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THE DEVELOPMENT AND IMPLEMENTATION OF ALGORITHMS FOR AN A-7E PE--ETC(U)

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Implementation was demonstrated on a desk computer, a hand held calculator and a microprocessor.

The Development and Implementation of Algorithms for an A-7E Performance Calculator

by

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Lieutenant, United States Navy
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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

In this thesis, the algorithms for an A-7E aircraft performance calculator were developed and then implemented on three small data processors of different programming levels and storage capabilities.

The utility of data is a function of several variables including accuracy and availability. The problem of retrieving performance data from the Naval Air Training and Operating Procedures Standardization (NATOPS) Manuals is significantly lessened by the devices demonstrated in this investigation. Nine performance chart groups, yielding data usually considered necessary for flight, were reduced to a series of analytical expressions. These analytical expressions were demonstrated to reproduce NATOPS Manual data to a high degree of accuracy.

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For the original development concepts and enthusiasm for this investigation completion, LCDR W.M. Siegel is hereby acknowledged.

I. INTRODUCTION

The Naval Air Training and Operating Standardization (NATOPS) Manual is the official standard of the United States Navy for "...information on all aircraft systems, performance data, and operating procedures required for safe and effective operations." [1]

The purpose of this thesis was to develop algorithms of the more often used NATOPS performance charts for the A-7E aircraft, examine their accuracy and implement them on small data processors that might be adaptable to shipboard or aircraft onboard use. The interpretation of NATOPS performance charts is an error prone and time consuming procedure even for experienced users. The need for a system to eliminate this laborious process has been fully documented in a thesis completed in June 1978 by LCDR W.M. Siegel [2]. In his investigation, LCDR Siegel devised an efficient procedure to develop algorithms from the NATOPS performance charts and exercised this procedure on the problems of "Takeoff Ground Roll Distance" and "Takeoff Airspeed".

This investigation is an extension of the aforementioned work. The original scope of this investigation was to develop algorithms for eleven of the most often used performance problem chart groups and implement them on the Texas Instruments-59 (TI-59) hand held calculator (HHC). All of the NATOPS performance charts were not reduced because of research time limitations. Of the eleven performance chart groups studied, two performance problems, "Time to Climb" and "Fuel Required to Climb" were rejected because of implementation difficulties on the TI-59 HHC (discussed fully in "Development Difficulties"). Therefore, nine performance chart groups were reduced to analytical expressions and implemented on the TI-59 HHC. To show further possibilities and feasibility of implementation of the algorithms, they were 1) fully implemented on the Hewlett Packard-9830 (HP-9830) desk computer, 2) demonstrated on a microprocessor (INTEL Corporation Microcomputer System-48), and 3) considered for implementation on the A-7E onboard digital computer and a microprocessor utilizing a recently developed number processing chip by the National Semiconductor Corporation (MM57109).

II. DEVELOPMENT

A. GUIDELINES

The scope of this investigation was established after a firm set of guidelines was defined.

Being the official United States Navy standard for the A-7E aircraft, the A-7E NATOPS Manual was the sole source of performance data used to develop the algorithms. As such, and being subject to changes during the aircraft's life cycle, the need for possible future updates to the algorithms was acknowledged. The effective date of the NATOPS Manual from which these algorithms were developed is March 1975. Since the performance data yielded by the algorithms was identical to NATOPS Manual performance curves, the same restrictions and limitations apply. For example, takeoff airspeed calculation restricts the NATOPS Manual user to trailing edge flap positions between 20 and 40 degrees down (Figure 1). For that reason, one could not expect to calculate the flaps up takeoff airspeed using the developed algorithms. An additional feature provided by the algorithms was higher order interpolation. While the inexperienced NATOPS user might attempt to interpolate linearly between non-linearly spaced curves, the algorithms do not.

An important guideline for the user's benefit was to ensure the execution of these algorithms after implementation was simple enough so very little training was required for the users. Intended users were Naval Flight Officers and Aviators.

TAKEOFF SPEED (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
MILITARY RATED THRUST
LANDING CONFIGURATION
LEADING EDGE FLAPS DOWN

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTE

Data basis is 26% MAC. Increase speed 1/2 knot per 1% forward CG shift. Decrease speed 1/2 knot per 1% aft CG shift.

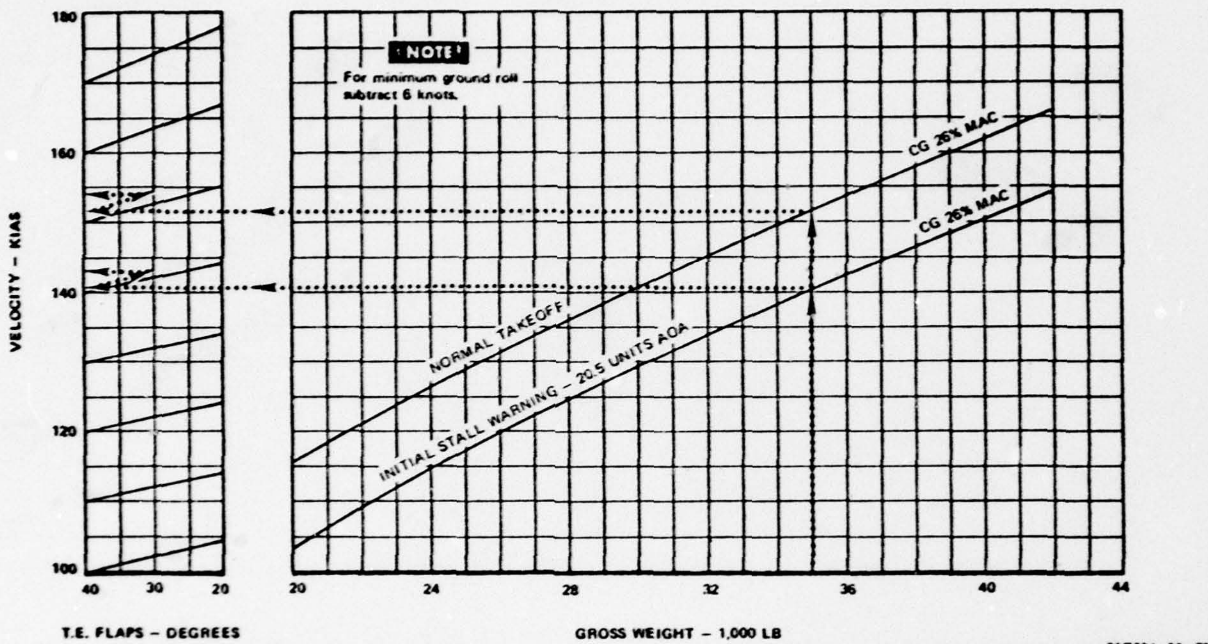

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Figure 1

Takeoff Speed NATOPS Chart

Not included in the scope of this thesis is an introduction to the TI-59 HHC, HP-9830 desk computer and the INTEL Microcomputer System-48; however, to follow the computer programs written for these devices would required their basic understanding.

Another guideline established was that the performance calculators be light and small enough to be physically suited for its environment. For example, the TI-59 calculator and microprocessor could be used in a cockpit, briefing room or Air Operations Center. The HP-9830 desk computer would be restricted from cockpit use.

Reliability was a necessary guideline.

To make algorithm implementation on the TI-59 HHC feasible and since the program storing chip, the Continuous Read Only Memory (CROM), was limited to 5000 calculator program steps, the library of nine programs was required to fit into that space [3].

Finally, accuracy was a necessary consideration. The results obtained from the algorithms were required to be at least as accurate as following the performance charts manually. These accuracy requirements established were: One knot of airspeed, 100 feet of altitude or ground roll distance, 100 pounds of weight, ten seconds of time and one nautical mile of distance.

B. PERFORMANCE CHART REDUCTION

The reduction of the NATOPS Manual performance curves into analytical expressions was accomplished by a historically proven mathematical procedure, "least squares curve fitting". This method was applied to certain A-7E performance data by LCDR W.M. Siegel (see Introduction, Section I). His brief explanation of the "Least Squares Fit Approximation (LSFA)" is included in Appendix A.

Many performance charts from the NATOPS Manual contain three variables (two independent, one dependent) and are depicted as a two-dimensional space with the third dimension illustrated by a family of curves. The reduction of such a chart can be accomplished as follows:

1. Determine order of curves in family (i.e, second order, ($y = A_1 + A_2x + A_3x^2$).

2. Apply LSFA to every member of the family of curves.

3. Since the order of the curve families may vary, a general curve family could be depicted as follows:

$$y = A_{11} + A_{12}x + A_{13}x^2 + \ldots\ldots A_{1m}x^{n-1} \quad \text{(for curve } z_1\text{)}$$
$$y = A_{21} + A_{22}x + A_{23}x^2 + \ldots\ldots A_{2n}x^{n-1} \quad \text{(for curve } z_2\text{)}$$
$$\vdots$$
$$y = A_{m1} + A_{m2}x + A_{m3}x^2 + \ldots\ldots A_{mn}x^{n-1} \quad \text{(for curve } z_m\text{)}$$

4. Apply LSFA to the coefficients. For example, plot A_{11}, $A_{21}, \ldots\ldots A_{m1}$ versus $z_1, z_2, \ldots\ldots z_m$, respectively, yielding

$$A_1 = B_{11} + B_{12}z + B_{13}z^2 + \ldots\ldots B_{1r}z^{r-1}.$$

Doing the same with all coefficients,

$$A_2 = B_{21} + B_{22}z + B_{23}z^2 + \ldots B_{2r}z^{r-1}$$
$$\vdots \quad \vdots \quad \vdots \quad \vdots \quad \vdots$$
$$A_n = B_{m1} + B_{m2}z + B_{m3}z^2 + \ldots B_{mr}z^{r-1}$$

5. Given z and x, y can now be calculated by:

a. Computing coefficients from equations generated in Step 4.

b. Applying coefficients to $y = A_1 + A_2x + \ldots A_nx^{n-1}$.

6. It is important to note that although all curve family members must be of identical order, the equations representing the coefficients as a function of "z" need not be of similar order.

Although applying LSFA to the family of curves and then to their coefficients was the normal method of chart reduction, it was not always used for the following reasons:

a. Some charts were two-dimensional (LSFA still used).

b. Some charts were reduced by inspection.

(1) Linear curve families with linear spacing.

(2) Time, distance, speed charts ($d = v/t$).

c. Algorithm anomalies (see "Development Difficulties").

When used, the LSFA was accomplished by a program pre-written by the Hewlett Packard Corporation for use with the HP-9830. This program, although greatly facilitating the development portion of this investigation, was written for a two-dimensional problem and had to be executed at least once for each curve and once for each set of coefficients.

A listing of all of the equations making up the performance algorithms are contained in Appendix C. The A-7E performance chart groups from which they were developed are contained in Appendix B. They are in order:

1. Low Level Cruise Performance.

2. Takeoff Ground Roll Distance.

3. Maximum Range Cruise Time and Speed at Constant Altitude.

4. Maximum Range Cruise Fuel Required at Constant Altitude.

5. Maximum Range Climb Airspeed Schedule.

6. Takeoff Airspeed.

7. Maximum Refusal Airspeed.

8. Optimum Endurance Altitude.

9. Cruise Ceiling.

Future reference in this thesis is made to algorithms and programs by the numbers above.

C. EXAMPLE OF CHART REDUCTION

An example of the procedure discussed in the previous section is presented below. The chart chosen for reduction is the lower graph of Figure 2, from Phase II of the A-7E Cruise Performance chart group.

