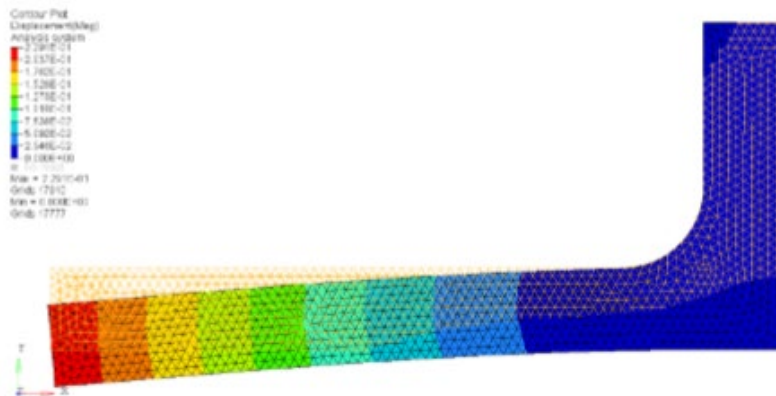
This section repeats in brief the common assessment criteria detailed on previous pages. The *extent* to which these are demonstrated by you determines your mark. Using these criteria, tick the box that best indicates the level of achievement you feel you have achieved with regard to each of them.

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			

CAN FEA REPLACE PHYSICAL TESTING



ADVANCE STRESS ANALYSIS & FEA

BENG MOTORSPORT ENGINEERING

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1 INTRODUCTION

In today's industry, it is normal practice for companies to carryout Finite Element Analysis (FEA) alongside physical testing. In this report we will try and understand why this is so, also to look at areas where physical testing may be correlated to FE modelling. The report will then look at the evidence from both positive and negative perspective in the use of FEA and to decide whether physical testing can or should ever be replaced by FEA.

The report will initially look at the origin of FEA and how the analysis system works, then the report will turn to the challenges companies are facing in the commercial world and how FEA can help. Then the report will discuss the various different ways of correlating physical testing to FEA, where FEA can helps to validate design concepts or predicting and correcting product failure, with further discussion on the topic of replacing physical testing with FEA.

2 WHAT IS FEA

To understand the relationship between FEA (Finite Element Analysis) and physical testing. It is necessary to understand what is FEA.

FEA is the computerized analysis method to envisage how a manufactured product will react to the physical world. The analysis helps with understanding issues like how the product will behave in the real-world physical condition as it is exposed to Forces, Heat Transfers, Vibrations, Fluid/Air Flows and more. FEA is then used to predict if the product is going to Break, Tear, Wear Out or behaving in such a way that it is supposedly to do as it is manufactured for.

2.1 FEA Design

FEA allows any design of products or equipment to be analysed in detail, it is also beneficial in the analysis of more complex materials such as carbon fibre. In some industry sector, FEA analysis can be a prerequisite to certification or validation of components.

The designs can be constructed, refined and optimised before the product or prototype is manufactured. FEA can be used as a 'standalone option' or as part of a suite of analysis options that are used in developing and evaluating a product during the design process.

There are Computer Aided Design (CAD) product in the market that are with FEA function, although most of these products are as powerful as pure FEA products, they could still provide simple solution for the user, these types of product have become more powerful, and CAD product has become more user friendly and diversified.

2.2 Pre-Phases

There are fundamentally three main phases in FEA, Pre-processing, Analysis and Post-Processing during the pre-phases, all setting determine the accuracy of the FE model. Below are the key factors to achieve greater accuracy:

2.2.1 Material Information

Normal FEA package would provide several material's information to the user. The user can customise own material information to generate more accurate result.

2.2.2 Meshing

FE model are made from numerous elements, the elements are then combined to recreate the origin model. Each element has a few nodes, the nodes are the point to apply equation to calculate for the result. The mesh model will not be identical to the origin model, since to make an identical true model requires infinite number of nodes. In theory the more elements and nodes used in the meshing model translates to a more accurate result. However, the computing power or time needed to solve the model would increase accordingly.

