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THESIS

INVESTIGATION OF CARD PROGRAMMABLE AND CHIP PROGRAMMABLE POCKET CALCULATORS AND CALCULATOR SYSTEMS FOR USE AT NAVAL POSTGRADUATE SCHOOL AND IN THE NAVAL ESTABLISHMENT

by

Harry Rudolph Kruse
and
Hugh Alan Burkett

March 1977

Advisors: H.J. Larson
R.H. Shudde

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This thesis investigates the usefulness of card programmable pocket calculators in the Management curricula of the Naval Postgraduate School and in the fleet, based upon manufacturer-provided information on the HP-67, HP-97, SR-52, TI-59, and NS-7100 calculators; NPS classroom experimentation; "hands on" programming of the HP-67 and SR-52; interviews; and the literature. All aspects of calculator

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Chip Programmable Pocket Calculators
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in the Naval Establishment

by

Harry Rudolph Kruse
Lieutenant Commander, United States Navy
B.S., University of Arizona, 1960
L.L.B., LaSalle University, 1970

and

Hugh Alan Burkett
Lieutenant Commander, Civil Engineer Corps, United States Navy
B.S., University of Oklahoma, 1966

Submitted in partial fulfillment of the
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NAVAL POSTGRADUATE SCHOOL
March 1977

Authors: Harry R. Kruse
Hugh Alan Burkett

Approved by: Harold J. Larson
Thesis Advisor

Rex H. Shudde
Thesis Advisor

Chairman, Department of Administrative Sciences

Dean of Information and Policy Sciences

ABSTRACT

This thesis investigates the usefulness of card programmable pocket calculators in the Management curricula of the Naval Postgraduate School and in the fleet, based upon manufacturer-provided information on the HP-67, HP-97, SR-52, TI-59, and NS-7100 calculators; NPS classroom experimentation; "hands on" programming of the HP-67 and SR-52; interviews; and the literature. All aspects of calculator functions, programming and programmability are surveyed with particular emphasis on educational and practical applications. Thus, this is a baseline document for study by potential purchasers and users. This study concludes that these machines provide significant advantages in teaching or learning mathematical concepts and that the pocket calculator is a potentially important management and tactical support tool navy-wide. In addition, "thinking process transmutation", discovered during this study, is concluded to be an inevitable and important by-product of calculator programming which significantly improves the user's overall analytic capacity.

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ERRATA

Page	Line #/Item	Should Read
14	21 - after "document"	(Page 37)
23	21 - after "often"	do not
25	3 - along	among
26	2 - after "materials"	[8]
44	16 - IV.E(9)C.(8)	IV.E(9)c(9) on page 108
45	18 - +7 = & 7+	÷ 7 = & 7 +
47	9	delete AOS
58	4 - DEC DEG	DEC → DEG
	8 - DEG DEC	DEG → DEC
	10 - DEG RAD	DEG → RAD
63	6 - X Y	X ⇄ Y
76	"user keyed labels" blocks a, c, e	add N'; r; n
77	Step 1 key entry	fLBLA
	Step 65 key entry	RCL4
81	"user keyed labels" diagram	draw lines only to match page 76
89	"user keyed labels" (E')	± Δi → DO NPV
	Flags: Block 0	insert "if $n < N$"
	Step 1 - call	call →
	Step 6 -	Δi →
90	Step 37 - +PVn REG 69	+PV → REG 69
	Step 54 - if n = N	← if n = N GTO STEP 193
91	Step 100-/i_t/REG	/i_t/ → REG 98

Page	Line #/Item	Should Read
92	Step 131 - key entry .Ø	9
	note- Δi REG	Δi → REG 96
93	Step 182 - REG GO	REG 60
	Step 191 note (Clr) REG 99	(CLR) → REG 99
94	"user keyed labels" - e Δi DO	± Δi → DO NPV
	Step 18 key entry	hR↑
	Step 20 note	← G TO LBL 1
95	Step 44 note (#n) REG	#n → REG
	Step 46 note (N+1) REG	N+1) → REG
96	Step 83 note LBL C	LBL c
	Step 96 key entry h R	h R↑
	Step 98 key entry h R↑	h R↓
	Step 118 note i REG	i → REG
97	Step 135 note -11) REG	-11) → REG
	Step 148 note it) REG	it) → REG
	Step 166 key entry	h ST I
	Step 175 note -26) REG	-26) → REG
99	Add title top of page	(Initial Data Entry Operations)
102	7 - (i_t stored)	(+i_t stored)
	15 - (n ≠ 0) & (n ≤ 20)	(n < o) and (n > 20)
106	5 - Display column	0.0639
	13 - Press key column	B

Page	Line #/Item	Should Read
109	21 - after program	program card
113	23 - IV.C	IV D
121	1 - on	or
	13 - Figure 2	Figure 3
123	9 - one equally	are equally
	13 - Figure 2	Figure 3
125	5 - Figure 5	Figure 6
128	5 - 5.	6.
135	10 - Figure 6	Figure 7
137	2 - Figure 6	Figure 7
138	2 - after "Explanation" add	of Figure 7 (page 142)
141	2 - Figure 7	Figure 8
142	add 3rd line (above C')	Card 1
	"user keyed labels" block D aij REG	aij → REG
	Step 4 add note	(Cj= 90+j → REG 99)
	Step 26-29 note	bracket 1, 11, 91, 84 REG
143	Step 71 - Run	Run →
	Step 79 - aij	aij →
	Steps 96, 100, 104- cost	cost →
145	add title (above C')	Card 2
	"user keyed labels (C')" - REG ØØ	REG → 00
	(D) K PR	K → PR
	(E) K PR ROW	K → PR → ROW
	K-PR	K•PR

Page	line#/item	should read
145 (con't)	Step 7 - under K note K PR	$\xrightarrow{K}$ $\xrightarrow{K \rightarrow PR}$
	Step 11 - P_{ROW}	$\xrightarrow{P_{ROW}}$
146	Step 36 - RUN	$\xrightarrow{RUN}$
	Step 66 - $\overline{P_{ROW}}$	$\xrightarrow{P_{ROW}}$
148	Step 1 - key entry	gLBLa
149	Step 32 key entry	gFRAC
154	15 - (Table 3)	(Figure 3)

I. INTRODUCTION

A. GENERAL

Card programmable electronic pocket calculators offer portable computational power and versatility heretofore unknown at an astonishingly low cost. Most problems which require the analysis of numbers can be programmed into and automatically solved by this new breed of machine at the touch of a few buttons. This new ability to execute complex computations, on demand, in the field, and in seconds can enable one to significantly improve his professional efficiency in almost any profession. In the opinion of the authors, the next generation of card programmable calculators is going to have a greater ultimate effect on the modern world than did the computer itself in recent years.

The invention of the logarithm by Napier in 1614 [1] simplified and speeded mathematical computations by mankind. The calculator revolution of today is comparable to the revolution in mathematics brought about by the logarithm. The non-programmable electronic calculator has already all but eliminated the market for the sliderule while providing greater accuracy at a lower cost. On the other hand, sophisticated calculators are now beginning to compete with larger computers. The first card programmable calculator, the Hewlett-Packard HP-65, was introduced in 1974. In January of 1976, Texas Instruments Incorporated (TI)

introduced the SR-52 card programmable calculator in competition with the HP-65. Hewlett-Packard (HP) answered the challenge in June 1976 with the HP-67 which provided more than twice the capability of the HP-65. National Semiconductor intends to introduce their Model 7100 before summer of 1977. It will have 480 user programmable steps plus 4000 library steps. In June 1977, TI will replace the SR-52 with the TI-59, which will have as many as 960 user programmable steps plus a 5000 step library cartridge. This relatively rapid evolution in hand-held calculators is the result of high consumer demand, and market competition. It is believed by the authors that hand-held computers with up to 20K of step processing capability will be available within the next decade.

B. PURPOSE

The beginning for this thesis started with the purchase of programmable calculators (HP-25's) for use by the authors in course work at the Naval Postgraduate School (NPS). Having gained the ability to program the purchased calculators, it was soon determined that more capability was desired in order to solve more complex problems. This phenomenon is described by Thompson [2] as the "fill-up" principle where the user tends to "fill-up" the capability of the machine and thus, outgrow it.

In 1976, NPS purchased more than sixty SR-52 machines for use in a pilot project designed to determine if such

machines should be formally incorporated into the various curricula. Additionally, the NPS faculty questioned whether or not the use of these calculators in the fleet could improve the capability of managers, i.e., if rapid and concise analysis of data could enable managers to arrive at better decisions which might lead to improved operational readiness.

It is, therefore, the purpose of this study to investigate the potential of card programmable pocket calculators as a tool for both educational endeavors and management support in conjunction with the NPS pilot project.

C. STUDY METHODOLOGY

(1) The Management Science curricula of the Naval Postgraduate School (NPS) was used for educational program guidelines. NPS Management Science students come from diverse educational backgrounds; many of the students have minimal formal mathematical training. The Management Science curriculum encompasses the following disciplines that include numerical computation:

a. Mathematics

b. Probability

c. Statistical Methods

d. Financial Accounting

e. Management Accounting

* Particular courses are listed in Appendix A.

(2) The Hewlett Packard HP-67 and the Texas Instruments SR-52 were studied "hands on" and compared on the basis of:

a. Machine language

b. Programming and programmability

c. Machine functions and capabilities

d. Use in the educational process

e. Use at NPS and in the Fleet.

Comparable functions and capabilities of the NS Model 7100 and the TI 59 are listed in Appendix B. Samples of these two machines were not available during the time frame of this study; therefore, listed data is informational only, as provided by the manufacturers. The authors had opportunity only to observe factory emulators which could accomplish most of the functions predicted for the actual production models of these machines.

(3) Additional information was collected through:

a. Interviews and surveys of users

b. A search of the literature

c. Telephonic and written interview of researchers and educators

d. Review of written information provided by educators and researchers

e. Review of information provided by manufacturers.

(4) There is little in the literature to indicate the impact of card programmable calculators in the educational

and fleet environments. This thesis is written with the expectation that it will be disseminated to readers who have various levels of familiarity and needs concerning these calculators. These underlying factors necessitated a baseline study that includes technical information, as well as non-technical, as deemed important to the various audiences. Therefore, the reader may extract information as considered appropriate.

II. CARD-PROGRAMMABLE CALCULATORS AND EDUCATION

A. THE CALCULATOR AS A TEACHING AID?

Whether or not the calculator is usable as a teaching aid is a multi-faceted question.

Rogers [3] believes that a good teaching aid must be enduring if it is to be of value in the educational process; i.e., as enduring as the blackboard. She lists four features that seem to separate enduring teaching aids from others:

1. Inexpensive and/or durable
2. Controllable by learner
3. Does what the learner wants done
4. Flexible usability

The question of expense and durability is simply one of value analysis. Such analysis must necessarily evaluate (a) initial incremental cost, (b) initial support cost, and (c) recurring cost. Support costs include publications and peripheral equipment required to take full advantage of the system. Recurring cost of calculators is primarily a function of machine failure rates. A suggested method of value analysis on this subject is located elsewhere in this document.

A hand held calculator is certainly controllable by the student, particularly when the student is allowed to take it home with him. Equally obvious is that the machines surveyed in this thesis are usable in almost any course of instruction

that requires numerical computation and are capable of doing what the student wants them to do. In addition, these instruments can be used to great advantage in the fleet after graduation. In short, hand held calculators have an advantage that even the blackboard cannot compete with: portability.

Bell [4] points out that there is considerable agreement that calculators should play an important role in the educational process as a result of their availability and use outside the world of schools. He also reports that almost invariably there is high initial interest which persists over a long time provided students are given interesting things to do with the calculators.

Suydam [5] lists the two fundamental arguments regarding the use of calculators in the educational process in general:

Proponents argue:

> "The hand-held calculator is the tool used in society today for calculations. Schools are 'burying their heads in the sand' if calculators are not recognized and used as the calculational tool that they are."

Opponents argue:

> "The principal objectives of mathematics instruction (at least in grades K-9) are that children learn the basic facts and paper-and-pencil algorithms. Such learning will not occur if calculators are made available in schools."

The opposing view is also argued at the college level, although calculators are not forbidden in most college classrooms and numerous schools have taught a basic sliderule

course. It is agreed that a certain amount of computational skill must be required before calculators can be used entirely effectively. But the authors do not see much distinction between "paper-and-pencil" and calculators, and even less between sliderules and calculators. I.e., what is the difference between using paper-and-pencil and using calculators in the learning process? At best, it would seem to be a moot point.

Available literature indicates to the authors that the benefits of using calculators strongly outweigh not using calculators. Interestingly, no evidence has been found that calculators or sliderules negate the learning process. Paper and pencils are *merely different* forms of tools. Any tool that facilitates learning should be accepted on its relative merits rather than being eliminated through emotional recrimination. To put it simply, correct answers instill confidence and it is inescapable that learning will take place while using calculators. The degree of learning depends upon the student, the teacher and how well the tools available are used. Calculators will not replace the thinking process but will enhance its capabilities to accomplish more, as did the sliderule for the engineering profession.

The authors find no substantial reason against using calculators as an educational tool per se and fully support the proponents viewpoint.

Peripherally, an additional aid is on the market for use by instructors — the "Edu-Calc." It is manufactured by Educational Calculator Devices, Inc., in Laguna Beach, California. It is an electronic repeater unit coupled with a calculator, produced as an integral unit. With a calculator on the top of the unit for operation by the instructor, the display faces the students for them to follow.

This integral unit is supplied in a brief case, which makes it easy for the instructor to carry it with him from class to class.

At present, the unit is manufactured using only Hewlett-Packard calculators. When queried as to the possible incorporation of other manufacturers calculators, Mr. George Schultz, Manager, Academic Sales, stated that such an eventuality would not be considered at this time due to machine reliability factors. No "Edu-Calc" machines have been returned for repair during the life of their production (approximately one year). He provided a rough estimate that an HP-67 model "Edu-Calc" could be made available for approximately $1200 [6].

B. THE NPS PILOT PROJECT: CLASSROOM USE OF CARD PROGRAMMABLE CALCULATORS

The project began with the issuance of SR-52 card programmable calculators to fifteen beginning students in the Naval Intelligence curriculum. The calculators were incorporated in the course "Mathematics for Naval Intelligence" (MA 2310); this course is described as [7]:

> "A review of linear, logarithmic, sinusoidal and exponential functions, with graphical emphasis; differentiation and integration with both analytical and numerical procedures, continuation to include introductory treatments of Fourier analysis; the Fourier integral, spectral analysis, differential equations, and the Laplace transformation."

The course was completed during the October-December 1976 quarter.

In addition to the calculators, students were issued a text [8] that had been adapted by the instructor to take best advantage of the calculators. The students received 5 hours of classroom lectures and 3 laboratory hours each week for 11 weeks.

During the first two weeks of the quarter, the class concentrated on learning machine capabilities and programming. The balance of the quarter was spent learning mathematics.

The students completed survey forms during the fourth and twelfth weeks of the quarter and were interviewed throughout the quarter. These students will continue to use the calculators in follow-on courses.

Following is an analysis of available information:

a. Ages of students: 29 ± 5

b. Previous degrees: BA/BS 87%

c. Highest level math previously taken:

college algebra	40%
calculus	46%
differential equations	14%

d. No student had previous experience in programming calculators or computers.

e. Average use of calculators per student over 11 week period: 97.08 hours (37.8 hrs without programming; 59.28 hrs programming and using programs).

f. 100% of the students believe that the calculator oriented course was a worthwhile educational endeavor that has enabled them to acquire an ability useful in further education.

g. 93% of the students foresee the use of programmable calculators in future billets (versus 67% in the 4th week) and are generally willing to buy a calculator (versus 73% in the 4th week). However, that willingness is predicated on (a) billet requirements and (b) the belief that if the government benefits, the government should purchase them.

h. 93% of the students believe that using a programmable calculator and programming has helped them to understand mathematical concepts (as compared to 53% at the 4th week).

i. 100% of the students rate handout materials better (each student ranked them 4 on a scale of 1 to 5) than manufacturers publications. They also believe that these materials were of significant help in learning mathematical concepts.

j. 20% of the class experienced machine failures (machine would not print cards or would not accept manual program input). Not only did these students rate programming lower as a learning mode, but they also received the lowest grades in the class.

k. 87% of the students believe a printer would be useful in programming.

l. Machine features that the students particularly liked included its card-programmability; 11 particularly disliked its inability to exponentiate negative numbers (Y^X) without indicating an error condition.

m. It is noted that most answers concerning questions about future applications were guarded. Students stated that they did not know future course requirements, therefore, were not sure of particular uses.

n. It is clear that the students perceive a strong potential for the application of programmable calculators in future billets.

o. Comparison of survey/interview results at the fourth week with those of the twelfth week indicates a strong increase in enthusiasm and confidence in the ability to carry out computations of increasing complexity. One particularly common statement among the students was that they were able to

compute much faster and solve many more problems, and, therefore, were able to devote more time to studying theory. All students have the desire to learn more about the machine, programming and applications. Some students are already writing programs for future uses.

Each student interviewed indicated that he now views algorithms in a different way; in the way of a flowchart or the way it could be programmed most efficiently. In addition, each confirms that he now tends to think about problems outside mathematics in a similar manner.

p. This class began the quarter with the same text material as covered by previous classes (except for adaptation of the material to the calculator-teaching mode). The instructor, after reviewing student records, initially estimated that this particular class would have difficulty in completing the text (records of this class in prior mathematics courses indicated an overall grade point average of 2.0 or C). However, he found that the class had completed the text during the ninth week and he was able to include additional materials that would prove very useful in future courses. He observed that students gained a great deal of insight and intuition through writing programs and solving

repetitive computations. He stated that the major advantages of calculator usage included "breaking the ice", students obtained correct answers, developed confidence and learned mathematics extremely well. Not only were the students able to cover significantly more material (15% more depth), they were also able to complete a final examination that the instructor judged to be 20% more difficult (complex) than any previous examination in this course.

q. The class of the previous quarter, without benefit of card programmable calculators, attained an overall grade point average of 3.62 ± .43. This class attained an overall grade point average of 3.60 ± .44.

r. As a result of the success experienced by this class, the instructor began the following quarter (second quarter for the students) by teaching the students to compute cumulative/inverse, cumulative normal and binomial distribution values rather than referring to tables. He has also taught the Runge-Kutta method for solving differential equations, carrying out fifty cycles during a class period. Normally these methods are too time consuming to be demonstrated past the "exposure" level. Accordingly, it certainly appears that card programmable calculators have provided a significant advantage to this class.

s. The mathematics courses in the Naval Intelligence curriculum are similar to those in the Management Science curriculum. Therefore, the information collected from this class is entirely adaptable to the following discussion concerning the Management Science curricula.

C. PROPOSED USE OF PROGRAMMABLE CALCULATORS IN THE NPS MANAGEMENT SCIENCE CURRICULA

Appendix A lists the courses that are considered to be logical candidates for the incorporation of card programmable calculators in the teaching process. The investigators believe that each of these courses could be taught in a much more efficient manner by adapting the computational portions to algorithms, demonstrating the algorithms to the students and having the students program them, and, finally, having the students carry out several exercises for practice and application.

The authors believe that the essence of the educational process lies in being able to apply knowledge once gained. Unfortunately, most students seem to do well in the classroom but all too often not really know how to apply their new capabilities.

It is axiomatic that an acquired skill will become "rusty" or will be lost, if not exercised. However, that tendency is ameliorated when a student is made aware of when and how to use a particular algorithm to solve a

particular problem. In other words, teach the student how to recognize a problematic situation, show him how to break it down into its components, analyze each component and reconstruct the situation to efficiently accomplish the task.

The NPS Management Science curriculum includes a wide variety of disciplines, each with its own procedures and techniques. The generally accepted method of instruction combines classroom lectures concerning theory with several hours of homework "crunching numbers." Realistically, little time is left available in the classroom to review homwork problems or theory. Consequently, if the student does not understand some aspect of the course, he is left substantially to his own devices to completely comprehend theory, numerical manipulation or both. A student who misses a critical point early in the quarter may suffer the balance of the quarter by not understanding an important aspect in the progression of course material. Given that the student is carrying more than one course, this effect may take place in several areas. The effect can then become pryamidal with the student demonstrating less than that of which he is capable. Concomitantly, some students simply cannot manipulate numbers rapidly, in spite of the fact that they fully comprehend the material. These students appear to be "poor students" at examination time, yet may be as capable as most any student in the long run.

This investigation has led the authors to believe that all of these effects could be ameliorated to a great degree, with significant gains along all students, through incorporation of the card programmable calculator in NPS Management Science curricula as well as other NPS curricula. In addition, the student could take several programs (recorded on cards) with him to the fleet for use in his next billet.

D. A RECOMMENDED COURSE STRUCTURE

Based upon the pilot project, the authors believe unequivocally that a course of instruction in card programmable calculators can lead to a significantly improved Naval Postgraduate School product and that a beneficial effect would carry over into the fleet.

Such an initial course should be structured in the following manner:

a. Offered during the first quarter of study in the undergraduate portion of the curriculum.

b. The course should be no less than two two-hour classroom periods per week for four weeks, to become proficient with the calculator, followed by two one-hour classroom periods during the remaining seven weeks for applications.

c. The course should be designed to include the use of all functions of the calculator coupled with flow charting and programming.

d. It should be provided as an initial course in mathematics.

Professor Gaskell, NPS Mathematics Department, has already developed text materials that could provide a basis for the accomplishment of these goals. Basically, his programmed text incorporates the teaching of algorithms commensurate with teaching applications and the full capability of the machine.

Obtaining this education early in the curriculum would enable the student to allay the fear and drudgery of numerical analysis. He would be much better prepared for advanced mathematics and the early computer programming courses. CDR Gibfreid, Chairman, NPS Computer Science Department [9], believes that a course in programmable calculators would enable the doubling of the length of time now available for teaching management information systems (MIS) applications.

E. THINKING PROCESS TRANSMUTATION: AN IMPORTANT BY-PRODUCT

Another important effect which would be developed through the recommended course, however, is considered to be even more powerful and far-reaching: This is the effect of thought process transmutation which occurs as an almost inescapable by-product during some four to six weeks of such study.

The process discovered during this research, occurs in the following manner:

(1) Initially, the neophyte programmer is merely impressed with the capabilities of the machine; he attempts to rush into programming without sufficiently studying the

operators manual. His initial success is thus limited, so he begins to conscientiously study the manual to determine how the machine operates.

(2) As his ability to use the machine improves, he discovers the various methods of flow charting. He now has a visual aid that he developed, enabling him to see the program in graphic form.

(3) Once he has developed some amount of expertise in flow charting and programming, he begins to visualize formulas and processes in a new way. For all practical purposes, his analytical thinking processes take on the characteristics of a flow chart or program. As he gains even more expertise in the art, he takes on the challenge of improving the efficiency of his programs through redefinition and more complex methods for eliminating unnecessary steps.

He has inescapably, but subtly, reorganized his thinking processes. He now has developed a new capability to organize his thoughts concerning any particular task, to graphically display the steps necessary to the task, to make logical comparisons and distinctions between facts and hypothesis, and to then develop the most efficient procedure to accomplish the task.

This subtle transmutation seems to take place whether or not the student recognizes it. The transmutation results in the enhancement of personal organization and efficiency of thinking that cannot help but carry over into other areas of the individual's life.

This process alone has the potential of becoming a powerful tool for every individual that experiences it. The process cannot be experienced through the use of a non-programmable calculator; the same process was not experienced by the authors while using the HP-25 (a lower capacity machine with 49 step capability).

Not only was the HP-25 rapidly outgrown by the authors but keying in a program each time limited the efficiency of programming, particularly when more machine capacity was required. With the lower capacity machine, the only mental effects encountered seemed to be those associated with tailoring a program to fit the machine, if it would fit at all.

In short, the individual's mental faculties were not taxed to the degree necessary for transmutation to take place. Lower capacity machines, however, may be entirely sufficient to teach programming and/or transmutation at lower educational or experience levels [10].

Conversely, a 224 step machine has sufficient capacity for the vast majority of problems (as indicated in the appendices), while longer problems e.g., those used in linear regression, queuing, etc., tend to tax the mental comprehension of the individual while constructing programs.

As a result of programming the HP-67 and the SR-52, and experiencing the transmutation process, it is suspected that machines of greater capacity (greater than 224 steps)

may not result in equal or greater transmutation capability. It is feared that students would simply write programs that fit within the capacity of the machine, without regard for further efficiency. Programming would be sloppy because programming space would allow sloppiness. Hence, although a student who begins with a larger capacity machine may develop intricate programming and thinking capabilities, nothing forces the process. Thus, if the aim is to increase overall analytical ability as quickly as practicable, students ought to begin with machines of no greater capacity than the SR-52 or the HP-67. It is suspected that greater machine capacity will lead to a longer time for transmutation to take place.

It is strongly believed by the authors that the refinements and complexities developed through the described process carry over into other fields of endeavor and, especially, that the more refined and more complex the thinking process change becomes, the greater the analytical capacity of the user.

Thinking process transmutation is a most desirable effect to be created as early as practicable in the educational program of a student. The student could be expected to be much better prepared to meet the challenge of later courses. It is axiomatic that educators within the above described process could surpass all previous records in improving the ability of their students. More importantly,

graduates would be significantly more valuable to their employers.

F. CONCLUSIONS

The drudgery and fear of manipulating complex formulas is no longer necessary. An educator can now provide the student with the algorithm to solve a problem, have him program it and carry out several computations, and then be able to spend a greater share of instructional time teaching theory and applications. There is little question that the student will gain greater intuition and understanding of mathematical concepts by following this procedure.

The card-programmable calculator itself is clearly an enduring teaching aid. Its portability is a great advantage, enabling the student to carry exceptional computing power in his pocket.

Educators should have no fear of this device. If used properly, much more can be accomplished in the classroom, in both quantity and depth of coverage of material. Accordingly, educators can significantly advance their teaching capabilities and improve the quality of graduates thereby.

Thinking process transmutation is a phenomenon that ought to be studied in more detail. At this time, it can be said that such transmutation occurs during four to six weeks of calculator usage. The phenomenon has occurred with every person interviewed who has had four to six weeks experience in programming (card-programmable) calculators.

It is clear to the investigators that before providing more machine capacity (more than 224 step capability) to the student, the phenomenon should be studied further in order to assure that it occurs at the earliest time in the curriculum. In addition, more work needs to be done to determine an appropriate measure of the phenomenon. It may be that thinking process transmutation can be enhanced by "stacking" machines of increasing capacity in the educational process, i.e., 224 step, 500 step, 1000 step, etc.

When selecting a calculator for an educational program, machine reliability should be a strong consideration. Although it cannot be said with certainty, machine failure seems to have been a strong factor with the students who received the lowest grades in the pilot project. At the very least, a failed machine is of little use and could create an administrative burden to get machines repaired.

Ideally, sponsors should provide students with calculators upon matriculation for use during their educational program and after graduation. Instructors should be issued calculators with printing capability, both for the benefit of students and instructors. Additionally, an aid, such as the "Edu-Calc", should be provided for classroom instruction.

Unfortunately, far too many educators are not yet aware of the potential of this most valuable tool. The authors are convinced that, provided exposure and knowledge is given, the vast majority of people soon begin to realize

the diverse applications of the instrument and the new abilities that they command. Conversely, a failure to exploit the advantages of the card-programmable pocket calculator in the educational process could be contradictive of the tenets of the process itself.

III. FLEET USE OF CARD-PROGRAMMABLE CALCULATORS

A. GENERAL

The use of card-programmable calculators in fleet operations is certainly a feasible eventuality considering their usability and adaptability. A dramatic example of fleet usefulness is that portrayed by Commander, Patrol Wings U.S. Pacific Fleet and Commander, Patrol Wings U.S. Atlantic Fleet who have been using several HP-67's for approximately one year for airborne search detection problems [11]. An HP-65 (no longer in production), a predecessor of the HP-67, was used as a backup for the onboard computer system on the Apollo-Soyuz linkup mission [12]. Several civilian ships navigators use card-programmable calculators for speed and accuracy of calculations [13]. Appendix C is a short list of some of the places where card-programmable calculators should be used in the Navy and is by no means a complete list. Specific examples of usefulness are listed in Appendix D. In short, appendices C and D indicate that practical and feasible application in the fleet within innumerable disciplines is limited only by imagination.

The simple fact that a great deal of time can be saved while analyzing data, coupled with unparalleled accuracy at a relatively low cost, is a strong reason for implementing the use of these calculators throughout the fleet. This

fact alone would enable managers to make more timely decisions based upon thoroughly analyzed and accurate data.

It is obvious that decisions supported by accurate information are usually better decisions. Better (and faster!) decisions would form the very heart of improved management that could lead to improved operational readiness throughout the Navy.

B. MACHINE CAPACITY REQUIREMENTS

Based upon this study, the capacity of machines currently in production (the SR-52 and HP-67) is probably sufficient for the vast majority of fleet applications. Lieutenant Commander Harvey states [14] specifically that he believes machines of greater capacity would not provide significant gains in tactical capability. Comparisons of appendices C and D and the NPS Pilot project [supra] support that belief. It is therefore clear that 224 step capacity is adequate.

If a particular problem is beyond the capacity of currently available machines, it might be more efficient to use available computers. Alternatively, a great deal of management information, no longer available due to computer operation cost, could be regained by fleet users, e.g., daily maintenance material management (3M) summaries could be produced in abbreviated form by 3M analysts.

C. ADDITIONAL ADVANTAGES OF FLEET USE

As an additional advantage, fleet exchange of programs and programmed cards could be an excellent vehicle for the

transfer of technology among fleet users at a very low cost. LCDR Harvey [supra] indicates that the publication of 700 copies of one tactical program costs approximately $1000, including programmed cards and all supporting publications.

There is little doubt that fleet exchange of programs would lead to a certain amount of standardization in programming. However, directed standardization of all programming would not be in the best interests of the Navy if programmable calculators become a standard Navy item. Specifically, strict standardization of programming would probably stifle individual creativity and investigation. This aspect is considered vital in order to obtain the benefit of all fleet talent available. Put simply, the Navy should take advantage of the natural curiosity and investigation that will occur among users.

D. MACHINE RELIABILITY

If card programmable calculators are purchased for use in the fleet, machine reliability should be a prime consideration. COMPATWINGSPAC experience shows that HP-67's operated on aircraft electrical systems (115 VAC, 400 Hz) have incurred less than a five percent failure rate although operating temperatures are eight degrees higher than in normal (115 VAC, 60 Hz) usage. Unfortunately, no data has been found for the SR-52 under similar conditions.

The above mentioned degree of reliability, or better, is necessary, if such a machine is to be used to make

tactical decisions, even if the cost of returning machines to the factory for repair is not considered.

E. CONCLUSIONS

The potential impact of the card-programmable calculator upon fleet operations must be considered as enormous. Such a machine can provide significant advantages in tactical employment, management efficiency and the transfer of technology. Although this broad range of applications has been shown, many specific uses are yet to be defined.

The authors will attempt to define further specific uses upon returning to the fleet after graduation.

Although these machines are not a panacea for solving all management problems in the fleet, the Navy should take every advantage of their computing power.

IV. PROGRAMMING AND PROGRAMMABILITY

A. GENERAL

Programming and programmability of card programmable calculators is the most important area to be studied when attempting to decide on the kind of system to use. In simplistic terms, programming is only a matter of putting an algorithm in a particular form for the machine to accept it and then compute a correct answer. On the other hand, programmability depends upon several factors.

Programmability is defined here as a combination of:

(1) machine language

(2) merging of key strokes in program steps

(3) type and number of program steps available

(4) ease of programming.

Each of these factors must be compared on its own merits. Then, the user must decide which combination will best suit his needs within his budget. The aforementioned interrelated factors are discussed further in following subsections concerning value analysis, basic and advanced programming techniques.

B. A METHOD OF VALUE ANALYSIS

Once the determination has been made as to the system (or systems) that will satisfy the particular need, the question of value analysis arises. Certainly, a part of that value analysis was determining the need in the first

place. However, here to be discussed is the primary question of cost.

Cost(s) of a card programmable calculator should be viewed as system(s) cost. Accordingly, cost(s) to be considered are more than just the purchase of a calculator. They include a) initial machine cost, b) cost of additional support such as program card libraries to be purchased or published, text materials, replenishment items, etc., c) recurring cost, i.e., replacement and/or repair cost (this is primarily a question of machine failure rates).

The decisionmaker must determine (or make the best estimate) each of these costs for the various systems on the market, and then, compare them as to the need to be satisfied and the money he is willing to spend.

It is up to the decision maker to decide the weight to be given to each particular item of the analysis. For instance, initial machine cost may be determined to be more important than reliability or vice versa. As an aid in making these many judgements, the decision maker ought to obtain the benefit of the knowledge of as many users as practicable.

Necessarily, the end use of the system(s) will likely be the major consideration in the analysis of costs and benefits. There are no hard and fast rules concerning any particular item. Again, it is up to the decision maker to determine which system(s) will satisfy the needs and the money he is willing to spend to obtain the best value.

However, the decision maker must also consider at least these two factors:

(1) Increased simplicity, speed, or convenience (which can be gained from the new calculator) not available under the current procedures.

(2) Additional capabilities which can be expected to accrue as expertise on the new calculator(s) occurs.

Most purchasing decisions appear to be based more upon the former than the latter. In the opinion of the authors, the latter is much more important. Thus decision makers should assume such benefits will be available to higher levels if more capable, more convenient calculators are purchased.

Manufacturer's suggested retail prices, as of this writing (March 1977) are:

SR-52	$249.95
HP-67	$450.00
HP-97 (Includes Printer Capability)	$750.00
NS-7100 (Projected)	$400.00
TI-59 (Projected)	$300.00
PC-100A Printer for SR-52 or TI-59:	$199.95
TI-58	$125.00

C. ALGEBRAIC VS REVERSE POLISH NOTATION

1. Description

The machines compared herein operate either in an Algebraic Operating System (AOS) (SR-52) or in the Reverse

Polish Notation (RPN) (HP-67) system.

The AOS enthusiast states, "I put the problem into the machine as it is normally written down", while the RPN enthusiast states, "I put the problem into the machine as it is normally calculated." Neither statement is entirely correct. For instance, consider the following formula:

$$Q = \sqrt{2KD/k_c}$$

For computation, the following (conceptual) sequences must normally be followed on the two machines: (The machines have no actual commas; commas are inserted below to group concepts only.)

