

CAD Assignment

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Abstract

Introduction

CAD

Computer aided design (CAD) and Computer aided engineering (CAE) often get confused, but they are distinct. CAD refers to the process of using computational software to assist an engineer of producing a properly designed, optimised and thoroughly tested design. This can allow for an engineer to provide a well-designed product that fits a clients need with out the time or expenditure of going through rounds of physical testing and prototyping that would have to be done without it. CAE refers specifically to the use of simulation software to test a designed component. This assignment includes both. The type of CAE used in this assignment is Finite element analysis (FEA). This a simulation method that tracks details of set points often laid out in a mesh and applies mathematical calculations to each point to model what happens to them over time. This can be used to track weak points in a design, where a component may fail and damage that can be expected to happen to an object.

Scenario

The hypothetical scenario that this assignment focusses on is of a comparison between the effects of an arrow impact on plate armour to allow for a better understanding of what happens during impact to further plate armour design. This scenario allows for a good comparison to conventional ballistics for the purposes of validation of the software and of material properties acquired. It also is a good representation of ballistic impact modelling as it is simpler than a more complex munition but still shows the same sort of damage a modern munition causes to armour.

CAD Modelling and Assembly

Modelling Assumptions

In an ideal world, the simulations done would be complete replicas of reality, however, due to limitations of computers and the known equations that represent the real world that tends to be impossible. This means that assumptions and simplifications are an inherent part of the simulation process. This is often done by scientists with the infamous example of ignoring air resistance or assuming an object is a sphere to make calculations simpler. These steps are taken as it is viewed that the inaccuracy caused by their omission is insignificant compared to the advantage gained by simplifying the mathematics. An inherent assumption that simply using

FEA makes is that a system can be represented by an average of their points and that the density of the mesh used is representative of a real system. Another big assumption is that the material properties used for the simulation would apply to the specific scenario no matter how accurate they were known to be when taken. There are a lot of assumptions made when modelling and it is important to take into account what effect this may have on the final outcome. If the luxury of time is afforded, then tests can be done to determine the effect of each assumption but models can only give a close idea rather than an exact answer so they can never fully substitute for physical tests.

Specifically to this model there are a few additional assumptions made. The assumption that a circular flat plate would represent armour accurately, that the wearer was not wearing additional armour such as mail or gambesons. There's also the assumption that the fixed boundary used wouldn't cause reflections that may cause fracture where there otherwise wouldn't be. These assumptions were made to allow for a simpler model which means that the model is less likely to fail as added complexity such as compound curves or multiple layers of non-metallic materials can strain models to the point of crashing. The last major assumption was that the tip of the arrow would be the only part of the arrow of relevance as this is the part that makes impact and is assumed to be the majority of the mass of the arrow and the fact that it wasn't hollow would counterbalance the fact that the wooden shaft was excluded.

Design Inspiration

The inspiration behind this specific scenario derives from an interest and experience with ballistic modelling and a passion for history. The initial plan was to compare a cross bow bolt to a Mongol war bow, however during research, 2 papers presented themselves. One was by someone who had done the planned study before and detailed the process they went through [PLACEHOLDER], the other was a study of different arrow types impacting metal plates. This caused a pivot in the planned study to a broader analysis of arrows from many different bow types to look into their penetrative effect on plate armour.

Validation

Introduction to validation

Validation is one of the most important steps in the whole modelling process. It is the foundation that the accuracy of the model is based on. Validation is the process of using existing examples, be that experimentation results or previous validated models, to compare to the model being produced. This provides evidence that a model properly simulates a scenario and provides a solid basis to assume that the

results produced by subsequent models is reliable and can be used to provide a well supported answer to any clients.

Validation performed

Normally each individual validation study would be done individually to ensure that each variable was independently tested, ensuring that they would not influence each other. Due to time constraints, this was impossible to do. This means the validation performed here was less effective than performing individual studies however, the influence this has seems to be negligible due to the success of the validation model run. The two focuses of the validation model was to look at the suitability of the software for modelling projectiles and to look into how the material properties would react under a ballistic scenario.

The way this was performed was by using a very simple ballistic scenario and using the intended materials for the models themselves as the projectile and target in the simple scenario. This allowed for both interests to be looked into at once and shows that both the model and the materials can be used reliably together in a successfully completing model that gives reasonable and expected results.

For all of the models done for this assignment, Johnson-Cook material properties were used [PLACEHOLDER]. This is a method of simulating materials requiring relatively few material properties to successfully model. Due to this simplicity, it is easy to use and is more stable than other methods however it does struggle with materials with complex stress strain graphs so metal-like materials which tend to stay in their linear stage for longer than other materials. The Johnson-Cook values that were used in the validation and then taken through to the main models are shown below:

Properties of Outline Row 4: Arrow Head				
	A	B	C	D E
	Property	Value	Unit	
1				
2	Material Field Variables	Table		
3	Density	7.85	g cm ⁻³	
4	Specific Heat Constant Pressure, C _p	460	J kg ⁻¹ C ⁻¹	
5	Johnson Cook Strength			
6	Strain Rate Correction	First-Order		
7	Initial Yield Stress	92	MPa	
8	Hardening Constant	310	GPa	
9	Hardening Exponent	0.26		
10	Strain Rate Constant	0.014		
11	Thermal Softening Exponent	1.03		
12	Melting Temperature	1400	C	
13	Reference Strain Rate (/sec)	1		
14	Shear Modulus	8.18E+10	Pa	
15	Shock EOS Linear			
16	Gruneisen Coefficient	2.17		
17	Parameter C1	4569	m s ⁻¹	
18	Parameter S1	1.49		
19	Parameter Quadratic S2	0	s m ⁻¹	

