

BACHELORS DEGREE ASSIGNMENT SPECIFICATION

Student name:	CHAPPELL	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I declare that this assignment is all my own work and that I have acknowledged all materials used from the published or unpublished works of other people.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	15.9
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	16.2
3. Analysis Analysis, evaluation and synthesis; logic, argument and judgement; analytical reflection; organisation of ideas and evidence		
(N/A)	0	
4. Practical Application and Deployment Deployment of methods, materials, tools and techniques; application of concepts; formulation of innovative and creative solutions to solve problems.		
(Assessed in point 3)	30	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	5.8

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)		55.9 %
	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			

Advanced FEA and Stress Analysis Report

CAN FEA REPLACE PHYSICAL TESTING?

Raoul Chappell (P151140) | BEng Extreme sports engineering | 20/03/2020



1. Introduction

Throughout history, the design process has had multiple stages to go through before a final product is produced. The first design processes began with trial and error and gaining experience when things went wrong. From this experience, practical guides were developed which aided in the consequent design of different products. The later development of both experimental and mathematical models drastically changed the design process enabling better predictions of how a product will perform without the need to produce a large number of prototypes, the testing of which had the potential to be dangerous for those involved.

In the past 60 years, the design process has seen another large step in terms of what is possible. With modern computing technology, the ability to not only calculate but also to simulate what could happen to a product during use has enabled engineers to better design parts in a wide variety of industries from aerospace to construction.

This report aims to qualitatively assess whether Finite Element Analysis could or should replace physical testing. To do this case studies on protective headwear will be used to support the findings.



2. Why companies typically carry out FE analysis alongside physical testing.

2.1. PHYSICAL TESTING

Physical testing can take two forms, destructive testing is used to test a part to failure. Whether that is in a single loading scenario or a repeated or cyclic loading scenario. Destructive testing is used to find the maximum load or stress a part can withstand before failure. The definition of failure in destructive testing can either be the elastic limit beyond which the part is permanently deformed or the.... Common forms of destructive testing include tensile or impact testing.

The second form of physical testing is non-destructive testing. Non-destructive testing can be used to find material properties of a material or locate damage in a part without causing any permanent damage to the part common forms of non-destructive testing include thermal imaging and ultrasonic testing. (Hofer, 2018)

2.2. FINITE ELEMENT ANALYSIS (FEA)

FEA is a computerised simulation tool that allows engineers to assess how a component, part or product will behave within a certain scenario. There are many different forms of FEA such as computational fluid dynamics The FEA process is defined by the acronym **SIMPLE**

Split the part into small elements

Interpret the geometry

Material information

Physical properties

Loading

Evaluation of the results

The FEA process works by splitting a part into much smaller sections called elements that can be assessed using simpler equations. Once the geometry has been split and assessed and material information and loading conditions have been input into the model the solver will run the necessary calculations at each node (element vertices or vertices and mid sides for second order elements) the solver will also calculate the values iteratively to account or any deformation caused. Because of the high number of calculations required a very accurate solution can take a long time, this can be mitigated by using larger elements or first order elements where possible. (Lake, 2018-2020)

2.3. BENEFITS OF USING FEA IN THE DESIGN VALIDATION PROCESS

FEA allows the designer to assess how the part/product would behave under certain loading conditions without the need to create the part(s) and conduct physical testing. This reduces the number of prototypes required and therefore accelerates the entire process, whilst also reducing the cost of the development. This can also benefit the company as tooling does not need to be created for a part that may be determined as a failure or destroyed prototype after physical testing. (Dascotte, 2004)

The FEA process also reduces the need for physical testing of the final product by validating the FE model and testing method (as described in section three of this report) meaning any further testing can be carried out using the same solver. This is a substantial benefit in applications or

projects where a part is too large, too dangerous or too expensive to conduct blind physical testing. (Dascotte, 2004)

The use of FEA in the design process can also benefit the user by identifying areas of high stress concentration or deformation, allowing the designer to focus their interests in these areas when conducting any further computational analysis or physical testing.

The implementation of FEA lead design benefits the company by further hastening the design process by inputting the fixed points and constraints, using the FEA software to create a base design that meets all the mechanical requirements of the part, then implementing CAD to create a full design instead of designing a part, testing it, adjusting the design, testing again until the final part is created. As shown in the diagram below. (Lake, 2018/19)

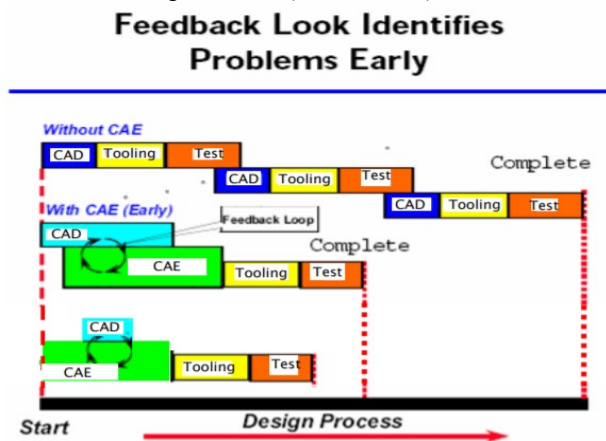


Figure 1 A diagram showing how time is saved by earlier implementation of CAE (Lake, 2018/19)

2.4. CASE STUDIES

Currently, sports helmets are primarily tested by physically testing the products using dummies or cadavers. To assess the effectiveness of the product, however, this does not provide reliable data on intracranial pressure, stress or strain induced by the impact on brain tissues.

