UTILIZATION OF ELECTRONIC SPREADSHEETS FOR LABORATORY DATA ANALYSIS

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ABSTRACT

The utilization of business spreadsheets for laboratory data manipulation is discussed. The spreadsheet, LOTUS 1-2-3, is presently being utilized to store and analyze data obtained from a deep cavity resonator type apparatus. Methodology for the analysis, from non dimensionalization of parameters, to relavent plotting of data pairs, is presented. All discussions are based upon current theory, and laboratory observations of flow induced resonance in deep cavities.

NOMENCLATURE

AR	Aspect ratio - L/D
C	Local sonic velocity
Cp	Pressure coefficient
d	Cavity diameter
f*	Frequency ratio
f	Frequency
L	Cavity length
M	Mach number
Prms	RMS fluctuating pressure
Ø	Momentum thickness
Ør	Momentum thickness ratio
ρ	Fluid density
Re	Reynolds Number
S	Strouhal number
μ	Viscosity
V	Main flow velocity

INTRODUCTION

Analyses of data obtained during laboratory testing can be made more efficient through the use of microcomputer based electronic spreadsheets. Depending on the method of testing, data is either obtained in quantities too large for expedient reduction by hand, or in such varied states that the required book-keeping becomes unwieldy. The utilization of a microcomputer as an aid in data analysis can reduce the time required to produce meaningful results, without requiring the operator to develop new software for each application.

Anyone who has used commercially available spreadsheets, such as LOTUS 1-2-3 is immediately made aware of their potential for fields outside of which they were designed, whether it be for simple data storage, or other more elaborate manipulations. The ease with which data can be entered and stored alone makes utilization of such software very logical in any laboratory environment. In addition, many features of the software allow the analyst to simultaneously produce labelled plots of various configurations, and depending on the software, word-processed discussions of the graphics.

This article presents a methodology currently being employed at the Worcester Polytechnic Institute Fluid Dynamics and Thermal Processes Laboratory for the analysis of data being generated from a spectrum analyzer processing acoustic signals. The acoustic signal is being obtained from the flow induced vibrations of a shear layer/side branch resonator type of apparatus. Of primary concern in the analysis are the peak resonant frequencies and the corresponding intensities, and their change with variations in fluid velocity and cavity aspect ratio. The spreadsheet analysis is being used to determine interdependence among the controllable parameters through non dimensionalization, scaling variables, and subsequent plotting of various data pairs. References for further information on cavity resonators are provided at the end of the paper.

GENERAL DESCRIPTION OF A CAVITY RESONATOR

The phenomenon of cavity resonance is apparent in many fluid dynamic systems such as bottle type Helmholtz resonators, to more complex shallow cavity resonators occuring when surface recesses are present in fluid boundary flows. The tone produced by blowing over a wine bottle is a curiosity, but the flow induced cavity resonances in aircraft equipment bays can result in high noise levels and equipment damage. In order to avoid resonance, it is desirable to be able to predict both the onset of a resonant condition and the expected intensity of the resonance.

The type of cavity resonator currently being examined is a low Mach number, pipe wall mounted side branch. The apparatus itself is unique since the mouth of the cavity intersects a curved surface, in contrast to the plane intersection previously investigated in most wind tunnel studies. Flow over the side branch is provided by a high pressure centrifugal blower, which has been modified to produce a relatively low noise spectra in the air stream. Instrumentation for the cavity includes a piezoelectric microphone mounted in an adjustable piston, which is used to vary the length of the cavity. Signals from the microphone are delivered to a signal analyzer and recorded on a graphics plotter. Computing hardware includes an IBM PC equipped with an expansion board for a total RAM size of 512K.

TESTING METHODOLOGY

In order to optimize the experimental program, it was desirable to explore non-dimensional groups of the controlled parameters and identify suitable groups from a limited data set. For the system in question, it was desired to correlate sound pressure levels with both changes in mean flow velocity, and side branch cavity depth. The geometry of the cavity interface with the main flow duct was held constant for each set of tests. The fluid used in the system was air, and flow temperatures were relatively constant in all of the tests.

Data was obtained by selecting a cavity depth, and gradually increasing or decreasing the fluid velocity over the cavity. Plots of the sound pressure frequency spectra were obtained at regular velocity and cavity length increments.