2.3 Different FEA Models and Use

FEA can calculate 1D, 2D and 3D model. Before engineers use Finite Element to help solve engineering problems the structural analysis was restricted to elements connected to only two points in space. The development of FEA had first started with structural analysis restriction to 1D, later evolved to 2D and 3D analysis (Wilson, 1999) Even though 3D analysis could provide more accurate calculations and results, to save time, 1D and 2D analysis are still widely used for basic tasks. For example, to proof of concept and correlation.

Tube structure often used 1D analysis to save time. However, it could not analysis plane structure such as supporting plate, therefore a mixture of 1D and 2D analysis could be made for that purpose.

In 3D FEA model brick element can provide a better quality meshing, but the meshing and solving time will be longer, the Tetrahydro Element have the worst quality due to the angle of the elements, but its solution time is faster.

2.4 Yield Criterion and Force Loading

There are two type of forces that can be applied to the FE model, static and dynamic loading. Static loading is to apply one loading once and then review the results, while dynamic loading means applying the same or different loading in a period and looking at the results at the FE model through that period.

There are also equations to calculate such as the reaction from the material to the forces, the different type of material requires different type of yield criterion, the common type is Von Mises, where Von Mises Stress is a value used to determine if a

given material will yield or fracture. It is mostly used for ductile materials such as metal (Simscale, 2020).

2.5 Analysis

During the analysis phase, the result is being calculated. There are CAD product with FEA function in the market which will automatically go back to the pre-processing phase and refined the model for result analysis immediately after calculation.

2.6 Post Processing

Post processing is where the user can extract and view the results. The user can look at the results and draw conclusions. There are lots of results that can be calculated though FEA. The list below are the solutions that could be found using FEA from the automobile industry (Crisfield, 1995), different type of results could be found in one FEA simulation.

- Stress Analysis – Stress, Strain, Failure Points, Fatigue, Creep
- Thermal Analysis – Conduction, Convection, Radiation, Conjugate Heat Transfer
- Vibration Analysis – Modal, Harmonic, Random, Transient Dynamic
- Seismic Analysis – Equivalent Static, Response Spectrum, Transient Dynamics
- Impact & Crash Analysis – Equivalent Static, Short-Duration Explicit Simulation.

There are two results that are often look at, the displacement of where the product had deformed, so that the designer can improve on the weaker parts of the product. The other is the stresses on the product, whether the stresses can be applied evenly, and is there any concentration points to cross to avoid inaccurate results.

3 ISSUES COMPANIES FACE IN THE COMMERCIAL WORLD

Before FE methods were introduced to help solve engineering problems, products were often being over-design with redundant and costly Factor Of Safety (FOS) features. In order to eliminate or to minimize such wasteful features, it was necessary for engineers to deploy the “Build and Break” Cycle, where initially a prototype (with enough FOS) is built, this is then tested. From the testing results of the experiment on the prototype, necessary change in design and further prototype production and testing were further carried out, this process was then repeated at the high cost and time to reach a final satisfactory product (MacDonald, 2011).

3.1 Costs and Time

Today, the target project timescale from concept to prototype definition are very aggressive in the automobile industry, with a typical timescale of no more than 18 months from product conception to finished prototype. The JOINING and ASSEMBLY

needs of manufactured components can account for up to 30% of product total manufacturing costs and up to 50% of its total manufacturing time (Kraskiewicz, 2015).

3.2 Criticality of the Correct Product

The increasing use of common auto-parts and common auto-suppliers across multiple model lines, as well as multiple automakers, puts ever increasing pressure on getting the product right first time for component manufacturers.

In 2016, passenger vehicles recall by manufacturers in the USA had reached 53.2 million units, representing an increase of 7% when compared to the previous year. Such costly exercise helps to remind us time and time again, to minimise or even to eliminate mistakes before going into full production (Gareffa, 2017).

