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Develop a Tool for Democratising Knowledge within Small and Medium Enterprises in Simulations

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Abstract. Given the growing importance of simulation in engineering and its increasing adoption by SMEs, it's crucial to find ways for these smaller enterprises to use simulation tools efficiently, despite having fewer experts than larger organizations. After reviewing literature on how knowledge-based engineering can involve non-expert users and examining simulation workflows. A system has been proposed that will allow non users to conduct certain FEA analysis. This system enables non-expert users to adjust parameters within templates created by a simulation expert. It was found that the system could produce results that were very similar to the results of the expert users initial analysis.

Background

Finite element analysis (FEA) is a simulation tool used by engineers since the 1960s. In that time, it has rapidly grown to be a powerful tool to aid engineering understanding of how a product will respond to expected conditions. Its use is increasingly seen in smaller companies looking to improve production or reduce costs. These smaller companies, however, do not have the resources or knowledge base to properly exploit the use of FEA, commonly relying on design engineers to do the analysis or employing a single analyst to perform all analyses. As such, there is an increasing demand for a cost-effective way to improve the efficiency of analysis tasks, with a popular method being the democratization of knowledge. This sees people sharing expertise to expand a team's capabilities by distributing the workload whilst maintaining relevant knowledge levels, as can be seen in [1] . Another method for achieving this is using a quality management system (QMS), which acts as a framework to guide other team members in performing analyses and hence reduces the number of errors.

1 Literature Review

1.1 Knowledge-based engineering. Knowledge-based engineering (KBE) continues to grow in both academia and industry. This growth is, for the most part, driven by the increasing use of AI. However, KBE can also be used to investigate tools that help democratise organisational knowledge [2]. Reference [3] looks at many established methods for using KBE; however, these are not always used within the industry due to time and cost penalties.

1.2 Knowledge management. Companies cannot always rely on having the same capabilities throughout their operations when centering around personal knowledge. This is even more true for SMEs, where knowledge is concentrated on a more individual level, resulting in a greater risk of knowledge loss [4]. Therefore, disseminating knowledge within an organisation can reduce this risk.

Reference [5] shows that with knowledge management, there are four distinct drivers: motivational, technological, people interaction and organisational. This has led to using tools and software within organisations that act as a central repository for knowledge [6](.This allows people in different departments to access and seamlessly alter documents. While it can store knowledge, it also needs to store the context in which that knowledge is used, as this context is mainly taught within the company [7]. This can cause issues as time passes and knowledge is lost, leading to gaps previously understood within the organization.

1.3 QMS. QMSs provide a documented procedure to follow when conducting tasks. This ensures that results are easily repeatable by streamlining tasks done frequently. This can give some benefits, as outlined in [8]. However, if not implemented to the company's needs, it can cause disadvantages such as increased costs arising from the software and specialists using the selected software, as outlined in [9].

1.4 Design and simulation communication. A significant obstacle toward the democratisation of knowledge, is the need for design and simulation engineers to be able to communicate necessary information. Refernce [10] looked at potential barriers to communication. Twenty barriers were identified. They can be split into five categories: people, data, tools, process, and product. Their sixteen recommendations were laid out in [11], which focuses on ensuring clear communication, such as "definition of clear and specific objectives" or "Interaction and sharing questions, ideas, and values".

Reference [12] Went on to survey a limited number of companies to obtain their perceptions of the barriers and recommendations, with the main barrier being the "inefficient use of CAD-integrated FEM systems". The primary recommendation they all felt was used to great advantage was "utilising knowledge from experienced designers."

These studies provide some insight into industrial sentiment but do not provide detailed information on implementing their proposals. They highlight a preference for relying on experienced engineers for their knowledge but make no mention of issues that arise when that knowledge base leaves or how that knowledge can be captured

1.5 Democratisation of knowledge. When it comes to democratising the use of software in the company, a popular approach is to use designer-oriented simulation. These tools allow those with fewer specialist skills within the simulation space to run a simulation and obtain meaningful results [13]

1.6 Workflows. Several workflow flows have been developed for use within simulation environments. [14] has a detailed workflow that uses the MATLAB system workflow tool. These tools aid analysts with creating finite element models by automating the more repetitive and time-consuming tasks.

