

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	TRELEAVEN	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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:	<i>Assignments will not be accepted without a signature here</i>	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	

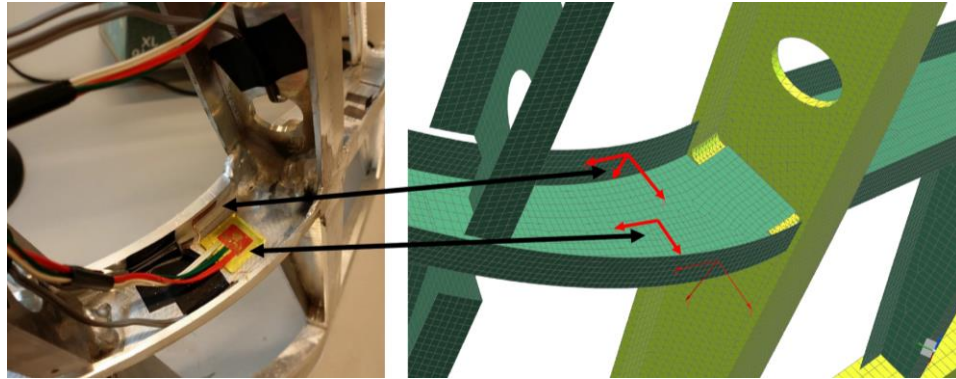
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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	18
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	17.4
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
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	6.5

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)		59.9 %
	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
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15/03/20

Can FEA replace physical testing?

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1 Why companies typically carry out FEA alongside physical testing?

Finite Element Analysis, or FEA, creates a computational model to be analysed and tested under certain loads by dividing the model into lots of small sections, elements, for a detailed analysis. FEA is commonly used alongside physical testing by many companies to save time, money, resources and for safety. There are many applications that can benefit from the use of FEA; stress, thermal, vibration, seismic and impact & crash analysis (FEA uses). This report refers to the case study of Jaguar Land Rover, JLR, with their use of computational analysis through their testing process for Jaguar cars.

Cost reduction is a big incentive for companies such as JLR to use FEA alongside their physical testing. It is cheaper to create and test an FE model as there are no physical materials or machinery being used to produce the model for testing. The only required cost associated with FEA is the initial software cost. Then a company may need to spend money on training employees to use the software. There is also minimal maintenance with software, such as updates and possibly a licensing fee (FEA maintenance). These one time or annual costs are minimal compared to the cost of hardware and materials used in creating and testing multiple prototypes models.

Another way FEA is cost effective is how much it speeds up the manufacturing of a product through its design and testing phase. A designer can instantly find weak points and work through them or see how a component will respond in certain positions and conditions in the car. Using FEA allows the design cycle to be quicker as it reduces the time and resources wasted on creating so many physical models before the final prototype is ready. At JLR, every component experiences hundreds of hours of optimisation using software packages, including FEA packages, before a physical component is produced (Jaguar, 2020). Using these software packages can save months off the development process for each component (Jaguar, 2020). Using FEA also has the benefit of allowing for a component or product to be tested in different materials without it actually being manufactured which would cause a massive cost of money as well as time for a company.

FEA allows for early evaluation and optimisation of the critical design parameters. This allows the initial designer to see if a component will behave as desired before passing the design on to other team members. This means less time is spent in the design stage and the amount of time products are sent back to be completely redesigned is minimised and usually totally eradicated.

Fatigue testing to find the lifetime of a product is an example of this. JLR demonstrates this with their Ingenium engine. If it can reach at least 10^7 cycles it can be deemed to last a lifetime (Jaguar, 2020). To test this on a physical prototype would take weeks or longer whereas this can be simulated in FEA in a lot less time. The Ingenium engine experienced two million kilometres of testing through its

development where the majority was doing using software packages, such as FEA (Jaguar, 2020). This allowed the time spent testing over the five-year development period to be reduced drastically compared to if most of the testing was carried out with physical prototypes.

From a design point of view, FEA can be more useful than physical testing. The results gained are clearer and it is easier to interpret where points would become weak, damaged or even brake (clearer results). This makes it easier to pin point a problem and solve it more efficiently and effectively.

Another benefit to the design cycle of using FEA is the ability to optimise each model (optimise). This means that multiple tests can be carried out on one model without it effecting results, where as with physical testing a fresh model is needed each time so the previous results of the testing doesn't ruin the results of the new test. The same model can not be tested on twice as it is not always obvious if any damage has occurred and where it has happened.

The control on variables is another advantage to using FEA. Physical tests can be affected by Enviromental variables such as the temeperture, the weather or road contitions. Depending on the type of componant being tested these can have a severe impact on results. FEA can also simulate harder to find enviromental factors for testing such as extream temperatures, humidity and physical barriers. This is particully useful for enviromental factors which are unrelaible or hard to find such as snow, or extream heat. JLR demonstarted the use of this factor when they test their Jaguar chassis and suspension by exposing the car to situations such as kerb impacts, object strikes and pothole braking, as well as testing the safety of the chassis through simulated crash tests (Jaguar, 2020). Also alongside physical testing JLR also use a FEA when carrying out a vehicles aerodynamic profile testing. This is done in the form of Computational Fluid Dynamics, or CFD, in a virtual wind tunnel (Jaguar, 2020). This helps to minimise the drag of a vehicle to produce better fuel economy and lower emmisions. Using FEA also helps to view solutions to improve engine and brake cooling where just physical testing alone could be a challenge.