4 BENEFITS OF FEA FOR COMPANY

As computation power grew exponentially, outstripping the speed of FEA development itself, we can now see FEA application applied in all major engineering disciplines. Today, it is a fact that Finite Elements Analysis requires the power of computers, for without computers the FE methods of analysis would be like trying to move an automobile without a motor! (Crisfield, 1995).

4.1 Reduce Physical Testing using FEA

The benefits of influencing design earlier can reduce the number of design cycles, and thus eliminating much of the physical testing needed, analysis is KEY to product design. it can help estimate the performance of a product before it even exists. With the application of FEA, it can also identify the causes of existing or potential product failures, it can be used to help design and optimise new solutions within the constraints of any existing geometry.

Enhanced design and early evaluation of critical design parameters by Virtual Prototyping capability, meaning fewer physical prototypes, are required and which are aligned to rapid prototyping, this method is efficient and less expensive for the design cycles, it helps to increased productivity and profit.

4.1.1 Less Risk in the Design Process

Reports can be produced as part of quality control and audit processes, it helps to maximise performance through material selection and cost-efficiency, reduced R&D and development costs.

4.1.2 Certification and Verification

The simulation data output is only as good as the input data. We have the engineering experience, expertise, and calibre to identify any potential anomalies, this will help cross-check and carry out calculations to ensure the data output is correct.

4.2 Material Choice and Cost Consideration

New materials are constantly being developed to address new consumer demands, like performance, customization, personalization, sustainability, and countless more. With these new engineered materials come new manufacturing processes that have interrelated impact on the material performance.

FEA is a digital way to test designs, built with various materials not only limiting to metallic materials, but can also be Plastic, Rubber, Ceramic/ Composites etc, against predictable forces to determine whether a design will fail, and if so, when and how the material will deform, snap, or collapse. The failure penalty for components are high, as a result, any spending on FEA to product development projects can easily be justified.

4.3 Problem with Large Structure Testing

It is not realistic to build a full-scale test for some products, due to the time and cost needed in building one. For large structures, such as a building on the ground or a rocket ship for the sky, FEA can help to analyse the whole structure.

The FE Method had been an analysis tool that complemented many engineering with their analytical and experimental research activities, such as in the below engineering projects (Wilson, 1999):

- Reinforcing Buildings and Bridges.
- Earthquake Study & Engineering.
- Bridge and Flyover behaviours.
- Manned Space Program.
- Offshore Drilling to Nuclear Reactors, the analysis in the use of new materials in mechanical engineering.

5 CORRELATING PHYSICAL TESTING TO FEA

When checking for computation accuracy, we can also look at the correlation it has with any actual physical testing results, often simply by manual calculation checking the mathematical result with the algorithmic computed results. This manual testing data can also be collected by physical measurement from physical models and prototypes.

Where the physical strain gauge measurements and stress comparison readings can be correlated to the strain energy and residuals result data from the FEA, where physical natural frequency comparisons can also be correlated to the reaction forces and moments data from the FEA

When faced with non-linear FEA, no matter how robust the built-in model can become, engineers will appreciate there will always be the potential for the structure to suffer Elastic Knockdown, that is why there is the stronger need for physical testing on

prototypes. Engineers must always bear in mind that any compressive axial load on a structural member will tend to decrease its bending stiffness and vice versa for the tensile axial load (Ross, 1998).

5.1 Verification and Validation

It is very important when designers are using FE model to change the design, they must first correlate the baseline before suggesting any changes. If the baseline design does not correlate to the test results, confidence on any of the designer suggestions will be irreparably damaged.

Baseline for validation are set differently for different industries, one would expect a tighter standard for the aerospace industry. In general, a 5% to 10% difference in FEA solution to the physical test can be considered as an acceptable result.

5.2 Checking Mesh Quality

Designers must ask if elements in the critical areas/regions need further refinement, the aim is for the mesh to be representative of the true shape of the physical object.