By inspection, all A_1 and A_2 coefficients are equal to zero. The curves appear parabolic and therefore second order, yielding $N = A_3M^2$. The example follows:

N = intermediate result

M = mach number

D = drag count

CRUISE PERFORMANCE (A-7E)

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PHASE II — AIRCRAFT REFERENCE NUMBER

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

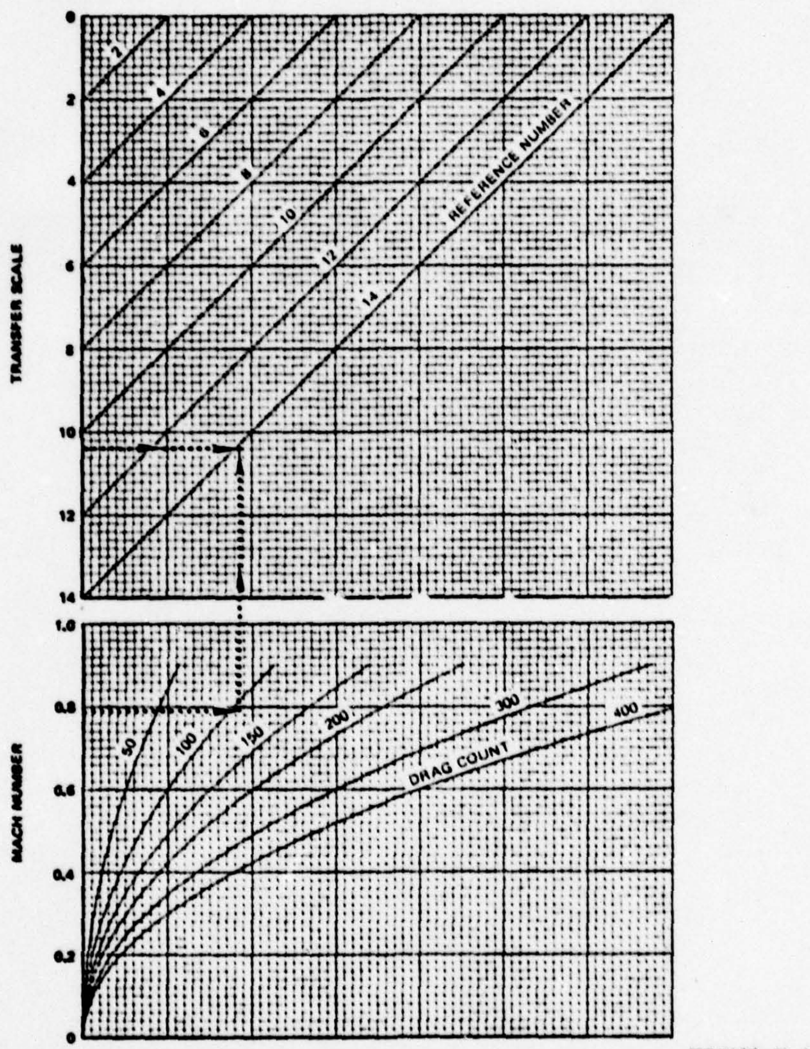


Figure 2

Cruise Performance
Phase II NATOPS Chart

DRAG COUNT LINE	CURVE EQUATION
50	$N = 1.3915M^2$
100	$N = 2.7787M^2$
150	$N = 4.1658M^2$
200	$N = 5.5530M^2$
300	$N = 8.3273M^2$
400	$N = 11.102M^2$

By plotting the A_3 coefficients versus D (drag count), the LSFA yields:

$A_3 = (4.3732E-3) + .027743D$ and therefore,

$N = ((4.3732E-3) + .027743D)M^2$.

This was a particularly simple chart to reduce but illustrates the procedure.

D. DEVELOPMENT DIFFICULTIES

The normal method of reducing performance curves did not always yield useful information. One reason was although the NATOPS Manual Performance curves were constructed from experimental data, families of curves occasionally had very unusual spacing. They also were not always a true curve family; that is, they were of varying order. This can be visually detected in the lower graph of Phase III of the A-7E Cruise Performance chart group (Figure 3). The unequal and varying spacing between curves with different "reference numbers" is obvious. Although the coefficients for each curve can be calculated, the coefficients determined for a LSFA equation for an intermediate curve would be incorrect. To be usable for the normal

CRUISE PERFORMANCE (A-7E)

PHASE III – POUNDS OF FUEL PER NAUTICAL MILE

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

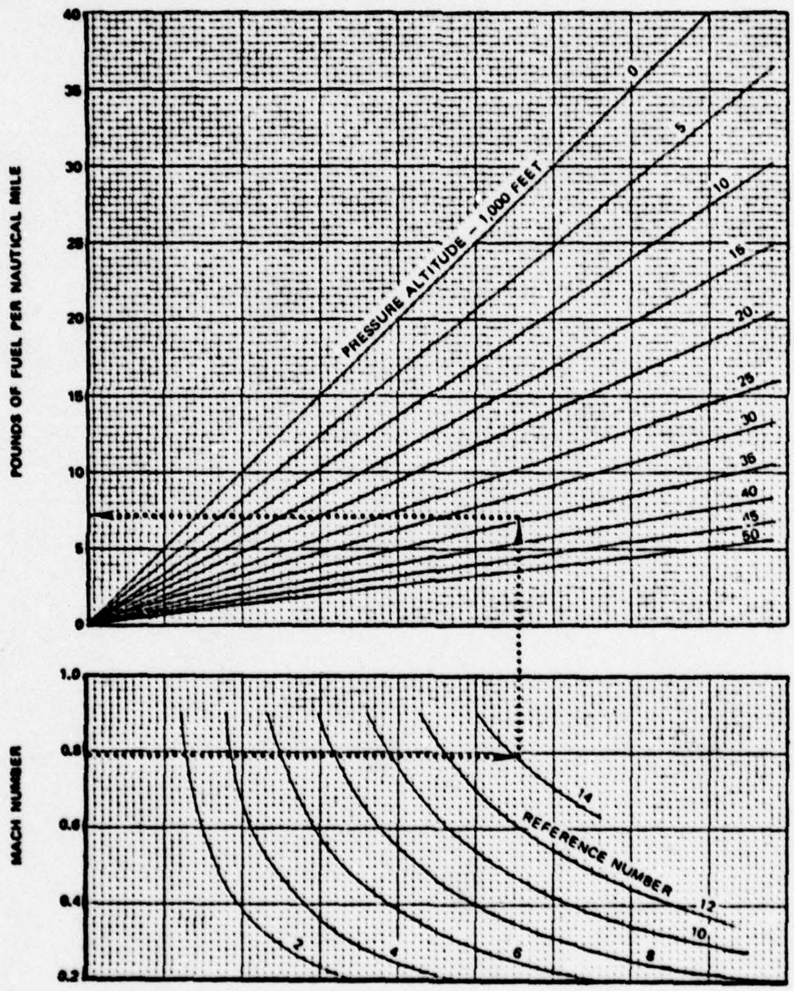


Figure 3

Cruise Performance
Phase III NATOPS Chart

method of chart reduction, a chart must have equal, constantly increasing, or constantly decreasing spacing between curves. When such an incompatible chart was encountered, it was necessary to interpolate between them. Two chart groups eliminated from consideration, "Fuel Required" and "Time to Climb from Sea Level to Selected Altitude", contained so many such curves (11), that very high order expressions would have been required to compute the coefficients, making implementation on the TI-59 HHC impractical. The A-7E Cruise Performance lower chart of Phase I had the same anomaly (Figure 4). Because of the importance of the low level mission, however, the algorithm for this chart was developed, for sea level only though. The multiple algorithm was not developed but could have been for implementation on a desk computer.

Another reason a straight application of LSFA was not always appropriate was the uniqueness of the upper graph of Phase I of the A-7E Cruise Performance chart group (Figure 4). This chart requires entry from the lower chart. A line is traced upward until the user contacts the appropriate Drag Count Line (dotted lines). The first pass through the Mach Number axis, a result of the lower chart, was defined M*. Instead of now tracing horizontally to the Transfer Scale axis (this value defined TS*), one must trace "between the solid guidelines" to the interception with a line traced vertically upward from the desired Mach number, M. The Transfer Scale would now be manually obtained by tracing horizontally to the

CRUISE PERFORMANCE (A-7E)

PHASE I – CLEAN AIRPLANE TRANSFER SCALE

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

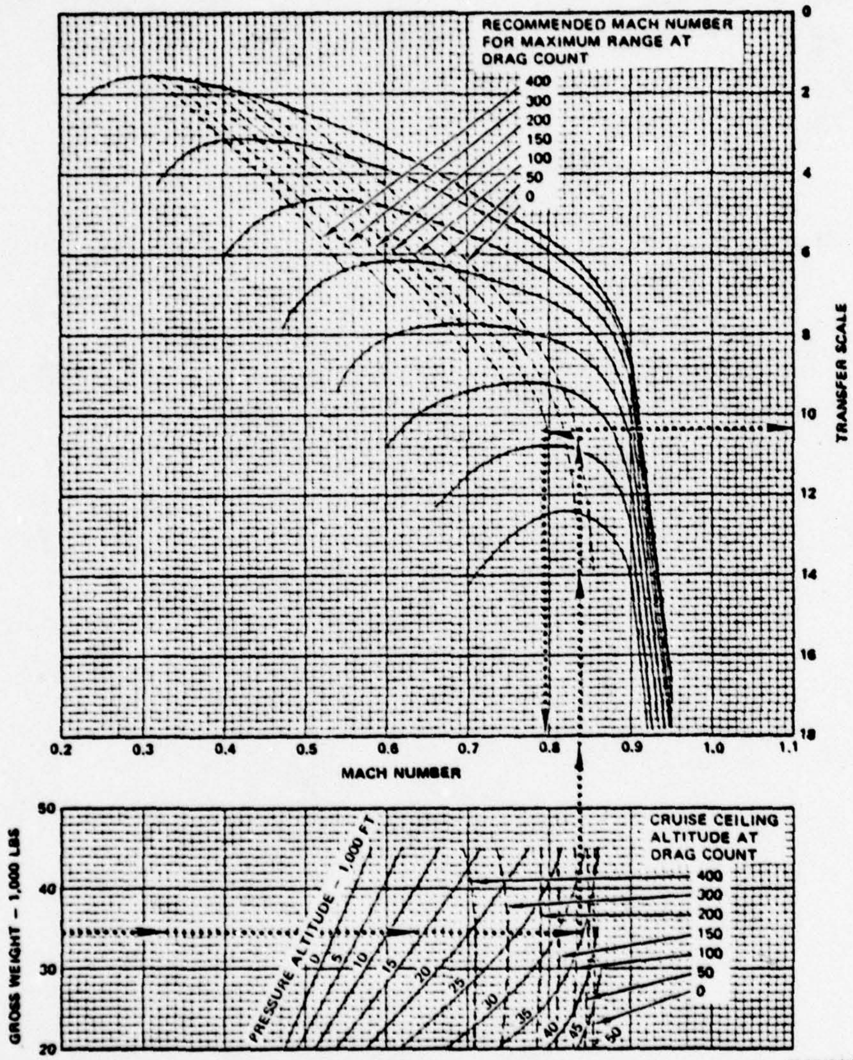


Figure 4

11–57

Cruise Performance
Phase I NATOPS Chart

vertical axis. To develop the algorithm for this problem, the equations of the guidelines were also calculated as a function of Mach number. The values of the Transfer Scale resulting from M* intercepting the guidelines and tracing horizontally to the vertical axis were called TS_1^*, TS_2^*, ...TS_m^*, from top to bottom. The original position, (M*, TS*), could now be determined in relation to (M*, TS_n^*) and (M*, TS_{n+1}^*). "n" and "n+1" indicate the upper and lower guidelines, respectively, which bracket (M*, TS*). This ratio provided the initial position relative to the guidelines:

$$R = (TS^* - TS_{n+1}^*)/(TS_n^* - TS_{n+1}^*)$$

Using the desired Mach number, M, the Transfer Scales for the same two enclosing guidelines were calculated (TS_n and TS_{n+1}). The final position relative to the guidelines was maintained using the original ratio by solving:

$$R = (x - TS_{n+1})/(TS_n - TS_{n+1}) \text{ for } x.$$

"x" is the Transfer Scale with which the user now proceeds to Phase III of this performance chart group. Figure 5 depicts this problem graphically.

