ADVANCED ENGINEERING CALCULATORS

Don't Overlook Them!

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I recently attended a conference on engineering education where one of the sessions concerned the use of computers in the chemical engineering curriculum, during which the speakers described the use of process simulation software and spreadsheeting techniques in their teaching programs. At the end of the session I asked if they had ever given any consideration to including an instructional component regarding the use of calculators. In short, the answer was "no," and I got the impression that the matter was regarded as trivial by the majority of educators present. I also noted an inconsistency: the speakers had proudly outlined a "keyboard familiarity" component in their introductory computing program, yet with regard to calculators they voiced the opinion that "one should not have to teach the students absolutely everything—some things they should learn by themselves!"

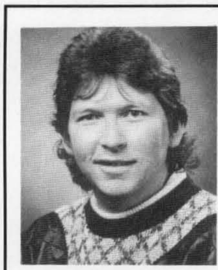
I agree wholeheartedly with the latter belief. Indeed, it is fundamental to the university teaching concept that students must take the major responsibility for their own learning. I also applaud the inclusion of computing skills in the curriculum; the proliferation of affordable and powerful personal computers over the past decade and the emergence of spreadsheets as an engineering tool combine to make this essential for the engineering graduate.

But I take issue with the commonly held belief that calculators are only a trivial component of the myriad of tools available to the professional engineer. How many of today's engineering educators would be surprised to learn that the calculator that I currently hold in my hand is capable of storing more than one megabyte of information, available as RAM, and ten megabytes of numeric information using data compression? By way of comparison, this magnitude of memory has only recently become widely available for personal computers.

The amount of available memory is only one aspect of today's advanced calculators; the real power of these tools lies in how the information is utilized, and I submit that it is this aspect that should be treated seriously in the engineering curriculum. In the following discussion I will lean heavily on my personal experience with one advanced calculator; the Hewlett-Packard HP48SX Scientific Expandable. It is not intended to be an endorsement of this particular product or brand—in my opinion other makes of calculators will likely soon rival the HP48SX, if they do not do so already.

COMPUTERS EMBRACED—CALCULATORS IGNORED

Before elaborating on the calculator's capabilities, I want to give my view of how today's attitudes towards computers and calculators developed. I believe the main reasons for the different attitudes are 1) that, unlike the PC, the advanced calculator does not occupy a position of usefulness in the general populace, and 2) that these two tools were introduced at opposite ends of the utility spectrum. The PC was driven by commercial (industrial) implementation and was viewed as a way of putting mainframe computing power in the hands of a single user. Huge efforts in software development and the advent of user-friendly software interfaces, pioneered by Apple's Macintosh, have made the personal computer an invaluable tool. This was quickly recognized by the educational sector and accordingly was incorporated into the curricula. Teaching efforts were at first directed toward the development of programming skills but, arguably, the evolution of spreadsheets and other



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user-friendly packages have made this aspect (for chemical engineers at least) less important in recent years. The personal computer has been embraced by educators.

In contrast, the calculator (at least in its affordable form) had its origin at the very lowest level of the utility scale, and it has never enjoyed the commercial development to the extent that the personal computer has. Whereas personal computers can be used across a whole range of disciplines, from musical composition to nuclear physics, the advanced calculator requires some measure of mathematical sophistication of its user. This dramatically limits its market.

At first, the calculator offered only the four basic mathematical functions, replacing the slide rule. It was seen by the old guard as not only unnecessary but also as an actual threat to the development of "essential" basic mathematical skills. To a certain extent those fears have been realized—we of the latest generation of engineers are probably neither as quick at "in-the-head" calculations nor as good at estimating magnitudes as our predecessors were. (The argument could be made that these skills are not as necessary as they once were. Perhaps the necessity of "in-the-head" calculational skills for an engineering professional is itself a subject for debate.)

The calculator evolved to incorporate trigonometric and hyperbolic functions and, eventually, also elementary statistical functions. Programmable calculators appeared, but they were limited by available memory to low-level languages and a finite number of steps. Although various software applications became available, the initial programming capability was basic and time-consuming. For the student, the usefulness of programming came mainly from the automation of short, but tedious, repetitious number-crunching during laboratory classes.

Alphanumeric displays soon followed, and the student was now presented with higher-level languages, the ability to write user-friendly software, and the capability of storing information. With the advent of larger displays came the ability to quickly and easily plot functions and experimental data. Today, built-in functions allow an engineer to enter eight or ten data points and perform a regression analysis on the spot, within a few minutes, without programming.

