

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

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declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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

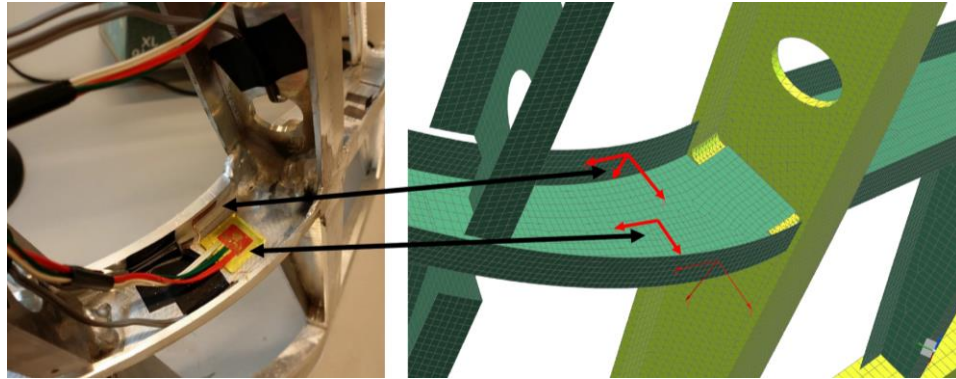
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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	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	18.6
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	18.9
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	6.7

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 %
	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?
M6X00420

Aidan Chapman
P149661
26/04/2020

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2 Introduction

This report will outline a Case Study undertaken into Finite Element Analysis, and its use within the manufacturing industry. The study will consider the practical application of FEA, and its effect on the design process and manufacturing lead times. Alongside this, it will be decided whether, in its current application, FEA can, or should, replace live testing within the sector identified.

The Case study will be conducted on the use of FEA within the manufacturing process of composite goods, and whether the software available can replace real-life testing completely.

2.1 What is FEA

Finite Element Analysis (FEA) is the simulation of various observable physical phenomena, through the use of the Finite Element Method (FEM). This method implements the use of differential equations pertinent to the phenomena, to numerically quantify an observable response from the inputted stimuli.

FEA is used to solve many Complex Mathematical occurrences, including fluid dynamics, wave propagation and stress analysis. As noted by (English, 2019), most phenomena can be quantified using partial differential equations, however FEA is the leading mathematical approach when considering complex calculations requiring multiple variable equations.

Through the use of modern technology, FEA has developed to a point of a user being able to “simulate reality whatever the situation on complexity” (Femto, 2017). Using CAD and FEA software, these techniques can now give the user a visual simulation alongside the mathematical analysis to provide a real-life example of what is being studied. This can lead to shorter lead times and remove some of the necessity of prototyping.

FEA works by reducing larger problems, into groups of smaller problems, known as finite elements, usually using a mesh. This allows designers to test each elements behaviour, and their reaction to physical forces, and then to predict the resulting outcome of the whole object. (Gigante, 2019)

FEA enables a risk reduction in the design and manufacture of single parts and whole projects, in terms of materials, profits and time management, by predicting potential design issues without the need for constant manufacturing (Caliber Design, 2015).

2.2 Aims

To outline how FEA is used within the composite industry, including its accuracy and reliability to perform true to real life testing.

To decide whether FEA software is capable of out-performing physical testing, and if it should fully replace those manufacturing methods.

3 Can FEA Replace Physical Testing?

3.1 How is FEA used in composite manufacture?

Within the manufacture of composite parts, FEA is typically used to simulate potential failure modes and to help mitigate damage, such in the work of (Las & Zemcik, 2008); Whom used FEM techniques, such as Puck's Failure Criterion, to quantify the damage incurred and to predict local failure in composite panels under load. In such tests, the required structure needed to be considered 'failure free', therefore the use of FEA has allowed the prediction of the cooccurrence of the first instability, not just total failure. With the means of simulated testing, within this instance, many physical tests would be required to quantify the same information given from the software. As such, this would require a high volume of composite materials, due to the nature of composite materials generally being non-recyclable.

