

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

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declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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

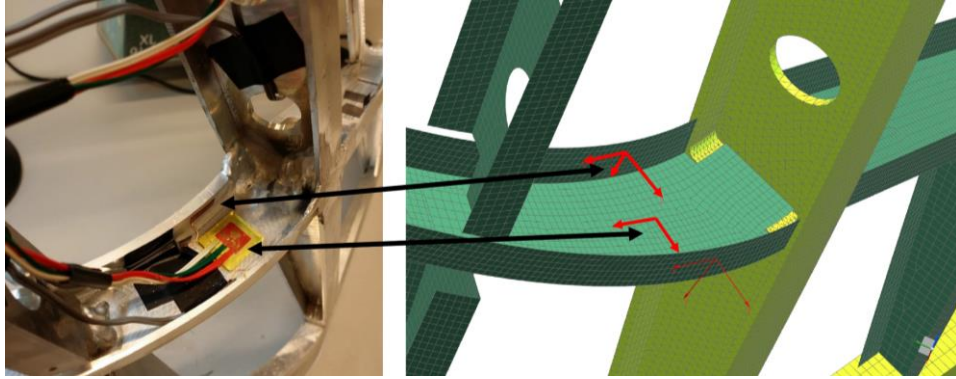
Learning Outcomes tested (from module syllabus)	Assessment Criteria To achieve each outcome a student must demonstrate the ability to:
Demonstrate an ability to analyse a range of engineering problems using advanced stress analysis principles.	

- 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	20.4
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	21.6
3. Analysis Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence		
(N/A)	0	
4. Practical Application and Deployment Deployment of methods, materials, tools and techniques; application of concepts; formulation of innovative and creative solutions to solve problems.		
(Assessed in point 3)	30	21
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	7.4

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)		70.4 %
	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?

James Gregory

P148409

BEng (Hons) Mechanical Engineering

18/04/2020

Advanced Stress Analysis & FEA

M6X00420



Prifysgol Cymru
Y Drindod Dewi Sant
University of Wales
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2 Introduction

As competitiveness, productivity and efficiency increase in the engineering and manufacturing sector, companies are discovering innovative ways to develop and introduce products to market, in progressively shorter time, while reducing product life cycle (Reche, et al., 2019). The Product Development Process (PDP) is a critical stage in companies and involves taking a product from concept to production to market, and is often associated with engagement from key customers and suppliers (Cooper, et al., 1997). The development of a new product, whether for personal, commercial or industrial use, will involve a benchmark which should be considered, including time scale, product quality, production costs, customer expectations and product requirements and regulations. For this reason, good PDP is essential (Santiago, et al., 2017).

Nonetheless, the introduction of Computer-Aided Engineering (CAE), in particular, Finite Element Analysis (FEA), has been widely adopted and dramatically transformed PDP (Hamri, et al., 2010). Engineers can now analyse simple and intricate designs effortlessly while in the form of adaptable 2D or 3D Computer-Aided Design (CAD) models, yielding quick turnaround times and prompt implementation of results (SAE International, 2020). When used appropriately, FEA can become a magnificent productivity tool, assisting engineers in reducing production time, prototypes, experiments and cost. However, as of yet, FEA is not a requirement in the PDP, whereas conventional methods, for instance, physical testing is, and are therefore still dominant; and also a preferred choice, particularly for studying a components behaviour and collecting, and analysing data (Uniscient, 2017).

This report explores FEA and the role it plays in the product development of wind turbine blades: specifically, how FEA corresponds and correlates to conventional physical testing methods, which are primarily preformed on rotor blades. In order to understand and determine this, three questions will be answered, which will explore why and how FEA is used and the role it will have in the future of blade testing:

1. Why Company's Adopt FEA Alongside Physical Testing?
2. How a Physical Test May Be Correlated to an FE Model?
3. Can (or should) FE Analysis Replace Physical Testing?

3 Why Company's Adopt FEA Alongside Physical Testing?

The development of FEA for studying wind turbine blades presents an economical and sustainable alternative to manufacturing new and maintaining existing blades. Companies in this industry financially benefit from FEA due to increasing costs associated with physical testing as blades become larger (Veers, et al., 2003; Overgaard & Thomsen, 2009). Finite Element (FE) tools are frequently used due to their ability of predicting complex loads, whereas for a laboratory test, only idealised loads can be imposed (Freebury & Musial, 2000). Conventional experimental tests are often performed in FEA due to the simplicity of assessing the simulation and results, as well as analysing why blades fail prior to their expected lifespan (Marín, et al., 2008). FEA has established itself in the design stage and allows companies to introduce innovative, efficient and robust blades, as well as promote accurate designs (Mahendran, 2007). Furthermore, FEA can analyse complex loads or conditions that cannot be implemented or measured physically (Zhang & Pan, 2009).

To stimulate confidence in designs, turbine blades are subjected to various structural tests such as static, dynamic, crash and modal. These tests are mandatory to ensure current blade specifications are consistent with actual blade performance, according to the International Electrotechnical Commission (IEC) standard IEC 61400-23:2014 (Malhotra, 2010). However, physical testing is considered time consuming, expensive and often times ineffective and inaccurate, with specialist equipment needed (Ferrari, 2009). This is why FEA is typically integrated alongside laboratory testing, because it is a quick substitute which enables engineers to replicate and simulate structural tests effortlessly, in a short period of time and with no extra costs; in addition to, predicting the same behaviours that are being analysed physically. The simulation results gathered are used to validate experimental results and express a level of accuracy for the existing FE model (Peeters, et al., 2018). A reliable FE model, can provide accurate predictions of structural behaviour and performance before the actual blade undergoes production; in addition to, identifying opportunities for blade optimisation and eliminating the need to conduct further physical tests, thus, saving development time and costs (Abdullah, et al., 2016).

