

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	JONES	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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
			✓
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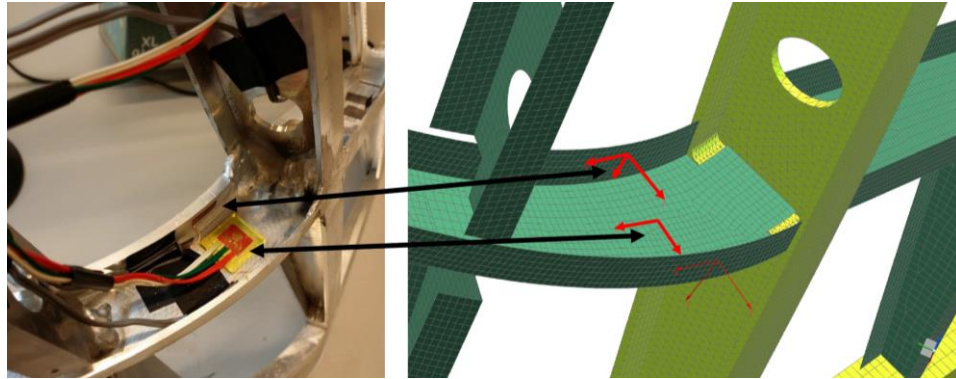
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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	22,8
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	22,2
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	22,5
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	7,5

Assignment Mark Overall (Assessment marks are subject to ratification at the Exam Board. These comments and marks are to give feedback on module work and are for guidance only until they are confirmed.)	Late Submission Penalties (tick if appropriate)		75 %
	Up to one-week late		
	Over one week late		

COMMON ASSESSMENT AND MARKING CRITERIA

	OUTRIGHT FAIL	UNSATISFACTORY	SATISFACTORY	GOOD	VERY GOOD	EXCELLENT	EXCEPTIONAL
Assessment Criteria	0-29%	30-39%*	40-49%	50-59%	60-69%	70-79%	80-100%
1. Research-informed Literature Extent of research and/or own reading, selection of credible sources, application of appropriate referencing conventions	Little or no evidence of reading. Views and findings unsupported and non-authoritative. Referencing conventions largely ignored.	Poor evidence of reading and/or of reliance on inappropriate sources, and/or indiscriminate use of sources. Referencing conventions used inconsistently.	References to a limited range of mostly relevant sources. Some omissions and minor errors. Referencing conventions evident though not always applied consistently.	Inclusion of a range of research-informed literature, including sources retrieved independently. Referencing conventions mostly consistently applied.	Inclusion of a wide range of research-informed literature, including sources retrieved independently. Selection of relevant and credible sources. Very good use of referencing conventions, consistently applied.	A comprehensive range of research informed literature embedded in the work. Excellent selection of relevant and credible sources. High-level referencing skills, consistently applied.	Outstanding knowledge of research-informed literature embedded in the work. Outstanding selection of relevant and credible sources. High-level referencing skills consistently and professionally applied.
2. Knowledge and Understanding of Subject Extent of knowledge and understanding of concepts and underlying principles associated with the discipline.	Major gaps in knowledge and understanding of material at this level. Substantial inaccuracies.	Gaps in knowledge, with only superficial understanding. Some significant inaccuracies.	Evidence of basic knowledge and understanding of the relevant concepts and underlying principles.	Knowledge is accurate with a good understanding of the field of study.	Knowledge is extensive. Exhibits understanding of the breadth and depth of established views.	Excellent knowledge and understanding of the main concepts and key theories. Clear awareness of challenges to established views and the limitations of the knowledge base.	Highly detailed knowledge and understanding of the main theories/concepts, and a critical awareness of the ambiguities and limitations of knowledge.
3. Analysis Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence	Unsubstantiated generalisations, made without use of any credible evidence. Lack of logic, leading to unsupportable/missing conclusions. Lack of any attempt to analyse, synthesise or evaluate.	Some evidence of analytical intellectual skills, but for the most part descriptive. Ideas/findings sometimes illogical and contradictory. Generalised statements made with scant evidence. Conclusions lack relevance.	Evidence of some logical, analytical thinking and some attempts to synthesise, albeit with some weaknesses. Some evidence to support findings/ views, but evidence not consistently interpreted. Some relevant conclusions and recommendations, where relevant	Evidence of some logical, analytical thinking and synthesis. Can analyse new and/or abstract data and situations without guidance. An emerging awareness of different stances and ability to use evidence to support the argument. Valid conclusions and recommendations, where relevant	Sound, logical, analytical thinking; synthesis and evaluation. Ability to devise and sustain persuasive arguments, and to review the reliability, validity & significance of evidence. Ability to communicate ideas and evidence accurately and convincingly. Sound, convincing conclusions / recommendations.	Thoroughly logical work, supported by evaluated evidence. High quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Strong, persuasive, conclusions, justifiable recommendations.	Exceptional work; judiciously selected and evaluated evidence. Very high quality analysis, developed independently or through effective collaboration. Ability to investigate contradictory information and identify reasons for contradictions. Highly persuasive conclusions
4. Practical Application and Deployment Effective deployment of appropriate methods, materials, tools and techniques; extent of skill demonstrated in the application of concepts to a variety of processes and/or contexts; formulation of innovative and creative solutions to solve problems.	Limited or no use of methods, materials, tools and/or techniques. Little or no appreciation of the context of the application.	Rudimentary application of methods, materials, tools and/or techniques but without consideration and competence. Flawed appreciation of the context of the application.	An adequate awareness and mostly appropriate application of well established methods, materials, tools and/or techniques. Basic appreciation of the context of the application.	A good and appropriate application of standard methods, materials, tools and/or techniques. Good appreciation of the context of the application, with some use of examples, where relevant.	A very good application of a range of methods, materials, tools and/or techniques. Very good consideration of the context of the application, with perceptive use of examples, where relevant. Evidence of some innovation and creativity.	An advanced application of a range of methods, materials, tools and/or techniques. The context of the application is well considered, with extensive use of relevant examples. Application and deployment extend beyond established conventions. Innovation and creativity evident throughout.	Outstanding levels of application and deployment skills. Assimilation and development of cutting edge processes and techniques.
5. Skills for Professional Practice Demonstrates attributes expected in professional practice including: individual initiative and collaborative working; deployment of appropriate media to communicate (including written and oral); clarity and effectiveness in presentation and organisation.	Communication media is inappropriate or misapplied. Little or no evidence of autonomy in the completion of tasks. Work is poorly structured and/or largely incoherent.	Media is poorly designed and/or not suitable for the audience. Poor independent or collaborative initiative. Work lacks structure, organisation, and/or coherence	Can communicate in a suitable format but with some room for improvement. Can work as part of a team, but with limited involvement in group activities. Work lacks coherence in places and could be better structured.	Can communicate effectively in a suitable format, but may have minor errors. Can work effectively as part of a team, with clear contribution to group activities. Mostly coherent work and is in a suitable structure.	Can communicate well, confidently and consistently in a suitable format. Can work very well as part of a team, with very good contribution to group activities. Work is coherent and fluent and is well structured and organised.	Can communicate professionally and, confidently in a suitable format. Can work professionally within a team, showing leadership skills as appropriate, managing conflict and meeting obligations. Work is coherent, very fluent and is presented professionally.	Can communicate with an exceptionally high level of professionalism. Can work exceptionally well and professionally within a team, showing advanced leadership skills. Work is exceptionally coherent, very fluent and is presented professionally.

