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Integrating MS Excel in Engineering Technology Curriculum

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Abstract: All STEM (Science, Technology, Engineering, and Mathematics) fields require fundamental knowledge and application of problem simplification, model synthesis, calculations, and results interpretation. As educators, it is our job to impart those skills to our students. Classic education in Engineering Technology (ET) typically involves course work in the basic sciences as well as mathematics. More advanced training is offered in specific disciplines related to engineering such as solid mechanics, fluid mechanics, materials, machines and mechanisms, etc.

Beginning in the last half of the twentieth century, computers and hand held calculators became increasingly integrated in the technical problem solving process. What began as a means to quickly and accurately perform mathematic calculations has evolved into very sophisticated design, simulation, and analysis tools as computing power has increased exponentially over the past few decades. Nearly all companies and educational institutions have adopted these technological tools to solve engineering problems that only a few years ago would have been impossible to solve with anything approaching the level of efficiency, sophistication, and accuracy now possible.

Along with the power and flexibility of these modern software packages comes a high cost of acquisition and maintenance, as well as demanding computer hardware requirements that sometimes drive costs prohibitively high. Additionally, most of these high end software packages come with a steep learning curve requiring specialized training to learn the intricacies of the program. Many of these advanced software suites can require many months or even years of continued use to master.

Contrary to the elaborate and often expensive software used in the design and analysis arena, Microsoft (MS) Excel is bundled as part of the MS Office suite of software, typically available on most computers used in educational and industry environments. In additional to being widely available and comparatively inexpensive, MS Excel does not have strict hardware requirement to operate correctly. MS Excel has been used in several courses taught in the Mechanical Engineering Technology (MET) department to reinforce fundamental concepts, model problems difficult to solve using more conventional means, reduce and interpret experimental data, and provide a platform for students to formulate and apply engineering models and approaches to solving various problems. To date, the effort to use MS Excel as an instructional tool has been effective. Students are responding well to the instruction. Not only are they being exposed to alternate approaches to problem solving, they are gaining a software skill that is very portable to future jobs in the professional sector.

This paper will discuss the specific techniques used to integrate MS Excel into class curriculum. It will also describe the various courses where MS Excel has been implemented at Weber State

University, and the educational outcomes. Additionally, the paper includes step-by-step examples explaining how to recreate two of the cited examples.

Background: In a traditional MET program, students will typically be required to successfully complete courses in college algebra, trigonometry, and calculus. This foundation in mathematics will become essential as they progress into engineering courses in solid mechanics, fluid mechanics, materials, and machine design. Over the centuries that humans have been developing the various branches of engineering science, equations have been derived with related systems of units to describe the physical phenomena being modeled and described. Almost all technical problems in science and engineering require quantified information to be manipulated into a useful form, with potentially many calculations being performed to arrive at the final solution.

Almost without exception, in engineering coursework, students are instructed in the fundamental science of a given subject, the governing equations, and techniques used to arrive at desired solutions to problems. Typically this process involves evaluating the question being posed, and deciding which equations are appropriate for formulating a solution. Once a strategy is established, the students are taught how to interpret the known parameters, and set up the appropriate mathematics to calculate an answer. Attention to such things as dimensional consistency and units are also emphasized. Once a solution is arrived at, students are taught how to evaluate the accuracy of the solution, as well as interpretation of the significance of the answer as it relates to the question at hand. For the most part, conventional mathematics is employed to perform the required calculations. If a closed form solution to the problem does not exist, students are taught basic strategies to make assumptions to simplify the problem such that a solution can be accomplished.

Alternately, if a problem has a level of uncertainty or sophistication beyond conventional techniques, numerical or iterative schemes may be employed to achieve an approximate solution. For these types of solutions, an electronic computer capable of billions of calculations per second is an extremely useful tool. In fact, for most cases, solving problems of this nature without a computer would be an impossible task. In select MET curriculum, using a computer to help solve various engineering problems is implemented to achieve the following two educational goals:

First, students develop a better understanding of the fundamental science and mathematics of a particular problem, as they are required to construct a computational model.

Second, students gain a basic understanding of a specific software tool which is portable to industry, thus making them more marketable and prepared to enter the work force.

For classes where computer software is employed, it is typical to use the customary commercial codes that are available. Basic instruction into the operation of this software is presented as part of the standard course curriculum. One required course (MET 3300 Computer Programming Applications in MET) requires students to learn a high level programming language to formulate solutions to various engineering problems by coding a solution and running their software to validate the approach. Hence, our students are given basic instruction in fundamental computer programming as well as exposure to various specialized engineering software. The introduction of MS Excel examples in select courses, is used to further expand students understanding of possible analytical tools that can also be exploited to solve problems.

Discussion: With the rise of the electronic computer during the mid-twentieth century, tremendous strides were made with regards to the speed, accuracy, and sophistication of mathematic calculations. As computer technology continued to evolve, not only in lower costs of acquisition and use, but in speed and the level of graphic display sophistication possible, very advanced analysis and simulation software became increasingly available in engineering fields both commercial and academic. At present, the market is full of useful software tools to assist in performing engineering calculations.

In most modern engineering and engineering technology programs throughout institutions of higher learning around the world, many of these commercial software codes have become staples in degree curriculum. Software packages such as AutoCAD, SolidWorks, PTC Creo Elements (formerly Pro/E), CATIA, NX (formerly Unigraphics), and many other are capable of not only CAD modeling, but are useful tools for motion analysis and geometric simulation and measurement. Many of these CAD tools have add on or bundled Finite Element Analysis (FEA) or Computational Fluid Dynamics (CFD) software available. These advanced analytical tools are capable of very complex simulations of structures, heat transfer, fluid mechanics, etc. In addition to the CAD and analysis software, programs such as MathCAD, Mathmatica, Maple, TK Solver, Matlab etc. offer advanced computational capabilities, calculation automation, programing, and technical documentation functionality.

Detailed instruction in many of these various software packages is available in courses offered throughout the curriculum provided in our program. Although, good foundational instruction is provided in our various coursework, expert level mastery of most advanced engineering software tools is beyond the scope of a typical undergraduate level class. Given the overall sophistication of these software packages, learning to become proficient in their use requires a great deal of experience. Most of these software packages take months or even years of use to become an expert user. Many of these software suites also come with very high acquisition and maintenance costs, and require very powerful computer hardware to operate correctly. As such, they are not typically available in a wide fashion such as more common word processing or spreadsheet software. Additionally, most of the mathematic and algorithm details occur behind the scenes as the code executes, forcing the user to trust that programs are indeed functioning correctly and providing an accurate solution. Hence, the user approaches the software as somewhat of a “black box” by feeding in design parameters and trusting the corresponding output to be correct. With the actual solution to the problem obscured as the software executes, students get little or no exposure to the mechanics of the problem solving itself. They gain valuable experience in setting up the appropriate simulation model with correct design assumptions and boundary conditions, and they are required to assess the accuracy and correctness of the output solution, but have little or no visibility to the mechanics of the problem solving.

As with all Mechanical Engineering and Mechanical Engineering Technology programs, a broad and diverse curriculum in engineering science is required. As faculty, we are always investigating better ways to introduce concepts, present correct approaches to problem solving, and then assess student mastery and performance against learning outcomes. It is very valuable in an educational setting, to not only present material and have students practice solutions, and later be tested on those concepts, but to present information in alternate or unique ways so that the students can have the best chance possible to comprehend the material and be able to utilize it correctly. Using a simple, and commonly available software package, to present and practice concepts in an ancillary way is just one way to assist in the learning process. Additionally, as students transition out into industry, some of the high-level software tools used in school may not always be available in the workplace, but MS Excel will most likely be available, and can potentially be utilized as they have had former experience with it for solving technical problems.

It is the author's experience, during multiple decades working in industry, for several different companies, it was somewhat unlikely that a specific company may have, for example, a license of MathCAD or a C++ compiler, but they were almost certain to have multiple licenses of MS Excel that could be utilized for engineering analysis. Of course, the spreadsheet software is not always capable of the level of sophistication required for certain problems or simulations, nor should it be used that way, but in many cases it can be a very useful analysis tool with minimal associated cost or complexity.

Application of MS Excel in Course Curriculum: As noted above, the use of high end simulation tools can sometimes be overkill, and possibly counterproductive in a classroom instruction environment. The goal in education is to not only teach a student how to achieve a correct solution, but to thoroughly understand and appreciate the science and mathematics used to formulate the problem. Using computers and software to quickly, and in a simple way, communicate principles and problem solving techniques, is a useful bridge between high level computing and traditional pencil and paper analysis.

MS Excel can be a low cost and relatively simple tool used to demonstrate and reinforce concepts in the classroom, as well as encourage students to build simulations from scratch, utilizing the basic equations to build higher level solutions to engineering problems. Although the software is best known for its financial and budgetary uses, it actually has fairly sophisticated computational capabilities as well. In addition to its mathematical function library, the software is easy to use, and has reasonable graphing functionality. Beyond the core functionality, the software also has basic logic and data analysis features. Also available to the more experienced user is a programming interface using a Visual Basic shell to create more elaborate applications. Most importantly, the software is readily available, as it ships bundled in the standard MS Office suite for a relatively low cost. The entire MS Office suite is available for a few hundred dollars, as compared to thousand or tens of thousands of dollars for other engineering analysis suites. According to data published by Microsoft on its website, it is estimated that MS Office is used by more than one billion people worldwide.[1] Therefore, it is probably one of the most commonly available software packages in existence. For this reason, it was chosen as a good candidate for the simple engineering model examples presented. Other low-cost or shareware software does exist that is comparable in power and functionality to MS Excel. An example of this would be Google Sheets, which is a free spreadsheet software developed by Google. However, MS Excel does have the largest marketplace exposure and overall usage by educational institutions as well as in industry. Hence, it was chosen as the software tool of choice for various classroom examples.

MS Excel is implemented in various course curriculum to introduce students to its flexibility and available functionality as it relates to various engineering problems. It is also used to reinforce various concepts, by having students walk through the synthesis of a problem, and program the spreadsheet to solve it, thus reinforcing their problem solving strategies. It is not intended to be a replacement to some of the high end design and analysis tools. It is intended to be used as a possible alternative, in some cases, to these software packages, and more often, a companion to be used in conjunction with more sophisticated engineering software. Students in the MET program are trained in other software, and are expected to develop knowledge and skills using various CAD and FEA packages. MS Excel is used to illustrate various concepts, and improve visibility to possible alternative solutions. Without elaborate custom programming, MS Excel will only be able to handle simpler problem solving, and its core functionality would certainly not replace any commercial codes that are highly specialized, and used for high-level engineering design and analysis. However, in some cases, it can be used as a cost effective, simple, and quite useful tool to perform analysis or automate tedious and error prone tasks and calculations.

Over the past four years, several MS Excel examples and projects have been implemented into the MET curriculum to illustrate concepts being taught in various courses. Additionally, periodic student assignments using MS Excel have been used to further reinforce basic concepts as well as give cursory instruction into the functionality and use of spreadsheet software in an engineering environment.

The courses where MS Excel has been implemented were identified as candidates for this approach due to the nature of the course material and its possible applicability in a spreadsheet example. Criteria included such things as reasonable mathematic simplicity within the capabilities of the spreadsheet core functionality, limited requirements for graphic output, and fairly limited programming requirements to achieve a solution. Of interest also were potentially tedious or error prone calculation processes, where a spreadsheet would be particularly helpful, especially in the case of iterative design studies or high volume repetitive calculations. These types of subjects within various courses were identified as possible good candidates for a spreadsheet example, and follow-on student projects to create their own functioning spreadsheet models. It was also intended to use MS Excel in several different courses with diverse subject matter to accomplish three goals:

First, illustration of the possible diverse applications of the software.

