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Integrating Spreadsheet Templates and Data Analysis into Fluid Power Instruction

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Introduction

Fluid Power in one manner, shape, or form is found in most Industrial Technology curriculum. It may be taught under other names such as Industrial Hydraulics, Hydraulics and Pneumatics, or Industrial Hydraulics and Pneumatics. Regardless of its name, the main intent of this course is to provide students with a fundamental understanding of fluid power concepts with an emphasis on the physical properties of fluids, component design and operation, and circuit design and analysis.

In fluid power instruction various techniques and training aids are used to promote understanding and learning. Many of the techniques and aids used and the rationale for their incorporation include: (a) manual or computer-based calculations to promote an understanding of the principles of system and component operation; (b) visual and schematic displays to promote an understanding of component design and construction; and (c) hydraulic and pneumatic trainers to promote hands-on experiences with working systems.

Since the development of an understanding of system principles and design involves mathematical calculations, a spreadsheet program can be used to show time savings capabilities of custom-designed templates. Consequently, it is the intent of this paper to demonstrate various ways in which

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spreadsheet templates and spreadsheet-based data analysis can be incorporated into fluid power instruction. It should be noted that no attempt will be made at this time to compare and contrast instructional approaches or software packages both generic as spreadsheets or hydraulic-specific as Automation Studio and HydraCalc; each approach and software has its own merits and advantages provided the emphasis is effective and meaningful integration.

Spreadsheet Program Selection and Integration

Although there are a multitude of spreadsheets programs available today, only two would probably be considered for fluid power integration, Microsoft Excel or Lotus. Experience has shown that Excel should be given integration consideration for three reasons: (a) it is an inherent part of the Microsoft Office suite to which many universities, departments, and students hold license to; (b) its extensive charting and graphing capabilities; and (c) its data analysis capability. If students are familiar with spreadsheet basics, only a review of the following would normally be needed to get them up and running with fluid power-based templates.

- entering formulas and text;
- using and integrating functions;
- creating tables, graphs, and charts.

Designing hydraulic and pneumatic systems requires many simple calculations. Spreadsheet templates, once constructed, are a very appropriate tool for performing these calculations. With respect to entering formulas, students should be reminded that the “=” sign must be entered prior to formula entry; without it, all formulas will be treated as text and will not be able to perform their intended purpose. Functions, on the

other hand, are special purpose, formula-based expressions. Microsoft Excel User’s Guide (1994) indicated that there are over 300 functions that are divided into 12 categories for ease of selection. The function selection dialog box is accessible by selecting functions under the *Insert* menu. A useful aid incorporated with the function selection dialog box is a sample expression of the way in which the function must be entered and a short description of its intended use.

Middleton (1997) indicated that the visual display of data in charts and graphs is an important aspect of any analysis. Chart and graph creation using table information is relatively easy in Excel through the use of the chart wizard. Various procedures for generating effective charts and graphs that incorporate a pleasing appearance and integration with established tables include (a) using the “on this sheet” option instead of the “on new sheet” option when creating new charts and graphs; (b) including column and row labels in charting cell range for automatic axis labeling; (c) selecting the appropriate chart type (line, XY scatter, etc.) for a given table data; (d) resizing of charts or graphs for effective integration with existing tables; and (e) determining internal chart formatting, items such as legend information inclusion or exclusion, number formatting, label orientation and sizing, and axis scaling.

Fluid Power Problem-Solving Using Spreadsheet Templates

One of the most powerful facets of a spreadsheet program is its “what if” analysis capability. Academic business departments have known of and utilized this capability for many years. If a spreadsheet template is designed with the intent of conducting “what if”

analyses and incorporates proper cell referencing and input data structuring, the usefulness of the template can be significantly increased. One of the principal advantages of the “what if” analysis structure is the overall time savings it provides; tedious and repetitive manual calculations are not required. Most templates that are designed and constructed for integration in fluid power instruction will automatically possess this capability to varying degrees and can be modified to further enhance this capability.