E. ACCURACY

A large number of results comparisons between the generated algorithms and manually traced performance problems were made. An infinite number of comparisons would be required to check all possibilities, but since the mathematical theory was so basic, the number of checks accomplished were considered sufficient.

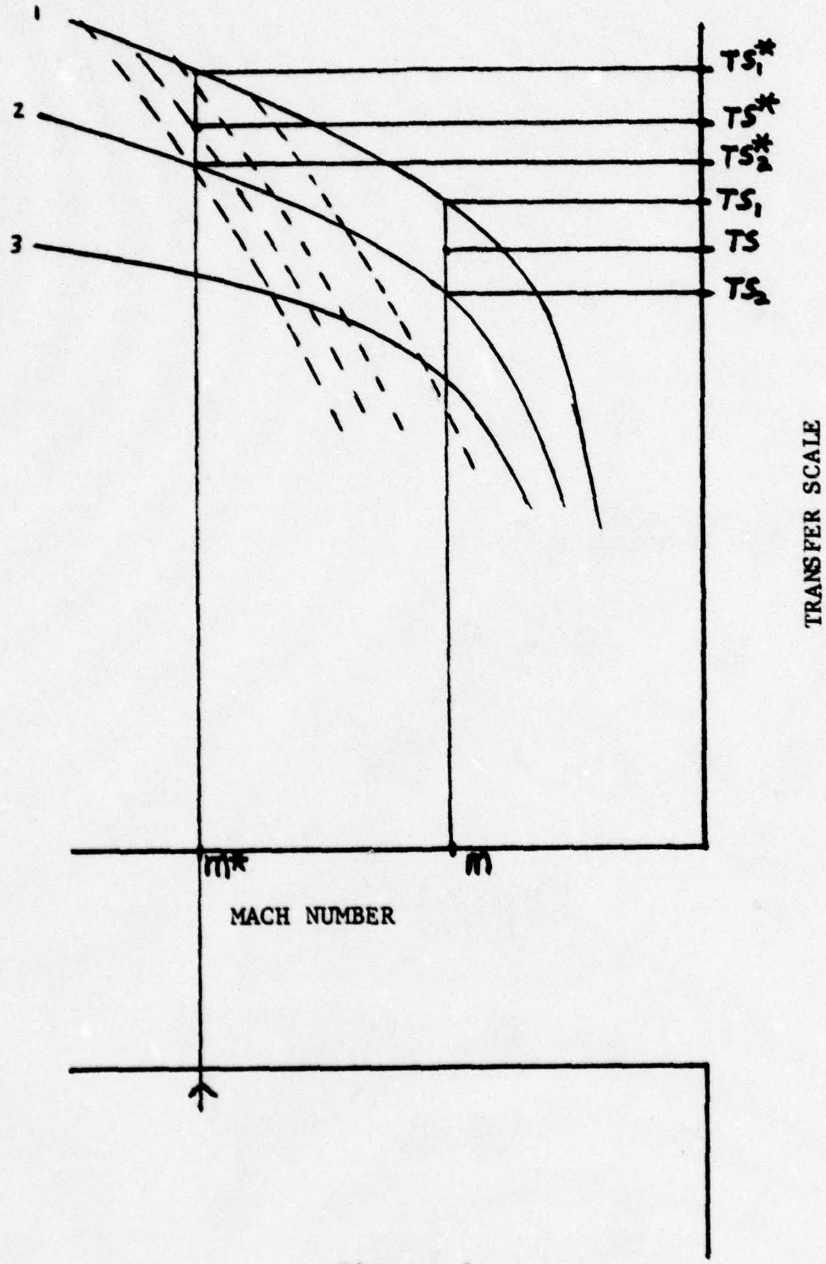


Figure 5

Guideline Chart Solution

All nine algorithms were checked for accuracy on the HP-9830 desk computer. The number of checks for each algorithm was proportional to the ease of manually tracing through the performance charts. The author spent considerable time obtaining performance results from the NATOPS Manual charts and a relatively small amount of time computing the problems on the desk computer once the algorithms had been implemented. In a significant number of instances, the results disagreed, but after rechecking, the solution obtained manually was in error. This supported the contention that manual manipulation of the performance charts is an error prone procedure, even with an experienced user.

In a few rare instances, the author entered the required given data incorrectly into the desk computer. These miskeying errors, not procedural, were noticed as soon as the answer was produced. A user familiar with the A-7E performance characteristics would normally notice an answer resulting from grossly incorrect data input. It is acknowledged, however, that there is no failsafe check on the programs. When using a desk computer, the required input data can be printed along with the answer to ensure the user of the correctness of the input data. For a hand held calculator, however, computing a performance problem twice would provide a check, which is what many NATOPS Manual users often do. As with all computer programs, a desired result requires accurate input data.

Except for those noted below, the results of programs checked (using five significant figures) were indistinguishable from the answers obtained by manually manipulating the performance charts. Answers produced from the algorithms were rounded off to the nearest digit.

PROGRAM	MAXIMUM DEVIATION
Maximum Refusal Speed	2 knots
Takeoff Airspeed	1 knot

III. IMPLEMENTATION

A. DESK COMPUTER

The use of a desk computer capable of producing A-7E performance information within seconds (less than three seconds computation time for the longest algorithm) would be ideal for a squadron briefing room or Air Operations Center use. The HP-9830 desk computer was used for this implementation stage. Very little training would be required for personnel to load the programs stored on a cassette tape cartridge and execute them.

A knowledge of "basic" computer language is required to fully understand the nine HP-9830 programs in Appendix D [4]. The nine programs are in the same order as the algorithms of Appendix C.

Only in the Low Level Cruise Performance program are subroutines required for linear interpolation or for the iterative method to find the Transfer Scale (see "Development Difficulties"). All other programs are straight forward, sequential computations. In these programs, the coefficients defining a curve (y = f(x)) for a given set of conditions are calculated. That chart result, "y", is then calculated for the given independent variable "x". The next chart of that group is similarly treated and so on until the "final result" is achieved.

The HP-9830 programs are very useful since they prompt the user to supply the correct information. Most of the programs "request, then accept" those inputs required for the applicable NATOPS Manual performance chart. The HP-9830 then prints the data just entered (ensuring the user that data input was as desired) followed quickly by the solution. The computer is instantly ready to receive new data for another calculation.

Programs 1, 2, 3, 4 and 7 (as identified in "Performance Chart Reduction, section II-B), are written in this "request, then accept" format. The shorter programs, 5, 6, 8 and 9, were written with an initial set of input data already in the program. This format allowed the computer to step incrementally through the allowable range of values for the input data, thus calculating a "table of performance data" for the applicable performance chart group. These programs are easily altered to the "request, then accept" format by some simple edit commands [4].

The variables used in the programs are defined following each program in Appendix D.

B. HAND HELD CALCULATOR

The many favorable features of the hand held calculator encouraged its implementation of the performance algorithms. Its small size allowed consideration for use in the cockpit. Its simplicity and reliability was an advantage making it especially suited for users of varying experience (including no experience). Although its execution speed was the slowest of all devices used, the computation time was still much faster than using the NATOPS Manual.

The Texas Instruments-59 (TI-59) programmable hand held calculator (HHC) was selected for implementation. This selection was made for several reasons. At the time, it was the only calculator available to the author which allowed permanent program storage (on magnetic cards). Additionally, the Texas Instruments Corporation had the capability to combine all prewritten performance programs, up to a 5000 program step limit, onto a Continuous Read Only Memory (CROM) chip, making the A-7E performance programs a permanent part of the calculator. This CROM chip can also be used on the less expensive TI-58 HHC. These features made the TI-58/59 (with CROM) a practical system for the A-7E Naval Aviation community.

One might consider the calculator's inability to prompt the user for inputs a shortcoming of this implementation candidate, but a company spokesman, Mr. Richard Cuthbert, stated a new face could be fitted onto the calculator, identifying different buttons with the input data categories such as GW for gross weight, FLPS for flap position, T(°C) for temperature, and so on [3].

Some time was required for the author familiarization with the TI-59 HHC and its capabilities. For a detailed explanation of comments in this section involving TI-59 programming and Appendix E, consult the user's manual [5].

All programs were entered with the calculator memory partitioned to allow 879 program steps and ten memory storage locations. The loss of program steps in order to provide coefficient storage locations (ten to one) was the reason for partitioning in this manner. Only five significant figures were considered necessary for computational accuracy. Considering the number possibilities (1.2345 to 1.2345E-12) might take from six to ten program steps, this was less than the absolute ten program steps sacrificed for a storage location. The ten memory storage locations were used to store the input data at program execution start but were often reused after the input data storage was no longer required.

The programming language level of the TI-59 HHC is below the HP-9830's and above a microprocessor's (discussed later) in sophistication. The algorithms were computed in a more space-saving manner than on the HP-9830. For example, in computing a first order polynomial, the HP-9830 program functioned as follows:

$$B(0) = A_{11} + A_{12}z$$

$$B(1) = A_{21} + A_{22}z$$

$$y = B(0) + B(1)x.$$

The TI-59 HHC was programmed to compute as follows:

$$(A_{11} + A_{12}z) + (A_{21} + A_{22}z)x = y.$$

In the Low Level Cruise Performance program, the linear interpolation and iterative methods to follow guidelines (discussed in previous section) was still accomplished using the more tedious TI-59 HHC language.

Using the partitioning already described, a program limit of 879 program steps was imposed (filling two magnetic cards). Two programs, "Takeoff Ground Roll Distance" and "Low Level

Cruise Performance", exceeded this limit and had to be continued on extra cards. These programs were written to allow storage of an intermediate result into the T-register. The rest of the cards could then be read in, any lost or newly acquired input data entered, and program execution would continue, automatically retrieving the stored intermediate result from the T-register. These artificial necessities for program completion using the magnetic cards would not be necessary if the programs were stored permanently in the CROM.

The total number of steps required for the nine performance algorithms programmed on the TI-59 HHC was 5461 steps. By sub-routining (340 steps of programming are common to two programs), the total number could be reduced to 5121 steps. The elimination of the artificial steps required for the oversized programs would reduce the overage more. The sole intent of this implementation phase was not to fit these nine programs into the 5000 step CROM. If the inclusion of all nine programs was desired, streamlining aid offered by engineers from the Texas Instruments Corporation plus the reduction of significant figures in a non-critical area would accomplish this.

The program listings, storage location usage, user instructions, and execution times are included in Appendix E.

C. MICROPROCESSOR

1. Single Board Computer using Software for Mathematical Operations

The single board computer (SBC) implementation was investigated both as an extension of thesis work and to meet the course objectives of AE-4900, Air Data Systems. Work toward this effort was also done by LCDR W.M. Siegel. The performance algorithms were to be processed on a SBC using an INTEL Corporation 8048 Programmable Read Only Memory (PROM), external random access memory (RAM) and a program counter. Software development was completed on the INTEL Prompt-48 (Microcomputer System-48 language) using an INTEL 8035 arithmetic logic unit (ALU). Although a SBC using the 8048 PROM and requiring a digital keyboard and display was never actually constructed because of the time limitations, the software operation was successfully demonstrated on the Prompt-48.