Second, continued reinforcement and practice in software skills.

Third, to reinforce the technical and mathematical background of various subjects, as well as practice problem solving skills.

It is important to note, that where appropriate, high end analysis tools were demonstrated in conjunction with MS Excel examples to illustrate their power and functionality, and to validate possible simpler solutions to the exact same problem.

Prior to the introduction of the MS Excel projects in various Mechanical Engineering Technology courses, it has been observed that most students have some basic knowledge of MS Excel, but others are relative novices. It has also been noted that even students who have some advance knowledge of the software, often have no idea of the flexibility and functionality available to perform engineering analysis prior to exposure in the MET classroom environment.

Based on the course selection criteria noted above, presented below are examples of various courses where the MS Excel teaching tool or projects have been used:

MET 3400 – Machine Design: Two specific MS Excel examples have been developed for use in the upper division machine design course required of all Mechanical, Manufacturing, and Design students.

The first spreadsheet example is used to illustrate combined stress fields, specifically transformed stress, principal stresses, and maximum shear stress. Prior to the machine design class, students are required to successfully complete a statics and strength of materials course. In that course, basic strengths of materials concepts are taught. However, detailed instruction in stress transformation and principal stress is not presented.

Following classroom introduction of transformed stress using a traditional lecture, and numerous example problems, the stress element rotation spreadsheet is presented. The learning outcome expected from demonstrating this spreadsheet is for the students to better understand the fundamental concepts of transformed stress as well as its relationship to the principal stress equations. A copy of the transformed stress spreadsheet is made available to the students after its classroom introduction. They are then encouraged to interrogate the programming as well as to use it as a means to check their homework problems.

The spreadsheet is designed to show a 2-D plane stress element incrementally rotated through 180 degrees with the representative transformed stress calculated and plotted on a graph. The user inputs the multi-axial stress field (σ_x, σ_y, τ_{xy}) into the designated cells. Utilizing the user supplied stress values, the spreadsheet then calculates the transformed stress based on the rotation angle (θ) using the following equations: [2]

$$\sigma_{x'} = \frac{\sigma_x + \sigma_y}{2} + \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos(2\theta) + \tau_{xy}\sin(2\theta)$$

$$\sigma_{y'} = \frac{\sigma_x + \sigma_y}{2} - \left(\frac{\sigma_x - \sigma_y}{2}\right)\cos(2\theta) - \tau_{xy}\sin(2\theta)$$

$$\tau_{x'y'} = -\left(\frac{\sigma_x - \sigma_y}{2}\right)\sin(2\theta) + \tau_{xy}\cos(2\theta)$$

$\boldsymbol{\sigma_x}$ = x-direction stress
$\boldsymbol{\sigma_y}$ = y-direction stress
$\boldsymbol{\tau_{xy}}$ = Shear stress
$\boldsymbol{\sigma_{x'}}$ = Transformed x-direction stress
$\boldsymbol{\sigma_{y'}}$ = Transformed y-direction stress
$\boldsymbol{\tau_{x'y'}}$ = Transformed shear stress
$\boldsymbol{\theta}$ = Stress element rotation angle

The angle is incremented by one degree per step, and the corresponding transformed stress values are tabulated. Note that the corresponding angle in radians, rather than degrees, is calculated as well. This is due to the fact that MS Excel only performs trigonometric functions using radians.

The tabulated values of transformed stresses are then used to create and x-y scatter plot illustrating the transformed stress values as a function of rotation angle. The spreadsheet also searches through the iterative results to determine the maximum and minimum normal stresses (1^{st} & 2^{nd} Principal Stress) as well as the approximate maximum shear stress. Adjacent to the approximate solution, the exact results are presented. The exact principal stress solution is calculated using the following equations: [2]

$$\sigma_1(\sigma_{\max}),\ \sigma_2(\sigma_{\min}) = \frac{1}{2}(\sigma_x + \sigma_y) \pm \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$$\tau_{\max} = \sqrt{\left(\frac{\sigma_x - \sigma_y}{2}\right)^2 + \tau_{xy}^2}$$

$\boldsymbol{\sigma_x}$ = x-direction stress
$\boldsymbol{\sigma_y}$ = y-direction stress
$\boldsymbol{\tau_{xy}}$ = Shear stress
$\boldsymbol{\sigma_1}$ = Maximum stress (1^{st} principal stress)
$\boldsymbol{\sigma_2}$ = Minimum stress (2^{nd} principal stress)
$\boldsymbol{\tau_{max}}$ = Maximum shear stress)

Available for inspection is the side by side comparison of the iterative versus the exact solution for the principal stresses and maximum shear stress. The transformed stress spreadsheet is presented in Figure 1.

ANGLE (DEG)	ANGLE (RAD)	σx'	σy'	τx'y'
0	0.0000	10.0000	10.0000	10.0000
1	0.0175	10.3490	9.6510	9.9939
2	0.0349	10.6976	9.3024	9.9756
3	0.0524	11.0453	8.9547	9.9452
4	0.0698	11.3917	8.6083	9.9027
5	0.0873	11.7365	8.2635	9.8481
6	0.1047	12.0791	7.9209	9.7815
7	0.1222	12.4192	7.5808	9.7030
8	0.1396	12.7564	7.2436	9.6126
9	0.1571	13.0902	6.9098	9.5106
10	0.1745	13.4202	6.5798	9.3969
11	0.1920	13.7461	6.2539	9.2718
12	0.2094	14.0674	5.9326	9.1355
13	0.2269	14.3837	5.6163	8.9879
14	0.2443	14.6947	5.3053	8.8295
15	0.2618	15.0000	5.0000	8.6603
16	0.2793	15.2992	4.7008	8.4805
17	0.2967	15.5919	4.4081	8.2904
18	0.3142	15.8779	4.1221	8.0902
19	0.3316	16.1566	3.8434	7.8801
20	0.3491	16.4279	3.5721	7.6604
21	0.3665	16.6913	3.3087	7.4314
22	0.3840	16.9466	3.0534	7.1934
23	0.4014	17.1934	2.8066	6.9466
24	0.4189	17.4314	2.5686	6.6913
25	0.4363	17.6604	2.3396	6.4279
26	0.4538	17.8801	2.1199	6.1566
27	0.4712	18.0902	1.9098	5.8779
28	0.4887	18.2904	1.7096	5.5919
29	0.5061	18.4805	1.5195	5.2992
30	0.5236	18.6603	1.3397	5.0000
31	0.5411	18.8295	1.1705	4.6947
32	0.5585	18.9879	1.0121	4.3837
33	0.5760	19.1355	0.8645	4.0674
34	0.5934	19.2718	0.7282	3.7461
35	0.6109	19.3969	0.6031	3.4202
36	0.6283	19.5106	0.4894	3.0902
37	0.6458	19.6126	0.3874	2.7564

INPUTS			APPROXIMATE SOLUTION			EXACT SOLUTION		
σx=	10.0000	ksi	σ_1=	20.0000	ksi	σ_1=	20.0000	ksi
σy=	10.0000	ksi	σ_2=	0.0000	ksi	σ_2=	0.0000	ksi
τxy=	10.0000	ksi	τ_{max}=	10.0000	ksi	τ_{max}=	10.0000	ksi

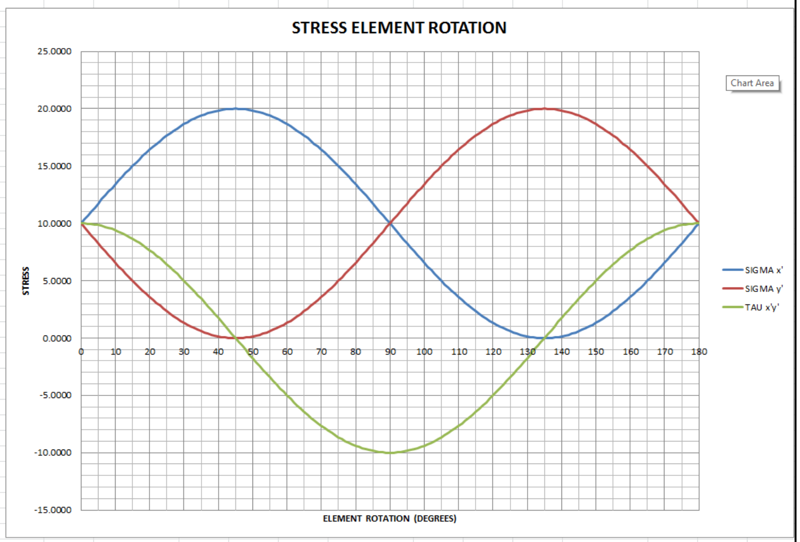


FIGURE 1 – Stress Element Transformation Spreadsheet

A second MS Excel tool is used in the MET 3400 class to demonstrate its uses as an automation tool to quickly perform calculations and perform iterative / "what-if" design studies. The spreadsheet is used to calculate the resulting stresses in a bushing / sleeve assembly due to the contact forces initiated by a press fit assembly. The desired learning outcome is for the students to be further exposed to the flexibility of MS Excel as an engineering tool, as wells as appreciate the advantage of automating processes that are tedious or error prone.

The spreadsheet is designed for the user to input both the sizes of the outer sleeve and inner bushing as well as the intended interference fit. Based on material properties picked by the user, the contact pressure at the fit interface, stresses, and diametral deflections in the parts are calculated. Using the respective sizes of the parts and material properties, the interface pressure is calculated using the following equation: [3]

$$p = \frac{\delta}{2b\left[\frac{1}{E_o}\left(\frac{c^2+b^2}{c^2-b^2}+\nu_o\right)+\frac{1}{E_i}\left(\frac{b^2+a^2}{b^2-a^2}-\nu_i\right)\right]}$$

p = Pressure at the mating surface of the sleeve & bushing
δ = Total diametral interference
E = Modulus of Elasticity (***o*** = outer piece, ***i*** = inner piece)
ν = Poisson's Ratio (***o*** = outer piece, ***i*** = inner piece)

Once the interface pressure is determined, the tensile and compressive stresses in the sleeve and bushing are calculated using the standard equations for thick walled cylinders: [3, 4]

$$\sigma_{ob} = p\left(\frac{c^2+b^2}{c^2-b^2}\right)$$

$$\sigma_{ib} = -p\left(\frac{b^2+a^2}{b^2-a^2}\right)$$

$$\sigma_{oc} = \left(\frac{2pb^2}{c^2-b^2}\right)$$

$$\sigma_{ia} = \left(\frac{-2pb^2}{b^2-a^2}\right)$$

$\boldsymbol{\sigma_{ob}}$ = Tensile stress in outer piece (at interface)
$\boldsymbol{\sigma_{ib}}$ = Compressive stress in inner piece (at interface)
$\boldsymbol{\sigma_{oc}}$ = Tensile stress in outer piece (at OD)
$\boldsymbol{\sigma_{ia}}$ = Compressive stress in inner piece (at ID)
a = Inner radius of inner piece
b = Interface radius
c = Outer radius of outer piece
p = Pressure at the mating surface of the sleeve & bushing

The deflection of the inner and outer rings is calculated using the following equations: [3]

$$\delta_o = \frac{2bp}{E_o}\left(\frac{c^2+b^2}{c^2-b^2}+\nu_o\right)$$

$$\delta_i = -\frac{2bp}{E_i}\left(\frac{b^2+a^2}{b^2-a^2}+\nu_i\right)$$

$\boldsymbol{\delta_o}$ = Total diametral deflection (outer piece)
$\boldsymbol{\delta_i}$ = Total diametral deflection (inner piece)
p = Pressure at the mating surface of the sleeve & bushing
a = Inner radius of inner piece
b = Interface radius
c = Outer radius of outer piece
E = Modulus of Elasticity (***o*** = outer piece, ***i*** = inner piece)
ν = Poisson's Ratio (***o*** = outer piece, ***i*** = inner piece)

Additionally, this spreadsheet project illustrates the use of imported graphics to display a schematic of the assembly being analyzed, as well as the applicable equations used in the spreadsheet simulation. The intent of these features is to illustrate steps that can be employed during the set-up of the spreadsheet to make it more user friendly. Additionally, the spreadsheet also includes simple instructions as to the use as well as standardization of colors (yellow for user inputs and green for calculated values) to further aid the user as to the correct use of the tool. The press-fit calculator spreadsheet is presented in Figure 2.