Another issue with the current physical testing method is low bio fidelity between the dummy or cadaver in comparison with an in vivo test subject. Physiological condition and mechanical properties of the cadaver or dummy can vary largely, therefore, decreasing the validity of the results. In vivo testing of this nature is strictly prohibited so to improve on the current testing methods an image-based FEA model of the human head has been created to be able to test the helmets. This

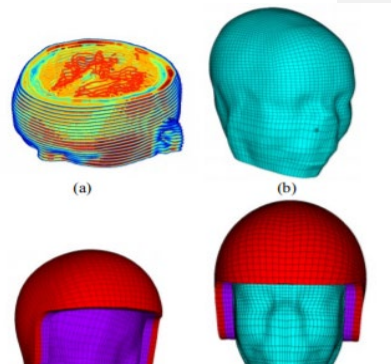


Figure 2 (a) a stack of medical images of the head; (b) head finite element model; (c) subject-specific design of helmet; (d) helmet-head system model (Luo & Liang, 2013)

enables a better understanding of the effects that an impact has on both the skull and the brain. (Luo & Liang, 2013)



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

3.1. MODEL VALIDATION

Model validation differs from design validation in that the aim is not to validate the product as much as it is to validate the simulated FE model and testing method.

The reason for model validation is to show that the simulated model is accurate enough to be comparable with a real-life scenario. This is especially important in products that will not undergo or undergo very little physical testing such as products that have a high unit manufacture cost, therefore, physical testing needs to be kept to a minimum.

Another reason to correlate FEA results with physical test data is any unnoticed errors or uncertainties. There are two types of error in an FE model physical uncertainty which includes

- Boundary and initial conditions- impact angle, impact velocity, drag, friction etc
- Material properties- yield stress density manufacturing defects etc
- Geometry- manufacturing tolerances, thicknesses etc
- Loading- application of load (sudden vs steady), unexpected loads (gusts of wind etc)

There are also numerical uncertainties such as

- Conceptual modelling- insufficient system knowledge or physical process data
- Mathematical modelling- the accuracy of the mathematical model
- Discretization error uncertainties- element sizing, element type, mesh density, geometric accuracy
- Numerical solution uncertainty- convergence tolerances, rounding etc
- Human mistakes- typing errors, mistakes in units or data

(Dascotte, 2004)

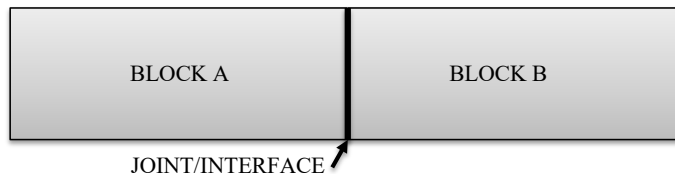
There are numerous methods for conducting this validation process, detailed below.

3.2. CORRELATION METHODS

Simplified model testing

Physical testing can be used to validate an FEA model by producing a part with similar but simplified geometry to but not identical to the prototype, then testing it before comparing the results with an FE model of the same part exposed to the same loading conditions and constraints. The FE model and validation test procedure must be as close as possible to the actual conditions the part/product will endure during use to ensure the validation process is maintained throughout. (Mayes, 2008)

The whole product may be split to sub-assemblies to determine uncertainties in the interfaces between each component and the effects that they may have on the model as a whole (Mayes, 2008). This may be tested for a flexural test example as shown below,



If tested as shown above and where blocks A and B were considered as one single block of material the difference would provide the flexural stiffness of the joint. For FEA this could enable the designer to implement more realistic contact conditions. (Lake, 2020)

The use of FEA can also be used before physical testing to locate high stress/strain areas which can then be used to help locate sensors and gauges during physical testing. This would provide more accurate results from the physical testing. (Wasserman, 2017)

Mesh size and Mesh quality

Mesh size and mesh quality can also have a large impact on the results from a finite element analysis. Physical tests can theoretically be considered the same way that FE models are except that the elements and timesteps are infinitely small this means that the smaller the element size the better the simulation and physical test will be correlated. Another way to increase the accuracy of the analysis is to use second order elements that have nodes on both the vertices and the midpoints of the elements size. This will reduce the distance between nodes increasing the accuracy but will also slow down the analysis as more calculations will be needed. FE models are simplified models of a real scenario, the degree of simplification must be decided by the engineer conducting the analysis as to the accuracy of analysis possible within both the timescale for the analysis and the computational hardware capabilities of the PC that the software is being run on.