To preserve the programs between operation periods, the Prompt 48 was hand wired as specified in the user's manual to an ASR-35 Teletype set which allowed paper tape storage [6]. The Prompt-48 provided 1024 by two bytes of RAM and 64 by two bytes of resident memory. Although the MCS-48 instruction set will not be discussed in this thesis, a basic understanding of assembly level language is necessary to understand the developed software presented in Appendix F [7]. This microprocessor program listing includes the MCS-48 instructions in hex code and literal mneumonics and includes full documentation to facilitate interpretation.

A full performance algorithm was not implemented on the Prompt-48 because of its memory storage limitations. The original intent was to exercise the software of the complete A-7E Takeoff Ground Roll Distance algorithm on the Prompt-48.

After the necessary routines were written and stored, only room for three coefficients remained (98 coefficients required for this algorithm). Since implementation capability was the desired result, the computation of a second order polynomial was considered sufficient. Although this effort was software oriented, the necessary RAM storage for the additional coefficients and executive routine could have been easily provided for a SBC.

The software development for algorithm implementation required routines for input/output (I/O), executive direction, binary to binary coded decimal (BCD) and BCD to binary conversions, and floating point binary addition and multiplication routines. The I/O and executive routines were written by LCDR Siegel. The nonavailability of a number oriented microprocessor at the time of this effort required the development of the mathematical package described above. The advantages for such a capability will be discussed in the following section.

In addition to the microprocessor software developed by the author and LCDR Siegel, the I/O and display routines would require alteration for SBC implementation since a digital display and keyboard would replace the Prompt-48.

Figure 6 illustrates the solution method. Figure 7 is a flow chart of the program execution sequence. Figures 8 and 9 show the Prompt-48 RAM and resident register memory, respectively.

SBC SOLUTION METHOD

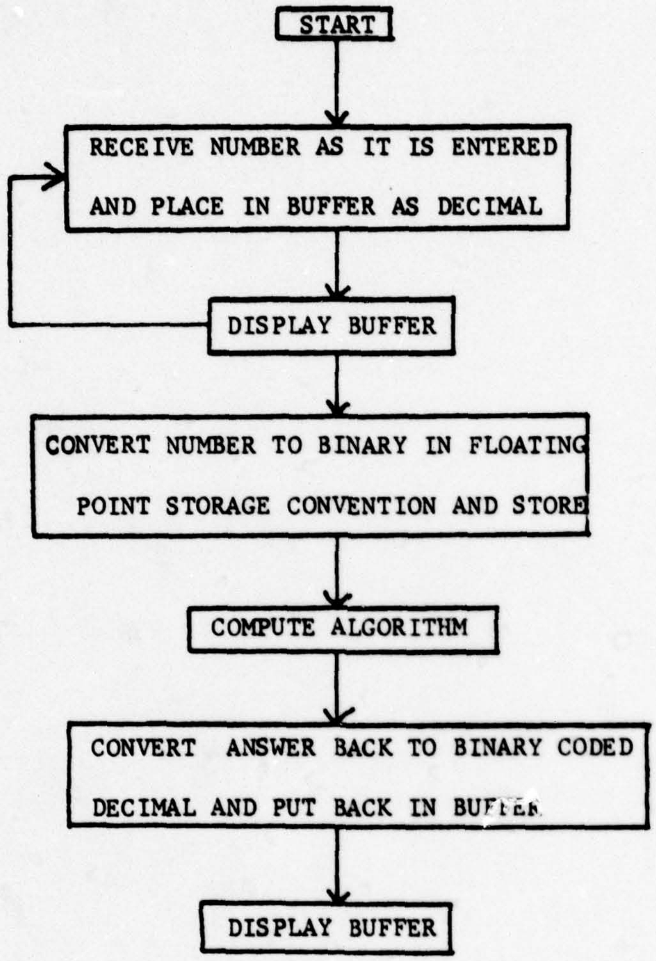


Figure 6

SBC Solution Method

SBC PROGRAM EXECUTION SEQUENCE

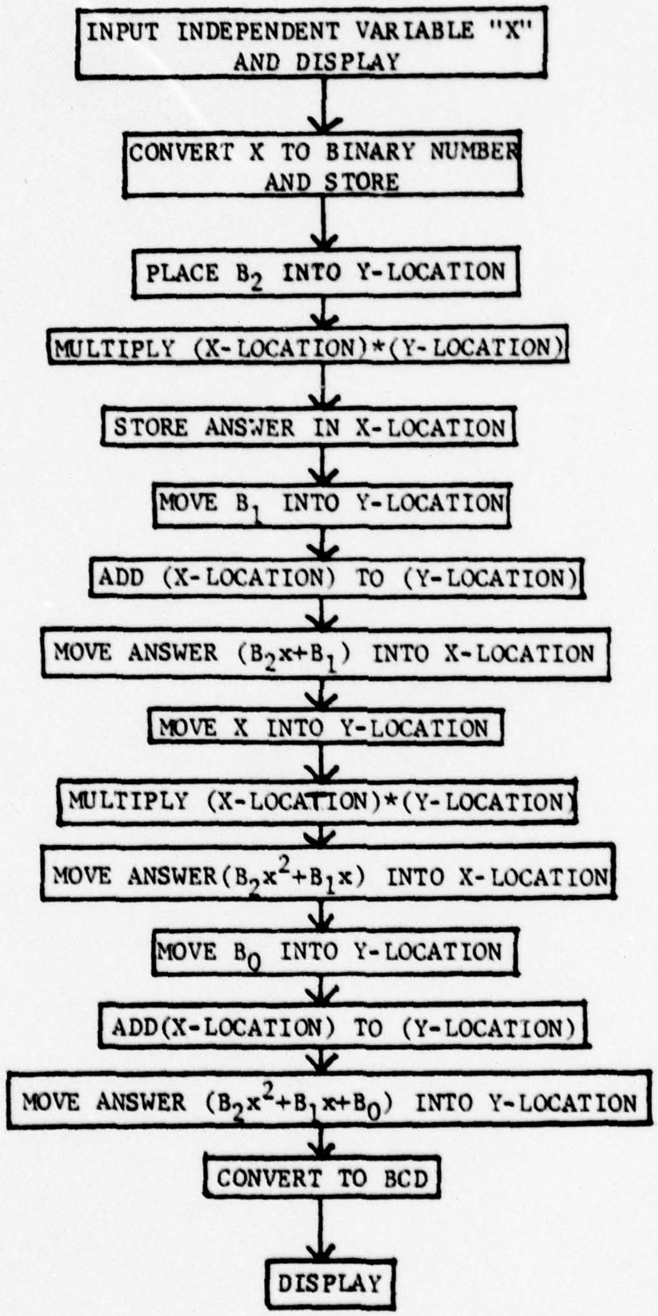


Figure 7

SBC Program Execution Sequence

RANDOM ACCESS MEMORY MAP

ADDRESS	USE
000-069	INPUT AND DISPLAY
06A-06F	EXECUTIVE ROUTINE SEGMENT
070-079	COEFFICIENT STORAGE
07A-0C6	MAIN EXECUTIVE ROUTINE
0C8-0E2	BINARY TO BCD EXECUTIVE ROUTINE
0E5-0FF	MISCELLANEOUS SUBROUTINES
100-2EC	ADDITION AND MULTIPLICATION SUBROUTINES
300-3FF	BCD TO BINARY EXECUTIVE ROUTINE AND CONVERSION SUBROUTINES

Figure 8

Random Access Memory Map

RESIDENT REGISTER MAP

ADDRESS	USE	ADDRESS	USE
20	LSB	30	
21	X-LOCATION	31	
22	ARITHMETIC REGISTER	32	LSB
23	MSB	33	DISPLAY HEX
24	EXPONENT	34	BUFFER
25	LSB Y-LOCATION	35	MSB
26	MSB ARITHMETIC REGISTER	36	DECIMAL POINT MASK
27	EXPONENT	37	CHARACTER COUNTER
28	LSB BCD-BINARY	38	LSB
29	MSB CONVERSION	39	
2A	EXPONENT	3A	DISPLAY
2B		3B	
2C		3C	BIT
2D		3D	
2E		3E	PATTERNS
2F		3F	MSB

Figure 9

Resident Register Map

The second order polynomial, $y = B(0) + B(1)x + B(2)x^2$, was calculated using a mathematical executive routine (alterable for any size polynomial and any number of polynomials). The only mathematical operations required were multiplication and addition of positive or negative numbers. For speed, binary arithmetic was used. For increased storage capability and mathematical efficiency, a floating point capability was included.

The calculation routine proceeded as follows:

$B_2 * x = (B_2 x)$

$(B_2 x) + (B_1) = (B_2 x + B_1)$

$(B_2 x + B_1) * x = (B_2 x^2 + B_1 x)$

$(B_2 x^2 + B_1 x) + B_0 = (B_2 x^2 + B_1 x + B_0)$

Although all mathematical operations are performed in the 8-bit (2-byte) accumulator register of the 8035 ALU (for a SBC, the 8048 PROM), a working accumulator using five registers (resident memory registers two through six), was established. All numbers in the program (independent variable "x" after conversion to binary, coefficients stored in RAM 070-079 and the 'result') were in one of two binary conventions. While in storage, the numbers were in "storage" convention. The numbers were shifted from "storage" to "working" convention only when transferred from the X and Y locations (see resident register memory map, Figure 9) to the working accumulator (registers two through six). When the desired operation was completed, the result was returned to the "storage" convention and moved to the "X" location. Figure 10 displays the "storage and working" conventions.

This software was successfully demonstrated on the Prompt-48. The user instructions for the Prompt-48 to repeat the demonstration are listed below:

(1) Ensure the 8035 ALU or 8048 PROM is inserted in the "execution" socket of the Prompt-48.

(2) Enter the program in hex code in the proper storage locations as listed in Appendix F.

On the Prompt-48, press the following keys to clear the resident register memory:

"C"

"Registers"

"0"

","

"4"

"8"

Do not press "Program Memory" instead of "registers" or the program just entered will be erased.

(3) To execute the program, press the following keys:

"A"

"2"

"Execute"

"Go"

"No Break"

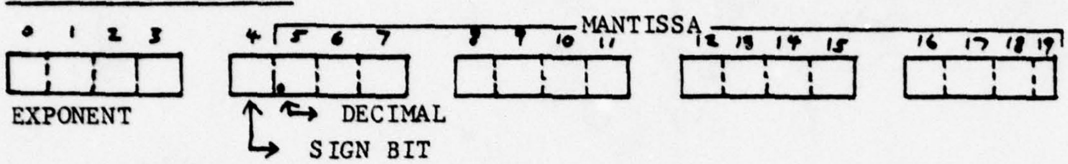
"0"

"Execute"

BINARY CONVENTIONS

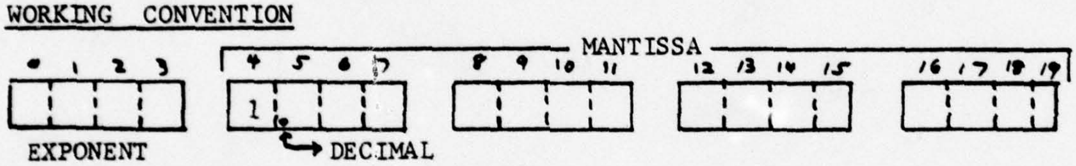
Each large block depicts 1 byte which includes 4 bits. The compartmented blocks represent 1 bit.

STORAGE CONVENTION



In storage convention, the mantissa is left justified to bit 5. A positive number is denoted by 0 in the first bit of the second byte(sign bit); a 1 indicates a negative number.

WORKING CONVENTION



In working convention, the mantissa is left justified to bit 4. The sign bit is stored in F0(X-location number) and F1(Y-location number) flags of the program status word.