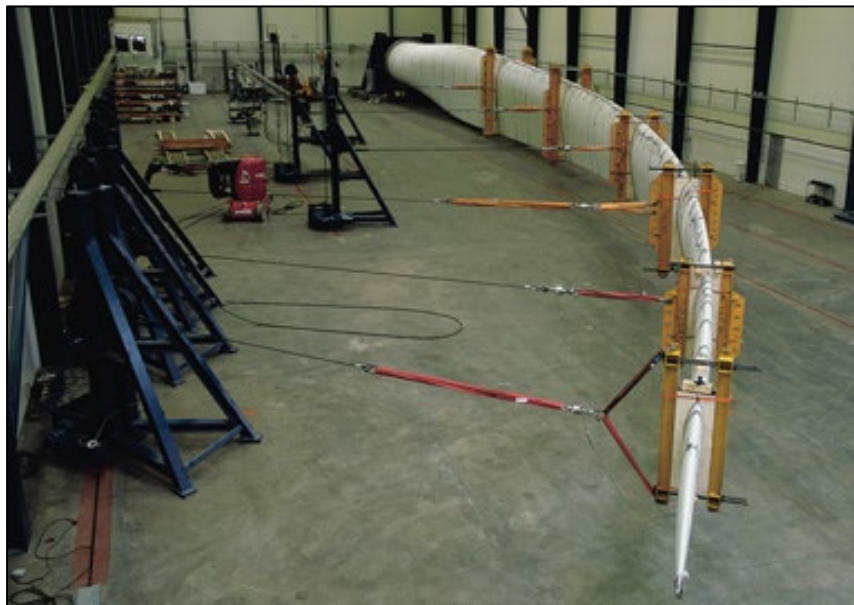
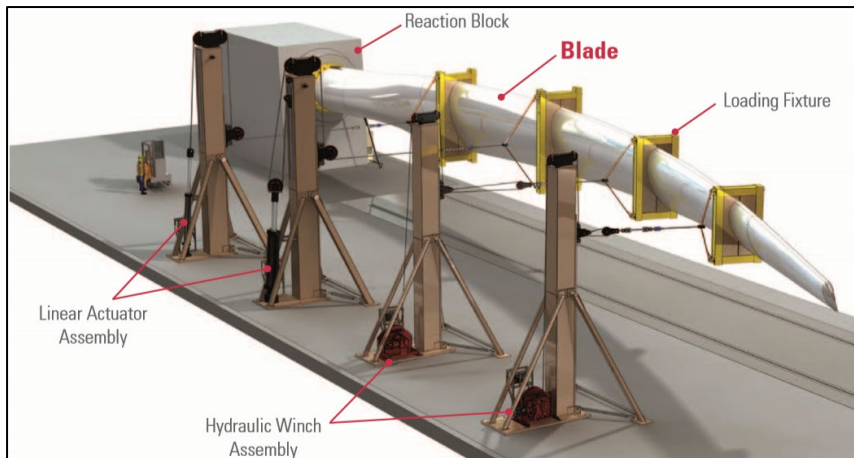


Figure 1: Typical wind turbine static test (MTS Systems Corporation, 2012; CompositesWorld, 2010)

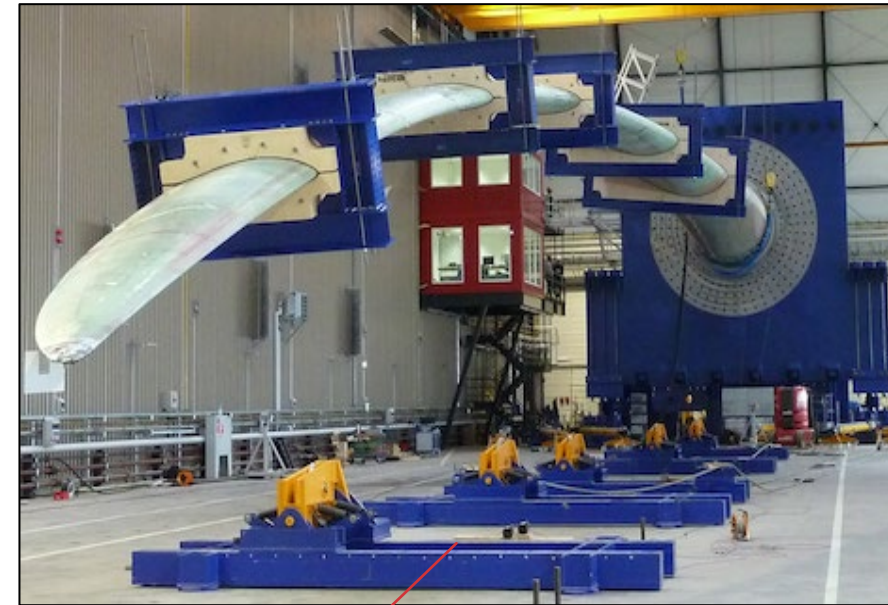
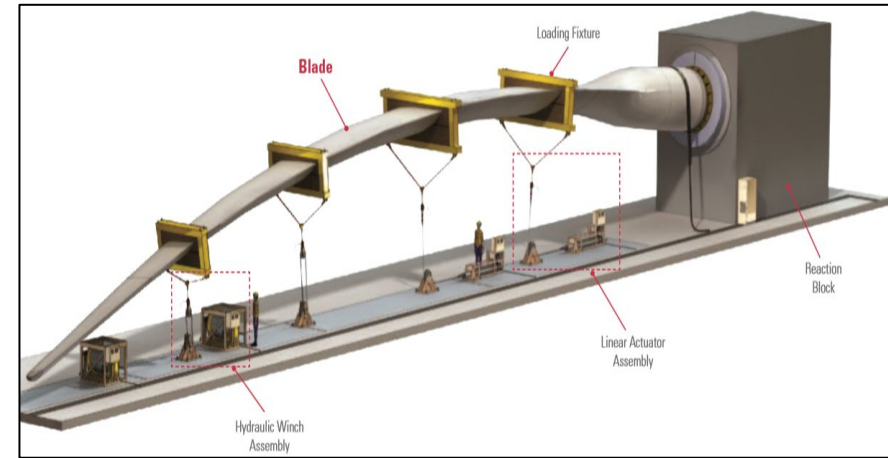