AOS	RPN
2, XK, XD, $+k_c$, =, $\sqrt{\ }$	2 ENTER, KX, DX,
or	k_c+, $\sqrt{\ }$
(2, XK, XD, $+k_c$), $\sqrt{\ }$	

The reader should note that the formula had to be rewritten in all cases to enable machine computations. Neither AOS nor RPN allow entry of the square-root function operator prior to completion of all other operations. This problem must be worked from the inside to the outside in all cases: i.e., in all cases the machine must be told to compute the

result of $(2KD/k_c)$ and <u>then</u> be told to find the square root of that result. It cannot, as <u>one</u> concept, be told to compute the square root of $(2KD/k_c)$. The same argument holds for sin x, cos x, tan x, ln x, log x, x!, x^2, and 1/x operations on both machines, as well as to the Y^x and $\sqrt[x]{Y}$ two function operations. Obviously, then, the AOS user uses a considerable amount of RPN notation.

The AOS enthusiast also argues that he doesn't have to learn a new language. Again, there is disparity – in addition to the examples of the previous paragraph. Returning to the generalized formula, $Q = \sqrt{2KD/k_c}$, note that there are neither any parentheses nor any internal equality signs on the right-hand side of the equation as were required for the AOS example above. General formulas do not always have parentheses, and rarely, if ever, show implied internal equality signs. Instead, it is assumed that the user will intuitively group variables and mathematical operators as if these <u>implied</u> symbols were, in fact, present. This being the case, the AOS user must usually stop to remember where the <u>implied</u> symbols go and insert them. On the other hand, the RPN user must remember to <u>always</u> enter the operator <u>after</u> the variable. Hence, it is clear that for either AOS or for RPN, the user must, to some extent, "learn a new language". The RPN enthusiast usually argues that he must only enter the variable(s) and then "tell the calculator what to do with them". Truly, the RPN user must remember

only one rule: The operator(s) is(are) always entered after the variable(s).

Only two registers are required to solve a simple problem such as W + X + Y + Z in either AOS or RPN. In AOS, additional registers will allow varied grouping of the variables with parentheses, but will not permit additional forms to solve the same problem; i.e., regardless of parentheses, each operator is entered before the variable it will ultimately operate on. In RPN, additional registers will allow the problem to be structured in varied ways, all of which separate variables and their operators to different degrees. For example:

	AOS	RPN
(Base Case)	W + X + Y + Z =	W Enter X + Y + Z +
or	W + X + (Y + Z) =	W Enter X + Enter Y Enter Z ++ *
or	W + (X + Y + Z) =	W Enter X Enter Y + Z + +
or	W + (X + (Y + Z)) =	W Enter X Enter Y Enter Z + + +
or	(W + X) + (Y + Z) =	W Enter X + Enter Y Enter Z + + *
		* or:
		W Enter X + Y Enter Z + +

In short, an RPN machine gives flexibility that is not available in an AOS machine. This feature becomes a powerful benefit when writing programs in RPN. It also saves the time of rewriting an equation [begin inside, work out, operator after variable], an option the AOS user usually does not have if he wants the most efficiency [3].

Using Hewlett-Packard terms [4], the automatic stack operates as follows:

Data is entered:

5 ENTER 6 ENTER 7 ENTER 8

The stack registers then can be visualized as:

5.00	T	
6.00	Z	
7.00	Y	
8.	X	(DISPLAY)

Pushing the "roll-down" key once results in the following change:

8.00	T	
5.00	Z	
6.00	Y	
7.00	X	(DISPLAY)

Now, pushing the "roll-up" key twice changes the display to:

6.00	T	
7.00	Z	
8.00	Y	
5.00	X	(DISPLAY)

Adding 5 to 5 in display by pressing 5 + changes the stack to:

7.00	T	
7.00	Z	
8.00	Y	
10.00	X	(DISPLAY)

As noted above, keying in 5 pushed 6 out of the stack. When + was pressed, the two 5's were added to put 10 in display and the stack dropped. The 7 in T is duplicated in Z. The dropping and lifting of the stack enables the user to position intermediate results in long calculations without the necessity of reentering the numbers. The stack coupled with RPN creates an efficiency of the language that is not within the capability of AOS. On the other hand, AOS programs are easier to "translate" because of the almost direct algebraic notation used therein.

2. Accuracy

Accuracy of the last several digits displayed by the SR-52 or HP-67 subsequent to executing calculations varies slightly between the machines. For example, refer to the "Internal Rate of Return" (IRR) nine place results calculated in Section IV.E(9)C.(8). The accuracy of either calculator is adequate for all but the most esoteric uses.

3. Execution Time

Execution time is generally slightly less on the SR-52 than on the HP-67 for identical functions. The SR-52 executes exponentiation to positive powers much faster than the HP-67; conversely, the SR-52 creates an error condition with the correct, but unsigned, number in the display when attempting to exponentiate to negative powers. Thus the SR-52 programmer must include three steps such as IF ERR, A; +/- or five steps such as IF ERR, 123; +/- (to ensure that the program will continue) if the program can accept negative

exponentiation values. Even when such steps are required, execution time is less on the SR-52 than in the normal execution time on the HP-67. Then the HP-67 runs slower, but uses less program space for negative exponentiation.

D. BASIC CALCULATOR PROGRAMMING CONCEPTS

Basic programming is nothing more than routinization of repetitively occurring mathematical equations in terms of equation variables as stored by the user into particular storage registers. For example, consider the calculation of $\sqrt{9 \text{ X } 26/7}$. One routine mental (or pencil-and-paper) approach to this calculation is to multiply 9 X 26 yielding the product of these two terms, dividing this product by 7 yielding a quotient and, finally, extracting the square root of the quotient. This process can be manually keyed into SR-52 or HP-67 calculators as follows:

	SR-52	HP-67
	9 X 26	9 Enter 26 X
	+ 7 =	7 +
	2nd $\sqrt{x}$	f $\sqrt{x}$
Resulting in:	5.78174467	5.781744670

Naturally, a program written specifically to generate this unique result would never be written unless one had some reason to constantly be reminded that $\sqrt{9 \text{ X } 26/7}$ = 5.78174467(0). Conversely, a program written

to generate $\sqrt{A \times B/C}$ for any given value of the variables might prove most useful. Such a program is readily accomplished merely by storing the value of A in Storage Register (Reg) #1, the value of B in Reg #2, the value of C in Reg #3, and defining the calculation process in program memory. This translation process is best begun by rethinking $\sqrt{A \times B/C}$ in language the calculator can understand, i.e., as $\sqrt{(\text{Reg \#1 Contents}) \times (\text{Reg \#2 Contents}) \div (\text{Reg \#3 Contents})}$. For calculator keying, the Recall (RCL) instruction orders the proper storage register contents into operation. (In SR-52, the primary storage registers are numbered 00 through 19; in HP-67 as 0 through 9 and Secondary (S) 0 through S9.) Hence, $\sqrt{A \times B/C}$ translates in concept as:

SR-52	HP-67
$\sqrt{\text{RCL 01} \times \text{RCL 02} \div \text{RCL 03}}$	$\sqrt{\text{RCL 1} \times \text{RCL 2} \div \text{RCL 3}}$

The manual keystrokes to store the variable values used above into appropriate storage registers would be:

SR-52	HP-67
9 STO 01	9 STO 1
26 STO 02	26 STO 2
7 STO 03	7 STO 3

The manual keystrokes to accomplish the previous example would then be:

SR-52	HP-67
RCL 01 X RCL 02	RCL 1 ENTER RCL 2 X
+ RCL 03 =	RCL 3 +
2nd $\sqrt{x}$	f $\sqrt{x}$

In order to convert each of the above keystroke sequences into a program, it is only necessary to assign each subroutine a beginning point, or Label (LBL) and a stopping point. Labeling requires three keystrokes in either the AOS HP-67 or the SR-52: the stopping point requires only one keystroke. For a Label named "A", these keystrokes would be:

	SR-52	HP-67
LABELING:	2nd LBL A, normally abbreviated: *LBL A	f LBL A
ENDING:	HLT (Halt)	R/S (Run/Stop)

[Program space actually required is less on the HP-67: see section IV.E(6).]

The respective Labels can be used either for storing the variables in desired registers or for operating on the stored variables. Hence, an entire program for the previous example might be:

SR-52	HP-67
*LBL A STO 01 HLT	f LBL A STO 1 R/S
*LBL B STO 02 HLT	f LBL B STO 2 R/S
*LBL C STO 03 HLT	f LBL C STO 3 R/S
*LBL D	f LBL D
RCL 01 X RCL 02	RCL 1 ENTER RCL 2 X
÷ RCL 03 =	RCL 3 ÷
*$\sqrt{x}$	f $\sqrt{x}$
HLT	R/S

This program can be manually keyed into program memory exactly as listed above. The manual keystroke sequence to calculate the prior example, on either an SR-52 or HP-67 calculator, is now reduced to eight keystrokes as follows: (Commas are never keystrokes, but are used herein to clarify operations): 9 A, 26 B, 7 C, D. The calculator will now respond almost immediately with the answer, 5.78174467(0). More importantly, the calculator will not "forget" the contents of any storage register unless those contents are changed by the user. Thus, in order to calculate $\sqrt{9 \text{ X } 32.5 + 7}$ (immediately following calculation of the previous example) it is only necessary to change the value of "B" from 26 to 32.5 and rerun the calculation process defined by Label D. This is accomplished by the keystrokes 32.5 B, D. The calculator will this time respond almost immediately with 6.464187055 (AOS) or 6.464187056 (RPN). Similarly, a completely new problem, such as $\sqrt{44.3 \text{ X } 13.6 \div 89.66667}$ can be entered as 44.3 A, 13.6 B, 89.66667 C, D--yielding 2.59212414(0), etc.

The programs developed above are quite basic and thus are not particularly efficient. Both can be substantially refined. A more complete discussion of advanced programming follows.

E. ADVANCED PROGRAMMING TECHNIQUES FOR SR-52 OR HP-67

1. Introduction

Basic calculator programming concepts are introduced in the previous subsection but an in-depth discussion of basic and intermediate programming techniques is not provided herein since such discussion is readily available in manufacturer's handbooks, manufacturer's promotional literature, user club publications and other sources listed in the bibliography. Instead, the discussion which follows is designed to clarify the difference between AOS and RPN advanced programming techniques, regardless of the reader's prior familiarity with either system. Of course, since the following discussion constantly compares the two systems, readers already familiar with either AOS or RPN are likely to find this discussion to be lighter reading. On the other hand, this information is also designed to help readers who are presently unfamiliar with either system to determine which system can best meet their personal or organizational needs. In this respect, the information provided is especially designed to enable managers, staff analysts and procurement officers to determine which system is optimal for the organizational requirements being encountered. As far as

can be determined by the authors, the only currently available literature which significantly facilitates such management and procurement decisions is published by the respective manufacturers. Accordingly the following discussion attempts to create an unbiased comparison which can be used for managerial/procurement decisions.

Data obtained from the various manufacturers by the authors — sometimes on a non-disclosure basis concerning specifics — indicates, in general, that the comparisons provided herein are likely to stand inviolate for at least ten years. The introduction of new machines within the next decade, as currently envisioned by the manufacturers, will do little to change the analysis which follows. Thus, readers in management positions are especially encouraged to study the following analysis in detail. On the other hand, persons unfamiliar with either AOS or RPN should be able to determine which system best fits their individual idiosyncracies and personal preferences after studying the material which follows. Hence, this material should greatly enhance <u>personal</u> purchasing decisions as well as organizational purchasing decisions. This information should be especially useful to students, educators, or others considering the purchase of a personal card-programmable calculator.

3. <u>Color Coding</u>

In order to minimize the number of keys required on the machines, all manufacturers use most keys for at least

two purposes – and sometimes three or four. So, most keys have a primary function and one or more secondary function(s). Typically, the primary function is centered in one color upon the flat upper surface of the key itself, whereas each secondary function is listed in a different color above the key, below the key, or upon an angled face of the key. Therefore, a key may have associated functions listed in one, two, three, or four different colors and the primary colors of the keys themselves vary according to purpose.

In order to enable the calculator to determine which listed key function is desired when a key is pressed, color-coded, dedicated, "Second-Function" keys are pressed <u>first</u> to designate secondary key functions similarly colored. Typically, the primary function listed upon a key is executed simply by pressing that key; the secondary function is executed by <u>first</u> pressing a second-function key (which matches color with the color of the desired secondary function) and <u>then</u> pressing the key; the alternate secondary function, if any, is executed by <u>first</u> pressing an alternate (third) second-function key (which matches color with the color of the third function) and <u>then</u> pressing the key, etc. AOS systems such as the SR-52 or TI-59 have one second function key (Yellow: 2nd) whereas the HP-67 has three (Yellow: f), (Blue: g), (Black: h). The AOS notation "2nd" corresponds directly with the thought process involved, i.e., use the matching-color 2nd function listed – whereas the HP-67

notation corresponds indirectly by using standard symbols for mathematical functions (f, g, h) such that the user can easily modify the thought process to: "Use the function of the key (f of key, g of key, h of key) by first pressing the color matched and appropriately labelled second function key (f, g, h)." The reader should note that the color coding greatly simplifies actual usage and complicates only the reading of documented programs by novice users, e.g., a novice user would tend to look at the keyboard, see what color a desired function is and then push appropriate keys to execute the function without difficulty. The novice is not required to memorize that $\sqrt{x}$ is always preceded by 2nd or *f* since the color coding, in actual usage, readily prompts appropriate action. On the other hand, the documentation of programs normally includes all keys which must be pressed, such that $\sqrt{x}$ becomes 2nd $\sqrt{x}$ or * $\sqrt{x}$ or *f* $\sqrt{x}$, which may take a little getting used to. However, new or different does not necessarily equate to difficult. Thus the often-heard cry of novice users that documented programs are "difficult to read" appears to be unfounded.

3. Programming Language

Fear of having to learn a "new language" in order to operate a card-programmable calculator is, in general, unfounded. True, the user may be required to supply implied parentheses or equality signs (AOS) or be required to always (RPN) or sometimes (AOS) enter the operator after the mathematical variables, and be required to become familiar with

a long list of abbreviations — but none of these requirements can be considered to be a new language. In fact, the "language" required by either AOS or RPN is best defined as merely a simple abbreviation system for normal mathematical language, similar to abbreviations that most high-school graduates are already familiar with. Thus, learning the language of the calculator is simply a matter of adapting prior personal abbreviation habits to the abbreviations listed on the calculator keys. Once the novice has learned to recognize the listed abbreviations, he is ready to operate or to program. Further, since many abbreviations are common to both AOS and RPN, individuals can quickly master a second system. Additionally, many of the abbreviations are phonetic or otherwise quite straightforward. Hence, it is feasible to learn the great majority of these abbreviations, adequate for almost all calculators on the market, in less than half a day.

Table 1 lists most abbreviations commonly found, as well as a brief definition of each abbreviation. (For full description of each function, the reader is referred to handbooks published by the various manufacturers.)

The first column in Table 1 lists abbreviations which are used by the authors to amplify documented programs in the remainder of this work, especially in the remarks sections of the programs themselves. This notation largely duplicates keystroke abbreviations found on the various calculators or amplifies such abbreviations. The reader

can, therefore, more easily translate any of the programs which follow — on either machine — by studying this consistent notational system in lieu of studying the particular keystrokes actually required. In other words, instead of learning two systems, the reader can concentrate on the one "translation system" which is provided throughout. Viewed in another way, this notational system is also a first step toward a universal calculator language; the average reader will find it useful for annotating his own future programs.

The reader is warned not to equate the charted list of key abbreviations to functional capabilities (see Appendix B for functional capabilities). Many functions require sequenced keystrokes and thus are not in Table 1; e.g., on the SR-52, the arc sine is executed by pressing INV SIN and e^x is executed by pressing INV Lnx, but neither ARC SIN nor e^x appear, on the SR-52, as key abbreviations.

The second column of Table 1 defines the abbreviations as used by the authors. Such use usually, but not always, corresponds to the designed primary use of the same abbreviation by the calculators. The abbreviations duplicate notation actually found on the machines to the maximum extent feasible, adding or changing only where necessary to achieve the desired consistent set of abbreviations which can then be used to amplify either HP-67 or SR-52 programs as discussed previously.

The final columns show the relationship between the definitions and the labeling used on the machines.

Direct correlation of both the abbreviation and its meaning to a key found on one of the calculators is indicated either by "P" (Primary function of one key) or by "*" (Secondary function of one key) or by S (Manual Switch) as listed under each calculator. Additionally, alternate abbreviations used on the calculators are listed opposite the appropriate definition. Finally, the entry "(OU)" in these columns means that the same abbreviation is used for some other use on the calculator in each case the other use can be found elsewhere in the same column. For example, "(OU)" is located in the right column opposite the left-column abbreviation "DEG", which is defined as "Degrees" for use in this study. Several entries below the "(OU)" entry in the same (right) column, "DEG" appears, opposite "DEG MODE" in the left column, which is the abbreviation used for "Degrees Trigonometric Mode" throughout this study. Other entries on this same latter line of Table 1 indicate both what the abbreviation "DEG" designates as used by the particular calculators and what "DEG MODE" designates as used by the authors, i.e., that the abbreviation "DEG" appears as a second-function key designation (*) on the HP-67 designating "Degrees Trigonometric Mode" and as a switch designation (S) on the SR-52 designating "Degrees Trigonometric Mode."

Hence, Table 1 defines how the authors use particular abbreviations throughout the remainder of this work; whether such usage corresponds directly to usage on the

particular machines, and (if the correspondence is not direct) how the same abbreviations are used on the calculators or what different abbreviations are used on the calculators.

Novice calculator users are advised to concentrate only upon the two left columns of Table 1. More advanced readers can use Table 1 to determine if a specific abbreviation used by this study also appears as an abbreviation on the SR-52 or HP-67. However, all readers are again warned that Table 1 lists abbreviations, not functional capabilities. After achieving basic familiarity, readers can restudy Table 1 and Appendix B, together with the discussion which follows, in order to better determine which calculator's system appears to best fit personal or organizational purchase parameters.

4. Key Code Systems

Both the HP-67 and SR-52 use a key code system which closely corresponds (for primary functions) to the location of each key in an imaginary superimposed, second quadrant, xy matrix. The y-value is read first, neglecting the minus sign; i.e., row, column. Thus the primary function of the key at topmost, leftmost (the A key) is coded 11 the primary function of the key at fourth row down, third column to the right is 43, etc. As one exception to this pattern, on both machines, numeric keys are directly coded 00, 01, ..., 09. This exception causes no confusion both because it is direct and because there is no "zero row" of keys.

TABLE I. KEY ABBREVIATIONS

Abbreviation	Meaning as Used by Authors	SR-52		HP-67	
A	User-defined Label	P		P	
A'	User-defined Label	*			
a	User-defined Label			*	
B	User-defined Label	P		P	
B'	User-defined Label	*			
b	User-defined Label			*	
BST	Backstep (Program Mode)	*		*	
C	User-defined Label	P		P	
C'	User-defined Label	*		*	
c	User-defined Label	*		*	
CHS	Change Sign of Display	P	+/-	P	
CLR	Clear	P	(OU)	P	
CLR	Clear Entry or Arrest Flashing Error	P:	CE	P	CLX
CLR DSP	Clear Display	P	CLR	P	CLX
CLR FLAG	Clear Flag			*	CF
CLR PRGM	Clear Program			*	CLPRGM
CLR REG	Clear (Primary) Registers			*	CLREG
COORD	Coordinates				
COS	Cosine	P		*	
COS^{-1}	Arc Cosine			*	
D	User-defined Label	P		P	
D'	User-defined Label	*			
d	User-defined Label			*	

TABLE I. (Continued)

Abbreviation	Meaning as Used by Authors	SR-52		HP-67	
DEC	Decimal				
DEC DEG	Convert DEC DEG(HR) DSP - Format to DEG(HR), MIN, SEC, DSP - Format			*	H.MS
DECR	Decrement by 1				
DEL	Delete Step (PRGM MODE)	*		*	
DEG	Degrees				(OU)
DEG DEC	Convert DEG(HR), MIN, SEC DSP-Format to DEC DEG(HR) DSP-Format	*	D.MS	*	H
DEG MODE	Degrees Trigonometric Mode	S	D	*	DEG
DEG RAD	Convert Degrees to Radians	S	R	*	R
DO	Compute or Execute				
DSP	Display or X-Register				(OU)
DSZ	Decrement DSP (or I-Reg) by 1, Skip Step if Result is Zero	*			
DSZ(i)	DSZ (Indirectly in REG Addressed by I-REG)			*	
E	User-defined Label	P		P	
E'	User-defined Label	*			
e	User-defined Label			*	
EEX	Enter Exponent	P	EE	P	
ENG DSP	Engineering Display Format				ENG
ENTER	Lift STACK; Enter DSP into STACK Y-REG			P	
ERR	Error			*	
e^x	Xth Power of e			*	
EXCH	Exchange	*	EXC	*	

TABLE I. (Continued)

Abbreviation	Meaning as Used by Authors	SR-52		HP-67	
EXP	Exponent				
f	2nd-Function Call-Key	P	2nd	P	
FORMAT	Set Display Format				
FUNC	Function				
FIX DSP	Fixed Decimal Display Format	*	FIX	P	DSP
FLG	Flag				
FLOAT PT	Floating Decimal Display Format				
FRAC	Fractional Portion			*	
g	2nd-Function Call-Key	P	2nd	P	
GRAD	GRADS TRIG MODE			*	GRD
GTO	Go To	P		P	
h	2nd-Function Call-Key	P	2nd	P	
(i)	I-Register			P	(OU)
IF ERR	If Error is Displayed (Flashing)	*			
IF FLAG	If Flag is Set	*	if flg	*	F?
IF x=y	If Display = Y-register			*	x=y
IF x≤y	If Display ≤ Y-register			*	x≤y
IF x≠y	If Display ≠ Y-register			*	x≠y
IF x>y	If Display > Y-register			*	x>y
IF x=0	If Display = zero	*	if zro	*	x=0
IF x≥0	If Display ≥ zero	*	if pos		
IF x≠0	If Display ≠ zero			*	x≠0
IF x<0	If Display < zero			*	x<0
IF x>0	If Display > zero			*	x>0

TABLE I. (Continued)

Abbreviation	Meaning as Used by Authors		SR-52		HP-67
INCR	Increment by 1				
IND	Indirect	*		P	(i)
INS	Insert Step (Program Mode)	P			
INT	Integer Portion			*	
INV	Inverse Function of ...	P			
ISZ	Increment DSP (or I-Reg) by 1; Skip Step if result is zero	*		*	
ISZ(i)	ISZ (In REG Addressed by I-REG)			*	
LBL	Label	*		*	
LBLf	Label			*	
LASTx	Entry Prior to Last Operation			*	LSTx
LIST	List Program	*			
LN	Logarithm, Base e	P	ln x	*	
LOG	Logarithm, Base 10	*		*	
LRN	Learn (Shift to Program Mode)	P		S	W/PRGM
MEM	Memory				
MERGE	Merge Steps (Program Mode			*	
ON/OFF	Switch Machine ON/OFF	S		S	
OPS	Operations				
OW	Otherwise				
PAPER	Advance Paper	*	pap		
PAUSE	Pause from Operation (for data entry)			*	
P→R	Convert Polar Coordinates to Rectangular		P/R		R

TABLE I. (Continued)

Abbreviation	Meaning as Used by Authors	SR-52			HP-67
PRI	Primary				
PRGM	Program				
PRGM MODE	Program Mode	P	LEARN	S	W/PRGM
PROD	Product (Multiplication in Register)	*			
P⇄S	Primary/Secondary Register Exchange			*	
R↓	Roll Down Stack Registers			*	
R↑	Roll Up Stack Registers			*	
RAD	Radians				(OU)
RAD→DEG	Convert Radians to Degrees			*	D
RAD MODE	Radians Trigonometric Mode	S	R	*	RAD
RCL	Recall	P		P	
RCL(i)	RCL (Indirectly from Register Addressed by I-REG)				
READ	Read Card	*			
RECT	Rectangular Coordinates				
REG/ REG	Register/Store in REG				(OU)
R→P	Convert Rectangular Coordinates to Polar	*			
REVU REG	Review Primary Register			*	REG
REVU STACK	Review Stack Register			*	STK
RND	Round Off			*	
RSET	Reset Counter to 000	*			
RTN	Return Control to Calling Routine (or Keyboard)	*		*	
RUN	Run Routine (Program)	P		P	R/S

TABLE I. (Continued)

Abbreviation	Meaning as Used by Authors	SR-52		HP-67	
s	Sample Standard Deviation			*	
SBR	Subroutine	P			
SCI DSP	Scientific Notation Display Format			*	
S_n	Secondary Register n (n=1,...,9)				
SIN	Sine	P		*	
SIN^{-1}	Arc Sine			*	
SPACE	No Operation (Skip Step or Space)			*	
SST	Single-Step (Program Mode)	P		P	
STACK	X,Y,Z,T Register Group				
SET FLAG	Set Flag (Turn On)	*	ST FLG	*	SF
STO	Store	P		P	
STO(i)	Store (Indirectly, in Register Addressed by I-REG)				
STOP	Stop (Halt)	P	HLT	P	R/S
SUM	Sum to (Add to Register)	P			
TAN	Tangent	P		*	
TAN^{-1}	Arc Tangent			*	
THRU	Through				
W/	With				
WRITE	Write Data Onto Card			*	W/DATA
X	Times, Multiplication Operator	P		P	
x	X-Register or Display				
$\overline{x}$	Arithmetic Mean			*	
X!	Factorial	*		*	N!

TABLE I. (Continued)

Abbreviation	Meaning as Used by Authors	SR-52		HP-67	
-x-	Flash Display (x-register)			*	
|x|	Absolute Value of x			*	ABS
$\sqrt{x}$	Square root of x	*		*	
x y	Exchange x and y register			*	
$x\sqrt{y}$	xth root of y	P			
x^2	Square of x-register (Display) value	P			
y	y-register	*			
y DEG +	Add y-register DEG,MIN,SEC to Display			*	
y^x	xth power of y	*		*	
z	z-register				
*	2nd-Function Key	P	2nd	P	f,g,h
+	Addition Operator	P		P	
.	Decimal Point	P		P	
÷	Division Operator	P		P	
=	Equality Operator	P			
==>	Implies				
(	Parenthesis, left	P			
)	Parenthesis, right	P			
%	Percentage			*	
%CH	Percent Change			*	
π	Pi (3.141492654)	*		*	
#	Number				
-	Subtraction Operator	P		P	

Table I. (Continued)

Abbreviation	Meaning as Used by Authors	SR-52	HP-67
$\Sigma+$	SUM: x to S4, x^2 to S5, y to S6, y^2 to S7, xy to S8, +1 to S9		P
$\Sigma-$	SUM: -x to S4, $-x^2$ to S5, -y to S6, $-y^2$ to S7, -xy to S8, -1 to S9		*
0	Zero	P	P
1	One	P	P
1/x	Reciprocal of Display	*	*
2	Two	P	P
3	Three	P	P
4	Four	P	P
5	Five	P	P
6	Six	P	P
7	Seven	P	P
8	Eight	P	P
9	Nine	P	P
10^x	x^{th} power of 10		*

Notes: P = Primary function of one key found on the calculator

* = Secondary function of one key found on the calculator

S = Manual Switch; not a key

The machines differ only concerning the coding system for secondary functions. Although the HP-67 can handle one, two, or three two-digit numbers in its coding displays when in programming mode, the SR-52 can handle only one two-digit number in its coding display. Thus, secondary functions are coded on the HP-67 exactly like primary functions, the only difference being that two or three two digit numbers are displayed for secondary function entries which require two or three keystrokes, respectively. Thus f LOG on the HP-67 is displayed as 31 53 and f LBL A is displayed as 31 25 11, etc. Conversely, on the SR-52, the coding system itself is modified to handle secondary functions. Since the calculator is only 5 keys wide, the column code for all primary functions is defined by the digits 1 through 5, leaving 6 through 9 and 0 available. Further, all secondary functions on the SR-52 are printed above the key. Hence, by mentally folding the remaining available digits over the first five digits in each row, each secondary function is assigned a number of its own. As an example, the coding for the third and fourth rows of the SR-52 is as follows:

Third Row:	Secondary Functions:	36	37	38	39	30
	Primary Functions:	31	32	33	34	35
Fourth Row:	Secondary Functions:	46	47	48	49	40
	Primary Functions:	41	42	43	44	45

Although the need for ten codes per row puts the last secondary code out of sequence in each row, the system does have logic and is easily learned: higher locations of abbreviations on the keyboard itself correspond to higher-numbered keycodes (with exception of the right column secondary functions). The above method solves both the coding for secondary functions and the two-digit display limitation. Since the secondary-function code cannot be created without pressing the "2nd" key, there is no need to ever display the key code for the "2nd" key – as is required to distinguish between the three available second keys on the HP-67. Hence, "2nd LOG" becomes 28, period, on the SR-52: "2nd LBL A" becomes 46 (2nd LBL) as one step and 11 (A) as another step; etc.

5. Key Coding Formats

Key coding displays, on both machines, naturally include the program step number. Thus, if the examples above begin at step #136, the complete formats would be:

SR-52		HP-67	
Keystrokes	Display	Keystrokes	Display
2nd LOG	136 28	f LOG	136 31 53
2nd LBL	137 46	f LBL A	137 31 25 11
A	138 11		

Such displays are extremely useful for verifying or editing programs. The user can always determine what key instruction is stored as a given step number by merely counting (down

and over) the rows and columns indicated by the respective keycode system.

6. HP-67 and SR-52 Program Storage Capacities

It is often assumed that since the HP-67 can store up to three keycodes per step of program memory whereas the SR-52 stores only one, the effective program capacity of the HP-67 must be three times as large. This is simply untrue, as evidenced above, because the third HP-67 keycode is never used for anything other than to designate one of the second-function keys, a designation that is never separately required at all on the SR-52. The HP-67 program capacity is slightly larger than the SR-52 capacity, but the reason is the way keystrokes are merged per step on the HP-67, not because three keycodes are displayed per step. This merging applies primarily to all addressing and labeling. Thus, returning to step 137 in the above example, the SR-52 code "46" relays the same amount of information as do the HP-67 codes "31 25". But the HP-67 program capacity is increased because the "A" requires an additional step for its code on the SR-52, whereas the "A" is merged as "11" in the codes for step 137 on the HP-67. Similarly, recalling or storing data in a given register requires three steps on the SR-52 but only one step on the HP-67. Hence, the maximum ratio of obtainable program capacities, ever encountered by the authors is approximately 2.4:1, with a more common long-term ratio of between 1.3:1 and 1.6:1, in favor of the HP-67,

for advanced programming. Conversely, novice programmers commonly encounter a ratio slightly higher than 2:1. As an example, Figures 2 and 3 (Single or Bivariate Statistical Analysis) are written with identical algorithms and program sequencing on each machine, disregarding special functions available on each machine which could be used to significantly shorten the programs (HP-67 in particular). In other words, these programs are intentionally written inefficiently in order to achieve a typical comparison of the number of program steps actually required to place identical programs in either machine. The result is 2.196:1, for these particular programs. The ratio would favor the HP-67 even more if special functions, such as the Σ+key available only on the HP-67, are included; conversely, program optimization techniques as addressed later in this study will do more to reduce SR-52 steps (for the common functions) than to reduce HP-67 steps, because the HP-67 steps are more compact in the first place. In summary, many programs do not require extensive use of special functions found on only one of the machines. In such cases, the program capacity ratio appears to be between 1.3:1 and 1.6 to one in favor of the HP-67, but certainly is not 3:1 except in unique cases.

7. Magnetic Card Formats

Standard SR-52 and HP-67 magnetic cards are reproduced (actual size) below. The lower reproduction is a HP-67 card placed upon the backside of a SR-52 to better show relative sizes.

Figure 1

Single or Bivariate Statistical Analysis (SR-52)

(Sheet 1 of 7)

USER KEYED LABELS									
	A'	N'	B'		C'	Calculate r	D'		D'	n
	A	X	B	Y	C	Calculate Regression	D	X*/Y	E	Y*/X

FLAGS: OFF/ON

0		X	
1		X	
2		X	
3		X	
4		X	

OTHER LABELS

NOTES

See Sheets 6 and 7.