Figure 10

Binary Conventions

The display will blank, awaiting the input of the independent variable "x". To enter "x", enter the digit keys for numbers (base 10) and "D" for decimal point. "x" will be displayed on the digital display as it is entered. To compute the algorithm (second order polynomial), press "E". The answer will rapidly appear. To calculate the polynomial with a new value for "x", start at Step 3.

(4) To prevent the time consuming reloading of the program, it is advisable to store the program on a peripheral device (paper tape, disc, etc.).

2. Single Board Computer using Number Oriented Microprocessor

Very recently, the National Semiconductor Corporation began production of a chip intended for use in number processing applications [8]. This chip, the MM57109 MOS/LSI, is capable of all scientific calculator functions, test and branch capabilities, internal number storage, and I/O instructions. Of the specific calculator functions, only addition, subtraction and multiplication would be used.

A SBC using this chip would need the 8048 PROM for coefficient and executive routine storage but would not need the space consuming mathematical package of the SBC in the last section. A program counter would still be required but external RAM would not. The computation time would be increased over the demonstrated SBC (approximate computation time of a HHC), but the simplicity of programming would make this proposed SBC very attractive.

D. A-7E TACTICAL COMPUTER

In February 1978 the author made a trip to the Naval Air Facility at China Lake, California. The purpose of this visit was to receive indoctrination on the TC-2/2A tactical computers and obtain a programming manual for these devices. The desired goal was implementation of selected performance algorithms on the laboratory bench computer run by the A-7 Program Office of the Naval Weapons Center (NWC). A thorough understanding of the computer's capabilities and limitations was provided by Mr. Robert Westbrook, a software technician.

The A-7E computer provides very accurate navigation and weapons guidance capability. The TC-2 and TC-2A computers are a generation apart, the TC-2A being over two times faster and having twice the storage capability of its earlier version. Both computers are operational at this time. Specific design and programming information is available from the programming manual [9].

The instruction set of the tactical computer provides fixed point arithmetic, logical transfer of control (branching), address modification and single word input/output instructions specifically intended for operations primarily involving arithmetic. These features made the implementation of algorithms a logical decision. Several factors made this implementation by the author impractical. The computer design was quite old, the instruction set being very tedious and difficult to interpret. The computer's inability to function using floating point arithmetic would require a significant software effort in that area alone. The time required to become fully familiar with the instruction set, write the software, and load and test the programs at NWC would have been prohibitive for this investigation.

It is hoped that the programmers at NWC will be able to implement those algorithms deemed desireable to achieve an onboard capability. Takeoff Airspeed and Maximum Refusal Airspeed are considered ideal for implementation.

IV. CONCLUSIONS AND RECOMMENDATIONS

Nine of the A-7E NATOPS Manual performance chart groups were reduced to a series of analytical expressions or algorithms. These algorithms, accurate to five significant figures, are as accurate as results obtained by manual manipulation of the performance charts.

Implementation was made on three data processors of different programming levels and storage capabilities. These devices and degrees of implementation were:

(1) HP-9830 Desk Computer - complete implementation with successful demonstration.

(2) TI-59 Hand Held Calculator - complete implementation with successful demonstration.

(3) Microprocessor - partial implementation with successful demonstration.

In view of the success of this investigation, recommendations concerning implementation possibilities are listed below:

(1) Complete reduction of the NATOPS Manual performance charts could be accomplished and implemented onto a desk computer as one large program capable of performance data computation within seconds. The desk computer would be ideal for mission planning on a squadron or air wing level or for Air Operations Center use.

(2) The programs written for the TI-59 HHC could be consolidated onto a CROM and used with a TI-58 HHC for use on a

squadron level. As an alternative, the software could be rewritten for any HHC of comparable capability.

(3) Although implementation on a single board computer using a number oriented microprocessor is completely feasible, because of programming ease and cost consideration, the HHC is considered a superior implementation possibility at this time.

(4) The A-7E tactical computer could easily be programmed by software engineers at NWC, China Lake, California, to produce an onboard capability.

APPENDIX A

Least Squares Fit Approximation

References 10 and 11 describe the Least Squares Fit Approximation in detail. In general the problem is to represent a set of "n" data points in two-dimensional space

$X_i, Y_i \quad i = 1 \text{ to } n$

by a polynomial expression of a curve whose degree is less than "n". Two classes of problems exist:

(1) Linearly independent - those in which the degree (d) of the polynomial is one less than the number of data points

$$d = n-1 \qquad (1)$$

(2) Linearly dependent - those in which the degree (d) is less than n-1

$$d < n-1 \qquad (2)$$

As an example, a set of four (4) data points randomly spaced was chosen. If a third degree polynomial of the form

$$Y = A + BX + CX^2 + DX^3 \qquad (3)$$

were desired, and the data points X_i and Y_i were inserted (i = 1 to 4) into four such equations, an exact solution for the four unknown coefficients would exist. These four unknowns could be found from the four equations by numerous conventional techniques (Direct substitution, Cramer's rule, etc.). The polynomial expression generated would be termed a "col-location" polynomial because its plot would pass through all data points.

It is often advantageous to describe a set of data points by a curve that does not pass through each point. This type of polynomial would be termed a "regression" equation. For any set of data points an infinite number of regression expressions exist for any specified degree (except the linearly independent case) and the object of the Least Squares Method is to find the polynomial coefficients of the chosen degree that best describe the data points. In the previous example of four data points, assume that, instead of the third degree form chosen, a second degree equation were selected of the form

$$Y = A + BX + CX^2 \tag{4}$$

With four data points, the polynomial is overspecified and thus linearly dependent. For this case an infinite number of solutions exist for the coefficients a, b and c. If an error term (δ) were defined for any given X,Y pair as

$$\delta_1 = |Y_1 - A + BX_1 + CX_1{}^2| \tag{5}$$

a total squared error term (E) could then be defined by squaring and summing the terms attained:

$$E = \sum_{i=1}^{N} \delta_1{}^2 \tag{6}$$

If E were them minimized for any given degree chosen, the best Least Squares Fit would have been achieved.

If the values for δ from Equation 5 were inserted in Equation 6 and the partial derivative of E were taken with respect to the coefficient A, an equation would be generated that when set equal to zero (0) would define a minimum value of E for a given value of A. If the same operation were performed with respect to the coefficients B and C then three equations would be generated with three unknowns (A, B and C). The solution of these simultaneous equations would produce the coefficients A, B and C, that would minimize the value of E and hence would produce a Least Squares Fit approximation to a set of linearly dependent equations.

A numerical procedure has been developed to accomplish this task. An example of this procedure has been included in the following paragraphs [10, 11].

Least Squares Fit Method Example

Given the following set of data:

X	0	1	2	4	7
f(X) = Y	0	1	3	12	20

fit a curve of the form

$$f(X) = Y - A + BX + CX^2$$

STEP 1: Substitute all pairs of data into the form equation yielding the fact that the coefficients (A, B and C) must satisfy all the following:

$$0 = A + B(0) + C(0)^2$$

$$1 = A + B(1) + C(1)^2$$

$$3 = A + B(2) + C(2)^2$$

$$12 = A + B(4) + C(4)^2$$

$$20 = A + B(7) + C(7)^2$$

Now multiply each expression by its coefficient of A in that expression and add all equation yielding

$$36 = 5A + 14B + 70C$$

Now multiply each expression by its coefficient of B in that expression and add all the equations yielding

$$0 = 0(A) + 0(B) + 0(C)$$
$$1 = A + 1B + 1C$$
$$6 = 2A + 4(B) + 8(C)$$
$$48 = 4A + 16(B) + 64(C)$$
$$\underline{140 = 7A + 44(B) + 343(C)}$$
$$195 = 14A + 70(B) + 416(C)$$

Now multiply each expression by its coefficient C in that expression and add all the expressions yielding

$$0 = 0(A) + 0(B) + 0(C)$$
$$1 = 1(A) + 1(B) + 1(C)$$
$$12 = 4(A) + 8(B) + 16(C)$$
$$192 = 16(A) + 64(B) + 256(C)$$
$$\underline{980 = 49(A) + 343(B) + 2401(C)}$$
$$1185 = 70A + 416B + 2674C$$

Now solve the following three previously generated equations for the coefficients A, B and C yielding

$$36 = 5A + 14B + 70C$$
$$195 = 14A + 70B + 416C$$
$$1185 = 70A + 416B + 2674C$$
$$A = -.99,\ B = 2.6,\ C = .065$$

and

$$Y = -.99 + 2.6X + .065X^2$$

The following plot and chart depict the original data and the data obtained from the equation for the fitted curve:

	Original	Fitted Curve Polynomial
X	Y	Y
0	0	-.98
1	1	1.67
2	3	4.48
4	12	10.46
7	20	20.41

Q.E.D.

APPENDIX B

NATOPS Manual Performance Charts

These charts from which the performance algorithms were developed are listed below in order:

CRUISE PERFORMANCE (A-7E)

PHASE I – CLEAN AIRPLANE TRANSFER SCALE

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

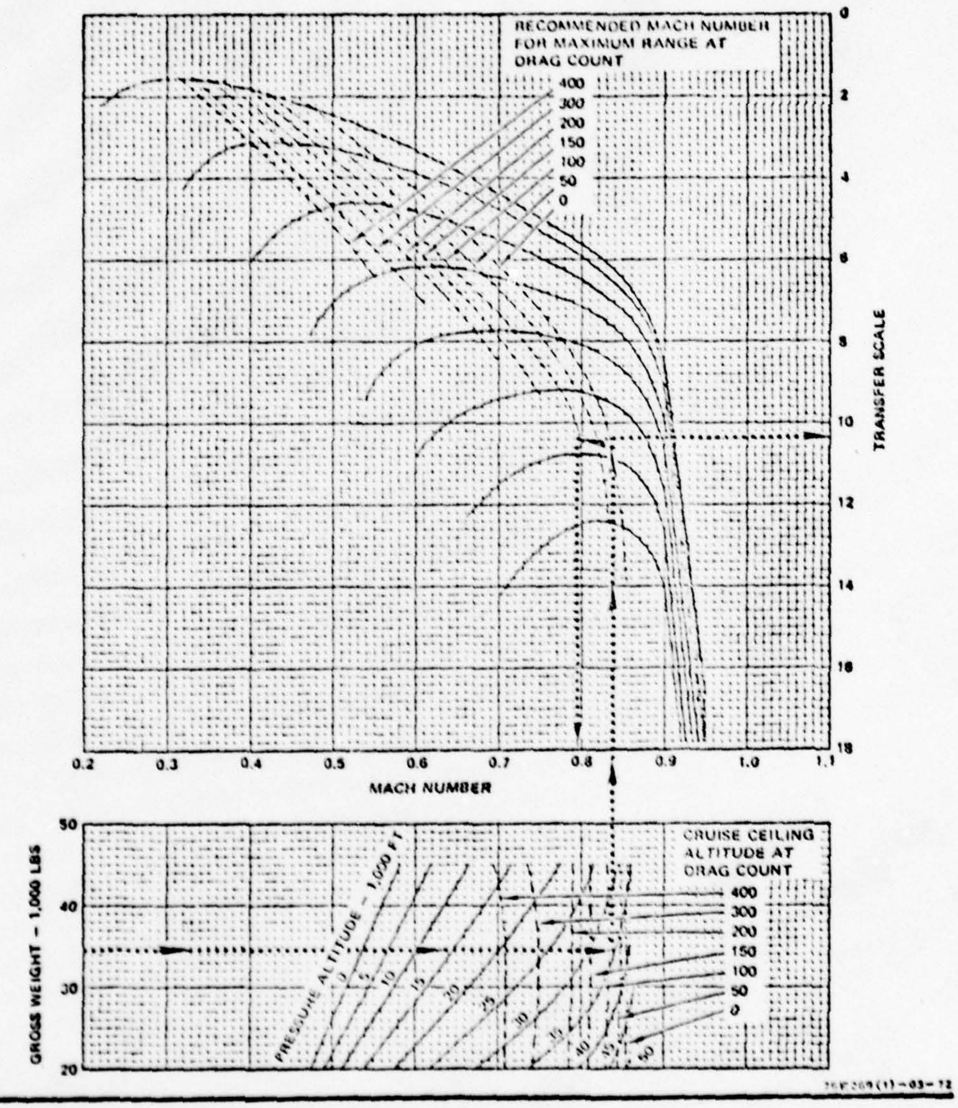


Figure B1

Cruise Performance, Phase I

CRUISE PERFORMANCE (A-7E)