The frequency of the flow induced resonance which occurs in a wall mounted cavity can be analytically predicted by specifying the boundary conditions of the cavity. For a tube with one end open, and the other end closed, it can be shown that a pressure node will exist at the closed end, and a pressure antinode will exist at the open end. As a result, the expected resonant frequencies in such a tube are predicted by the relationship:

$$f_n = nc/(4L); \text{ where } n=1,2,3,\ldots$$

Fundamental theories are unable, presently, to predict additional characteristics of the resonance other than the expected frequency. In order to begin to characterize the phenomenon, it would be convenient to obtain plots of dimensionless groupings which demonstrate systematic functional dependence. The first step for such an analysis is to identify the system variables, and assemble them into dimensionless groupings. Expressing, for example, the root mean square pressure fluctuation as the dependent term:

$$P_{rms} = f(L,d,\emptyset,V_\infty,c,\rho,f_n,f_r,\mu)$$

Invocation of the Buckingham Pi theorem suggests that there are seven independent dimensionless parameters. By inspection, most are immediately evident as customary parameters:

$$S_\infty = fd/V_\infty \qquad \emptyset_r = \emptyset/R \qquad f^* = f_r/f_n$$

$$Re = V_\infty d\rho/\mu \qquad M = V_\infty/C \qquad AR = L/D$$

$$C_p = 2P_{rms}/(\rho V_\infty^2)$$

These parameters, and combinations thereof should be adequate to describe the observed phenomena in a generalized fashion. Assembling them in an orderly and logical fashion, and subsequent analysis of these non dimensional data pairs is simplified through the flexibility of LOTUS 1-2-3.

Having input these four characteristic values, one simply inputs the equations for each dimensionless parameter at a location in the spreadsheet. Once having filled this equation table, new data sets can be analyzed by simply transferring data blocks via commands in the worksheet. Also, it is possible to window the worksheet to compare values of parameters between dimensionless groupings.

Data to be used in the analysis was obtained by varying the length of the cavity over five equal increments and varying the velocity over seven intervals, up to a Mach number of slightly greater than 0.1. The resulting data set consisted of forty eight points, grouped by cavity length.

The data record was structured to allow simple file transferring. A typical data file is shown below in Table 1.

LENGTH (INCHES)	VELOCITY (FPS)	PEAK RESONANT FREQUENCY (Hz)	INTENSITY (dB)
10	70	350	110
10	75	350	114
10	82	355	121
10	89	355	128
10	93	350	131

TABLE 1. Typical Data File Record

The first characteristic investigated was the variation of resonant frequency with velocity. The resonant frequency at which maximum sound pressure levels occurred was observed to change slightly with velocity but by varying amounts, depending on cavity length. The non dimensional groupings which correspond to frequency and velocity are as follows:

$$Re = Vd\rho/\mu \qquad f^* = f_r/f_n$$

The frequency ratio is expected to be located around a value of unity. Figure 1 shows the results of this analysis. It can be seen that a general trend to approach f*=1 occurs as the Reynolds number increases.

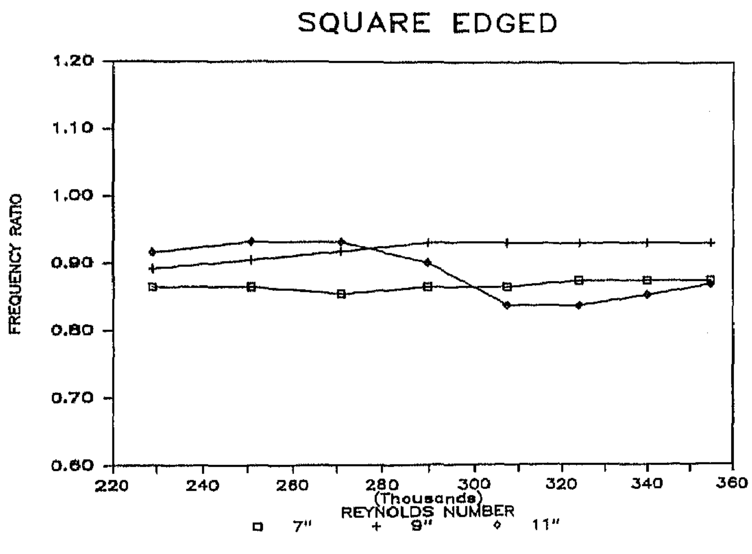

Figure 1. Frequency ratio variation with Reynolds Number. (7-11 inch cavities)

