

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

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declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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

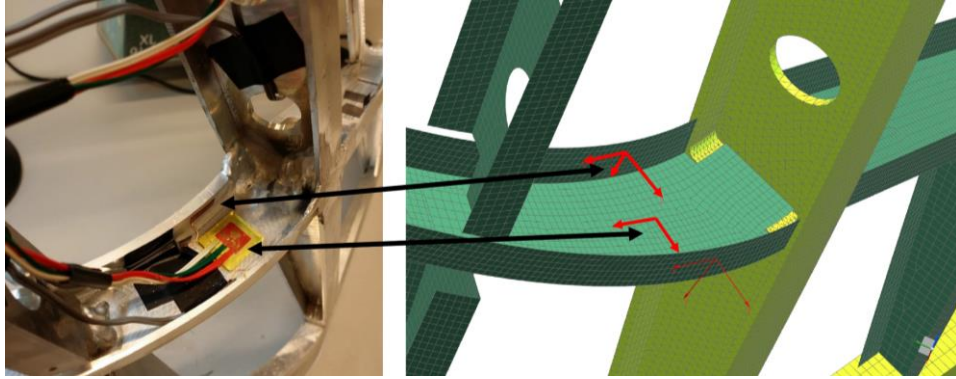
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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	21.6
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	22.5
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	21.9
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	7.2

Assignment Mark Overall (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)	Late Submission Penalties (tick if appropriate)		73.2 %
	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?

Carl P. Engelbrecht
P150898

Advanced Stress Analysis & FEA
M6X00420
Motorsport Engineering

30 April 2020



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
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Introduction

Once only utilised by large engineering and manufacturing companies the likes of general motors or Boeing, the use of computer aided engineering (CAE) or finite element analysis (FEA) has since been widely adopted in a vast range of engineering and design driven fields. One area in particular focused upon in this report is the use thereof in the development of an improved bicycle frame.

The reason for such wide adoption and one of the main benefits is cost reduction and reduced product development cycles through reduced physical prototypes. Products also exhibit higher quality in most cases and more efficient usage of material mass. In many cases the FEA study material reaction to loads are very accurate to that of the physical test, well showcased in the video (Development, 2011). Thus, the large involvement of FEA in modern engineering is understood.

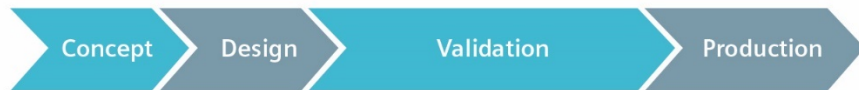
Accurate results need to be correlated between the model and physical testing to ensure an accurate representation and subsequent reaction to the studied situation is produced. There are various physical measurement techniques utilised today as well as data correlation tools to optimise the process.

With such advances in computational power to handle finer meshes, greater degrees of freedom, optimised CAE packages and previous practical knowledge on a specific load case (think years of bicycle frame testing) is there a point where it is sensible to forgo physical testing? Through discussing how the two work together the report will aim to answer the proceeding question as well as should it?

FE Analysis and Physical Testing

CAE with the most notable being FE analysis has become an ingrained element in the modern design cycle within an engineering company in conjunction to physical testing due to the benefits it produces over traditional design methods. At current there are up to 500 different market offerings of FEM specific software packages, as well as over 25,000 research papers on the subject. This has largely been driven by the accessibility and affordability of modern computational offerings (nptelhrd, 2014). To clarify FEA is a computational analysis process otherwise known as finite element method (FEM) used to determine any physical phenomenon of a component under specified loading conditions through numerous simultaneous mathematical equations based on element interactions. Processing is done through what is known as a solver, MSC's NASTRAN, originally developed for NASA, is a popular variant which many modern market offerings are based off of. The forbearing benefit and widespread inclusion of FEA is illustrated in the design cycle figure below. The use thereof reduces the time taken for the design-to-manufacture cycle as potential design flaws or weaknesses can be identified early on before prototypes are produced, allowing rapid redesign. Many alternative and distinct designs can be tested with negligible financial impact compared to prototype production. Many novel designs are a product of optimisation methods, expanded upon in later. Naturally the time taken in the design stages are increased however this minimal to the time savings in physical prototype validation. Costs are reduced as fewer physical materials need to be acquired, less time is spent developing and fabricating test rigs and the hire/operational time of test laboratories would decrease. Although more relevant to computational fluid dynamic software the same concept applies within aerodynamic testing. The hire of a wind tunnel is approximately £80,000 (Aero Performance Engineering Ltd., 2016) for a small development, and time which can be reduced in testing through initial computer testing can drastically reduce the cost during the wind tunnel development stage. Another benefit to the use of FEA is the ability to visualize the results of complex geometric shapes under loading conditions which otherwise would not be clear. Many programs offer increased deformation and stress gradient colouring further detailing the components reaction to loading. (Altair University, 2020)