Figure 1 Material Properties Arrowhead

Properties of Outline Row 3: Armour				
	A	B	C	D E
1	Property	Value	Unit	
2	Material Field Variables	Table		
3	Density	7.85	g cm ⁻³	
4	Specific Heat Constant Pressure, C _p	460	J kg ⁻¹ C ⁻¹	
5	Johnson Cook Strength			
6	Strain Rate Correction	First-Order		
7	Initial Yield Stress	210	MPa	
8	Hardening Constant	165	MPa	
9	Hardening Exponent	0.36		
10	Strain Rate Constant	0.022		
11	Thermal Softening Exponent	1		
12	Melting Temperature	1400	C	
13	Reference Strain Rate (/sec)	1		
14	Shear Modulus	8.18E+10	Pa	
15	Shock EOS Linear			
16	Grunisen Coefficient	2.17		
17	Parameter C1	4569	m s ⁻¹	
18	Parameter S1	1.49		
19	Parameter Quadratic S2	0	g m ⁻¹	

Figure 2 Material Properties Plate

These materials were then used in the layout chosen to represent ballistic scenarios. This was of a round reminiscent of 9mm round being projected at roughly the speed of a 9mm round into a target. The round started at near impact to reduce run time which reduces the time it takes for the model which is always beneficial it allows for more models to be run in the same time span. This model was a success and the plate deformed in an expected manor and fractured at expected places in an expected way. Images from this model show the final frame below.