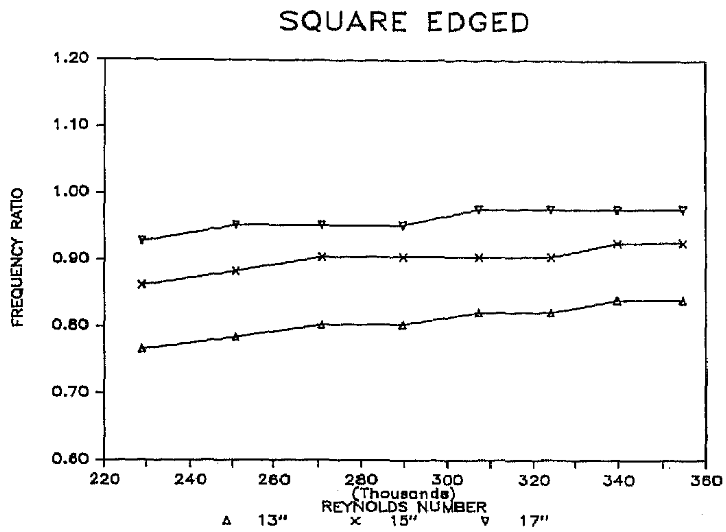

Figure 1. Frequency ratio variation with Reynolds number. (13-17 inch cavities)

A second method of analyzing how the resonant frequency varies is to plot it against changes in cavity length. It is possible that the frequency is a function of the impedence of the cavity, which would vary with the length of the cavity. The non dimensional grouping which corresponds to the cavity length is the aspect ratio. Figure 2 shows that the relationship is nearly linear when plotted in this fashion.

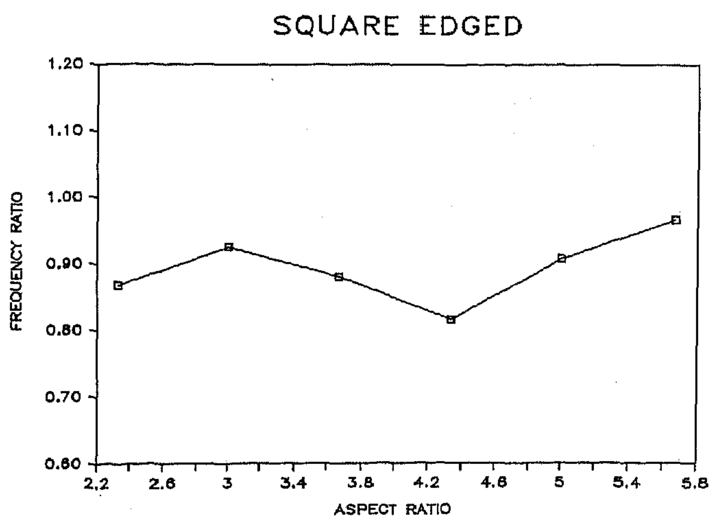

Figure 2. Frequency ratio variation with Aspect Ratio

The pressure coefficient relates the root mean square pressure fluctuation at the peak resonant frequency, to the dynamic pressure of the main flow. The first combination of data pairs tried was the pressure coefficient and the Reynolds number. Figure 3 shows that there is not an immediately obvious functional dependence in plotting the data in this fashion.