Below are 2D samples of meshes (Lake, 2020):

Mesh refinement of different sizes:

- a. 4 elements = 1.6MPa
- b. 8 elements = 2.06MPa
- c. 16 elements = 2.48MPa
- d. 64 elements = 3.02MPa

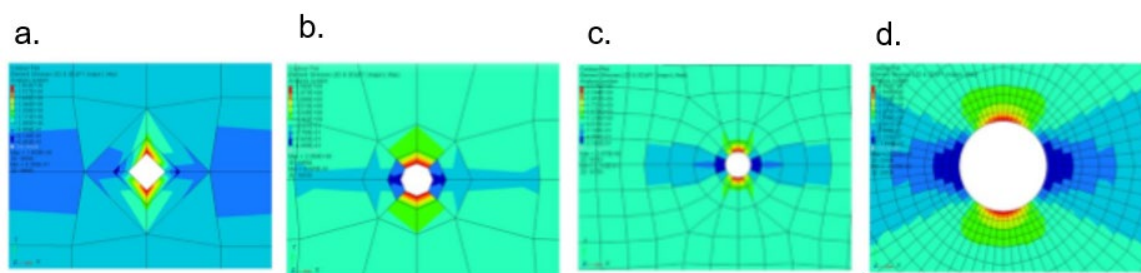
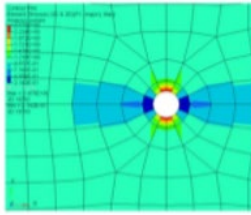


Figure 5-1 2D Different Sizes of Mesh to the Same Object

Through mesh refinement is helpful to designer, but to determine the right size to best achieve the accurate result is also important, as there is the danger of over meshing and can cause delay to reaching solution.

e. Quadrilateral



f. Triangle

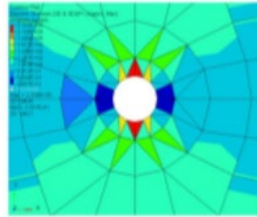


Figure 5-2 Different Types of Elements in Meshing

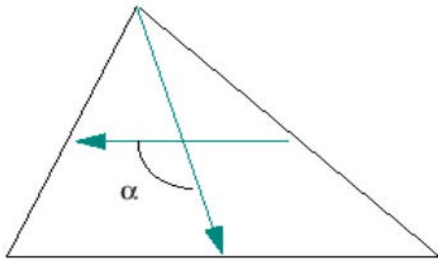
The above shows two different types of elements we can use for meshing, here the use of quadrilateral shapes has shown to be more representative than triangle shapes, so the use of quadrilateral shapes are recommended where ever possible.

Also for best result, the ideal shape for a quadrilateral is a square, while the best triangle shape is an equilateral triangle. The further the inner angles of the element changes to their ideal shape (for example the angle becomes very sharp or very wide) then the element would be consider as being very poor and may even lead to error in the solution.

There are also other programmes available to help check the mesh quality.

5.2.1 Skewness Check

We can check the skewness of a triangle element by finding its minimum angle between the vector from each node to the opposing mid-side of the element, the vector between the two adjacent mid-side at each node of the element is the triangle skew.



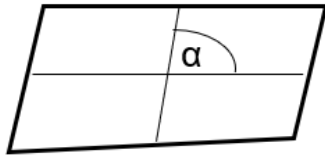
$$\text{Triangle Skew} = 90^\circ - \alpha$$

Figure 5-3 Triangle Skew Element

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The skewness of a quadrilateral element is found by its minimum angle between the two lines joining the opposite mid-sides of the element. The skew check is performed in the same fashion on the 2D element as it is on all the faces of the 3D elements.



$$\text{Square Skew} = 90^\circ - \alpha$$

Figure 5-4 Square Skew Element

5.2.2 Aspect Ratio Check

Aspect ratio in 2D element. Dividing the max length side of the element by the minimum length side of the element. The check performed on 2D elements is the same fashion that can be used on all faces of 3D elements as well.