REGISTERS

0	
1	LAST X
2	Σx_i
3	Σx_i^2
4	n
5	LAST Y
6	Σy_i
7	Σy_i^2
8	$\Sigma x_i y_i$
9	ns^2_y
0	$\bar{x}$
1	$\bar{y}$
2	r
3	nsxy
4	S_x
5	S_y
6	$\hat{b}$
7	ns^2
8	$\hat{a}$
9	

SET STATUS

DISPLAY		TRIG	
	SCI	X	DEG
	ENG		RAD
	FIX		GRAD
X	FLOATING PT		

STEP	KEY CODE	KEY ENTRY	
000	46	*LBL	
1	11	A	COMPUTE X VALUES
2	42	STO	
3	00	0	
4	01	1	
5	44	SUM	
6	00	0	
7	02	2	
8	40	*x^2	
9	44	SUM	
010	00	0	
1	03	3	
2	01	1	
3	44	SUM	
4	00	0	
5	04	4	
6	43	RCL	
7	00	0	
8	02	2	
9	55	÷	
020	10	*E'	
1	95	=	
2	42	STO	
3	01	1	
4	00	0	
5	40	*x^2	
6	65	x	
7	10	*E'	
8	95	=	
9	94	+/-	

STEP	KEY CODE	KEY ENTRY	NOTES
030	85	+	
1	43	RCL	
2	00	0	
3	03	3	
4	95	=	
5	42	STO	
6	01	1	
7	07	7	
8	55	÷	
9	10	*E'	
040	95	=	
1	30	*$\sqrt{x}$	
2	42	STO	
3	01	1	
4	04	4	
5	10	*E'	
6	56	*RTN	
7	46	*LBL	
8	10	*E'	n counter
9	43	RCL	
050	00	0	
1	04	4	
2	56	*RTN	
3	46	*LBL	
4	12	B	compute Y values
5	42	STO	
6	00	0	
7	05	5	
8	44	SUM	
9	00	0	
060	06	6	
1	40	*x^2	
2	44	SUM	
3	00	0	
4	07	7	
5	53	(	
6	43	RCL	
7	00	0	
8	06	6	
9	55	÷	
070	10	*E'	
1	95	=	
2	42	STO	
3	01	1	
4	01	1	
5	40	*x^2	
6	65	x	
7	10	*E'	
8	95	=	
9	94	+/-	

STEP	KEY CODE	KEY ENTRY	NOTES
080	85	+	
1	43	RCL	
2	00	0	
3	07	7	
4	95	=	
5	42	STO	
6	00	0	
7	09	9	
8	55	÷	
9	10	*E'	
090	95	=	
1	30	*$\sqrt{x}$	
2	42	STO	
3	01	1	
4	05	5	
5	43	RCL	
6	00	0	
7	01	1	
8	65	X	
9	43	RCL	
100	00	0	
1	05	5	
2	95	=	
3	44	sum	
4	00	0	
5	08	8	
6	56	*RTN	
7	46	*LBL	
8	13	C	compute Regression
9	43	RCL	
110	00	0	
1	08	8	
2	75	-	
3	53	(	
4	53	(	
5	43	RCL	
6	01	1	
7	01	1	
8	65	X	
9	43	RCL	
120	01	1	
1	00	0	
2	54	)	
3	65	X	
4	10	*E'	
5	54	)	
6	95	=	
7	42	STO	
8	01	1	
9	03	3	

STEP	KEY CODE	KEY ENTRY	NOTES
130	55	÷	
1	43	RCL	
2	01	1	
3	07	7	
4	95	=	
5	42	STO	
6	01	1	
7	06	6	
8	65	X	
9	43	RCL	
140	01	1	
1	00	0	
2	95	=	
3	94	+/-	
4	85	+	
5	43	RCL	
6	01	1	
7	01	1	
8	95	=	
9	42	STO	
150	01	1	
1	08	8	
2	56	*RTN	
3	46	*LBL	
4	16	*A'	N'
5	02	2	
6	65	X	
7	43	RCL	
8	01	1	
9	04	4	
160	95	=	
1	55	÷	
2	53	(	
3	93	.	
4	00	0	
5	02	2	
6	05	5	
7	65	X	
8	43	RCL	
9	01	1	
170	00	0	
1	54	)	
2	95	=	
3	81	HLT	
4	46	*LBL	
5	15	E	Y*/X
6	65	X	
7	43	RCL	
8	01	1	
9	06	6	

STEP	KEY CODE	KEY ENTRY	NOTES
180	95	=	
1	85	+	
2	43	RCL	
3	01	1	
4	08	8	
5	95	=	
6	81	HLT	
7	46	*LBL	
8	14	D	X*/Y
9	75	-	
190	43	RCL	
1	01	1	
2	08	8	
3	95	=	
4	55	÷	
5	43	RCL	
6	01	1	
7	06	6	
8	95	=	
9	81	HLT	
200	46	*LBL	
1	18	*C'	Compute r
2	43	RCL	
3	01	1	
4	03	3	
5	55	÷	
6	53	(	
7	10	*E	
8	65	X	
9	53	(	
210	43	RCL	
1	01	1	
2	04	4	
3	65	X	
4	43	RCL	
5	01	1	
6	05	5	
7	54	)	
8	54	)	
9	95	=	
220	42	STO	
1	01	1	
2	02	2	
3	81	HLT	END OF PROGRAMMABLE MEMORY
4			
5			
6			
7			
8			
9			

FIGURE 1

Single or Bivariate Statistical Analysis (SR-52)

Program Description, Equations, Variables, etc.

This program provides $\bar{x}$, s_x, $\bar{y}$, s_y, b, a, r, x* given y, y* given x for bivariate samples. In addition, N' (optimum sample size with 95% confidence) may be determined using data from x_i calculation.

a) N' is computed with the formula

$$\left(\frac{\sigma^2 x_i}{.025 \bar{x}_i} \right)^2$$

described in Chapter 12 of the Production Handbook; Carson, Bolz and Young; Ronald Press, N.Y.; 1972.

b) The balance of the program is based upon Chapters 9 and 10, Introductory Statistics; Zehna; Prindle, Weber & Schmidt, Inc, Boston; 1974.

c) Single variable samples can be analyzed for $\bar{x}$, s_x and N'

d) Confidence level for N' may be changed by inserting a different $\alpha/2$ in steps 164-166.

Note: *E' is used for a subroutine in the program to recall n. Pressing *E' will place n in display.

Step	User Instructions	Input Data/Units	Press	Output Data/Units
1.	Record program and initialize:			
2.	a) for single variable sample	x_i		x data
	(n will be in display after each x_i)			
	b) for bivariate sample	x_i	A	x data
	(last $(x_i)(y_i)$ will be in display)	y_i	B	y data
	c) after x_i and y_i are entered		C	
	linear regression is calculated			
	d) estimated correlation coefficient		*C'	r
	can now be calculated			
	e) N' is calculated from x_i data (in A)		*A'	N'
	f) X* may be calculated by placing a			
	Y in display and pressing D	Y	D	X*
	g) Y* may be calculated by placing an	X	E	Y*
	X in display and pressing E			
	h) balance of data may be recalled			
	using RCL and appropriate			
	register number.			

Figure 2

Single or Bivariate Statistical Analysis (HP-67)

USER KEYED LABELS	a	b	c	d	e
	A Xi	B Yi	C Calculate	D X*/Y	E Y*/X

FLAGS: OFF/ON

0		X	
1		X	
2		X	
3		X	

OTHER LABELS

NOTES

See Sheets 6 and 7

REGISTERS

0	Σx_i
1	$\bar{x}$
2	S_x
3	$\Sigma x^2 i$
4	$\bar{y}$
5	S_y
6	Σy_i
7	Σy_i^2
8	$\Sigma x_i y_i$
9	n
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
A	nS_x^2
B	nS_y^2
C	nSxy
D	Last $x/\bar{b}$
E	Last $y/\hat{a}$

SET STATUS

DISPLAY		TRIG	
	SCI__		DEG
	ENG__		RAD
	FIX__		GRAD
	FLOATING PT		

STEP	KEY CODE	KEY ENTRY	
0			
1	31 25 11	CLBL A	CALCULATE X values
2	33 14	STO D	
3	33 61 00	STO +0	
4	32 54	gx^2	
5	33 61 03	STO +3	
6	01	1	
7	33 61 09	STO +9	
8	34 00	RCL 0	
9	34 09	RCL 9	
010	81	÷	
1	33 01	STO 1	
2	32 54	gx^2	
3	34	09	
4	71	X	
5	42	CHS	
6	34 03	RCL 3	
7	61	+	
8	33 11	STO A	
9	34 09	RCL 9	
020	81	÷	
1	31 54	f√X	
2	33 02	STO 2	
3	34 09	RCL 9	
4	84	R/S	
5	31 25 12	fLBL B	CALCULATE Y values
6	33 15	STO E	
7	33 61 06	STO +6	
8	32 54	gx^2	
9	33 61 07	STO +7	

STEP	KEY CODE	KEY ENTRY	NOTES
030	34 06	RCL 6	
1	34 09	RCL 9	
2	81	÷	
3	33 04	STO 4	
4	32 54	gx^2	
5	34 09	RCL 9	
6	71	X	
7	42	CHS	
8	34 07	RCL 7	
9	61	+	
040	33 12	STO B	
1	34 09	RCL 9	
2	81	÷	
3	31 54	$f\sqrt{X}$	
4	33 05	STO 5	
5	34 14	RCL D	
6	34 15	RCL E	
7	71	X	
8	33 61 08	STO +8	
9	84	R/S	
050	31 25 13	fLBL C	CALCULATE Regression
1	34 08	RCL 8	
2	34 09	RCL 9	
3	34 01	RCL 1	
4	34 04	RCL 4	
5	71	X	
6	71	X	
7	51	-	
8	33 13	STO C	
9	34 11	RCL A	
060	81	÷	
1	33 14	STO D	
2	34 01	RCL 1	
3	71	X	
4	42	CHS	
5	34 04	$CL 4	
6	61	+	
7	33 15	STO E	
8	84	R/S	
9	32 25 11	gLBL a	CALCULATE N'
070	34 02	RCL 2	
1	02	2	
2	71	X	
3	83	.	
4	00	0	
5	02	2	
6	05	5	
7	34 01	RCL 1	
8	71	X	
9	81	÷	

STEP	KEY CODE	KEY ENTRY	NOTES
080	32 54	gX^2	
1	84	R/S	
2	32 25 13	gLBL c	CALCULATE r
3	34 13	RCL C	
4	34 02	RCL 2	
5	34 05	RCL 5	
6	34 09	RCL 9	
7	71	X	
8	71	X	
9	81	÷	
090	84	R/S	
1	31 25 14	fLBL D	CALCULATE $X^*/^Y$
2	34 15	RCL E	
3	51	-	
4	34 14	RCL D	
5	81	÷	
6	84	R/S	
7	31 25 15	CLBL E	CALCULATE Y*/X
8	34 14	RCL D	
9	71	X	
100	34 15	RCL E	
1	61	+	
2	84	R/S	
3	32 25 15	fLBL e	RECALL n
4	34 09	RCL 9	
105	84	R/S	END OF PROGRAM. (End of Programmable Memory at Step #224)
6			
7			
8			
9			
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			

FIGURE 2
Single or Bivariate Statistical Analysis (HP-67)

Program Description, Equations, Variables, etc.

1. This program provides $\overline{X}$, Sx, $\overline{Y}$, Sy, b, â, r, X* given Y, Y(given X for bivariate samples. In addition, N' (optimum sample size with 95% confidence) may be determined using data from X_i calculation.

   a) N' is computed with the formula

$$\left(\frac{2\sigma_{xi}'}{.025\overline{x}_i} \right)^2$$

   described in Chapter 12 of *Production Handbook*; Carson, Bolt and Young; Ronald Press, N.Y., 1972.

   b) The balance of the program is based upon Chapters 9 and 10, Introductory Statistics; Zehna; Prindle, Neber & Schmidt, Inc., Boston; 1974.

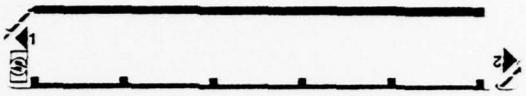
   c) Single variable samples can be analyzed for $\overline{x}$, Sx and N'.

   d) Confidence level may be changed by inserting a different $\alpha/2$ in Steps 73-76.

Step	User Instructions	Input Data/Units	Press	Output Data/Units
1.	Record program and initialize			
	a) for single variable sample (n will be in display after each X_i)	X_i	A	X data
	b) for bivariate sample (Last $(x_i y_i)$ will be in display)	X_i	A	X data
		Y_i	B	Y data
	c) After X_i and Y_i are entered linear regression is calculated		C	
	d) Estimated correlation coefficient can now be calculated		c	r
	e) N' is now calculated from X_i data (in A)		a	N'
	f) X* may be calculated by placing a Y in display and pressing D		Y	X*/Y
	g) Y* may be calculated by placing an X in display and pressing E		X	Y*/X
	h) balance of data may be recalled using RCL and appropriate register number.			

SR-52
STANDARD
CARD

HP-67
STANDARD
CARD



HP-67 CARD
ON
SR-52 CARD

Both the SR-52 and HP-67 have 5 user-definable keys as the top row of keys, labeled A through E. The second functions of each of these are also user-definable, labeled A' through E' on the SR-52 or labeled a through e on the HP-67. The functions defined for each label are written on the card as desired by the programmer. The following notation is used throughout this work to represent the 10 user keyed labels, as those labels would actually be completed upon the card itself:

USER KEYED LABELS	—	—	—	—	—
	A	B	C	D	E

The labels for the top row, of course, are completed to correspond to the keys on the machine under discussion in each case.

8. Recording or Reading Magnetic Cards

After keying a program into memory, the program can be permanently stored on a magnetic card by passing the card through the card reader. Initializing the card reader to record requires the proper setting of a switch on the HP-67 or several keystrokes on the SR-52. Data from storage registers can also be permanently stored on cards. Initializing the card reader for data requires the setting of a switch and two keystrokes on the HP-67; a special prior program card must be used together with blank data card on the SR-52, using two keystrokes with each card.

Stored programs or data remains on the cards until the information in intentionally altered by the user; i.e., the cards are reusable or can be permanently filed for dedicated purposes. Various systems are used on the different calculators to prevent accidental altering of cards, or to abort protections used to prevent accidental destruction of card information in order to reuse "permanent" cards. All of these systems work well, hence, these differences will not be addressed herein.

Reading previously programmed magnetic cards requires only the proper setting of a switch on the HP-67; two or three keystrokes per card side are required on the SR-52. Additional machine functions which are automatically executed when a card is read differ between calculators. This subject is addressed in Section IV.E.10.h.

9. Advanced Programmability Comparisons, SR-52 and HP-67

The authors believe that this work is relatively unbiased toward these two machines. Both have unique capacities and constraints which can apply to a given situation, but full discussion of each would unnecessarily triple the length of this section. Thus, programming concepts in this section are presented on whatever machine appears to be most pertinent for that particular concept, with no attempt to "yes but" the alternate machines alternate capabilities for some other concept. Further, since more readers are expected to already be familiar with algebra than with reverse polish notation – and for uniformity – SR-52 programs are normally discussed first. This is not intended to degrade the HP-67 or HP-97 in any manner.

a. General – Internal Rate of Return (IRR) As A Model

In order to provide a problem simple enough to be readily understood by the majority of readers, yet intricate enough to necessitate complex programming techniques, an Internal Rate of Return program is developed herein, upon the HP-67 and SR-52, as a vehicle for clarifying differences between these machines and programming systems. These programs are also compared with literature (programs) available from the manufacturers in order to yield additional insights concerning both available programs and programming potentials and limitations.

b. Internal Rate of Return (IRR) Concepts

IRR programs incorporate concepts involving the time value of money; specifically, the net present value (NPV) of a series of n future (periodic) cas flows (CF's) CF_1, CF_2, ..., CF_n, after the incurrence of some initial investment. The discrete interest rate (i) which will make the sum of discounted cash flows equal the initial investment is defined as the IRR, and reflects the effective discrete interest rate that will be earned upon the investment. For a series of twenty future cash flows, using the above notation, the formula for NPV is:

$$NPV = \sum_{n=1}^{20} \frac{CF_n}{(1+i)^n} - INVEST$$

A negative NPV indicates that, at the chosen interest rate, a shortfall (below the amount which would be expected at that interest rate) equal to the magnitude of the negative NPV will occur; a positive NPV indicates that, at the chosen interest rate, an <u>additional</u> gain (above the amount which would be expected at that interest rate) equal to the magnitude of the NPV will occur; i.e., the defined interest on the original investment has been exceeded by the positive NPV amount.

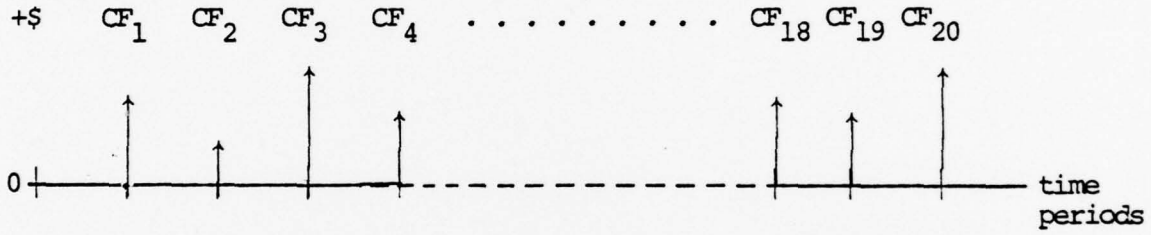
The quantity $\frac{CF_n}{(1+i)^n}$ is defined as the discounted present value (PV) of each flow n, written PV_n. In order to determine IRR, the above formula must be solved for the value of i which makes the difference zero; i.e.,

$$0 = \sum_{n=1}^{20} \frac{CF_n}{(1+i)^n} - \text{INVEST}$$

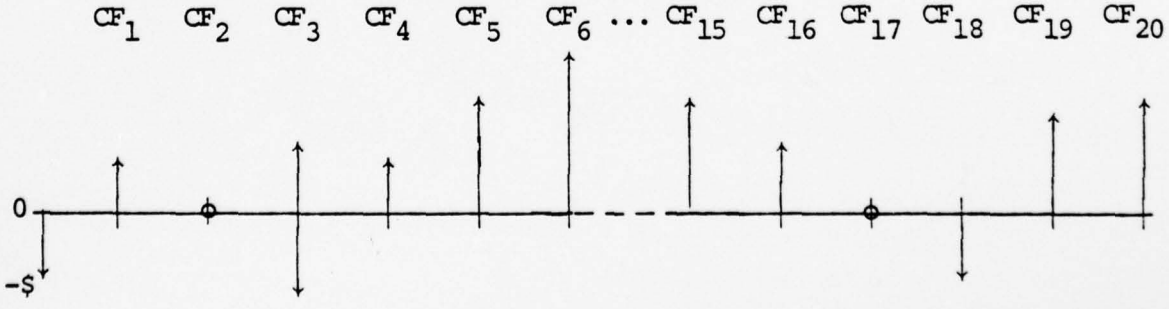
or

$$0 = \sum_{n=1}^{20} PV_n - \text{INVEST}$$

Graphically, the cash flow process can be pictured on a time line as follows:



The future cash flows may also include zero or negative (additional future investment) values. Hence, a more complex case can be pictured on a time line as:



c. IRR Program Capabilities

(1) The programs developed herein will provide the discrete IRR for any conceivable periodic (equally-spaced) set of 21 positive, zero or negative cash flows. The programs solve for two decimal places beyond the integer percentage value (i.e. 7000%, .62% or 6.39% or 0.03%) unless instructed by the user to proceed further; accuracy up to the machine display capability (10 significant digits), if desired, may be initially requested by the user. The programs will also solve for a negative IRR, i.e., where net undiscounted income is less than net undiscounted investments.

Either program will permanently store an initial (positive, zero, or negative) "investment" and twenty additional future positive, zero, or negative periodic cash flows. In addition to the IRR, either program will compute the NPV of these flows at any positive or negative trial interest rate; the initial value (investment) or the trial interest rate may each be individually modified by the user at any time; the trial interest rate may also be incremented or decremented by the user at any time (in lieu of reentering a many-digit rate where only the last digit or last several digit sequence is to be changed); the number of cash flows (data entry values exclusive of the value normally used for the initial investment) is automatically accumulated and stored for possible later recall by the user and each value can be individually modified or deleted

(changed to zero) at any time; previously unused data points from the twenty available may be automatically added (on the end) at any time without recall of the number of entries used previously; and the manual entry of long sequences of zero values may be avoided by instructing the calculator to jump over them in its automatic accumulation. Most of the above processes are executed exclusively on the 10 user-defined keys. Accordingly, this program is satisfactory for IRR, NPV or Profit analysis of any periodic sequence of 21 unique values or for an Investment followed by either 20 unique values or by 20 identical (annuity) values. The HP-67 program will also calculate the undiscounted breakeven point for the series of values but this subroutine is omitted from the SR-52 for lack of program memory space. In summary, these programs are satisfactory for rather complete analyses of any 21 flows spaced by uniform intervals — days, weeks, 12 day periods, months, quarters, years or whatever. Each of these programs will perform the function of at least three of the programs published by the respective manufacturers — using only user defined keys. Additional manufacturer programs can be accomplished by including limited manual use of other keys.

Functionally similar subroutines are arranged in a different sequence for each calculator in order to take advantage of the program search patterns unique to each calculator and thus minimize execution time for each. Since these different arrangements make direct

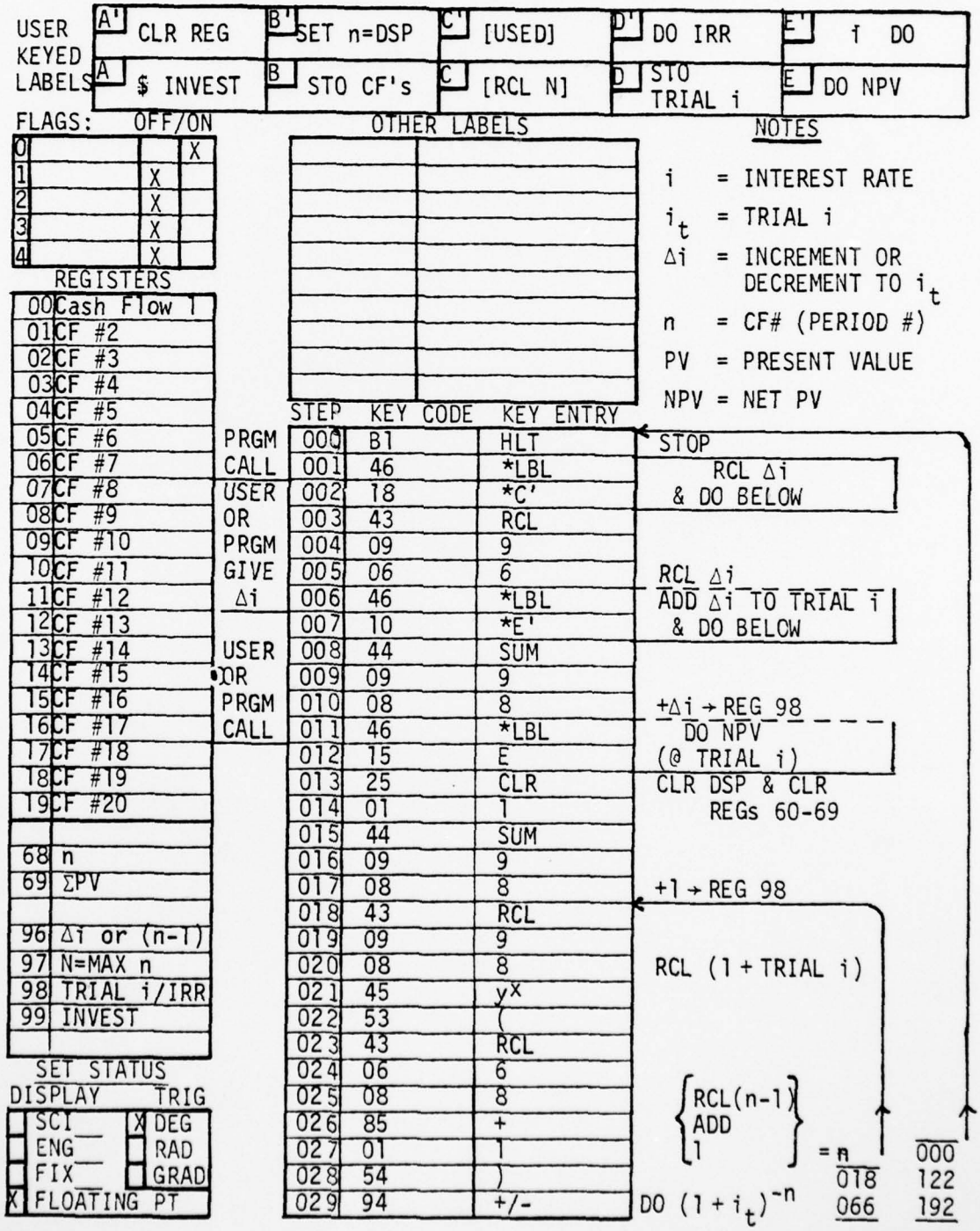
comparison of the programs difficult, applicable functional subroutines are individually reproduced within the analysis which follows, in addition to the complete listings provided for each program. Meanwhile, the reader should concentrate primarily upon the first page of each program.

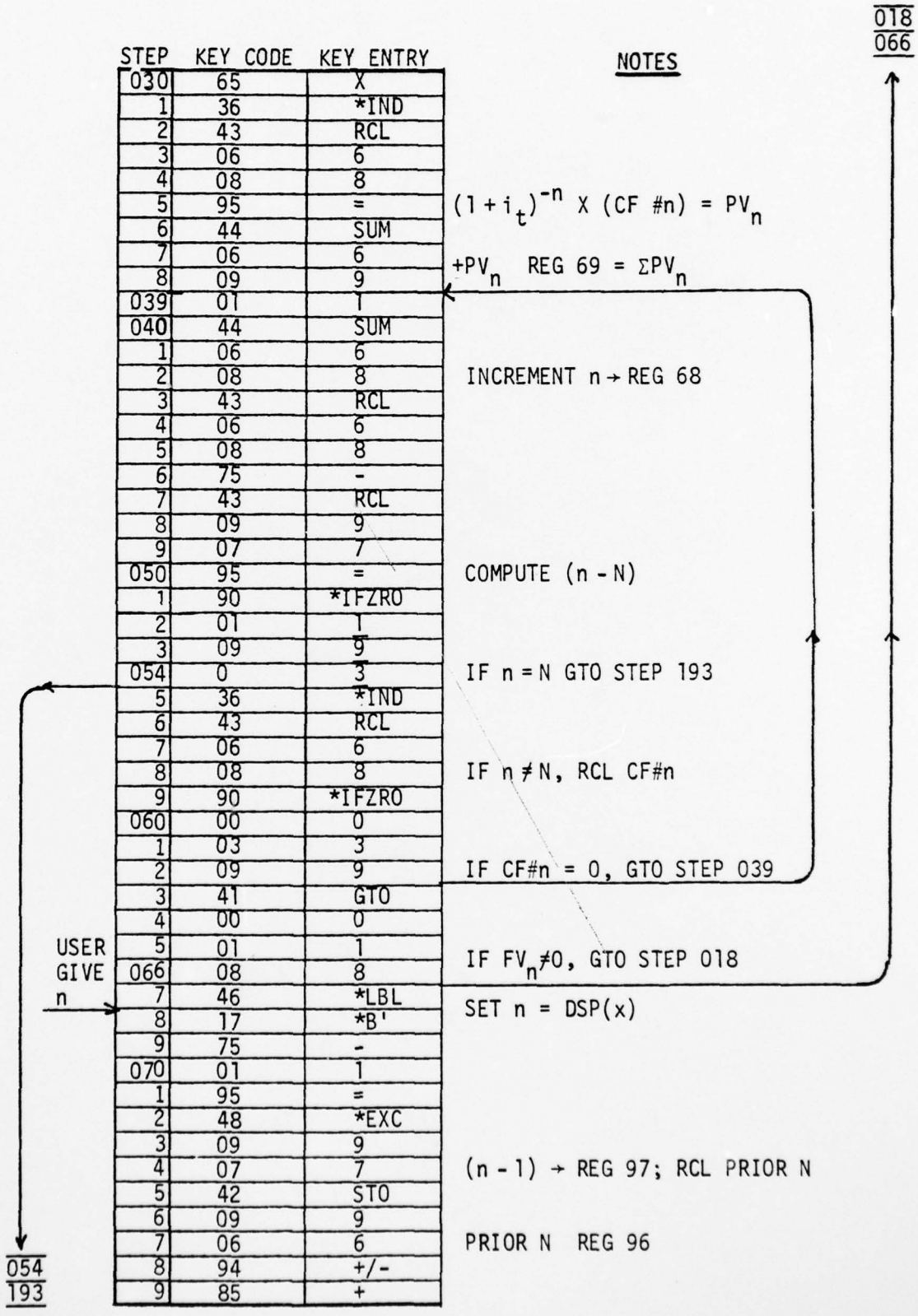
(1) Step Ratios. Because the following programs are advanced and optimized programs, the SR-52/HP-67 step ratio is approximately 1.32, i.e., the number of steps required on the HP-67 to accomplish all of the functions which can be accomplished by the 208 step SR-52 program is 158. The remaining 50 HP-67 steps are used for additional functional, informational, and user-prompting subroutines not programmable on the SR-52 because of program memory space constraints. (The SR-52 program does not use 16 steps in order to make available two extra data registers. Thus the HP-67 program additionally uses these steps for additional routines not programmable on the SR-52.)

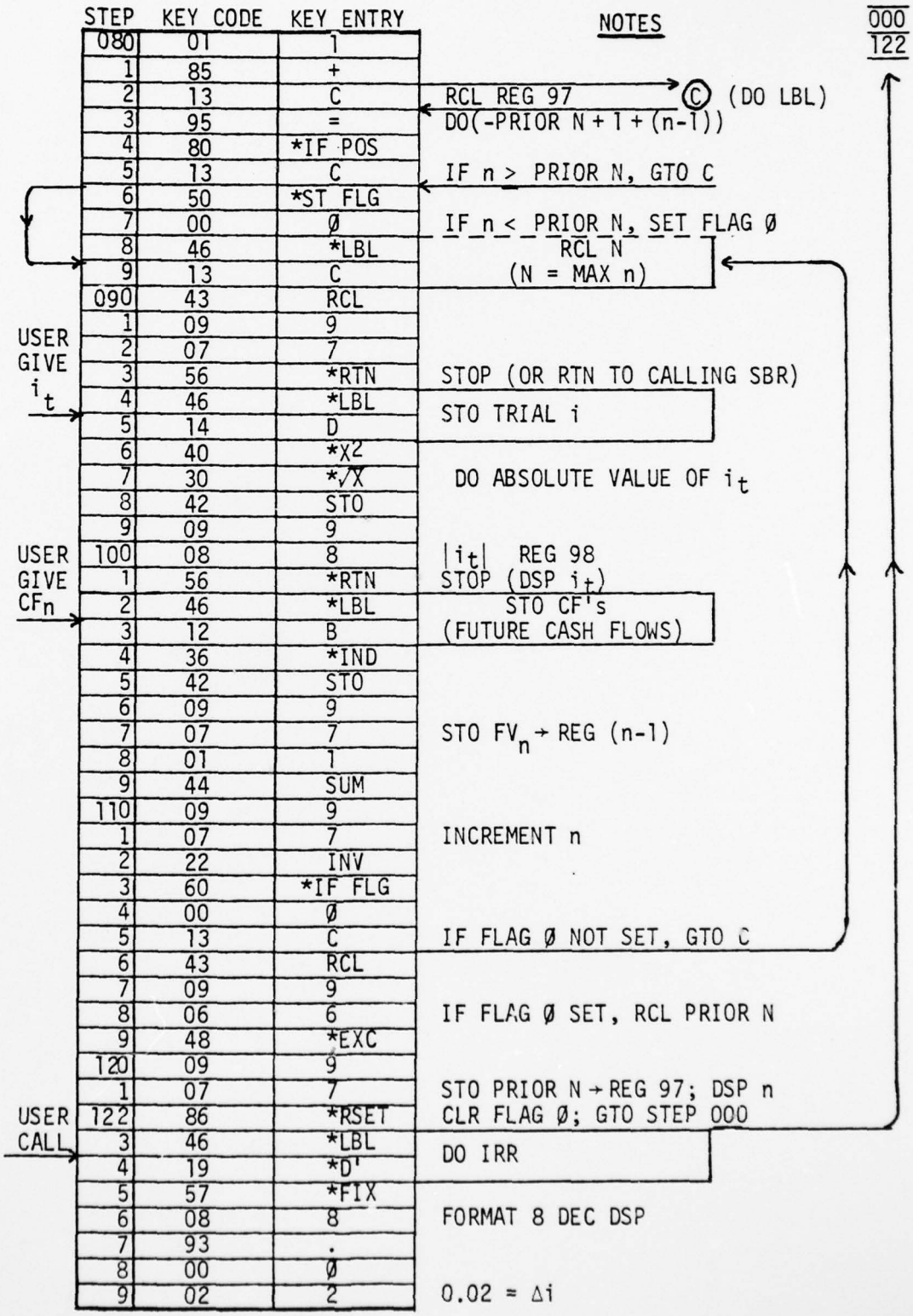
(2) Initial Data Entry Operations. Typical operations which can be performed by either of these single-card programsare: (p 99)

FIGURE 3

INTERNAL RATE OF RETURN (SR-52)




018
066
STEP KEY CODE KEY ENTRY
NOTES
030 65 X
1 36 *IND
2 43 RCL
3 06 6
4 08 8
5 95 =
6 44 SUM
7 06 6
8 09 9
039 01 1
040 44 SUM
1 06 6
2 08 8
3 43 RCL
4 06 6
5 08 8
6 75 -
7 43 RCL
8 09 9
9 07 7
050 95 =
1 90 *IFZRO
2 01 1
3 09 9
054 0 3
5 36 *IND
6 43 RCL
7 06 6
8 08 8
9 90 *IFZRO
060 00 0
1 03 3
2 09 9
3 41 GTO
4 00 0
5 01 1
066 08 8
7 46 *LBL
8 17 *B'
9 75 -
070 01 1
1 95 =
2 48 *EXC
3 09 9
4 07 7
5 42 STO
6 09 9
7 06 6
8 94 +/-
9 85 +
$(1+i_t)^{-n}$ X (CF #n) = PV_n
$+PV_n$ REG 69 = ΣPV_n
INCREMENT n → REG 68
COMPUTE (n - N)
IF n = N GTO STEP 193
IF n ≠ N, RCL CF#n
IF CF#n = 0, GTO STEP 039
IF $FV_n \neq 0$, GTO STEP 018
SET n = DSP(x)
(n - 1) → REG 97; RCL PRIOR N
PRIOR N REG 96
USER GIVE n
054
193