Workflows can take many different forms and can be used by people with varying levels of expertise, which is why how the workflow communicates its function to both new and existing users is important, as highlighted by [15].

1.7 Automation. When it comes to automation, it is important that different individuals can use the same inputs and acquire the same outputs. This can done through a documentation strategy. Reference [16] looked at information that should be recorded to ensure the repeatability of simulations.

1.8 Best practices. Refernce [17] has looked at using software to democratise simulation knowledge and highlighted three basic informational requirements for the analysis: geometry, loads, and material data. These reports also state that the software should not be able to perform the analysis without these three inputs.

The paper does not investigate scenarios in which the workflow already has some of these factors locked into the simulation, i.e., the model already has its load and materials loaded, and the user only needs to change the geometry. This situation could significantly reduce the skills and understanding needed to answer simple one-dimensional changes.

2 Analysis Autoamtion

2.1 Analysis qualtiy management. Before an analysis is democratised, it must move through a QMS document to ensure the simulation setup has a sound foundation. This QMS document records all the decisions made about the simulation setup, the justification for these decisions, and any verification and validation done on the model. When the simulation has been approved by the analyst and the responsible designer, it can then be democratised

The initial step is to determine the subject's purpose, and the information required from the analysis. This information helps guide the creation of simulation by justifying the boundary conditions and methods of result extraction.

The load cases that the simulation will use should be agreed. If possible, the load cases should result in balanced loads, as it will simplify the constraints applied. This also ensures that the model is loaded as the designer intended.

The geometry used in the simulation must be agreed upon. It should also be discussed what geometry dimensions should be parametric to allow for modification in later studies.

The analyst should now be able to identify any remaining constraints to ensure that the model is sufficiently constrained.

Once the designer has signed off on the simulation, the analyst can create it and perform any necessary verification and validation to ensure that the analysis's results are reliable. The simulation can then become a template for later use

Within this work, Simcenter (a simulation solution produced by Siemens) [18] has been used to implement simulation democratization. Simcenter has many tools that are useful for automating the simulation process by providing alternative methods to alter the simulation with existing tools. These include:

- Running simulations from batch files. This allows for external inputs to be used in the simulation without the need to open the graphical user interface (GUI).
- Equation driven parameters with values being derived from external spreadsheets.
- Tools for synchronous modelling allowing geometric features of imported parts in a nonnative file type to be altered. Hence simple parameter driven changes to the geometry can be made without needing to go back to SolidWorks
- Direct import of SolidWorks files. This keeps the names applied to faces and bodies but removes the feature trees.

2.2 Access levels. A system where the user can have different access levels would allow non-expert users to modify controlled parameters and safely run simulations based on their limited knowledge. The outputs can then be tailored to the levels of knowledge to make this information actionable.

The structure of the system developed in this work can be broken down into five access levels, as shown in Fig 1. These access levels are determined by the user's role within the organisation.

Level one is aimed at people outside the engineering team who might be interested in the capabilities of the product e.g. sales get an inquiry that falls outside the initial load case. This level has the lowest level of access for the app, restricted to only being able to select existing geometry and enter loads for the simulation. This level of access allows for simulation runs that do not need much user input and give results that display elements and nodes on a pass/fail measure.

Level two of the system is now focused on members of the engineering team who are not experts in FEA simulation. This level of access gives greater freedom, allowing the user to change geometry details, types of material, and loads. This level is intended to provide a deeper understanding of the effect of making alterations to existing geometry and provides feedback on how these changes can be utilized in further product development. The results given to the engineers from this have increased granularity to allow for a deeper assessment of design changes.

Level three is focused on members of the design team who are trained to be able to create and run simple linear and thermal analyses and is the level where they can use more complex geometry changes that would be difficult to detail with spreadsheet changes.

Level four provides full access to FEA tools for specialists who can use the software to conduct complex, nonlinear analysis.