$$\text{Aspect Ratio} = \frac{L_{max}}{L_{min}}$$

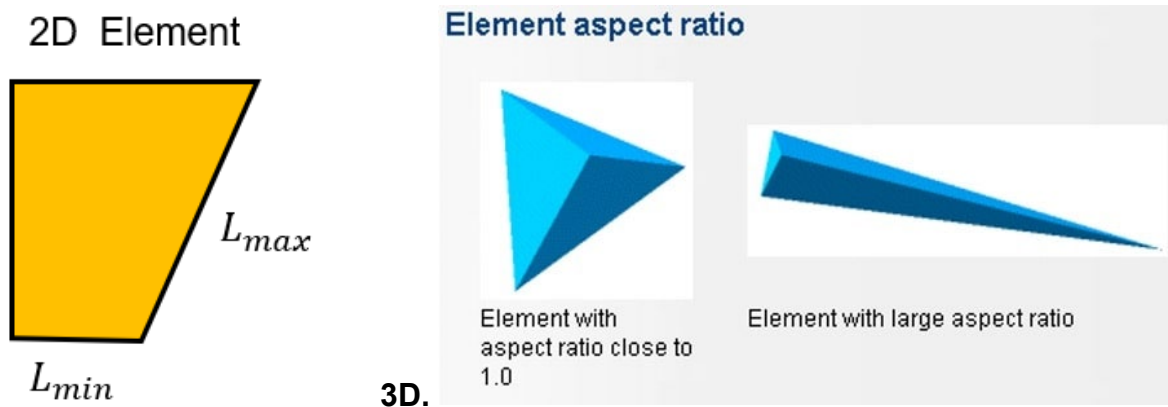


Figure 5-5 Elements Demonstrating Aspect Ratio (SEACAD, 2018)

The ideal Aspect Ratio is equal to 1, but generally an Aspect Ratio up to 5 is acceptable.

5.2.3 Warpage Check

Warpage in 2D element is calculated by splitting a quadrilateral element (see 1) into two triangles (see 2) between the two planes which the triangle form.

The quadrilateral element is then split again, but this time using the opposite corners and forming a second set of triangles (see 3)

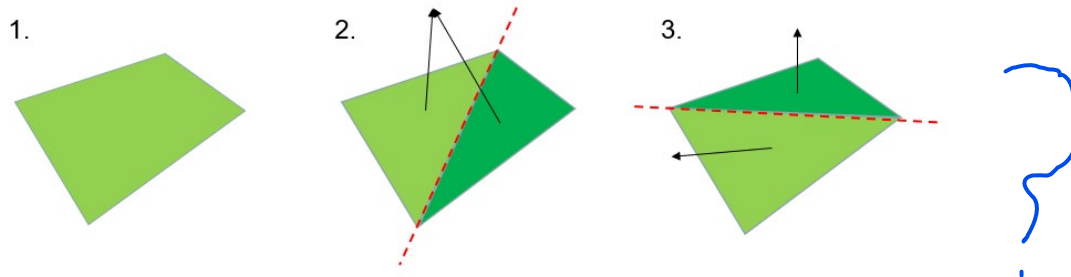


Figure 5-6 Warpage Illustration for an Element

The angle between the two triangle planes can then be found, the maximum angle between the two planes is the warpage of the element (note that the warpage on a triangle shape element is zero).

The check performed on 2D elements is the same fashion that can be used on all faces of 3D elements as well, and the ideal warpage is zero degree, but generally a warpage up to 10 degrees is acceptable.

5.2.4 Matching Meshing Element Quality with the Program

The FEA system operator needs to input the tolerance from company requirement in each area to the Mesh-Quality-Checking program, the system will then indicate to the operator if the mesh quality chosen was acceptable for use. Below shows an example of a mesh quality checking system in action.