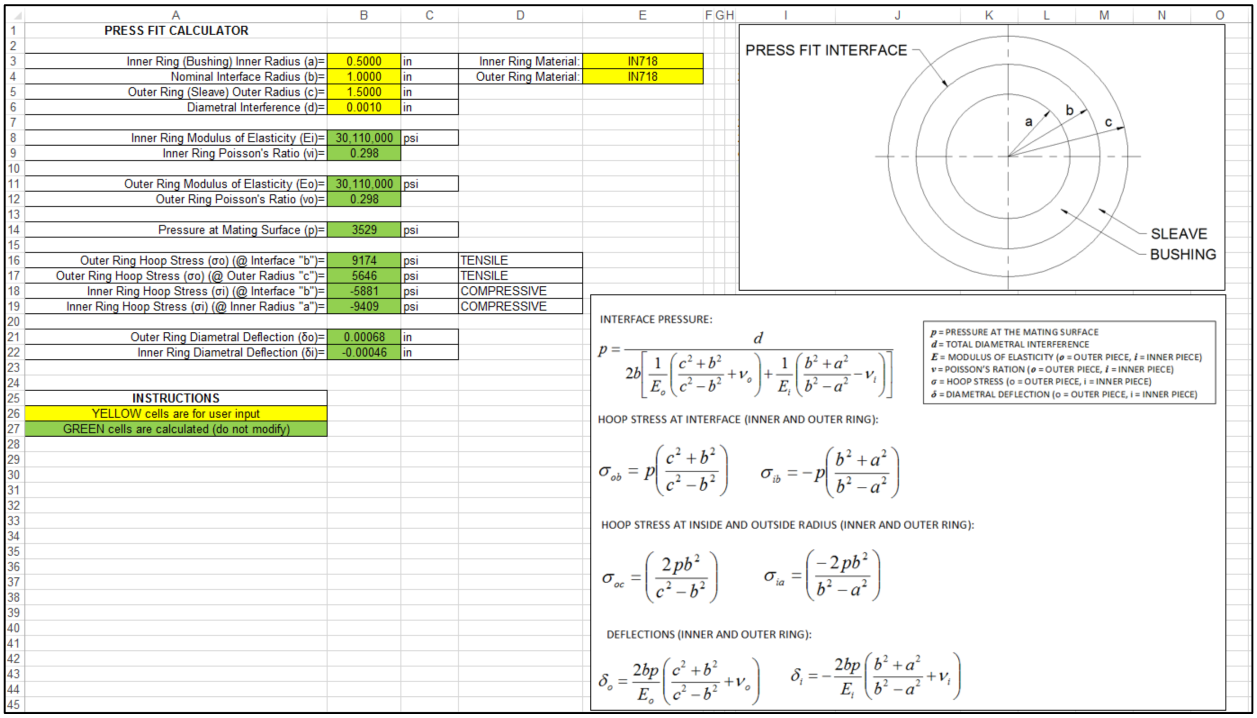


FIGURE 2 – Press Fit Calculator

The use of pull down pick lists as well as automatically selecting values from tables of data is demonstrated in this project as well. The spreadsheet user can select the materials from a pick list, and the spreadsheet will automatically query a data table to assign the appropriate Modulus of Elasticity and Poisson's Ratio for the subsequent calculations. An illustration of this functionality is presented in Figure 3.

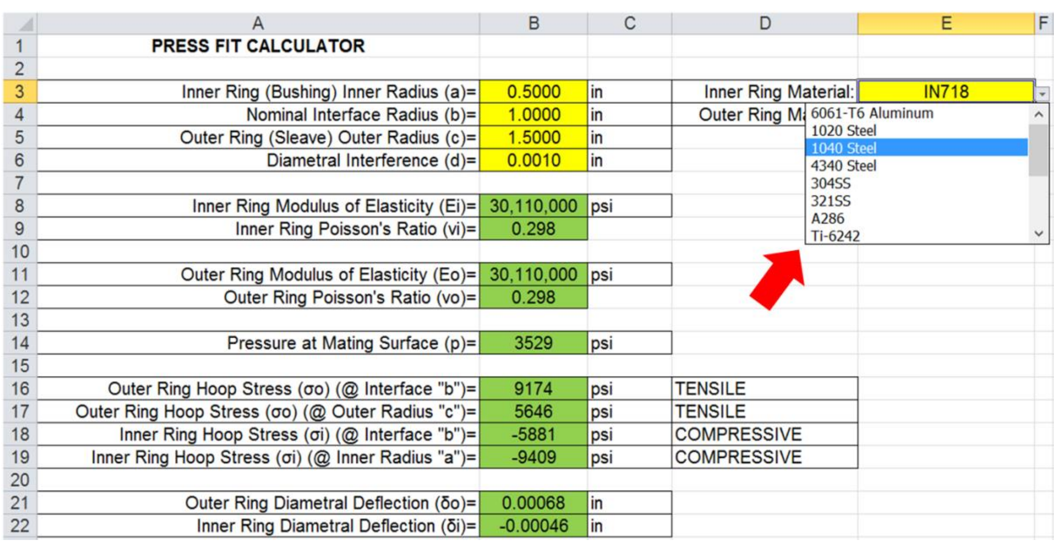
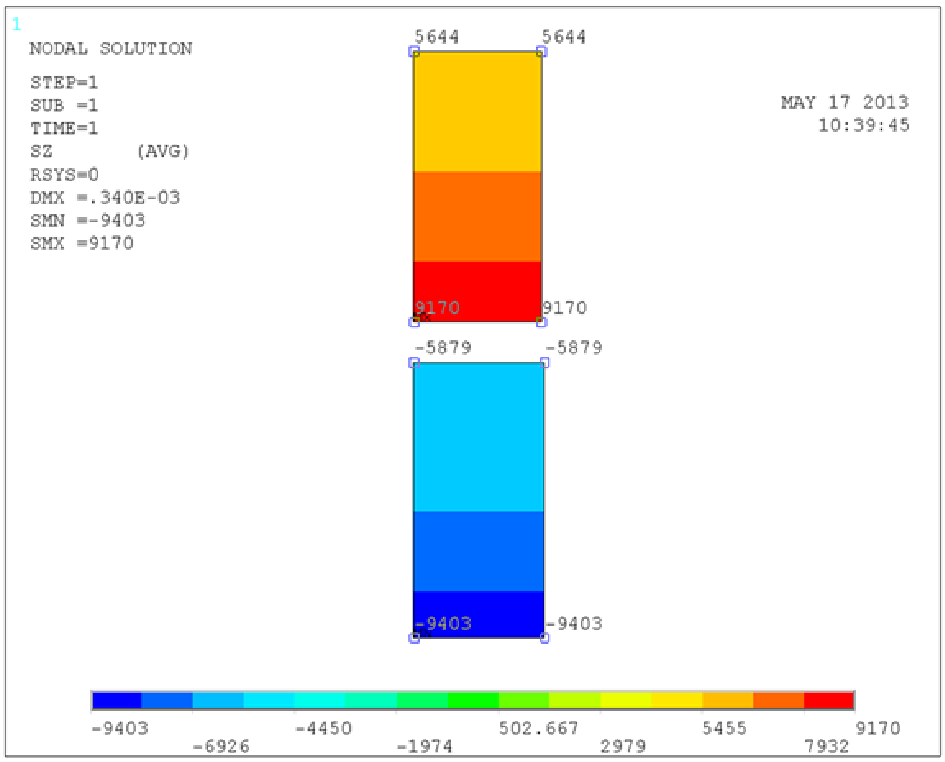


FIGURE 3 – Pull Down Menus & Pick Lists

In addition to the press fit calculator stress predictions, the results of a more sophisticated analysis, using ANSYS finite element analysis (FEA) software, is presented to the students. The FEA simulation was performed on 2-D axisymmetric model using constraint equations to establish the appropriate interference fit. For the specific case analyzed, the FEA results indicate very close correlation to the spreadsheet calculations using the established strengths of materials equations. The intent of the follow on analysis using advanced FEA software is to illustrate an alternate approach to solving the problem using much more elaborate methods. The FEA result and spreadsheet equivalent result are presented in Figure 4.



	A	B	C	D	E
1	PRESS FIT CALCULATOR				
2					
3	Inner Ring (Bushing) Inner Radius (a)=	0.5000	in	Inner Ring Material:	IN718
4	Nominal Interface Radius (b)=	1.0000	in	Outer Ring Material:	IN718
5	Outer Ring (Sleave) Outer Radius (c)=	1.5000	in		
6	Diametral Interference (d)=	0.0010	in		
7					
8	Inner Ring Modulus of Elasticity (Ei)=	30,110,000	psi		
9	Inner Ring Poisson's Ratio (vi)=	0.298			
10					
11	Outer Ring Modulus of Elasticity (Eo)=	30,110,000	psi		
12	Outer Ring Poisson's Ratio (vo)=	0.298			
13					
14	Pressure at Mating Surface (p)=	3529	psi		
15					
16	Outer Ring Hoop Stress (σo) (@ Interface "b")=	9174	psi	TENSILE	
17	Outer Ring Hoop Stress (σo) (@ Outer Radius "c")=	5646	psi	TENSILE	
18	Inner Ring Hoop Stress (σi) (@ Interface "b")=	-5881	psi	COMPRESSIVE	
19	Inner Ring Hoop Stress (σi) (@ Inner Radius "a")=	-9409	psi	COMPRESSIVE	
20					
21	Outer Ring Diametral Deflection (δo)=	0.00068	in		
22	Inner Ring Diametral Deflection (δi)=	-0.00046	in		

FIGURE 4 – Finite Element Analysis Verification of the Press Fit Calculator

MET 3050 – Dynamics: A MS Excel example and student assignment has been developed to illustrate projectile motion in the senior level dynamics class required of all MET majors.

Following classroom instruction and homework problems related to predicting projectile motion of a particle, a spreadsheet example is shown with a follow-on take-home project for students to complete. The assignment requires the students to create, from scratch, their own spreadsheet model to predict the flight path of a skier going off of a jump. Variable parameters include the initial take-off angle, take-off speed, height of the jump above the run-out slope, and the angle of the run-out slope downhill. Students are required to determine the horizontal and vertical distances traveled by the skier as well as the linear distance traveled from the jump take-off to the touchdown point. The students submit their own completed spreadsheet model with the specific solution asked for by the instructor. Following evaluation of their submitted spreadsheet models, the students are provided a solution spreadsheet to compare to their individual effort.