The following anecdote highlights the inaccessibility of advanced calculators to the public at large (and even to other professional groups), which contrasts distinctly to the accessibility (and hence the popularity) of personal computers. A consulting engineer was giving expert court evidence for the defense and was asked by the prosecution to estimate the outcome of an hypothetical situation. The engineer replied that he could not give an immediate answer since he did not have his calculator with him. Smelling blood, the prosecuting attorney offered the use of his own calculator, which had the four basic mathematical functions. The engineer reiterated his inability to give an immediate answer without his own calculator, at which the prosecutor, this time smelling victory, cried, "And you call yourself an expert?" This naive attempt to question the engineer's competence backfired when it became evident that the calculation required a more sophisticated calculator and that the prosecutor obviously did not understand the point of his own question. The lesson is clear: the calculator has evolved from its basic form into a device that requires considerable mathematical sophistication to simply comprehend its potential utility.

Rather than viewing this as just another subject vying for attention . . . , perhaps it should be looked at as a way of easing the teaching load, alleviating the drag caused by those students who are overloaded with mathematical tasks of dubious educational value.

For this reason it is only the knowledgeable users who have driven its evolution and incorporated it into everyday use. At each stage of its advancement students have recognized the potential advantages of the calculator's latest implementation (some cynics might say it is only a result of the student's general tendency to find the easiest route through any course), whereas educators have consistently lagged behind and have blocked its use by banning them from exams. In all cases, the bans have eventually been relaxed, but the negative knee-jerk reaction to new technology persists at each stage.

CAPABILITIES OF THE LATEST CALCULATORS

I agree with the conference speakers that up until the above stage of development, students could learn to use calculators to their full capacity by themselves. After all, these devices merely offered quick number-crunching. Once you knew where the "cosine" button was, what more was there to learn? But the current generation of calculators has surpassed mere number-crunching and in the process has outstripped the student's ability to comprehend their potential uses, let alone to readily assimilate the available functions. My own calculator comes with an 852-page manual, plus an additional 230 pages for one of the expansion cards, not to mention the 290-page external programmer's development manual.

To illustrate my points further, let me describe my calculator. (Once again, I advise that the following is not intended to be an endorsement of a particular product, and it obviously doesn't even approach an objective, critical analysis of functionality!)

I have owned an HP48SX for about eighteen months now and still have not grasped its entire functionality. (I had previously owned two earlier models of the same make.) The calculator has a 131x64 pixel graphics display (which acts as a window onto a much larger display area), divided into seven lines for text. It has forty function keys, each having four built-in functions and up to six user-defined functions, giving 400 immediate-entry functions. In addition, there are six "softkeys" which take on various functions according to the particular mode the calculator is in. For instance, in the "Statistics" mode, these six keys have 35 functions (plus user-defined functions) displayed on-screen in hierarchical sets of up to six functions at a time. In all, the calculator has 2100 built-in functions.

It has, built in, 32k of ROM and 32k of RAM, with two expansion slots for plug-in 32k, 128k, or 512k cards that can be operated as ROM or RAM. In addition, the calculator uses kermit protocol to communicate with remote devices (*e.g.,* a personal computer) via an RS232 port and features an infra-red communication port for transferring data to a printer or to another calculator. The power of the above features alone is considerable. I also have eight megabytes of application software for the calculator, stored on my PC, which I can download or upload at any time.

Do you still think the calculator is a trivial tool? Read on . . .

The calculator is capable of symbolic algebraic manipulation, differential and integral calculus, so I can enter a function in algebraic mode (without programming) and isolate a variable, simplify the expression, differentiate any variable (and define others as functions of one or more variables), and integrate between limits. It can even handle differential equations. With the calculator, I can perform vector and matrix algebra and solve systems of linear equations. Application software offers Gaussian elimination, row reduction, and determination of eigenvectors and eigenvalues. Think of the advantage, for the student learning process control, offered by a calculator that can perform Laplace transformations, solve partial fractions, and produce Bode plots. This one can do all of that.

The calculator has 147 built-in units which can be combined in any consistent way and allows user-defined units to be stored. It not only converts between units, but also allows the user to attach units to any value and perform mathematical manipulations, keeping track of unit consistency. For example, I can add 10 ft/s to 10 mph and get 25 ft/s. (10 ft/s + 10 psi rightly gives an error.)