Design process without simulation



Design process with simulation

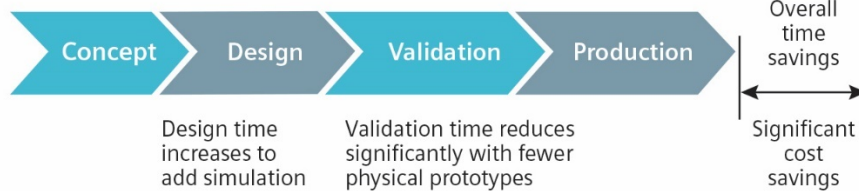


Figure 1 - Improved time to market within the design cycle of a product through the use of FEA. (Naidoo, 2017)

Optimisation and the efficient use of material as touched upon previously is one of the unique features of FEM which make it such a powerful design tool. Streamlining the design process the designer is able to define the packaging constraints, fastening constraints, assign an appropriate material, apply a load and define the optimisation output for desired minimum stiffness as an example (well illustrated in Figure 2). The results of the calculation provide answers as to where is it that material can be removed and where to place stiffening ribs and so forth. Although it requires an experienced design engineer with specific knowledge relative to the problem to interpret the information into a final design. This ability can allow alternative material types to be tested allowing for potential cost savings, or lighter weight in the case of a production sports car wishbone.

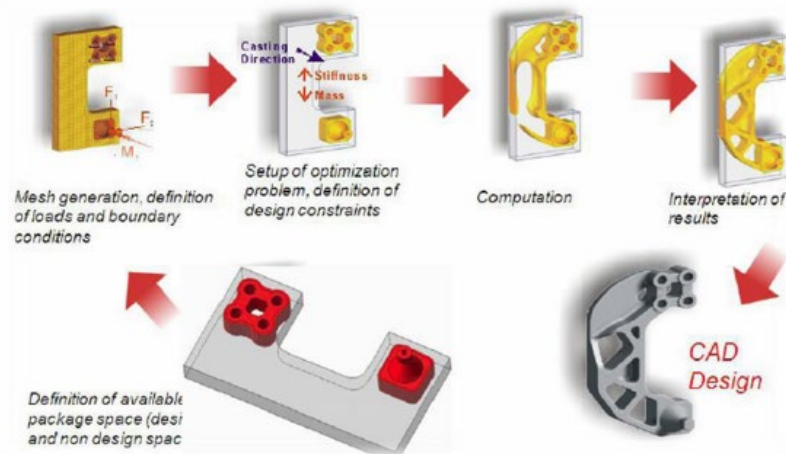


Figure 2 - Optimisation process. (Altair University, 2020)

Now it is understood why FEA is widely adopted and the benefits it brings to the design process, in many cases it is still used alongside physical testing. In the case of the development of a novel monocoque composite bicycle frame presented in (Lessard, et al., 1994) the stiffness of the frame was of interest due to the affects it has on rider comfort and the transfer of power to the wheels. In order to evaluate the validity of the stiffness within the novel design without producing a physical prototype a series of steel tube bicycle frames were modelled and tested. The same frame was tested in a specially developed testing rig and measurements taken at various points. The stiffness result of the FEA model and physical model showed a difference of 7%, which according to (Altair University, 2020) is in the acceptable amount within 15%. Further testing on alternative frames with similar result deemed it feasible to conclude that the FEA result would be accurate. Thus, showcasing the use of physical testing for validation and accuracy of results which can be relied upon. Other reasons for joint testing could be the need specified by a ruling organisation to satisfy regulations and prove the validity of a design outcome, a common requirement in the aviation industry (Safarian, n.d.). This is especially essential with components within the transport sector where the design failure could lead to disastrous outcomes.