The demonstration version, as well as the student project version of the spreadsheet, has the user input the various parameters describing the initial motion of the skier (speed, angle of take-off, jump height off the ground, slope of the run-out below the jump). The spreadsheet is designed to calculate the position of the skier at discrete points in time, as well as present the x & y position at the respective time index. A graph of the skier's flight path is produced using a scatter plot. Also present on the plot is a line representing the ground below the skier's flight path.

The equations used to determine the skier's position as a function of time are: [5]

$$x = x_0 + v_0 \cos(\theta_0) t$$

$$y = y_0 + v_0 \sin(\theta_0) t - \frac{1}{2} g t^2$$

v_0 = Initial velocity
x = x-position (at specific time)
x_0 = Initial x-position
y = y-position (at specific time)
y_0 = Initial y-position
g = Gravitational acceleration
t = Time
θ_o = Initial angle of trajectory

For any given x,y coordinate calculated for the skier, the total linear distance traveled is calculated simply by using the Pythagorean (also known as Pythagora's) Theorem based on the current location and known coordinates of the take-off point (0,0 in this example). From visual inspection, the user can identify the approximate point of touchdown and evaluate the distance traveled. The ski jump spreadsheet is presented in Figure 5.

SKI JUMP PROBLEM

Skier			
Time (s)	x-Position (ft)	y-Position (ft)	Linear Distance (ft)
0.0	0.0	0.0	0.0
0.1	3.5	0.8	3.6
0.2	7.1	1.3	7.2
0.3	10.6	1.4	10.7
0.4	14.2	1.2	14.2
0.5	17.7	0.7	17.7
0.6	21.3	-0.1	21.3
0.7	24.8	-1.2	24.8
0.8	28.3	-2.7	28.5
0.9	31.9	-4.5	32.2
1.0	35.4	-6.6	36.0
1.1	39.0	-9.0	40.0
1.2	42.5	-11.8	44.1
1.3	46.0	-14.9	48.4
1.4	49.6	-18.3	52.8
1.5	53.1	-22.0	57.5
1.6	56.7	-26.0	62.4
1.7	60.2	-30.4	67.4
1.8	63.8	-35.1	72.8
1.9	67.3	-40.1	78.3
2.0	70.8	-45.4	84.1
2.1	74.4	-51.1	90.2
2.2	77.9	-57.0	96.6
2.3	81.5	-63.3	103.2
2.4	85.0	-70.0	110.1
2.5	88.5	-76.9	117.3
2.6	92.1	-84.2	124.8
2.7	95.6	-91.7	132.5
2.8	99.2	-99.7	140.6
2.9	102.7	-107.9	149.0
3.0	106.3	-116.4	157.6
3.1	109.8	-125.3	166.6
3.2	113.3	-134.5	175.9
3.3	116.9	-144.0	185.5
3.4	120.4	-153.8	195.4
3.5	124.0	-164.0	205.6

Ski Slope	
x (ft)	y (ft)
0.0	0.0
0.0	-15.0
134.6	-160.4

Take-Off Velocity=	25.0	MPH	=	36.667	ft/s
Take-Off Angle=	15.0	Degrees	=	0.262	Radians
Jump Height=	15.0	ft			
Run-Out Slope=	50.0	Degrees	=	0.873	Radians
Gravity=	32.2	ft/s^2			

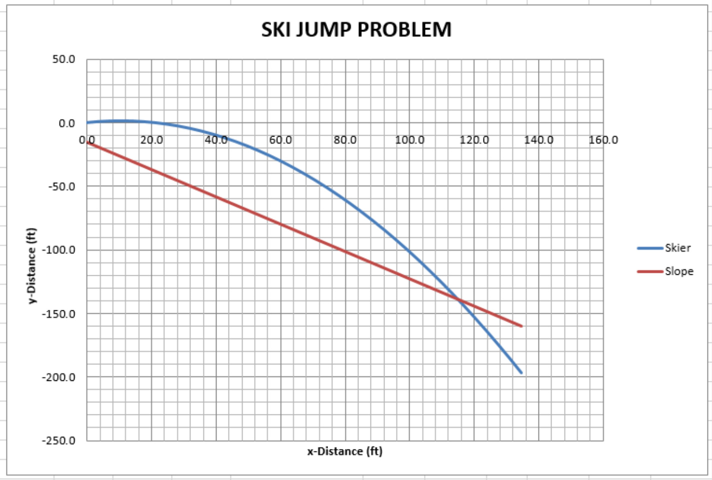


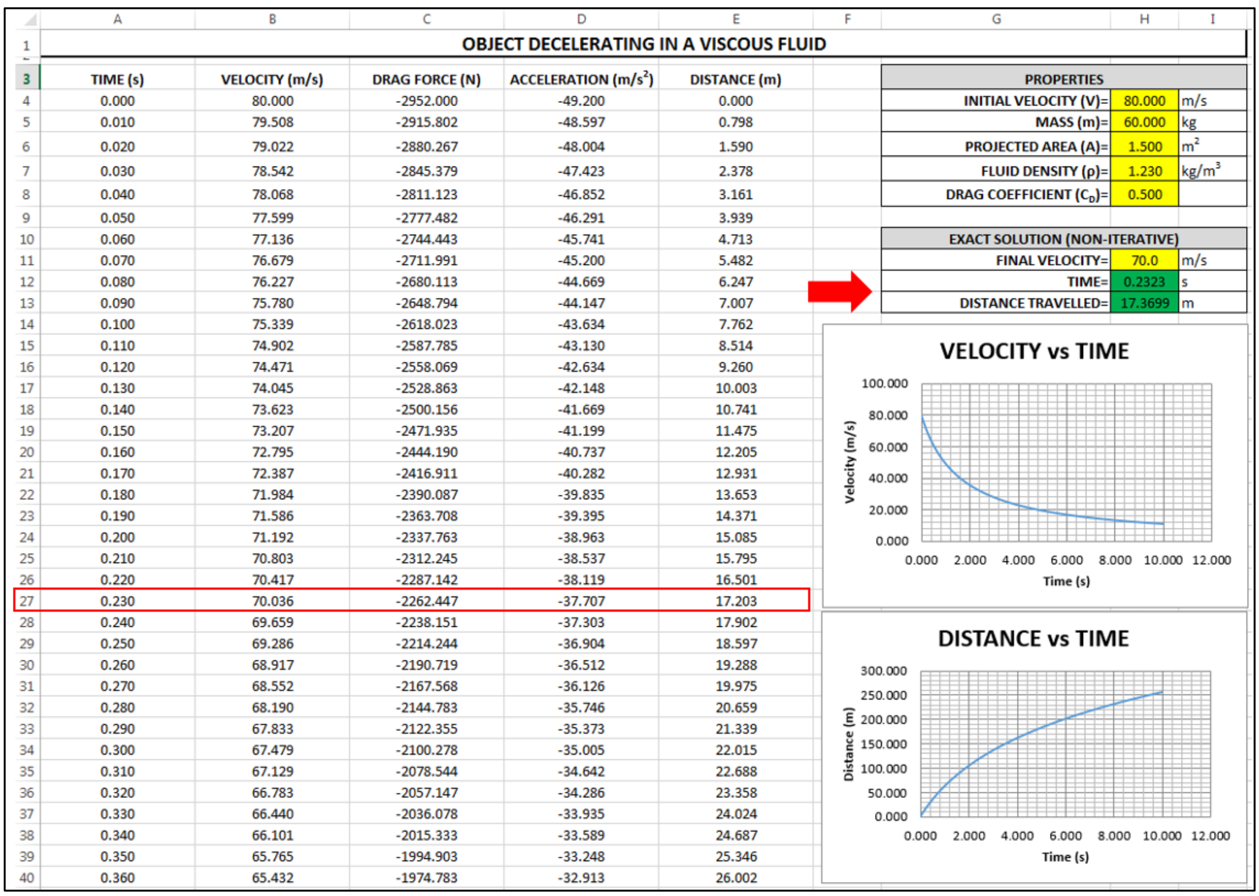
FIGURE 5 – The Ski Jump Problem

MET 2500 – Modern Engineering Technologies: An example of calculating the motion of a bluff body moving through a viscous fluid is used in a lower division engineering class to illustrate the effects of drag force on a body moving in a fluid. The MET 2500 class is intended to be a survey of modern technology and its applications in engineering. Modules are taught on subjects such as power generation, transportation technologies, materials, advanced manufacturing, and high technology engineering tools.

In the transportation technologies module, a lecture is taught regarding drag forces on aircraft, trains, and automobiles. The theory and mathematics of calculating drag are derived and presented. A spreadsheet example is used to further reinforce these concepts and principles. Following review of the spreadsheet simulation, the students are assigned a special project to create their own spreadsheet simulation of a particular problem.

A closed form solution predicting the object motion requires solving differential equations, is beyond the scope of the required prerequisites for the course. The derivation of the solution is presented to the class to illustrate the mathematic complexity involved. Following the presentation of the long solution, the spreadsheet is demonstrated. The spreadsheet basically assumes constant acceleration for small time intervals. Assuming constant acceleration over short time intervals greatly simplifies the problem allowing a very accurate approximate solution provided the time intervals are very small. Essentially the problem is solved by using a Riemann sum.

For the homework assignment based on this spreadsheet, the students are required to create their own spreadsheet model, and then compare their iterative approach to the problem with the solution predicted by the provided equations. Their spreadsheets are submitted and evaluated for their completeness and accuracy as related to the stated problem. Following evaluation of their submitted models, a solution is provided so they compare their solution to the instructor's spreadsheet. The bluff body in viscous drag spreadsheet is presented in Figure 6.


OBJECT DECELERATING IN A VISCOUS FLUID

TIME (s)	VELOCITY (m/s)	DRAG FORCE (N)	ACCELERATION (m/s^2)	DISTANCE (m)
0.000	80.000	-2952.000	-49.200	0.000
0.010	79.508	-2915.802	-48.597	0.798
0.020	79.022	-2880.267	-48.004	1.590
0.030	78.542	-2845.379	-47.423	2.378
0.040	78.068	-2811.123	-46.852	3.161
0.050	77.599	-2777.482	-46.291	3.939
0.060	77.136	-2744.443	-45.741	4.713
0.070	76.679	-2711.991	-45.200	5.482
0.080	76.227	-2680.113	-44.669	6.247
0.090	75.780	-2648.794	-44.147	7.007
0.100	75.339	-2618.023	-43.634	7.762
0.110	74.902	-2587.785	-43.130	8.514
0.120	74.471	-2558.069	-42.634	9.260
0.130	74.045	-2528.863	-42.148	10.003
0.140	73.623	-2500.156	-41.669	10.741
0.150	73.207	-2471.935	-41.199	11.475
0.160	72.795	-2444.190	-40.737	12.205
0.170	72.387	-2416.911	-40.282	12.931
0.180	71.984	-2390.087	-39.835	13.653
0.190	71.586	-2363.708	-39.395	14.371
0.200	71.192	-2337.763	-38.963	15.085
0.210	70.803	-2312.245	-38.537	15.795
0.220	70.417	-2287.142	-38.119	16.501
0.230	70.036	-2262.447	-37.707	17.203
0.240	69.659	-2238.151	-37.303	17.902
0.250	69.286	-2214.244	-36.904	18.597
0.260	68.917	-2190.719	-36.512	19.288
0.270	68.552	-2167.568	-36.126	19.975
0.280	68.190	-2144.783	-35.746	20.659
0.290	67.833	-2122.355	-35.373	21.339
0.300	67.479	-2100.278	-35.005	22.015
0.310	67.129	-2078.544	-34.642	22.688
0.320	66.783	-2057.147	-34.286	23.358
0.330	66.440	-2036.078	-33.935	24.024
0.340	66.101	-2015.333	-33.589	24.687
0.350	65.765	-1994.903	-33.248	25.346
0.360	65.432	-1974.783	-32.913	26.002

PROPERTIES		
INITIAL VELOCITY (V)=	80.000	m/s
MASS (m)=	60.000	kg
PROJECTED AREA (A)=	1.500	m^2
FLUID DENSITY (ρ)=	1.230	kg/m^3
DRAG COEFFICIENT (C_D)=	0.500	

EXACT SOLUTION (NON-ITERATIVE)		
FINAL VELOCITY=	70.0	m/s
TIME=	0.2323	s
DISTANCE TRAVELLED=	17.3699	m

FIGURE 6 – Bluff Body / Viscous Drag Problem

A detailed description of this problem and the specific spreadsheet features are presented in Appendix A. The spreadsheet example is based on an example problem presented by White, *Fluid Mechanics.* [5, 6]

MET 3700 – Testing & Failure Analysis: A required upper division materials course examines fatigue, wear, and corrosion as they relate to the prediction of material failure. Various techniques regarding the testing of materials and collection of data, as well as the application of that data to predict failure are discussed. One module of the course examines the evaluation of fatigue data and the different techniques used to develop appropriate S-N curves. Simple approaches are taught to use MS Excel to generate lifing curves by plotting the respective data points with simple trend line generation to illustrate curve fitting.