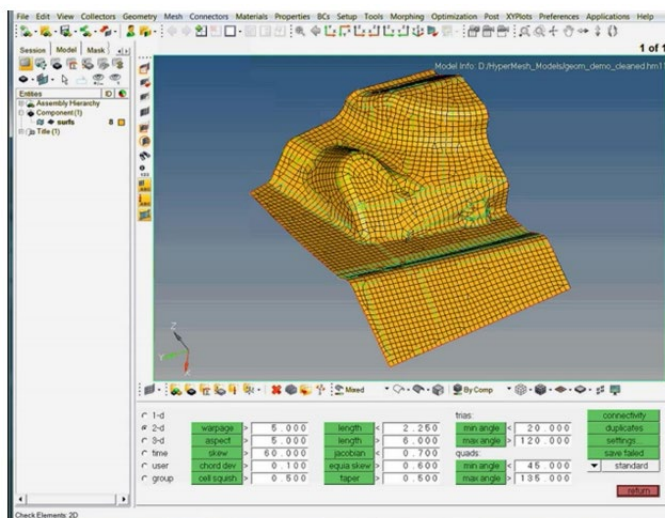


Figure 5-7 Mesh Quality Checking (Lake, 2020)

5.3 Accuracy on Convergence

It is difficult to decide how many elements are required in a model for best convergence result. We know that for the result to be accurate, then converge to solution must be independent of mesh size, that means further mesh refinement will not affect the result anymore (the results here on is said to be independent of mesh).

Using an interesting example found on the Web (Xceed Eng, 2020)

Where an experiment on a rectangular steel beam had been made, the experiment had deployed a varying number of elements along the beam width, depth and span, the different cases were then solved by FEA, creating the below table of mesh size versus deflection and solve time.

FEA Mesh Characteristics	Case		1	2	3	4	5	6	7	8	9
	Number of Divisions	Width	2	2	2	2	4	4	8	8	8
		Depth	2	4	4	8	8	8	16	32	32
		Span	10	10	20	50	60	120	120	240	480
		Number of Elements	40	80	160	800	1920	3840	15360	61440	122880
FEA Results	Maximum Deflection (in)		-0.066	-0.135	-0.224	-0.272	-0.270	-0.277	-0.275	-0.277	-0.278
	Solve Time (hh:mm:ss)		0:00:05	0:00:07	0:00:10	0:00:23	0:01:32	0:03:01	0:22:47	1:19:43	3:05:54

Figure 5-8 Experient Table on Mesh Size Vs Deflection and Solve Time

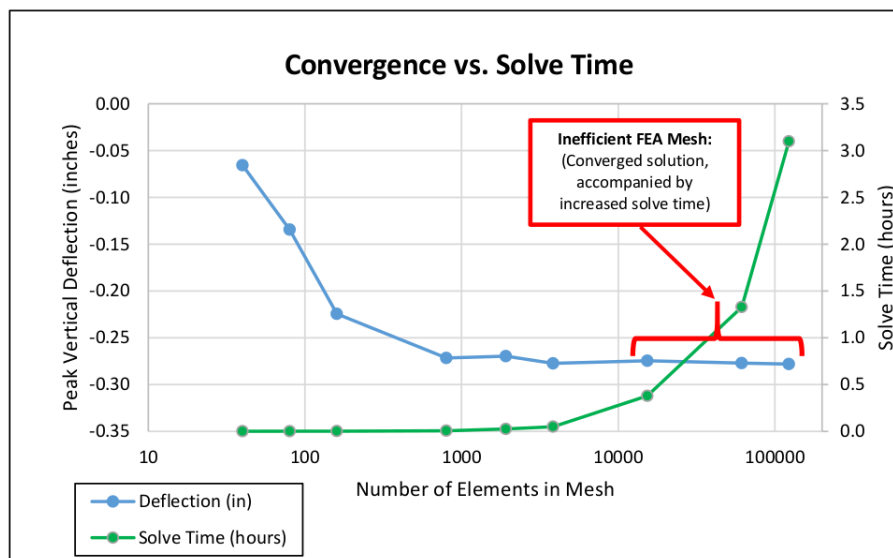


Figure 5-9 Experiment Chart on Vertical Deflection Vs Number of Elements

A chart was plotted with maximum vertical deflection against the number of elements used in the mesh, the response of the system converges to solution. It was found that the refinement of the mesh (i.e. the addition of more elements to FEA) has little or no effect on the solution after passing a certain point. It is fair to say the FE model has managed to capture the system behaviour and has become independent of mesh size, this will in turn help us decide what best mesh size to use.