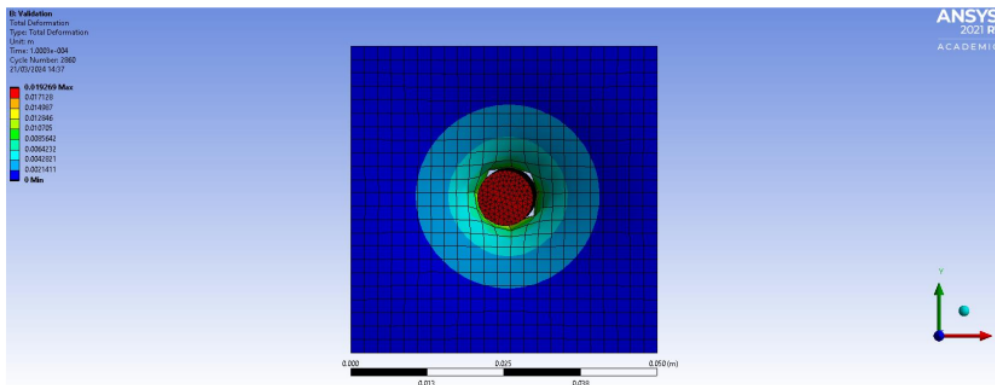


Figure 3 Model Validation Front View

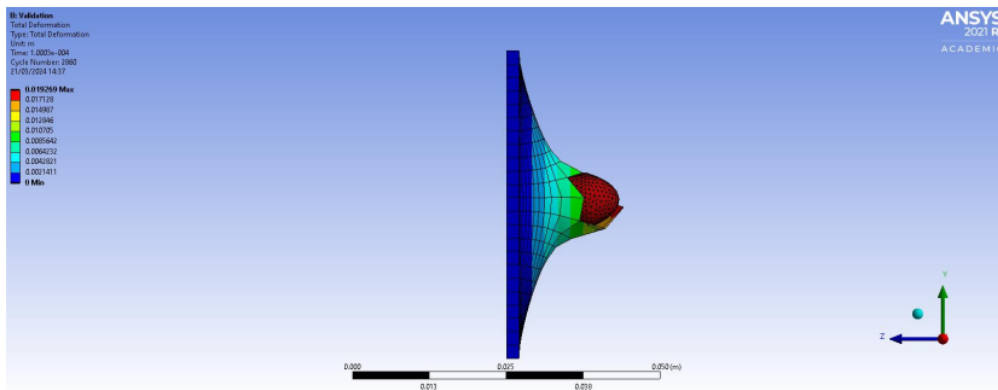


Figure 4 Model Validation Right View

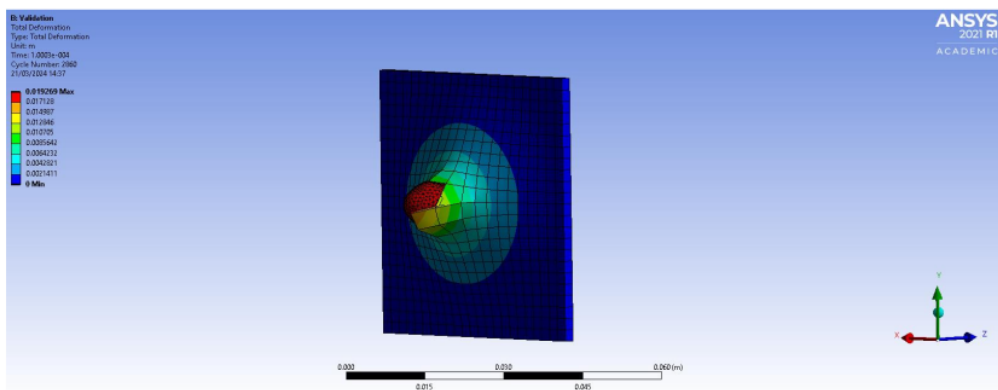


Figure 5 Model Validation Isometric View

Although the two things being validated were tested at the same time, the validation model served its purpose well and proved to a suitable standard that the model and materials were suitable for this model and could be used in the models going forward.

Kinematic Simulation

Layout

The first step of the process for testing the effect of each bow was to construct a model in SolidWorks that could be used in the modelling software. This ensures that the only differences between tests is what is being tested and is akin to using the same projectile for every test in real life. This involved producing, independently, a projectile that is representative of an arrowhead [PLACEHOLDER] and a target that is representative of period armour. During the process of testing the layout it was discovered that a larger mesh density was beneficial to the stability of the model and quality of the results but greatly increases the time it takes for the simulation to complete so a smaller section in the centre was added so that region could have the

increased mesh density and the rest could have lower density. This allows for the benefits of the mesh density increase with a reduced increase in simulation time. This section was decided to be a hexagon as the automatic meshing the software does uses tetrahedrons, this means that it can struggle with curved areas due to them being constructed of straight lines. To assist with this, straight lines can be included in the geometry. This will prevent messy mesh geometry which can make the simulation more unstable. The SolidWorks design is shown below.

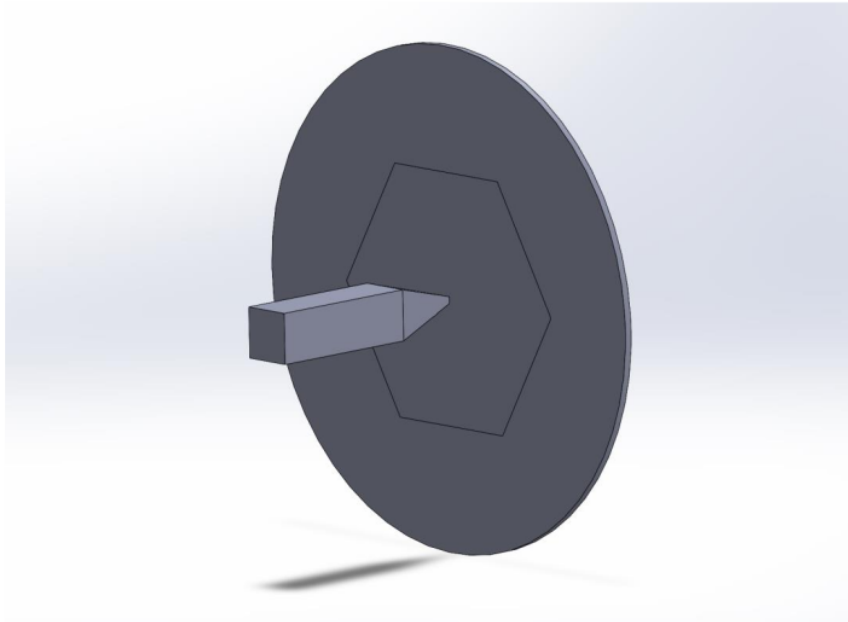


Figure 6 SolidWorks Design

After this was made, this could be imported into the software chosen to simulate the tests, ANSYS. ANSYS is a physics modelling software that allows the user to implement multiple different simulation modules that focus on different things such as fluid motion or thermos-dynamic or in this scenario deformation. The module used for this model was Explicit Dynamics, this is a FEA module that allows the user to look into how objects will move and transform under certain forces. This perfectly fits the scenario required as the interest is focused on the level of deformation caused and the speeds of the projectile post-penetration. To setup a model in this module it needs materials, geometries and input parameters to be provided to it and setup. The materials and geometries have already been discussed; this leaves only the input parameters. These include things like starting velocities and boundary conditions. This also requires the assigning of materials to components individually. Upon the completion of this the first model could be run as its own sort of validation to show that everything that needed to be done was completed to a sufficient level. With the success of the first test model the different tests could be setup with the correct velocity and executed

Results

150lbs Crossbow

The first test to talk about is the initial inspiration for the project, the crossbow. The crossbow model still used the same model which is somewhat unusual for history but due to the simplified geometry that the model uses this shouldn't have much of a noticeable effect. The projectile was given the initial velocity of 87 m/s [PLACEHOLDER] and was then run in explicit dynamics. The model ran to just under 600 μ s rather than all the way to the designated 1ms as the model was not stable enough to complete fully, however, it did get to a point where it had penetrated the plate and it failed as the projectile was moving through the plate which shouldn't have too much of an effect. Images from the last frame are shown below