Figure 2: Typical wind turbine dynamics test (MTS Systems Corporation, 2012; Steel, 2016)

Engineers use FEA alongside physical testing to analyse the blades structural integrity and global behaviour, for instance: eigenfrequencies, tip deflections, and global stress/strain levels (Jensen, et al., 2006). In addition, determine structural displacements, stresses and strains, and heat transfer for a given load; as well as perform non-linear buckling, modal, deformation and crash analysis (Laird, et al., 2012). This enables engineers to understand the behaviour of the blade and predict its failure characteristics and mechanisms prior to undergoing physical testing. Similarly, using FEA to replicate physical tests and verify whether results from the simulation closely or exactly relate to conventional testing results and real-world conditions. FE simulations typically predict results, for instance, global stiffness and stresses with good accuracy, due to a simple shell model used to represent global behaviour of the blade (Abraham, et al., 2016). A major benefit of using FEA is that, once the model is built and calibrated, engineers have greater control and flexibility testing the blade under actual wind conditions (Tenguria, et al., 2010).

A study was conducted by (Chen, et al., 2014), to investigate and analyse an experimental failure test of a 52.3 m long composite wind turbine blade, under static loading with help from FE simulation. The experimental setup was as follows: two sets of static bending tests performed. The first test followed full-scale test requirements for wind turbine blades according to certification bodies, and the second test was performed with intention of overloading the blade until failure. FEA was then used to complement the experiment by assisting in the post-mortem process to clarify and gain an insight into the failure of the blade, such as: failure characteristics, processes and mechanisms, through Progressive Failure Analysis (PFA) and global-local blade modelling. The final conclusion of the study showed that during the structural tests, the blade failed catastrophically due to total loss of load-bearing capacity under flap-wise bending. Major failures such as: delamination, debonding, laminate fracture, and shear web failure were located at the transition region of the blade. The tests were reconstructed in an FE simulation, where a CAD model of the blade was built, and the loading history was numerically reproduced. As a result, the complex failure characteristics observed at the transition region were competently predicted in the FE simulation, using PFA techniques and global-local modelling. The global-local modelling approach proved capable and effective in determining the failure behaviour, while reducing complications in modelling an entire blade.



Figure 3: Blade test scene (Chen, et al., 2014)

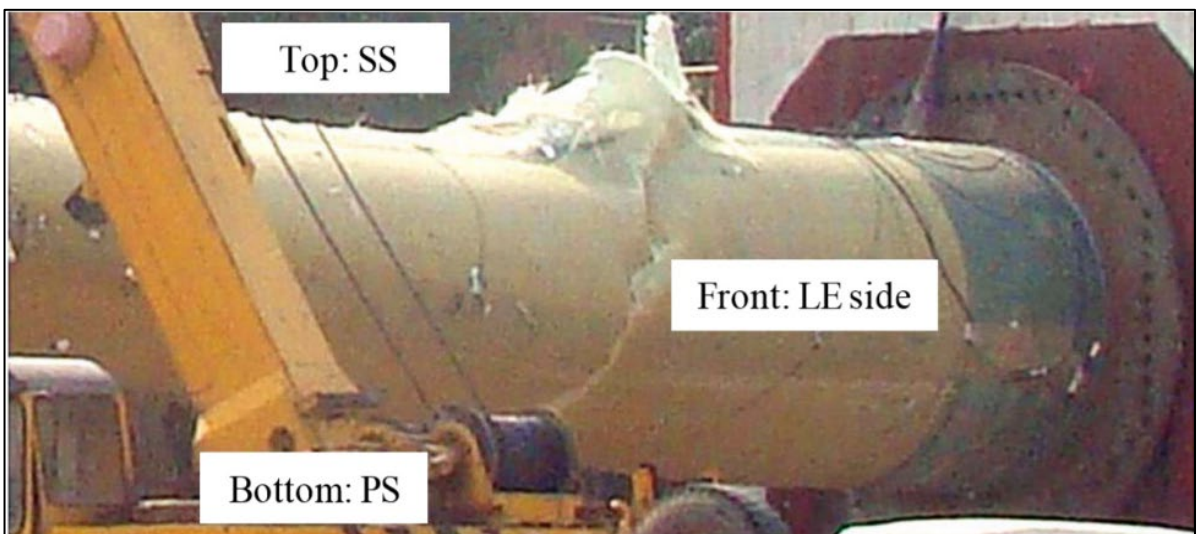


Figure 4: Final external failure of blade at transition region (Chen, et al., 2014)