In simulated testing, (Bak, 2017) explains that most software analyses composites using a Micromechanical approach, wherein the smallest component in the design is a lamina. It is highly unlikely that a micromechanical approach would be used, as the required mesh would have to be fine enough to model the individual fibres. Such approaches would usually thus be limited to research studies only. Alongside this, depending on how the model is generated, (i.e. as a layered shell or solid element) varying assumptions begin to be assigned by the model, such as continuous lamina displacements, which can lead cause to linear-through thickness strains.

Within the design of composite pressure vessels, (Halawa & Al-Huniti, 2019) used FEA modelling and minimum safety factors to accurately predict the minimum wall thickness required to hold the necessary pressure. By running a range of tests including the use of moisture effects on composite materials, it was possible to predict the minimum thickness, as well as the potential weight saving over conventional metals. Without the use of FEA in this process, the required physical testing would essentially be a trial and error phase, without the ability to find thicknesses within a specified safety factor, therefore making a real-world test practically impossible. However, without the use of physical testing, the results remain a 'prediction' without the validation of the hypothesis created by the software.

Within the design of composite structures, the usage of FEA software has allowed designers to produce safer, more robust designs. As outlined by (Main, 2017), the use of software allows designers to avoid previous general assumptions that were made through composite design, and also opens up the possibilities for non-linear analysis. Such techniques that are now made accessible through FEA include progressive failure analysis, virtual crack closure and cohesive zone modelling, which were previously considered to be near impossible to calculate manually. However, a designer should also be fully aware of both the advantages and limitations of such software use.

In the Aerospace industry, (Nurhaniza, et al., 2010) uses simulated FEA software to predict the mechanical response of unidirectional E-Glass. The predicted results were generated across a range of experiments, that would have required a much larger time frame if such tests were to be conducted physically. However, these results were later tested against physical data to validate their responses, finding error ranges from 10%-25% and upwards. The report is then concluded with the following statement:

"If the composition of the laminate structure is known enough, the FEA look like well suit for predicting the mechanical response of composite structure. However, if the composition of laminate structure is unsure, the difference between simulation and experimental results can logically be even 100% and it is supported by the results obtained."

The closing statement clearly shows that without full experience with FEA software, and an understanding of the subject of Composite theory of elements, that the results can easily generate vast errors. With such possibilities, there is a clear need for the continuation of physical testing to fully understand and validate such work completed, with FEA being used as a tool to replicate such processes, errors, and changes much faster than physical testing could be carried out.

3.2 How are Results Correlated?

Results are correlated between the use of mathematical modelling, potentially using both FEA software and the use of equations to validate the software outcomes. These results can then be verified using single-run physical tests to correlate data. This is best visualised by (Abbey, 2015), who visualised the Verification and Validation Method using FEA.