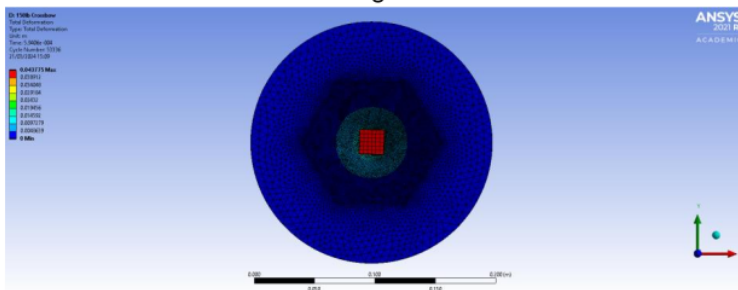


Figure 7 150lbs Crossbow Front View

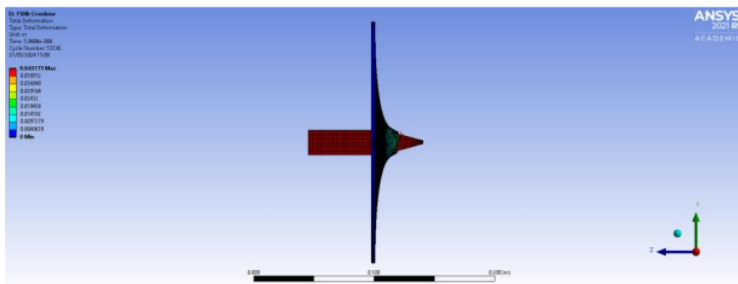


Figure 8 150lbs Crossbow Right View

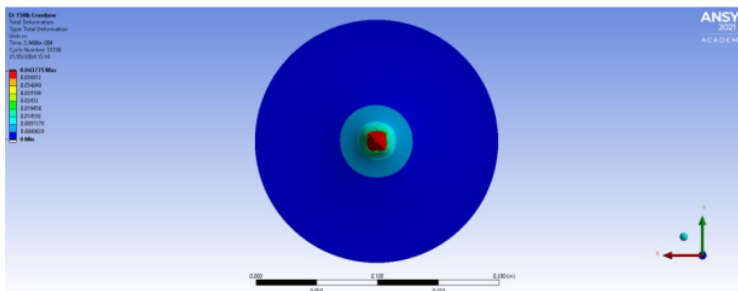


Figure 9 150lbs Crossbow Back View

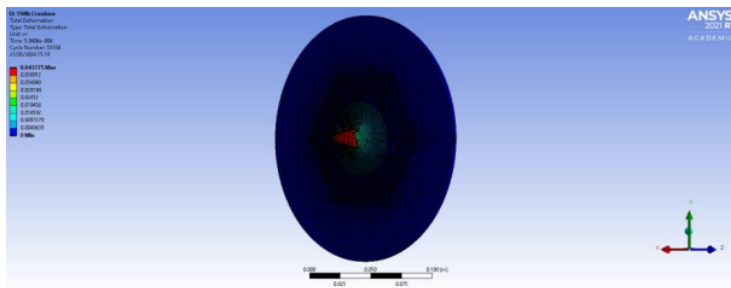


Figure 10 150lbs Crossbow Isometric View

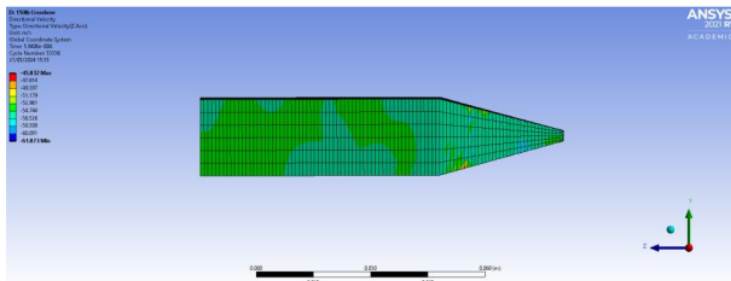


Figure 11 150lbs Crossbow Velocity Right View

With these images, it is clear that the arrow had made its way through the plate just not entirely. With the completion, albeit failed completion, of the model data could be extracted and handled to give useful results beyond just the animations of the model. Due to how the model was constructed, the direction of travel of the projectile was in the -Z direction meaning all the velocity data was negative so all of the data had to be normalised so that it would all be positive to give more comparable and easier to understand. The software provides 3 values for velocity, the lowest for an object at a time step, the largest for an object at a time step and then the average for the object at a time step. The decrease in speed seem to be constant from the graph below but with a slight curve, that curve may flatten out if the model didn't fail and the projectile passed all the way through the plate however due to not being much effected by the plate it is clear that the penetrating power of the relatively low power crossbow is still very high