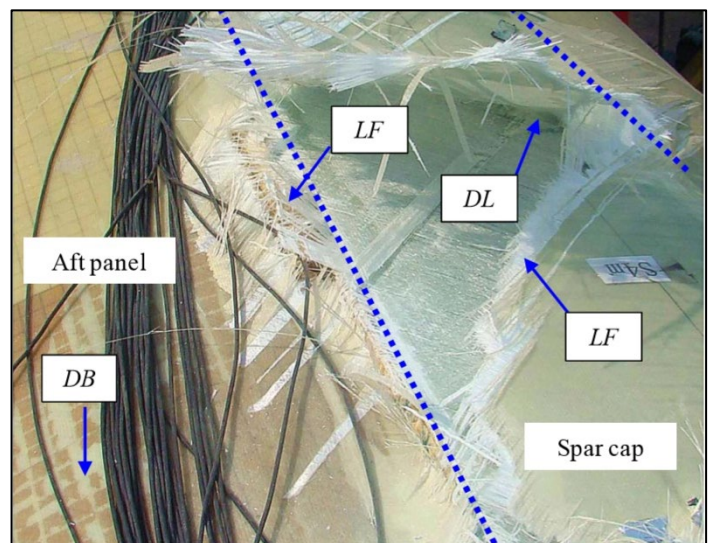
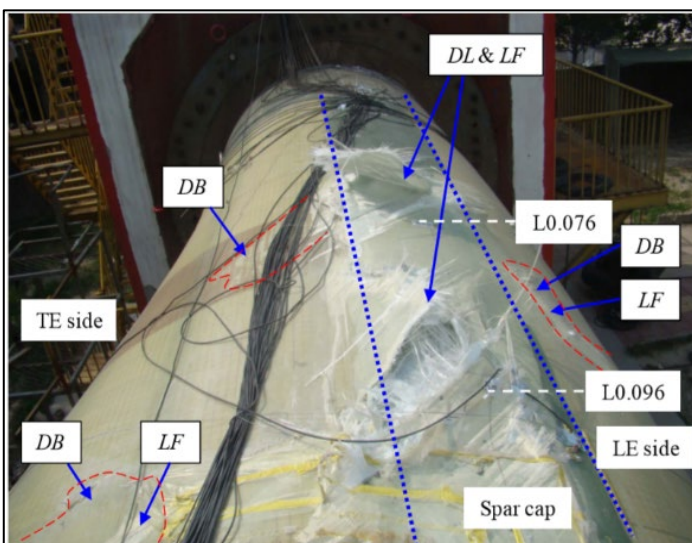


Figure 5: Failure modes detected at suction side (SS) of the blade: laminate fracture (LF), delamination (DL) & debonding (DB) (Chen, et al., 2014)

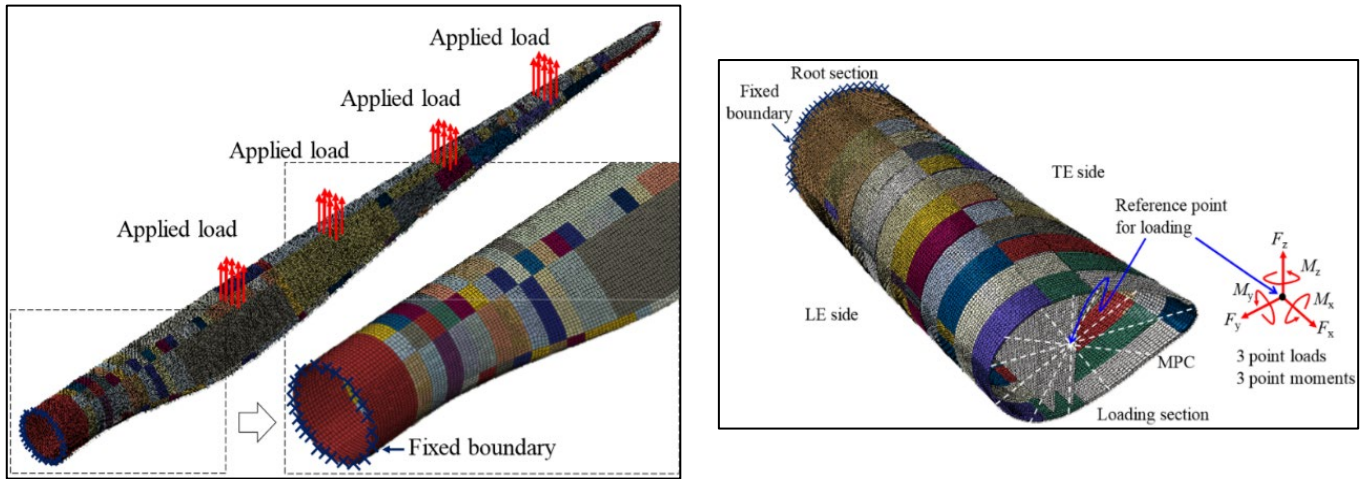


Figure 6: (LEFT): FE global shell model with applied loads; (RIGHT): Local solid model with applied loads calculated from shell element model (Chen, et al., 2014)

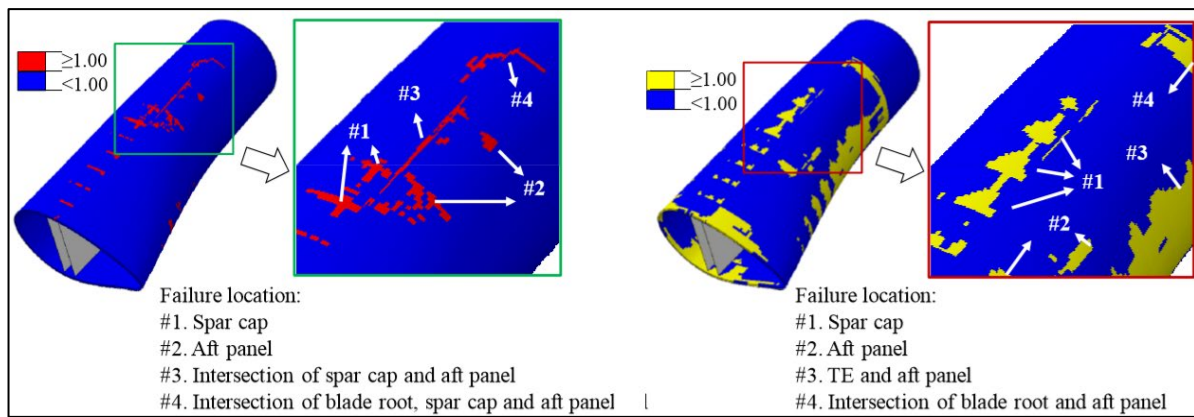


Figure 7: Final failure predicted from FE simulation. (LEFT) LF at blade shells; (RIGHT) DL and DB failure (Chen, et al., 2014)