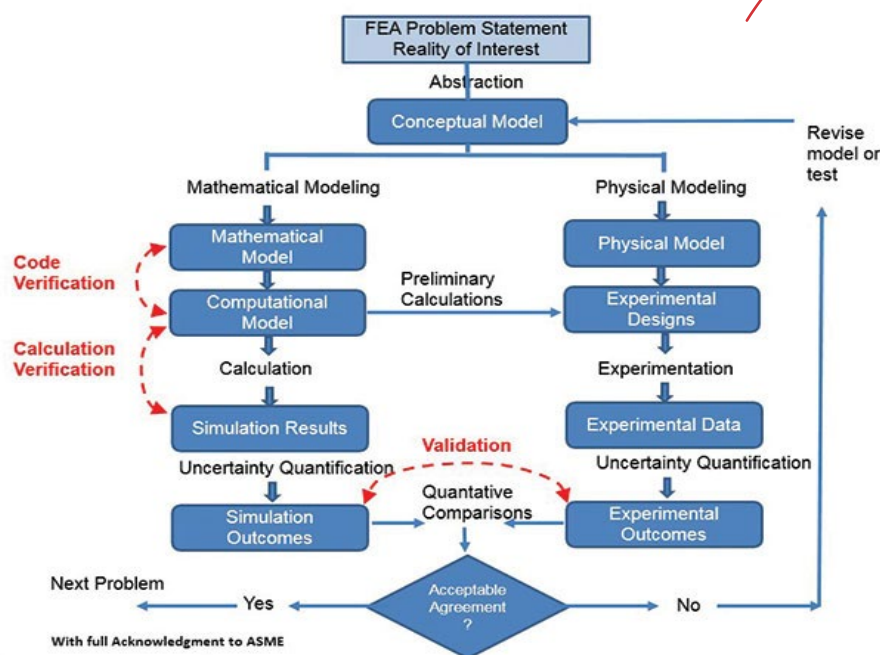


Figure 3-1: ASME Verification and Validation flowchart (Abbey, 2015)

Within the composites industry, this method would allow for the best interpretation between simulated testing and real-world testing. After conceptualising the idea, the model is generated both through CAD and real-world techniques, and then the tests are completed under the same conditions. Once the tests are completed, the results are compared through a range of results (the more comparisons observed the greater the validation). If the results are within a specified range of agreement, then the design process can continue to the next stage; If not, the tests are scrutinised to find the root cause or causes.

The hierarchy framework consists of two major steps in the design process. Firstly, verification is a process used to determine whether an FE model is accurately representing the underlying mathematical problem. This process is usually completed using calculations, cross comparisons and sound technical judgement. From here, the design moves onto validation, which is the process of determining whether the model accurately portrays the real world perspective, which is usually completed through the use of physical testing, where once again, the results are scrutinised to find either agreement or disagreement (ASME, 2014).

As shown in the work of (Ghasemi-Nejhad, et al., 2005), the use of FEA testing alongside experimental testing of laminates allows for cross comparison between data sets. Their data shows clear correlation between the two, and thus provides an acceptable agreement of how the product is likely to perform. Without the real-world data, it would provide little confidence in the accuracy of the FE model, as potential errors could have been unknowingly included.

Much like the work of (Naderi & Maligno, 2012), whom found their FE data to be in very good agreement with experimental results when testing fatigue life in carbon/epoxy laminates, except for some small deviations at high stress levels due to the functions used for the model. Highlighting one of the major problems when using FE software with composite materials, being that non isotropic materials have not been fully understood yet, and thus, there are currently a variety of different methods to predict such functions. Such variety can thus lend themselves to more confusion within understanding the best approach to successfully solving various designs, as one method of testing may not be suitable for solving the next required test, sometimes even requiring a different set of software.

Likewise, (Coelho, et al., 2008) used the validation and verification technique to test dentin to composite bonding for use in the dental industry. From their tests, it was found that the first test, showed good agreement between both the FEA and physical testing. However, in their second test, there was no correlation observed, and have therefore had to outline the basis for a further, more in-depth and detailed analysis to further try to verify the testing completing. Without the use of both forms of testing, such errors would go unnoticed until physical manufacture of the product as a whole and would cause future problems for both manufacturing and company image.

In the research of (Okoli & Abdul-Latif, 2002) on failure in composite laminates, the findings found that the FE results showed an accurate prediction of the 'real' world with tests carried out using an impact load of less than 2 m s^{-1} . Results above this threshold were found to generate increasing errors outside of an acceptable agreement, however, did still give some indication of the material behaviour. To increase accuracy in these ranges, the FE model and the failure mode observed would need to be modified, further highlighting both the advantages and limitations of such software.

BRIEF

3.3 Is it Suitable for FEA to completely Replace Physical Testing?

In its current state, it would not be suitable for FEA to fully replace physical testing within the manufacture of composite goods. However, there is good grounds to continue the use of the forms of testing throughout all engineering mediums.