3 Implementation

3.1 Analysis definition and control. In Sim Centre, templates are best set up using the selection recipe feature. This relates simulation objects to CAD features that have certain user-defined attributes. This ensures that the boundary conditions are applied consistently as the analyst intends and allows for quick modifications to the applied surfaces without the need to leave the CAD environment later.

An app has been developed called the AE analysis app with a graphical user interface (GUI)

This GUI allows the user to create the inputs for the simulation external to the simulation software. This GUI can be access restricted, reducing the risks of the simulation outputting unusable results.

The AE analysis app removes the users' interactions with the comparatively complex simulation software GUI and replaces it with several simple forms.

The GUI login page allows the AE analysis app to identify the tools the users should be able to use. Levels one and two are directed straight to pages that allow them to create and submit inputs for a simulation.

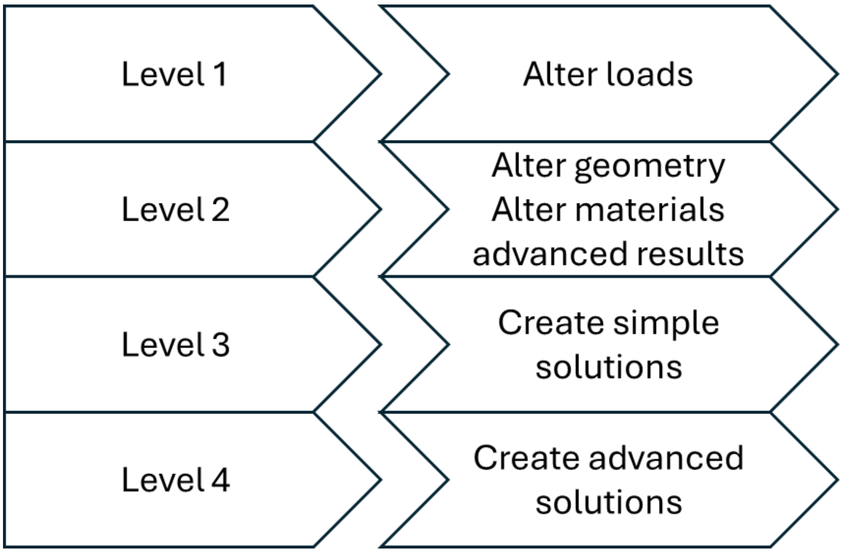

Fig. 1. Levels and tool access

Levels one and two see different input screens as shown in fig 2 which shows the inputs that a level one user will see and be able to manipulate and fig 3 which shows the inputs that a level two user or higher will be able to use. For level one, the dimensions and materials options are hidden, allowing only loads to be changed. This ensures that the user cannot accidentally change the simulation definition.

The loads are edited using an Excel template that contains the calculations required to generate load values that are consistent across the simulations.

The geometry is edited with another Excel template file specifically for the dimensions. This allows consistency for geometry to be modified in pre-defined directions.

The materials selection GUI differs depending on the selected product type. This screen allows the user to view what materials are used and what bodies have these materials applied by default as seen in fig 4. The user can then either change the material of an existing group, create a new group or move the desired bodies into this new group.