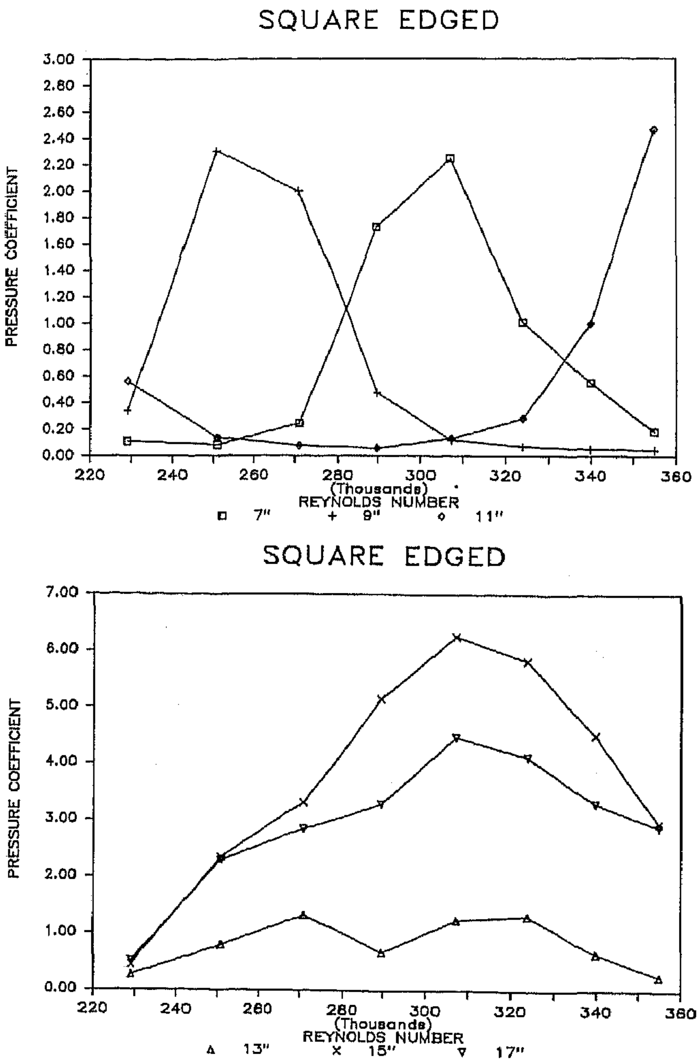

Figure 3. Pressure coefficient variation with Reynolds Number

Normalizing the velocity with different parameters was apparently needed. Since the velocity and the width of the cavity might control the shear layer instability, these parameters were grouped. A frequency measure was then needed to complete the non dimensionalization. The natural frequency of the cavity is likely to determine the shear layer oscillation frequency at resonance. Therefore, an inverse Strouhal number appeared as a likely candidate for the argument of the pressure coefficient functional dependence. The result of this grouping is plotted in Figure 4.

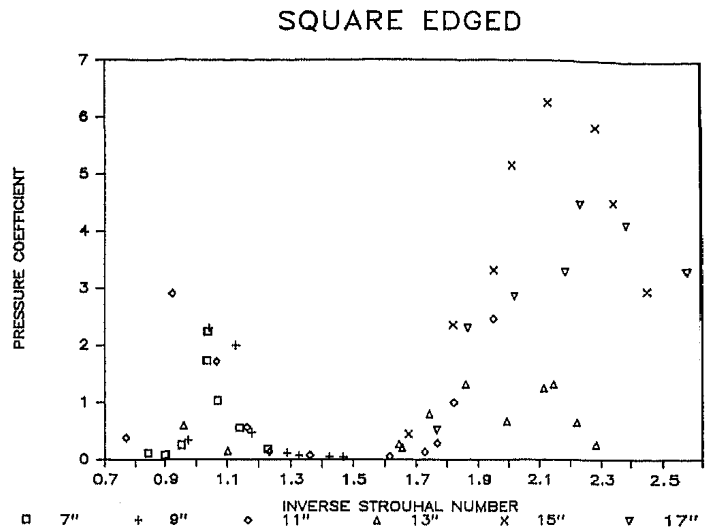

Figure 4. Pressure coefficient variation with inverse Strouhal number

It appears that there are two ranges of Strouhal number in which all cavity lengths show large pressure coefficients. Plotting the strength of a tone in decibels, where a decibel is defined as:

$$dB = 20LOG(P_{rms}/P_0)$$

serves to better illustrate the amplitude scale since the pressure coefficient is also related to the RMS pressure fluctuation of the cavity pressure. Plotting the inverse Strouhal number versus the common logarithm of the pressure coefficient thus may provide a clearer insight into the dependence. Figure 5 demonstrates that this operation indeed aided in graphically expressing the trend of the data points to achieve relative peaks at two values of the inverse Strouhal number. The frequency of the shear layer oscillation is also velocity dependent, and the two observed peaks represent different shear layer modes.