Student Self Evaluation Form

Student name:		Student P number:	
Programme:		Year of programme	
Assignment Title:			

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

Common Assessment Criteria Applied	Level of Achievement						
	REFER		3 rd	2:2	2:1	1 st	1 st
	OUTRIGHT FAIL	UNSATISFACTORY	SATISFACTORY	GOOD	VERY GOOD	EXCELLENT	EXCEPTIONAL
1. Research-informed Literature	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
2. Knowledge and Understanding of Subject	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
3. Analysis	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
4. Practical Application and Deployment	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐
5. Skills for Professional Practice	0-29% ☐	30-39% ☐	40-49% ☐	50-59% ☐	60-69% ☐	70-79% ☐	80-100% ☐

PLEASE COMMENT ON AREAS IN WHICH YOU FEEL THAT YOU HAVE PERFORMED WELL	PLEASE COMMENT ON AREAS YOU FEEL THAT YOU NEED TO DEVELOP

Student's Name		Date	
Student's Signature			



University of Wales Trinity Saint David

School of Engineering

Can FEA Replace Physical Testing?

Advanced Stress Analysis and FEA (M6X00420)

George Jones

P149914

(BEng) Motorsport Engineering

25.04.2020

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1. Introduction

This paper will assess the contribution of Finite Element Analysis (FEA) in commercial engineering applications. The motorsport sector will be used to give context to design practices at the cutting edge of the automotive industry, where aggressive timescales (concept-to-prototype) exist for technology driven products.

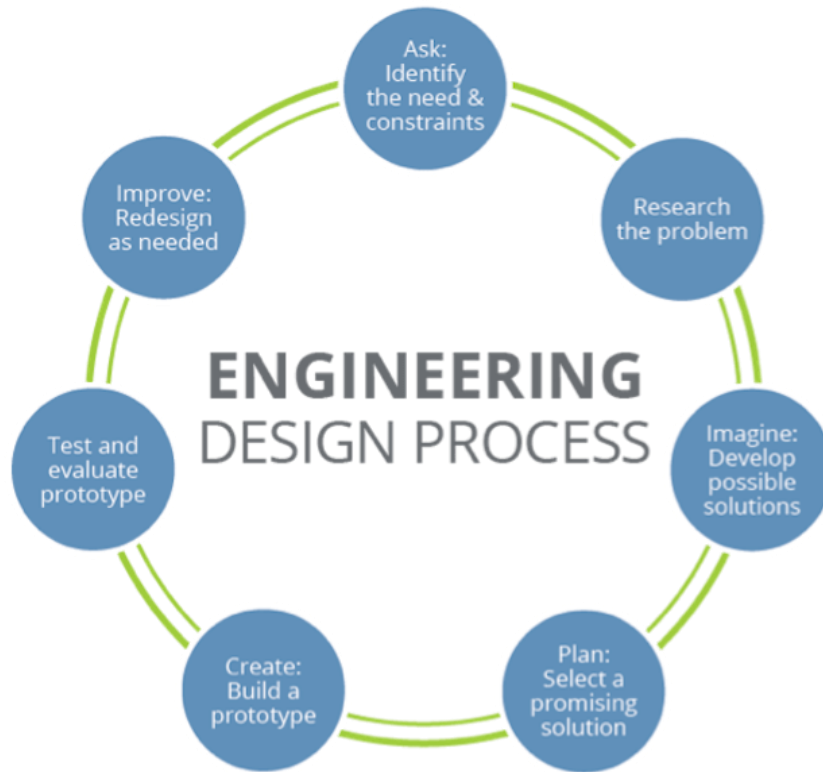


Figure 1 - Design Process (Shih et al., 1998)

Figure 1 gives example to the constituent stages of a typical engineering design process. (Shih et al., 1998) and (Shih, Kuan and Somnay, 2002) suggest how a concentrated effort in FEA can be implemented to accelerate this cycle towards product completion with a decrease in cost and physical resources required. This is achieved through estimating the stresses, strains and deflections of specific component geometries and materials within a virtual environment.

The concept-to-prototype procedure is iterative, indicating a high probability of failure and scope for optimisation at initial design phases. Physical testing is conducted to gather empirical data, guiding the designer to an appropriate solution. The combination of FEA and physical testing will be explored through relevant case studies where a streamlined design process is achieved to maximise commercial productivity.