Consideration must also be made to the quality of the mesh especially for analysis such as CFD where a small change in the analysed surface could have a large impact on the resulting airflow characteristics. In stress analysis FEA this is important as misshapen geometries can cause stress concentrations where there should be none. The mesh must also be checked to ensure that all of the nodes that should be attached to each other are and are not just occupying the same space. This would be checked by comparing the number of elements and number of nodes. This is important as unattached elements would increase the computational time of the analysis. (Schneider, et al., 2018)

3.3. CASE STUDIES

FEA is increasingly being used in both the design of protective helmets and in the analysis of head trauma caused by impact to determine the effectiveness of the helmet. To correlate the findings of their studies many researchers will use comparable physical test data (Mayes, 2008). Due to the requirement that the physical tests be conducted anyway there is no additional cost in using the same data to validate the FE model. The model validation process when testing any form of safety equipment especially protective headwear is of paramount importance due to the risks involved for

the end user. The continued research and model validation may in time lead to physical testing of protective headwear becoming unnecessary in the future. FE model validation is also important so that a better understanding of the impact energy and forces during impact can be gained allowing a better understanding of how impact affects the brain which could in turn lead to a better helmet design. (Liu & Chen, 2017) (Pinnoji, et al., 2010)



4. If you think that FE analysis can (or should) ever replace physical testing.

4.1. ARGUMENTS FOR

Finite Element Analysis provides a substantial benefit to the engineering sector both financially and in time saved.

Finite Element Analysis (FEA) allows the designer to assess how the part/product would behave under certain loading conditions without the need to create the part(s) and conduct physical testing. This can also benefit the company by meaning that they don't have to create tooling for a part that may be determined as a failed or destroyed prototype after physical testing. (Dascotte, 2004)

The FEA process also reduces the need for physical testing of the final product by validating the FE model and testing method (as described in section three of this report). This is a substantial benefit in applications or projects where a part is too large, too dangerous or too expensive to conduct blind physical testing. (Dascotte, 2004)

The use of FEA in the design process can also benefit the user by showing areas of high stress concentration or deformation allowing the designer to focus their interests in these areas when conducting any further computational analysis or physical testing.

FEA lead design benefits the company by accelerating the design process by inputting the fixed points and constraints and using the FEA software to create a base design that meets all the mechanical requirements of the part. (Lake, 2018-2020)

FEA software can also be used to create topology studies which show areas that are of little structural benefit to the product allowing the designer to remove unnecessary material. This is especially beneficial in products that have a high economic or environmental material cost. (Morgan, 2019)

4.2. ARGUMENTS AGAINST

A large barrier to this is the legal requirements for many products to undergo standardised testing (CE, EN, ASTM). FEA could still reduce the amount of physical testing required by calculating and simulating the results of physical testing. (Parliamentary Under Secretary of State, 1998)

The first step splitting the geometry into small elements, the size of these elements should be determined by the engineer and depends on a wide variety of factors such as the shape and size of the part. The size of these elements may have a large affect on the computational time and results of the analysis.

During the FEA process, there are assumptions made that may cause contrast between the simulated and physical test data. These include manufacturing defects, internal damage, residual stresses etc. (Lake, 2018-2020)

Finally, the CAD model is often simplified in larger models to save computing time. Methods such as removing unnecessary or unaffected parts and removing features such as bolt holes if they are not likely to significantly affect the results. This is done at the discretion of the engineer conducting the analysis, who needs to balance accuracy with computing time, there is no benefit to having the most accurate result if the deadline is missed. (Lake, 2018-2020)

4.3. CASE STUDIES

There is a clear benefit for the use of FEA in the design of protective helmets both inside and outside of the extreme sports industry. Although the FEA process is thought to be more accurate than current experimental methods there are also too many assumptions and approximations made, therefore, for the FE model cannot be considered as a definite assessment suitable for a product with such high consequences if it fails. As mentioned above currently all helmets must be certified by a safety standards agency (CE, EN, ASTM) a process which includes multiple physical tests, therefore, making the complete replacement of physical testing impossible.

Commented [ED1]: Does it have a part to play in partial testing? Initial testing before prototype

YOU HAVE PRESENTED QUITE
A WEAK CASE STUDY THAT
DOES NOT REALLY ADDRESS THE
BRIEF. HAVING SAID THAT - GOOD
CONCLUSION.

5. Conclusion

In conclusion there is a clear benefit to the combined implementation of both FEA and Physical testing and although there may be a small number of products that are suitable to be tested through FEA studies alone protective helmets are not one of them. This is due to the high risk for the end user and current regulations that mean a helmet must be certified by a standards agency which requires Physical testing.



References

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