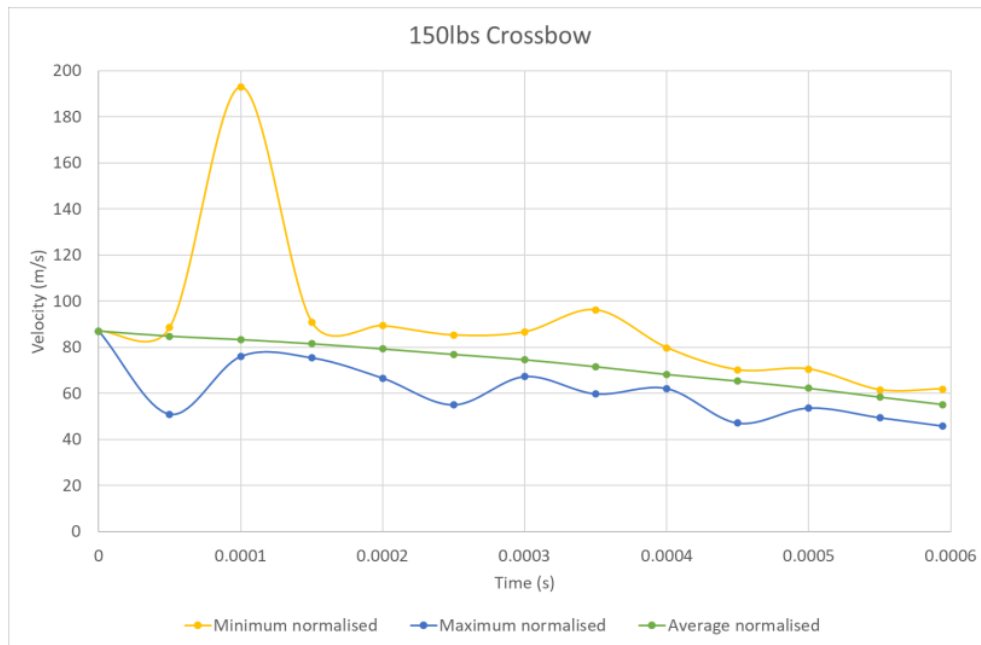


Figure 12 150lbs Crossbow graph

40lbs Recurve Bow

The 40lbs recurve bow was the 2nd projectile looked into. Like with the last the last test the model setup up was largely the same this time with the only difference being that the projectile was given a speed of 67m/s . This bow is much like the classic