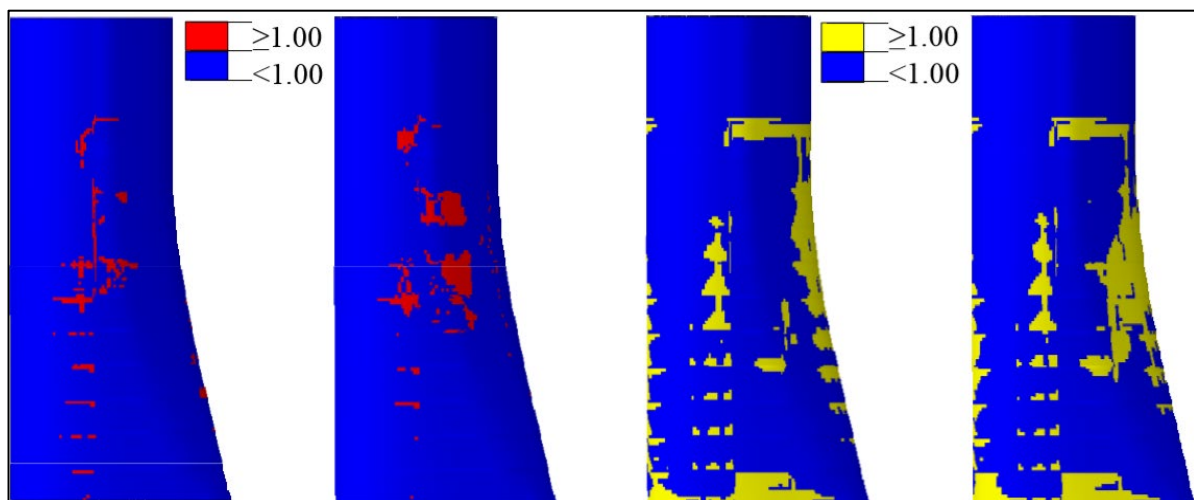


Figure 8: Effect of different material degradation on final failure prediction. (a) LF Present; (b) FL Nagesh; (c) DL&DB Present; (d) DL&DB Nagesh (Chen, et al., 2014)

4 How a Physical Test May Be Correlated to an FE Model?

As the need to constantly reduce cost, prototypes, experiments, along with, optimising rotor blades, FEA is becoming a standard, but essential part of today's PDP. Motivated by lightweight designs and reducing the number of physical tests has become an ambition for manufacturers, though, to achieve this requires a balanced correlation between physical testing and FEA. Still, a correlation between these methods can be problematic due several reasons, for instance: measurement approximations, boundary conditions, combination of loads, safety factors, size and scale of blade, meshing strategies etc. In addition, irregularities with results are more likely to occur with physical testing as a result of tolerances with measuring apparatus, defective equipment, and human and random errors. Thus, these anomalies can turn the correlation into a laborious, expensive and time-consuming process (Altair Engineering, 2016).

Verification and Validation (V&V) is a procedure imposed to correlate FEA with physical testing to develop trustworthy computational models that can make engineering predictions; provide confidence in designs and reduce the time, cost, and risk associated with experimental testing. Furthermore, the V&V process enables engineers to measure uncertainties for both physical and simulation results, so the reliability and predictive accuracy of the model can be assessed and measured (Thacker, et al., 2004). Figure nine, illustrates the general procedure of V&V during model development and demonstrates how numerical simulation and physical testing correlate to develop a reliable computer model. Before beginning the procedure, a conceptual model must be agreed between experiment and simulation by considering aspects of the blade, computational objectives and degree of agreement between results. Tests conditions are then created to achieve information needed to V&V the model (Vakilzadeh, 2013).

The simulation (right) part of figure nine, is the development of mathematical models which emphasises the physics and consists of constitutive laws and conservation equations as Partial Differential Equations (PDEs) which determine boundary and initial conditions. The mathematical equations represent computer models, which are implemented using discretization methods, such as; Finite Difference (FD) or Finite Element Methods (FEM) and solved using numerical techniques. Here, verification considers the mathematics of the model and removes

errors by comparing numerical solution with benchmark solutions. In addition, eliminating errors from the computer code (code verification) and measuring and reducing errors introduced by discretization, and numerical algorithms (calculation verification). Finally, a study involving different theories, for example: probability theory is conducted to analyse the influence of uncertainties introduced by the numerical algorithm, modelling strategy and other assumptions on the simulation (Babuska & Szabó, 2011).

The experimental (left) side of figure nine, is the development of a physical experiment to gather information to validate the computational model. Therefore, assumptions made on conceptual model previously should be clear during the experiment and pre-test calculations should be performed to determine effective locations for sensors. The experimental test provides evaluation data, in addition to quantifying test-to-test variation, for test samples. Uncertainty quantification is then carried out to assess the effect of measurement and construction errors, as well as, design tolerances. Once both experimental and simulation uncertainties are quantified, validation begins. Validation considers the physics of the model and establishes (to a degree) if the model accurately represents real-world conditions and expected performance. If the validation outcome is unsatisfactory: either the model or experiment will be revised and involve assessing, and possibly adjusting boundary or initial conditions, parameters or assumptions of the simulation, or alternatively, changing the test design or measurement system to improve the reliability of experiment outcome to the simulation outcome (Koutromanos, et al., 2018).