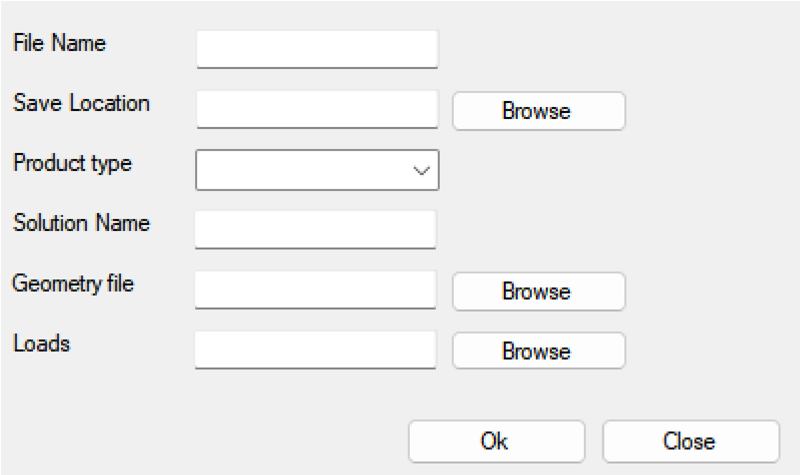

Fig. 2. Level one landing screen

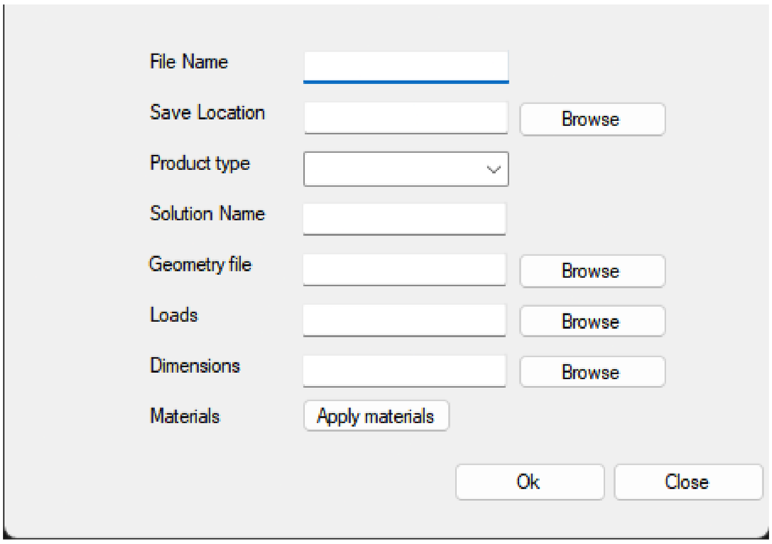

Fig. 3. Level two landing screen

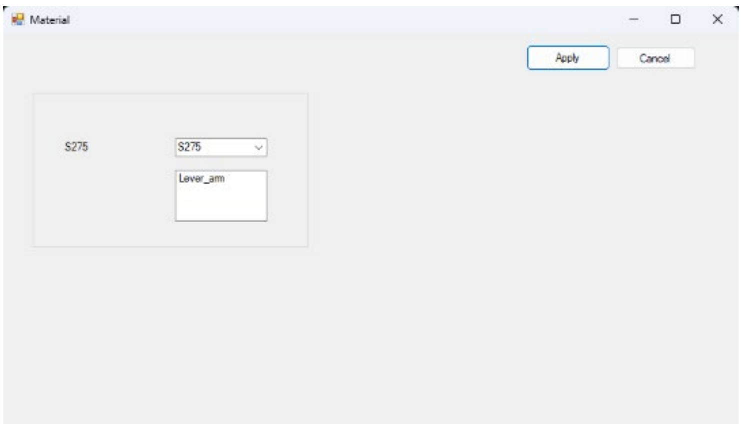

Fig. 4. Material application

The user would then click the OK button, which walks the user through the final steps of the input process seen in fig 5 shows an example of how a user would input values for the loads applied and fig 6 shows an example of how the user would alter the dimensions of the geometry used. This involves filling in the yellow boxes in the Excel worksheets for the load and geometry input. Green boxes are calculated values that cannot be edited. Once this step is completed, the software takes the important user inputs and the selected files and sends them as an email to the inbox of the individual who has access to the analysis software.

Levels 3 and 4, have two options: an option to move to the same page or since these levels will have direct access to the FEA software, a page that has tools that can be used to help in creating the analysis or converting the analysis to a template. These tools can range from getting the results needed for comparison with real-world tests to giving the features of geometry meaningful names that can then be made to apply boundary conditions consistently when the geometry is changed.

3.2 Analysis submission. When levels one through 4 submit the information, the request is placed in a queue, and when the queue reaches the request, it downloads the user's inputs for the geometry, loads and dimensions and takes the material information as lines of text. In the case of geometry and loads, it then opens a master version of the analysis Excel sheet, which is determined by the product type and geometry file, pastes in the user's value, and saves these new values in the file that the simulation then reads the values from. A batch file uses these inputs to run the desired simulation and produce pre-agreed outputs.

