A Review of Finite Element Analysis with respect to Experimental Results

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***Abstract*– As capabilities improve in supercomputing, finite element analysis continues to be utilized to determine a physical outcome before an experiment is conducted. Finite element allows the user to optimize a design or system to find the best design variables, which can save time and resources. However, with so many technological advances, still many articles show varying differences between simulation and experimental results. This study compares the results of finite element and experimental results to determine the effectiveness of computer software, and whether over time efficiency has improved.**

Keywords—Finite element analysis, FEA, finite element method, simulation

I. Introduction

Applications of Finite Element Analysis (FEA) date back to the 1960's, and as computers have increased in processing speed, so too has FEA's integration into modern research [1]. Researchers use FEA to build models to predict and optimize their designs before building a prototype. The benefit of FEA is that a computer can calculate stresses, fracture points, deflection, magnetic fields, fluid flow and modal analyses in a static or dynamic environment many thousands of times faster than a human can. Breaking up a design space into a discretized grid or "mesh", the computer solves ordinary differential equations at each node in the design. Figure 1 depicts a fixed beam with an applied load on the right-hand side, illustrating FEA's use of nodes and elements.

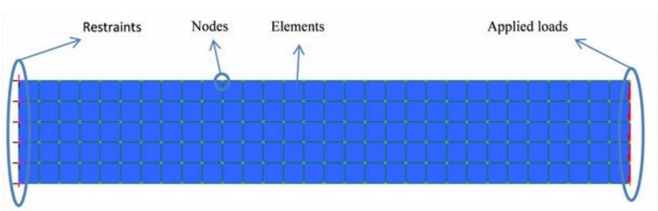

Fig. 1: Catilever beam, fixed on the left end with an applied force acting on the right end. The beam is discretized, the nodes are located where the mesh intersects, while in this case the elements are represented by squares. [2]

FEA analysis for a fixed beam generally looks at the global deflection vector {U}, given a known force vector {F} and the global stiffness matrix [K]. Within each global matrix or vector is the data for each element. Equation 1 describes the relationship between the three variables.

$$[K]\{U\} = \{F\} \tag{1}$$

The global stiffness takes in to account the material properties of the beam being displaced by the applied load/force. Depending on the application, FEA uses the governing equations of motion to calculate the results of the analysis.

For heat transfer on a lateral surface, different variables are used but have the same structure as Equation (1). In Equation (2), the specific heat matrix [C] and the time derivative of temperature $\{\dot{T}\}$ are multiplied on the left side of the equation. For steady state problems, [C]$\{\dot{T}\}$ = 0.

$$[C]\{\dot{T}\} + [K_T]\{T\} = \{R_T\} \tag{2}$$

$$\{R_T\} = \{R_B\} + \{R_h\} + \{R_Q\} \tag{3}$$

$[K_T]$ is equal to the sum of the global stiffness matrix [K] and the boundary convection matrix [H]. {T} represents the nodal temperature vector, and $\{R_T\}$ is heat flow vector which is comprised of the heat flux vector $\{R_B\}$, boundary convection vector $\{R_h\}$, and the heat generation vector $\{R_Q\}$. If Figure 1 is converted into a heat transfer problem, the applied load becomes heat flow, and nodal temperature would take the place of displacement. As the number of nodes increases, so does the number of times the equations must be solved, increasing the run time required to solve the problem. Initial values are required to run the analysis, so any constraints, loads, and material properties should be defined before starting the analysis.

II. Simulation versus Experimental Results

For this research, the type of finite element analysis was not limited to just solid mechanics problems or only electromagnetic simulation/experiments. In addition, the comparison between simulations and experiments is not limited to one FEA software. Instead, this paper gauges overall improvement for all software and types of problems. The reason for this methodology was to include as many papers as possible; finding a large enough sample size for one type of problem and one software was not feasible.

Each paper analyzed in this paper uses one FEA simulation method and then verifies the simulation with an experiment. The expectation was that as the years go by, there would be an overall improvement in the FEA software's ability to predict experimental results. This of course makes certain assumptions about the research, for example that the researches were aiming at creating the most realistic simulation possible and not just to painting a broad stroke to get an idea of what to expect from their experiments. The validity of the inputs is critical to preserving the integrity of the analysis outcome.