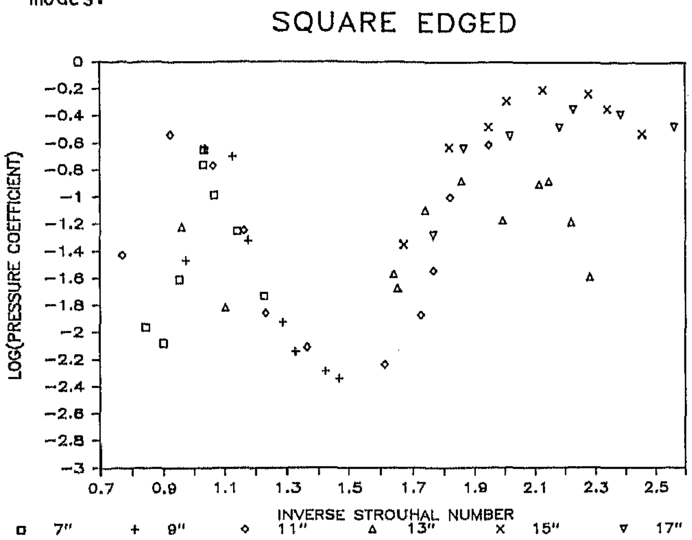

Figure 5. Logarithmic pressure coefficient variation

Previous research suggests that the shear layer wavelength decreases with increasing velocity. As plotted, the first peak would represent the first shear layer mode, while the second peak would correspond to the second mode of the shear layer.

The inverse Strouhal number possesses little significance for most situations. Therefore, for the sake of the avoiding esoteric groupings, it may be advantageous to change the ordinate parameter to the Strouhal number. This plotting should show the trend of decreasing velocity on the pressure coefficient. Figure 6 demonstrates that this change in fact causes the data to cluster more distinctly around two values of the Strouhal number, 0.5 and 1.0

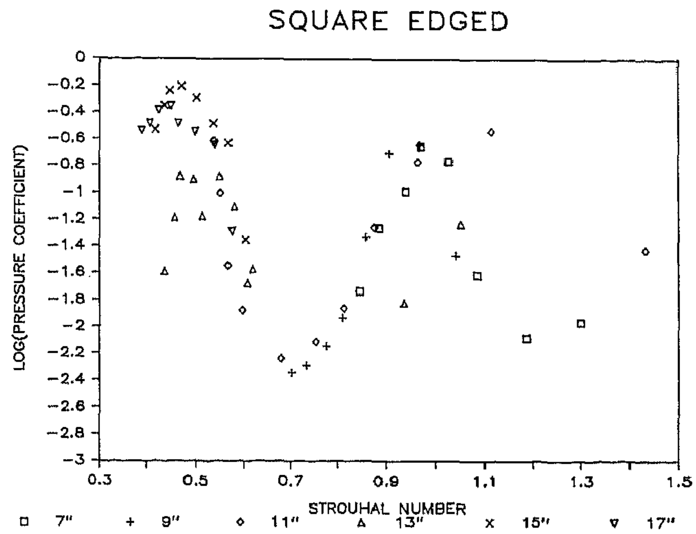

Figure 6. Logarithmic pressure coefficient variation with Strouhal number

DISCUSSION

The utilization of LOTUS 1-2-3 for date input and subsequent manipulation greatly accelerated the generation of a meaningful description of data dependence. In addition to the original data files, each dimensionless parameter was calculated and entered into the spreadsheet. It was then very simple to create any other dimensionless grouping simply by multiplying terms, or performing the indicated mathematical operations. Rapid, visual comparison of dimensionless groupings was allowed via spreadsheet windowing and graphing commands, which are not readily available to the average BASIC or FORTRAN programmer.

A danger associated with this type of data manipulation is that excessive time can be spent learning the minutest details of the software, when they do not actually apply to the problem at hand. Discipline must be exercised to use the software to its fullest without becoming overwhelmed by the extraneous details of its operation.

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