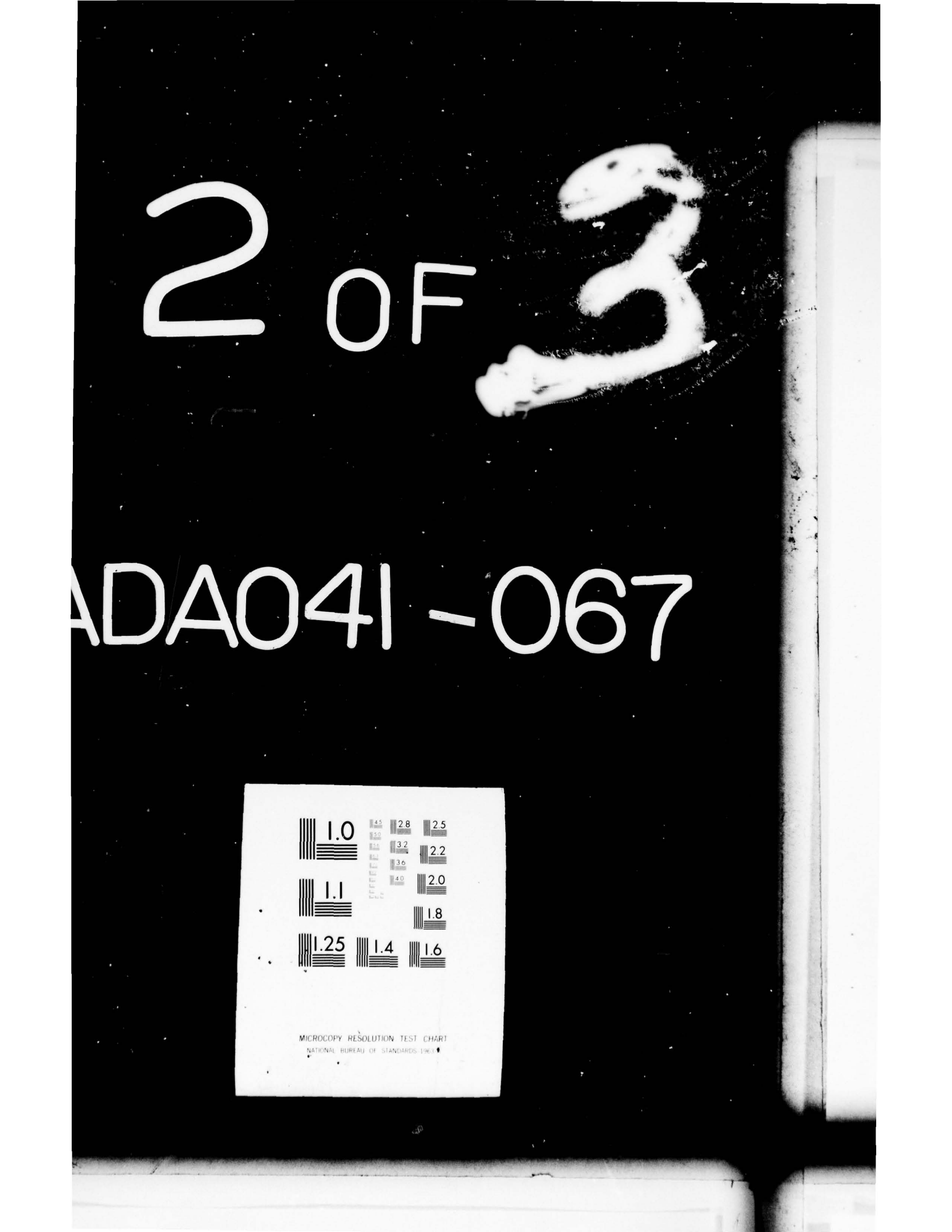

STEP
KEY CODE
KEY ENTRY
NOTES
000
122
080 01 1
1 85 +
2 13 C
RCL REG 97
Ⓒ (DO LBL)
3 95 =
DO(-PRIOR N + 1 + (n-1))
4 80 *IF POS
5 13 C
IF n > PRIOR N, GTO C
6 50 *ST FLG
7 00 Ø
IF n < PRIOR N, SET FLAG Ø
8 46 *LBL
RCL N
9 13 C
(N = MAX n)
090 43 RCL
1 09 9
USER GIVE i_t
2 07 7
3 56 *RTN
STOP (OR RTN TO CALLING SBR)
4 46 *LBL
5 14 D
STO TRIAL i
6 40 *X²
7 30 *√X
DO ABSOLUTE VALUE OF i_t
8 42 STO
9 09 9
USER GIVE CF_n
100 08 8
$|i_t|$ REG 98
1 56 *RTN
STOP (DSP i_t)
2 46 *LBL
STO CF's
3 12 B
(FUTURE CASH FLOWS)
4 36 *IND
5 42 STO
6 09 9
7 07 7
STO FV_n → REG (n-1)
8 01 1
9 44 SUM
110 09 9
1 07 7
INCREMENT n
2 22 INV
3 60 *IF FLG
4 00 Ø
5 13 C
IF FLAG Ø NOT SET, GTO C
6 43 RCL
7 09 9
8 06 6
IF FLAG Ø SET, RCL PRIOR N
9 48 *EXC
120 09 9
1 07 7
STO PRIOR N → REG 97; DSP n
USER CALL
122 86 *RSET
CLR FLAG Ø; GTO STEP 000
3 46 *LBL
4 19 *D'
DO IRR
5 57 *FIX
6 08 8
FORMAT 8 DEC DSP
7 93 .
8 00 Ø
9 02 2
0.02 = Δi

AD-A041 067 NAVAL POSTGRADUATE SCHOOL MONTEREY CALIF F/G 9/2
INVEST OF CARD PROGRAM AND CHIP PROGRAM POCKET--ETC(U)
MAR 77 H R KRUSE, H A BURKETT

UNCLASSIFIED N/L

2 OF 3

ADA041-067


2 OF 3
ADA041-067
1.0
1.1
1.25
1.4
1.6
2.8
3.2
3.6
4.0
2.5
2.2
2.0
1.8
MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963

	STEP	KEY CODE	KEY ENTRY	NOTES
	130	42	STO	
	1	09	Ø	Δi REG 96
	2	06	6	
	133	18	*C'	DO NPV → (*C') (DO LBL)
	4	80	*IF POS	
	5	01	1	
	6	03	3	
	7	03	3	IF NPV NOT NEG, GTO STEP 133
	8	02	2	
	9	94	+/-	
	140	22	INV	
	1	49	*PROD	IF NPV NEGATIVE:
	2	09	9	-(Δi÷2) = Δi' → REG 96
	3	06	6	
	144	18	*C'	DO NPV (*C') (DO LBL)
	5	22	INV	
	6	80	*IF POS	
	7	01	1	
	8	04	4	
	9	04	4	IF NPV STILL NEG, GTO STEP 144
	150	93	.	
	1	02	2	
	2	94	+/-	
	3	49	*PROD	
	4	09	9	IF NPV POS OR Ø:
	5	06	6	(-0.2)XΔi = Δi" REG 96
	6	43	RCL	
	7	09	9	
	8	06	6	(Δi" = NEW Δi)
	9	75	-	
	160	02	2	
	1	52	EE	
*	162	04	4	
	3	94	+/-	(LOW LIMIT = 0.0002)
	4	95	=	
	5	22	INV	
	6	52	EE	DO (Δi - LOW LIMIT)
	7	80	*IF POS	
	8	01	1	
	9	03	3	
	170	03	3	IF Δi > LOW LIMIT, GTO STEP 133
	1	43	RCL	
	2	09	9	IF Δi < LOW LIMIT:
	3	08	8	RCL IRR
	4	22	INV	
	5	57	*FIX	FORMAT FLOATING PT DSP
USER	6	56	*RTN	STOP (DSP IRR)
CALL →	7	46	*LBL	CLR REG
	8	16	*A'	
	9	47	CMS	CLR REG 00 THROUGH 19

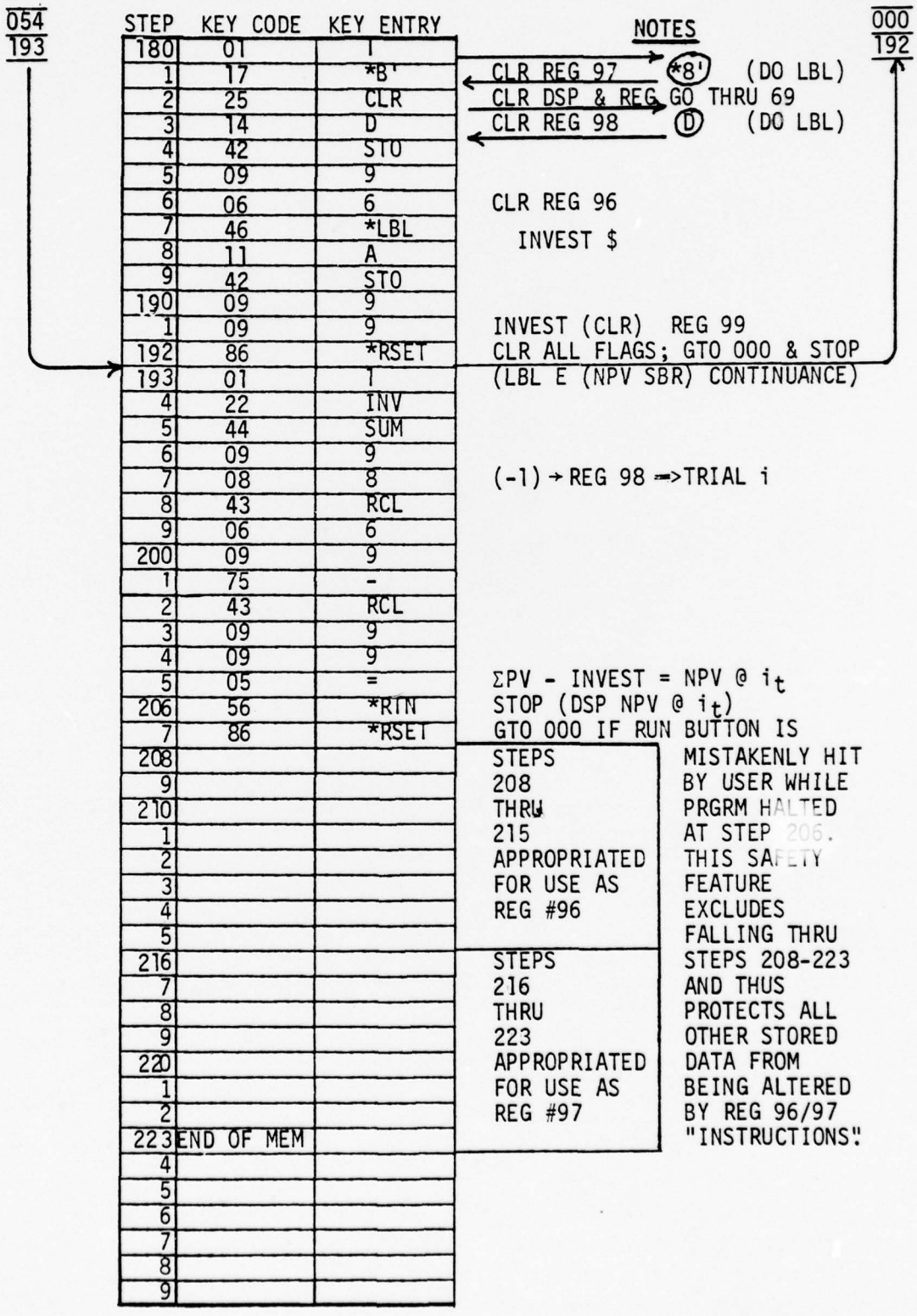
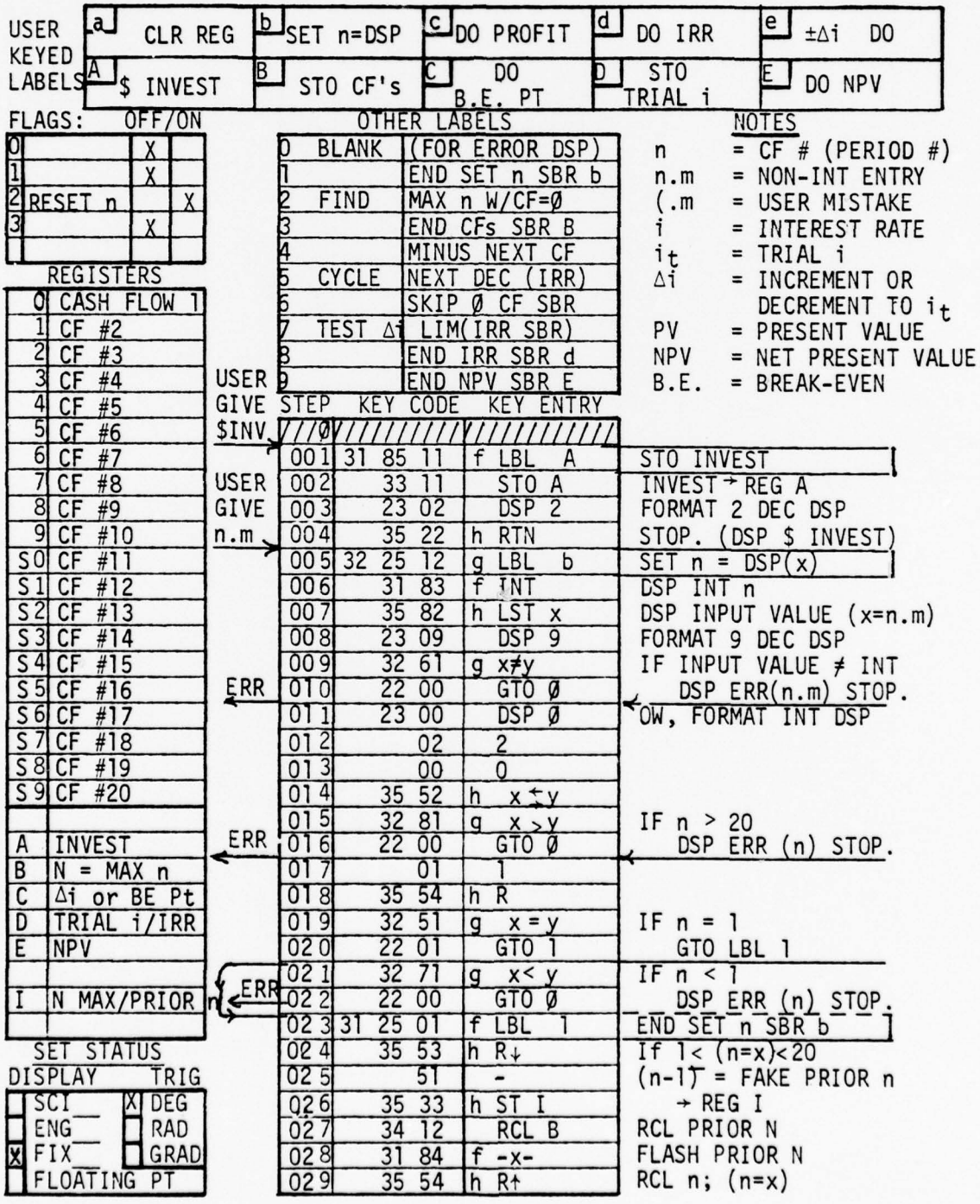
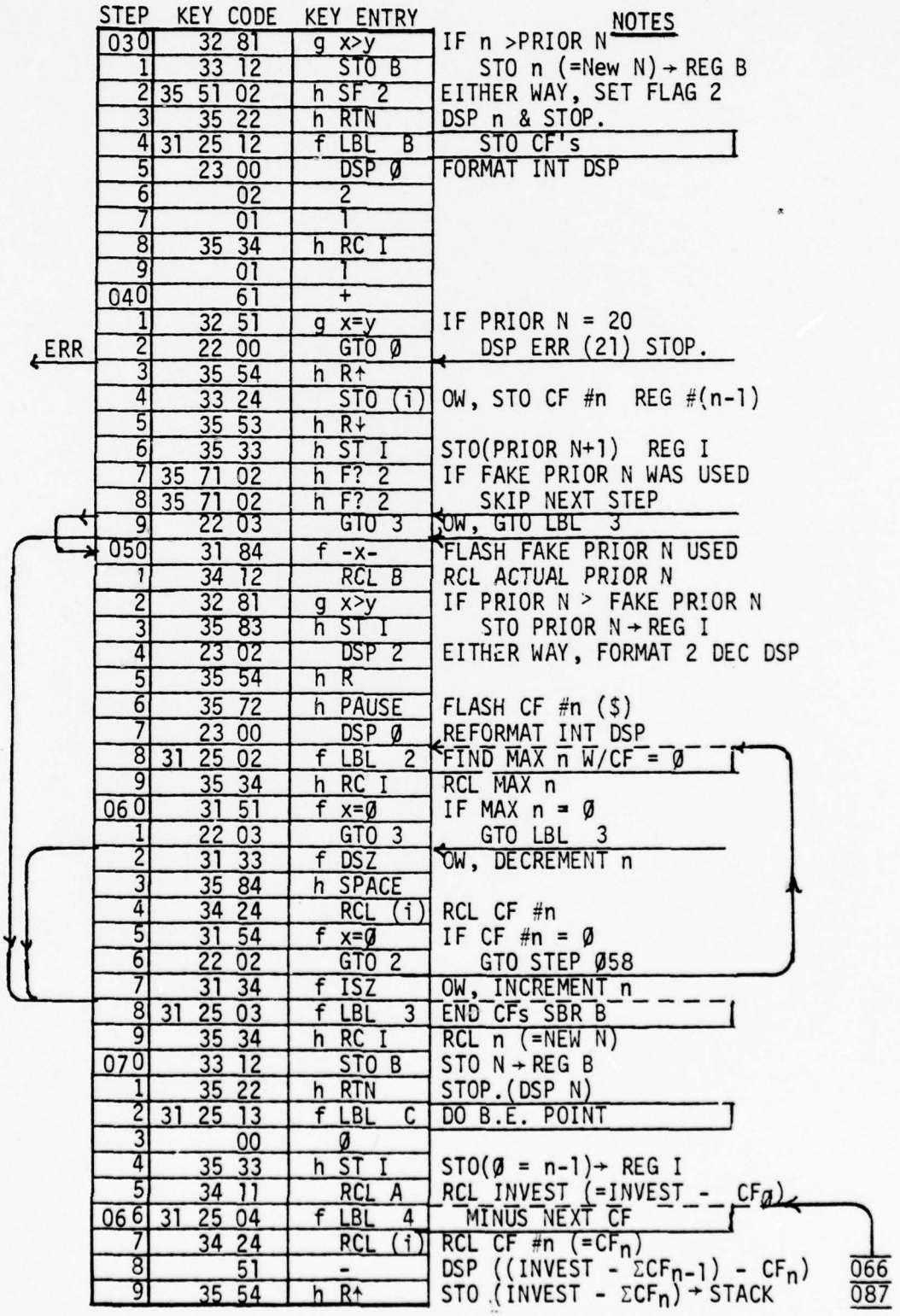

054
193
STEP
KEY CODE
KEY ENTRY
NOTES
000
192
180 01 I
1 17 *B'
2 25 CLR
3 14 D
4 42 STO
5 09 9
6 06 6
7 46 *LBL
8 11 A
9 42 STO
190 09 9
1 09 9
192 86 *RSET
193 01 1
4 22 INV
5 44 SUM
6 09 9
7 08 8
8 43 RCL
9 06 6
200 09 9
1 75 -
2 43 RCL
3 09 9
4 09 9
5 05 =
206 56 *RTN
7 86 *RSET
208
9
210
1
2
3
4
5
216
7
8
9
220
1
2
223 END OF MEM
4
5
6
7
8
9
CLR REG 97 *8' (DO LBL)
CLR DSP & REG GO THRU 69
CLR REG 98 D (DO LBL)
CLR REG 96
INVEST $
INVEST (CLR) REG 99
CLR ALL FLAGS; GTO 000 & STOP
(LBL E (NPV SBR) CONTINUANCE)
(-1) → REG 98 ⇒TRIAL i
ΣPV - INVEST = NPV @ i_t
STOP (DSP NPV @ i_t)
GTO 000 IF RUN BUTTON IS
MISTAKENLY HIT
BY USER WHILE
PRGRM HALTED
AT STEP 206.
THIS SAFETY
FEATURE
EXCLUDES
FALLING THRU
STEPS 208-223
AND THUS
PROTECTS ALL
OTHER STORED
DATA FROM
BEING ALTERED
BY REG 96/97
"INSTRUCTIONS".
STEPS
208
THRU
215
APPROPRIATED
FOR USE AS
REG #96
STEPS
216
THRU
223
APPROPRIATED
FOR USE AS
REG #97

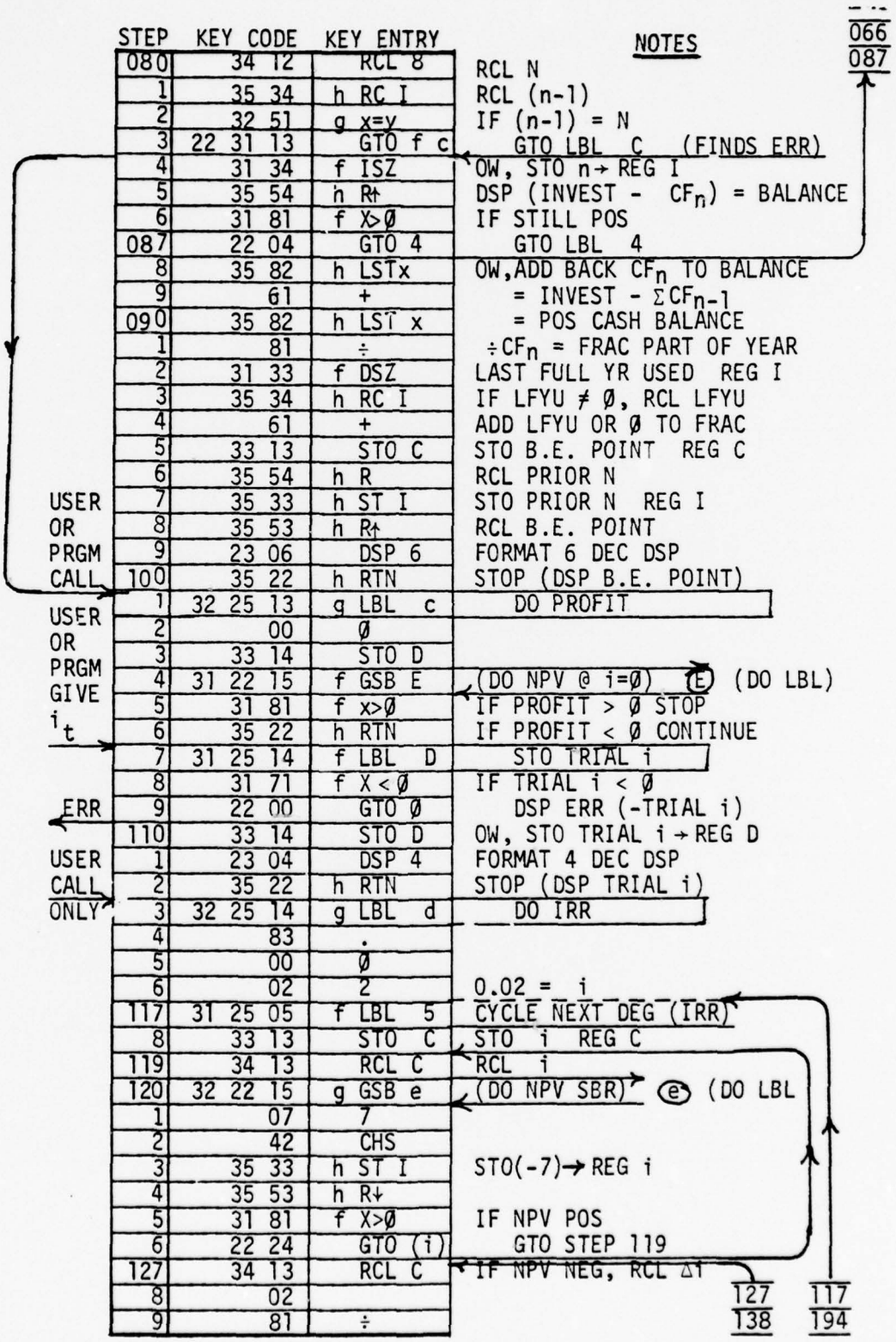
FIGURE 4

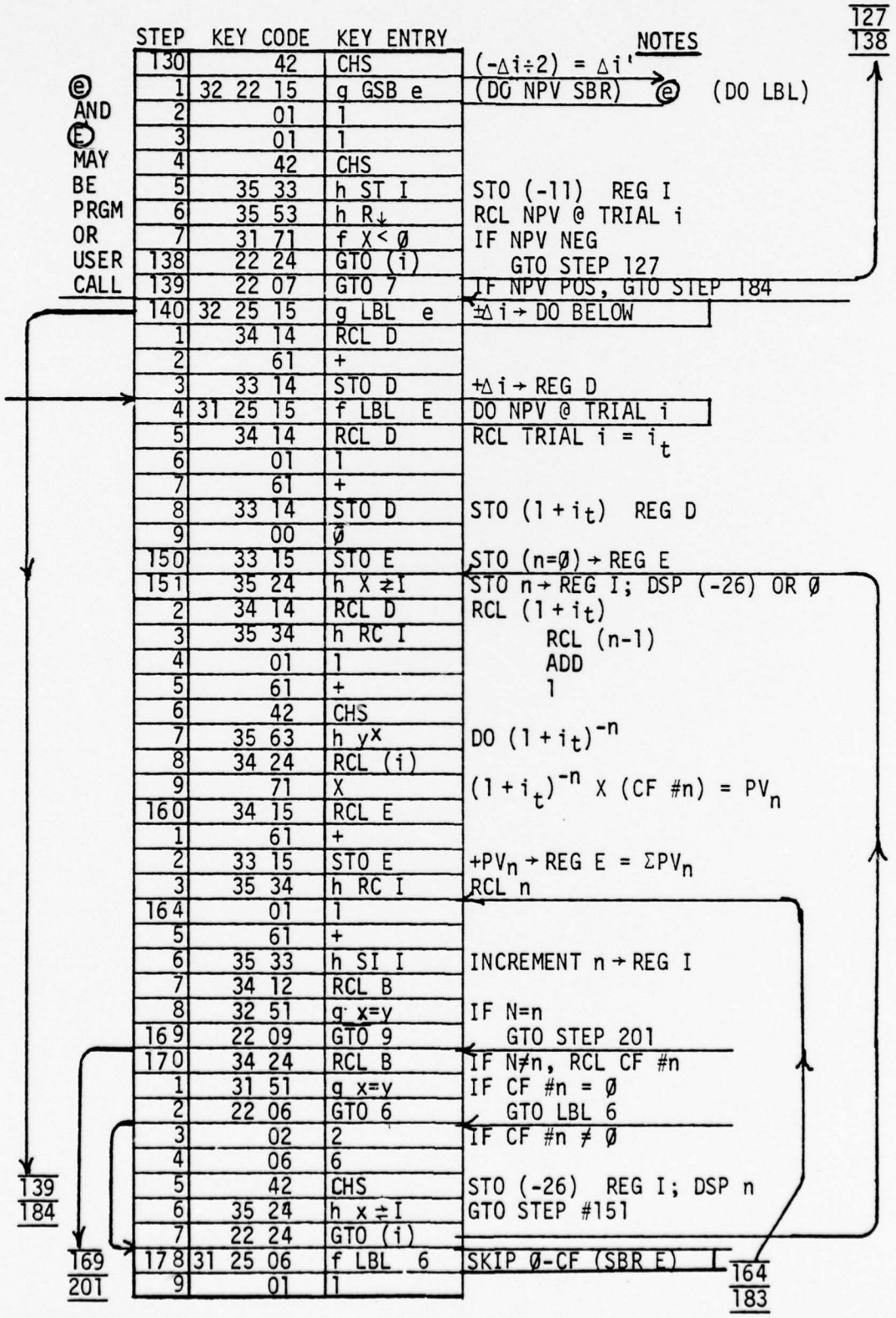
Internal Rate of Return (HP-67)

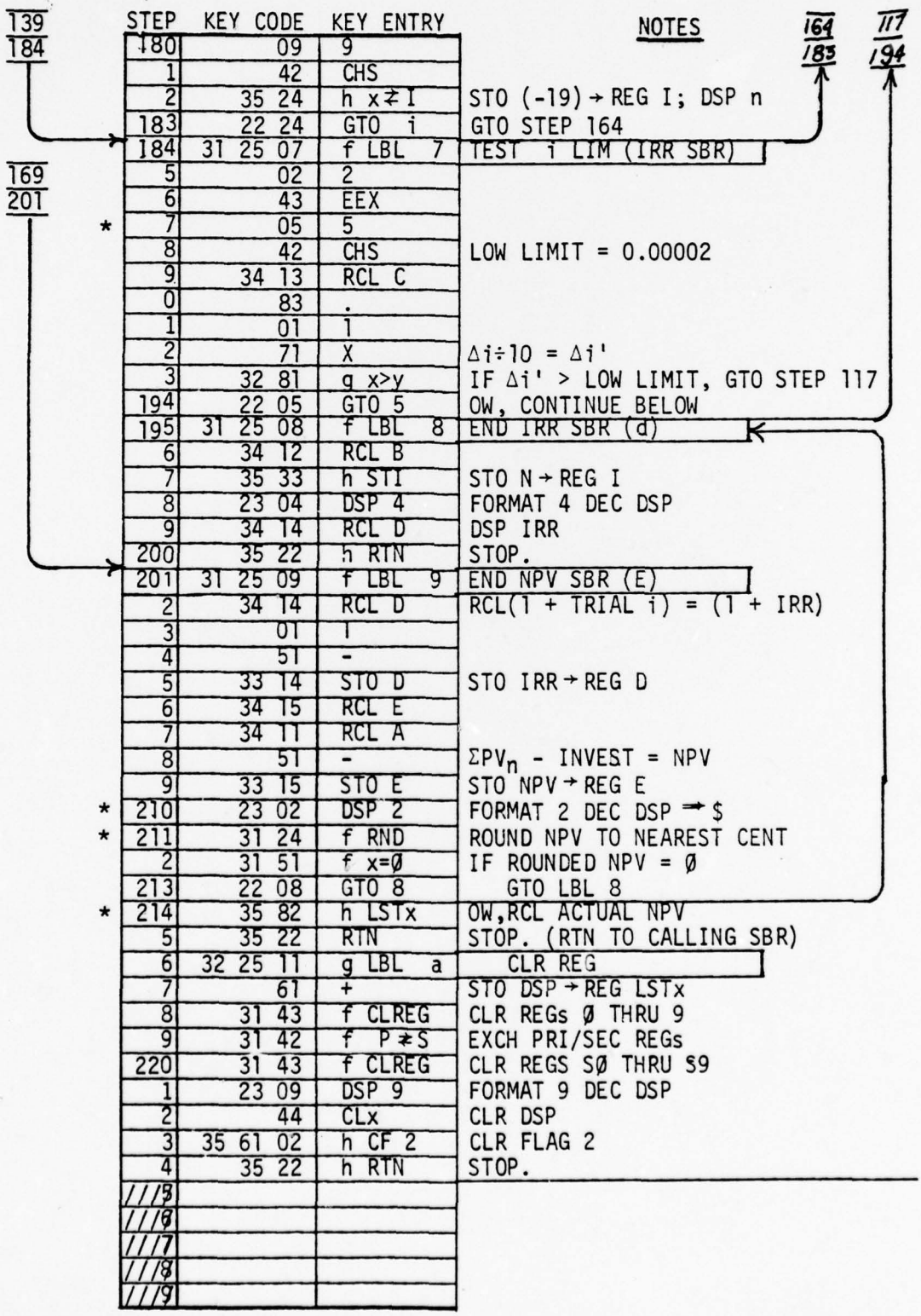




STEP	KEY CODE	KEY ENTRY	NOTES
030	32 81	g x>y	IF n >PRIOR N
1	33 12	STO B	STO n (=New N) → REG B
2	35 51 02	h SF 2	EITHER WAY, SET FLAG 2
3	35 22	h RTN	DSP n & STOP.
4	31 25 12	f LBL B	STO CF's
5	23 00	DSP Ø	FORMAT INT DSP
6	02	2	
7	01	1	
8	35 34	h RC I	
9	01	1	
040	61	+	
1	32 51	g x=y	IF PRIOR N = 20
ERR 2	22 00	GTO Ø	DSP ERR (21) STOP.
3	35 54	h R↑	
4	33 24	STO (i)	OW, STO CF #n REG #(n-1)
5	35 53	h R↓	
6	35 33	h ST I	STO(PRIOR N+1) REG I
7	35 71 02	h F? 2	IF FAKE PRIOR N WAS USED
8	35 71 02	h F? 2	SKIP NEXT STEP
9	22 03	GTO 3	OW, GTO LBL 3
050	31 84	f -x-	FLASH FAKE PRIOR N USED
1	34 12	RCL B	RCL ACTUAL PRIOR N
2	32 81	g x>y	IF PRIOR N > FAKE PRIOR N
3	35 83	h ST I	STO PRIOR N → REG I
4	23 02	DSP 2	EITHER WAY, FORMAT 2 DEC DSP
5	35 54	h R	
6	35 72	h PAUSE	FLASH CF #n ($)
7	23 00	DSP Ø	REFORMAT INT DSP
8	31 25 02	f LBL 2	FIND MAX n W/CF = Ø
9	35 34	h RC I	RCL MAX n
060	31 51	f x=Ø	IF MAX n = Ø
1	22 03	GTO 3	GTO LBL 3
2	31 33	f DSZ	OW, DECREMENT n
3	35 84	h SPACE	
4	34 24	RCL (i)	RCL CF #n
5	31 54	f x=Ø	IF CF #n = Ø
6	22 02	GTO 2	GTO STEP Ø58
7	31 34	f ISZ	OW, INCREMENT n
8	31 25 03	f LBL 3	END CFs SBR B
9	35 34	h RC I	RCL n (=NEW N)
070	33 12	STO B	STO N → REG B
1	35 22	h RTN	STOP.(DSP N)
2	31 25 13	f LBL C	DO B.E. POINT
3	00	Ø	
4	35 33	h ST I	STO(Ø = n-1) → REG I
5	34 11	RCL A	RCL INVEST (=INVEST - CFØ)
066	31 25 04	f LBL 4	MINUS NEXT CF
7	34 24	RCL (i)	RCL CF #n (=CF_n)
8	51	-	DSP ((INVEST - ΣCF_{n-1}) - CF_n) 066
9	35 54	h R↑	STO (INVEST - ΣCF_n) → STACK 087


STEP
KEY CODE
KEY ENTRY
NOTES
080 34 12 RCL 8
1 35 34 h RC I
2 32 51 g x=y
3 22 31 13 GTO f c
4 31 34 f ISZ
5 35 54 h R↑
6 31 81 f X>Ø
087 22 04 GTO 4
8 35 82 h LSTx
9 61 +
090 35 82 h LST x
1 81 ÷
2 31 33 f DSZ
3 35 34 h RC I
4 61 +
5 33 13 STO C
6 35 54 h R
7 35 33 h ST I
8 35 53 h R↑
9 23 06 DSP 6
100 35 22 h RTN
1 32 25 13 g LBL c
2 00 Ø
3 33 14 STO D
4 31 22 15 f GSB E
5 31 81 f x>Ø
6 35 22 h RTN
7 31 25 14 f LBL D
8 31 71 f X<Ø
9 22 00 GTO Ø
110 33 14 STO D
1 23 04 DSP 4
2 35 22 h RTN
3 32 25 14 g LBL d
4 83 .
5 00 Ø
6 02 2
117 31 25 05 f LBL 5
8 33 13 STO C
119 34 13 RCL C
120 32 22 15 g GSB e
1 07 7
2 42 CHS
3 35 33 h ST I
4 35 53 h R↓
5 31 81 f X>Ø
6 22 24 GTO (i)
127 34 13 RCL C
8 02
9 81 ÷
RCL N
RCL (n-1)
IF (n-1) = N
GTO LBL C (FINDS ERR)
OW, STO n→ REG I
DSP (INVEST - CFn) = BALANCE
IF STILL POS
GTO LBL 4
OW,ADD BACK CFn TO BALANCE
= INVEST - ΣCFn-1
= POS CASH BALANCE
÷CFn = FRAC PART OF YEAR
LAST FULL YR USED REG I
IF LFYU ≠ Ø, RCL LFYU
ADD LFYU OR Ø TO FRAC
STO B.E. POINT REG C
RCL PRIOR N
STO PRIOR N REG I
RCL B.E. POINT
FORMAT 6 DEC DSP
STOP (DSP B.E. POINT)
DO PROFIT
(DO NPV @ i=Ø) (E) (DO LBL)
IF PROFIT > Ø STOP
IF PROFIT < Ø CONTINUE
STO TRIAL i
IF TRIAL i < Ø
DSP ERR (-TRIAL i)
OW, STO TRIAL i → REG D
FORMAT 4 DEC DSP
STOP (DSP TRIAL i)
DO IRR
0.02 = i
CYCLE NEXT DEG (IRR)
STO i REG C
RCL i
(DO NPV SBR) (e) (DO LBL
STO(-7)→ REG i
IF NPV POS
GTO STEP 119
IF NPV NEG, RCL Δi
066
087
127
138
117
194
USER OR PRGM CALL
USER OR PRGM GIVE i t
ERR
USER CALL ONLY