Lever arm	
hydraulic force	10000
hub reaction force	10000
bolt pattern	
number of pattern	2
bolt distance	0.038891
moment arm	0.0689
toruqe	689
balancing force	8858.113

Fig. 5. Load Excel table

10	thickness

Fig. 6. Dimension Excel table

The outputs are currently in the form of image files and comma separated variable (CSV) files. The images are of locations of interest in the simulation results, agreed upon between the analyst and the designers when the simulation is initially created. The CSV contains relevant results from the elements and nodes on the face within the area of interest. The graphical results are accompanied by a legend and colour scheme that is determined based on the user's level of access. At level one, the user receives results that are split into two colours: a passing colour and a failing colour, normally blue and red. The fail colours are used when the value is above a specified criteria. At levels 2 and up the results are shown on a more granular scale where red is again used to display elements that fail the criteria

The CSV is converted to an Excel sheet and condition formatting is applied based on the outputs agreed upon during the simulation's initial setup. Level one users receive confirmations through email if any of the elements fail, whilst level 2 users and higher will get a copy of the Excel sheet. The Excel sheet contains three pages. Page one states if any elements have failed. Page 2 lists all relevant elements and nodes on the face's surface. Page 3 contains details of elements that have failed the desired criteria. These results are then emailed back to the user and automatically saved to the user's PC.

4 Example Application

An example of a lever arm used in a linear actuator is presented. This lever arm has a pin that slides in a channel to control its position.

This analysis allows the user to adjust the load applied to the lever arm at its maximum position in this channel as well as information about the bolting pattern and the thickness of the lever arm.

4.1 Single component (initial creation). fig 7 shows an analysis of the lever arm is initially created by an expert user with the use of the FEA software. This setup is then used as the basis for the template.

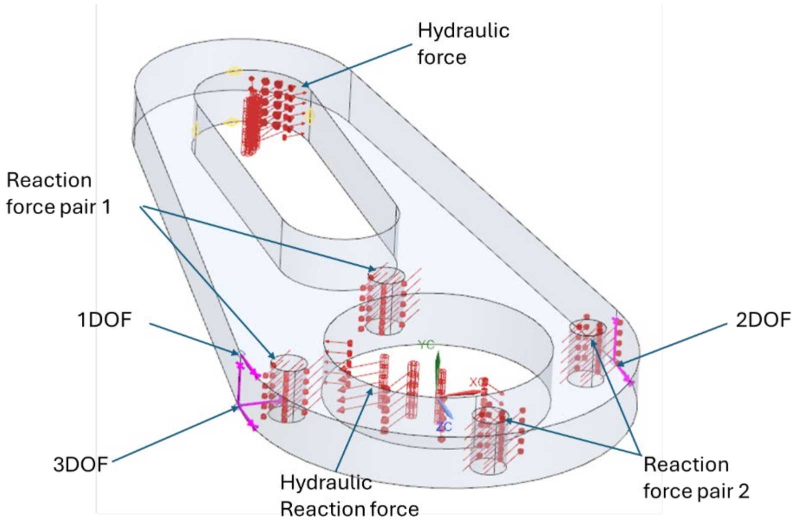

Fig. 7. Lever arm analysis setup

The hydraulic force is provided by the customer as a direct input from the product specification.

The hydraulic reaction force is then equal and opposite to this force acting on the hub side of the lever arm

$$F_H = F_{Hr}. \tag{1}$$

F_H= hydraulic force
F_{Hr}=hydraulic reaction force

The hydraulic force and its reaction force generates a moment that is reacted by the bolts that attach the lever arm the Hub. The value of this force is calculated using equ 2-3

$$T = F_H * m_a. \tag{2}$$

$$F_{mr} = \frac{T}{B_{pair} * B_{dist}}. \tag{3}$$

T=torque
m_a= moment
B_{pair}= number of bolts pairs
B_{dist}= bolt distance
F_{mr}= moment reaction force

now that the forces are balanced a three-point constraint system is created to make the constraint of the solution Fig 8 shows the results of the simulation before it was converted into a template that the AE analysis app could use. The image is taken directly from the FEA software. The results here show areas where the yield stress is exceeded in red and lower levels of von Mises stress in blue.