One of the most powerful features is the built-in equation-solver. With this I can enter an equation algebraically (no programming necessary), and the calculator automatically gives an on-screen menu of all variables involved and allows me to enter known variables (with or without units) and solves for the unknown. I can then change any values and re-solve. This provides a "what-if" platform with obvious value in design problems. Another available application is the multiple-equation-solver. It links equations together and solves for any unknowns. For example, in the plug-in Equations Library Card, one application has eight linked equations for fluid flow. They are

$$\rho\left(\frac{\pi D^2}{4}\right)v_{avg}\left(\frac{\Delta p}{\rho}+g\Delta y+v_{avg}^2\left(2f\left(\frac{L}{D}\right)+\frac{\sum k}{2}\right)\right)=w \tag{1}$$

$$\Delta p = p2 - p1 \tag{2}$$

$$\Delta y = y2 - y1 \tag{3}$$

$$M = \rho Q \tag{4}$$

$$Q = A\,v_{avg} \tag{5}$$

$$A = \frac{\pi D^2}{4} \tag{6}$$

$$Re = \frac{D\,v_{avg}\rho}{\mu} \tag{7}$$

$$n = \frac{\mu}{\rho} \tag{8}$$

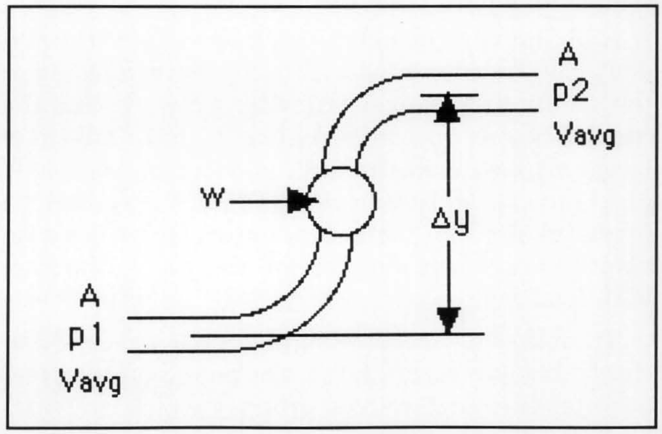

Figure 1. *Equations Library Card display of fluid-flow system*

(Nomenclature is standard and not worth including for the purposes of this discussion.)

The press of a softkey displays each of these equations in turn, and another softkey displays an on-screen picture of the system as shown in Figure 1. Another softkey yields a description of the variables and even the default units (the user may choose SI or English):

Δp	pressure change, kPa
p1	initial pressure, kPa
p2	final pressure, kPa
Δy	height change, m
	etc.

By plugging the known values into the given menu of all variables, the multiple-equation-solver can then be asked to search through all eight equations and solve for any unknown variables, repeating the process until all possible solutions for unknowns have been obtained from the given information. For identification purposes, calculated values are tagged differently from specified values.

The Equations Library Card has 128k ROM and includes 315 common equations, organized under fifteen categories (Columns and Beams, Fluids, Electricity, Solid Geometry, etc.). Also included are a financial calculation package with time-value-of-money, a set of engineering utilities (Re, friction factor, etc.), and a collection of 39 commonly used physical constants (gas constant, Boltzmann's constant, etc.). Finally, it includes a periodic table of the elements which contains all the chemical data that appear in a standard periodic table of the elements. The primary user-interface is the familiar grid of elements and the user can select any element and obtain a catalogue of 23 properties (melting point, conductivity, etc.), each of which may be plotted against atomic number. A molecular weight calculator allows typing in of formulae and quick calculation of atomic weights.

Still a trivial and readily assimilable tool?

I have made no mention of the calculator's abilities regarding complex numbers, binary arithmetic, or user-defined functions, and have barely touched on algebra, calculus, statistics, arrays, interactive plotting, etc. Finally, a high-level language is available to the user and an even more comprehensive instruction set (plus machine code) is available on the freeware set of PC development tools for creating and downloading application software for the calculator.

THE PRESENT AND THE FUTURE

The point of the above description is to show that calculators have now advanced far beyond the complexity and capacity at which computers were welcomed into the engineering curriculum. The abilities of today's advanced calculators go far beyond the immediate capabilities of most (particularly the less-advanced) undergraduates, yet their education could be enhanced considerably by incorporating instruction on the use of the latest tools into the curriculum. It is not sufficient to allow students to flounder about, applying tools beyond their level of comprehension and obtaining competence only (if at all) in piecemeal fashion.