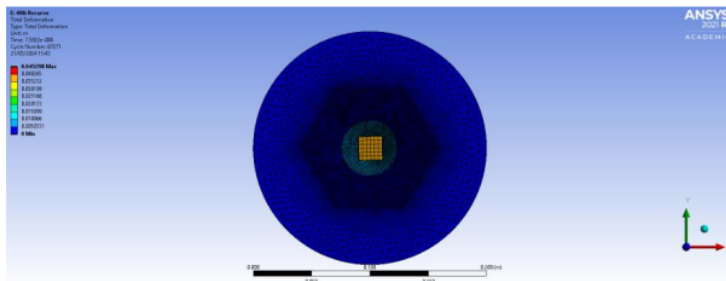


Figure 13 40lbs Recurve Bow Front View

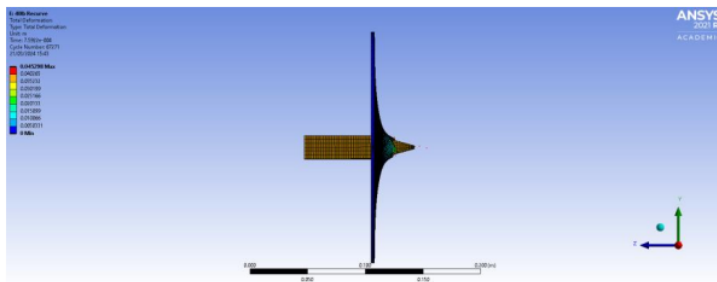


Figure 14 40lbs Recurve Bow Right View

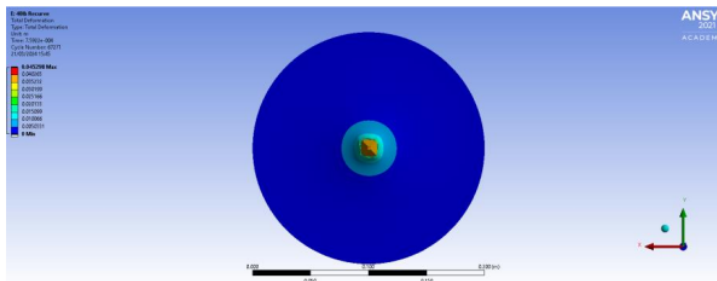


Figure 15 40lbs Recurve Bow Back View

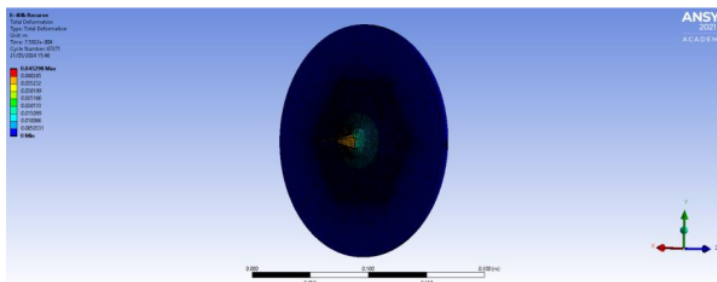


Figure 16 40lbs Recurve Bow Isometric View

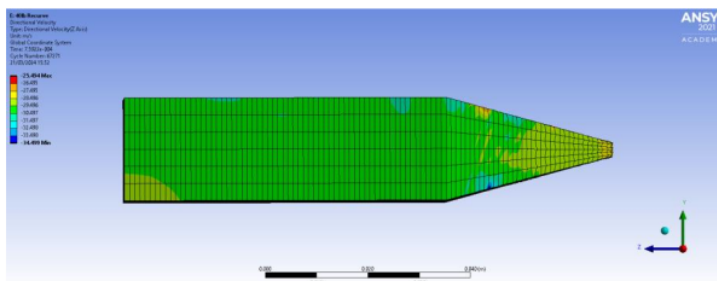


Figure 17 40lbs Recurve Bow Velocity Right View

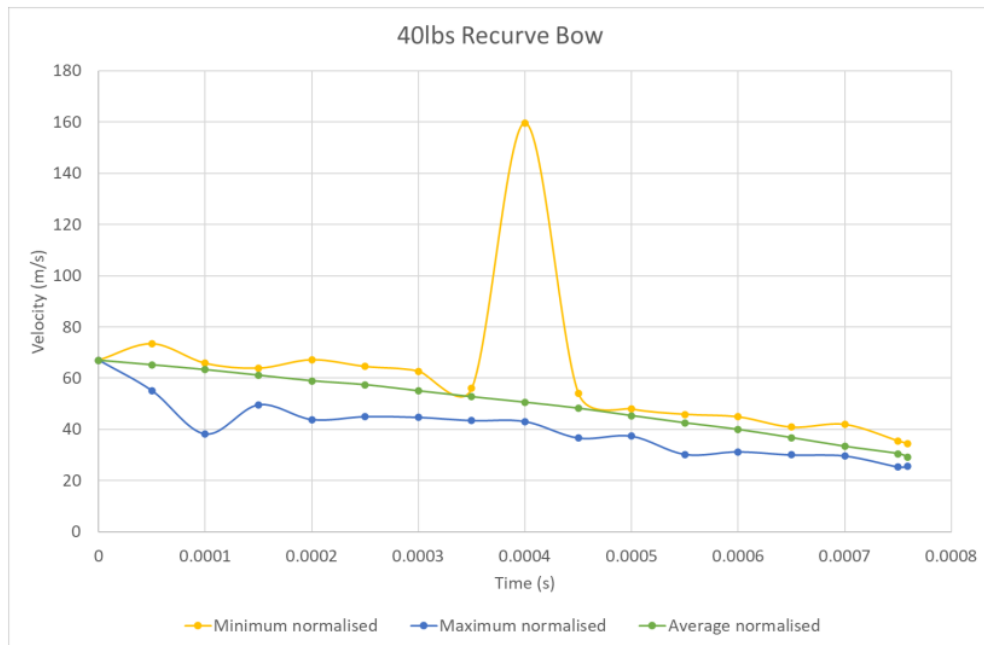


Figure 18 40lbs Recurve Bow graph

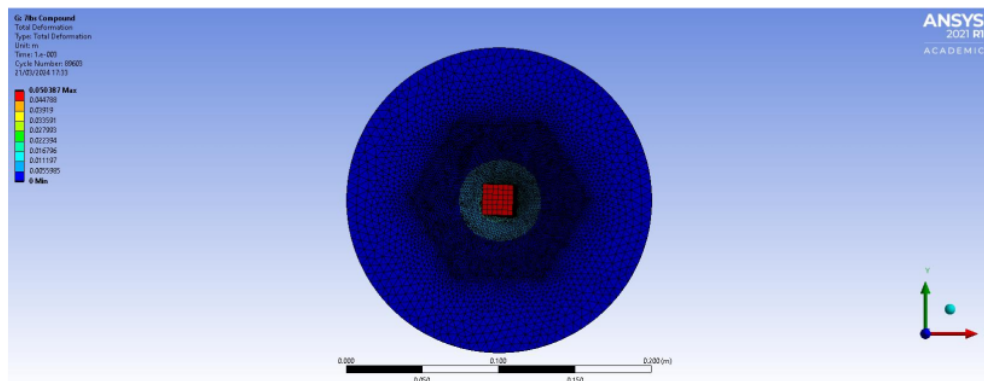


Figure 19 70lbs Compound Bow Front View

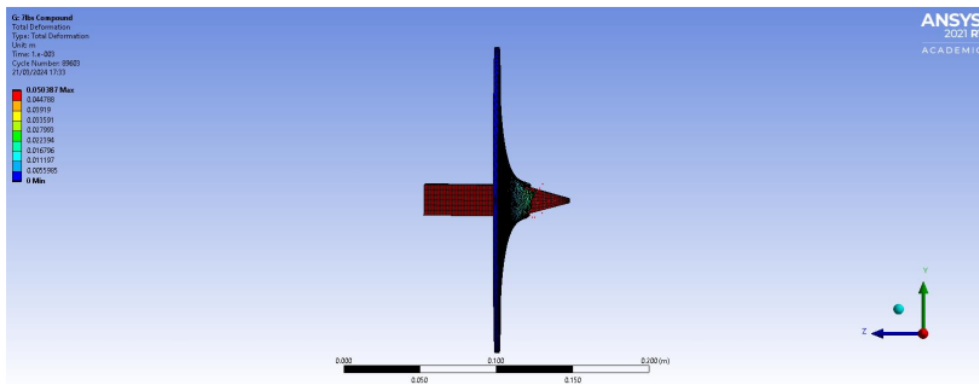


Figure 20 70lbs Compound Bow Right View

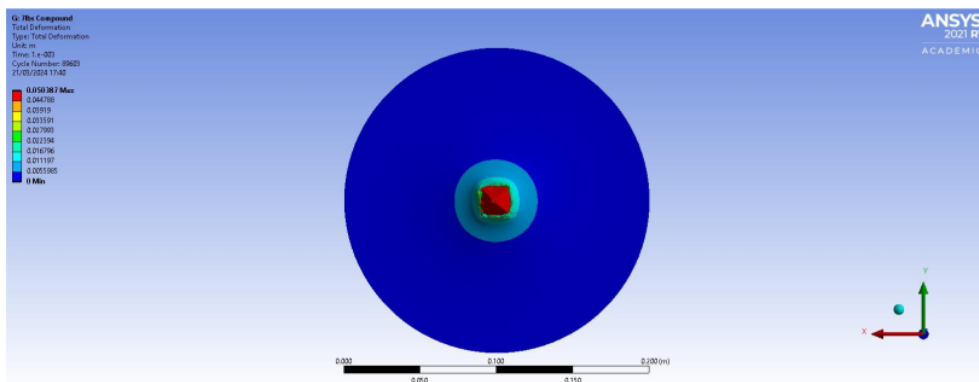


Figure 21 70lbs Compound Bow Back View

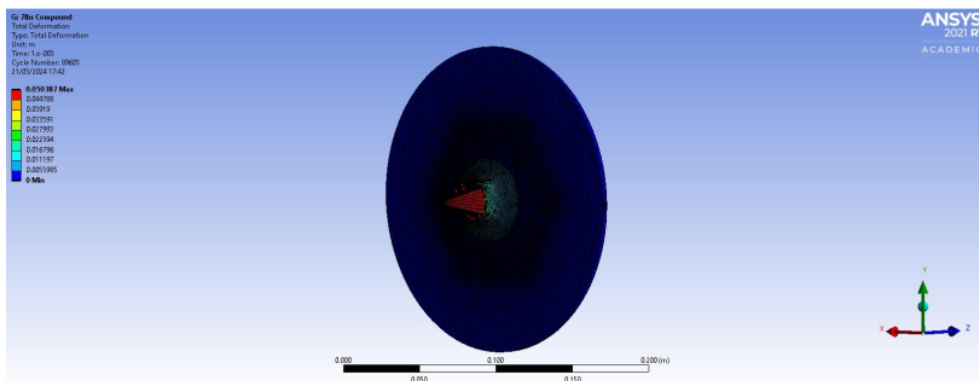


Figure 22 70lbs Compound Bow Isometric View

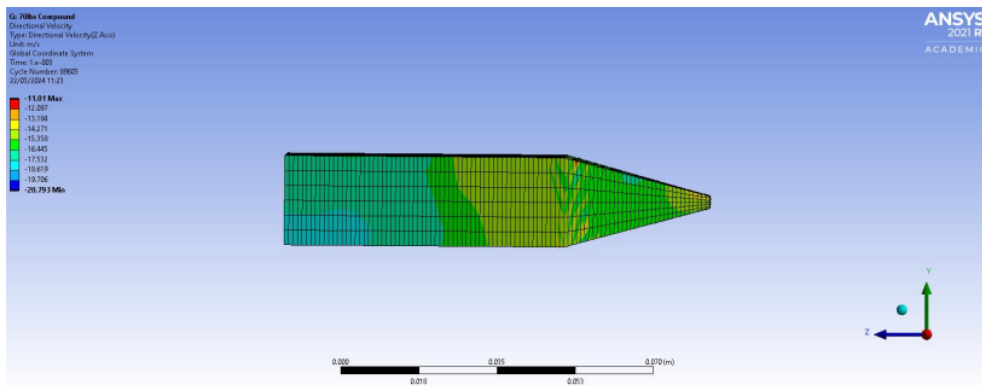


Figure 23 70lbs Compound Bow Velocity Right View

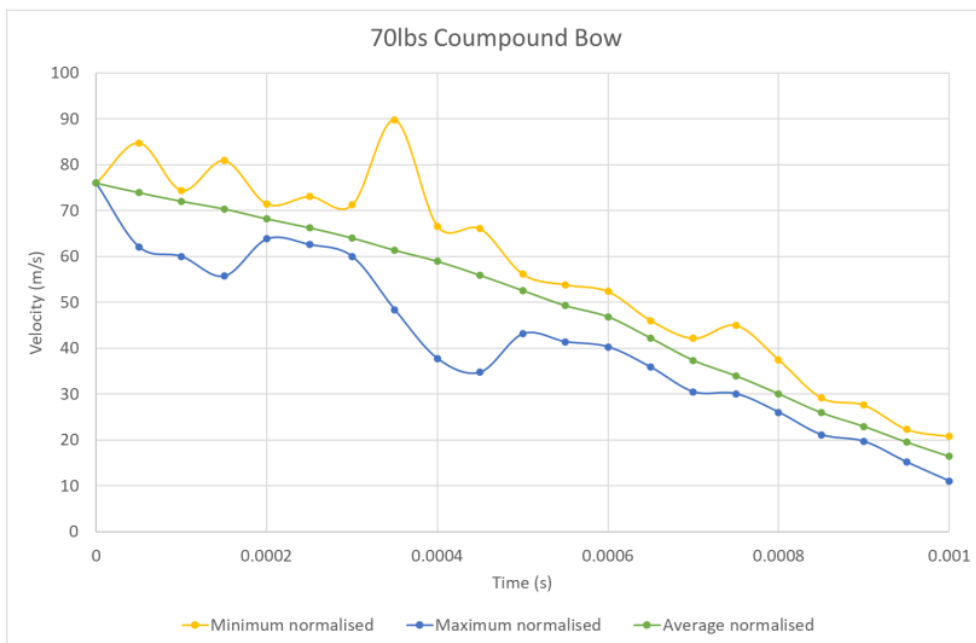


Figure 24 70lbs Compound Bow graph

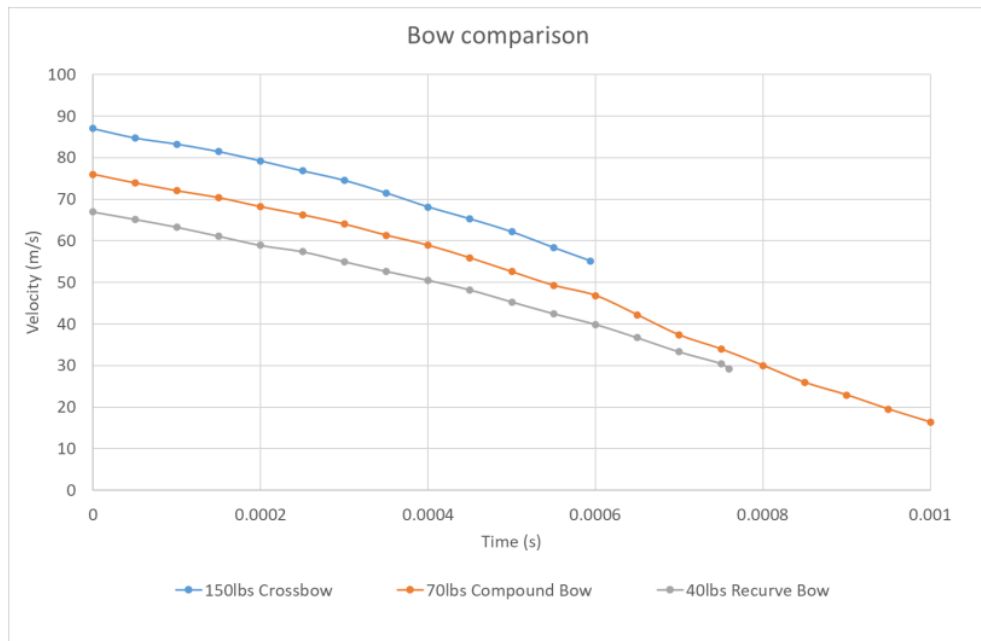


Figure 25 Comparison graph

Analysis and Comparison

Improvements

References

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<https://ptu-biuletyn.pl/resources/html/article/details?id=154411&language=en> – Polish paper

<https://www.worldcrossbow.com/Crossbow%20myths%20video%20text.pdf> – Velocities

<https://web.wpi.edu/academics/me/IMDC/IQP%20Website/reports/1314/bow.pdf> - president