(Benhayoun, 2019) suggests how simulation driven approaches in noise, vibration, and harshness (NVH) applications are improving to the point where traditional testing methods are being used less frequently.

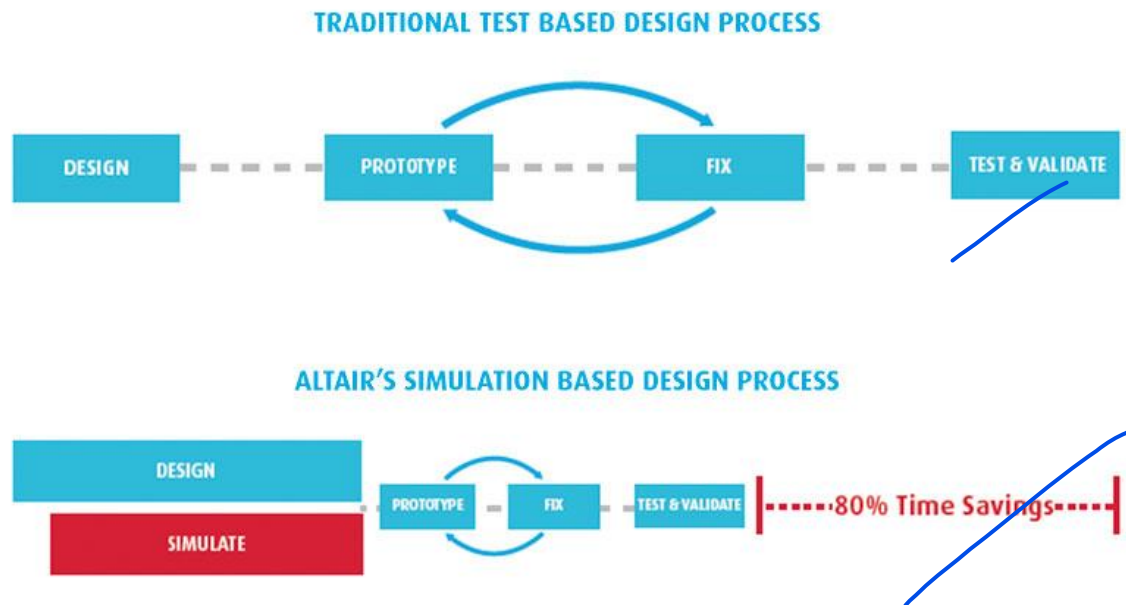


Figure 2 - Comparison of traditional design process and simulation driven process, (Shih, Kuan and Somnay, 2002)

However, (Cunningham, 2015) provides evidence from a ceramic coatings developer where real world testing of a race car competing in the British Touring Car Championship (BTCC), revealed the thermodynamic barrier produced by a ceramic coated exhaust reduced under bonnet temperatures by 37%, as well as improving turbocharger performance. These findings would be difficult to replicate through FE simulation, as multiple complex boundary conditions apply simultaneously in a dynamic environment.

As complexities increase through different materials and conditions, the necessity of validation and empirical feedback is strengthened. The intricacies of validation and the likelihood of removing physical testing from the design process entirely will also be examined through this study.

2. Why Companies Typically Carry Out FEA Alongside Physical Testing

The automotive industry benefits from including FEA in the early stages of the design process as a means of generating cost optimised and fully functional solutions, facilitated by the vast computational power available in modern day engineering. (Delprete, Rosso and Spadotto, 2008) explains the importance of shape/weight optimisation for high performance motorsport applications. In addition, (Culbertson, Browne and Dion, 1996) states development time must be minimal to achieve a competitive edge.

