

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

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declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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

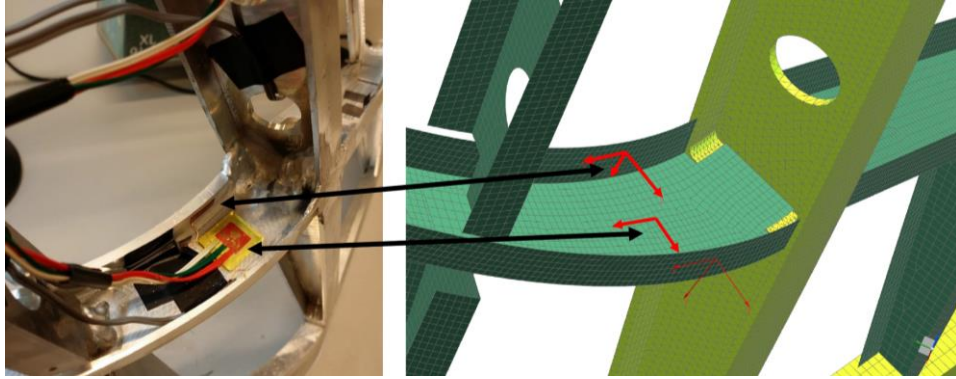
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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	18.6
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	18.9
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	6.4

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)		61.9 %
	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

School of Engineering

Can FEA replace physical testing?

Ewan Carter

P149336

30 April 2020

Advanced Stress Analysis & FEA

M6X00420

Contents

Introduction	3
1. Aims	3
2. Objectives	3
Why companies typically carry out FE analysis alongside physical testing	4
How a physical test may be correlated to an FE model.	7
Advantages and disadvantages of both Finite Element Analysis and physical testing	9
Should FEA replace Physical testing?	10
Conclusion	11
Works Cited	12

Introduction

Finite Element Analysis (FEA) is a method for predicting how a product may react to real-world forces acting upon it (Autodesk Inc., 2020). This shows whether this product would wear, wear out or fail in the way that it was designed to do; giving an engineer an idea of what is going to happen when the product is used.

The Finite Element method upon which FEA is based, is used in engineering to solve physical problems within a design (Bathe, 2014). This problem typically involves subjecting a structure to certain loads gathered from previous research or calculation. Turning this physical problem into a mathematical model may require certain assumptions that then lead to the creation of a mathematical model for the problem. As this is a numerical procedure, solution accuracy is something that must be considered when producing a finite element model. If the required accuracy is not met, this can be repeated with different solution parameters until the required accuracy is met.

1. Aims

The aim of this assignment is to discuss the following points in relation to Finite Element Analysis:

- Why companies typically carry out finite element analysis alongside physical testing
- How a physical test may be correlated to a finite element model
- If Finite Element Analysis can (or should) ever replace physical testing

2. Objectives

The objective of this assignment is to use case studies and research from various sources to discuss the above points in detail and make informed decisions on the third point listed above.

Why companies typically carry out FE analysis alongside physical testing

A company may typically carry out Finite Element Analysis (FEA) alongside physical testing for numerous reasons. One reason is to predict how a part may behave when loaded up under a buckling load, and when it may fail. (Caliber Design, 2015) To follow on from this, FEA can also be used to ensure that the design is on a suitable path to completion during the design process, as well as checking any calculations with the loading of the part when hand calculations may become too difficult to complete by hand.

A side effect of using FEA is that the use of this process will allow product designers to invest in virtual analysis earlier in the process than in the past. (Manor Tool & manufacturing company, 2020) This makes it easier for the product design team to identify suspect results in the model without the use of a physical prototype, thus reducing the number of prototypes that may be required. The use of FEA to reduce the number of prototypes also saves time when creating the test simulations compared to testing a physical product by using a Finite Element model allows the design team to input a Computer Aided Design (CAD) file straight into an FEA package to test it in place of having to spend time manufacturing a part just to destructively test it, which also saves on manufacturing costs.

FEA may also be used to simulate the transmission of sound waves through a panel, as demonstrated in a report by (Gur, Wagner, & Morman, 1999), which measures the change in sound transmission through a 3mm thick aluminium panel at varying frequencies. This report is using this to compare various methods of FEA and their results, as shown in figure 1.