In many instances of fatigue analysis, data may be presented for various levels of mean stress (or R-ratio). Typically this would require that multiple data curves be generated to use for life predictions. By transforming the maximum stress in the cycle into a Walker Equivalent Stress, or equivalent zero-to-tension stress, the presentation of the fatigue data can be simplified into a single lifing curve. To accomplish this, a fitting exponent must be determined to accurately fit the data. The determination of the fitting exponent can be accomplished by performing a multiple linear regression analysis of the fatigue data. Accomplishing this is significantly more complicated than simple 2-D trendline fitting of data points in a scatter plot.

The process involves using basic material fatigue data determined by testing, coefficients must be determined to provide the basis of the regression analysis. Once the coefficients are calculated, the final solution for the fitting constant can be performed.

The technique to construct the spreadsheet is presented to the class, and the steps required to perform the regression analysis are demonstrated. Subsequent homework assignments are made so that the students can step through the process of generating the Walker Equivalent Stress and corresponding lifing cuves. The student’s homework assignment isn’t as sophisticated as the one presented in the lecture, but they are still required to take raw data, construction a S-N chart using MS Excel, and generate the necessary curve fitting and corresponding equations. The Walker Stress / Regression analysis spreadsheet is presented in Figure 7.

	A	B	C	D	E	F	G	H	I	J
1	Smax (MPa)	Smean (MPa)	N (Cycles)	Smin (MPa)	Stress Ratio (R)	Seq (MPa)		y	x1	x2
2	241	0	3500	-241	-1.00	401		3.5440680	2.3820170	0.3010300
3	207	0	6500	-207	-1.00	344		3.8129134	2.3159703	0.3010300
4	172	0	17400	-172	-1.00	286		4.2405492	2.2355284	0.3010300
5	138	0	70000	-138	-1.00	229		4.8450980	2.1398791	0.3010300
6	103	0	754000	-103	-1.00	171		5.8773713	2.0128372	0.3010300
7	103	0	210000	-103	-1.00	171		5.3222193	2.0128372	0.3010300
8	303	69	3000	-165	-0.54	417		3.4771213	2.4814426	0.1888032
9	276	69	6500	-138	-0.50	372		3.8129134	2.4409091	0.1760913
10	241	69	14900	-103	-0.43	313		4.1731863	2.3820170	0.1545414
11	207	69	35000	-69	-0.33	256		4.5440680	2.3159703	0.1249387
12	207	69	43400	-69	-0.33	256		4.6374897	2.3159703	0.1249387
13	172	69	124200	-34	-0.20	196		5.0941216	2.2355284	0.0783388
14	152	69	168700	-14	-0.09	162		5.2271151	2.1818436	0.0382645
15	145	69	507400	-7	-0.05	150		5.7053505	2.1613680	0.0204756
16	362	138	3100	-86	-0.24	423		3.4913617	2.5587086	0.0925694
17	338	138	9300	-62	-0.18	382		3.9684829	2.5289167	0.0731433
18	338	138	6000	-62	-0.18	382		3.7781513	2.5289167	0.0731433
19	310	138	21800	-34	-0.11	335		4.3384565	2.4913617	0.0451967
20	276	138	48300	0	0.00	276		4.6839471	2.4409091	0.0000000
21	241	138	82200	35	0.15	215		4.9148718	2.3820170	-0.0681498
22	214	138	128500	62	0.29	167		5.1089031	2.3304138	-0.1485702
23	214	138	218700	62	0.29	167		5.3398488	2.3304138	-0.1485702
24	414	207	4500	0	0.00	414		3.6532125	2.6170003	0.0000000
25	372	207	9600	42	0.11	341		3.9822712	2.5705429	-0.0520290
26	345	207	25700	69	0.20	293		4.4099331	2.5378191	-0.0969100
27	310	207	63500	104	0.34	230		4.8027737	2.4913617	-0.1774945
28	293	207	152900	121	0.41	198		5.1844075	2.4668676	-0.2313392
29	276	207	315500	138	0.50	166		5.4989994	2.4409091	-0.3010300

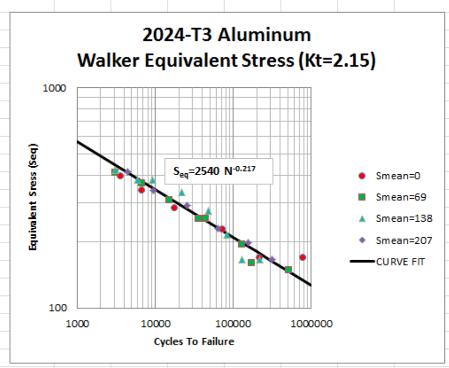


FIGURE 7 – Multiple Linear Regression Fatigue Chart

A detailed description of this problem and the specific spreadsheet features are presented in Appendix B. The spreadsheet example is based on an example problem presented by Dowling, *Mechanical Behavior of Materials*. [7]

Conclusions: The effort to implement MS Excel into to various MET course curriculum has been successful. Many students have commented that the simulation spreadsheets have been very helpful in reinforcing various concepts. They have also expressed appreciation in gaining further instruction in how to leverage available technology for their specific skill sets in engineering science. Some students who are currently employed in industry have reported that they have used what they learned in working with MS Excel in our courses to improve their efficiency on the job by implementing automated spreadsheet tools in the workplace. Some of the projects developed for the various courses have been shared between faculty members, and interest has been shown in how to further develop other examples and how to integrate them into other course curriculum.

The addition of the MS Excel examples to various courses was done in the spirit of continuous improvement advocated by ABET. It is the observation, based on student feedback and instructor opinion, that this effort has improved understanding and retention of some key engineering concepts as well as demonstrated alternate approaches to problem solving. However, controlled studies that quantify the overall effect of the MS Excel integration have not yet been conducted.

Although MS Excel is quite powerful, with a broad range of appliation in engineering science, it is definitely not the only, or best solution, in many cases. In fact, its broad scope of functionality applicable in many different unrelated disciplines does also create many limitations as it is not specialized enough to be useful in many cases. For example, the graphing and output display functionality is constrained to specific families of charts and graphs, with little built in functionality to change these, especially in the 3-D presentation of data. Additionally, complex itterative solutions can be difficult to perform without additional programming in Visual Basic. The built-in logic features are adequate in many cases, but can also be somewhat limiting when attempting to implement very complicated decision making into spreadsheet model.

As such, the MS Excel software does not have the inherit power and flexibility of high level programming codes or other more specialized tools. Many of these limitations are pointed out, and students are instructed to analyze what may be the best possible computing solution to the problem at hand, understanding that MS Excel may not lend itself well to a particular problem.

Recommendations: Although feedback from students regarding the use of MS Excel in various coursework has been overall positive, there is an opportunity to quantify and study the measureable effect the instruction is having on learning outcomes. Future efforts would involve the addition of new MS Excel simulations into coursework where it makes sense to do so. Additionally, it would be beneficial to attempt to better quantify through a statistical study the specific benefits of the additional instruction afforded by the various spreadsheet examples and student projects.

Future efforts would attempt to evaluate the mastery of a particular concept prior to initiating a MS Excel programming example, and then measure any contribution to learning a specific spreadsheet example and project has. Hard data would be collected relative to specific problems given on exams, and then re-tested after students have been required to complete a specific spreadsheet example to verify that the concept mastery has been improved. A specific example would be to quiz the student's mastery of a particular concept. Then create a control group using traditional homework problems. A second study group would be assigned a spreadsheet programming project. A follow-up exam will assess any learning advantage the spreadsheet programming project may have over traditional homework problems alone.

As noted above, some of the classes that use MS Excel examples use them only as instructional aids, where others actually have homework assignments for students to create their own working spreadsheet models, where applicable, it would be best for all in-class examples to include a representative student project as a hands-on learning exercise. This will also be a potential future improvement.

APPENDIX – A

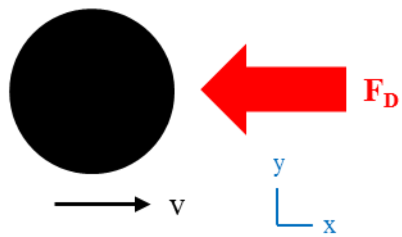


FIGURE 8 – Bluff Body in Viscous Flow Schematic

Solving for time as a function of velocity:

Begin with the equation of motion in the x-direction:

$$\sum F_x = ma_x$$

$$ma_x = -F_D$$

$$m\frac{dv}{dt} = -\frac{1}{2}\rho v^2 AC_D \quad \leftarrow \quad F_D = \frac{1}{2}\rho v^2 AC_D, \quad a_x = \frac{dv}{dt}$$

$$m\frac{dv}{dt} = -kv^2 \quad \leftarrow \quad k = \frac{\rho AC_D}{2}$$

$$\int_{v_0}^{v} \frac{dv}{v^2} = -\int_0^t \frac{k}{m}dt$$

$$\int_{v_0}^{v} v^{-2}dv = -\frac{k}{m}\int_0^t dt$$

$$\frac{v^{-1}}{-1} - \frac{v_0^{-1}}{-1} = -\frac{k}{m}t$$

$$\frac{1}{v_0} - \frac{1}{v} = -\frac{k}{m}t$$

$$\boxed{t = -\frac{2m}{\rho AC_D}\left(\frac{1}{v_0} - \frac{1}{v}\right)} \quad \leftarrow \quad k = \frac{\rho AC_D}{2}$$

m = Mass
a = Acceleration
F_D = Drag Force
t = Time
ρ = Fluid density
v = Bluff body velocity
v_0 = Bluff Body original velocity
x = Bluff body position
A = Bluff body projected area
C_D = Bluff body drag coefficient