11–117

PHASE II – AIRCRAFT REFERENCE NUMBER

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

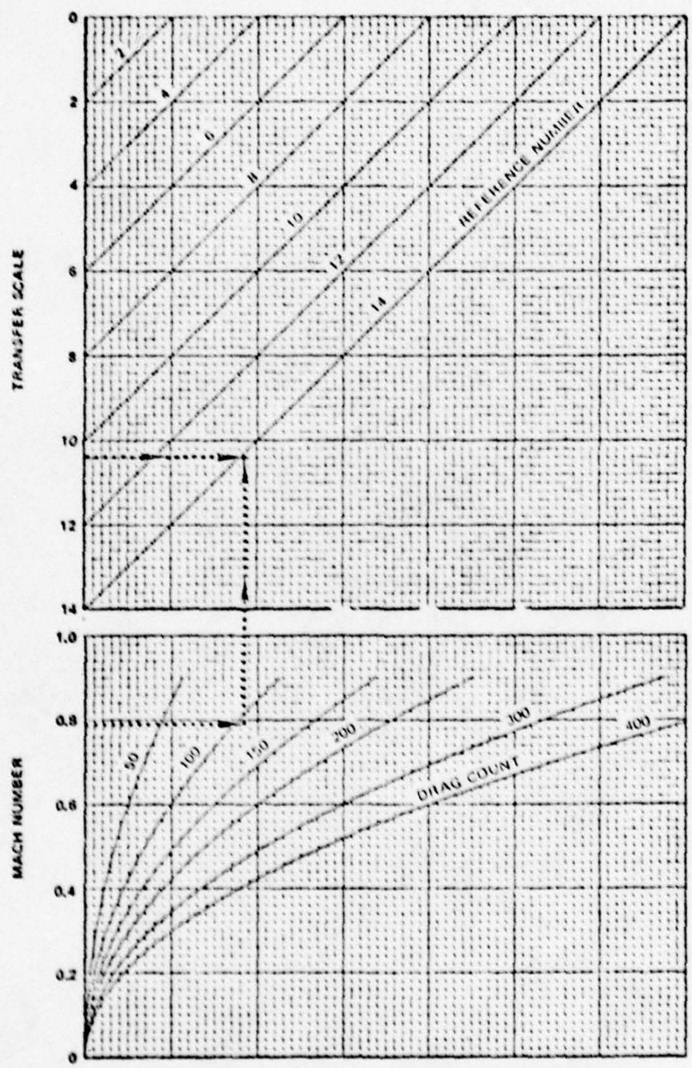


Figure B2

Cruise Performance, Phase II

CRUISE PERFORMANCE (A-7E)

PHASE III – POUNDS OF FUEL PER NAUTICAL MILE

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

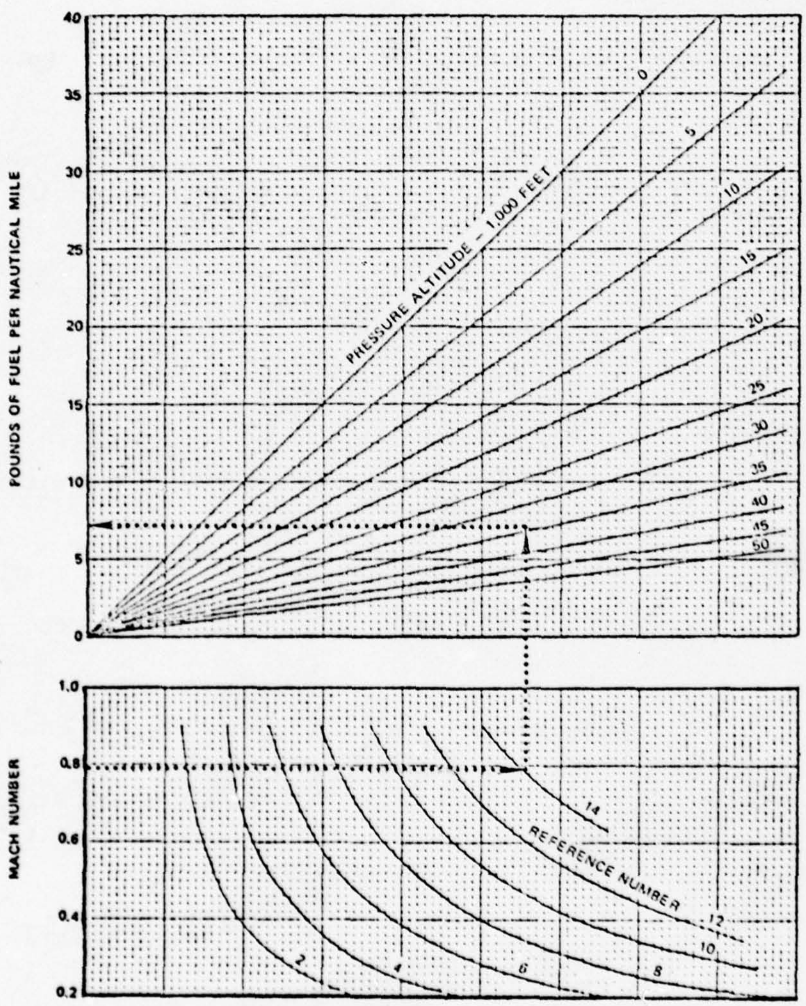


Figure B3

Cruise Performance, Phase III

CRUISE PERFORMANCE (A-7E)

PHASE IV – FUEL FLOW

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

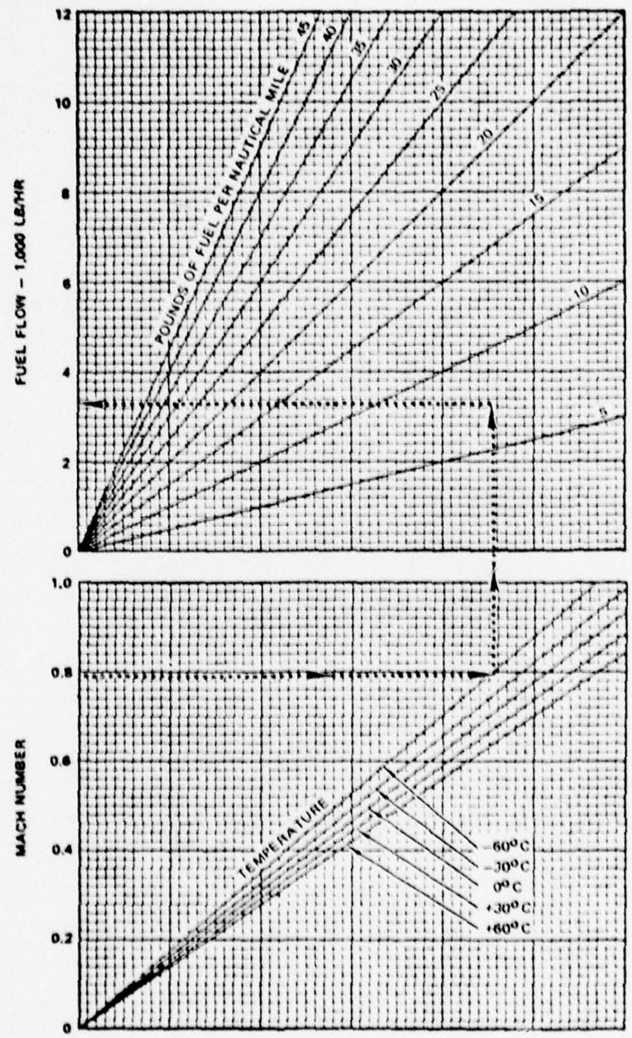


Figure B4

Cruise Performance, Phase IV

TAKEOFF FACTOR (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL.

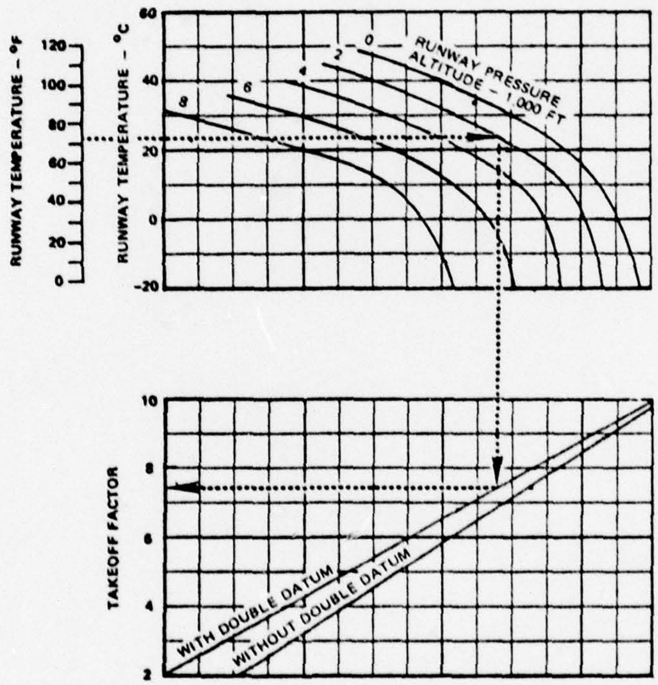


Figure B5

Takeoff Factor

TAKEOFF GROUND ROLL DISTANCE (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
LEVEL HARD SURFACE RUNWAY
MILITARY RATED THRUST
LANDING CONFIGURATION
ZERO HEADWIND
CG: 26% MAC
FULL FLAPS

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTE

For minimum ground roll corresponding to minimum lift-off speed, subtract 500 feet.

For humidity effects on takeoff distance, ground roll distances should be increased 1% for each 10% increase in the relative humidity above 40%.

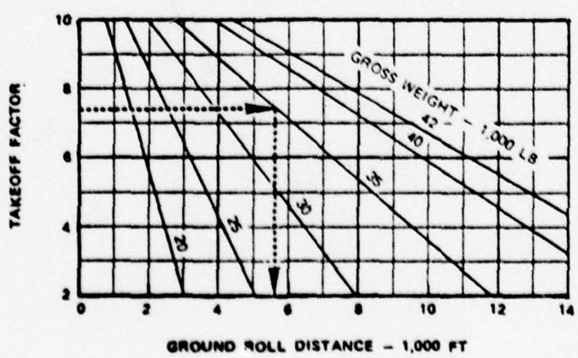


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Figure B6

Takeoff Ground Roll Distance

TAKEOFF GROUND ROLL DISTANCE (A-7E)

ADJUSTED GROUND ROLL DISTANCE

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
HARD SURFACE RUNWAY
MILITARY RATED THRUST
LANDING CONFIGURATION
LEADING EDGE FLAPS DOWN

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL.

NOTE

For humidity affects on takeoff distance, ground roll distances should be increased 1% for each 10% increase in the relative humidity above 40%.