1. Case Study: Touring Car Chassis & Roll Cage Design

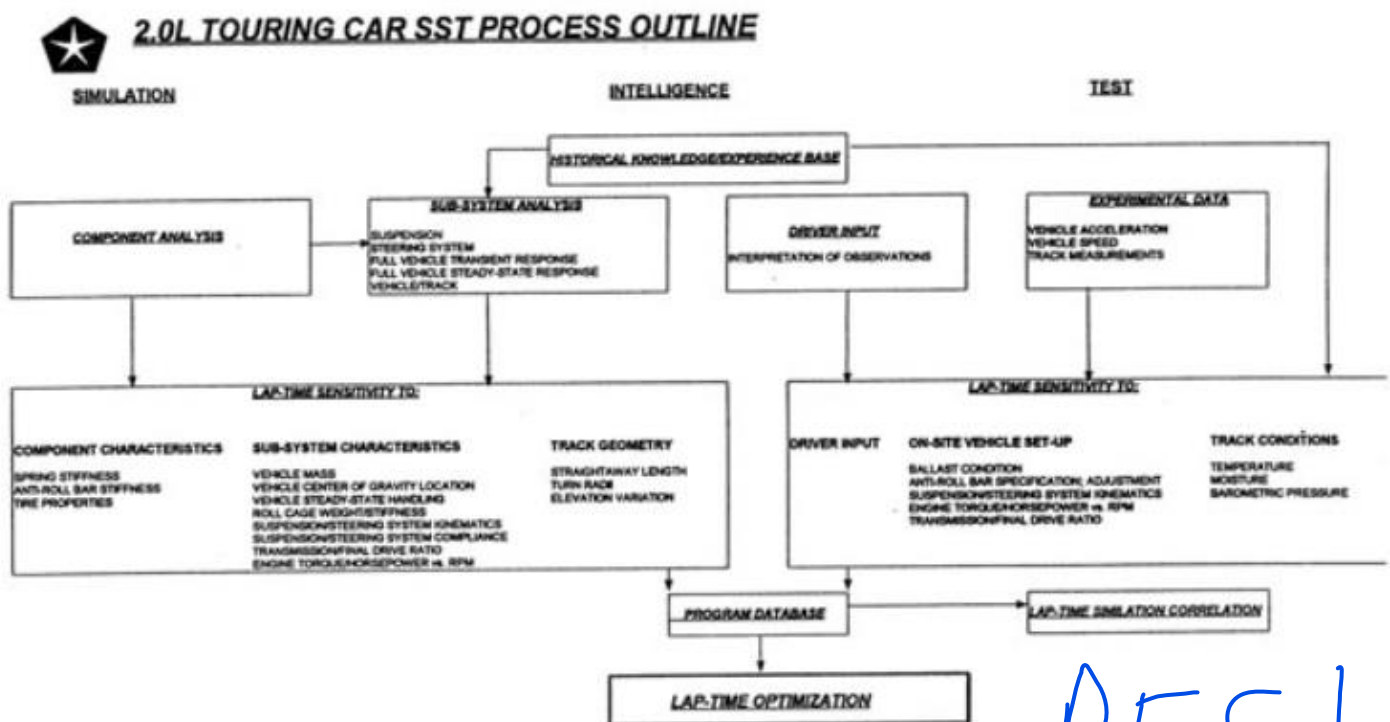


Figure 3 - Touring Car SST Process Outline, (Culbertson, Browne and Dion, 1996)

Figure 3 illustrates an example of a touring car design process with integrated FEA simulations for chassis and roll cage development. The paper by (Culbertson, Browne and Dion, 1996) defines the minimum safety requirements, geometric constraints and additional torsional rigidity that the final design must adhere to. The FEA was conducted on Nastran based software from a tier 1 automotive

company, with the processing power of a CRAY supercomputer. This combination allowed a 60,000-element chassis model to be created, including all structural members and the full roll cage.

The design strategy utilised intelligence gathered from previous experience to feed into the FEA model. The assembly was optimised by repeated elimination of the least effective components, until the structural degradation exceeded the benefits of weight reduction. This conclusion was formed via engineering decision. The final design was scrutinised in specialist post processing software from the tier 1 company to analyse all relevant stress related data.

The touring car went from concept to race ready in less than one year. The study proves that engineering experience and appropriate planning can maximise the cost and time saving benefits of introducing FEA to the design process. If FEA was not used, the engineers would have to rely on hand calculations, assumptions, and physical testing through each design iteration. This often translates to extended development lead times where stress analysis is conducted using experimental procedures on multiple prototypes as described by (Motta Barbosa *et al.*, 2016).

II. Advances in Computer Aided Engineering

Despite the satisfactory results from the 1996 touring car chassis design, finite element simulations have further progressed with the use of computational optimisation. Algorithms can now challenge the previously indispensable engineering knowledge, to suggest suitable solutions for specific

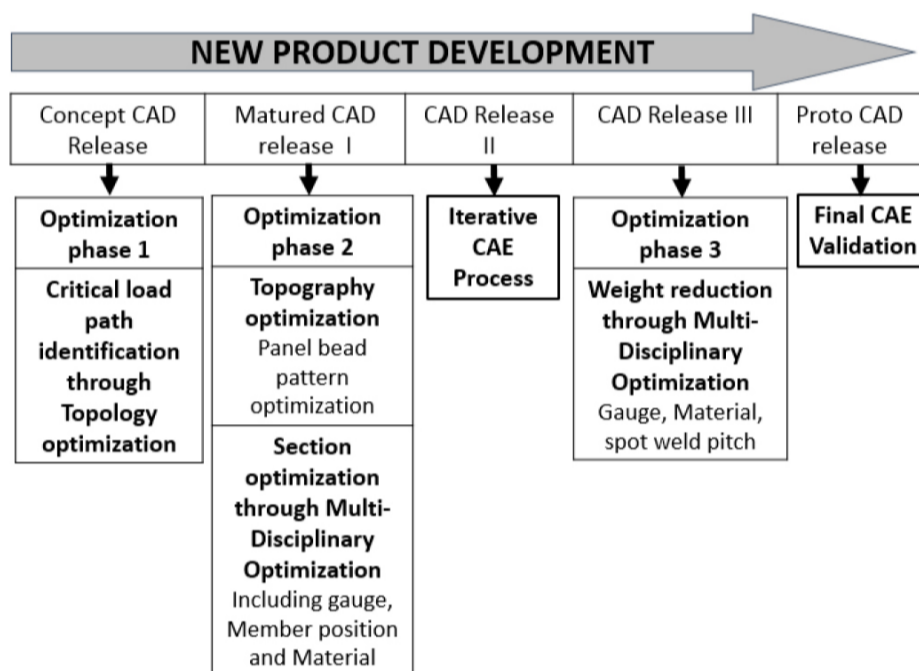


Figure 4 - Optimised Design Process, (Bhosale, Kalal and Sahu, 2017)

conditions. (Bhosale, Kalal and Sahu, 2017) proposes a multi-phase approach that comprises topology of a concept body in white (BIW) to ascertain critical load paths. Topography methods are then used to increase stiffness with a final mass optimisation process being conducted before completion, as shown in *Figure 4*.

Executing advanced computer aided engineering (CAE) techniques through early stages in the design process benefits from a large reduction in manual iterations. The combination of topology and topography result in excellent stiffness, both globally and locally. All of this is achieved from virtual prototyping and evaluation methods.