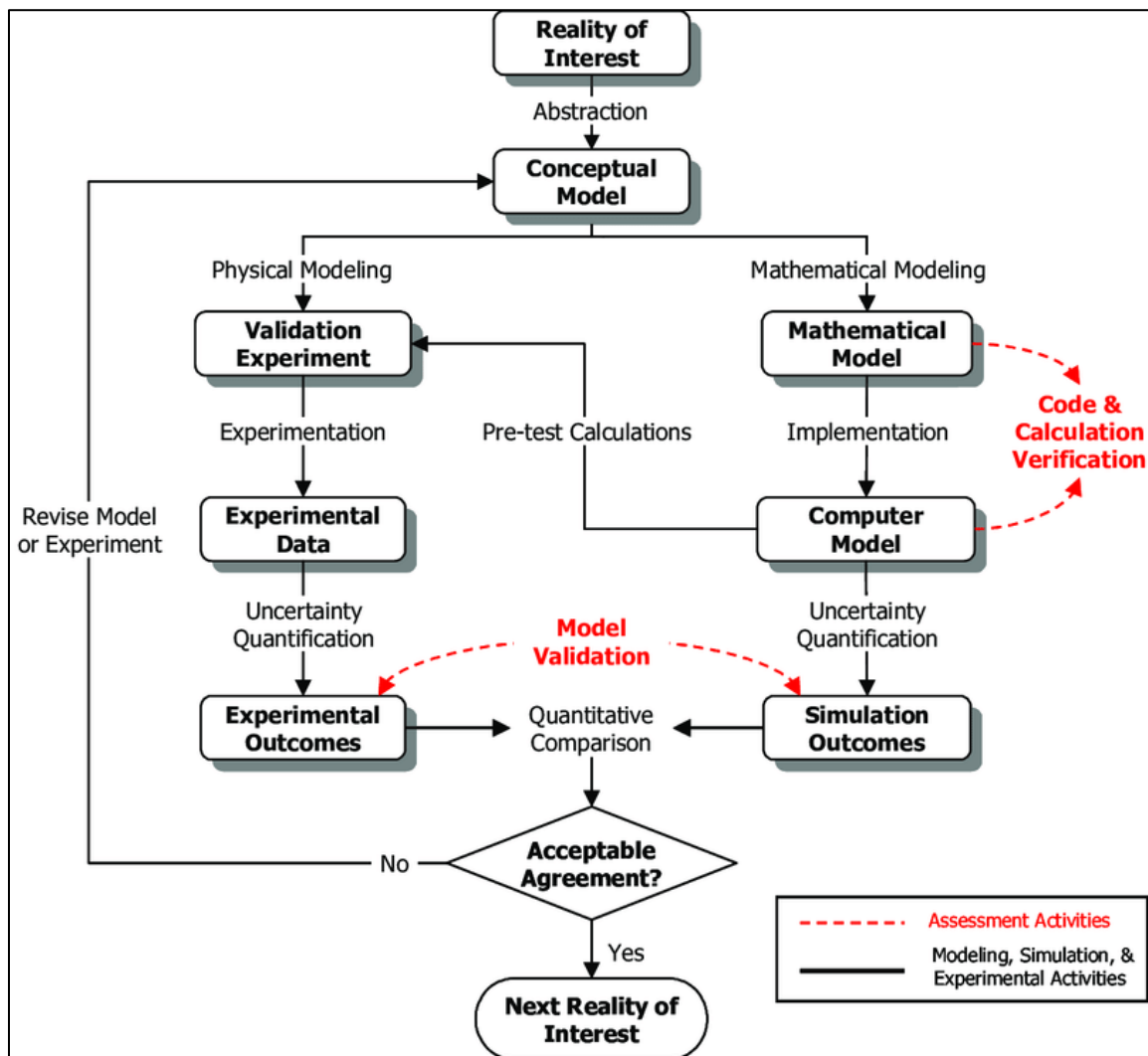


Figure 9: Detailed model flowchart of V&V process (Thacker, et al., 2004)

A study was conducted by (Babawarun, et al., 2019), they performed a structural static bending test on a 1.12 m long wind turbine blade in the flap-wise direction. The experimental setup was as follows: two load cases, a mass and an aerodynamic load were placed on the blade in order to verify if it was capable of withstanding sustained wind loads. A mass load in the form of weights were placed along sections of the blade, namely at: 350, 750 and 950 mm from blade root, followed by an aerodynamic (wind) load between 2.94 m/s and 12.75 m/s, which was applied parallel to the flap-wise direction. A CAD model of the blade was built and FEA performed to analyse the behaviour of the blade during simulated structural tests. The final conclusion of the study showed that during the structural tests, three different strains were measured, namely at: 350, 750 and 950 mm from the blade root. The results were measured and recorded during six loading, and five unloading conditions. The results gathered from the simulations were validated against experimental results and it was observed that the FEA results accurately reflected, and agreed with the physical test results, to within 5% error for two test loads cases. The third load case produced moderately higher percentage errors, below 25% of experimental results. The stress and strains identified in both the experimental and simulation results fell within 23% margin of error, and the first and second load cases presented a maximum percentage error of 5% and 1%. Therefore, representing a good correlation and validation between experiment and simulation results.