Solving for position as function of time:

$$\frac{1}{v_0} - \frac{1}{v} = -\frac{k}{m}t$$

Begin with the equation derived on the previous page

$$v = \frac{v_0}{1 + \frac{k}{m}v_0 t}$$

$$v = \frac{dx}{dt}$$

$$\alpha = \frac{k}{m}v_0$$

$$\frac{dx}{dt} = \frac{v_0}{1 + \alpha t}$$

$$\int_0^x dx = \int_0^t \frac{v_0}{1 + \alpha t}dt$$

$$\int_0^x dx = v_0 \int_0^t \frac{1}{1 + \alpha t}dt$$

$$x = v_0 \left(\frac{\ln(1 + \alpha t)}{\alpha} \right)$$

$$x = \frac{v_0}{\alpha}\ln(1 + \alpha t)$$

$$\alpha = \frac{k}{m}v_0$$

$$x = \frac{v_0}{\left(\frac{k}{m}v_0\right)}\ln\left(1 + \frac{k}{m}t\right)$$

$$\frac{k}{m} = \frac{\rho A C_D}{2m}$$

$$x = \frac{v_0}{\left(\frac{\rho A C_D}{2m}v_0\right)}\ln\left(1 + \left(\frac{\rho A C_D}{2m}v_0\right)t\right)$$

$$\boxed{x = \frac{2m}{\rho A C_D}\ln\left(1 + \left(\frac{\rho A C_D}{2m}\right)v_0 t\right)}$$

Iterative solution using MS Excel:

Begin by establishing cells for input and calculation results. (HINT: A color code system such as yellow for inputs and green for calculation output are user friendly features and reduce confusion)

G	H	I
PROPERTIES		
INITIAL VELOCITY (V)=	80.000	m/s
MASS (m)=	60.000	kg
PROJECTED AREA (A)=	1.500	m^2
FLUID DENSITY (ρ)=	1.230	kg/m^3
DRAG COEFFICIENT (C_D)=	0.500	
EXACT SOLUTION (NON-ITERATIVE)		
FINAL VELOCITY=	70.0	m/s
TIME=	0.2323	s
DISTANCE TRAVELLED=	17.3699	m

TABLE 1 – Spreadsheet Data Entry

User input (initial velocity, mass, projected area, fluid density, drag coefficient)

User input (final velocity)

Using the equation previously derived the distance travelled as a function of time is entered here.

$$x = \frac{2m}{\rho A C_D} \ln\left(1 + \left(\frac{\rho A C_D}{2m}\right) v_0 t\right)$$

Using the equation previously derived the time as a function of velocity is entered here.

$$t = -\frac{2m}{\rho A C_D}\left(\frac{1}{v_0} - \frac{1}{v}\right)$$

The next step is to establish the iterative calculations:

In the first row of the table, the value for initial velocity should be pulled directly from the user input cells. The initial distance (displacement) and time index are set to zero.

The value for drag force is determined using the formula:

$$F_D = -\frac{1}{2}\rho v^2 A C_D$$

The value for velocity in the equation is referenced from the current row in the table. The other values (density, area, drag coefficient) are referenced directly from the user inputs, and are unchanging. The value for acceleration is calculated using the drag force divided by the mass (also pulled directly from the user inputs).

The current velocity is calculated using the velocity from the previous calculation and applying the kinematic equation for velocity assuming constant acceleration:

$$v = v_0 + a_0(\Delta t)$$

The current distance travelled is calculated using the distance from the previous calculation and applying the kinematic equation for displacement assuming constant acceleration:

$$x = x_0 + v_0(\Delta t) + \frac{1}{2}a_0(\Delta t)^2$$

Establish a time index. Increments of 0.01 seconds is a reasonable value.

	A	B	C	D	E
1	TIME (s)	VELOCITY (m/s)	DRAG FORCE (N)	ACCELERATION (m/s^2)	DISTANCE (m)
2	0.000	80.000	-2952.000	-49.200	0.000
3	0.010	79.508	-2915.802	-48.597	0.798
4	0.020	79.022	-2880.267	-48.004	1.590
5	0.030	78.542	-2845.379	-47.423	2.378
6	0.040	78.068	-2811.123	-46.852	3.161

TABLE 2 – Iterative Solution Data

The final step is to create the graphs of the motion analysis:

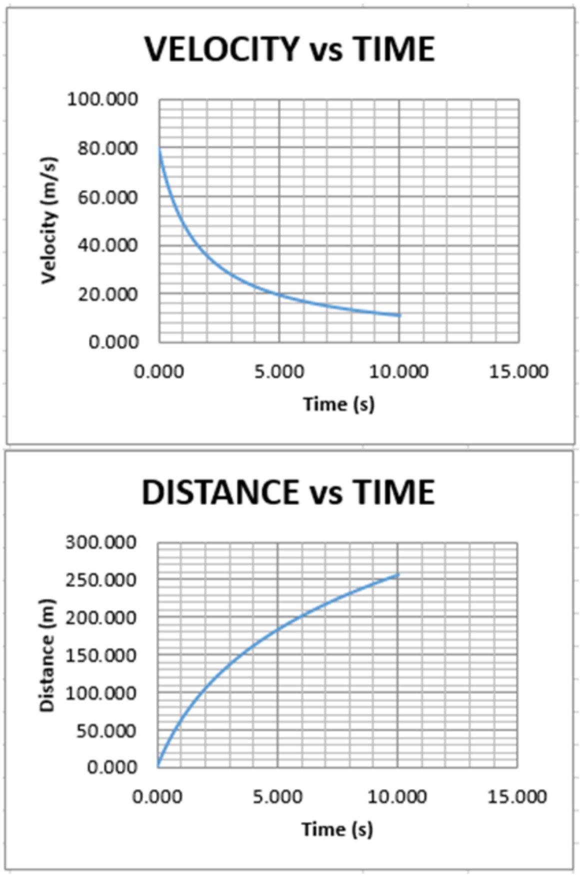


FIGURE 9 – Velocity & Distance Plots

Using a scatter (x,y) chart, the velocity as a function of time as well as the distance traveled as a function of time can be plotted.

APPENDIX – B

Multiple linear regression analysis using MS Excel:

Smax (MPa)	Smean (MPa)	N (Cycles)	Smin (MPa)	Stress Ratio (R)
241	0	3500	-241	-1.00
207	0	6500	-207	-1.00
172	0	17400	-172	-1.00
138	0	70000	-138	-1.00
103	0	754000	-103	-1.00
103	0	210000	-103	-1.00
303	69	3000	-165	-0.54
276	69	6500	-138	-0.50
241	69	14900	-103	-0.43
207	69	35000	-69	-0.33
207	69	43400	-69	-0.33
172	69	124200	-34	-0.20
152	69	168700	-14	-0.09
145	69	507400	-7	-0.05
362	138	3100	-86	-0.24
338	138	9300	-62	-0.18
338	138	6000	-62	-0.18
310	138	21800	-34	-0.11
276	138	48300	0	0.00
241	138	82200	35	0.15
214	138	128500	62	0.29
214	138	218700	62	0.29
414	207	4500	0	0.00
372	207	9600	42	0.11
345	207	25700	69	0.20
310	207	63500	104	0.34
293	207	152900	121	0.41
276	207	315500	138	0.50

TABLE 3 – Fatigue Data

In Table 3 are fatigue test results for 2024-T3 aluminum. The fatigue data is at various mean stress levels and/or R-ratios. The data is plotted below in Figure 10 for each of the mean stress levels, with a log-log curve fit for each mean stress.

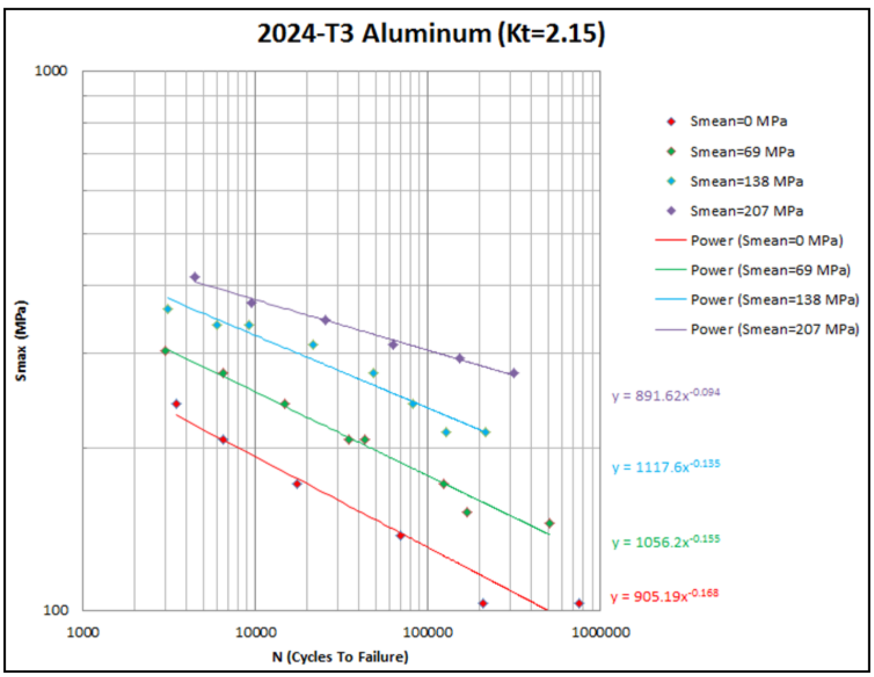


FIGURE 10 – Multiple Fatigue Plot

The walker equivalent stress can be used to transform fatigue data with any mean stress / stress ratio (r) into an equivalent zero to tension stress ratio (R=0).

The Walker equation is:

$$S_{eq} = S_{\max}(1-R)^{\gamma}$$

S_{eq} = Walker Stress
S_{max} = Maximum Stress
R = Stress Ratio (S_{min}/S_{max})
γ = Fitting Exponent

The fitting exponent (γ) is determined by fitting the data to a single trend line using multiple linear regression.

To solve for the Walker Exponent (***γ***), a multiple linear regression must be performed to fit the data.
The basic form of the equation is:

$$AN_f^B = S_{\max}(1-R)^{\gamma}$$

The unknowns we are curve fitting are ***A***, ***B***, and ***γ***.

This expression can be reorganized into:

$$\log A + B\log N_f = \log S_{\max} + \gamma \log(1-R)$$

Rearranging the equation yields:

$$\log N_f = \frac{1}{B}\log S_{\max} + \frac{\gamma}{B}\log(1-R) - \frac{1}{B}\log A$$

The equation is of the form: $y = m_1 x_1 + m_2 x_2 + c$

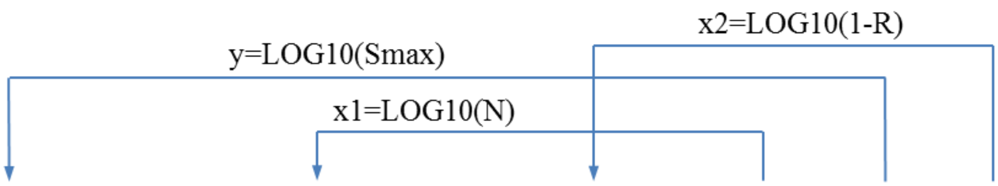
Where:

$y = \log N_f$ $\quad x_1 = \log S_{\max}$ $\quad x_2 = \log(1-R)$

$m_1 = \frac{1}{B}$ $\quad m_2 = \frac{\gamma}{B}$ $\quad c = -\frac{1}{B}\log A$

y is the dependent variable that is a function of the slope values, independent variables (***x***) and the intercept
m values are slopes for each value of ***x***
x values are the independent variables
c is the intercept
Basically, the regression analysis is fitting the points into the function of a plane in space. The coefficients used in the regression analysis are calculated from the original data as illustrated in the spreadsheet tables below:

(NOTE: LOG10 is the MS Excel command for a base 10 logarithm)