STEP
KEY CODE
KEY ENTRY
NOTES
130 42 CHS (-Δi÷2) = Δi'
1 32 22 15 g GSB e (DO NPV SBR) ⓔ (DO LBL)
2 01 1
3 01 1
4 42 CHS
5 35 33 h ST I STO (-11) REG I
6 35 53 h R↓ RCL NPV @ TRIAL i
7 31 71 f X< Ø IF NPV NEG
138 22 24 GTO (i) GTO STEP 127
139 22 07 GTO 7 IF NPV POS, GTO STEP 184
140 32 25 15 g LBL e ±Δi → DO BELOW
1 34 14 RCL D
2 61 +
3 33 14 STO D +Δi → REG D
4 31 25 15 f LBL E DO NPV @ TRIAL i
5 34 14 RCL D RCL TRIAL i = i_t
6 01 1
7 61 +
8 33 14 STO D STO $(1+i_t)$ REG D
9 00 Ø
150 33 15 STO E STO (n=Ø) → REG E
151 35 24 h X≠I STO n → REG I; DSP (-26) OR Ø
2 34 14 RCL D RCL $(1+i_t)$
3 35 34 h RC I RCL (n-1)
4 01 1 ADD
5 61 + 1
6 42 CHS
7 35 63 h y^x DO $(1+i_t)^{-n}$
8 34 24 RCL (i)
9 71 X $(1+i_t)^{-n}$ X (CF #n) = PV_n
160 34 15 RCL E
1 61 +
2 33 15 STO E $+PV_n$ → REG E = ΣPV_n
3 35 34 h RC I RCL n
164 01 1
5 61 +
6 35 33 h SI I INCREMENT n → REG I
7 34 12 RCL B
8 32 51 g x=y IF N=n
169 22 09 GTO 9 GTO STEP 201
170 34 24 RCL B IF N≠n, RCL CF #n
1 31 51 g x=y IF CF #n = Ø
2 22 06 GTO 6 GTO LBL 6
3 02 2 IF CF #n ≠ Ø
4 06 6
5 42 CHS STO (-26) REG I; DSP n
6 35 24 h x≠I GTO STEP #151
7 22 24 GTO (i)
178 31 25 06 f LBL 6 SKIP Ø-CF (SBR E)
9 01 1
ⓔ AND Ⓔ MAY BE PRGM OR USER CALL
127 138
139 184
169 201
164 183



	STEP	KEY CODE	KEY ENTRY	NOTES
	180	09	9	
	1	42	CHS	
	2	35 24	h x≠I	STO (-19) → REG I; DSP n
	183	22 24	GTO i	GTO STEP 164
	184	31 25 07	f LBL 7	TEST i LIM (IRR SBR)
	5	02	2	
	6	43	EEX	
*	7	05	5	
	8	42	CHS	LOW LIMIT = 0.00002
	9	34 13	RCL C	
	0	83	.	
	1	01	1	
	2	71	X	Δi÷10 = Δi'
	3	32 81	g x>y	IF Δi' > LOW LIMIT, GTO STEP 117
	194	22 05	GTO 5	OW, CONTINUE BELOW
	195	31 25 08	f LBL 8	END IRR SBR (d)
	6	34 12	RCL B	
	7	35 33	h STI	STO N → REG I
	8	23 04	DSP 4	FORMAT 4 DEC DSP
	9	34 14	RCL D	DSP IRR
	200	35 22	h RTN	STOP.
	201	31 25 09	f LBL 9	END NPV SBR (E)
	2	34 14	RCL D	RCL(1 + TRIAL i) = (1 + IRR)
	3	01	1	
	4	51	-	
	5	33 14	STO D	STO IRR → REG D
	6	34 15	RCL E	
	7	34 11	RCL A	
	8	51	-	ΣPV_n - INVEST = NPV
	9	33 15	STO E	STO NPV → REG E
*	210	23 02	DSP 2	FORMAT 2 DEC DSP → $
*	211	31 24	f RND	ROUND NPV TO NEAREST CENT
	2	31 51	f x=Ø	IF ROUNDED NPV = Ø
	213	22 08	GTO 8	GTO LBL 8
*	214	35 82	h LSTx	OW,RCL ACTUAL NPV
	5	35 22	RTN	STOP. (RTN TO CALLING SBR)
	6	32 25 11	g LBL a	CLR REG
	7	61	+	STO DSP → REG LSTx
	8	31 43	f CLREG	CLR REGs Ø THRU 9
	9	31 42	f P≠S	EXCH PRI/SEC REGs
	220	31 43	f CLREG	CLR REGS SØ THRU S9
	1	23 09	DSP 9	FORMAT 9 DEC DSP
	2	44	CLx	CLR DSP
	3	35 61 02	h CF 2	CLR FLAG 2
	4	35 22	h RTN	STOP.
	///			
	///			
	///			
	///			
	///			

DATA		ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES
INVESTMENT:	SR 52:	INVEST	A	INVEST	(As entered)
	HP 67:	INVEST	A	INVEST	($ and ¢)
CASH FLOWS:		CF#1	B	1.	
		CF#2	B	2.	
		⋮	⋮	⋮	
		CF#n	B	n.	
		⋮	⋮	⋮	
		CF#20	B	20.	
DECIMAL TRIAL INTEREST RATE (i)					
	SR-52	i_t	D	i_t	(As entered)
	HP-67	i_t	D	i_t	(n.wxyz)
EXAMPLES:	i_t=10%	.1	D	0.1000	
	i_t=7654.321%	76.54321	D	76.5432	(All digits stored)

(3) Data Modification Operations.

	ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES
CHANGE INVESTMENT	NEW INVEST	A	NEW INVEST	
CHANGE INTEREST RATE	NEW i_t	D	NEW i_t	
CHANGE CASH FLOW FOR PERIOD n (CF_n)				
SR-52:	n	*B	m.	(n-1)
	CF_n	B	n.	
HP-67	n	fb	N.	(flashes 4X)
			n.	
	CF_n	B	n.	(flashes 4X)
			CF_n	(flashes 1X)
			N.	(Highest n used*) [see *note next page]

*NOTE: If n = N and CF_n = 0 is entered, the HP-67 program will automatically redefine N as the highest period for which a non-zero cash flow is stored in memory. Accurate definition of N speeds program operations but is not required to obtain the solutions. Redefinition on the SR-52, if desired subsequent to the above entries, is accomplished by:

	ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES
		*B	M.	(N-1)
		*RSET	N.	(=Prior N-1)
INCREMENT i_t by ±Δi AND AUTOMATICALLY RUN NPV				
SR-52:	±Δi	*E	NPV	(10 DIGITS)
HP-67:	±Δi	fe	NPV	($ and ¢)
CLEAR ALL DATA FOR NEW CASE:				
SR-52		*A	0.	
HP-67:		fa	0.000000000	

(4) Undiscounted Subroutines.

	ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES
PROFIT MARGIN				
HP-67:		fc	PROFIT	($ and ¢; DESTROYS i_t)
SR-52:	0	D	0.	(i_t)
		E	PROFIT	(DIGITS APPLICABLE TO CF's USED)

	ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES
OTHER (HP-67 ONLY)				
FIRST BREAK EVEN POINT:		C	B.E.PT	(6 Decimal Places)
ESTIMATE i_t:		C	B.E.PT	
		fc	PROFIT	
		RCL C	B.E.PT	
		RCL A	INVEST	
		X ÷	i_t	(2 Decimal Places)
		DSP 4	i_t	(4 Decimal Places)
		f RND	i_t	
		D	i_t	(STORE D)

(5) Time-Valued Subroutines.

		ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES NOTES
NPV @ i_t:	SR-52		E	NPV	(10 DIGITS)
	HP-67		E	NPV	($ and ¢)
IRR :	SR-52		*D	IRR	(10 DIGITS)
	HP-67		fd	IRR	(4 Decimal Places)
INCREMENT/DECREMENT i_t & RUN NPV					Discussed Above

(6) Error Protections. (When User attempts to store invalid values)

	ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES
NEGATIVE TRIAL INTEREST USING (STO Trial i) Key				
RATE (i_t):				
SR-52:	$-i_t$	D	$+i_t$	(i_t Stored)
HP-67:	$-i_t$	D	Error	
		CLx	$-i_t$	(Not stored)
(IF NEGATIVE i_t DESIRED)				
SR-52	0	D	0.	
	$-i_t$	*E'	NPV	($-i_t$ stored)
HP-67	0	D	0.0000	
	$-i_t$	*fe*	NPV	($-i_t$ stored)
NEGATIVE (n 0) or TOO LARGE (n 20)				
USING (SET n=DSP) KEY.				
SR-52:	n	*B'	M	(n-1)

Although the display is normal, no data has yet been stored. Alert user will note minus signs and/or increments of n in wrong directions or beyond 0 to 20 limits. However, some data must be entered against key B in the usual manner in order to avoid undesired redefinition of N, i.e.,

	Any Value	B	n	(no data stored)
HP-67:	n	fb	Error	
		CLx	n	

	ENTER	PRESS KEYS	DISPLAY	FORMAT & NOTES
NON-INTEGER PERIOD NUMBER (±n.p) USING (SET n=DSP) KEY,				
SR-52:	±n.p	*B'	±m.p	((n.p)-1)
Same comments and process as above				
	Any Value	B	±n.p	(No data stored)
HP-67:	±n.p	fb	Error	
		CLx	±n.p	
21st CASH FLOW WHEN USING (STO CF's) KEY:				
SR-52:	CF#21	B	21.	(No data stored)
	CF#22,etc.	B	22.	(No data stored)
Error Noted by User. To correct:				(Redefine N)
		*B'	21.	
		*B'	20.	
		*RESET	20.	
HP-67:	CF#21	B	Error	
		CLx	21.	(No data stored)

(7) Sample Calculations, SR-52 IRR Program.

	ENTER	PRESS KEYS	DISPLAY	RUN TIME IN SECONDS
INVEST	$1000	A	1000.	0.8
CF#1	$ 500	B	1.	1.2
CF#2	$ 600	B	2.	1.2
TRIAL i (ANNUAL)	.1	D	0.1	0.8
DO NPV		E	-49.58677686	3.5
DECR. i,DO NPV	-.04	*E'	5.69597721	3.8
*DECR. i,DO NPV	-.0111	*E'	22.04961262	3.8
*DO IRR		*D'	0.0639	32.5
				47.6

*NOTE: LOWEST RUN TIME NORMALLY OCCURS WITH (i_t = IRR - 0.0111) e.g., WITH i_t = 0.0528, RUN TIME FOR ABOVE IRR IS 22.8 SECONDS.

CHANGE INVEST	$1200.75	A	1200.75	0.8
ADD CF#3	$ 100	B	3.	1.2
CHANGE CF#1	1	*B'	0.	1.8
	$ 555	B	1.	1.0
ADD CF#4	$ 200	B	4.	1.2
ADD CF#15	15	*B'	14.	1.8
	$ 352.16	B	15.	1.4
ADD CF#16	$ 100	B	16.	1.2
DELETE CF#16	(16)	*B'	15.	1.8
	0	B	16.	1.0
RCL N		C	16.	0.3

	ENTER	PRESS KEYS	DISPLAY	RUN TIME IN SECONDS
REDEFINE N		*B'	15.	1.8
		*RSET	15.	--
TRIAL i	.1	D	0.1	0.8
DO NPV		E	95.7016984	14.0
INCR i, DO NPV	.05	*E'	-41.07430984	14.5
DECR i, DO NPV	-.025	*E'	21.92961966	14.5
DO IRR		*D'	0.1332	179.0
				285.7
				(4'46")

NOTE: WITH i_t = 0.1221 (VICE .1250) RUN TIME FOR IRR is 64 SECONDS (VICE 179).

(8) Sample Calculations, HP-67 IRR Program.

	ENTER	PRESS KEYS	DISPLAY	RUN TIME IN SECONDS
INVEST	$1000	A	1000.00	0.8
CF#1	$ 500	B	1.	1.9
CF#2	$ 600	B	2.	1.9
DO B.E.PT(YRS)		C	1.833333	2.8
DO PROFIT		fc	100.00	5.0
TRIAL i (ANNUAL)	.1	D	0.1000	0.8
DO NPV		E	-49.59	6.1
(DISPLAY 9)			(-49.58677686)	

	ENTER	PRESS KEYS	DISPLAY	RUN TIME IN SECONDS
DECR i, DO NPV	-.04	fE	5.70	6.3
*DECR i, DO NPV	-.011	fE	22.05	6.6
*DO IRR		fD		53.8
				86.0

*NOTE: LOWEST RUN TIME NORMALLY OCCURS WITH (i_t = IRR-0.0111)
e.g., WITH i_t = 0.0528, RUN TIME FOR ABOVE IS
37.0 SECONDS.

CHANGE INVEST	$1200.75	A	1200.75	0.8
ADD CF#3	$ 100	B		1.9
CHANGE CF#1	1	fb	3. (Flashes 4X)	
			1.	7.1
	$ 555		1. (Flashes 4X)	
			555.00 (Flashes 1X)	
			3.	2.2
ADD CF #4	200	B	4.	1.9
ADD CF#15	15	fb	4. (Flashes 4X)	
			15.	7.1
	$ 352.16	B	15. (Flashes 4X)	
			352.16 (Flashes 1X)	
			15.	8.2
ADD CF#16	$ 100.00	B	16.	1.9
DELETE CF#16	(16)	fb	16. (Flashes 4X)	
			16.	7.1
			16.	
			16. (Flashes 4X)	

	ENTER	PRESS KEYS	DISPLAY	RUN TIME IN SECONDS
	0	B	0.00 (Flashes 1X)	
			15.	9.2
DO B.E. PT (YRS)		C	2.457500	3.9
DO PROFIT		fc	606.41	17.2
ESTIMATE i_t				
		RCL C		
		RCL A		
		X÷		
		DSP 4	0.2055	NA
TRIAL i		f RND	0.2055	
	(.2055)	D	0.2055	0.8
DO NPV		E	-154.36	19.4
DECR i, DO NPV	-.08		20.57	19.7
DO IRR		fd	0.1332	260.0
				460.4 (7'20")

NOTE: WITH i_t = 0.1221 (VICE .1255) RUN TIME FOR IRR IS 123 SECONDS (VICE 260).

(9) Redefining IRR Program Decimal Accuracy Limits. In order to carry the IRR calculations to a digit limit other than four (or to reset to four digits subsequently) the procedures are:

	ENTER	PRESS KEYS	DISPLAY
SR-52			
Go to Step 162		GTO 1,6,2	(0.1332)
Shift to Learn Mode		LRN	162 04
In same step, Reset Decimal Digit			
Limit (1 through 9):		9	163 94
Backstep to Review Change		*BST	162 09
Shift to Run Mode		LRN	(0.1332)
Enter Trial i	0.1221	D	0.1221
DO IRR:		*D'	0.133286694

Run time for above IRR is 7 minutes and 38 seconds for 9 decimal digits. Roundoff error (amount NPV misses zero at IRR) decreases from +22.371990 at IRR = 0.1332 to +0.0000130 at IRR = 0.133286694. Repeat above to reset number of digits again; do not reread card if same set of data needed for further analysis – data will be altered thusly in this program because it uses some program steps as data registers.

HR-67				
Shift switch to Program Mode	W/PRGM		--	
Delete Step 214	GTO.214	214	35	82
	h DEL	213	22	08
Delete Step 211	GTO.211	211	31	24
	h DEL	210	23	15

	ENTER	PRESS KEYS	DISPLAY
Delete Step 210		h DEL	209 23 15
Delete Step 187		GTO.187	187 05
		h DEL	186 43
Mentally add 1 to Decimal Limit Desired			
Enter limit (2 through 10)		1	187 01
		0	188 00
Shift switch to Run Mode		RUN	(0.1332)
Enter Trial i	0.1221	D	0.1221
DO IRR:		fd	0.1333
		DSP 9	0.133286694

Run time for above IRR is 12.0 minutes for 9 decimal digits. Roundoff Error (Amount NPV misses zero at IRR) decreases from +22.372000 ¢ at IRR = 0.1332 to 0.0000000 ¢ at IRR = 0.133286694, i.e., beyond the machine capability to determine. To reset number of digits to 4, merely reread card. To reset to some other number of digits, reread card and then repeat above process. No data will be altered.

(10) Comparison With Manufacturer Programs for IRR. The Hewlett-Packard "Internal Rate of Return" program and (BD1-01A) yields the same interest rate for the previous problem in 116.3 seconds (vice 260 seconds with the program developed above). However, this card uses 197 program memory steps to do nothing but IRR and always requires manual entry of all values, i.e.:

INVEST	$1200.75 → A	CF 8	0 → C
CF1	555 → C	CF 9	0 → C
CF2	600 → C	CF10	0 → C
CF3	100 → C	CF11	0 → C
CF4	200 → C	CF12	0 → C
CF5	0 → C	CF13	0 → C
CF6	0 → C	CF14	0 → C
CF7	0 → C	CF15	352.16 → C
		D	→ 13.32866940

If the user keys in a mistake, the entire data entry process must be begun anew. This program will not accept a negative or zero Investment but will accept up to 44 positive cash flows, limited to five digits each. However, for more than 22 cash flows, accuracy decreases to ± 0.01 % (.0001 decimal). If there are negative as well as positive cash flows, the program accepts up to 22 cash flows. This program may sometimes halt prematurely with ERROR in the display if the actual IRR is greater than 100% or if the sign of the cash flows is reversed more than once. Additionally, since more than one interest rate is considered correct in the mathematical sense when the sign of the cash flows is reversed more than once, the user has no way of determining which rate this program has found. (Conversely, the program developed by the authors of this thesis, if given a trial interest rate of zero, will always find the IRR (positive or negative) closest to zero.) Finally, this program will not warn the user of improper data entries or

results, and stored data cannot be used for other purposes but must be reentered against other programs to determine break-even point, profit, net present value, etc.

In summary, then, card BD1-01A is considered inferior to the program developed herein unless IRR is required for more than 20 positive cash flows (each limited to five digits) and no other information or analysis is desired. Otherwise, the card BDI-01A user must be satisfied with a program that may more quickly provide one of the possible solutions or may provide no solution at all, or may not provide the best solution. The BD1-01A user must also be very careful to avoid input errors since stored data is very difficult to review or to change.

The Texas Instruments "Variable Cash Flow (Present Value)" program card (FI1-23) will only accept ten cash flow values and hence will not work the previous problem. Card FI1-23 uses 204 program steps whereas the SR-52 card developed herein uses 224 to accomplish all of the previously discussed capabilities. Thus Card FI1-23 is considered to represent particularly inefficient programming; the card has little practical utility. It does work quickly and well for 10 values, and data can be individually reviewed or altered easily. This card, FI1-23, does yield rates dependent upon the trial interest rate, similar to the program developed by the authors. The five-cash-flow data set listed on page 131 in the Texas Instruments Finance Library for this card requires 151 seconds to run, as below, with accuracy

specified to nearest cent of NPV. Similar data runs on the program developed herein in 133 seconds without specifying accuracy, but additional accuracy (using the same trial interest rate) requires progressively longer times as shown below.

INVEST	$40,200
CF #1	400
CF #2	9,200
CF #3	11,560
CF #4	17,048
CF #5	45,484
Trial i	15%
Accuracy	.01 (Specified for FI1-23 only)

IRR Results:	Solution	Seconds	Amount NPV misses 0 @IRR
(FI1-23) :	0.1978193283	151	+ $0.0095657
Program Herein:	0.1978	133	+ $2.5701892
	0.19781	149	+ $1.2452525
	0.197819	196	+ $0.0528593
	0.1978193	223	+ $0.0131138
	0.19781939	265	+ $0.0011901
	0.197819398	321	+ $0.0001301
With Trial i = 0.1867:	0.197819398	235	+ $0.0001301

A shrewd user of the program developed herein, of course, would normally run the data once to obtain 0.1978 and then, if desired, modify the program and use a trial i of 0.0111 less as mentioned earlier; i.e., 0.1867, to obtain the value 0.197819398, as shown above, with a total running time of 133 + 235 = 368 seconds.

It should be obvious from the above that experienced programmers can, in many cases, develop programs more subtle or more efficient than the program found in the libraries published by any manufacturer. The manufacturers are motivated to sell calculators and calculator cards, not to create particularly efficient programs. Thus the typical approach appears to be that of including generally useful, but simplistic, programs in published libraries, so long as the programs function without error for most input possibilities.

On the other hand, the usefulness of the published programs to less experienced programmers is immense because the cards allow calculations such users might have no idea how to (mathematically) approach, much less program.

10. Advanced Programming Optimization Techniques

The previously developed IRR programs (Figures 3 and 4) and additional programs are used below to clarify subtle differences required when programming the SR-52 or HP-67.

a. Labeled, Direct, and Indirect Relative Addressing.

The simplest way to call a subroutine is merely to give it a label, as discussed previously in Section IV.C., and call the label as required. Equally simple direct addressing (not available on the HP-67) typically uses a "GTO XYZ" statement in lieu of a label. Thus "GTO 123", stored as program steps on the SR-52, will branch the program

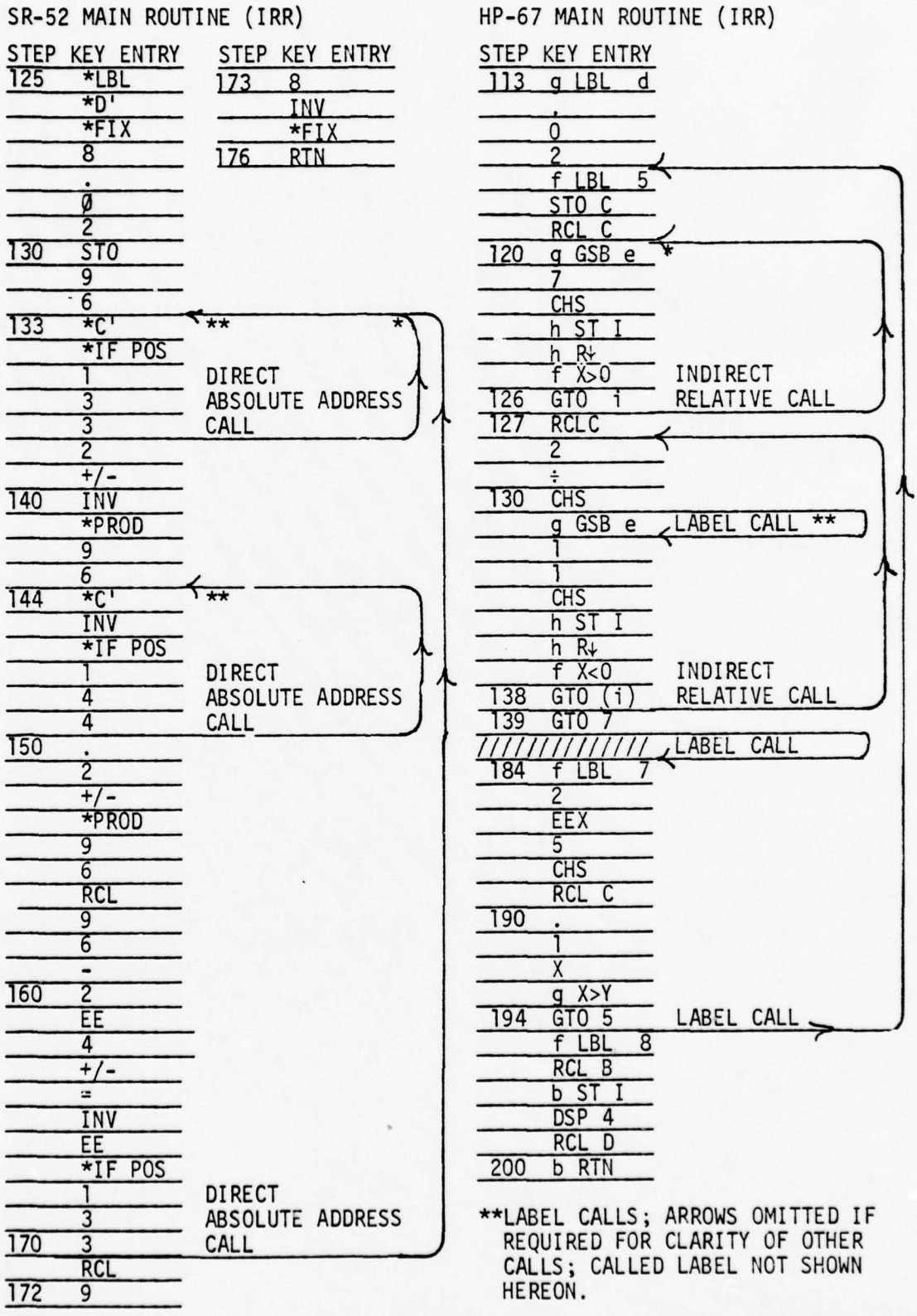
to step 123 whenever this calling instruction is encountered. But this branch is an unconditional transfer; the program does not return to the calling point. For true subroutines, the similar instruction of "SBR 123" is used instead; this call returns the program counter to the step immediately after the "3" when the program encounters a "RTN" instruction subsequent to step 123.

Indirect relative addressing is used on the HP-67, for unconditional branching, by first placing a negative integer in the I-Register such that when the instruction "GTO (i)" is next encountered during program execution, the program will halt, note its own current step number, backstep the number of steps specified by the current (negative) number in the I-register and there resume program execution. Similarly, f GSB (i) is used to call and execute a subroutine and then return to the step after the call. These features each require two or three extra steps, compared to the SR-52, of program memory for each branch thus defined; these features are not included or normally needed on machines such as the SR-52 which have direct addressing capabilities.

Examples of these types of addressing are extracted from Figures 3 and 4 (IRR Programs) and reproduced below, as Figure 5.

FIGURE 5

TYPES OF CALLS



**LABEL CALLS; ARROWS OMITTED IF REQUIRED FOR CLARITY OF OTHER CALLS; CALLED LABEL NOT SHOWN HEREON.

b. Label Search Mechanisms and Subroutine Locations.

The call for a labeled subroutine on the SR-52 causes the program step counter to immediately reset to 000 and then begin a downward search looking for "LBL". Each label thus encountered is then further tested to determine if it is the requested label. If so, execution of that label begins; if not, the downward search is resumed. Thus SR-52 label-location times are directly proportional both to the distance between 000 and the called label and to the number of intervening labels, but the step number of the call itself has little, if any, effect upon location time.

The call for a labeled subroutine on the HP-67 causes a search to begin downward from the point of call in a manner otherwise similar to the SR-52. Thus, HP-67 label location times are directly proportional to the downward distance between the step number of the call and the label, and to the number of intervening labels. (The HP-67 "falls through" its last step, 224, into step 001 if required during this process.)

For subroutines which are infrequently called by the program, the length of label location time is relatively unimportant. But for frequently called or for iterative routines, subroutine location often becomes the most critical factor in optimizing program run times.

Run time is minimized on the SR-52 by placing the most frequently called labeled-subroutines near the

beginning of the program or, as an alternative, placing a series of labeled GTO XYZ (Step Number) statements at or near the beginning; e.g., *LBL A GTO 046, *LBL B GTO 113, *LBL *C' GTO 214 defines three labeled subroutines (A, B, C') which, respectively, begin execution at steps 046, 113, and 214. In these cases the label names are merely moved, but the GTO XYZ instructions require four additional steps per label. Thus the method is only applicable where extra step space is available.

c. Nesting and Stacking Labels or Subroutines.

Program execution normally stops only when a "HLT" or "R/S" instruction is encountered, or when an error condition is created (such as dividing by zero or branching to a non-existent label) or when the "RTN" instruction is encountered in the primary routine being executed. Conversely, labels function only to identify the starting point of a called subroutine. Thus, encountering an uncalled label during program execution has no effect at all; the label is merely ignored. For this reason, labels can sometimes be nested such that the same single step number ends every subroutine in the nest. For example, consider the following SR-52 subroutine (assume any non-zero value, j, is stored in REG 00):

STEP	KEY ENTRY	LABEL CALLED	VALUE CALCULATED & STORED IN REG 99
001	*LBL		
2	C	C	7 + 73 + 10 + j = 90 + j
3	7		
4	+		
5	*LBL		
6	*D	*D	73 + 10 + j = 83 + j
7	7		
8	3		
9	+		
010	*LBL		
1	B	B	10 + j = 10 + j
2	1		
3	*LBL		
4	A	A	0 + j = j
5	0		
6	+		
7	RCL		
8	0		
9	0		
020	INV		
1	*IFZRO	If j≠ 0	
2	0		
3	2		
4	7		
5	+		
6	1		
027	=		
8	STO		
9	9		
030	9		
031	*RTN	STOP	

(j assumed to be needed for other purposes; hence, INV*DSZ features available on calculator not used.)

Similarly, if j=0:

C	7 + 73 + 10 + 0 + 1	= 91
D	73 + 10 + 0 + 1	= 84
B	10 + 0 + 1	= 11
A	0 + 1	= 1

If the above four labels are each individually written, 77 (vice 31) steps are required as listed below. (Assume Program Begins at Step 001.)

```
*LBL  C  :  90 + RCL 00 , INV * IFZRO 015,+1= , STO 99, *RTN.
*LBL *D' :  83 + RCL 00 , INV * IFZRO 036,+1= , STO 99, *RTN.
*LBL  B  :  10 + RCL 00 , INV * IFZRO 056,+1= , STO 99, *RTN.
*LBL  A  :       RCL 00 , INV * IFZRO 074,+1= , STO 99, *RTN.
```

If the common steps are combined into an unlabeled subroutine (beginning at step 035) 50 steps are required, i.e.,:

```
*LBL  C  :  90 , SBR 035 , *RTN.
*LBL *D' :  83 , SBR 035 , *RTN.
*LBL  B  :  10 , SBR 035 , *RTN.
*LBL  A  :       SBR 035 , *RTN.
Subroutine: + RCL 00 , INV * IFZRO 046,+1= , STO 99 , *RTN.
```

If the above subroutine is labeled A and used as a terminus vice as a subroutine 39 steps are required, i.e.:

```
*LBL  C  :  90 , + , GTO A
*LBL *D' :  83 , + , GTO A
*LBL  B  :  10 , + , GTO A
*LBL  A  :  RCL 00 , INV * IFZRO 034,+1= , STO 99 , *RTN.
```

Clearly, the most efficient use of memory space is demonstrated by the initial nesting method. Such nesting can also be shown to be the most efficient method on RPN calculators. Nesting always saves steps on either type of system simply because nesting completely avoids using any calls whatsoever for any subroutine properly sequenced in the nest, and also avoids repeating identical instructions within several subroutines. For many examples of complex nesting with RPN, see Figure 4. This program has 19 labels but only 8 RTN instructions; Labels 1, 2, 3, 4, 5, 8, and E are nested under other labels. In the comparable SR-52 program, Figure 3, labels *E', E, and A are nested under other labels.

Stacking is the process of minimizing program execution time by avoiding lengthy label searches, rather than a process designed to minimize program storage space. Stacking costs steps on the SR-52, but does not cost steps on the HP-67. On the SR-52, labels are stacked followed by GTO xyz statements as discussed in Section IV.E.(10)a above. On the HP-67, entire subroutines are stacked immediately after the subroutine(s) which call the stacked subroutines most often, in order of expected call frequencies.

Returning to Figure 4, Labels (Subroutines) 6, 7, 8, and 9 are stacked in order of expected frequency to accomplish such minimum average label-search times on the HP-67 during IRR calculations. Stacked subroutines may sometimes also be nested, as is Subroutine 8 in Figure 4.

d. Appropriating Program Steps on Registers for Data Memory

The SR-52 has 22 memory registers nominally available: Registers 0 through 19, 98 and 99. (Some of the Registers 60 through 69 may also be available, depending upon the number of pending operations being stored.) An additional 18 Registers (80 through 97) may be "purchased" by trading eight steps of program memory per extra register desired, working backwards from the end of the program. Thus trading of steps 216 through 223 "buys" register 97 and trading of steps 208 through 215 buys register 96, etc., down to the purchase of register 80 with steps 80 through 87. (This technique is demonstrated in Figure 2 to create two extra registers.) In this manner, a program which can be limited to 80 steps (000 through 079) can use at least 40 storage registers on the SR-52; a program limited to 112 steps (one side of a card) can use at least 36 registers, including 0 through 19 and 84 through 99.

The availability of so many storage registers allows the user to approach arrayed data with straightforward indexing techniques. For example, using the latter allocation above, some of the 36 available registers may be arbitrarily assigned to the following array (two-digit numbers equate to register address numbers):

Column No.:	1	2	3	4	5	6	7
ROW *D' :	84	85	86	87	88	89	90
ROW A :	01	02	03	04	05	06	07
ROW B :	11	12	13	14	15	16	17
ROW C :	91	92	93	94	95	96	97

Combining this array with the optimized nested routines of subsection (c) above then allows programmed indexing by column and row number. For example, if 3 (the column index) happens to be stored in REG 00 when LBL B (the row index) happens to be called, the nested program routines will generate the number 13 ($10 + j = 10 + 3 = 13$), the same number located in column 3, Row B of the array. A subsequent call for LBL C would generate 93, the number located in Column 3, Row C, etc. Thus, each register number listed in Column 3 could be generated, in succession, by the subroutine: 3 STO 00 , *D' , A , B , C . Similarly, if the number stored in the column indexer (REG 00) happens to next be changed from 3 to 4, a call for LBL A would generate 04, the number located in Column 4, Row A, etc.