FEA is a much safer form of testing compared to physical testing, so by using FEA alongside physical testing it allows a reduction in physical test therfore making the design process safer. There are no physical reproussions of testing a compnant using FEA as no debry can be exposed to humans and no chemical can be harm the environment. Whilst JLR have used FEA alongside physical testing it has reduced their enviromental impact of car production. Across the production of a Jaguar a reduction of 1.2 million kilometers of test driving is noticed as well as a reduction in produced chemicals such as 290 tonnes of CO2 (Jaguar, 2020).

To summarise, using FEA alongside physical testing allows a greater number of tests to be carried out on a product or component within a shorter time frame. FEA's obvious benefit to a company is its time saving but it also saves material and machinery costs as well as optimisation of models allowing Research and Development teams to spend their time and budget on other projects.

2 How a physical test may be correlated to a FE model?

The reason a physical test is correlated to a FE model is to improve the accuracy of the simulated testing. There are multiple ways to improve a simulation and correlating the results of a physical test is one of the most important. This process verifies how much the physical model and FE model agree with each other. This is very important when JLR are designing any component for their vehicles.

The first step in correlating a physical test to a FE model is to check that they are the exact same product by making sure the information inputted into the FE model is accurate and correct. The first check would be the geometry of the model this ensures that the FE model's dimensions are the same as the physical dimensions. The material thickness of the product should also be compared for accuracy (geometry).

The material used in the product may be tested to observe and record its specific material properties. These results then can be inputted into the material specification in the FE model. Values such as the Young's Modulus, density and stiffness can be recorded and inputted (YM). If these values are assumed with reasonable values then the result of the FEA may show the correct behavior and deformation but will likely have incorrect values so won't help in refining the product.

Another way a physical test can help improve the FE model is to measure the mass and calculate the location of the centre of gravity and then compare to the FE model. This will help confirm that both the geometry and material specifications are correct (geometry).

If a multi body model is being investigated then the way in which the bodies interact are another area to be correlated, a big part of this is the way the components mate to each other. The matings need to represent accurately how they are connected in real life. For example, if the components are held together via screws, as the head bolts on the Ingenium engine are, the model needs to represent this with the correct type of thread, such as UNF or UNC, as well as being tightened to the same torque. Also if the components are connected via bushings this will need to be carried out in the FE model as well ensuring the correct stiffness of the bushings, which can be collected by testing the material properties of the selected bushing in real life.

A more basic form of correlation is to compare the results of the FEA against a physical test to see if the product reacts as expected. Although this seems simple it is very important. If small deformations occur in real life then this would also happen in the FEA. When testing the strain of product they need

to be compared to ensure they share a correlation, this can be done using a virtual strain gauge (GAUGE). A virtual strain gauge can be placed on the FE model in a defined position. The strain recorded in the test can be compared to that of the result in the physical test. For example, on a suspension component of a Jaguar a uniaxial strain gauge can be installed, in the same location as the gauge on the model, to record the strain under real life testing (GAUGE). Testing can be done at low load values and the strain can be measured at nominal, but active, stress regions to correlate the results. This test should be repeated by moving the gauge slightly to check the sensitivity of the results. From this correlation the results in high stress area can then be trusted.

Another way to check the FE model is to use a virtual sensor. When testing a wishbone the virtual sensors can work alongside the virtual strain gauge to give complementary information. Information such as the displacement of the model can be compared to real life. This allows a better validation of the FE model by ensuring the boundary conditions, mass and stiffness distribution are correct (GAUGE).

At JLR, Daniel Buckley the Ingenium Programme Manager, believes that design validation is a pyramid (Jaguar, 2020). Virtual testing is the base of a pyramid and physical testing is only carried out to validate the results as the peak of the pyramid. This means that correlation between physical test and the FE model often uses real life test that were carried out on previous projects. This happened a lot in the design of the Ingenium engine which allowed JLR to iterate towards a far better final product that was reliable and optimised, quicker than previous projects (Jaguar, 2020).

Overall, the FE model is only going to give as accurate results as the information that is inputted into it, so it's important to correlate the model to the physical component as much as possible. This will ensure the most accurate simulation will be produced. By carrying out these correlation methods it will reduce the number of iterations of the designing and testing of the FE model as well as increasing the confidence the user will have in the FE results.