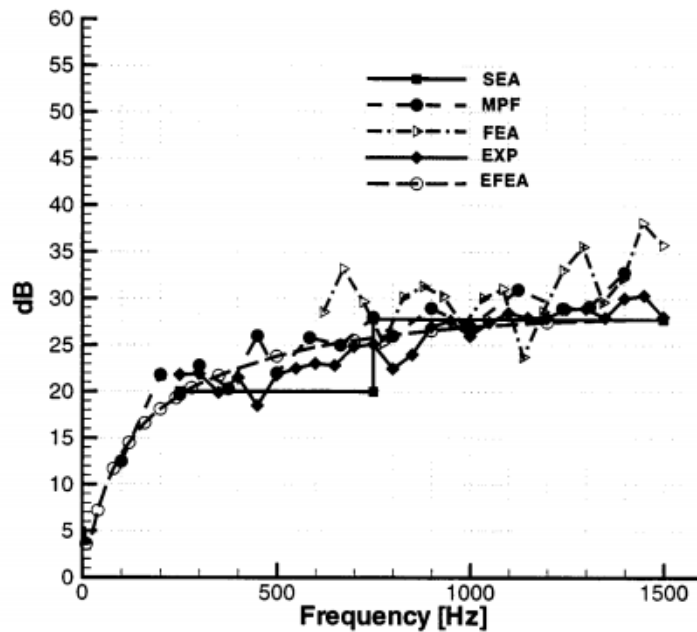


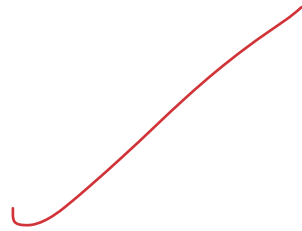
Figure 2. **Sound Transmission Loss Through a 3 mm thick Aluminum Panel**
 (EXP: Experiments, FEA: Finite Element Analysis, EFEA: Energy Finite Element Analysis, MPF: Modal Power Flow (Modal energy Analysis), SEA: Statistical Energy Analysis)

Figure 1 - A graph of results from Gur's report (Gur, Wagner, & Morman, 1999)

In terms of actual applications for real companies, this allows for car manufacturers, for whom noise, vibration and harshness are a large consideration, to predict how vibrations may propagate within the interior of a vehicle and thus take steps to reduce the effect of these before the vehicle reaches the prototyping stage. This again loops back into the point brought up by (Manor Tool & manufacturing company, 2020), in that this process reduces the amount of physical prototyping required, thus reducing costs, meaning more money can be spent elsewhere in the development of a vehicle.

Another form of Finite element analysis is the field of computational fluid dynamics. What this does is study the flow of fluid, usually air, through a given domain. Within motorsports, this is used to help optimise the shape of a racing vehicle to both reduce drag and, where possible, increase the overall efficiency of a given design. An example of this is (Fuller, 2012)'s report into the effectiveness of swan-neck rear wing mounts for the 2009 LMP1 regulations used this to illustrate the changes caused by changing from a more conventional wing mounting mechanism to the newer swan-mount mechanism. The result was an increase in downforce of 280 lbs for the swan neck configuration over the more traditional wing mounting method, caused by a reduction in flow separation on the underside of the rear wing that would have been caused by the rear wing supports had they been mounted to the underside of the rear wing.

CFD is also a very powerful tool in the aerodynamicist's toolbox because it allows for testing to be carried out on a number of test schemes without the use of a physical model in a wind tunnel. This reduces the cost required to both produce wind tunnel models, which can cost a large amount of money to produce, as well as the physical costs of running a wind tunnel, even when running scale models.



How a physical test may be correlated to an FE model.

In order to validate the results of a physical test, a finite element simulation may be employed. The way this is done may be to recreate the physical test's conditions within a finite element software package. In this section, the use of a wind tunnel and a corresponding Computational Fluid Dynamics study will be discussed as well as the use of finite element analysis in other fields.

Computational Fluid Dynamics may be used in conjunction with a wind tunnel test not only to check the results, but also to better visualise any flow regimes that may have been picked up within a wind tunnel testing environment.