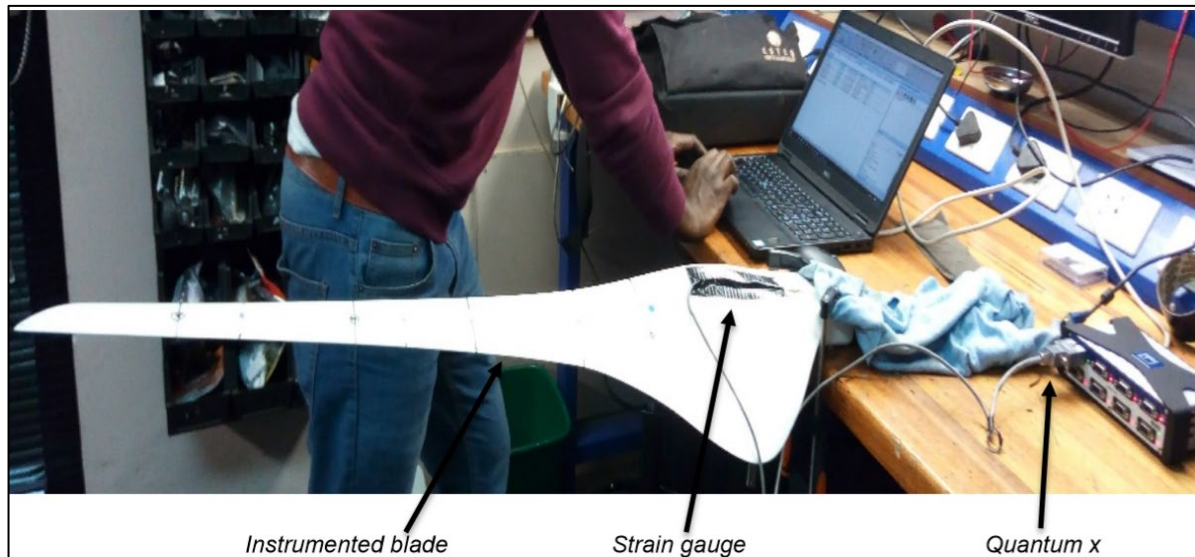


Figure 10: Experimental set-up (Babawarun, et al., 2019)

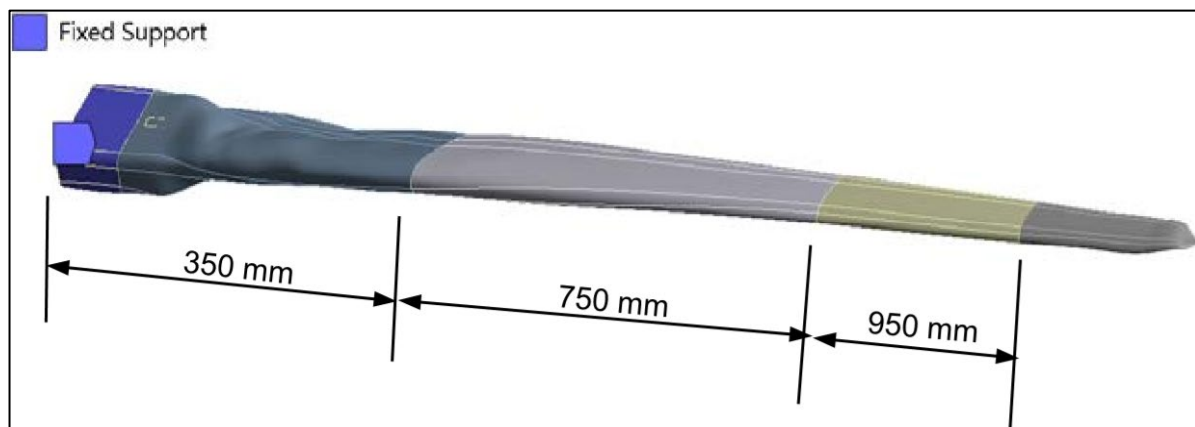


Figure 11: CAD model of blade demonstrating three test points and boundary condition (Babawarun, et al., 2019)

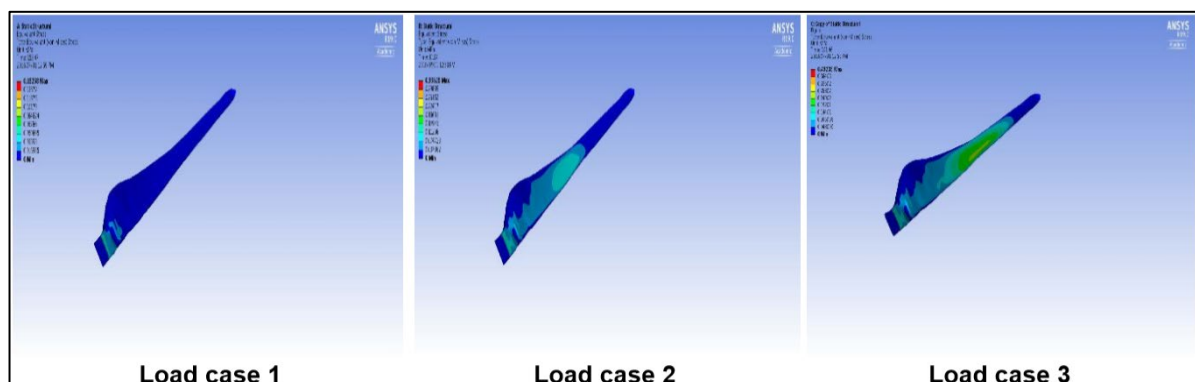


Figure 12: Three stress contour cases determined by the FE simulation (Babawarun, et al., 2019)

5 Can (or should) FEA Replace Physical Testing?

FEA has advanced since its introduction in the early 1940s and today, become a critical tool in the PDP of wind turbine blades. With many benefits to offer it is an integral part of product design and enables engineers to, dramatically, bring down development time and associated costs. In addition, predict defects at early stages of design, along with providing engineers the freedom to implement innovative ideas onto FE models. With today's technology, FEA has developed the ability of anticipating the behaviour of rotor blades with an acceptable amount competency, accuracy and reliability (Schubel & Crossley, 2012). As FEA advances further in the future, important questions remain regarding the practice of physical testing currently considered both a requirement and preferred choice among manufacturers, as well as, a means of validating stimulation results (Vyas, 2015).

- Can FEA replace physical testing in the future?
- Will FEA develop enough to understand and respond to real-world conditions accurately?
- If it is possible, what drawbacks limit FEA from becoming a requirement or a standard for product testing?