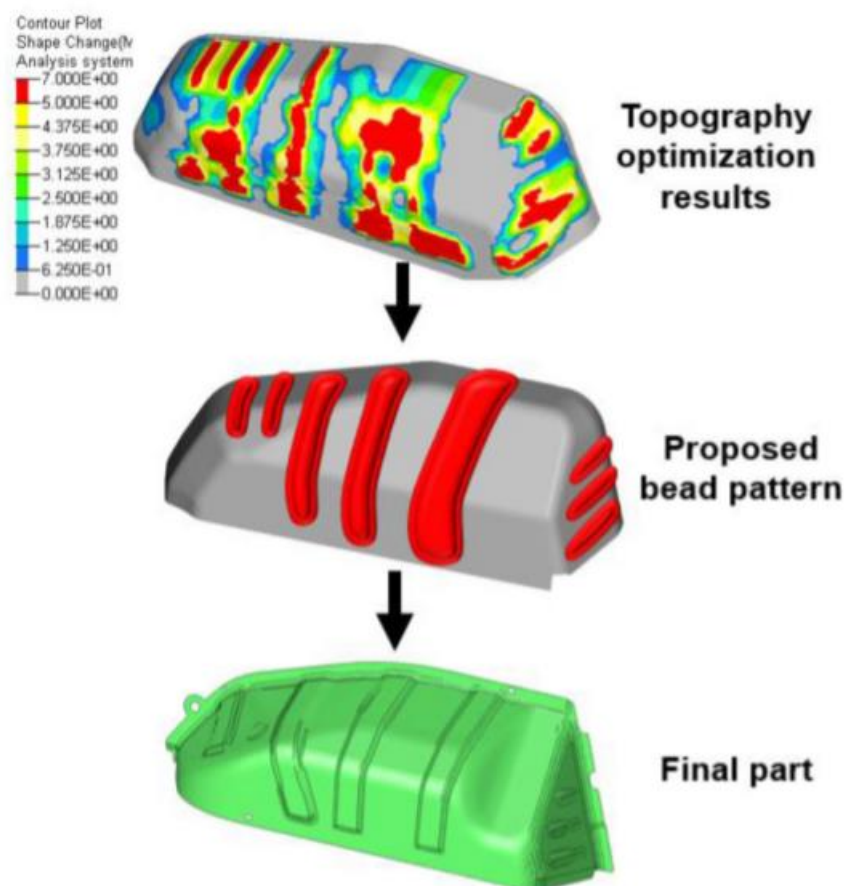


Figure 5 - Topology Process for Optimised Wheel Arch Design, (Bhosale, Kalal and Sahu, 2017)

Figure 5 demonstrates how FEA can be improved through Design of Experiment (DoE) and topography methods, to arrive at an ideal solution. This development technique is significantly more

efficient than traditional prototyping design processes. Models can be revised to achieve desirable features such as uniform stress and deflection control, much earlier in the product life cycle.

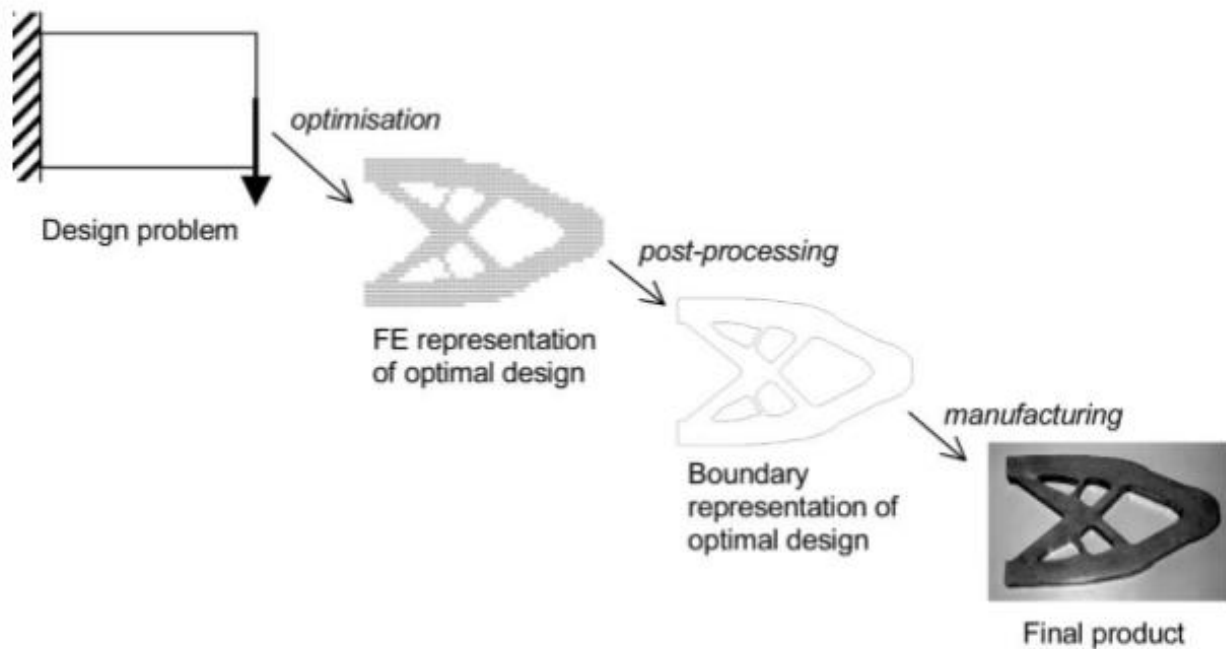


Figure 6 - Optimisation Process for Cantilever Beam, (Kim, Querin and Steven, 2002)

Figure 6 gives additional context to structural optimisation in engineering design, where an array of model constraints is incorporated to drive the design process of a cantilever beam. (Kim, Querin and Steven, 2002) describes this technique as a tool to assist the creativity and imagination of a designer, as well as improving the accuracy of analysis calculations. The prototyping/manufacturing process is also integrated to speed up the product cycle, where correlations between FEA and physical tests can be produced to give additional confidence in product performance.

The real-world performance of any design is critical for many aspects of engineering, most notably in automotive structural engineering, where companies risk accountability for loss of life if a product does not perform as expected. In this sense, using FEA alongside physical testing is advantageous.

Correlation of performance data between multiple testing platforms improves the accuracy of the results. (Azra, Ramesh Nayak and Appaiah, 2018) proves how the implementation of hand calculations, FEA and experimental testing can improve error detection and design flaws that may otherwise be neglected if only one analysis method is used. The accuracy of product characteristics can only be realised where all boundary conditions and constraints converge between test conditions and intended application.