4.2 Single component (app). The results produced via the AE analysis app, with the same model parameters as used previously are shown in fig 9. These results are taken from the output png provided by the program. These show a slight difference to the results in fig 8. It was found that this was due to the full template using a value extracted directly from an Excel sheet whilst the analyst reads the value from the Excel sheet and manually types it in. As such, the AE Analysis app uses more precise data; it can be concluded that the app template's setup is correct.

Fig 10 shows the results output for a level two or higher user showing the same maximum and minimum stresses with the maximum stresses in the same region as in fig 8 which indicates that the max and minimum for both of the app runs needed to produce these two images produced the same results.

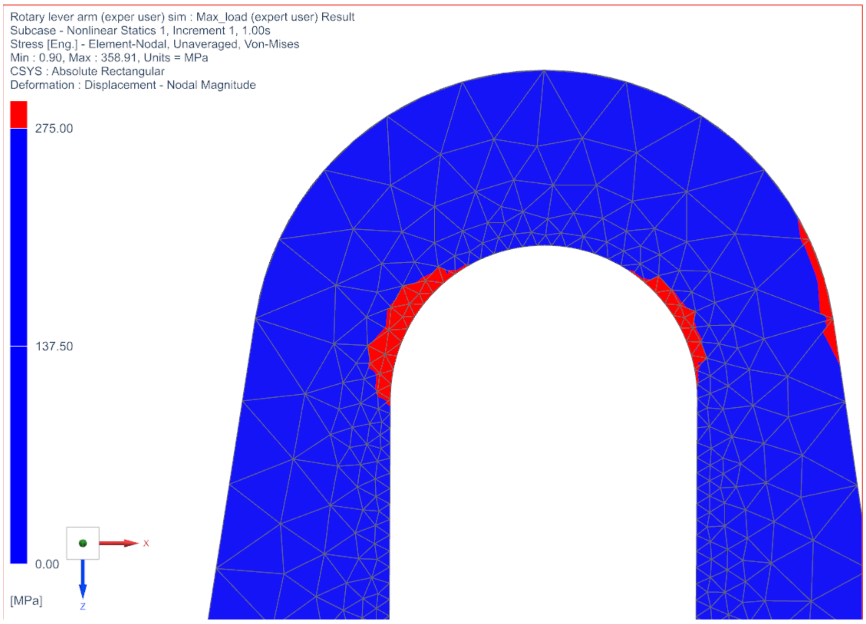

Fig. 8. PNG result analysis setup

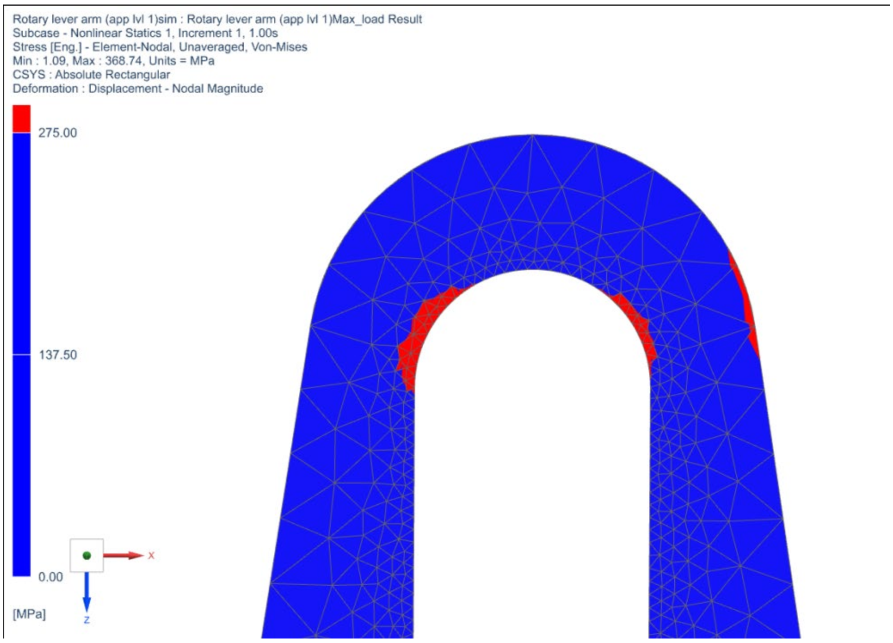

Fig. 9. PNG result template use

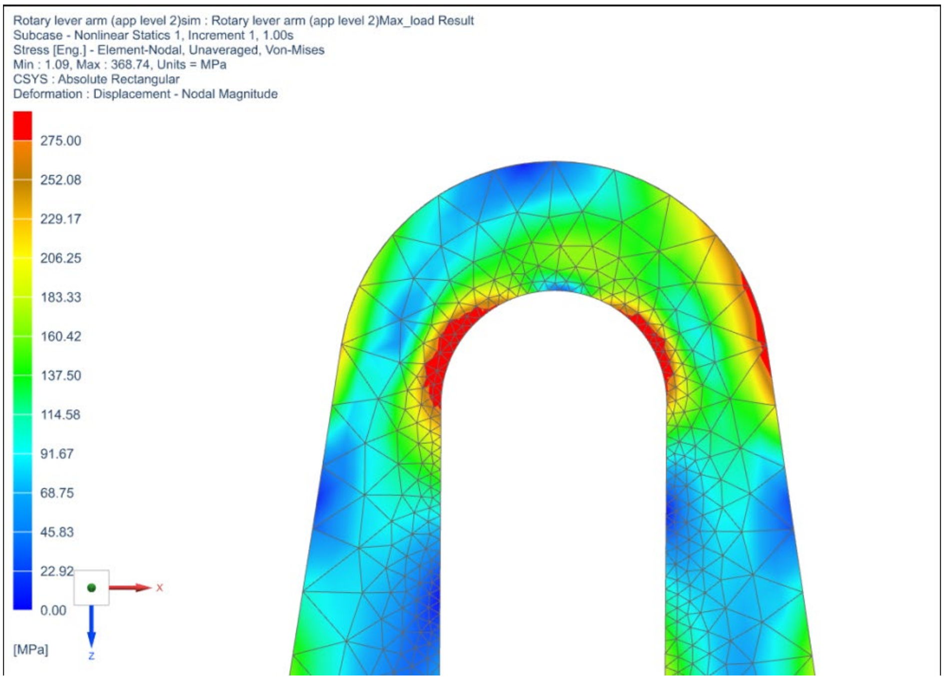

Fig. 10. PNG result template use

Now that the images have been compared which shows a slight difference in the maximum and minimum values we can check the nodal values.the nodes for this comparison are picked at random. Fig 11 shows the results extracted by the expert user, and the Excel sheet for the level one user. Fig 12 shows the results that are automatically