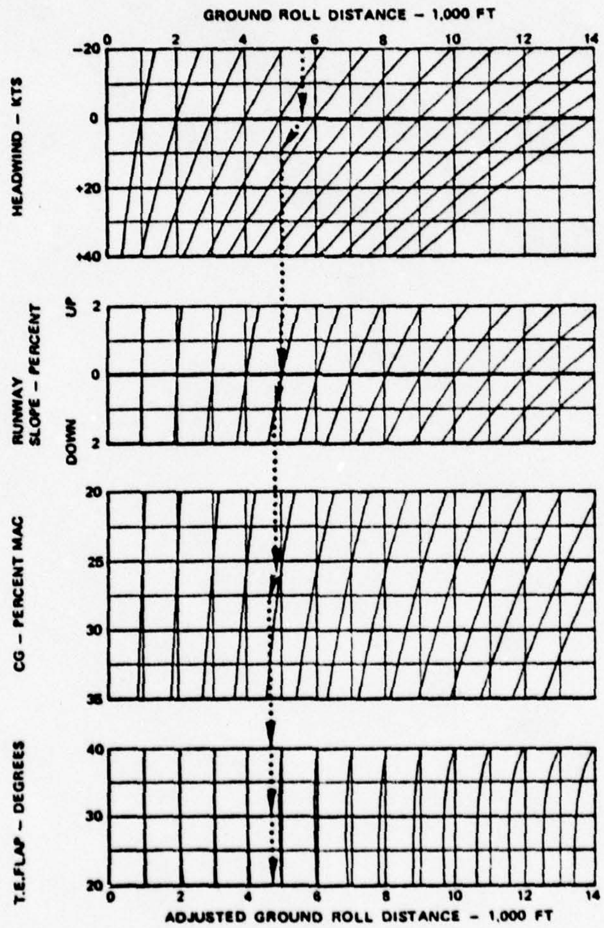

Figure B7

Adjusted Takeoff Ground Roll Distance

MAXIMUM RANGE CRUISE AT CONSTANT ALTITUDE (A-7E)

TIME AND SPEED

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

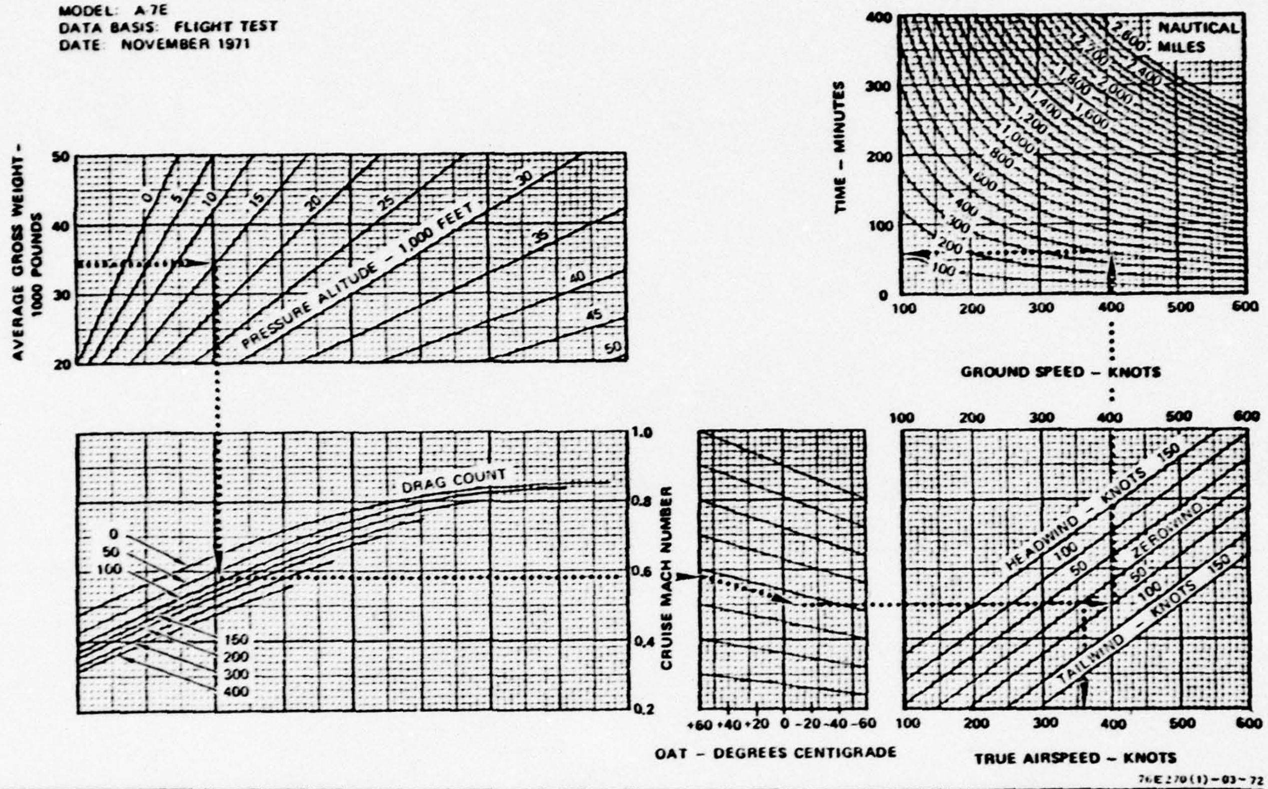

Figure B8

Maximum Range Cruise at Constant Altitude (Time, Speed)

MAXIMUM RANGE CRUISE AT CONSTANT ALTITUDE (A-7E)

FUEL REQUIRED

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

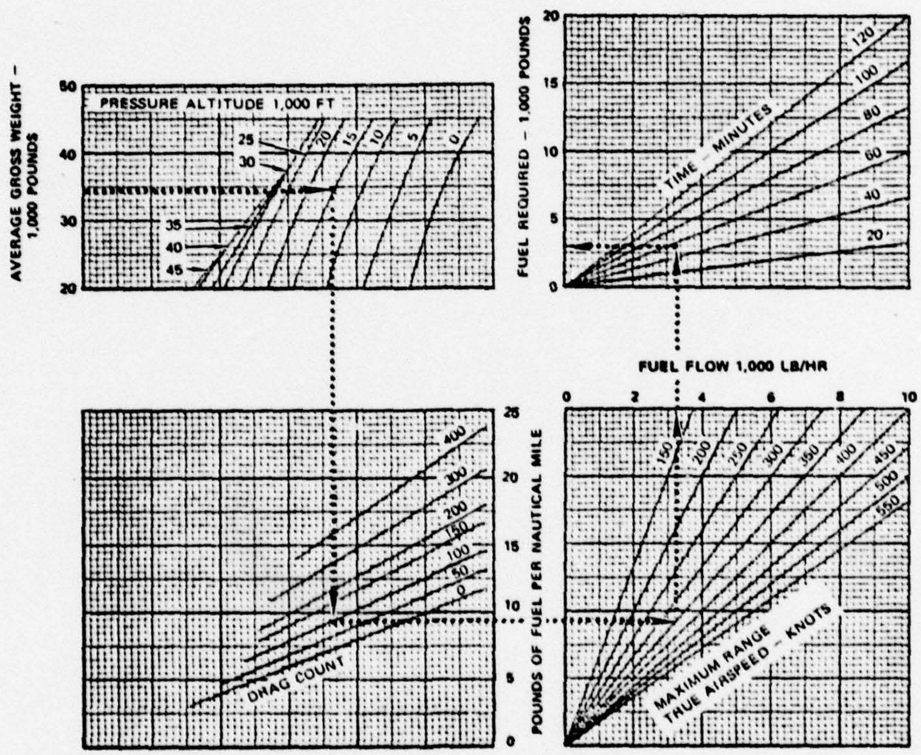

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Figure B9

Maximum Range Cruise at Constant Altitude (Fuel Required)

MILITARY POWER CLIMB (A-7E)

CLIMB SPEED SCHEDULE

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

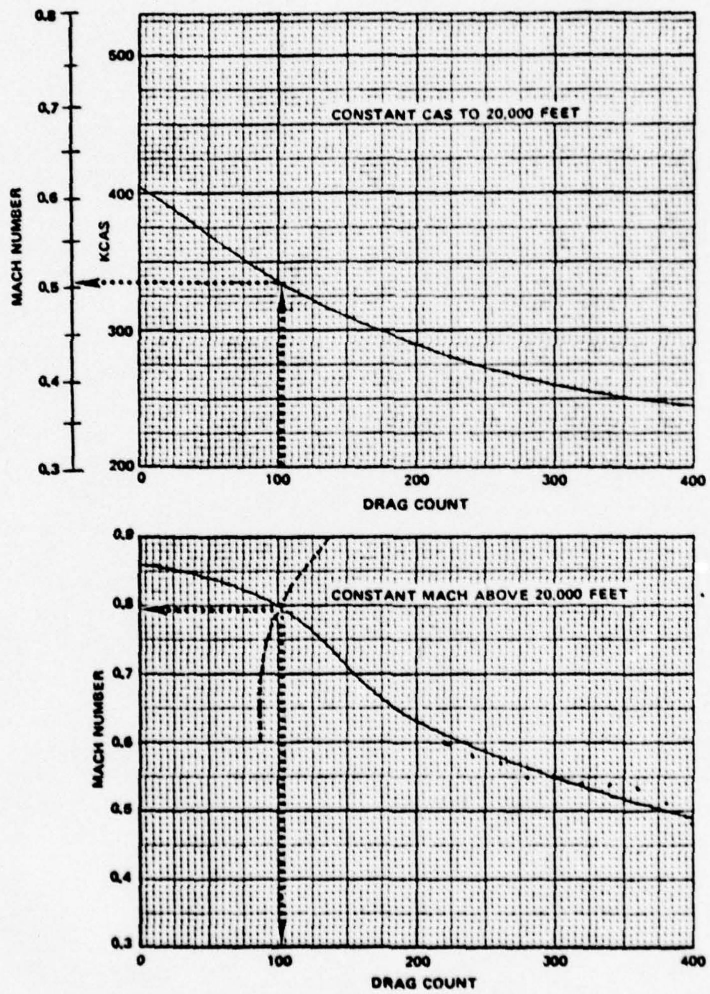


Figure B10

Military Power Climb Schedule

TAKEOFF SPEED (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
MILITARY RATED THRUST
LANDING CONFIGURATION
LEADING EDGE FLAPS DOWN

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

NOTE

Data basis is 26% MAC. Increase speed 1/2 knot per 1% forward CG shift. Decrease speed 1/2 knot per 1% aft CG shift.