Such finding is also helpful for the convergence test to correlating to the dynamic response comparison from physical testing.

5.4 Validation and Visual Inspection

FEA is approximate and it is not robust, that is why verification is so important as small errors in the initial modelling data input and boundary conditions can lead to much larger errors down the line, these errors can be relatively small and difficult to identify, nevertheless they can still have significant impact on the performance or service life of the final product.

Errors are inevitable in FE model, we can be sure that the more complex the model, the higher the probability that error is present, but the important thing is to have a process in place to help catch these errors before they do any real damage, thus the need for the verification process.

The analysis must first begin with clearly defined goals, accuracy requirements and key assumptions, making sure the simulation result matches the mathematical model, often by simply carry out manual calculation verification where need be. Troubleshooting techniques can be looking at the Boundary Condition, Material Properties, Presence of Residue Stresses, other localized effects such as welding, bolt torque, experimental error.

Or sometime simply by visual inspection and common sense, questioning all aspect of input to FEA. The below diagram shows how deformation becomes apparent when the FEA solution is deliberately scaled up to meet our visual inspection.

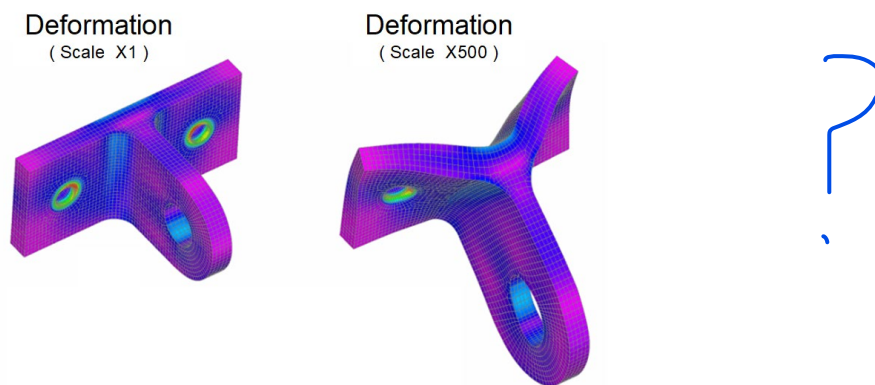


Figure 5-10 Scale Up Deformation for Visual Inspection (Puneekumar, 2017)

5.5 Testing Large Structure

Testing a large physical structure is not realistic in terms of finance and time needed, it would be prudent to dissect the structure into a number of smaller representative structures, and by using FEA to help validate each and every one of these smaller constituent structures so that once the results of all these smaller structures had been achieved, we can apply the same setting on FEA to represent the final larger structure. For example, if we need to build a large tank structure, we can break down the structure into its smaller constituent structures such as in the form of its supporting beams, metal sheet casings and so on.

6 REPLACING PHYSICAL TESTING WITH FEA

Although FEA can help to reduce time and cost, but without the correlation of Physical Testing to FE Modelling, the FEA finding will not be able to stand alone as valid solution to the problem. Real life factors are simply not addressed in FEA, considering all these left out or simply overlooked components to the problem, a 100% accurate solution from FEA may still be a tall order, even though we have taken into consideration the daily advance in computing power and FEA automation.

6.1 Real Life Factor

With homogenous material say steel at 99.9% purity, we can be reasonably confident how this material will behave, yet with non-homogenous material like Carbon Fibre Reinforced Plastic (CFRP) which contains carbon fiber reinforcement embedded in a matrix of epoxy resin, this means we have two distinct constituents where each of these constituents can affect the mechanical behaviour of the composite material. Though the carbon fibre will carry most of the load, when the fibers are discontinuous, the epoxy resin will also help transfer load among the reinforcements too!