Note, within the nested programs introduced earlier, that each call, in addition to generating the desired number, actually stores the generated number in REG 99. Thus REG 99 can be used as an addresser for the arrayed registers, in each case, by some other portion of the program. Additionally, the column number can

automatically incremented in REG 00 by still another portion of the program. In this manner, each of the values actually stored in the registers listed in a particular row of the array may be sequentially recalled and used by the program. Similarly, each register listed in any column of the array may be sequentially called prior to again changing the column indexer. These row and column call techniques and the above array are used in Subsection (h) below to facilitate a linear-programming problem, but one equally applicable to any other problems which must address a four by eight array of data.

A simple example of appropriated SR-52 program steps is shown in Figure 2, where only two extra registers were required. In summary, the user should always remember that useful extra registers are available on the SR-52 anytime the applicable program steps are not used.

An alternate method, packing registers in order to store two values per register, can be used on the HP-67 to create an additional register (or registers). This method is discussed in Section IV.E (10) h. below. The only limitation of this method appears to be that only 10 digits may be handled between both numbers, uniformly split as desired, e.g., 5/5 or 6/4, etc.

A different, but equally unique, feature of the HP-67 is its ability to store many "words" in its storage registers. Any word formed with the letters a, B, C, d, E, g, I, l, O, o, r, S, Y and Z may be normally, but not always

be created. For example, the following 11-space word groups (including mandatory period) can be stored in registers (not in program memory)

YES SIr .	IdEa rEadY.
I dEClarE .	I do SaY .
I IS rEadY .	I do AgrEE.
BOSS SaY .	o o o o .
good IdEaS .	gollY gee .
I do EaSY .	IdEa CraZY.
god BlESS .	alSO SOrrY.
go BaBY go .	I dISagrEE.

Cards containing 32 phrases may be obtained via the HP-65 Users Club [19] by club members, or from club members who have already obtained them; there is no copyright involved. There is no other published source at this time.

Only extremely advanced programmers can create words; the process involves understanding design architecture of the machine. Conversely, the words are transferred to the storage registers by merely reading the data card, once obtained.

e. Structuring Loop Controls and Counters

Loops are normally structured to begin with a given value and iteratively change that value until some specified limit is reached, at which point the program will exit from the loop. The given value may be either the

variable which is to be worked upon inside the loop or a simple (additional) counter which is incremented or decremented by the program during each pass through the loop. An example of the former (no counter), extracted from the IRR programs of Figures 3 and 4, is duplicated as Figure 5 below. In this example, the program begins with a given value of 0.02 (2%) as an increment for the trial interest rate supplied by the user. The increment is added to the trial interest rate and the program falls into the first loop, where it is immediately sent elsewhere to compute the net present value (NPV) of the Investment and cash flows stored. Upon returning, the newly calculated NPV is tested to determine if it is positive – if so, the program loops back to add the increment again and repeat the loop process. This continues until the NPV goes negative, at which point the program falls out of the first loop, divides the increment by minus two creating a decrement, and falls into the second loop. This loop cycles similarly until the NPV goes positive again, at which point the program falls out of the second loop, changes the decrement back in to the previous increment by multiplying by minus two, and tests to see if the increment has yet been reduced to the specified limit (0.0002). If not, the increment is divided by ten to move the decimal one place and the program loops back to the beginning of the first loop. (The HP-67 program changes the increment before the limit test and thus tests against 0.00002 instead.) The entire process above then repeats. When the SR-52 program

FIGURE 6

LOOP CONTROL BY SIGN OF VARIABLE

SR-52 IRR SUBROUTINE

STEP	KEY ENTRY
127	.
8	0
9	2
130	STO
1	9
2	6
3	*C'
4	*IF POS
5	1
6	3
7	3
8	2
9	+/-
140	INV
1	*PROD
2	9
3	6
4	*C'
5	INV
6	*IF POS
7	1
8	4
9	4
150	.
1	2
2	+/-
3	*PROD
4	9
5	6
6	RCL
7	9
8	6
9	-
160	2
1	EE
2	4
3	+/-
4	=
5	INV
6	EE
7	*IF POS
8	1
9	3
170	3
1	RCL
2	9
3	8
4	INV
5	*FIX
176	*RTN

IF (i - .0002) IS ZERO OR POSITIVE

HP-67 IRR SUBROUTINE

STEP	KEY ENTRY
114	.
5	0
6	2
7	f LBL 5
8	STO C
9	RCL C
120	g GSB e
1	7
2	CHS
3	h ST I
4	h R↓
5	f X>0
6	GTO (i)
7	RCL C
8	2
9	÷
130	CHS
1	g GSB e
2	1
3	1
4	CHS
5	h ST I
6	h R↓
7	f x<Ø
8	GTO (i)
9	GTO 7
	//////////////
184	f LBL 7
5	2
6	EEX
7	5
8	CHS
9	RCL C
190	.
1	1
2	X
3	g x>y
4	GTO 5
5	f LBL 8
6	RCL B
7	h ST I
8	DSP 4
9	RCL D
200	h RTN

IF NPV IS POSITIVE

IF NPV IS NEGATIVE

IF Δi > .00002

For details, See Figures 3 and 4

has completed the inner loops using the specified limit as the increment, or when the HP-67 has completed the inner loops using ten times the specified limit for the increment, the program stops with the IRR in the display.

The loop control method discussed above, which is actually a modified bisection search pattern using defined vice variable increments, is useful anytime the programmer needs to structure loops based upon a sign change of the variable being addressed within the program. This method also allows limiting accuracy to a specified number of decimal places to avoid unnecessary iterations. Differences between the machines for these loops are the order of increment division and test as already mentioned and the loop-back commands themselves. The SR-52 requires programming the step number of the beginning of the loop immediately below each sign test; the HP-67 requires either programming (prior to the sign test) the relative (minus) number of steps to get back to the beginning of the loop from the GTO (i) instruction which follows the sign test, or the programming of extra labels which can be used as addresses after the sign tests. Extra labels can also be used on the SR-52, but absolute numeric addresses are executed quicker. (On the HP-67, the relative (minus-step) addresses are quicker than label addresses for short distances.)

Both calculators have a register (the zero register) which can be automatically decremented by one and tested for zero; the program counter will skip one

address after the test if the register value has reached zero (the DSZ function). The HP-67 also has an ISZ function, and can also branch to an instruction, vice an address, in either case, if desired. (The user of the SR-52 can only increment negative numbers, and can only branch to an address.) The HP-67 can also use the DSZ or ISZ function against the value in the display; the SR-52 cannot.

Any storage register may be used as a counter and decremented or incremented by the program itself on either calculator, but this method is only used when the zero register is needed to store other data such that the automatic DSZ or ISZ cannot be used. Of course, this use of other registers as counters also requires that the stored value be recalled and tested by the program at the end of each loop iteration, similar to the process in Figure 5. Additional details are available in the manufacturer's handbooks.

f. Multiple (Alternate) Uses of One Subroutine

One example of multiple uses of one subroutine was provided in subsection (c) above, using nested labels. Another example is at step 104 of Figure 4, which is duplicated below:

Step	Key Entry	Explanation
101	g LBL c	Begins "Do Profit" Routine
102	0	
103	STO D	Sets Trial i = 0
104	f GSB E	Run NPV routine
105	f x > 0	If Profit > 0, Stop
106	h RTN	

This routine uses the fact that the NPV of a series of cash flows at an interest rate of zero is the same as the undiscounted profit margin. Hence, instead of writing a long separate routine to calculate the profit margin, the authors merely set i = 0 and branch to the NPV routine from the short routine above. This routine continues:

```
107     f LBL D       Begins "Do TRIAL i" Routine
  8     f x< 0        If TRIAL i < 0
  9     GTO 0            DSP ERR (-TRIAL i)
110     STO D         OW, STO TRIAL i in REG D
  1     DSP 4         FORMAT 4 DEC DSP
112     h RTN         STOP.(DSP TRIAL i)
```

During the breakeven point routine, not shown above, execution is branched to step 101 if a situation arises where all cash flows have been subtracted from the investment but the balance is still negative. In this case, the profit routine (which, in turn, uses the NPV routine) is used to recalculate the negative profit. This value then falls through step 107 to hit step 108, a step actually designed to catch negative input errors by the user for the trial interest rate. In this case, however, the value tested is the negative profit, and the program branches to 0, a nonexistent label in this program. This generates an error condition and halts program execution with "Error" in the display. If the user then presses any key on the keyboard, the key will not execute. Instead, the negative profit, with minus sign, will appear in the display. Thus the

routine has a third use – calculating negative profits. Of course, the negative profit was already in the stack when the program branched to step 101, so why was it recalculated? Simply because getting it out of the stack, halting execution, and displaying the error would require considerable program steps which are not available. Instead, then, the single step (#083, GTO f c), accomplished all that was required, since the steps 101 through 112 already existed for other purposes. Similar multiple use of subroutines can be designed into most programs with a little thought.

g. Error or User-Prompting Routines

In addition to the above example, there are four other places in Figure 4 where the program is ordered to branch to the unused label zero, creating an error condition. In each case, the value which will be displayed when the user pushes any key to clear the error display provides information concerning what error was made, only because this information is built into the program structure:

Step	Info Built into program	Error Which will be Displayed
010	None; User's error returned	Non-integer Period Number
016	None; User's error returned	Period No. Greater Than 20
022	None; User's error returned	Negative Period Number
042	21	21 (User attempted to store more than 20 Cash Flows)
109	None; User's error returned	Negative interest rate
109	Profit Routine as above	Negative profit margin for Break-even routine

Instead of generating an error, the SR-52 program (Figure 3) avoids negative inputs by taking the absolute value of inputs which can be incorrectly entered as negative. This is better than no protection, but program space in the IRR routine does not allow warnings similar to the above. In other programs with more space, similar devices could be used. The SR-52 flashes the error value automatically, instead of flashing "Error" once and halting with error in the display as does the HP-67. Either method is useful.

User prompting routines are more difficult to structure on the SR-52 since (unlike the HP-67) the SR-52 will not automatically halt in execution, flash a value, or accept input, and then automatically continue. Conversely, for the HP-67 IRR program (Figure 4), whenever the user decides to shift to another period number and change the cash flow for that period, and thus use key b (Set n = DSP(x)), the calculator announces the maximum period number already used (flashes it four times) and then displays the requested period number. This is designed to say to the user: "OK, you have N values in here now, now go change the one you asked for." Similarly, when the user enters the cash flow for the period requested, the HP-67 announces the period number which the cash flow was stored under (flashes it four times), the amount stored (flashes it once) and halts displaying the maximum period number which has a cash flow stored against it, after the change. This is designed to say to the user: "OK, you just changed the cash flow for

the nth period.... to the amount of $.... and you now have N values stored in the machine." (If the value zero is stored against the maximum period, the HP-67 program automatically searches out and displays the period number for the highest non-zero cash flow stored, as the third part of the above sequence.)

On the SR-52, in lieu of the above, the IRR program (Figure 3) provides a user key (C) that can be pressed to display the maximum N stored, prior to using the "Set n = DSP(x)" key (B'). Then, when the user enters the desired period number and presses the B' Key, the display responds with the desired period number minus one. Note that during automatic accumulation of cash flows using the "STO CF's" user-defined label (see Figure 3 or 4) on either machine, the period number is displayed for each cash flow stored in sequence. Thus the user is accustomed to having the previous period number in display immediately before each new cash flow is entered. The SR-52 IRR routine thus capitalizes on this familiarity when the period number is abruptly changed by the user via the "Set n = DSP(x)" key. This prompting is designed to say to the user: "OK, I (the machine) have switched to the customary cash flow accumulation mode, thus the period prior to the one you requrest — and that you will next enter a cash flow into — is in my display; now enter the desired cash flow." The user then enters the desired cash flow and presses the "STO CF's" key

This time, the calculator responds with the number of the period used (as originally requested by the user in the previous routine). The user can then check the total number of cash flows stored, if desired, by pressing C. Since the SR-52 program does not (for lack of program space only) automatically reset N if 0 is stored in N, this check will alert the user to reset N, if required, by pressing *B, *RSET. (See Section IV.E.(9)c(3).) Clearly, without the minus one routine discussed above, the user would be faced with the same period number both before and after entering the cash flow, which could more easily lead to user's forgetting which operation was just accomplished, especially if the user is interrupted during this process. Conversely, the two routines are tied together by the display itself with the above method. Similar display prompts can be designed into most programs.

Finally, the HP-67 use of "words" in storage registers (see Section IV.E.(10)d.) can also be used for user prompting at end of executing or user prompting of intermediate errors. Setting this process up, however, is somewhat difficult, because the user must use both a data card which contains the word-phrases and the program card prior to commencing operations. Additionally, one storage register per phrase desired must be available and otherwise unused by the program at any time, and the program must be structured to have the result (or error), normally to be displayed after the words, stored in the proper STACK REG.

The process will then work similar to the HP-67 flashing displays above. Thus a three phrase message might be transferred into the STACK in the event of an error such that the message, "IdEa CraZY. alSO SOrrY. I dISagrEE. -123.4567890" is flashed at the user for the result (or error) valued -123.4567890. If the sequence of desired phrases is longer, register review vice STACK review can be used similarly, except that all intervening values stored in the registers 1 through 9 and 20 through 25 would also be flashed. Alternately, a sequence which individually recalls each phrase, pauses to display it, and then repeats this cycle for the next phrase may also be programmed.

h. Multiple Card Operations

Either calculator may be programmed to read additional program or data cards in operation. Since this process is somewhat more difficult with the SR-52, the SR-52 will be used in this section in all examples. The HP-67 process is simpler to program because the HP-67 "smart" card reader does not require that the programs be structured to ensure that read instructions on one card appear in the same step number as do halt instructions on the next card. The HP-67 will also automatically distinguish between program and data, and will automatically reset all flags and the display mode as specified on the new card. Once programmed, however, the systems work similarly: A program card is read into the calculator and the user begins using

the user defined keys for entry of variables and/or to run calculations. Once calculations have begun, the user slips the leading edge of a second card into the card reader. This card will not be read until the program reaches a point specified in the program, at which time the second card is pulled through the card reader, modifying the program or supplying additional data, and execution continues. As an example, the authors designed a program which can be used by students being introduced to basic linear programming methods (Figure 6). The program will optimize an objective function subject to three equations containing seven variables each. The example below is subject to only two equations of five variables each, but is solved the same way. Thus, as an example, suppose the student is asked to:

$$\text{Maximize:} \quad 2x_1 + 5x_2 + 7x_3$$

$$\text{Subject to:} \quad 3x_1 + x_2 + 2x_3 + x_4 + 0x_5 = 150$$

$$x_1 + 3x_2 + 4x_3 + 0x_4 + x_5 = 250$$

(An explanation of linear programming is beyond the scope of this work [18]. Thus the following analysis is most useful to those readers already familiar with the technique. Remember, however, that the method of this example is a simplistic method for beginning students, not the most advanced method that can be programmed.)

The student is given the following instructions:

(1) Construct an expanded Simplex Tableau as shown below.
(2) Compute the $(c_j - z_j)$ row.
(3) Mark the maximum value in the $(c_j - z_j)$ row with one asterisk (*).
(4) Compute the ratio of each constraint to the value in the pivot (*) column.
(5) Mark the minimum ratio obtained with two asterisks (**) to define the pivot row.
(6) Mark the intersection of the pivot row and pivot column with the symbol (@) to define the pivot element.
(7) Multiply the pivot element, and every other element in the pivot row, by the reciprocal of the pivot element; enter this new row in the next section of the tableau.
(8) Multiply the new row by whatever factor is required such that when the multiplied row is added to a remaining row, in the previous tableau, the element in the pivot column becomes zero; bring down this zero (Ø) and the resulting sum for each other element in the same previous row into the new tableau.
(9) Continue with new tableaus until all elements in the $(c_j - z_j)$ row become zero or negative or some other informational condition is reached.

If required to work the example problem with the above instructions, the result might look like this:

COST	ROW	VARIABLE	x_1	x_2	x_3	x_4	x_5	x_6	
			2	5	7	0	0	P	
$C_4 = 0$	A	x_4	3	1	2	1	0	150	
$C_5 = 0$	B	x_5	1	3	4@	0	1	250	**
		$(c_j - z_j)$	2	5	7*	0	0	(0)	
$C_4 = 0$	A	x_4	2.5@	-0.5	Ø	1	-0.5	25	**
$C_5 = 7$	B	x_3	0.25	0.75	1	0	0.25	62.5	
		$(c_j - z_j)$	0.25*	-0.25	0	0	-1.75	(437.5)	
$C_1 = 2$	A	x_1	1	-0.2	0	0.4	-0.2	10	
$C_3 = 7$	B	x_3	Ø	0.8	1	-0.1	0.3	60	
		$(c_j - z_j)$	0	-0.2	0	-0.1	-1.7	(440)	

OPTIMAL.

As a teaching aid to the above process, and to avoid mathematical errors, the Program in Figure 6 can be used by the student, in lieu of pencil and paper algorithms, in the exact manner shown above. (This program does the computations one line at a time the same way the student would. The student must only learn to operate the program properly and to relate to the matrix developed in Section IV.E.(10)d., as reproduced below; the student must compute ratios and pick his own pivots in the usual manner – hence these steps do not appear below.)

Column Number:	1	2	3	4	5	6	7	8
Objective Row: *D'	84	85	86	87	88	89	90	
ROW A:	01	02	03	04	05	06	07	08
ROW B:	11	12	13	14	15	16	17	18
ROW C:	91	92	93	94	95	96	97	98

Although this matrix differs from the standard matrix typically learned for the Simplex method (a_{11},a_{12},etc.) it is similar and rather easily learned by the student; the subscripts normally learned do not happen to all be available as register numbers on the SR-52.

The process to use this two card program (one side programmed per card) is:

Explanation		Sample Entry	Press	Display
Read Card 1			*READ	
Set up OBJECTIVE ROW			*D'	84.
Set up row counter			D	84.
Enter OBJECTIVE ROW values	(Column 1)	2	RUN	84.
	(Column 2)	5	RUN	85.
	(Column 3)	7	RUN	86.
Set up ROW A			A	1.
Set up row counter			D	1.
Enter ROW A values	(Column 1 term)	3	RUN	1.
	(Column 2 term)	1	RUN	2.
	(Column 3 term)	2	RUN	3.
	(Column 4 term)	1	RUN	4.
	(Column 5 term)	0	RUN	5.
	(Column 6 term)	150	RUN	6.
Set up ROW B			B	11.
Set up row counter			D	11.
Enter ROW B values	(Column 1 term)	1	RUN	11.
	(Column 2 term)	3	RUN	12.
	(Column 3 term)	4	RUN	13.
	(Column 4 term)	0	RUN	14.
	(Column 5 term)	1	RUN	15.
	(Column 6 term)	250	RUN	16.
(Same process for ROW C when required)				
Set up for $(c_j - z_j)$ calculations			*RSET	(16.)
Enter highest column number used		6	E	0.
(Values for each)	(5th)		RUN	0.
(successively)	(4th)		RUN	0.
(smaller column)	(3rd)		RUN	7.
(compute in)	(2nd)		RUN	5.
(sequence)	(1st)		RUN	2.
Alternately, or to recheck a value, merely enter column number:		3	E	7.
		1	E	2.
		etc.		
Read Card 2			*E'	---
			HLT	(2.)
Multiply ROW B by (1/4 = .25) and Relist ROW B.		.25	D	0.25
			B	11.
(Column 1 term)			RUN	0.25
(Column 2 term)			RUN	0.75
(Column 3 term)			RUN	1.
(Column 4 term)			RUN	0.
(Column 5 term)			RUN	0.25
(Column 6 term)			RUN	62.5

Explanation	Sample Entry	Press	Display
Multiply new ROW B by -2 and	-2.	E	-2.
add to previous ROW A;		B	11.
list new ROW A		A	1.
(Column 1 term)		RUN	2.5
(Column 2 term)		RUN	-0.5
(Column 3 term)		RUN	0.
(Column 4 term)		RUN	1.
(Column 5 term)		RUN	-0.5
(Column 6 term)		RUN	25.
Reread Card 1 and Reset Counters		*E'	---
		HLT	(25.)
		*RSET	(25.)
Set up Cost Routine		*C'	(25.)
Enter Cost of ROW A	0	RUN	0.
Enter Cost of ROW B	7	RUN	7.
(Same process for ROW C when required)			
Set up for $(c_j - z_j)$ calculations		*RSET	(7.)
Enter highest column number used and			
compute as in previous tableau:	6	E	-437.5
(Column 5 term)		RUN	-1.75
(Column 4 term)		RUN	0.
(Column 3 term)		RUN	0.
(Column 2 term)		RUN	-0.25
(Column 1 term)		RUN	0.25
Reread Card 2		*E'	---
		HLT	(0.25)
Multiply ROW A by (1/2.4 = .4) and			
relist	.4	D	0.4
		A	1.
(Column 1 term)		RUN	1.
(Column 2 term)		RUN	-0.2
(Column 3 term)		RUN	0.
(Column 4 term)		RUN	0.4
(Column 5 term)		RUN	-0.2
(Column 6 term)		RUN	10.
Multiply new ROW A by -1/4 and add to			
previous ROW B; list new ROW B	-.25	E	-0.25
		A	1.
		B	11.
(Column 1 term)		RUN	0.
(Column 2 term)		RUN	0.8
(Column 3 term)		RUN	1.
(Column 4 term)		RUN	-0.1
(Column 5 term)		RUN	0.3
(Column 6 term)		RUN	60.

Explanation	Sample Entry	Press	Display
Reread Card 1 and Reset Counters		*E'	---
		HLT	(60.)
		*RSET	(60.)
Set up Cost Routine		*C'	(60.)
Enter Cost of Row A	2	RUN	2.
Enter Cost of Row B	7	RUN	7.
Set up for $(c_j - z_j)$ calculations		*RSET	(7.)
Enter highest column number used and compute as in previous tableaus	6	E	-440.
(Column 5 term)		RUN	-1.7
(Column 4 term)		RUN	-0.1
(Column 3 term)		RUN	0.
(Column 2 term)		RUN	-0.2
(Column 1 term)		RUN	0.
Problem complete. Recall maximum:	6	E	-440.
Result is $440.00.			

If the reader is wondering why this program uses two cards but only one side per card, the answer is that only the first 112 program steps are used as program. The remainder are used to create the storage registers 84 through 97. Of course, the two 112 step programs could be put on alternate sides of the same card anyway, but since the two programs use different user-defined labels, the use of one card for both purposes would be confusing.

On the HP-67, the necessary number of data registers can only be created by packing (storing values on opposite sides of the decimal) at least 20 of the 26 available registers. This limits inputs to values having no more than 5 significant digits, which is quite satisfactory for the above example. This entire program can, also, be listed on only one HP-67 card. Further, it is somewhat simpler to use

than the above SR-52 method. For interested readers, such a program is provided at Figure 7.

In a manner almost identical to the above, programs can be created which do not require secondary input from the user, other than start commands after initial input. Programs can even be created on loops of magnetic mylar instead of cards, loops which require only occasional starts by the user.

i. Program Space Versus Execution Time

In programs which compute solutions based upon non-iterative algorithms, or with minimal use of iterative (loop) algorithms, execution speed is not normally a consideration because SR-52 and HP-67 can both execute an average program of 224 instructions in less than 15 seconds (unless numerous exponentiations are required in the case of the HP-67). However, when numerous iterations of algorithmic loops are necessary, execution time becomes a critical factor. For example, note that the IRR examples discussed in Sections IV.E.(9)c(7) and (8) require 4 minutes 46 seconds on the SR-52 and 7 minutes 20 seconds on the HP-67. If these programs were not optimized for execution speed, execution could require more than two times these respective amounts of time. Extremely long program execution times are both inconvenient to the user and unnecessarily wasteful of battery power. Hence complex or iterative main routines should normally be designed to minimize execution time.

FIGURE 7

LINEAR PROGRAMMING AID (SR-52)

USER KEYED LABELS										
			B' (USED)		C' INIT. COST; A,B,C		D' SELECT OBJ. ROW		E' READ CARD 2	
A SELECT ROW A		B SELECT ROW B		C SELECT ROW C		D a_{ij} REG_{ij}		E $j \rightarrow (c_j - z_j)$		

FLAGS:

	OFF	ON	
0		X	
1		X	
2		X	
3		X	
		X	

REGISTERS

00	j Index	(COL)
01	a SUS. A1	
02	a SUS. A2	
03	a SUS. A3	
04	a SUS. A4	
05	a SUS. A5	
06	a SUS. A6	
07	a SUS. A7	
08	b SUS. A8	
09	Row A COST	
10	Row B COST	
11	a SUS. B1	
12	a SUS. B2	
13	a SUS. B3	
14	a SUS. B4	
15	a SUS. B5	
16	a SUS. B6	
17	a SUS. B7	
18	b SUS. B8	
19	Row C COST	
91	a SUS. C1	
92	a SUS. C2	
93	a SUS. C3	
94	a SUS. C4	
95	a SUS. C5	
96	a SUS. C6	
97	a SUS. C7	
98	b SUS. C8	
99	a SUS. ij	

SET STATUS

DISPLAY		TRIG	
	SCI	X	DEG
	ENG		RAD
	FIX		GRAD
X	FLOATING PT		

OTHER LABELS

84	COEF. x SUS. 1
85	COEF. x SUS. 2
86	COEF. x SUS. 3
87	COEF. x SUS. 4
88	COEF. x SUS. 5
89	COEF. x SUS. 6
90	COEF. x SUS. 7
68	P SUS. j
69	$(c_j - z_j)$

STEP	KEY CODE	KEY ENTRY	
000	10	*E'	
1	46	*LBL	SELECT ROW C
2	13	C	
3	07	7	
4	85	+	
5	46	*LBL	
6	19	*D'	SELECT OBJECTIVE ROW
7	07	7	
8	03	3	$(D_j = 83 + j \rightarrow REG\ 99)$
9	85	+	
010	46	*LBL	SELECT ROW B
1	12	B	
2	01	1	$(B_j = 10 + j \rightarrow REG\ 99)$
3	46	*LBL	SELECT ROW A
4	11	A	
5	00	Ø	$(A_j = Ø + j \rightarrow REG\ 99)$
6	85	+	
7	43	RCL	
8	00	Ø	
9	00	Ø	
020	22	INV	
1	90	*IFZRO	IF j ≠ 0
2	00	Ø	
3	02	2	
4	07	7	GTO STEP 027
5	85	+	IF j = 0, As Above,
6	01	1	$A_j = 1$
027	95	=	$B_j = 11$ → REG 99
8	42	STO	$C_j = 91$
9	09	9	$D_j = 84$

NOTES

SUS. = Subscript

COEF. = Coefficient

TO INITIALIZE:

PRESS HLT*RSET.

INSTRUCTIONS IN THESIS.

STEP	KEY CODE	KEY ENTRY
030	09	9
1	56	*RTN
2	46	*LBL
3	15	E
4	42	STO
5	00	Ø
6	00	Ø
037	19	*D'
8	25	CLR
9	01	1
040	34	+/-
1	17	*B'
2	11	A
3	43	RCL
4	00	Ø
5	09	9
6	17	*B'
7	12	B
8	43	RCL
9	01	1
050	00	Ø
1	17	*B'
2	13	C
3	43	RCL
4	01	1
5	09	9
6	46	*LBL
7	17	*B'
8	65	X
9	36	*IND
060	43	RCL
1	09	9
2	09	9
3	95	=
4	22	INV
5	44	SUM
6	06	6
7	09	9
8	43	RCL
9	06	6
070	09	9
1	56	*RTN
2	58	DSZ
3	00	Ø
4	03	3
5	07	7
076	56	*RTN
7	CONTINUED	
8	ON NEXT	
9	PAGE	

NOTES

$j \rightarrow (C_j - Z_j)$

*D'

*B' A

*B' B

*B' C

(USED)

USER PRESS RUN

STOP.

IF $j \neq 0$, GTO STEP 037

	STEP	KEY CODE	KEY ENTRY	NOTES
	///0			
	///1			
	///2			
	///3			
	///4			
PRGM	///5			
OR	///6			
USER	077	46	*LBL	
GIVE	8	14	D	$a_{ij} \rightarrow REG_{ij}$
a_{ij}	9	81	HLT	STOP.
	080	36	*IND	
	1	42	STO	
	2	09	9	
	3	09	9	
	4	43	RCL	
	5	09	9	
	6	09	9	
	7	85	+	
	8	01	1	
	9	85	=	
	090	48	*EXC	
	1	09	9	
	2	09	9	
USER	3	14	D	
GIVE:	4	46	*LBL	
ROW A	5	18	*C'	INIT. COST: A,B,C
COST	6	81	HLT	STOP.
	7	42	STO	
	8	00	0	
ROW B	9	09	9	
COST	100	81	HLT	STOP.
	1	42	STO	
	2	01	1	
ROW C	3	00	0	
COST	4	81	HLT	STOP.
	5	42	STO	
	6	01	1	
	7	09	9	
	8	56	*RTN	
	9	46	*LBL	
	110	10	*E'	READ CARD 2
	1	96	*READ	END OF CARD 1.
	///2	SEE		
	///3	NEXT		STEPS 112-223
	///4	PAGE		USED AS STORAGE
	///5	FOR		REGISTERS 84-97.
	///6	CARD		
	///7	NUMBER		
	///8	TWO		
	///9			

USER KEYED LABELS			C' STO K REG ØØ		E' REREAD CARD 1
	A SELECT ROW A	B SELECT ROW B	C SELECT ROW C	D K PR K·PR IN PR	E K PR ROW K·PR SUM IN ROW

FLAGS:

		OFF	ON
0		X	
1	IF		X
2	IF		X
3		X	
		X	

OTHER REGISTERS

84	COEF. x SUS. 1
85	COEF. x SUS. 2
86	COEF. x SUS. 3
87	COEF. x SUS. 4
88	COEF. x SUS. 5
89	COEF. x SUS. 6
90	COEF. x SUS. 7
68	P SUS. j
69	$(C_j - Z_j)$

NOTES

SUS. = SUBSCRIPT
COEF. = COEFFICIENT
PR = PIVOT ROW

TO INITIALIZE:

press hlt.