Two examples that demonstrate the use and application of spreadsheet templates in fluid power instruction can be seen in Problem-Solving Templates 1 and 2. Although both of these templates have given values in their problem statements and questions, the structure of the templates permit the entry of any value into the “givens” cells as well as the automatic recalculation of new solution values using new “given,” provided cell formulas and references are entered correctly. Another aspect of these templates that should be noted is their step-by-step solution approach (single formula calculations). This approach was used solely for instructional purposes. In reality, most experienced template designers would combine multiple solution steps into a single-step formula expression.

Regression Analysis of Fluid Power Data

Simple and multiple regression (macro-based) is an important aspect of analysis and is available in Excel through the *Data Analysis* option under the *Tools* menu or through the *Add-ins* option under the *Tools* menu, if *Data Analysis* is not listed as a *Tools* option. Simple regression analysis is also available using the *Trendline* option in Excel. This option, sometimes referred to as trend forecasting, is a graphics-based approach for conducting simple regression analyses. The usefulness of the trendline analysis lies in the ability of users to know when and how to incorporate and utilize the different regression analyses. Figures 1 and 2 indicate, respectively, the trendline

Problem-Solving Template 1: Solving for Flow Variables

A fluid is traveling through a 4 inch diameter pipe (D_1) at a velocity of 5 ft/sec. At some point in the pipe run (figure below) the pipe diameter (D_2) narrows to 2 inches.

- What is the flow rate in the pipe in ft^3/sec ?
- What is the flow rate in gallons per minute (gpm)?
- What is the velocity of the fluid in the 2 inch diameter [D_2] section of pipe?

Givens:	Ref:	Calculations:
<input type="text" value="4.0"/> [D_1] Pipe diameter (in.)	a)	<input type="text"/> Area of [D_1] pipe (ft^2)
<input type="text" value="5.0"/> [V_1] Fluid velocity (ft/sec)	a)	<input type="text"/> [Q] Flow rate in pipe (ft^3/sec)
<input type="text" value="2.0"/> [D_2] Pipe diameter (in.)	b)	<input type="text"/> [Q] Flow rate in pipe (gpm)
	c)	<input type="text"/> Area of [D_2] pipe (ft^2)
	c)	<input type="text"/> [V_2] Fluid velocity (ft/sec)

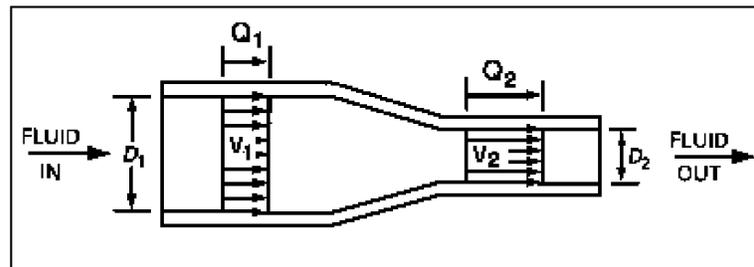
Formula Basis:

$$Q_1 = A_1 * V_1 = A_2 * V_2 = Q_2 \quad \text{where } Q = \text{flow rate (ft}^3/\text{sec)}$$

$$A = \text{Area (ft}^2)$$

$$V = \text{Velocity (ft/sec)}$$

Adapted from Esposito (1998)



types and display options available within Excel.