Think of an isotropic material which tends to have the same properties in all directions, and yet if we then look at a thin sheet of wood which is an orthotropic material, it will have different material properties in two directions!

Then there is the consideration of material failure due to fatigue, deformation, creeping and damping are just some of the many real life factors faced by design engineers.

6.1.1 Human and Machine Error in Manufacturing

Even the design of a product is flawless, during the manufacture of the product, it may be made not to the precise specification of the design. Human and even machine can introduce error to a manufacture processes, if a welder welds two pieces of metal together, the weld can not be the same every time. Even though automation can reduce error, it can not terminate the error, that is why manufacturer are still taking sample of their products for physical testing for quality control.

The pedestrian bridge in the Florida International University had collapsed on 18th March 2018, the reason for the collapse was before the bridge was fully installed, two

of the beams had already been damaged, but the installation had continued anyway causing the collapse (NTS USA, 2019).

6.1.2 Material Properties

Without doing any correlation with real testing, the material property could only be a guess and could not be refined in FEA. Even when the correct data is available on the material property, the quality of the material may be below the manufacturer's tolerance level, or that the property of the metal has changed due to corrosion, all these can affect the product result.

6.2 Issues from FEA

FEA is only as good as its designer, even with the best FEA package in the market, there are still factors in these FEA packages that can benefit from further improvement, and definitely these packages are not going to improve themselves without the ability to correlate with physical testing at the moment.

6.2.1 Simplified CAD Design

When solving problems in FEA, especially when solving 3D design problem, the original design may be further simplified due to time constrain in achieving solution by the system. Although such change is considered to be only a minor one, nevertheless it would still affect the overall result to the solution.

6.2.2 Meshing Element Quality

The mesh model can never be identical to the physical product, because to be identical to the real thing, the mesh model will have to have an infinite number of nodes. Then there is also the boundary condition, skinless and other factors yet to be inputted to the system.

An easier way for manufacturer is to allow the pre-processing phase to have tolerance parameters inputted to system that does match the company's own tolerance standard. In the real world, companies often do have their own standard of tolerance, by applying the already set up company tolerance figures, operator are sure of deriving acceptable solution within company tolerance, to enable the company to produce acceptable product for themselves.

Yet if we think about these company standards, we can see that they are dictated by years of experience in their industry, and it is ironic that such experience tend to have its roots at physical testing.

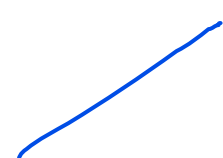
7 CONCLUSION

FEA is just a computer program, always keeping in mind of the reality that "Garbage In equals Garbage Out!", the FEA is only as good as what had been put into it by its designer. After reviewing all the facts found in this report and weighing the arguments for and against, believe FEA can only complement rather than outright replace Physical Testing in the near future.

Finite Element Analysis (FEA) has brought numerous opportunities for product design engineers and manufacturers and is now an integral part of product development process in the Automotive Industry as well. FEA does not eliminate the need for prototypes, but it can shorten the process to the actual prototype production. Often only one or two prototypes are needed to be built and tested before anything new goes into production. But when using FEA, the operator must first establish credibility by verification and validation, establishing a connection between modelling and the physical testing based on the correct principles of physics.

Although FEA is a powerful tool to help solve engineering problem in the motorsport industry, without correlation with physical testing, FEA would always just be a test with estimated data, such FEA result simply cannot be rely on when unchecked FEA solutions can easily be translated to life and death scenario!

WHILST YOU HAVE CLEARLY
BEEN ATTENDING LECTURES
& THIS REPORT CONTAINS
SOME GOOD INFORMATION,
MUCH OF IT DOES NOT
ADDRESS THE BRIEF.



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