The first way to make a wind tunnel study correlate to a CFD study would be to closely mimic the conditions within the wind tunnel within the CFD software. This means that the domain of the CFD study needs to be sized appropriately to match the cross-sectional area of the wind tunnel. While this means that often the object being studied is larger than the 1-1.5% of the total cross-sectional area stated in (Lanfrit, 2005)'s report, that same report states that the 1-1.5% figure is not applicable when modelling the domain size of a real wind tunnel. This also means that the boundary conditions need to match that of the actual wind tunnel being tested, for example all the outer edges that aren't being used as inlets or outlets would need to be set as walls within the CFD solver.

While on the topic of matching the conditions within the wind tunnel, it is imperative that the wind speeds within the wind tunnel and the CFD software match for correlation purposes. This is achieved by setting the wind speed to be as close as possible to the speed achieved in the wind tunnel.

Another thing to mention when talking about CFD correlation is the mesh settings. While a coarse mesh may solve quickly, a fine mesh of the domain will be much more accurate at the cost of increased solve time within the CFD package. The User should be able to determine which degree of resolution should be used to best suit the simulation.

In terms of getting correlation of results between a CFD study and a wind tunnel, there are a couple of ways to do this. One way is to physically calculate the forces produced by both methods of testing, which is good in automotive applications as it allows for a clear calculation of the lift and drag forces produced in the tests. What this doesn't allow is for accurate visualisation of the flow structures, which can be done using a multitude of methods. Figure 2 shows a visualisation of flow structures for both a wind tunnel test and a CFD study.

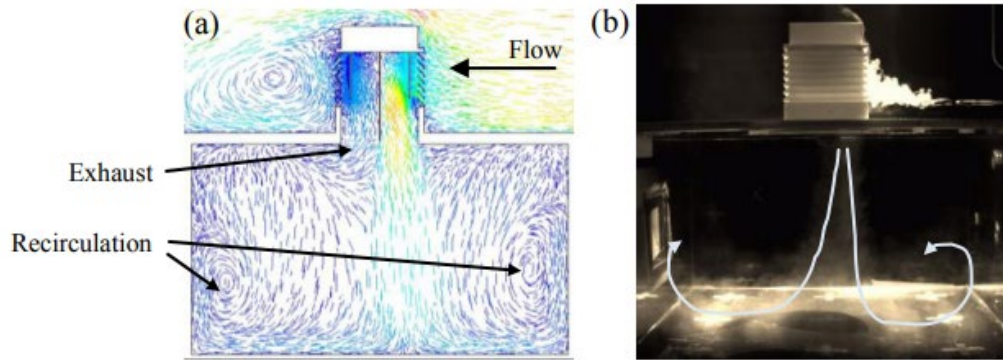


Fig. 7. (a) CFD flow visualisation; (b) Smoke testing in the wind tunnel

Figure 2 - Flow visualisation for the two different experiments tested. (Calautit, 2015)

Figure 2 shows the flow within a wind tower with Heat Transfer Devices inside and the recirculation of the air on the underside of it. From the annotations from (Calautit, 2015)'s report, it is made clear how the airflow circulates within the two testing methodologies. Judging by the fact that the two testing methodologies share common flow structures, which means the two testing methodologies have good correlation, showing that in this instance, a physical model is less likely to be needed.

AND?

Advantages and disadvantages of both Finite Element Analysis and physical testing

As a means of comparing FEA and physical testing, the disadvantages and advantages of both FEA and physical testing need to be discussed. While the advantages were discussed in the first section, for balance, the disadvantages need to be discussed as well as the advantages and disadvantages of using physical testing.

While Finite Element Analysis has its advantages, it also has a fair number of disadvantages to consider. For one, FEA results are only as good as the initial setup put into the simulation, meaning if the data is inaccurate or any of the simulation parameters such as mesh are wrong, this can lead to results that are wildly different from the actual results from a physical test or any hand calculations. Another disadvantage is that the accuracy of the results from the FEA study is linked directly to the density of the mesh. This means that too dense a mesh will take longer to solve, but too coarse a mesh will solve quickly but be largely inaccurate. An unskilled FEA technician may not be able to correctly identify where to use the correct mesh density, leading to extended solve times and increased operating costs.