Smax (MPa)	Smean (MPa)	N (Cycles)	Smin (MPa)	Stress Ratio (R)
241	0	3500	-241	-1.00
207	0	6500	-207	-1.00
172	0	17400	-172	-1.00
138	0	70000	-138	-1.00
103	0	754000	-103	-1.00
103	0	210000	-103	-1.00
303	69	3000	-165	-0.54
276	69	6500	-138	-0.50
241	69	14900	-103	-0.43
207	69	35000	-69	-0.33
207	69	43400	-69	-0.33
172	69	124200	-34	-0.20
152	69	168700	-14	-0.09
145	69	507400	-7	-0.05
362	138	3100	-86	-0.24
338	138	9300	-62	-0.18
338	138	6000	-62	-0.18
310	138	21800	-34	-0.11
276	138	48300	0	0.00
241	138	82200	35	0.15
214	138	128500	62	0.29
214	138	218700	62	0.29
414	207	4500	0	0.00
372	207	9600	42	0.11
345	207	25700	69	0.20
310	207	63500	104	0.34
293	207	152900	121	0.41
276	207	315500	138	0.50

Original Fatigue Data

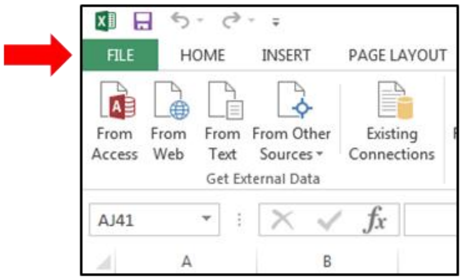
y	x1	x2
3.5440680	2.3820170	0.3010300
3.8129134	2.3159703	0.3010300
4.2405492	2.2355284	0.3010300
4.8450980	2.1398791	0.3010300
5.8773713	2.0128372	0.3010300
5.3222193	2.0128372	0.3010300
3.4771213	2.4814426	0.1888032
3.8129134	2.4409091	0.1760913
4.1731863	2.3820170	0.1545414
4.5440680	2.3159703	0.1249387
4.6374897	2.3159703	0.1249387
5.0941216	2.2355284	0.0783388
5.2271151	2.1818436	0.0382645
5.7053505	2.1613680	0.0204756
3.4913617	2.5587086	0.0925694
3.9684829	2.5289167	0.0731433
3.7781513	2.5289167	0.0731433
4.3384565	2.4913617	0.0451967
4.6839471	2.4409091	0.0000000
4.9148718	2.3820170	-0.0681498
5.1089031	2.3304138	-0.1485702
5.3398488	2.3304138	-0.1485702
3.6532125	2.6170003	0.0000000
3.9822712	2.5705429	-0.0520290
4.4099331	2.5378191	-0.0969100
4.8027737	2.4913617	-0.1774945
5.1844075	2.4668676	-0.2313392
5.4989994	2.4409091	-0.3010300

Coefficients

TABLE 4 – Regression Coefficient Table

Prior to performing the regression analysis, the appropriate analysis tools may need to be added to the MS Excel ribbon. The "Analysis ToolPak" will need to be activated to access the required functionality.

The following steps will illustrate this process:



1) Select "File" from the top menu bar.

FIGURE 11 – Top Menu Bar "File" Command

2) Select "Options" from the File menu.

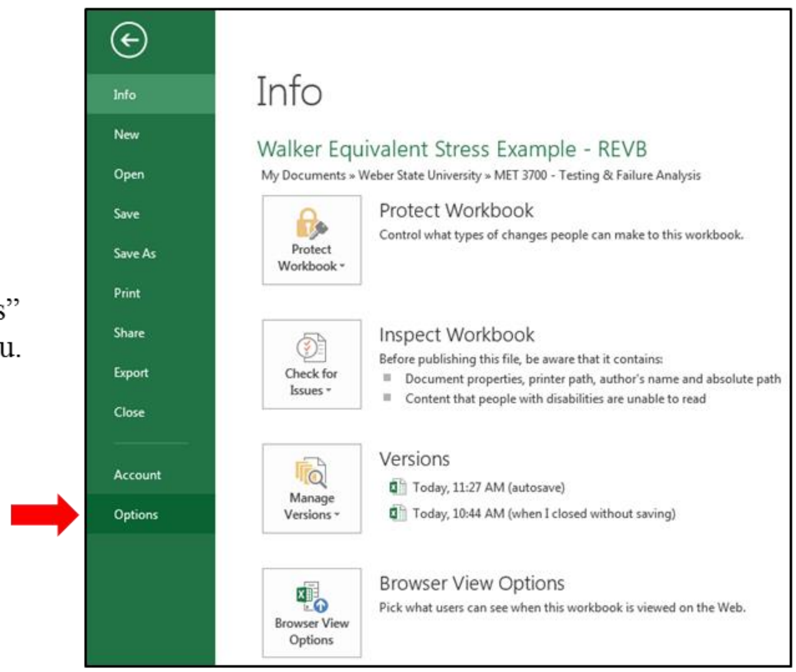


FIGURE 12 – "Options" in File Menu

3) Select "Add-Ins" from the Excel Options menu.

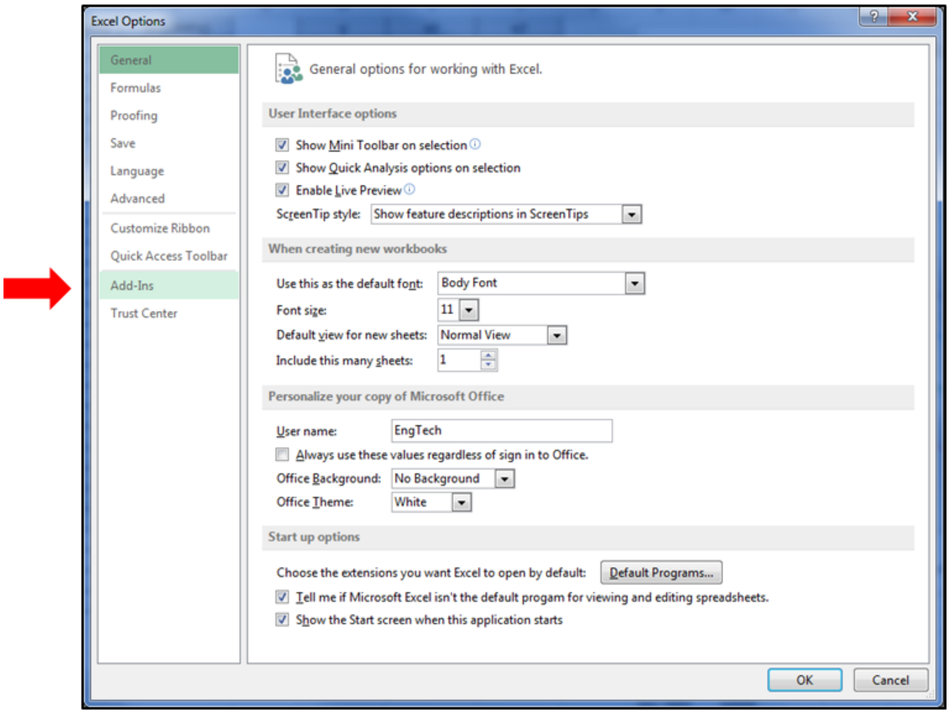


FIGURE 13 – "Add-Ins" in Options Menu

4) Highlight "Analysis ToolPak" and then select "Go".

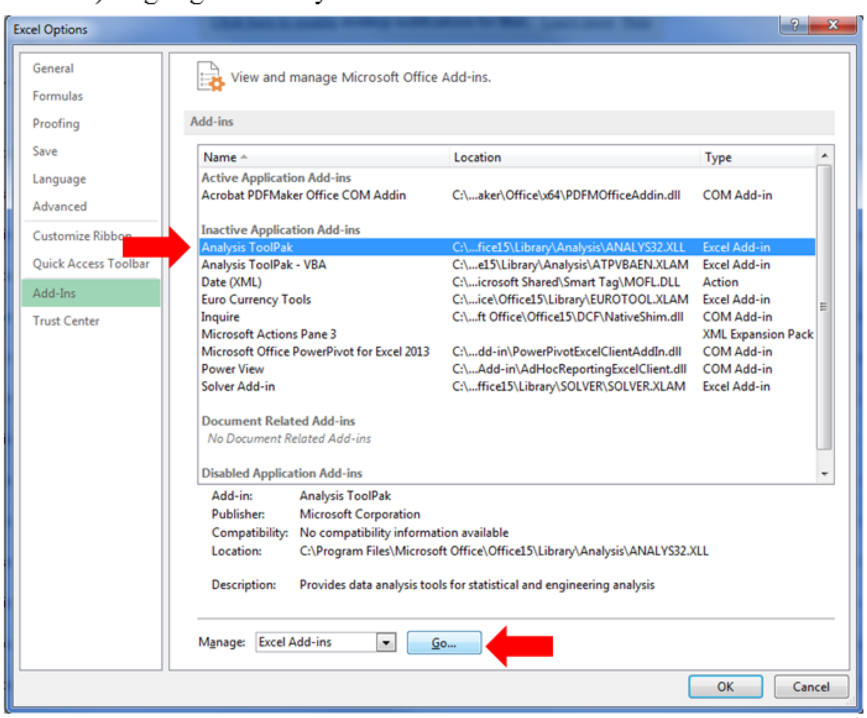
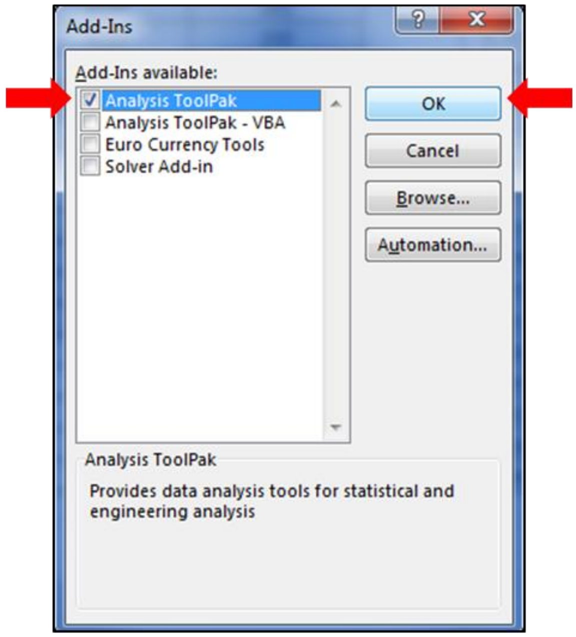


FIGURE 14 – "Analysis ToolPak" in Add-Ins



5) Check the "Analysis ToolPak" option in the Add-Ins dialog box. Then select "Ok".

FIGURE 15 – "Analysis ToolPak" Check-Box

FIGURE 16 – Ribbon Bar Showing Data Analysis Tools Active

6) Verify that under the "Data" tab on the top menu ribbon that the "Data Analysis" function is now present and ready for use.

If the “Data Analysis” functionality is activated, the following steps will perform the regression analysis:

1) Under the “Data” tab on the top ribbon menu select “Data Analysis”.

FIGURE 17 – Ribbon Bar Showing Data Analysis Tools Active

2) In the “Data Analysis” dialog box select “Regression” and then select “Ok”.