How a Physical Test May Be Correlated to An FEA Model

FEA can be carried out on any potential solution. (University, 2019) suggests how user defined environments can result in misleading results if components are constrained or loaded incorrectly. This section will investigate the details of validation through relevant case studies.

Physical test results may be compared with an accurate FEA model, providing both share identical loadings, boundary conditions and constraints. Strain gauges and Dial Tests/Potentiometers are some of the most common devices used to measure stresses and deflections through a physical test. (Plaskitt, Halfpenny and Roberts, 2015) demonstrate how virtual strain gauges are used in FEA to correlate local stress histories against real measurements. The position of these apparatus including direction of loadings are significant in achieving correlation.

Case Study: Strain Gauge Correlation

A study by (Gregefors and Gregefors, 2016) attempts to correlate strain gauge results to an FEA model at the teeth of a hypoid gear set, used in automotive differentials. *Figure 7* shows one of the four strain gauges (1.57mm x 1.57mm) superimposed to the FE model. 10 elements exist through the profile direction and 1 element in the face direction. This approximation does contribute to a small discrepancy in boundary conditions.

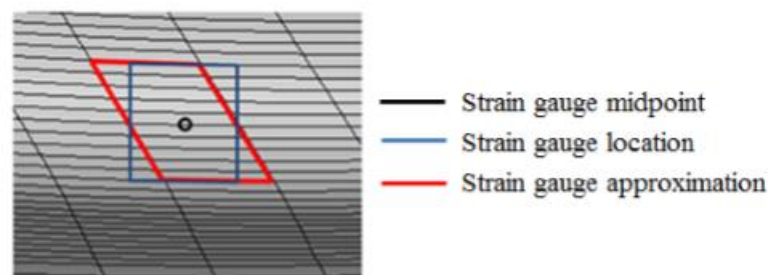


Figure 7 - Strain Gauge Placement in FEA mesh, (Gregefors and Gregefors, 2016)

The strain through the specified area was calculated and the relative error was found using,

$$\text{Relative Error} = \frac{\text{Test Strain} - \text{FE Strain}}{\text{Total Strain}}$$

This method gives direction to errors, with under-approximations displayed as positive. *Figure 8* and *Table 1* give results for physical test results and FEA.

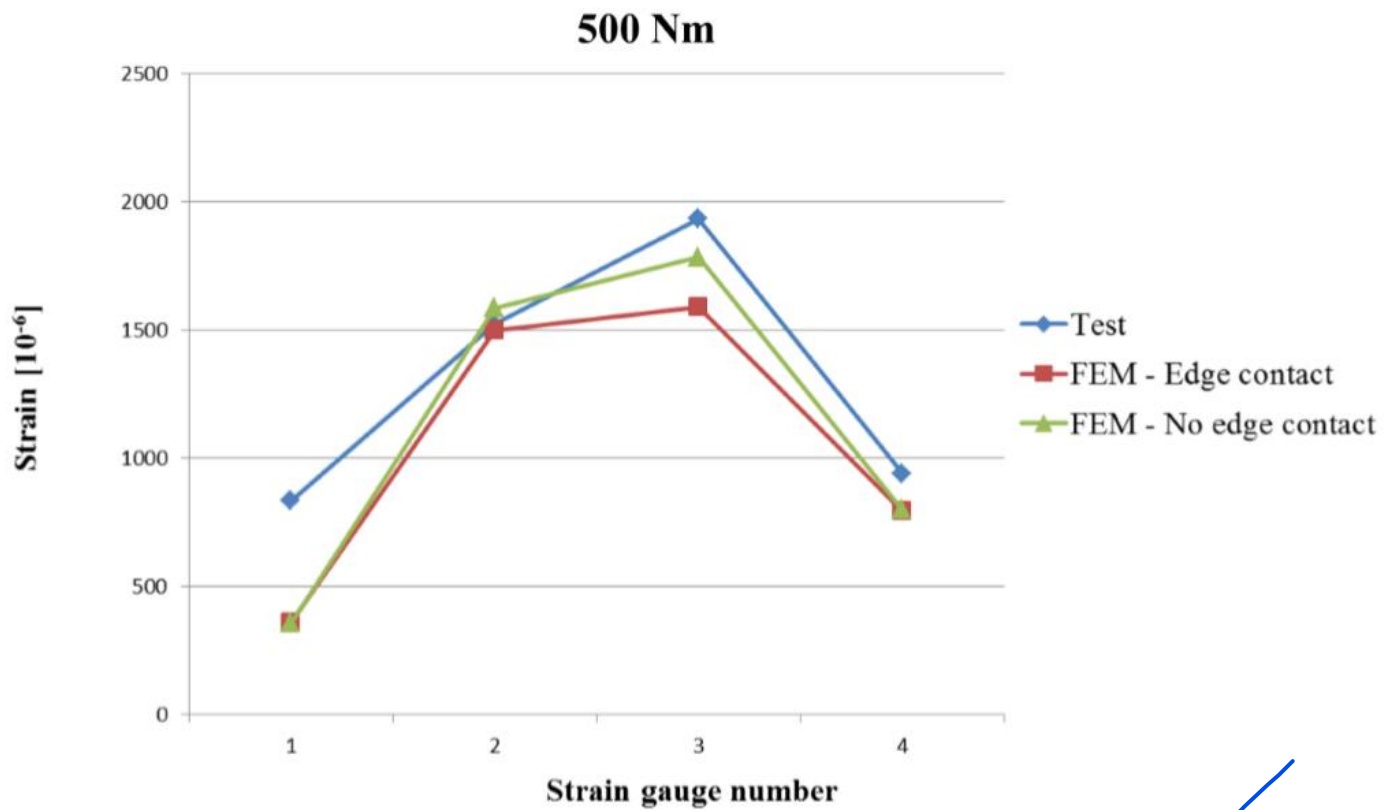


Figure 8 - Strain Gauge and FEM Results, (Gregefors and Gregefors, 2016)