Correlating FE Models to Physical Data

Finite element analysis produces an approximate result. An important point to highlight. It is possible to validate the accuracy of the FEA model through identifying irregularities in stress gradients and concentrations or run multiple studies various meshes sizes and element types. However, this may still only be 20% accurate to real world results therefore physical correlation becomes an important factor (Altair University, 2020). Data correlation is done through comparing the results data from the FEA model to that of a real-world test which replicates the exact same conditions or vice versa, such as the bicycle frame stiffness study previously mentioned. The majority of early correlation methods have been done statically on a worst-case loading scenario using 90th or 95th percentile loads. However more recently a greater need for dynamic (where an object undergoes a linearly increasing or oscillating load over a set amount of time) analysis correlation, mainly due to the recent hardware and software improvements, has become common.

There are two predominant methods of either static or dynamic correlation. The first is through virtual strain gauges which would be used to replicate the strain gauge used in physical testing, a node closest to that of the original attachment point will be used and the direction of measurement matched. The second method is through the use of a virtual sensor which can measure a multitude of different information such as displacement, motion data, reaction force etc. Again, this will then be able to replicate the sensor used in physical testing. (HBM PRENSCIA INC., 2020)

Returning to the case of the bicycle another study had been done on the natural frequencies of a mountain bike frame by (Sani, et al., 2016). A dynamic FE analysis was conducted to understand the vibrations present from road and rider interaction under different modes of bending and torsional stresses. In order to validate subsequently correlate the findings physical testing was done on the modelled frame in the form of experimental modal analysis (EMA). Illustrated in Figure 3, a fine striking instrument is used to excite the steel causing a vibration measured by the accelerometer sensors positions at specified points on the frame. The resultant correlation from the study showed a maximum error of 8.26% and an average of 5%, deemed accurate. This illustrates the importance of correlation, especially when designing new prototypes of products to be manufactured, such in the case of the novel composite frame discussed previously. The novel study data was correlated using measurements from load cells (strain gauges) to verify the analysis of 5 different frame types. High levels of agreement lead to the conclusion that the results from the novel design did not require validation and thus the outcome could be relied upon as accurate.



Figure 3 - EMA testing done on a mountain bike frame. (Sani, et al., 2016)

Correlation can also occur before the final result of the study on a smaller scale. The study of a complete airplane would prove challenging to test physically and subsequently to validate the result, therefore specific properties of components that make up the complete assembly can be tested. A bolt with a present or assumed stiffness property maybe be used in the initial assembly testing. An isolated study can be conducted at a later point on the bolt stiffness and the result thereof added to the study, removing known error and improving the outcome of the final result. The same can be done on sandwich panels under impact, such as in the study done by (Li, et al., 2015). Therefore, once the characteristics of a sample are validated within the model the rest of the model can be assumed correct to within a 15% margin.

Correlation requires accurate modelling and set up (boundary conditions, loading, constraints) to achieve the best result. Materials also have to be accurately defined to that exactly used in the physical product, assumption may attribute to error. Lastly, within a study the right analysis method will need to be chosen based to the requirements of the study. Two have already been mentioned, static and dynamic. Within the two a linear or non-linear analysis exists.

A linear study assumes that the material has a linear stress-strain curve of infinite length, illustrated in Figure 4. Leading to faster solve times and best suited to metals, it however may lead to inaccuracies and is up to the engineer to decide what is sensible while examining the maximum tensile strength of the material. A non-linear solver refers to the polynomial (non-linear) shape of a stress strain curve, best suited to materials with elastoplastic or elastic properties.

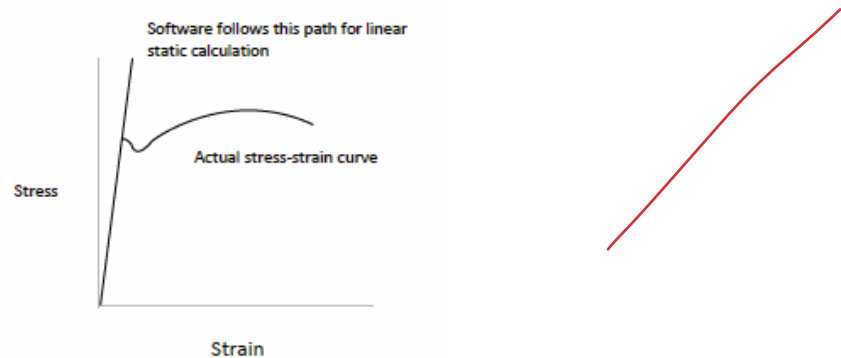


Figure 4 - Linear static assumption. (Altair University, 2020)

Should FE Analysis Replace Physical Testing?