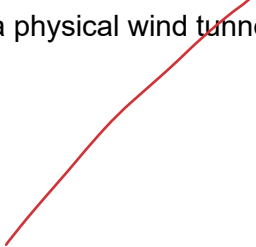
On the side of physical testing however, the main advantage is the ability of a physical prototype to produce repeatable results given the same constraints as the corresponding FEA study, as evidenced in (Calautit, 2015)'s report. On the downside, Physical prototypes take much longer to produce, and can cost a large amount more than the equivalent Computer-Aided Design model and may be destroyed when tested, leading to more expense to produce another model. Another disadvantage that physical prototypes have is that if any physical changes need to be made to the model, a new version of either the whole prototype or a part of the prototype needs to be produced at cost to the manufacturing company, which takes much longer than the changes that would be required to amend a Computer-aided model.

Should FEA replace Physical testing?

Given the research conducted in this paper, while FEA is a potent tool in the engineer's toolbox, it should not fully replace any physical testing that may need to be carried out during the development of a product. The reasoning for this is that all FEA results need to be correlated to either physical testing or hand calculations in order to be considered accurate within the development of a product. This means that at least some physical testing will need to be carried out at some stage of a product's development cycle. What FEA can be used for however is to develop the concept of a product to be somewhere close to the final result before using a series of tests on a prototype to ensure their accuracy. An example of this is the report by (Nastov & Caples, 2019) detailing the aerodynamic development of the C7 generation Corvette ZR1. In this report, a wind tunnel model was used to test the extra aerodynamic additions to the car for this performance model, with a CFD test used to validate the flow structures on the underside of the front splitter, with the pressure loads used to feed into an FEA stress analysis to predict the stress and deformation on this structure, meaning that this modern approach with combining the Finite Element Methods with physical testing is a very good way to move forward when developing any product within the engineering space.

Conclusion

This report provides an overview of why an engineering company may decide to employ Finite Element Analysis within the development of a product. The relative advantages and disadvantages of using both Finite Element studies and physical testing using a prototype for testing have been discussed as well as how a company may correlate its results from an FEA study to a physical test using a CFD study and a physical wind tunnel test as an example.



Works Cited

- Autodesk Inc. (2020). *FINITE ELEMENT ANALYSIS*. Retrieved from Autodesk:
<https://www.autodesk.co.uk/solutions/finite-element-analysis>
- Bathe, K.-J. (2014). An Introduction to the use of finite element procedures. In K.-J. Bathe, *Finite Element Procedures* (pp. 1-3). Watertown, MA: Massachussets Institute of Technology.
- Calautit, J. K. (2015). *CFD and Wind Tunnel Study of the performance of a Multi-Directional Wind Tower with Heat Transfer Devices*. Sheffield: Elsevier Ltd. Retrieved from
<https://core.ac.uk/download/pdf/81930792.pdf>
- Caliber Design. (2015). *Why Use FEA? - An introduction to finite element analysis*. Retrieved from <http://www.caliberdesign.co.nz/>: <https://www.caliberdesign.co.nz/wp-content/uploads/2015/05/Caliber-Design-HowToGuide-Intro-to-FEA.pdf>
- Fuller, M. J. (2012, January). The Rise of the Swan Neck. *Racecar engineering*.
- Gur, Y., Wagner, D. A., & Morman, K. N. (1999). *Energy Finite Element Analysis Methods for Mid-Frequency NVH Applications*. Traverse City, Michigan: SAE International. Retrieved from <https://saemobilus-sae-org.ezproxy.uwtsd.ac.uk/content/1999-01-1801/>
- Lanfrit, M. (2005). *Best practise guidelines for handling Automotive External Aerodynamics with FLUENT*. Darmstadt: Fluent Deutschland GmbH. Retrieved from
https://www.southampton.ac.uk/~nwb/lectures/GoodPracticeCFD/Articles/Ext_Aero_Best_Practice_Ver1_2.pdf
- Manor Tool & manufacturing company. (2020). *The Benefits of Finite Element Analysis in Manufacturing*. Retrieved from Manor Tool: <https://www.manortool.com/finite-element-analysis>
- Nastov, A., & Caples, D. (2019). Aerodynamic Development of the 2019 Chevrolet Corvette C7 ZR1. *SAE International*.