As mentioned previously, it is important for users to develop an understanding of the ways in which each of the trendline types can be used. For example, a comparison of R-squared values of four trendline types (linear, power, logarithmic, and exponential) can be performed to determine the regression method that yields the maximum accountability of variability (the greater the accountabil-

ity, the greater the validity of the regression equation). To begin the trendline analysis process, an XY scatterplot of the data is needed. The scatterplot is not only a necessary first step in the trendline analysis process but it can also be used to determine if a regression analysis data is actually warranted. An added advantage of the trendline analysis is that the regression equation and R-squared value can be incorporated on the chart of the plotted

data and will automatically update if there is a change in the data set. An example that demonstrates the effectiveness of the trendline analysis and R-squared comparison technique can be seen in an attempt to simplify the relationship between pressure, force, and area (PFA). As indicated in published textbooks, Industrial Hydraulics Manual (1992) and Esposito (1998), the PFA relationship is characterized through the following equation: Pressure (P) = Force (F) / Area (A). This formula is used extensively to determine system pressure requirements given a particular cylinder/piston diameter and output force requirement; variations of the formula are also used to conduct reverse order calculations. Regardless of the formula variation used, one aspect of all PFA calculations is the need to convert cylinder/piston diameter to an area. Since this conversion aspect adds an additional calculation to the entire process [Area (A) = $0.7854 * \text{Diameter}^2$], a simplified, single-step formula expression would be desirable. To determine the feasibility of establishing a simplified, single-step expression incorporating pressure, force, and diameter (PFD) variables, the following four-step analysis was conducted.

Step 1A: Establishing Primary Variables and Data. To begin the analysis process, four columns of data were generated. Diameter data was selected in increments of 0.25 inches starting with one inch and ending at six inches. Area data was calculated from the diameter data and used, along with the test force value of 500 lbs, to calculate theoretical pressure values. Diameter and Theoretical Pressure data were labeled as X and Y variables, respectively, for use in the Step 1B regression analysis.

Step 1B: Conducting Regression Analysis of Diameter (X) and Pressure (Y) @ Force = 500 lbs. The basis for this analysis was to determine the extent of the relationship between the identified X and Y variables as well as a valid regression approach and equation. It should be noted that any

Problem-Solving Template 2: Solving for Output Horsepower

An operator is using a hand-operated floor jack to raise a car. The pump piston has a diameter of 1.25 inches and the lift piston has a diameter of 6.25 inches. The rated lift capacity (force output) of the hydraulic floor jack is 3,000 lbs.

- a) What is the average input force (lbs) that must be applied by the operator?
- b) How many inches will the load move given 30 power strokes and a pump piston stroke of 5.4 inches?
- c) How many input strokes would be needed to raise the load 3.5 feet?
- d) What is the output horsepower (OHP) assuming a 83% efficiency and a pump operational time duration of 25 seconds?

Given:	Ref:	Calculations:
<input type="text" value="1.25"/> Pump piston diameter (in.)	a)	<input type="text"/> Area of pump piston (in ²)
<input type="text" value="6.25"/> Lift piston diameter (in.)	a)	<input type="text"/> Area of lift piston (in ²)
<input type="text" value="3,000"/> Maximum lift capacity (lbs)	a)	<input type="text"/> System pressure (psi)
<input type="text" value="5.4"/> Pump piston stroke (in.)	a)	<input type="text"/> Average input force (lbs)
<input type="text" value="30"/> Number of input strokes	b)	<input type="text"/> Fluid displacement per stroke (in ³)
<input type="text" value="42"/> Lift cylinder travel (in.)	b)	<input type="text"/> Fluid displacement for given strokes (in ³)
<input type="text" value="25"/> Pump time duration (sec)	b)	<input type="text"/> Lift distance for given input strokes (in)
<input type="text" value="83%"/> Output Efficiency (%)	c)	<input type="text"/> Strokes required for lift travel
	d)	<input type="text"/> Flow rate (gpm)
	d)	<input type="text"/> Hydraulic Horsepower (HHP)
	d)	<input type="text"/> Output Horsepower (OHP) @ given % efficiency

regression equation derived from this data set would only be valid with a force of 500 lbs. The results of this analysis, Figures 3A to 3D, indicated that the Power regression yielded the maximum accountability of variability (R-squared = 1.0) and thus, the most valid regression equation. This equation, Equation (1), was: $y_1 = 636.62 x_1^{-2}$, where y_1 = pressure (psi) and x_1 = diameter (in).