3 Can and should FEA replace physical testing?

In recent years, FEA has been more prominent in the research and development of components so less physical tests are carried out. The trend would indicate that physical testing could be eradicated. Since physical testing is far more expensive in both cost and time due to the amount of man power needed and big machinery for physical tests. This means that businesses would prefer product design to be carried out through computational methods such as FEA. However, they need their FEA results to be accurate so it is unlikely that physical testing could be eradicated completely due to the need of verification of the computational results. Another issue is that currently there are some products where there are limited packages or quality of packages available to carry out FEA, such as automotive tyres. This industry currently heavily relies on the physical testing of their products as the software is not available to give reliable results. However researchers at the Fraunhofer Institute for Industrial Mathematics have created a simulation package called CDTire/3D that might help with this issue (tyres).

REGULATIONS?

Another reason physical testing is still carried out is that customers like to see data from physical testing rather than computational ones (customers). So for companies to sell their product it is still used as a marketing test even if all the data tested is not used in the actual research and development stage.

Physical testing will most likely be used for many more years even if it is only in a small amount at the end of development to check FE results. To completely eradicate physical testing the software needs to be improved and a lot of reliance will be placed on the user to ensure every parameter is fully defined with no assumptions left in place. There is also a reliance on all the materials on the package behaving as they would in real life. For example, the speed at which a force is applied can effect a product but this isn't always accurately represented in a FEA (Mraz, 2015).

FE testing can replace a lot of physical tests as even with physical testing a safety factor is added to the production of a component. Therefore, if FEA replaced physical testing the safety factor could always be increased slightly to allow for the variation in results, however this could only happen with non-critical components. If a production of a performance component was being manufactured it would be beneficial in the design if physical testing was also carried out so that the component could be as light as possible whilst retaining the necessary rigidity.

Within the automotive industry, physical testing could easily begin to drastically reduce and start the process of being replaced by FEA. This is possible due to any physical testing that needs to be carried out can be done in the motorsport industry where data loggers record components being loaded to the extreme conditions (motorsport test).

However, physical tests are still needed to validate the FE results because the FEA packages will give trends of what's expected to happen but the values actual may not be the same as real life in it has not been correlated to real life scenarios. Also if the product is a safety product physical testing will still need to occur to ensure that there are no discrepancies caused to the product during the manufacturing process. Dr Parnell (2010), the senior manager at MSC Software, said “the more high-value the product is, the more critical it is to life and safety, then the more you need to do beyond basic simulation”. This means that any product that is being manufactured for a critical purpose will need further testing which could include a lot of physical testing or just a small physical test to correlate the FE model.

Within the automotive industry physical testing is still deemed important as it allows a combination of driver, fuel type and the venue to be tested together. Due to the importance of the need to see how many real world variables behave together (Engineering Materials, 2015). One company, see *figure 1*, have reduced the physical testing and totally eradicated some test with improved simulation models. The elimination of hardware testing in bumper layout and body cinematics and reduction in other areas has allowed the company to save over half a million euros (McKinsey & Company, 2017).

CAE simulation application	Classification of result reliability				Elimination of hardware tests		
	Very high	Good	Not fully satisfactory	Poor	Yes	CAE calibration	No
Crash		✓					
Dynamic, stiffness of trimmed body			✓				
Body cinematics	✓					€0.6 millions saved	
Bumper layout	✓						
Thermal flux engine compartment		✓					
Power train acoustics			✓				
Aerodynamics		✓					
Casting process				✓			

Virtual simulation hardware tests kept when risk not low enough

Figure 1 (McKinsey & Company, 2017)

Another benefit of replacing FEA with physical testing is for crash testing. As seen above in *figure 1*, it is still needed to calibrate the FE model, however one benefit of carrying out crash testing in a FE package is that the absorption of force is easily recorded, especially on the occupants. It's also possible to evaluate and control variables such as the age, gender, height and weight of occupant to see how they perform in a crash. Whereas this is not possible to do with physical tests. The software can

also be programmed so the occupants would react like a real person to analyse how the bodies would respond during the crash, where the dummies in real life can not do this (Abbey, 2014).

JLR have replaced physical tests with more FE modeling. This has happened on a big scale for Jaguar in the development of the Ingenium engine, where the majority of the testing, including two million kilometers worth of testing, occurred using virtual packageing such as FEA (Jaguar, 2020). Another huge milestone for Jaguar is when they produced the Jaguar XE. This was Jaguars' first car that had only 100% virtual testing for the aerodynamics, with no aerodynamic prototype built, then went into production. Despite this, it was the most aerodynamic efficient car Jaguar had ever put into production (HI-Tec CAE, 2015).

Overall, FEA will reduce the amount of physical testing however it is unlikely that it will totally replace it in the near future so there is still a need for it.

MANY OF YOUR POINTS WOULD BE CLEARER WITH DIAGRAMS
WHILST YOU HAVE DISCUSSED THE IMPACT OF FEA AS A VERIFICATION
TOOL, YOU HAVE NOT DISCUSSED ITS USE AS A DESIGN TOOL & THE POTENTIAL
IMPACT THAT IT CAN HAVE ON THE DESIGN PROCESS

4 References

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