CAD Assignment

GRADEMARK REPORT

FINAL GRADE

40/100

GENERAL COMMENTS

Unfortunately it seems the report was not finished, meaning that there is information missing in critical areas.

Report presentation and formatting has some good aspects to it, and looks like, had it been completed, would have yielded a good quality document. As it stands, there are clearly some issues with certain things missing and not presented in the way that I expect they would have been intended.

Use of literature is extremely limited in the report. Again, I feel this is a result of the timing issues rather than intent. There is a references list at the end, although not formatted correctly, and there are points in the document where I can see that citations would have been included, however in the form presented, there is minimal evidence of supporting literature being used in the report and as such the marks in this section are limited.

The introductory sections of the report have some good information in them, and the discussions about the limitation and known assumptions made in a CAE process are decent. Some supporting evidence to add validity to these statements would have been beneficial.

Your approach to performing validation has some good aspects to it, the general approach of testing how the software calculate high energy transfer scenarios like this was sensible. It is a shame that there were not comparative pieces of information, such as results from other studies to directly compare to to support your statements that the scenario had been modelled as expected. Some further discussion about material properties would have also been useful to better discuss how

these can be influential on the output of the solver.

The main studies run have generated some results that seem to follow an expected trend and you were building up a good data set to then start analysing. There were issues with the simulations which would have warranted further investigation to see if you could pinpoint what was causing the issues that were being encountered. Software has been used competently though to generate results from the studies which was encouraging.

Main issue is the lack of analysis in the report. This comes from it being unfinished it seems, however because of this the marks that can be awarded for analysis are rather limited. There are points where your discussions point towards this in areas, however not in great depth which is a shame.

With the way the marking scheme has worked out, it is just a pass, but was borderline. It is a shame that it was not completed as the results from the study, and approach you were showing to generating and collating your data would have been interesting to see the final product of.

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