Table 1 - Strain Gauge & FEM Results, (Gregefors and Gregefors, 2016)

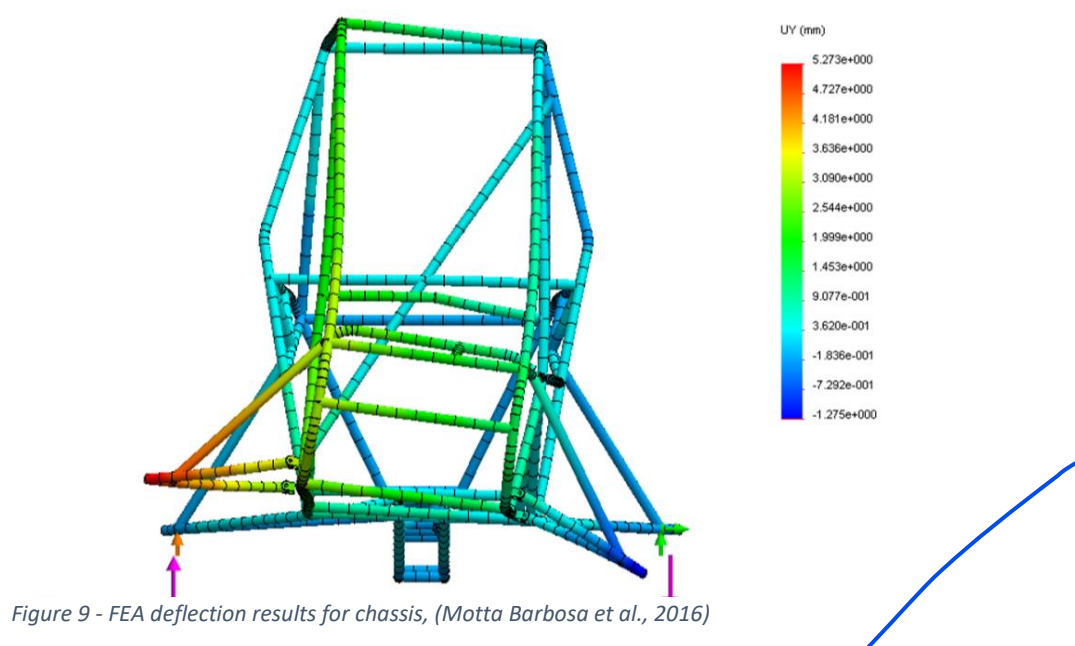
Strain gauge no.	Gauge 1	Gauge 2	Gauge 3	Gauge 4
Measured strain [10^{-6}]	835	1523	1936	942
Calculated strain [10^{-6}]	361	1499	1592	797
Strain difference [10^{-6}]	474	23,8	344	145
Relative error [%]	56,8	1,56	17,8	15,4
Stress difference [MPa]	98	49,3	71,1	30,1

Relative errors across the tooth prove the FE model underpredicts some of the strain gauge measurements. However, the overall trend does correlate. The complex interface of meshing gears is likely to cause some differences in FEA when compared to real boundary conditions and constraints, plus the strain gauge direction relative to the FE mesh will also have a small effect as mentioned. The test was repeated at different torques, with identical results; correlation in trends and underprediction of similar strain magnitudes through all strain gauges. The fact that the results are repeatable with a changing variable give confidence to the user that the physical tests correlate to the FEA calculated results consistently.

Case Study: Torsional Stiffness Correlation

(Thompson, Lampert and Harry Law, 1998) detail the design of a twist rig to measure torsional stiffness of a Winston Cup NASCAR chassis, where physical testing correlated to a specimen of known stiffness. Whilst this approach does contribute to the validation of experimental procedure, the error margin is susceptible to migration if the test specimen is much different to the chassis in torsion magnitude. The Finite Element Method (FEM) gives opportunity to numerically assess the design of the chassis with identical loading and constraints, to correlate with the physical test.

(Motta Barbosa *et al.*, 2016) used both FEA and experimental analysis to assess the torsional stiffness of a Baja SAE prototype chassis. FEA is conducted on a 3D model of the chassis first, with increasing complexity through each simulation case. One of the early simulations followed the same



constraints as those suggested by (Thompson, Lampert and Harry Law, 1998), providing evidence of early correlation with physical testing methods.

Figure 9 illustrates the chassis displacement through FEA with hypothesis of direction of twist and magnitude being satisfied. This suggests preliminary constraints and loads are correct.

A key factor for accurate FEA models is mesh quality, and whether the results are considered mesh independent. In this case study, mesh refinement is carried out on a simplified model, with suitable element types being applied to dissimilar shapes and structures of decreasing mesh size. This process is necessary to best predict the physics of the system, including material properties and loads. (Ajay, 2019), (Okereke and Keates, 2018) and (Sinclair, Beisheim and Sezer, 2006) prove how numerical convergence is improved with appropriate mesh settings.

The Baja SAE chassis was compared through FEA and experimental data to conclude a 13% difference in torsion results. The difference was accounted for through uncertainty analysis and the phenomenon of hysteresis acting through the physical chassis that was not predicted in the FEA model. This suggests how FEA can inform the engineer of potential variables that have not been previously considered in test procedures.

Can FEA ever replace physical testing?

The previous sections in this report prove the value of FEA in modern engineering applications. The ability to test products in a virtual environment does save time, money, and resources. FEA software, computing power and algorithm-based processes are constantly improving to assist engineers in creativity and optimisation of solutions.

FEA can give the user access to a variety of useful insights to product design, that would not be possible through physical testing alone. For example, using engineering decision for placement of strain gauges on a component can be further informed by the visual representation of stress contours through the entire component. In some instances, this can reveal otherwise unknown areas of potential concern. Another benefit from FEA is the ability to observe displacements through an exaggerated scale. This gives the user context to deformation behaviour that would also not be clear from physical testing in many cases.