TABLE I
JOURNAL PAPERS: DIFFERENCE IN SIMULATION AND EXPERIMENTAL RESULTS

Year	Appearance		
	Author	Type	Difference
2004	Jirathearanat, et al [3]	Fluid Mechanics	n/a
2004	Jang, et al [4]	Electromagnetic	3-5%
2005	Wang, et al [5]	Electromagnetic	15%
2006	Li, et al [6]	Electromagnetic	n/a
2007	Wood, et al [7] *	Solid Mechanics	8%
2009	Duan, et al [8]	Solid Mechanics	5%
2010	Maranhao, Davim [9]	Solid Mechanics	Varied
2013	Hsu, et al [10]	Fluid Mechanics	3%
2015	Thiagarajan, et al [11]	Fracture Mechanics	Varied
2017	Kan, et al [12]	Electromagnetic	1%

* The difference is the average of several simulation/experiments

Table 1 presents the differences between simulation and the experiments conducted in each respective journal paper. There are two early cases that did not include any quantitative simulation data. The objective in those papers was to illustrate that the simulation was able to yield similar magnetic field directions or fluid flow, without listing the difference in magnitude. There was good agreement in the direction of fluid flow/magnetic field, however, difficult to quantify the difference between simulation and experiment. In one case ([7]), there were multiple simulation and experimental test which were averaged to find the listed difference.

There are two publications ([9] and [11]) that have varied results. Maranhao, et al, had a problem identifying the friction coefficient, which had a significant impact on the outcome. Because they were not able to accurately define the initial conditions, their results varied greatly.

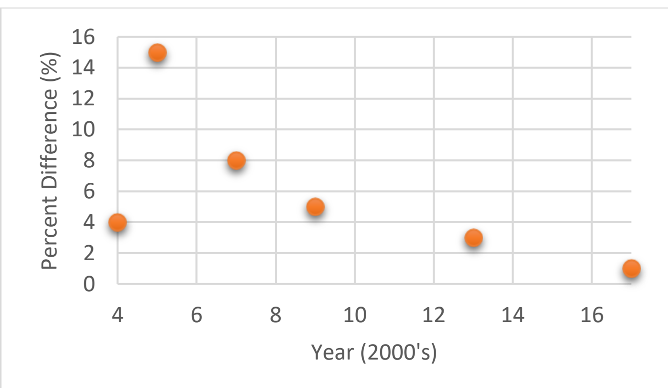

Fig. 2: Plotting the percent difference between simulation and experiment with respect to year of publication

In Figure 2, the data from Table 1 is plotted for greater clarity. While there isn't a clear increase or decrease in the percent difference in the simulation/experiment, there does seem to be a decline at least between 2005 and 2017. One paper ([5]) published in 2005 yielded the highest difference with 15%, while the most recent paper ([12]) yielded the lowest difference with 1%. The papers with varying results are not included in the Figure 2 to avoid confusion.

III. CONCLUSION & FUTURE WORK

The finite element analysis produced by the selected published papers resulted in varying degrees of difference between simulation and experimental data. In earlier works, some simulation results were purely qualitative, which were used as indicators that direction of flow or the magnetic field were similar to experimental values without including the magnitude. With the exception of the earliest paper in this study, there was a steady decrease in the difference between simulation and experiment, which indicates FEA accuracy improvement over time.

There are a couple of ideas for moving forward. First, a larger sample size of studies are needed, and they should be divided into thematic types and looked at individually. Finite element analysis for electromagnetism is more accurate than fluid mechanics but not as accurate as solid mechanics. All of the published papers in this survey look at steady-state or static problems. Doing the same analysis on nonlinear FEA problems would be of interest, as many real-world problems are nonlinear.

In addition, individual software should be separated out. It is possible that there are software that incorporate different techniques that yield more accurate results, all other things constant. Lastly, the reason FEA has become so commonplace in modern research is the power of computing. The time is takes to run a simulation has decreased, and it would be worthwhile to analyze the difference in run time during the same range of years.

ACKNOWLEDGMENT

Thank you to Dr. Renetta Tull, the National Science Foundation's Alliances for Graduate Education and the Professoriate (AGEP) program, and the PROMISE Staff for providing the opportunity to share our research and expand our borders.

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Digital Object Identifier: (to be inserted by LACCEI).
ISSN, ISBN: (to be inserted by LACCEI).

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