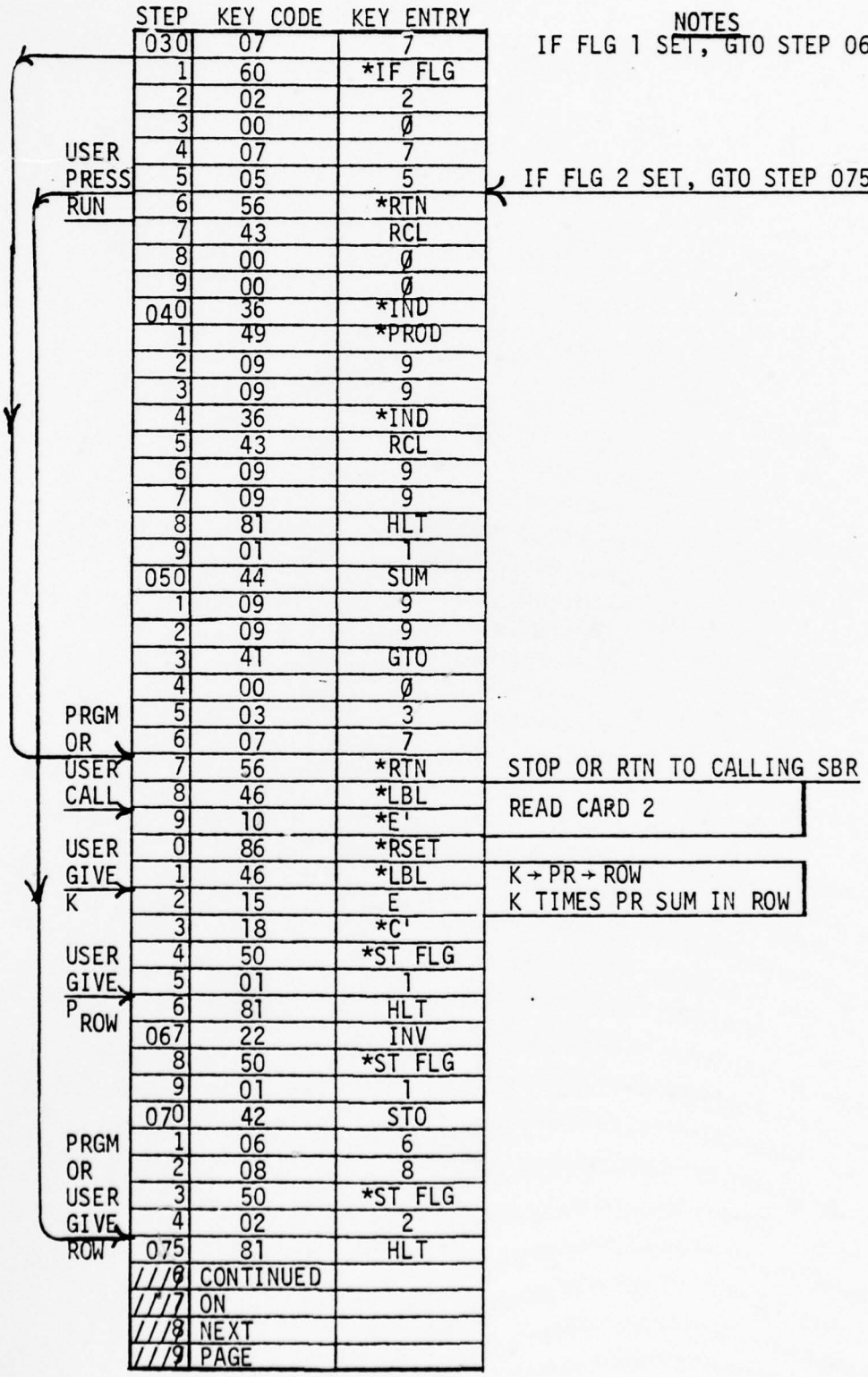
REGISTERS

00	j INDEX	(COL)
01	a SUS. A1	
02	a SUS. A2	
03	a SUS. A3	
04	a SUS. A4	
05	a SUS. A5	
06	a SUS. A6	
07	a SUS. A7	
08	b SUS. A8	
09	ROW A COST	
10	ROW B COST	
11	a SUS. B1	
12	a SUS. B2	
13	a SUS. B3	
14	a SUS. B4	
15	a SUS. B5	
16	a SUS. B6	
17	a SUS. B7	
18	b SUS. B8	
19	ROW C COST	
91	a SUS. C1	
92	a SUS. C2	
93	a SUS. C3	
94	a SUS. C4	
95	a SUS. C5	
96	a SUS. C6	
97	a SUS. C7	
98	b SUS. C8	
99	a SUS. ij	

STEP	KEY CODE	KEY ENTRY	
000	96	*READ	
1	46	*LBL	STO K REG ØØ
2	18	*C'	
3	42	STO	
4	00	Ø	
USER GIVE K 5	00	Ø	
6	56	*RTN	
7	46	*LBL	K PR K TIMES PR IN PR
8	14	D	
USER GIVE P ROW 9	18	*C'	
010	81	HLT	
1	46	*LBL	SELECT ROW C
2	13	C	(Set ij = 91+K)
3	08	8	
4	00	0	
5	85	+	
6	46	*LBL	SELECT ROW B
7	12	B	(Set ij = 11+K)
8	01	1	
9	46	*LBL	SELECT ROW A
020	11	A	(Set ij = 1+K)
1	01	1	
2	95	+	
3	42	STO	
4	09	9	
5	09	9	
6	60	*IF FLG	
7	01	1	
8	00	Ø	
9	06	6	

SET STATUS

DISPLAY		TRIG	
	SCI	X	DEG
	ENG		RAD
	FIX		GRAD
X	FLOATING PT		


STEP
KEY CODE
KEY ENTRY
NOTES
IF FLG 1 SET, GTO STEP 067
IF FLG 2 SET, GTO STEP 075
USER PRESS RUN
PRGM OR USER CALL
USER GIVE K
USER GIVE P ROW
PRGM OR USER GIVE ROW
030 07 7
1 60 *IF FLG
2 02 2
3 00 Ø
4 07 7
5 05 5
6 56 *RTN
7 43 RCL
8 00 Ø
9 00 Ø
040 36 *IND
1 49 *PROD
2 09 9
3 09 9
4 36 *IND
5 43 RCL
6 09 9
7 09 9
8 81 HLT
9 01 1
050 44 SUM
1 09 9
2 09 9
3 41 GTO
4 00 Ø
5 03 3
6 07 7
7 56 *RTN
8 46 *LBL
9 10 *E'
0 86 *RSET
1 46 *LBL
2 15 E
3 18 *C'
4 50 *ST FLG
5 01 1
6 81 HLT
067 22 INV
8 50 *ST FLG
9 01 1
070 42 STO
1 06 6
2 08 8
3 50 *ST FLG
4 02 2
075 81 HLT
///6 CONTINUED
///7 ON
///8 NEXT
///9 PAGE
STOP OR RTN TO CALLING SBR
READ CARD 2
K → PR → ROW
K TIMES PR SUM IN ROW

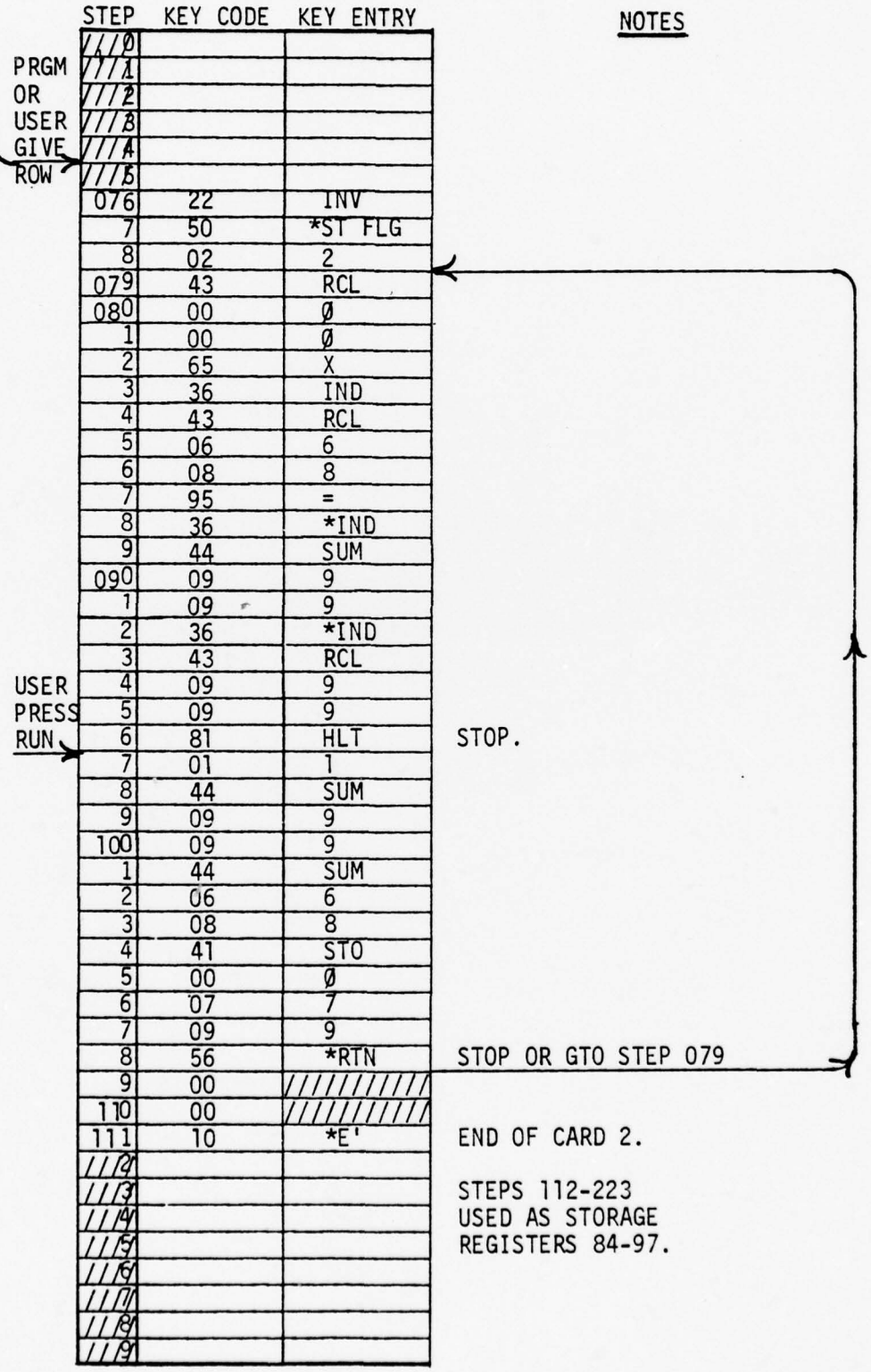

STEP
KEY CODE
KEY ENTRY
NOTES
PRGM OR USER GIVE ROW
076 22 INV
7 50 *ST FLG
8 02 2
079 43 RCL
080 00 Ø
1 00 Ø
2 65 X
3 36 IND
4 43 RCL
5 06 6
6 08 8
7 95 =
8 36 *IND
9 44 SUM
090 09 9
1 09 9
2 36 *IND
3 43 RCL
USER PRESS RUN
4 09 9
5 09 9
6 81 HLT
STOP.
7 01 1
8 44 SUM
9 09 9
100 09 9
1 44 SUM
2 06 6
3 08 8
4 41 STO
5 00 Ø
6 07 7
7 09 9
8 56 *RTN
STOP OR GTO STEP 079
9 00
110 00
111 10 *E'
END OF CARD 2.
STEPS 112-223
USED AS STORAGE
REGISTERS 84-97.

FIGURE 8

LINEAR PROGRAMMING AID (HP-67)

USER KEYED LABELS	a INITIALIZE LOADING	b	c INITIALIZE CONVERSION	d INITIALIZE PIVOT SEQ.	e INIT. Z_j SEQUENCE
	A ROW A	B ROW B	C ROW C	D ROW D	E Z_j

FLAGS: OFF/ON

0			
1			
2			
3			

OTHER LABELS

@	POSITIONING
1	CONTROLS
2	
3	
4	
5	
6	
7	

NOTES

Any row may be used as the Objective Row.

Costs of each row are manually stored as STO A, STO B, STO C, etc.

Pivot value manually stored as STO E.

REGISTERS

0	
P1	STO ROWS
2	A & B
3	
4	
5	
6	
7	
8	
9	
0	
S1	STO ROWS
2	C & D
3	
4	
5	
6	
7	
8	
9	
A	STORE
B	COSTS
C	
D	
E	PIVOT VALUE

STEP	KEY CODE	KEY ENTRY	
)			
001	32 25 11	a LBL a	INITIALIZE LOADING
2	01	1	
3	36 33	h STO I	
4	84	R/S	
5	31 25 06	f LBL 6	
6	31 42	f P≠S	
7	31 25 05	f LBL 5	
8	84	R/S	
9	31 25 13	f LBL C	LOAD ROW C
010	35 51 02	SF 2	
011	31 42	f P≠S	
2	31 25 11	f LBL A	LOAD ROW A
3	43	EEX	
4	02	2	
5	71	X	
6	31 83	f INT	
7	33 61 24	ST +i	
8	35 34	h RCL I	
9	01	1	
020	61	+	
1	35 33	h STO I	
2	35 71 02	F2?	
3	22 06	GTO 6	
4	22 05	GTO 5	
5	31 25 14	f LBL D	LOAD ROW D
6	35 51 02	SF 2	
7	31 42	f P≠S	
8	31 25 12	f LBL B	LOAD ROW B
9	43	EEX	

SET STATUS

DISPLAY		TRIG	
	SCI__		DEG
	ENG__		RAD
	FIX__		GRAD
	FLOATING PT		

STEP	KEY CODE	KEY ENTRY	NOTES
030	03	3	
1	81	÷	
2	32 83	gf RAC	
3	33 61 24	ST +i	
4	35 34	h RCL I	
5	01	1	
6	61	+	
7	35 33	h STO I	
8	35 71 02	F2?	
9	22 06	GTO 6	
040	22 05	GTO 5	
1	32 25 14	g LBL d	INITIALIZE PIVOT SEQUENCE
2	01	1	
3	35 33	h STO i	STO PIVOT VALUE IN E
4	84	R/S	
5	31 25 03	f LBL 3	
6	31 42	P≠S	
7	31 25 04	f LBL 4	
8	84	R/S	
9	31 25 13	f LBL C	PIVOT ON ROW C
050	31 42	f P≠S	
1	35 51 02	SF 2	
2	31 25 11	f LBL A	PIVOT ON ROW A
3	34 24	RCL i	
4	31 83	f INT	
5	34 15	RCL E	
6	43	EEX	
7	02	2	
8	71	X	
9	81	÷	
060	31 84	f -X-	
1	43	EEX	
2	02	2	
3	71	X	
4	31 83	f INT	
5	34 24	RCL i	
6	32 83	g FRAC	
7	61	+	
8	33 24	STO i	
9	35 34	h RCL I	
070	01	1	
1	61	+	
2	35 33	h STO I	
3	01	1	
4	51	-	
5	35 71 02	F2?	
6	22 03	GTO 3	
7	22 04	GTO 4	
8	31 25 14	f LBL D	PIVOT ON ROW D
9	35 51 02	SF2	

STEP	KEY CODE	KEY ENTRY	NOTES
080	31 42	f P S	
1	31 25 12	f LBL B	PIVOT ON ROW B
2	34 24	RCL i	
3	32 83	g FRAC	
4	34 15	RCL E	
5	43	EEX	
6	03	3	
7	81	÷	
8	81	÷	
9	31 84	f -X-	
090	43	EEX	
1	03	3	
2	81	÷	
3	32 83	g FRAC	
4	34 24	RCL i	
5	31 83	f INT	
6	61	+	
7	33 24	STO i	
8	35 34	h RCL I	
9	01	1	
100	61	+	
1	35 33	h STO I	
2	01	1	
3	51	-	
4	35 71 02	f2?	
5	22 03	GTO 3	
6	22 04	GTO 4	
7	32 25 13	g LBL C	INITIALIZE CONVERSION
8	01	1	
9	35 33	h STO I	
110	84	R/S	
1	31 25 07	f LBL 7	
2	31 42	f P≠S	
3	35 61 00	CFO	
4	31 25 00	f LBL 0	
5	84	R/S	
6	31 25 13	f LBL C	PIVOT/CONV. ROW C
7	35 51 00	SFO	
8	31 42	f P≠S	
9	31 25 11	f LBL A	PIVOT/CONV. ROW A
120	34 24	RCL i	
1	31 83	f INT	
2	43	EEX	
3	02	2	
4	81	÷	
5	35 71 02	h F?2	
6	22 02	GTO 2	
7	22 01	GTO 1	
8	31 25 14	f LBL D	PIVOT/CONV. ROW D
9	35 51 00	h SF 0	

FOLLOWING LABELS:
(1) PRESS LBL FOR PIVOT ROW
(2) PRESS LBL FOR ROW BEING CONVERTED

STEP	KEY CODE	KEY ENTRY	NOTES
130	31 42	f P≠S	
1	31 25 12	f LBL B	PIVOT/CONV. ROW B
2	34 24	RCL i	
3	32 83	g FRAC	
4	43	EEX	
5	03	3	
6	71	X	
7	35 71 02	h F?2	
8	22 02	GTO 2	
9	22 01	GTO 1	
140	31 25 01	f LBL 1	
1	33 13	STO C	
2	35 51 02	h SF 2	
3	35 71 00	h F? 0	
4	22 07	GTO 7	
5	22 00	GTO 0	
6	31 25 02	f LBL 2	
7	34 13	RCL C	
8	34 15	RCL E	
9	71	X	
150	51	-	
1	31 84	f -X-	
2	35 34	h RCL I	
3	01	1	
4	61	+	
5	35 33	h STO I	
6	35 71 00	h F? 0	
7	22 07	GTO 7	
8	22 00	GTO 0	
9	32 25 15	g LBL e	INITIALIZE Z_j SEQUENCE
160	01	1	STO ROW COST VALUES
1	35 33	h STO I	IN REGs A,B,C AND D
2	84	R/S	AS APPLICABLE
3	31 25 15	f LBL E	CALCULATE Z
4	44	CLX	
5	34 24	RCL i	
6	31 83	f INT	
7	43	EEX	
8	02	2	
9	81	÷	
170	34 11	RCL A	
1	71	X	
2	34 24	RCL i	
3	32 83	g FRAC	
4	43	EEX	
5	03	3	
6	71	X	
7	34 12	RCL B	
8	71	X	
9	61	+	

STEP	KEY CODE	KEY ENTRY	NOTES
180	31 42	f P≠S	
1	34 24	RCL i	
2	31 83	f INT	
3	43	EEX	
4	02	2	
5	81	÷	
6	34 13	RCL C	
7	71	X	
8	61	+	
9	34 24	RCL i	
190	32 83	g FRAC	
1	43	EEX	
2	03	3	
3	71	X	
4	34 14	RCL D	
5	71	X	
6	61	+	
7	31 84	f -X-	
8	35 34	h RCL I	
9	01	1	
200	61	+	
1	35 33	h STO I	
2	31 42	f P≠S	
203	84	R/S	END OF THIS PROGRAM
4			
5			
6			
7			
8			
9			
210			
1			
2			
3			
4			
5			
6			
7			
8			
9			
220			
1			
2			
3			
224			END OF PROGRAMMABLE MEMORY
///5			
///6			
///7			
///8			
///9			

Attempts to minimize execution times often conflict with attempts to minimize program space. Because of the search patterns used internally by either calculator, the shortest possible program is not normally the fastest. Thus the user must usually consider eliminating steps and tolerating slower execution speeds in order to squeeze in the primary program itself, or in order to add additional user-defined routines to the program, as opposed to minimizing execution speeds. The best choice is normally to minimize, to the maximum extent possible, the number of steps required by all secondary routines which are never, or infrequently, used by the primary routine(s). Conversely, the best choice for the primary routine(s) is normally to minimize steps only to the extent that execution time is not adversely affected by the exclusion of addressing techniques which require more steps, but which execute faster. These kinds of tradeoffs are incorporated in the IRR routines discussed earlier, for example. Nesting, stacking and even separating the parts of routines can often be used to increase execution speed, without requiring additional steps. Thus, the location of each routine within the program may also be analyzed by the programmer with regard to desires concerning program space or execution times.

In summary, the optimization of calculator programs requires tradeoffs which are based upon experience and published literature, whereas basic, less efficient (but useful) calculator programs can be created even by the novice user.

11. Machines of the Future

a. The National SemiConductor Model 7100 (NS-7100)

The projected capabilities of this calculator (Appendix B) are immense, exceeding the SR-52 and HP-67 by at least one order of magnitude. Its projected cost is $400. Its 4000-step basic library is structured as a semiconductor cartridge, comparable (theoretically) to about 18 full SR-52 or HP-67 cards. The non-volatile memory thus requires no drive motor in order to be read. Then, its keyable memory and user cartridge give another 240 steps, each. This totals an equivalent of 20 cards. Its projected hardwired functions are extensive.

It is difficult to comprehend the capacity of this calculator. For example, consider the IRR program developed earlier (Table 3) and multiply the capacity of that program by 20, or consider 20 equally complex programs all in your hand at one time and all usable in whatever sequence is desired, either in total or as subroutines of a user-keyed or user-stored additional program; subroutines of indexed library programs may also be called from the keyboard. This calculator does not have user-definable keys. Instead, multiple-digit call numbers, as specified on the library index, must be used to call a routine. This system is designed to correspond closely to normal usage of mathematical subscripting, but requires more keystrokes than do systems which use user-defined keys.

The 240 step cartridge programmable by the user is much bulkier and much more expensive ($15 vice 50¢ each) than a card of 224 steps. This may be considered, in some applications, as the price for security: unlike cards, semiconductor cartridges cannot be accidentally altered by an external magnetic field.

National Semiconductor is not planning to manufacture a printer for the NS-7100; another (independent) company is planning to do this.

Experience with the NS-7100 may show that most problems can be solved without much additional programming by the user, simply by using the extensively indexed routines available from each library cartridge. The authors of this work are biased, however, toward high use of individualized, permanently stored programs. Such an accumulation of programs on the NS-7100 user cartridges would be extremely expensive. It thus appears that the calculator may be better suited to users who do not mind keying in programs manually when required and who are otherwise satisfied to depend heavily upon preprogrammed routines, rather than generating large numbers of individualized programs.

b. The Texas Instruments Programmable Calculators 59 and 58 (TI-59; TI-58)

The TI-59 machine is the highest capacity hand-held calculator projected to be available in June 1977. The projected cost is $300. When combined with the PC-100A

printer it provides extensive alphanumeric formating (63 digits, letters, mathematical and Greek symbols) as well as discrete-point curve plotting (printable coordinate points 20 by n). This entire system will fit in a briefcase with room to spare. The TI-59 has extensive hardwired (semiconductor) functions, additional interchangeable 5000-step library semiconductor chips plug into the calculator's backside, and 480 step magnetic cards pass through its card reader for additional capacity. Only one card is required for the optional mode of 480 steps and 60 registers but an additional card may be used to store data in registers or to redefine step/register ratios; i.e., optional modes of 960 steps with no registers or 720 steps with 30 registers, etc. (The tradeoff is 10 registers per 80 steps, except that no more than 100 data-storage registers are available.) The calculator will also read cards during operation, as desired.

Key codes are double-merged, whereas they are unmerged on the SR-52 and triple merged on the HP-67 or NS-7100. Because of machine differences, the number of double merged TI-59 program steps required to accomplish programs equivalent to programs of triple-merged systems appear to yield a step ratio of 1.2 to 1. Hence its nominal mode of 60 registers and 480 card-steps (+5000 chip steps) roughly equates to 4567 NS-7100 steps or HP-67 steps. Of course, neither the NS-7100 or HP-67 has either this many steps or 60 storage registers.

Projected execution speeds are faster on the TI-59 than on the SR-52.

To introduce the reader to the data range available on the TI-59, several tape outputs of this system, obtained from Texas Instruments emulators, are reproduced below as Figures 9, 10, 11, and 12. These tapes show that this calculator retains all of the good features of its predecessor (the SR-52) but, evidently, few of the disadvantages of the SR-52. (See also Appendix B.)

(The HP-67 will also accomplish some types of graphical output by using the limit of each line printed, or figures within each line printed, to outline curves. An example of an HP-97 sine curve generated in this manner is provided as Figure 13 below for comparison with the TI-59 sine curves duplicated in Figure 11.)

The TI-59 is likely to be marketed longer than has been the case for many calculators. Instead of pursuing new machine designs, the manufacturers appear to be researching improvements to the interchangeable semiconducter chips which clip into the machine. Thus even more capacity, on the same machine, may become available in the future. Meanwhile, the TI-58 is projected for introduction at the same time as the TI-59, at a lower ($125) cost. The TI-58 is identical to the TI-59 except that it has no motor and doesn't read cards. In any event, until National Semiconductor provides a printing capability for the NS-7100, the TI-59 combined with the PC-100A printer is projected to be the most compact system available of equal capabilities.

FIGURE 9

TI-59 AVAILABLE ALPHANUMERICS

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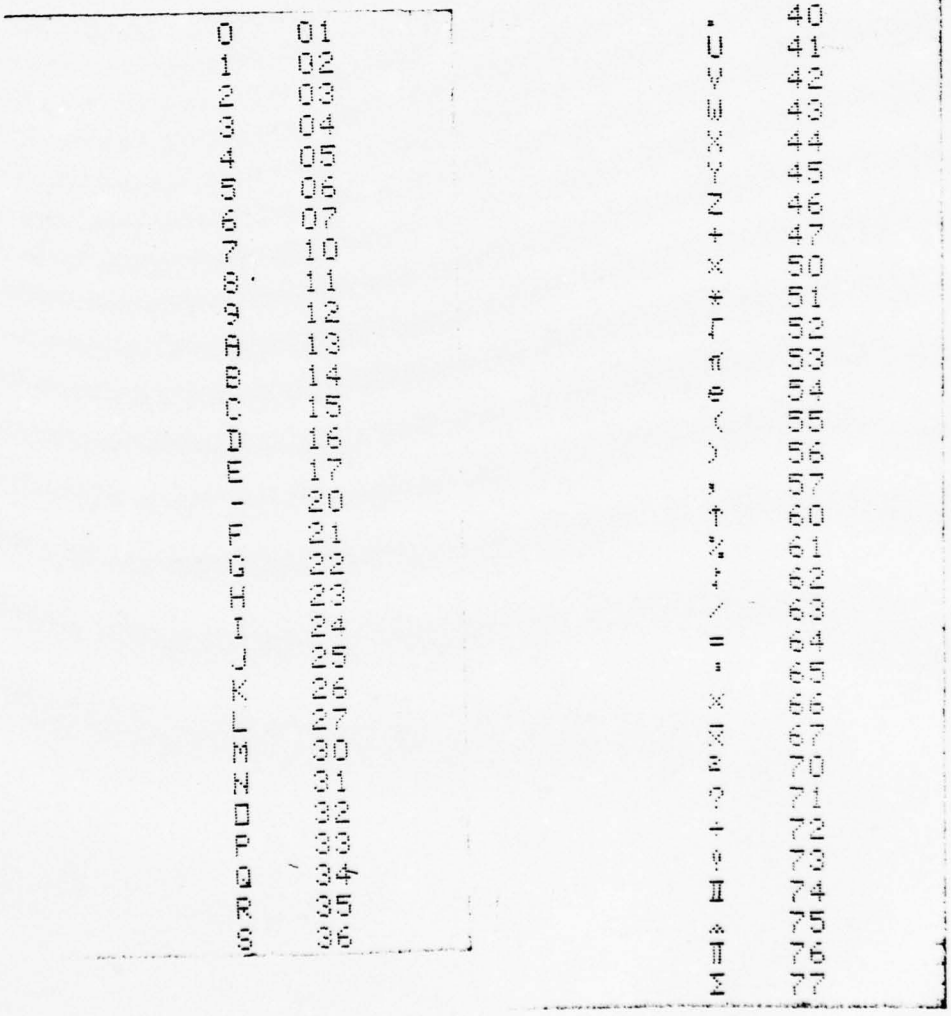

FIGURE 10

TI-59 KEY CODE LISTING (CODES 00-99)
(Output Tape Width Cut Off Examples)

000	00	0
001	01	1
002	02	2
003	03	3
004	04	4
005	05	5
006	06	6
007	07	7
008	08	8
009	09	9
010	10	E'
011	11	A
012	12	B
013	13	C
014	14	D
015	15	E
016	16	A'
017	17	B'
018	18	C'
019	19	D'
020	20	CLR
021	21	2ND
022	22	INV
023	23	LNX
024	24	CE
025	25	CLR
026	26	2ND
027	27	INV
028	28	LOG
029	29	CP
030	30	TAN
031	31	LRN
032	32	X↔T
033	33	X²
034	34	√X
035	35	1/X
036	36	PGM
037	00	00
038	37	P→R
039	38	SIN
040	39	COS
041	40	IND
042	41	SST
043	42	STO
044	00	00
045	43	RCL
046	00	00
047	44	SUM
048	00	00
049	45	Y×
050	46	INS
051	47	CMS
052	48	EXC
053	00	00
054	49	PRD
055	00	00
056	50	I×I
057	51	BST
058	52	EE
059	53	(
060	54	)
061	55	÷
062	56	DEL
063	57	ENG
064	58	FIX
065	00	00
066	59	INT
067	60	DEG
068	61	GTO
069	00	00
070	00	00
071	62	PG*
072	00	00
073	63	EX*
074	00	00
075	64	PD*
076	00	00
077	65	×
078	66	PAU
079	67	EQ
080	00	00
081	00	00
082	68	NOP
083	69	OP
084	00	00
085	70	RAD
086	71	SBR
087	00	00
088	00	00
089	72	ST*
090	00	00
091	73	RC*
092	00	00
093	74	SM*
094	00	00
095	75	-
096	76	LBL
097	00	0
098	77	GE
099	00	00
100	00	00
101	78	Σ+
102	79	x̄
103	80	GRD
104	81	RST
105	82	HIR
106	00	00
107	83	GO*
108	00	00
109	84	OP*
110	00	00
111	85	+
112	86	STF
113	00	00
114	87	IFF
115	00	00
116	00	00
117	00	00
118	88	DMS
119	89	π
120	90	LST
121	91	R/S
122	92	RTN
123	93	.
124	94	+/-
125	95	=
126	96	WRT
127	97	DSZ
128	00	00
129	00	00
130	00	00
131	98	ADV
132	99	PRT
133	00	0

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FIGURE 11

TI-59 SINE CURVE PROGRAM AND OUTPUTS (ACTUAL SIZES)

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PROGRAM

```
000   76 LBL
001   11  A
002   42 STO
003   00  00
004   92 RTN
005   76 LBL
006   12  B
007   42 STO
008   01  01
009   92 RTN
010   76 LBL
011   13  C
012   43 RCL
013   01  01
014   38 SIN
015   65  ×
016   09  9
017   85  +
018   01  1
019   00  0
020   95  =
021   69 DP
022   07  07
023   43 RCL
024   00  00
025   44 SUM
026   01  01
027   61 GTO
028   13  C
029   00  0
```

STANDARD SPACING

COMPRESSED SPACING

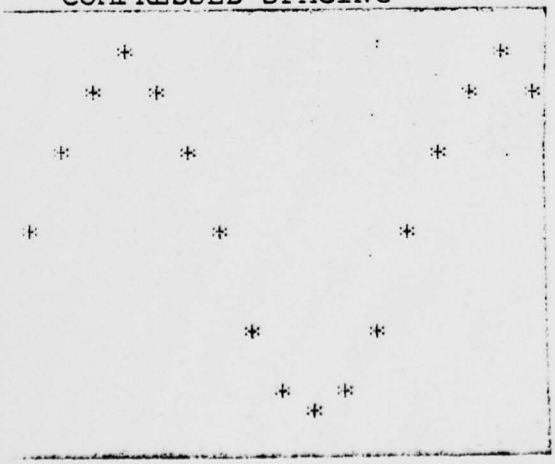

FIGURE 12

TI-59 ALPHANUMERIC CALENDAR OUTPUT
(Program Not Shown)

TEXAS INSTRUMENTS

1978.

JAN

S	M	T	W	T	F	S
1	2	3	4	5	6	7
8	9	10	11	12	13	14
15	16	17	18	19	20	21
22	23	24	25	26	27	28
29	30	31				

FEB

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28				

MARCH

S	M	T	W	T	F	S
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30	31	

APRIL

S	M	T	W	T	F	S
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30						

MAY

S	M	T	W	T	F	S
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

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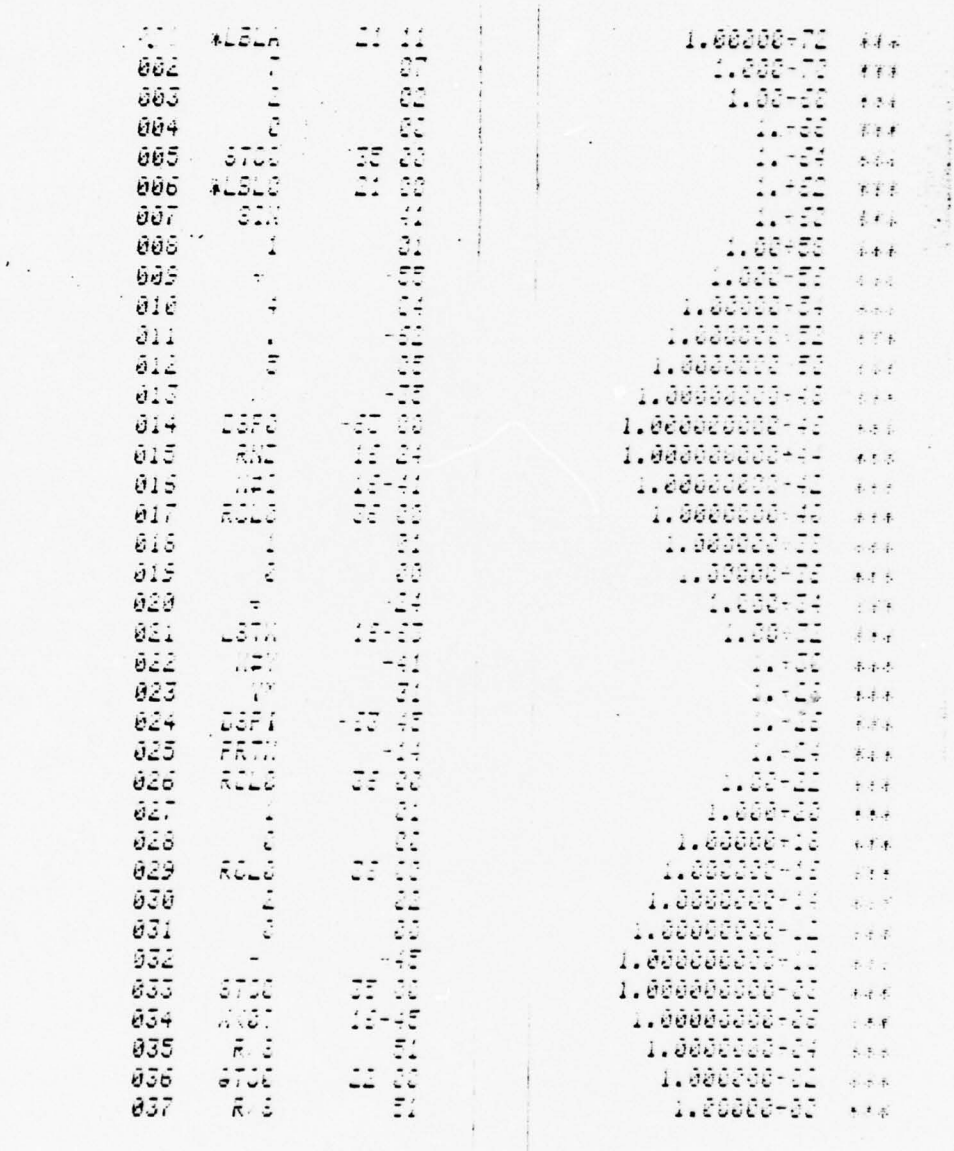
FIGURE 13

HP-97 SINE CURVE PROGRAM AND OUTPUT
(Actual Sizes)

Note: X-axis labeling in 10 degree increments printed with curve display.



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F. PROGRAMMABILITY CONCLUSIONS

Programming calculators, as discussed in this work, is the art of structuring algorithms such that the calculator executes those algorithms most efficiently. On the other hand, programmability relates to machine langauge; types and numbers of keystrokes required; merging of keystrokes in program steps; number of program steps available; functions available; program and data storage capacity; speed of execution; and ease of programming. All of these items have been discussed in detail. In the opinion of the authors, conclusions are:

(1) Programming calculators is certainly within the capability of the average college student and probably within the capability of most people at even lower levels of education or experience.

(2) Pragmatically, the differences in learning algebraic, AOS, or RPN languages are rather insignificant. However, RPN does add programming flexibility, once learned.

(3) Type and number of keystrokes required depends primarily upon functions available on the keyboard and, secondarily, upon the frequency that parentheses are used (in lieu of algebraic hierarchy) on non-RPN systems.

(4) Excluding use of the HP-67 "Σ+" key, the average number of merged program steps available on the HP-67 as compared to the SR-52 approaches a maximum ratio of 3 to 1, but the average ratio can be reduced to 1.3 to 1 for routine programming, dependent, of course, on abilities of the programmer.

(5) The number of steps available depends upon sub-paragraphs (2), (3) and (4), supra.

(6) Functional comparisons are as provided in Appendix B.

(7) The SR-52, compared to the HP-67, lacks an equivalent amount of program storage capacity. The SR-52 has easier access to extra registers for data storage whenever program steps can be sacrificed.

(8) Speed of execution is faster on the SR-52, and is particularly faster when exponentiation is used.

(9) The ease with which either calculator can be programmed depends more upon the experience and expertise of the programmer than upon the machine. However, the HP-67 is easier to use for merging programs or multiple card operations. Conversely, the direct addressing system used by the SR-52 is easier to use than the relative addressing used on the HP-67.

(10) The projected new machines (NG-7100 and TI-59) portend quantum improvements in capacity and capability. Questions concerning ease of use remain to be answered by actual usage; projections known to the authors are that Texas Instruments, Inc., intends to stop SR-52 production and start TI-59 production almost simultaneously. Both the projected NS-7100 and the projected TI-59 and TI-58 represent new levels of sophistication, but can only be theoretically compared to each other, at the time of this writing, since production models are not available to the authors.

Theoretically, none of these machines have serious competitors in the current market, with the possible exception of the HP-97 for some limited applications. Most information made available to the authors concerning these machines is represented by previous discussion and appendices hereto. In any case, such calculators indicate the beginning of a new generation of pocket calculators.