Step 2A: Establishing Secondary Variables and Data. It was noted that

the slope coefficient in the Power regression equation changed whenever the Test Force was varied. Consequently, it was deemed that an equation could be developed to replace the Equation (1) slope coefficient (636.62) to overcome the force limiting factor of the equation. Using the “what if” capability of Excel, the following table of Test Force (X) and Slope Coefficient (Y) data was generated by varying the Test Force in the Data Table of Primary Variables and recording the slope

coefficient change in the associated Power regression equation (Figure 3B):

Step 2B: Conducting Regression Analysis of Test Force (X) and Slope Coefficient (Y). The basis for this analysis was to determine the extent of the relationship between the X and Y variables in Table 2 as well as a valid regression approach and equation. The results of this analysis indicated that three regression analyses, linear, power, and polynomial, yielded R-squared values of 1.0 and any one of these three could be used. The Power regression equation detailed in Figure 4, was selected due to its simplicity. This equation, $y_2 = 1.273 x_2$ where $y_2 =$ forced-based coefficient and $x_2 =$ force (lbs), was labeled Equation (2). The regression equations of the linear and polynomial regression analyses that were not selected for use were, respectively, $y_2 = 1.273x - 0.0004$ and $y_2 = -9.0E-10x^2 + 1.273x - 0.0006$.

Step 3: Pressure, Force, Diameter (PFD) Equation Development.

As mentioned previously, the development of Equation (2) permitted the replacement of the slope coefficient in Equation (1) and enabled the determination of pressure at any applied force and diameter. Algebraically, the conversion was as follows:

Equation (1) $y_1 = 636.62 x_1^{-2}$
 where, $y_1 =$ Pressure (psi)
 $x_1 =$ Diameter (in)

Equation (2) $y_2 = 1.273 x_2$
 where, $y_2 =$ Forced-Based Coefficient
 $x_2 =$ Force (lbs.)

Equation (3A) $y_1 = y_2 * x_1^{-2}$
 where, Equation (1) coefficient (636.62) replaced with y_2 equation

Equation (3B) $y_1 = (1.273 x_2) * x_1^{-2}$

Equation (3C-1) Pressure = 1.273 * Force * Diameter⁻²

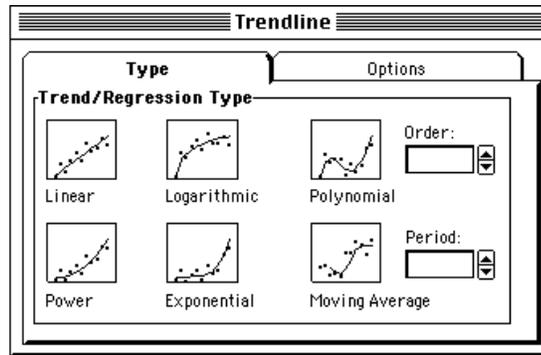


Figure 1. Trendline Type. To access the trendline type dialog box, create an XY scatter chart, double click the chart to enter the edit mode, single click on a plotted point, and select Trendline under the Insert pulldown. Adapted from Microsoft Excel.

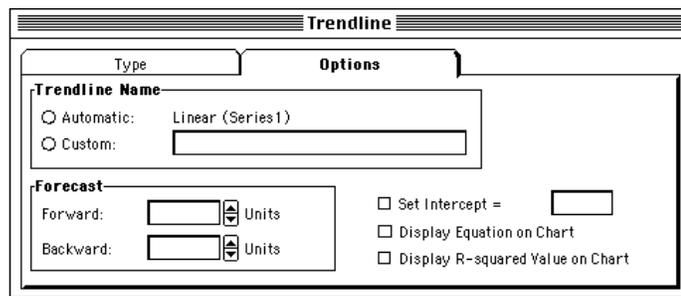


Figure 2. Trendline Options. The trendline options dialog box is accessible by selecting the Options tab whenever the trendline dialog box is displayed. If the trendline has already been created but needs to be edited, double click the chart to enter edit mode and double click the regression line. Adapted from Microsoft Excel.

