To: I. M. A. Engineer

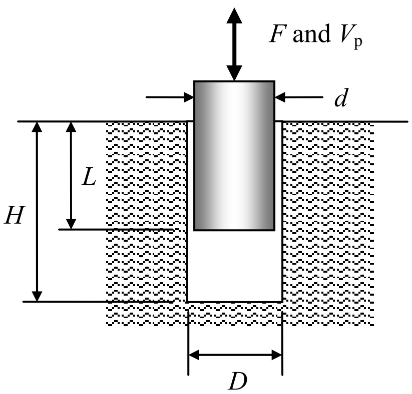
From: U. R. Boss, Project Manager, Stop-the-shakin', Inc. *URB*

Date: 3 December 2007

Subject: New viscous damper concept.

Stop-the-shakin', Inc. has acquired the patent rights for a viscous damper that provides a damping force that is proportional to velocity.

The damper consists of a cylindrical plunger of diameter d that moves vertically in a flooded cavity of diameter D. The cavity is of depth H, and the lower end of the plunger is positioned a distance L below the top of the cavity. The cavity is flooded with a liquid of viscosity μ and density ρ. When a force F is applied to the plunger, the plunger moves with a speed V_p forcing liquid out of (or into) the cavity. (Unless the weight of the plunger is supported in a null position, the plunger would slowly sink to the bottom of the cavity under its own weight.)



Viscous Damper Schematic

We have been asked to determine how the piston force F is related to piston speed and other parameters. The goal of this study is to be able to predict the force F as a function of piston speed V_p for specified operating conditions. Our senior staff believe the best way to study this problem is using experiments in combination with dimensional analysis and parameter variation to identify the important variables and the functional relationship, if any, between the variables.

As a first step, we have completed a series of experiments using two different size apparatus and three different fluids. We have a total of 21 data points using three different fluids. The raw data is attached to this memo. (A spreadsheet with the raw data can be found at www.rose-hulman.edu/ES202.)

Unfortunately, we have misplaced the original dimensional analysis calculations and you will have to repeat this work. The dependent variable in our study is the force F. The independent variables are D, d, L, ρ, μ and V_p. (Early experiments showed that H, the depth of the cavity, is unimportant as long as it was greater than L.) Thus, our problem is to determine the relationship:

$$F = f(D, d, L, \rho, \mu \text{ and } V_p)$$

If successful, our work will allow us to specify the six independent variables and uniquely determine the value of the force F.

Here is the plan we would like you and your partner to execute:

- Perform a dimensional analysis for the dependent variable in terms of the corresponding independent variables. (If you need a length variable or variables as repeating variables, use D first, followed by d and then L if more are required.) This process should give you a set of dimensionless groupings of variables—the π-terms. Clearly identify the independent and the dependent π-terms. Carefully document your analysis showing all steps. (Provide this analysis and documentation as Attachment 1 of your final report memo.)

- Examine the available experimental data. Plot F versus V_p for each fluid. Place the data for all three fluids on one graph using a different symbol for each fluid. Can you see any useful predictive relationship? Discuss what you can deduce from this plot. (Attach this graph as Attachment 2 of your final report memo.)
- Transforming the data from a *dimensional* form to a *non-dimensional* form. Calculate numerical values for the independent and dependent π-terms associated with each experimental data point. (Provide a table of raw data and π-term values as Attachment 3 of your final report memo.)
- Examine the dimensionless data to see if there is a predictive correlation between the dependent and independent π-terms. As a minimum, prepare a graph showing the dependent π-term (the one with the dependent variable) on the ordinate plotted against *an* independent π-term on the abscissa. If there is more than one independent π-term, you may be able to find data points where the additional π-term(s) has a constant value. (If variation of parameters is successful, the π-term plots, which are dimensionless, should collapse the data down onto a single curve or set of curves!) Consider using a log-log or semi-log plot if the numerical range of the data is large. (Attach the graph(s) as Attachment 4 of your final report memo.)
- Study the graph(s). If a curve fit looks reasonable, try one; however, the client said a useable graphical solution would be acceptable. Could you use these graphs to predict the behavior of a larger (or smaller) viscous damper? What, if any, are the limitations of the available dimensionless data in predicting damper performance?

    In addition to our correlations, we have been asked to predict the F vs. V_p for a new damper that will be used to stabilize a small electronics component mounted on an off-road truck. The new damper has a cavity diameter $D = 0.01$ m and uses SAE 50W motor oil as the liquid. (For SAE 50W motor oil: $\mu = 0.86$ kg/(m-s) and $\rho = 902$ kg/m^3.) Using the available experimental data, estimate the F-V_P relationship this new damper. Prepare a table showing the minimum and maximum values and at least three intermediate points. You must be careful to only interpolate behavior from the available data. Do not extrapolate outside the range of the available data. Supporting calculations and the results should be supplied in Attachment 5 of the final report memo.

Summarize your results in a *one-page* final report memo with the appropriate attachments. Please use a standard memo format and be sure that all authors initial the memo to indicate there agreement with the results and their participation in the analysis. Talk to your supervisor about when this memo is due.

ATTACHMENT

Viscous Damper Test Data

Run	Liquid	m	m	m	m	kg/m^3	N-s/m^2	m/s	N
		D	H	d	L	rho	mu	Vp	F
1	Water	0.1	0.1	0.095	0.05	998	0.001002	0.001	1.68E-02
2	Water	0.1	0.1	0.095	0.05	998	0.001002	0.002	3.37E-02
3	Water	0.1	0.1	0.095	0.05	998	0.001002	0.005	8.42E-02
4	Water	0.1	0.1	0.095	0.05	998	0.001002	0.01	1.68E-01
5	Water	0.1	0.1	0.095	0.05	998	0.001002	0.02	3.37E-01
6	Water	0.1	0.1	0.095	0.05	998	0.001002	0.05	8.42E-01
7	Water	0.1	0.1	0.095	0.05	999	0.001002	0.1	1.68E+00
8	Glycerin	0.05	0.05	0.0475	0.025	1264	1.519	0.001	1.28E+01
9	Glycerin	0.05	0.05	0.0475	0.025	1264	1.519	0.002	2.55E+01
10	Glycerin	0.05	0.05	0.0475	0.025	1264	1.519	0.005	6.38E+01
11	Glycerin	0.05	0.05	0.0475	0.025	1264	1.519	0.01	1.28E+02
12	Glycerin	0.05	0.05	0.0475	0.025	1264	1.519	0.02	2.55E+02
13	Glycerin	0.05	0.05	0.0475	0.025	1264	1.519	0.05	6.38E+02
14	Glycerin	0.05	0.05	0.0475	0.025	1264	1.519	0.1	1.28E+03
15	50/50 Glycerin-Water	0.1	0.1	0.095	0.05	1127	0.006	0.001	1.01E-01
16	50/50 Glycerin-Water	0.1	0.1	0.095	0.05	1127	0.006	0.002	2.02E-01
17	50/50 Glycerin-Water	0.1	0.1	0.095	0.05	1127	0.006	0.005	5.04E-01
18	50/50 Glycerin-Water	0.1	0.1	0.095	0.05	1127	0.006	0.01	1.01E+00
19	50/50 Glycerin-Water	0.1	0.1	0.095	0.05	1127	0.006	0.02	2.02E+00
20	50/50 Glycerin-Water	0.1	0.1	0.095	0.05	1127	0.006	0.05	5.04E+00
21	50/50 Glycerin-Water	0.1	0.1	0.095	0.05	1127	0.006	0.1	1.01E+01