The concept of FEA replacing physical testing entirely, however, does appear to be unrealistic at present. All case studies in this paper use examples of automotive (or motorsport) based applications. This sector is heavily regulated in safety and the impact of product failure can cost companies heavily (Heyes, 1998). For this reason, physical testing for a multitude of unknown component properties such as fatigue, stress and deflection are vital in gaining confidence in product performance before market.

A report by (You and Fricke, 2011) compiled modern virtual testing methods to review developments in product design and prototyping in the automotive industry. Hybrid simulation, mechanical hardware-in-the-loop (mHIL), Hybrid System Response Convergence (HSRC) and OpenFresco (algorithm based) methods were all considered.

In the case of (You and Young, 2003), a multi-body (6 DOF) simulation was produced to replicate a refrigeration unit on a vibration table in ADAMS. Fatigue analysis through this method concluded highly accurate results and, in this sense, virtual testing (FEA) can appear to replace physical testing. However, the study took reference from an actual vibration table with physically proven accuracy. These isolated systems can be very accurately modelled but must be correlated for confidence.

The paper by (Fricke, Frost and Ag, 2012) used HSRC methods to replicate dynamic behaviour for a damper application through an open loop system. This approach uses the output data from the physical test to input to the real-time simulation, as shown in *Figure 10*. Again, the simulations become extremely accurate through iterative error reduction but ultimately rely on physical testing.

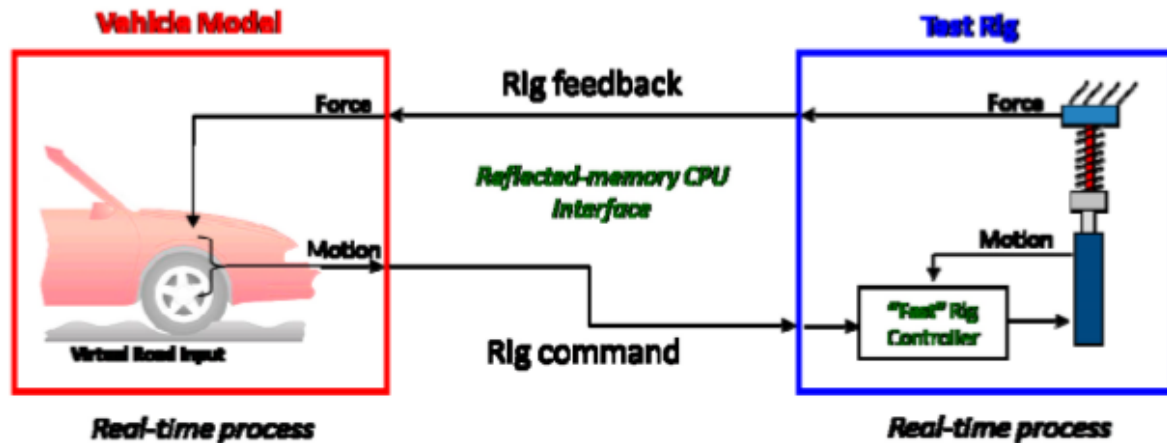


Figure 10 - "real-time" hybrid simulation system schematic, (Fricke, Frost and Ag, 2012)

Legislation for mandatory physical testing, type approval and optional testing programs such as those provided by (Thatcham, 2020) also suggest the importance of physical testing and inspections for new components and vehicles before market.

Case Study: Performance Failure without Physical testing

In Motorsport, physical testing of components is highly regarded to be irreplaceable. It is a well-known fact that motorsport teams can express how a lack of performance has been linked to poor correlation between their simulations and real-world conditions. (Smedley, 2019) explains how a Formula 1 car built over the duration of two years, from the input of hundreds of skilled engineers and workers using state of the art technology to drive simulations, can be tested for the first time only to find a severe lack in performance. Whilst all components may appear to be operating and the safety of the driver is not compromised, there exists a difference between reality and expectations. Limited physical testing is the root cause of this phenomenon and the use of wind tunnels (a form of physical testing) can also misinform where boundary conditions or acquisition techniques are not entirely accurate.

Conclusion

The evidence in this paper proves FEA results require physical test feedback to determine validity. The simulation trends are comparable to reality, but precise values are often inconsistent. The cause of such conflicts is always due to user input. This can take the form of incorrect fixtures applied to the component, mesh quality, boundary conditions, solver type and more. The important fact is underpinning numerical calculations are *always* correct.

Physical test procedures that are meant to replicate intended use of the component can also carry some similar traits, where incorrect test conditions will skew the reliability of results. However, employing the component for its intended use, in its intended environment has no replacement.

This form of testing is entirely conclusive where enough repetition is achieved. Reproduction of this form of test, with 100% confidence in a virtual environment without empirical knowledge to inform the scenario is not achievable at present.

YOU HAVE PRESENTED A REPORT THAT PUTS TOGETHER
A GOOD BALANCED ARGUMENT FOR THE POINTS RAISED
GOOD CONSIDERATION OF THE IMPACT OF FEA (& IN
PARTICULAR OPTIMISATION) ON THE DESIGN PROCESS.

- Ajay, H. (2019) 'What is Convergence in Finite Element Analysis?', *FEA*, 1. Available at: <https://www.simscale.com/blog/2017/01/convergence-finite-element-analysis/>.
- Azra, U. E., Ramesh Nayak, B. and Appaiah, M. (2018) 'Design of a mild steel specimen using FEA and tensile test data', *Materials Today: Proceedings*. Elsevier Ltd, 5(1), pp. 2605–2608. doi: 10.1016/j.matpr.2018.01.039.
- Benhayoun, I. (2019) *Why a Simulation-Driven Design Approach Saves You Time (and Money)*, *Altair Blog*. Available at: <https://blog.altair.com/why-a-simulation-driven-design-approach-saves-you-time-and-money/> (Accessed: 15 April 2020).
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