Although physical testing is an indispensable method and improves confidence in designs, it can often delay the PDP because of its close association with the design process. Nonetheless, it is mandatory and in order to certify wind turbine blades, must undergo physical testing to comply with performance requirements as stated by the IEC; in addition, demonstrate they are reliable, safe and durable. Furthermore, unbeknownst to engineers, a potential blade design may fail to meet requirements: contain defects or raise issues about manufacturability and maintainability. However, physical testing identifies these complications and presents them to engineers along with increasing confidence throughout the development process because it certifies the design and reduces risk and uncertainty. Therefore, it is crucial to product development (Tahera, et al., 2017). Despite this, physical testing is a lengthy, monotonous and costly process and delayed or undesirable results can compromise project schedules (Tahera, 2014).

The issue with physical testing is that it can be more expensive, time consuming and require a larger work force, particularly more so if the prototype fails during testing and needs to be redesigned, rebuilt and retested. Furthermore, if the blade is larger, experimental testing becomes less feasible and financial budgets can restrict engineers to a certain number of tests (King, 2017). Another significant limitation of physical testing is that the conditions of the test and equipment available are limited, whereas, FEA is more flexible and can vary loading, material and constraints over a range of alternatives at low cost. It is expensive to replicate a range of conditions with physical testing, therefore, often making it less desirable. Consequently, using FEA to design structural tests is useful, in addition, helps identify conditions that could or will cause failure and that might be overlooked in physical testing. More focus in FEA can, dramatically, reduce cost and better test the limits of rotor blades (Heisig, et al., 2010).

FEA is a suitable alternative to building and testing a physical prototype and saves time, effort and money by reducing physical tests needed, however, it does not completely eliminate the necessity for laboratory testing. There are a number of significant limitations concerning FEA and other FE tools, which affects their pre-eminence over this method, such as they cannot simulate exact physical conditions, because the method is based on mathematical approximations, numerical errors, for example, number of significant digits, rounding-off and truncation errors limit the models results: as well as, the need for ample computing power and reliable software. Consequently, these limitations can cast doubts over FEA and restrict it from completely replacing physical testing. However, what FEA will do is limit the number of prototype tests needed and provide design insight to optimize the component. Nevertheless, as technology progresses so does the capabilities of numerical simulation, which continues to improve with each new version of the software and better simulates real-world conditions (King, 2017) .

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6 Conclusion

The aim of this study was to explore FEA and the role it plays in the PDP of wind turbine blades. In particular, how it is used alongside and correlates with, conventional testing methods during the product development cycle. Moreover, determining whether FEA and other numerical simulations will completely replace physical testing in the future.

From conducting this study, it was discovered that although FEA is not mandatory, engineers willingly use it alongside laboratory testing to validate experimental results and vice versa. It provides engineers a chance to view the behaviour and performance of the blade from a different perspective, and with technology more modern; in addition, gain an insight into opportunities for blade optimisation, which could provide a break-through for more efficient and sustainable blade designs. Furthermore, FEA is often correlated with physical testing, by means of conducting a V&V process, which enables engineers to indicate a level of predictive accuracy between the experimental and simulation tests, as well as, accurately represent real-world conditions and intended blade performance. However, although FEA is a prevalent tool, which has found acceptance among engineers in studying wind turbine blades, and many other components for that matter; questions and doubts still remain that overshadow the capability, accuracy and reliability of the method. The disadvantages that FEA can bring along with it, such as, mathematical approximations, numerical errors, computing power, unreliable software; it cannot fully replicate and simulate real-world conditions, these are factors which could have significant impact on the failure of the blade.

Therefore, laboratory testing still remains as a preferred choice among manufactures at the moment. However, as technology becomes more advanced, computational power improves and software becomes more reliable, FEA may become a more viable option and could potentially set a new standard of testing, not just for wind turbine blades but many other components.

7 References

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8 Appendices

8.1 What is FEA?

The FEM is a numerical technique used to perform FEA to accurately solve complex engineering and physics problems, as well as understand and measure natural physical phenomena like structural behaviour, heat and mass transfer, fluid flow behaviour, acoustics and electromagnetism (Pepper & Heinrich, 2017). The technique has become well-established and predominant and considered the best approach in solving a diverse range of practical problems efficiently and effectively (Gosz, 2017). Furthermore, FEA has become an area of active research, not just for engineers but for scientists and mathematicians. One of the reasons for its popularity within engineering is because of its ability to solve various problems simply by changing the input data (Rao, 2017).

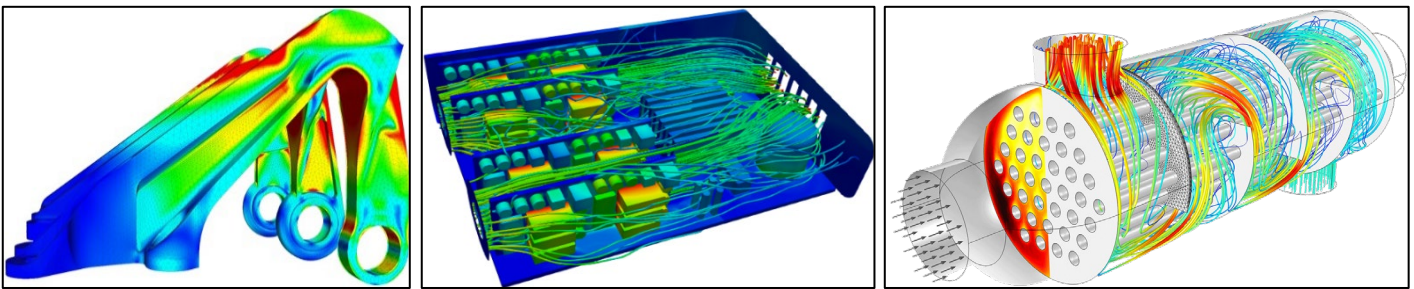


Figure 13: Applications of FEA, from left to right: aircraft's bearing bracket, electrical cabinet and shell and tube heat exchanger (Harish, 2020) and (COMSOL, 2015).