In summary, the prospective user should determine which of the above capacities, constraints, and (as yet) unproven manufacturer's projections, when compared to the somewhat different prices of these current and projected calculators, best fit his own parameters and yield the best value for the specific situation.

APPENDIX A

EDUCATIONAL GUIDELINES: CANDIDATE COURSES IN THE MANAGEMENT SCIENCE CURRICULA, NAVAL POSTGRADUATE SCHOOL [15]

The following listed required courses are considered to be readily adaptable for incorporation of the hand held card programmable calculator as an educational tool:

Mathematics

MA 2040 - Matrix Algebra

MA 2305/2306 - Calculus I-II

MA 2045 - Computational Matrix Algebra

MA 1100 - Calculus and Vector Analysis

Accounting

MN 2150 - Financial Accounting

MN 3161 - Managerial Accounting

MN 4151 - Internal Control and Auditing

MN 4152 - Decision Making for Financial Management

MN 4154 - Financial Management in the Navy

MN 4161 - Controllership

MN 4162 - Cost Accounting

Probability and Statistics

PS 3005 - Probability

MN 3011/3012 - Probability and Statistics for Management I-II

MN 3211/3212 - Operations Analysis for Management I-II

OS 3062 - Intelligence Data Analysis

OS 3201/3202 - Fundamentals of Operations and Systems Analysis

OS 32-3 - Survey of Operations and Systems Analysis

In addition to the foregoing, use of hand-held card programmable calculators in the required curricula is considered to be of importance in preparation for and/or utilization in the following courses:

CS 0110 - Fortran Programming

CS 0113 - COBOL Programming

MN 3183 - Management Information Systems and the Computer

MN 3214 - Operations Research Methodology

MN 3645 - Investigative Methods of Economics

MN 4145 - Systems Analysis

MN 4181 - Applications of Management Information Systems

OA 3604 - Linear Programming

OA 3620 - Inventory I

OA 3704 - Stochastic Processes

OA 4510 - Selected Topics of Probability and Statistics

OA 4614 - Methods and Practices of Systems Analysis

OA 4633 - Networks, Flows and Graphs

OA 4634 - Games of Strategy

OA 4651 - Search Theory and Detection

OA 4654 - Combat Models

APPENDIX B

COMPARISON OF CALCULATOR FUNCTIONS

	SR 52	TI* 59	HP 67	NS* 7100
Logic System	AOS	AOS	RPN	ALG
Memory				
Parens	9	9		9
Automatic four memory stack			X	
Last X			X	
Program	224	480(1)	224	480(2)
Pending Operations	10	8	4	10
Addressable Memory (dedicated)	20	60(1)	26	26(2)
Algebraic hierarchy	X	X		X
Positioning Operations				
Stack roll down			X	
Stack roll up			X	
X, Y exchange			X	X
X, I exchange			X	X
X, Register nn exchange	X			
Fixed notation	X	X	X	X
Scientific notation	X	X	X	X
Engineering notation		X	X	X
Auto-overflow into scientific	X	X	X	(3)
Enter exponent	X	X	X	X
Change sign	X	X	X	X
Improper op and low battery indicator	X	X	X	X
X, T exchange		X		X
Programming Features				
Program review - back step/ single step	X	X	X	X
Insert/delete	X	X	X	X
Overwrite	X	X	X	
Relative Step number addressing			X	X
Relative Branching			X	X
Direct Branching Label	X	X	X	X
Direct Branching to Step no.	X	X		X
Pause		X	X	X
Condition Tests	5	12(4)	8	9
Flags	5	10	4	8
DSZ	X	X	X	X
ISZ (looping)		X	X	

	SR 52	TI* 59	HP 67	NS* 7100
Subroutine levels	2	6	3	4
File reader				
Stores programs and data		X	X	
Merges programs and data			X	
Automatic prompting	X		X	
Labels	72	72	20(5)	64
User-definable keys	10	10(6)	10	
Indirect control of:				
Data Storage and Recall	X	X	X	X
Storage arithmetic	X	X	X	X
Unconditional branching	X	X	X	X
Subroutine branching	2	6	3	9
DSZ	X	X	X	X
ISZ		X	X	
Display			X	X
Clearing options				
Clear entry	X	X	X	X
Clear T		X		
Clear all	X(a)			X
Clear registers	X	X	X	X
Clear program	X	X	X	X
Clear register nn	X(b)	X(b)		X
Built in Statistical Functions				
Mean, Standard deviation (no. variables)		2	2	1
Factorial	X		X	X
Summation $(n,\Sigma x,\Sigma x^2,\Sigma y,\Sigma y^2,\Sigma xy)$		X	X	
$(n,\Sigma x,\Sigma x^2)$				X
Built in Scientific/Mathematical Functions				
Trigonometric				
Decimal degrees	X(c)	X	X	X
Radians	X	X	X	X
Grads		X	X	X
Sin, Cos, Tan (plus inverses)	X	X	X	X
Rectangular/Polar conversion	X	X	X	X
Decimal angle time/degree angle time (H.M.S.)	X	X	X	X
Degree/Radian conversion	X		X	X
Conversion any angular measure to any other				X
Logarithmic	X	X	X	X
Log x, 10^x	X	X	X	X
Ln x, e^x	X	X	X	X
Exponentiate negative number	(d)	(d)	X	X

	SR 52	TI* 59	HP 67	NS* 7100
Other Built in Functions				
Y^x , x , x^2 , Pi , 1/x	X	X	X	X
+ , - , x , ÷	X	X	X	X
X Root of Y		X		X
%			X	X
% change			X	X
Absolute value		X	X	X
Integer/fraction truncation		X	X	X
Rounding key			X	
Merge programs			X	
Conversions: in/cm, gal/liter Kg/lb, Newtons/lb force, Deg C/Deg F, BTU/Foot lb force				X
Printing Features [7]				
Print X	X	X	X	
List stack registers			X	
List data		X	X	
List labels		X	X	
Paper advance	X	X	X	
Variable print modes	X	X	X	
Print space	X	X	X	
List program	X	X	X	
List crom program [8]		X		

NOTES:

*Based solely on manufacturers claims. NS7100 uses chip vice card to record programs.

(1) 480 steps nominal (mainframe) with 60 registers. Alternate levels: 160 steps with up to 98 registers or 960 steps with 0 registers; plus 5000 step library CROM.

(2) 240 mainframe and 240 permanent file cartridge. Mainframe retains program plus data as long as batteries are charged; or 240 mainframe plus 4000 + library cartridge. Can retrieve particular numbers from pending operations (total of 37 registers.)

(3) Rounds as ordered.

(4) Compare X to T (4 tests) plus compare X to registers (8 tests).

(5) Labels are reusable.

(6) 10 user definable functions plus call label.

(7) SR52 and TI59 plug into a separate printing unit. HP67 cards must be printed with an HP97. All functions of HP67 and HP97 are the same except for the integral printing unit. No printer presently available for NS 7100 (see 8 below).

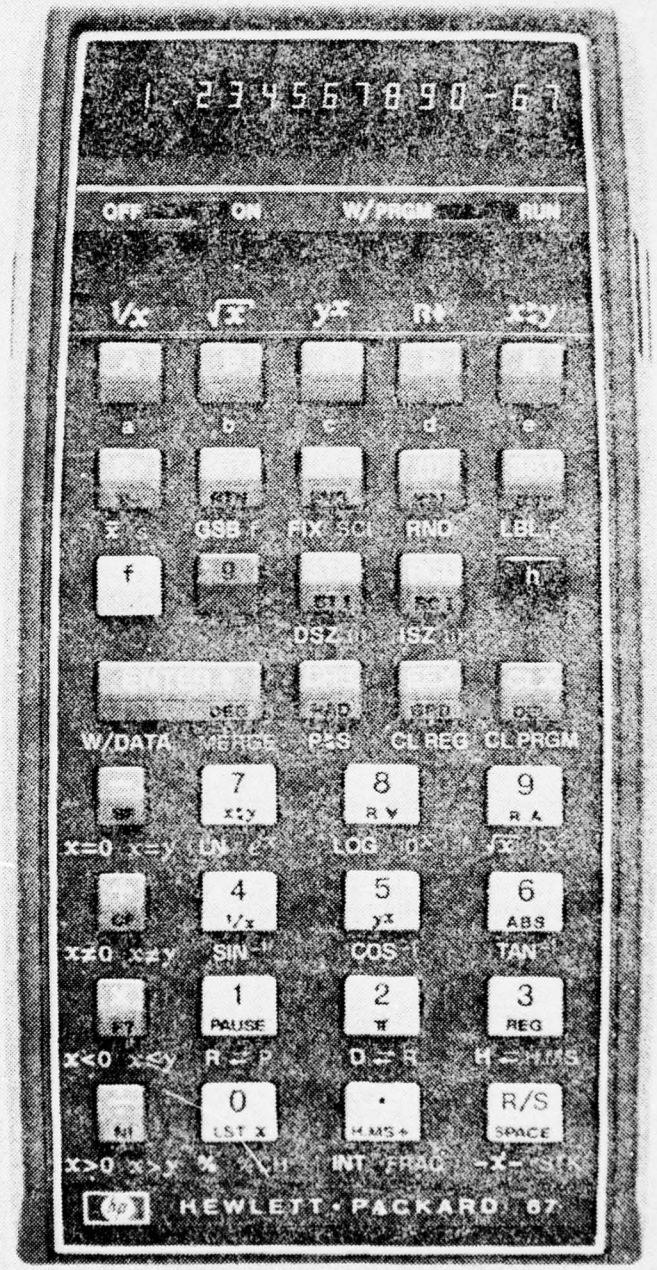
(8) The TI59 CROM (library chip) is coded by "page." A complete CROM has 10 "pages" with 500 steps per "page." NS 7100 printer to be manufactured by separate manufacturer. In addition NS 7100 will have full input/output capability with other systems. Also, NS 7100 displays GTO, label and shift codes.

(a) except registers 20-99

(b) only registers 60-69 all at once

(c) activated by a switch vice a button

(d) will work but gives error flash; will halt a running program


OFF
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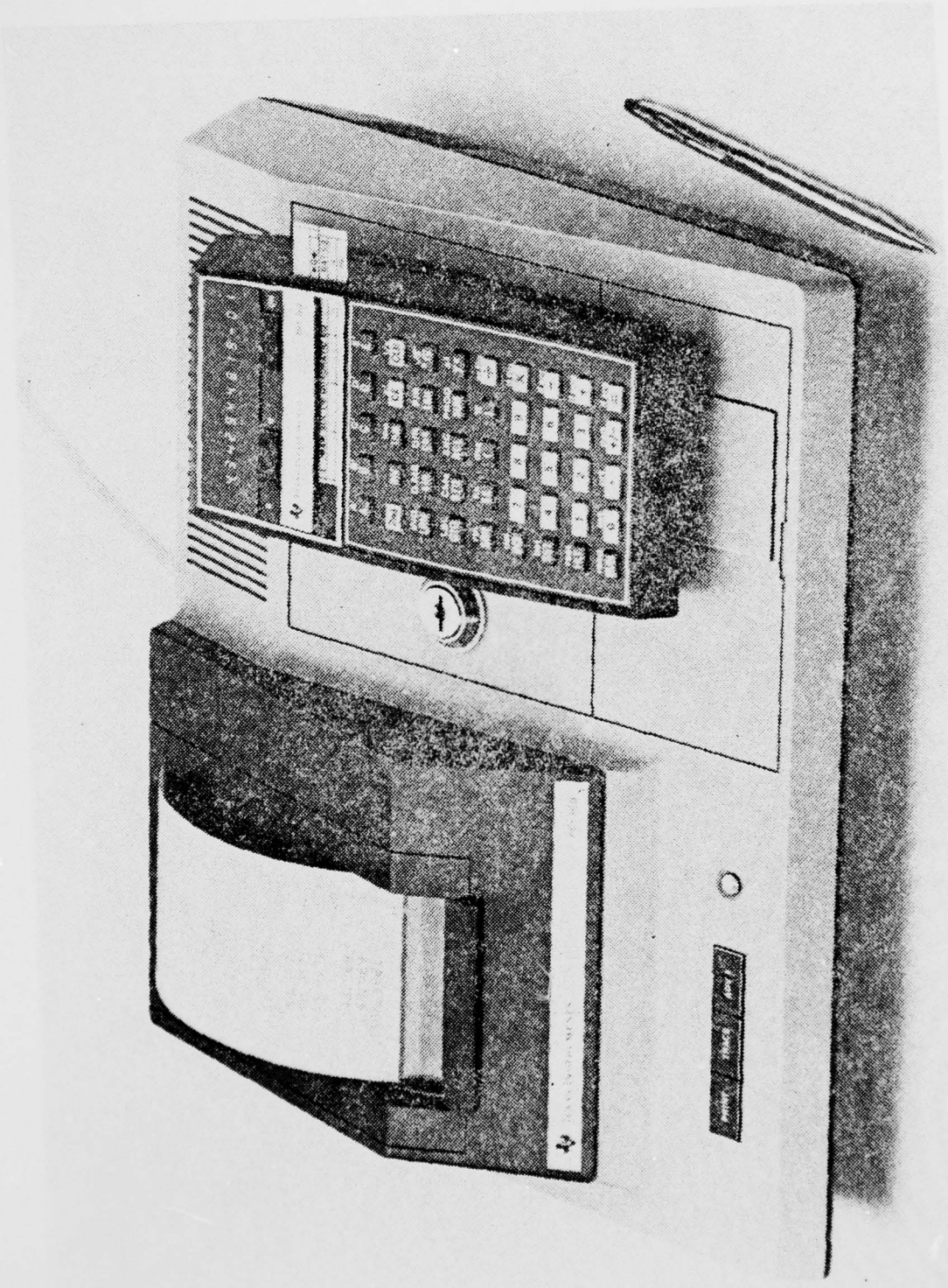
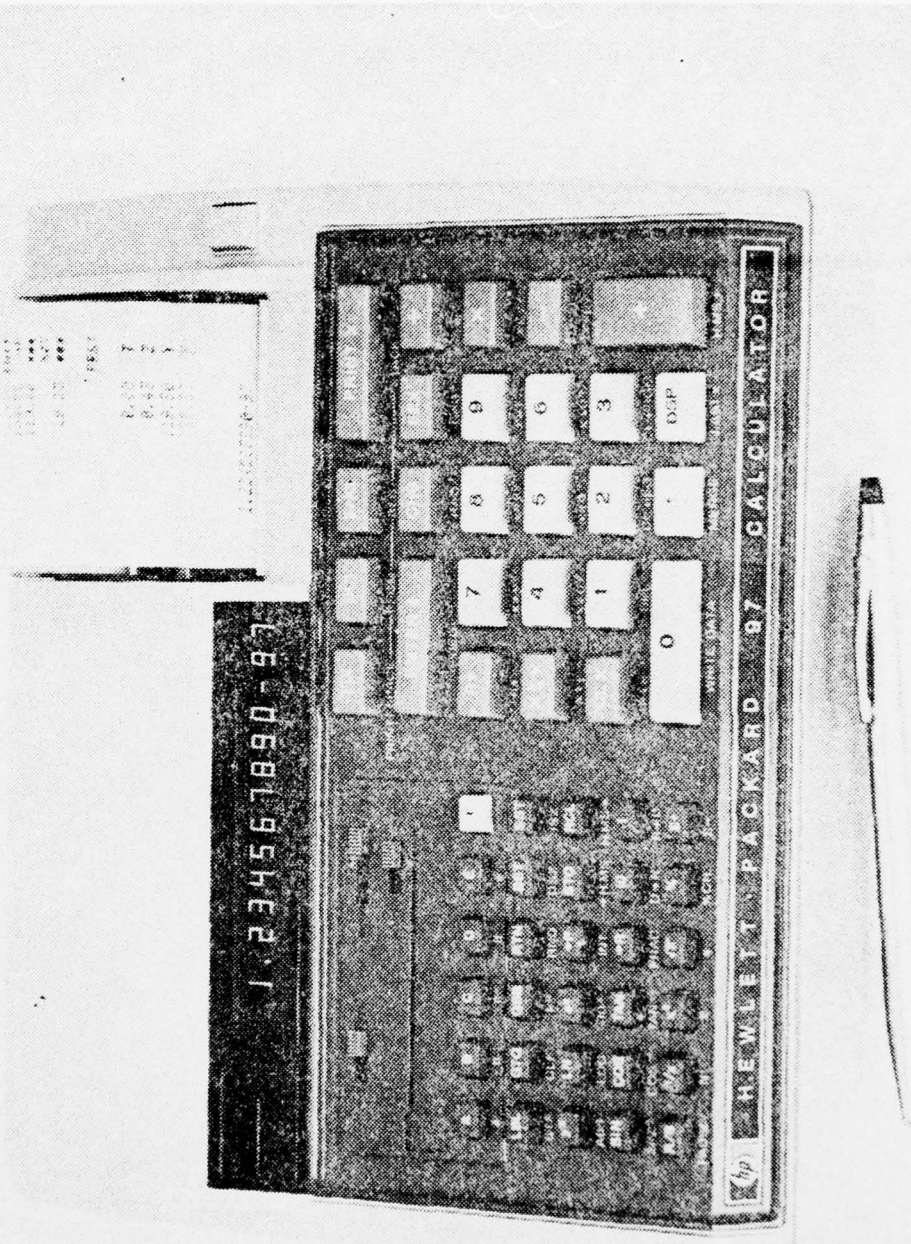
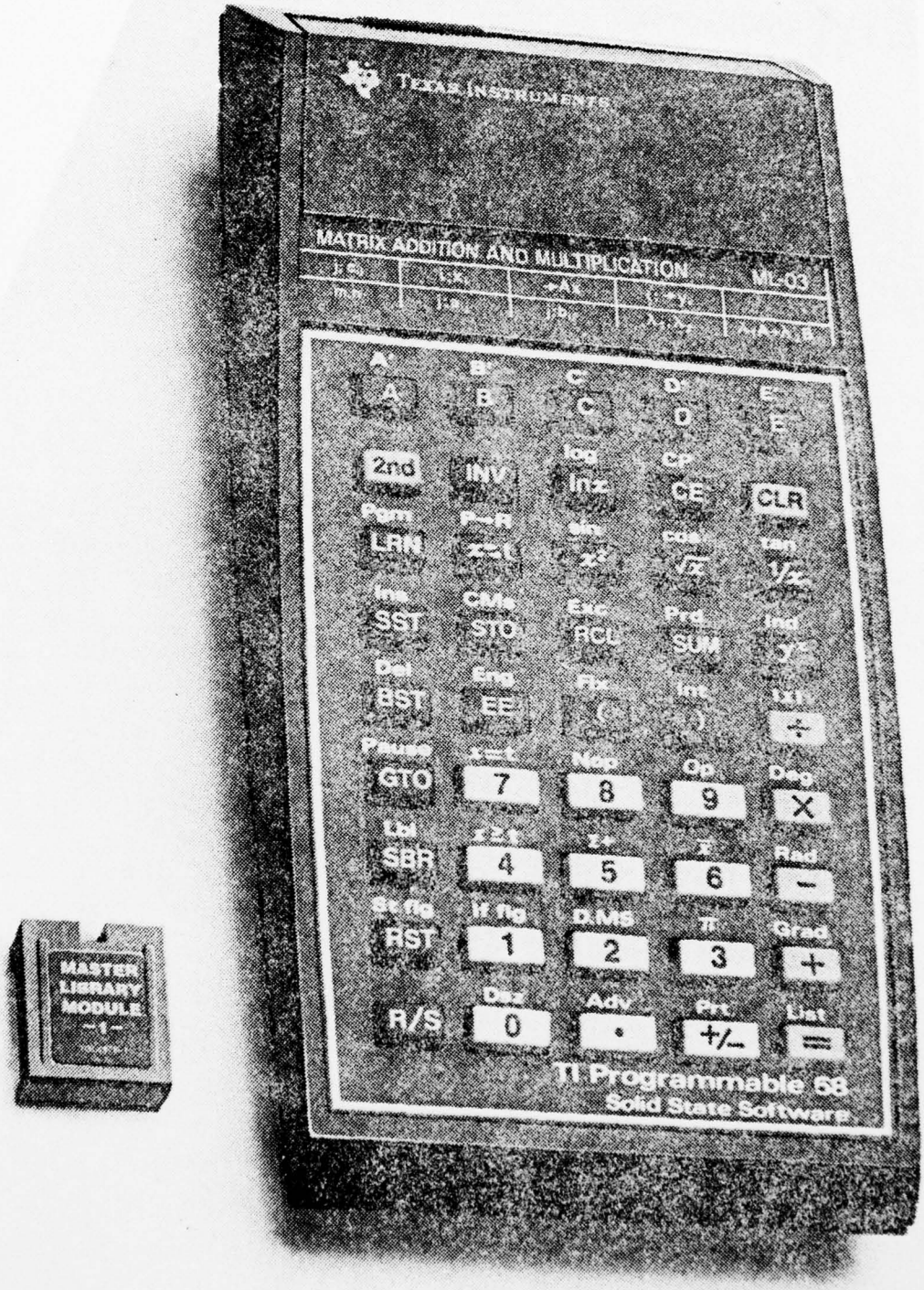
W/PRGM
RUN
HEWLETT-PACKARD 67



SR-52 Mounted on PC-100



HP-97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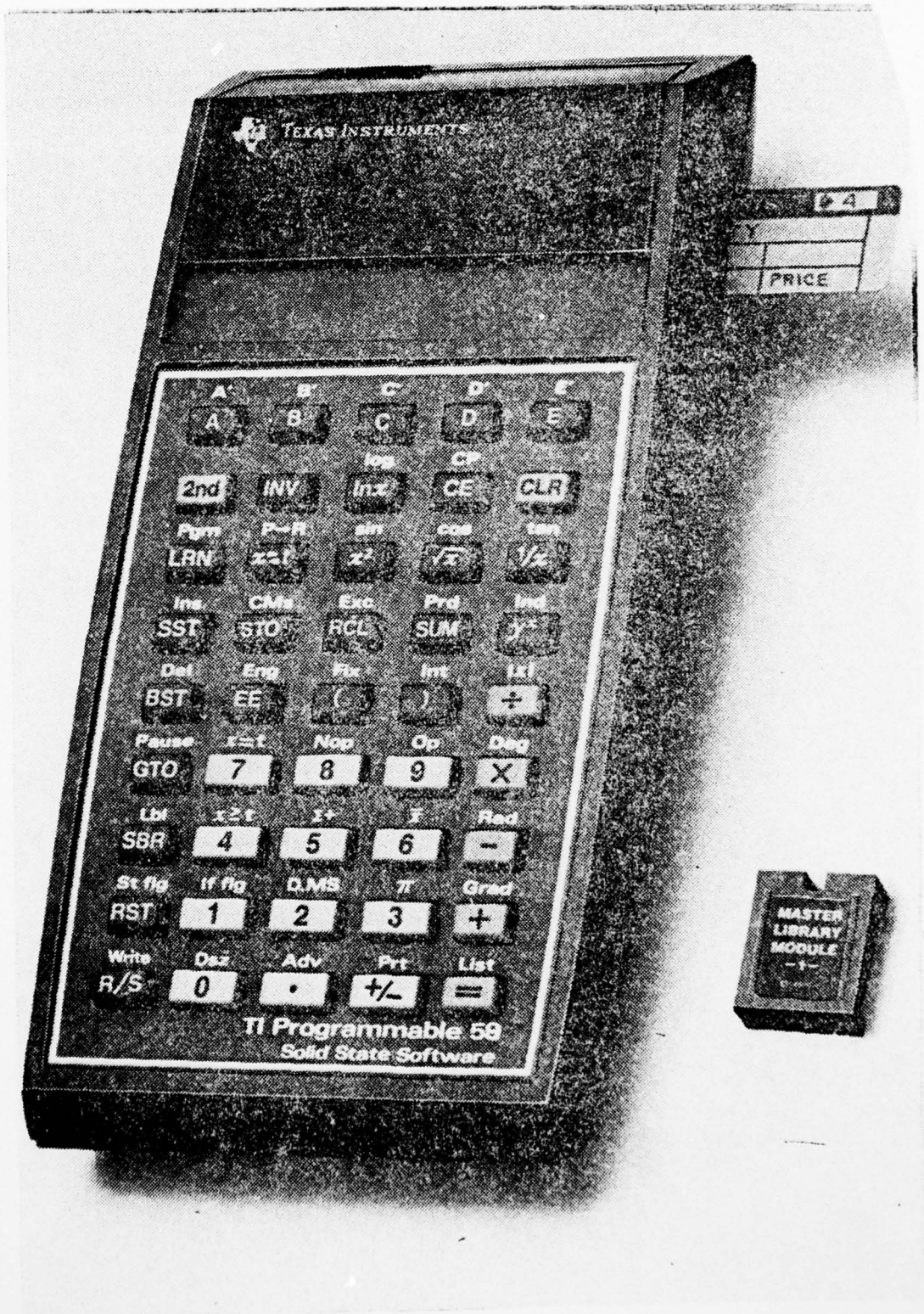
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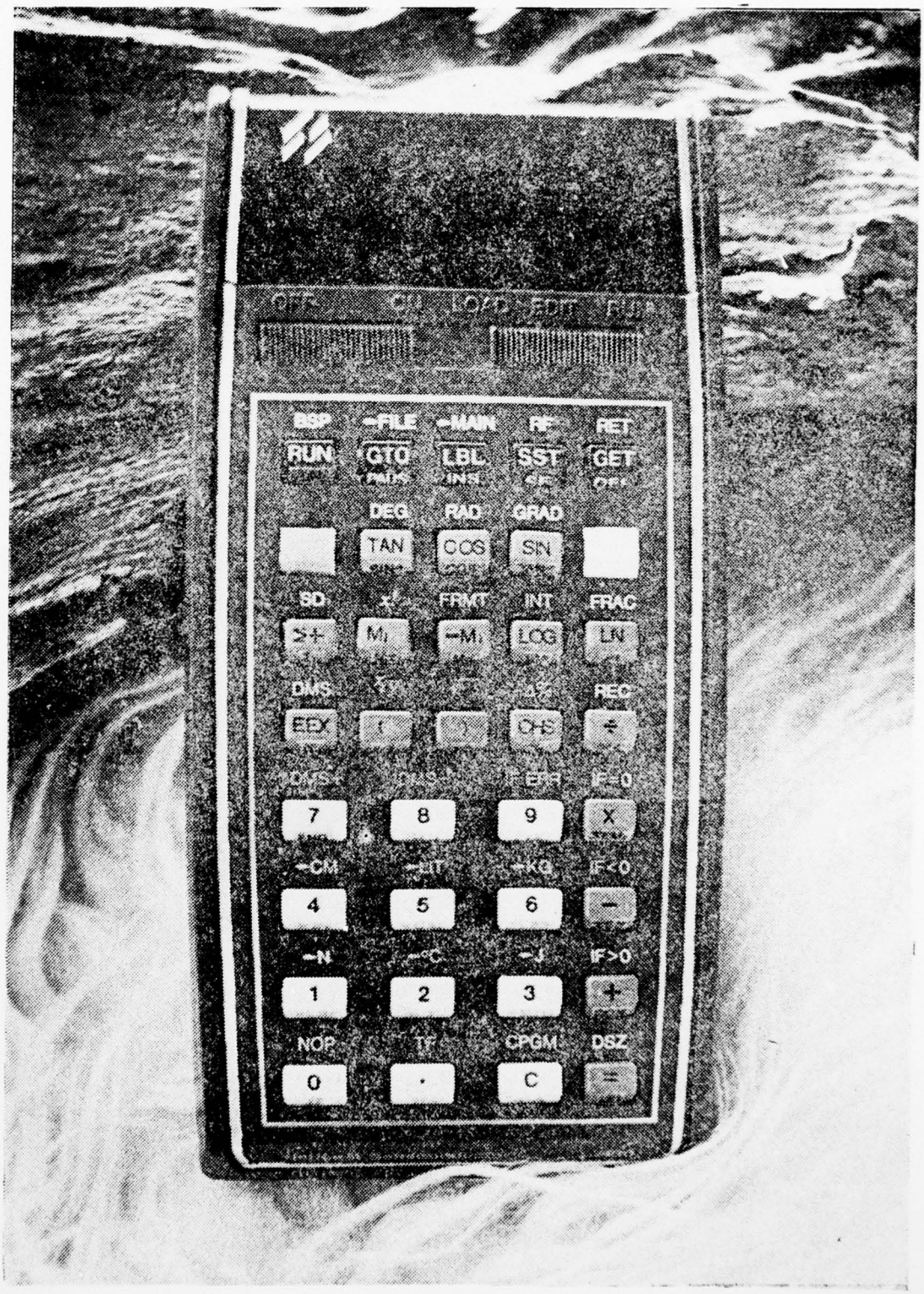

NS Model 7100

APPENDIX C

FLEET USES

The following non-exhaustive list of fleet functions indicates the broad range of applications for programmable calculators:

Aviation:

- Tactics
- Navigation
- Flight profiles
- Weight and balance (particularly cargo)
- Analysis of Maintenance Material Management Data
- Trend analysis (quality assurance)

Surface:

- Tactics
- Navigation and plot
- Analysis of Planned Maintenance System Data
- Trend Analysis (quality assurance)
- Damage Control
- Ships Engineering

Civil Engineer Corps:

Surveying

Structural design

Roadway design

Construction

Financial Analysis

Medical Corps:

Biological Analysis

Pathological Analysis

Meteorology:

Analysis of Meteorological data

Prediction

Research and Development:

All forms of weapons system design, research and development analysis.

All of the following kinds of officers should be issued card-programmable calculators:

Aeronautical Engineering Duty

Aviation Maintenance Duty

Weapons Engineering Duty

Civil Engineer Corps

Supply Corps

P-coded Operations analysis and engineering officer billets

P-coded Managerial billets

APPENDIX D

EXAMPLES OF USER-SUBMITTED PROGRAMS [16,17]
(Extracted from some 5000 available programs)

BUSINESS

- Experience curve for manufacturing cost
- Summation of Ledger Columns
- Amortization Schedule
- New Product Growth Factor - Gompertz Method
- Multi-Family Land Use Evaluation
- Manufacturing Learning Curve - Unit and Cumulative Cost
- Pert Estimating
- Universal Rate of Return
- Multivariate Corporate Failure Prediction Model

MATHEMATICS

- 4 x 4 Determinant and Simultaneous Equations
- Complex Arithmetic
- Complex Functions
- Radar Range-height Calculation
- Function and Derivatives
- Maxima and Minima
- La Grange Polynomial Interpolation
- Numerical Integration
- Differential Equations

ENGINEERING

Phase Shift Oscillator Design

Rectangular Waveguide Calculations

Transmittal Laser Pulse Energy

Aircraft Flyby Look - Angles and Rates

Bode of Transfer Function with Eighth Order Polynomial

Phase Locked Loop Design, Acoustic Horn Evaluation

Ballistic Missile, Range, Elevation Angle

Biomechanics

Two-Instrument Radial Survey

COMPUTER SCIENCE

Binary Coded Decimal with Parity to Decimal Conversion

Control Data Computer Octal Dump Decoding

Decimal to IBM 370 Floating Point Hexadecimal Conversion

Octal Debug Aid

Optimum Disk File Blocking

Timesharing Wait Model

Sentential Logic

PROBABILITY AND STATISTICS

Moments, Skewness and Kurtosis

Permutations and Combinations

Two-State Markov Chain Matrix

Five Variable Regression Analysis

Chi Square Proportion Difference

Biserial Correlation Coefficient

The Cochran Q Test

QUALITY ASSURANCE/RELIABILITY

- Redundant System Reliability
- Aerhenius Chemical Reaction Rate
- X Bar and R Control Charts
- Correlation: Reliability and Validity

NATURAL SCIENCES

- Environmental Noise Levels
- Acid-base Balance
- Creatinine Clearance
- Enzyme Kinetics
- ECG Data Optimization
- Blood Acid-Base Status
- Fick Cardiac Output
- Oxygen Saturation and Content
- Tumor Growth
- Absorption Spectroscopy Calibration
- Orbital Mechanics

GAMES

- Casino Game Model for Study of Behavior
- Simulation Wargame
- Combat Odds
- Space Ship Landing Simulator
- Underwater Submarine Hunt
- Biorhythms
- Space Battle
- Space Docking

AIR NAVIGATION

Flight, Plan and Verification

Predict Freezing Level

Dead Reckoning

Rhumbline Navigation

Great Circle Flying

Position and Navigation by One VOR

Weight and Balance

Moon Sight Reduction

MARINE NAVIGATION

Course Made Good from Three Bearings

Map Initialization

Running Fix from One Object

Planet Location

Sextant Correction

Storm Avoidance

Distance and Bearing to the Mark Sun Sight Reduction

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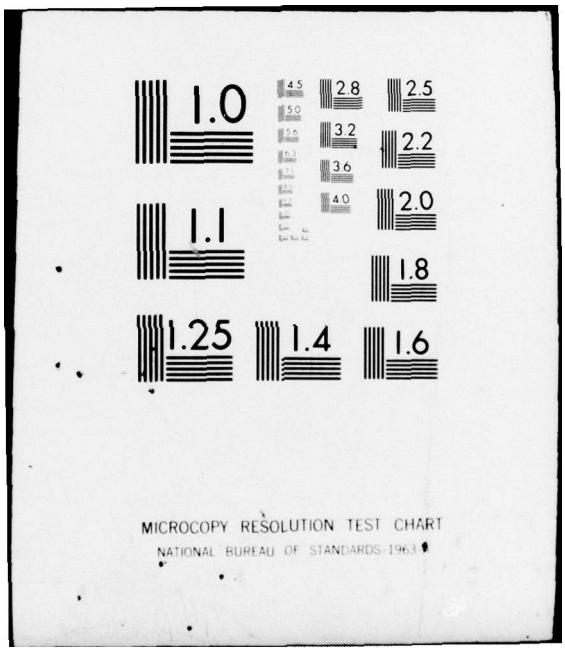
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U.S. Pacific Fleet
NAS Moffett Field, California 94035

13. Mr. Richard Nelson — 1
HP 65 Users Club
2541 W. Camden Place
Santa Ana, California 92704

14. Mr. Ron Eldrid — 3
Advanced Products Division
Hewlett Packard Company
3003 Scott Blvd
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New York University
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P.O. Box 22283
Dallas, Texas 75222

25. Mr. R.C. Vanderburgh 1
52 Notes
9459 Taylorsville Road
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Head, Programmable Calculator Support Group
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