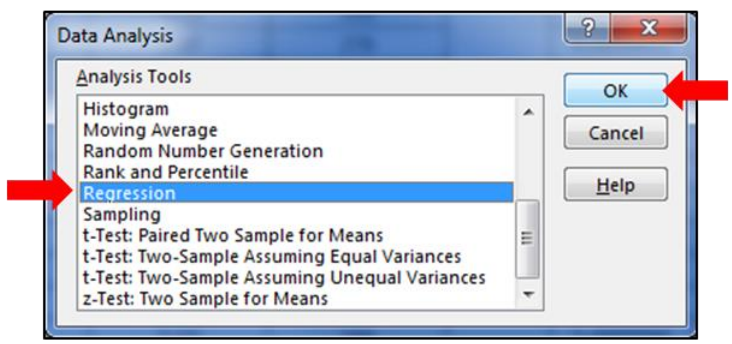


FIGURE 18 – Regression Analysis Option in Data Analysis

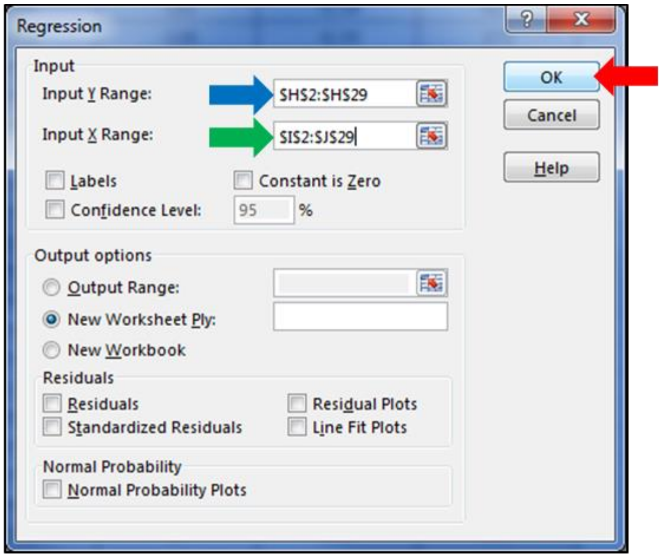


FIGURE 19 – Regression Dialog Box

H	I	J
y	x1	x2
3.5440680	2.3820170	0.3010300
3.8129134	2.3159703	0.3010300
4.2405492	2.2355284	0.3010300
4.8450980	2.1398791	0.3010300
5.8773713	2.0128372	0.3010300
5.3222193	2.0128372	0.3010300
3.4771213	2.4814426	0.1888032
3.8129134	2.4409091	0.1760913
4.1731863	2.3820170	0.1545414
4.5440680	2.3159703	0.1249387
4.6374897	2.3159703	0.1249387
5.0941216	2.2355284	0.0783388
5.2271151	2.1818436	0.0382645
5.7053505	2.1613680	0.0204756
3.4913617	2.5587086	0.0925694
3.9684829	2.5289167	0.0731433
3.7781513	2.5289167	0.0731433
4.3384565	2.4913617	0.0451967
4.6839471	2.4409091	0.0000000
4.9148718	2.3820170	-0.0681498
5.1089031	2.3304138	-0.1485702
5.3398488	2.3304138	-0.1485702
3.6532125	2.6170003	0.0000000
3.9822712	2.5705429	-0.0520290
4.4099331	2.5378191	-0.0969100
4.8027737	2.4913617	-0.1774945
5.1844075	2.4668676	-0.2313392
5.4989994	2.4409091	-0.3010300

TABLE 5 – Data Selection Fields

3) In the "Regression" dialog box, select the "y" data points from the spreadsheet into the "Input Y Range" field.

4) After the "y" data is selected, Select the "x1" & "x2" data points from the spreadsheet into the "Input X Range" field.

5) Select "Ok".

After the regression analysis is completed, the following report will appear in a separate sheet in the workbook:

	A	B	C	D	E	F	G	H	I
1	SUMMARY OUTPUT								
2									
3	*Regression Statistics*								
4	Multiple R	0.972438307							
5	R Square	0.945636261							
6	Adjusted R Square	0.941287161							
7	Standard Error	0.172786444							
8	Observations	28							
9									
10	ANOVA								
11		*df*	*SS*	*MS*	*F*	*Significance F*			
12	Regression	2	12.98297249	6.491486	217.4326745	1.5537E-16			
13	Residual	25	0.74637888	0.029855					
14	Total	27	13.72935137						
15									
16		*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
17	Intercept	15.65838593	0.559821907	27.9703	2.19284E-20	14.50541113	16.81136073	14.50541113	16.81136073
18	X Variable 1	-4.598122018	0.233043128	-19.7308	9.30857E-17	-5.078083324	-4.118160712	-5.078083324	-4.118160712
19	X Variable 2	-3.368566987	0.218082403	-15.4463	2.69942E-14	-3.817716104	-2.919417871	-3.817716104	-2.919417871
20									
21									

TABLE 6 – Regression Analysis Output

The calculated coefficients are the in the lower left hand corner are the data needed to complete the analytical model.

Variable used in regression analysis:

$$m_1 = \frac{1}{B} \qquad m_2 = \frac{\gamma}{B} \qquad c = -\frac{1}{B}\log A$$

	Coefficients	
Intercept	15.65838593	← **c**
X Variable 1	-4.598122018	← $\mathbf{m_1}$
X Variable 2	-3.368566987	← $\mathbf{m_2}$

TABLE 7 – Regression Coefficients

Solving for ***A***, ***B***, and γ:

$$B = \frac{1}{m_1} = \frac{1}{-4.5981} = -0.217$$

$$\gamma = m_2 B = \frac{m_2}{m_1} = \frac{-3.3686}{-4.5981} = 0.733$$ ← **NOTE: This is the Walker Exponent**

$$A = 10^{-cB} = 10^{-15.65838(-0.21748)} = 2540$$

The equivalent stress was calculated for each data point using the equation:

$$S_{eq} = S_{\max}(1-R)^{\gamma}$$

<u>NOTE</u>: Using multiple linear regression, the Walker Exponent (γ) was determined to be 0.733 in this example.

A column can then be added to the original fatigue data calculating the Walker Equivalent Stress per the equation above.

Smax (MPa)	Smean (MPa)	N (Cycles)	Smin (MPa)	Stress Ratio (R)	Seq (MPa)
241	0	3500	-241	-1.00	401
207	0	6500	-207	-1.00	344
172	0	17400	-172	-1.00	286
138	0	70000	-138	-1.00	229
103	0	754000	-103	-1.00	171
103	0	210000	-103	-1.00	171
303	69	3000	-165	-0.54	417
276	69	6500	-138	-0.50	372
241	69	14900	-103	-0.43	313
207	69	35000	-69	-0.33	256
207	69	43400	-69	-0.33	256
172	69	124200	-34	-0.20	196
152	69	168700	-14	-0.09	162
145	69	507400	-7	-0.05	150
362	138	3100	-86	-0.24	423
338	138	9300	-62	-0.18	382
338	138	6000	-62	-0.18	382
310	138	21800	-34	-0.11	335
276	138	48300	0	0.00	276
241	138	82200	35	0.15	215
214	138	128500	62	0.29	167
214	138	218700	62	0.29	167
414	207	4500	0	0.00	414
372	207	9600	42	0.11	341
345	207	25700	69	0.20	293
310	207	63500	104	0.34	230
293	207	152900	121	0.41	198
276	207	315500	138	0.50	166

TABLE 8 – Fatigue Data w/ Walker Equivalent Stress Added

The Walker Equivalent Stress can now be plotted using a single curve (See Below). Note in the second plot that the equation for the trend line interpolated in MS Excel reflects the coefficients as determined by the Multiple Linear Regression.

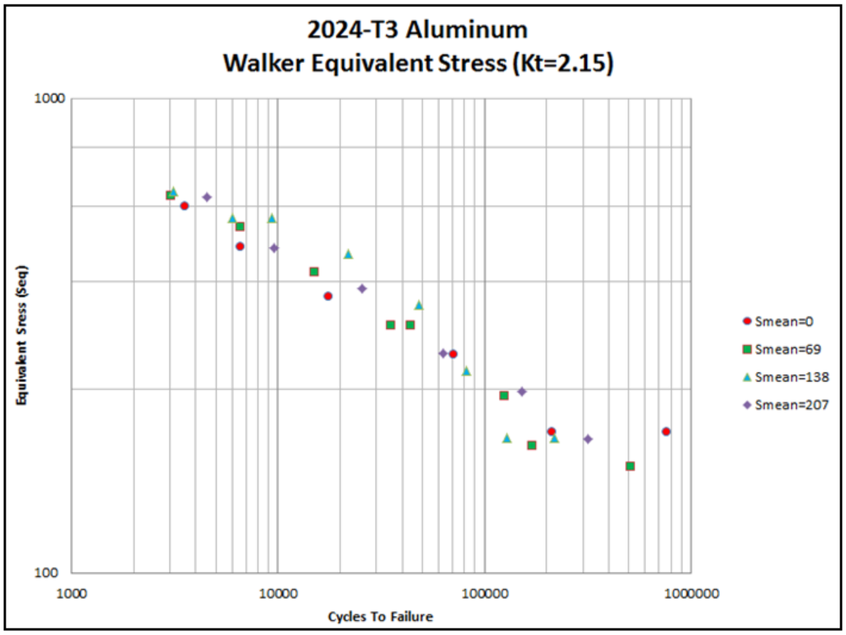


FIGURE 20 – Walker Equivalent Stress Scatter Plot

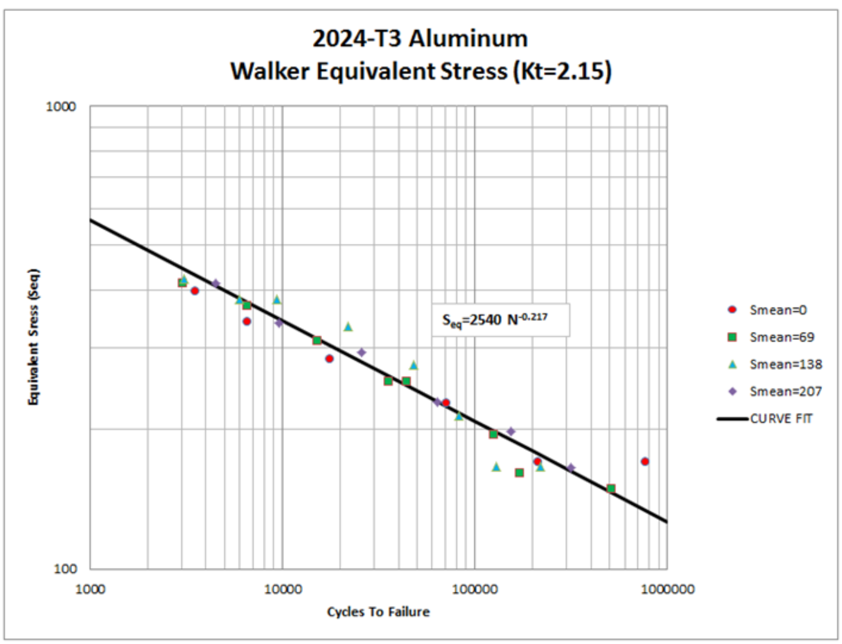


FIGURE 21 – Walker Equivalent Stress Trendline

Bibliography:

[1] Microsoft Website, http://news.microsoft.com/bythenumbers/index.html, Referenced January 17, 2015

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[3] Mott, Robert, *Machine Elements in Mechanical Design*, 5th ed., Pearson, 2014, pp. 496-497

[4] Cook, Young, *Advanced Mechanics of Materials*, 1st ed. Prentice-Hall, 1985, pp. 92-96

[5] Hibbeler, R.C., *Engineering Mechanics: Dynamics*, 12th ed. Prentice-Hall, 2010, pp. 5-40

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