For those readers whose first instinct is to identify and ban the most advanced calculators, I urge you to think again. Recent history shows that such bans do not last and instead a redesign of the things we are testing is required. Indeed, if the advanced calculators are such a threat during exams, then their value as tools is self-evident! But many educators tend to ignore them during the student learning process and attempt to abolish them during the student evaluation process. This is a surprising oversight for supposedly liberal institutions of higher education. Are we doing justice to the teaching process if we ignore these tools at the very time that an emerging professional requires the most guidance?

Our students use, and will continue to use, increasingly sophisticated calculators on their own throughout their university years and certainly beyond them. The knowledge-base of students has steadily risen from year to year (the derivation of Schrodinger's equation is standard first- or second-year chemistry and superconductors are now old-hat). We must allow more and more sophisticated tasks to be delegated to number-crunching tools in order to make room for the new knowledge. Should our students really be spending their time struggling through eigenvector and eigenvalue calculations when they could instead be studying the relevant application in more depth? (This is not to say, however, that students needn't thoroughly understand the concepts of eigenvectors and eigenvalues.)

Are those of us in the educational sector of the engineering profession ignoring an opportunity to contribute to the direction of the calculators' continued development? After all, they *will* continue to develop, with us or without us. With the substantial increases in solid-state memory capacity which are certain to come, perhaps we will see the advanced calculator being aimed at specific disciplines. That is, instead of being aimed merely at business or engineering professionals in general, as they are at present, we may see calculators aimed specifically at chemical engineers. Such a series of calculators might consist of a common hardware core, with large-capacity plug-in modules of extremely specific information and operations which customize the calculator for particular professions.

My own view is that the computing component of the engineering curriculum should include serious treatment of advanced calculators and that their use in all aspects of engineering education (including student performance evaluations) should be encouraged. I do not suggest offering a course specifically on calculator usage for two main reasons. First, how could one justify the selection of one brand over another, or indeed the selection of calculators *per se* over, for instance, spreadsheets as a topic worthy of instruction? Second, the utility of such material would rely heavily on existing technology which quickly becomes outdated, leaving the graduate no further ahead.

Rather than viewing this as just another subject vying for attention in an already overcrowded curriculum, perhaps it should be looked at as a way of legitimately easing the teaching load, alleviating the drag caused by those students who are currently overloaded with mathematical tasks of dubious educational value. In particular, using advanced calculators could give the instructor an opportunity to place greater emphasis on "what if"-type problems from which the students can quickly grasp the effect of varying the parameter values on the outcome of a solution without significantly increasing the time required for completing the assignment.

Certainly, the future of calculators is aimed at more comprehensive and sophisticated utility for the engineering professional. We should take them seriously. ❒

Cooperative Study Groups

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Review: Process Dynamics

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has costs and benefits. The most evident cost is that a sequential reading gives a repetitious treatment of some topics. Material regarding PID implementation is found in at least three different parts of the book. Stability is treated in different parts with distinctly different approaches. Counting the degrees of freedom in a process is discussed in both the first and last parts of the book. A more subtle penalty is that this already large book doesn't have room for more detail on some important topics. Anti-reset windup, for example, is mentioned in passing. Thus, an instructor has to carefully plan an approach to the book and what parts to emphasize or omit. Students also have to be patient with the discursive nature of the book.

Of course, the positive side of modularity is that the book can be adapted to a variety of uses. This is a strong feature, given that process control courses are often by academics who are not experts in the field. This is enhanced by the large set of well-chosen, end-of-chapter problems.

References to widely available tools for computer-aided control analysis are given in a separate appendix. Unfortunately, these are not incorporated into the text or problems. Matlab and its associated toolboxes have been widely adopted in many universities. A low-cost student edition of Matlab is now available which would be a good supplementary text for a course based on this book.

Process control is a rapidly growing subject driven by advances in computing technology, needs for improved process automation, and new theory. This text gives a contemporary overview in an accessible, teachable format. I suspect that the ideal turn-of-the-century course will deemphasize complex variables in favor of statistics, optimization, and model predictive control. But in the meantime, this book is a worthy competitor for market dominance among existing process control textbooks. ❒