Piston Diameter (in)	Piston Area (in ²)	Test Force (lbs)	Theoretical Pressure (psi)
D	A	F	P
X			Y
1.00	0.79	500	637
1.25	1.23	500	407
1.50	1.77	500	283
1.75	2.41	500	208
2.00	3.14	500	159
2.25	3.98	500	126
2.50	4.91	500	102
2.75	5.94	500	84
3.00	7.07	500	71
3.25	8.30	500	60
3.50	9.62	500	52
3.75	11.04	500	45
4.00	12.57	500	40
4.25	14.19	500	35
4.50	15.90	500	31
4.75	17.72	500	28
5.00	19.64	500	25
5.25	21.65	500	23
5.50	23.76	500	21
5.75	25.97	500	19
6.00	28.27	500	18

Table 1. Data Table of Primary Variables

Equation (3C-2) Force = Pressure / (1.273 * Diameter⁻²)

Equation (3C-3) Diameter = [Pressure / (1.273 * Force)]^{-0.5}

Step 4: Pressure, Force, Diameter (PFD) Equation Validation. Equation validation is an important aspect, especially one that incorporates two regression equations. To validate the PFD equation, the traditional, two-step PFA equation was used to calculate the theoretical pressure that would be required to lift a force of 500 lbs using a cylinder with a 2.5 inch diameter piston. The results of this calculation were as follows:

Traditional PAF Equation:

$$\begin{aligned} \text{Pressure} &= \text{Force} / \text{Area} \\ &= 500 \text{ lbs} / 4.91 \text{ in}^2 \\ &= 101.83 \text{ psi} \end{aligned}$$

$$\begin{aligned} \text{Area} &= 0.7854 * (\text{Diameter})^2 \\ &= 0.7854 * (2.5 \text{ in})^2 \\ &= 4.91 \text{ in}^2 \end{aligned}$$

The tradition approach indicated that a system pressure of approximately 102 psi would be required. Using the single-step Equation (3C-1), the theoretical pressure was calculated using the same force and diameter values, 500 lbs and 2.5 inch, respectively. The results of this calculation were as follows:

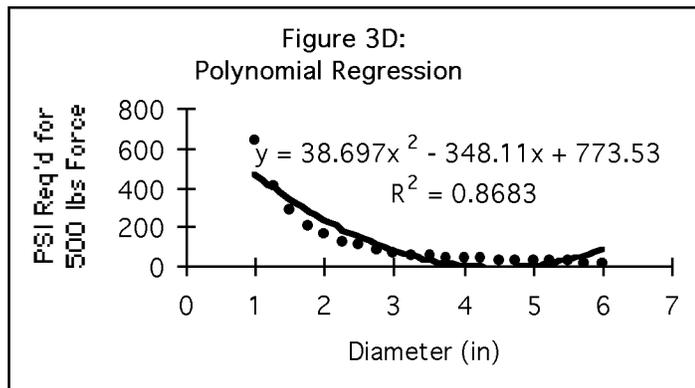
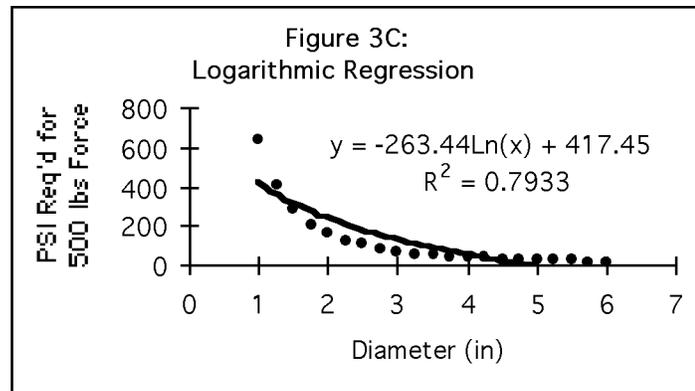
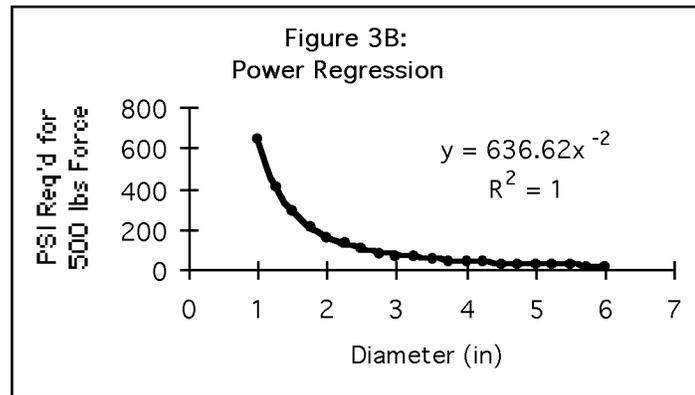
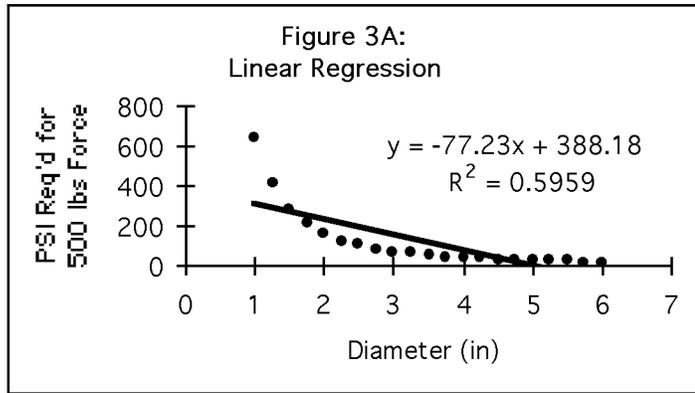
PFD Equation (3C-1):

$$\begin{aligned} \text{Pressure} &= 1.273 * \text{Force} * \text{Diameter}^{-2} \\ &= 1.273 * 500 \text{ lbs} * (2.5 \text{ in})^{-2} \\ &= 636.5 * 0.16 \\ &= 101.84 \text{ psi} \end{aligned}$$

The PFD equation indicated that a theoretical system pressure of approximately 102 psi would also be required to lift a force of 500 lbs using a cylinder with a 2.5 inch diameter piston; formula validation was successful and can be used in fluid power calculations.

Summary

This paper is intended to aid professionals in the field into the ways



and means upon which a spreadsheet templates can be integrated into a Fluid Power instruction. The inherent flexibility and adaptability of spreadsheet templates in data and formula-driven classes make it a useful instructional tool. If spreadsheet integration is successful, student learning of Fluid Power concepts can be enhanced; thereby, strengthening students' problem solving skills, facilitating better and faster decision-making, and increasing their marketability as Industrial Technologist. It should also be noted that the experiences provided through spreadsheet-based instruction can provide students with valuable insight for the utilization of this software in other classes or on-the-job before and after graduation.

References

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 Vickers Incorporated (1992). Industrial hydraulics manual. Rochester Hills, Michigan: Vickers Incorporated Training Center.

Test Force (lbs)	Slope Coefficient
X	Y
100	127.32
125	159.15
150	190.99
175	222.82
200	254.65
225	286.48
250	318.31
275	350.14
300	381.97
325	413.80
350	445.63
375	477.46
400	509.29
425	541.13
450	572.96
475	604.79
500	636.62
600	763.94
700	891.27
800	1018.59
900	1145.91
1000	1273.24

Table 2. Data Table of Secondary Variables