extracted by the app. The comparison of these randomly selected nodes shows a good correlation between the expert user and app runs to 4 significant figures. this should provide confidence that the results that the app generated will be as reliable as the results that are produced by an expert user.

element ID	Node ID	Stress(MPA)
423	5537	275.2643E+0
1100	5394	278.9623E+0
1127	5448	275.4910E+0
7077	5365	275.1805E+0
7362	5656	275.8981E+0
7720	5475	276.1589E+0
8322	5297	275.4562E+0
8501	5468	276.1013E+0
8701	5562	276.2300E+0
9667	4588	276.0746E+0

Fig. 11. Random Selection of results in the FEA model

element ID	Node ID	Stress(MPA)
423	5537	275.2643
1100	5394	278.9623
1127	5448	275.4910
7077	5365	275.1805
7362	5656	275.8981
7720	5475	276.1589
8322	5297	275.4562
8501	5468	276.1013
8701	5562	276.2300
9667	4588	276.0746

Fig. 12. Same results points as figure 11 but from the app excel file

Conclusions

- The AE Analysis app drastically reduces the user's required skill set by removing them from both the creation of the simulation and restricting their interactions with software to simple GUIs or common workplace programs such as Excel.
- The AE Analysis app allows for quick modifications to an existing analysis to see how these changes affect the results.
- The AE analysis app allows controlling user inputs based on a user's knowledge without affecting the result.

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