Finite Element analysis has been proven to shorten the time spent on prototypes, however, does it have the capability of doing without any physical testing at all and producing a viable final design. In the initial studied paper by (Lessard, et al., 1994) the final design was concluded upon without physical testing, but through a range of data correlation of multiple frame and complimentary FE analysis'. Thus, with enough empirical data the final design was deemed accurate, and therefore physical testing of the final product was mitigated. Hence it can be considered that with enough empirical data in a specific area it is possible to create a final design without the need for a physical test. This does not mean that a novel bicycle frame can be drawn up and analysed with reasonable outcomes and be considered as the final design for production, no. A multitude of empirical data would need to be referenced and correlated against in order to proceed, and for this purpose correlation tools do exist. Another method which physical testing can be avoided is through the consideration of the safety factor (governed by the materials ultimate tensile strength respective to the element and test situation) and maintaining stresses well below the limit, thus ensuring the point of yield or failure would not be reached. In some application areas this is deemed sensible if well backed (Safarian, n.d.). Consumer products of low risk can be considered a design item/component which could forgo physical testing, such as a lamp, bookshelf etc... The advances in technology allow for that. A recent technological achievement demonstrating this was the design of Philippe Starck's A.I. chair for Kartell, chair designed through prototype generative design software (Jordahn, 2019). Though fully defining the requirements, manufacturing process, loads etc. the software package was able to output a final functioning product.

The main area of concern arises when areas of high risk are being considered. Transportation mediums are all high risk with aviation being believed to be at the top of the list, (Brooke, 2019) argues that the automotive safety concerns are higher due to the more modes of failure and varied conditions. Temperature testing ranges from -40°C to 125°C, it is important to consider if that large range of material temperature data is needed to replicate such studied accurately. With such high demands and the strain on rapid turn around being hindered by rigorous testing some companies are suggesting that "it was time to loosen the adherence to Automotive Grade Practices...Deploy first validate later." Said in reference to the production of computer chips the concept equally applies to component design through FEA. Less validation would improve product turn around but impact the level of safety and integrity of the end product. The case of the bicycle teeters in the middle of this range, a general consumer bicycle used for daily commuting and ridden on public roads could result in a fatal accident if a failure would occur during the lifespan of the vehicle and can be looked upon in the same situation as the passenger vehicle. A performance bike involved in competition series undergoes rigorous development aimed at producing marginal gains in performance from one season to the next. This means very short development times and thus the least amount of physical testing would save time and spare the financial resources. Minimal testing would be preferred, and it is thus up to the engineer and team to decide what is a reasonable risk to take.

Therefore, the replacement of physical testing is dependant of situational factors. If the item is a consumer product within a low risk application, the need for physical testing is low and can be done at the final stages of product development. The load case will need to be thoroughly understood and would require experience in that field. High risk applications where the safety concerns are weighed with that of performance gains such as in the case of a race bred bicycle frame, physical testing can again be minimised on for greater risk. Lastly, high risk options which feature the final use by the public with varied use conditions can not forgo physical testing as validation is required to ensure the safety of the end user. Within this over arching statement exceptions do exist even in a high-risk design case, where enough empirical data and a high safety factor can go without physical testing if deemed appropriate. This would typically be applicable to a component within an assembly. However, the general opinion is that there must be some form of validation present which more than likely would take shape as a physical test.

Conclusion

The vast adoption of FEA can be clearly understood through the ability it allows to model complex engineering problems, in addition to the cost and time savings it brings to the design process. The time spent on physical testing is drastically reduced however not made obsolete as it is still relied upon, whether directly or indirectly applied to the end product as showcased in the case of the novel composite bicycle frame.

It is understood that the analysis result of a study is only an approximate result, a key point as discussed. Therefore, methods are required to validate a study and as a result correlation and correlation tools play an active role. Alternative methods of validation apart from physical testing do exist but do not offer a definite answer. The use of correlation is found in either the complete assembly or components which make up the study, especially when it is as large as an airplane, both adding to the final accuracy. Correlation is done largely through the replication of a physical test and comparing data produced from a virtual strain gauge or sensor to that of the physical test variant.

"Is the need to speed development worth loosening the industry's adherence to Automotive Grade Practices?", the benefits of FE analysis is vast but above all it saves time, the question sums up the dilemma of can and should physical testing by the former be replaced. The answer which can concluded upon is not straight forward and thus depends on the situations. In the case of consumer product of low risk, such as the AI design chair this route is logical and physical testing can be avoided. Within high risk application the safety and validation of results are important thus it would not be wise to forgo physical testing especially with the range of usage conditions. The final decision of if it should be done rests on the designer especially when it comes under competition situations. Is the win worth the risk?

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