Firstly, the use of FEA has had a major impact on the design process, by lowering the usage of raw materials, reducing design lead times, and increasing the safety and durability of products. As mentioned by (Schmitz, 2016), simulations allow the user to identify material configurations, be that types or lay-ups of composites, prior to physical testing, allowing substantial time saving on the original design space. To further this, physical tests can now focus more on targeted groups that can include multiple parts in conjunction with one another, instead of single specific pieces. The formation of physically tested outliers is massively reduced, along with the ability to conduct inexpensive virtual testing on configurations that may not have been previously considered.

The research of (Sabau, et al., 2017) records that the use of FEA software to analyse the composite parts design, had allowed a reduction in the need for costly prototypes and allowed for savings in time and developmental costs. FEA software had allowed for maximum control over the various lay-ups and material properties to find the optimum product performance. However, they do give note

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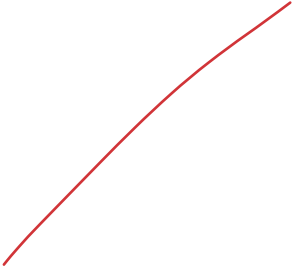
that the use of physical testing has allowed for the FEA to be fully validated through the generation of a good agreement between the physical and virtual tests.

Alongside this, (Schmitz, 2016) also notes the case of “garbage in, garbage out”. Such problems would mostly be negated by the user having both knowledge and caution when setting up the design parameters and the use of cross calculations, however without the validation of physical testing, smaller mistakes and errors may go unnoticed. Finishing with the statement, “In summary, simulation doesn’t replace validation and certification testing, but offers a path to greater testing efficiency.”

To further this, (Thornton, 2011) raises the point of questioning the credibility of FEA. Stating that validation is the biggest potential challenge of any FEA simulation. Clearly, without the use of closely monitored physical tests, it is never truly known if such models will line up with ‘real life’ scenarios. With simulations becoming more comprehensive and detailed with multiple parts, it is no longer possible to gain full confidence using judgement and calculations, therefore providing an even greater need in such selective physical tests.

With the increased usage of FEA software over physical testing, the new dependence on increased ‘cost reduction’ starts to bring in new problems. In situations where physical tests can be costly, such as motorsport and automotive testing, such physical tests are usually reserved to a minimum amount and pushed towards the final stages of the project. (Cunningham, 2015) notes that the main problem with reduced physical testing, is when the results don’t match. On these occasions, projects can become significantly delayed, and in some cases, can nullify the cost saving capabilities of using such software in the beginning.

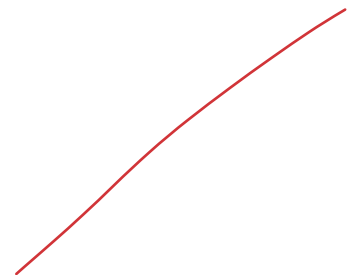
Without the use of physical testing, these potential problems would end up in the hands of the consumers, who would essentially become the first real world testers. Such practices would lead to product wide recalls and costly re-investment into products that could have been tested prior to release. Alongside the economical impacts, would be the social implications of releasing untested products. The composite industry provides a large majority of extreme sports equipment. The delivery of such untested products to a wide audience could potentially result in the loss of human life, along with lasting image damage to the company in question.



4 Conclusions

In conclusion, it has been found that FEA has a significant impact on the design process within the composite manufacturing sector. It has allowed designers to test previously disregarded ideas with little to no implications in the design process. Alongside this, the usage of FEA has allowed for more in-depth testing, with more variations to allow designs to find the optimum set ups for their designs, thus increasing design integrity and stability. FEA has allowed all this, whilst also providing a reduction in design/test associated costs and shorter lead times for designers. However, all of this is only achievable with a designer that is confident with the software and has prior extensive knowledge with the processes associated with virtual and mathematical analysis.

However, there is still a massive need for physical testing. Without such physical tests, a designer cannot be fully confident in the results gained from virtual testing. Physical tests are required to provide validation of designed parts, albeit now on a smaller, specified, but more impactful scale. Without validation, it would be unknown whether a designed part would respond in the same way the simulated does, or whether there are any problematic areas within the simulation itself, which is heavily dependant on human error and judgement.



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