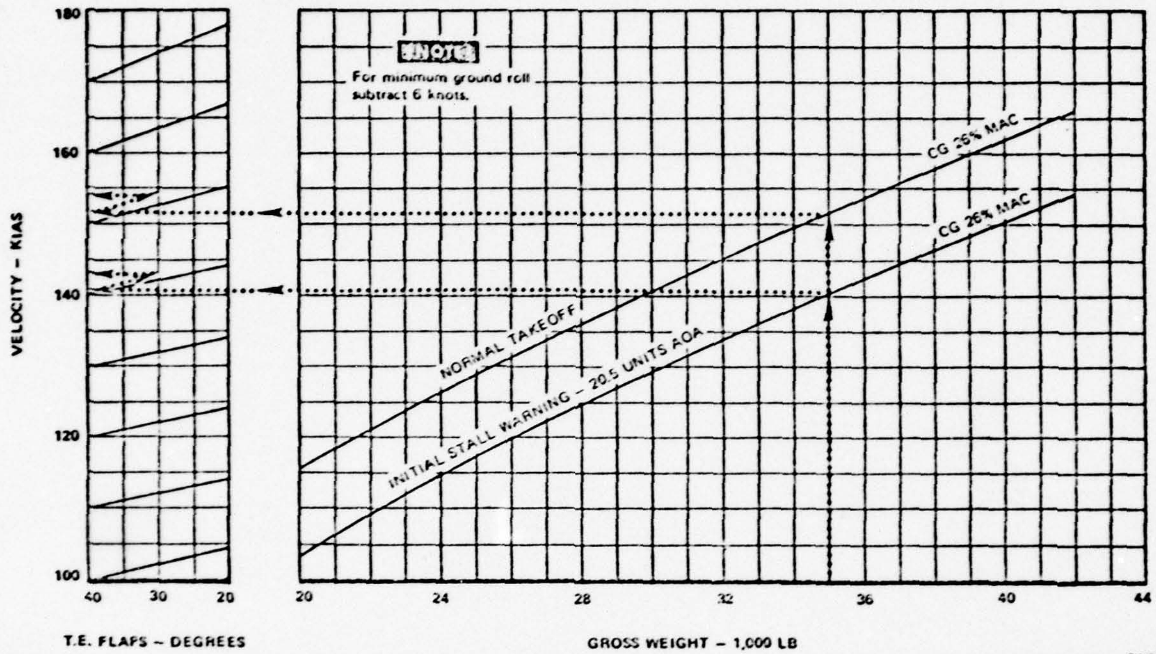


Figure B11

Takeoff Speed

MAXIMUM REFUSAL SPEED (A-7E)

WITH ANTI-SKID

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

CONDITIONS:
MILITARY RATED THRUST
HARD SURFACE RUNWAY
LANDING CONFIGURATION

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL

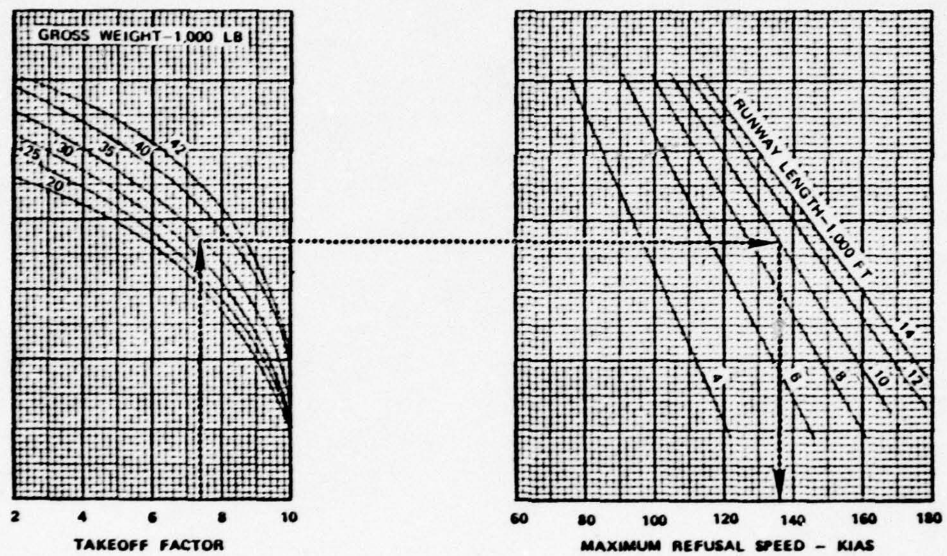


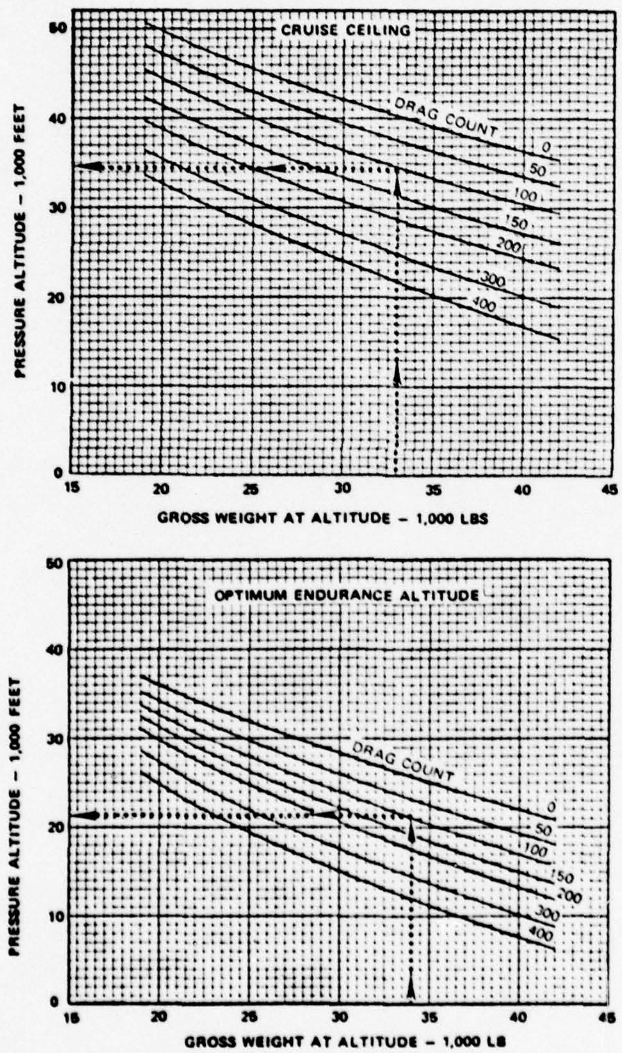
Figure B12

Maximum Refusal Speed

CRUISE CEILING AND OPTIMUM ENDURANCE ALTITUDE (A-7E)

MODEL: A-7E
DATA BASIS: FLIGHT TEST
DATE: NOVEMBER 1971

ENGINE: TF41-A-2
FUEL GRADE: JP-5
FUEL DENSITY: 6.8 LB/GAL



11-53

Figure B13

Cruise Ceiling and Optimum Endurance Altitude

APPENDIX C

Generated Algorithms

LOW LEVEL CRUISE PROGRAM

Phase I

$$M1 = -92.512 + 236.896G$$

Transfer Scale Versus Drag Count

$$A0 = -2.3287 - .26316D + .0073327D^2 - (7.513E-5)D^3 + (3.5396E-7)D^4 - (7.78E-10)D^5 + (6.462E-13)D^6$$

$$A1 = 4.835 + 1.0956D - .030653D^2 + (3.1912E-4)D^3 - (1.5276E-6)D^4 + (3.408E-9)D^5 - (2.8692E-12)D^6$$

$$A2 = 10.284 - 1.0719D + .031094D^2 - (3.2878E-4)D^3 + (1.595E-6)D^4 - (3.6009E-9)D^5 + (3.0634E-12)D^6$$

$$S1 = A0 + (A1)(M1) + (A2)(M1)^2$$

Transfer Scale Versus Guidelines

$$B0 = 22.819 - 31.734I + 41.33I^2 - 5.0953I^3$$

$$B1 = -154.98 + 217.51I - 261.73I^2 + 35.905I^3$$

$$B2 = 405.08 - 525.56I + 607.49I^2 - 88.737I^3$$

$$B3 = -445.62 + 542.98I - 611.55I^2 + 92.894I^3$$

$$B4 = 184.78 - 204.42I + 225.89I^2 - 35.189I^3$$

$$S = B0 + (B1)(M1) + (B2)(M1)^2 + (B3)(M1)^3 + (B4)(M1)^4$$

Phase II

$$R = S + 2[(4.3732E-3) + .027743D]M^2$$

Phase III

$$B0 = 5.6253 - 1.989R + 3.0252R^2 - 1.0761R^3 + .17675R^4 - .013095R^5 + (3.526E{-}4)R^6$$

$$B1 = 205.3012 - 248.9317R + 91.66355R^2 - 15.55218R^3 + 1.224432R^4 - .0395333R^5 + (2.896385E{-}4)R^6$$

$$B2 = -1052.123 + 1231.24R - 487.4233R^2 + 91.6522R^3 - 8.662962R^4 + .3953974R^5 - .006905535R^6$$

$$B3 = 1680.142 - 1950.139R + 788.8513R^2 - 152.5733R^3 + 15.03819R^4 - .7274139R^5 + .013707R^6$$

$$R3 = R$$

$$R1 = 2\ (\text{Integer}\ (R/2))$$

$$R2 = R1 + 2$$

$$N1 = B0 + (B1)(R1) + (B2)(R1)^2 + (B3)(R1)^3$$

$$N2 = B0 + (B1)(R2) + (B2)(R2)^2 + (B3)(R2)^3$$

Using Linear Interpolation

$$N = N1 + [(N2-N1)(R3-R1)/2]$$

$$P = 4.9746N + (7.9043E{-}6)N^2$$

Phase IV

$$N4 = [6.4375 + .010426T - (6.8925E{-}6)T^2 + (4.9127E{-}7)T^3]M$$

$$F = .1(N4)P$$

TAKEOFF DISTANCE PROGRAM

$$B0 = 13.086 - .00017113A - (2.0655E{-}7)A^2 + (3.6861E{-}11)A^3 - (2.4156E{-}15)A^4$$

$$B1 = -.045635 - (7.8931E\text{-}6)A + (3.7545E\text{-}9)A^2 - (9.7088E\text{-}13)A^3$$
$$+ (6.997E\text{-}17)A^4$$

$$B2 = -.001317 - (8.2558E\text{-}7)A + (4.0739E\text{-}10)A^2 - (8.548E\text{-}14)A^3$$
$$+ (5.4964E\text{-}18)A^4$$

$$B3 = -(1.9097E\text{-}5) + (1.3671E\text{-}8)A - (9.4694E\text{-}12)A^2 + (2.0434E\text{-}15)A^3$$
$$-(1.4617E\text{-}19)A^4$$

$$C = B0 + B1(B) + B2(B)^2 + B3(B)^3$$

If double datum on,

$$E = 1.9773 + .56598C$$

If double datum off,

$$E = .54178 + .65876C$$

$$G0 = -(4.8896E+5) + (8.4974E+1)G - (5.7856E\text{-}3)G^2 + (1.9373E\text{-}7)G^3$$
$$-(3.1744E\text{-}12)G^4 + (2.0446E\text{-}17)G^5$$

$$G1 = (5.8621E+4) - (1.0146E+1)G + (6.8807E\text{-}4)G^2 - (2.292E\text{-}8)G^3$$
$$+ (3.7387E\text{-}13)G^4 - (2.3964E\text{-}18)G^5$$

$$H = G0 + G1(E)$$

If relative humidity $< 40\%$, $K = H$

If not, $K = 4\{[(I-40)/1000]+1\}$

$$L0 = 67.124 + .89509K + (2.3306E\text{-}5)K^2 - (1.6254E\text{-}9)K^3$$
$$+ (3.3728E\text{-}14)K^4$$

$$L1 = -9.0995 - (1.0856E\text{-}2)K + (2.1754E\text{-}7)K^2 - (2.5327E\text{-}11)K^3$$
$$+ (1.197E\text{-}15)K^4$$

$$L2 = (1.4782E\text{-}1) - (2.1666E\text{-}6)K + (3.4274E\text{-}9)K^2 - (2.7817E\text{-}13)K^3$$
$$+ (9.3077E\text{-}18)K^4$$

$$M = L0 + L1(L) + L2(L)^2$$

If winds calm, $M = K$

$$X0 = (4.5704E+1) + .93429M + (2.2265E-5)M^2 - (2.338E-9)M^3 + (7.941E-14)M^4$$

$$X1 = 7.9472 + .014914M + (9.0708E-6)M^2 - (7.1235E-10)M^3 + (3.0684E-14)M^4$$

$$X2 = 5.3616 - .0085136M + (3.5914E-6)M^2 - (4.5932E-10)M^3 + (1.9889E-14)M^4$$

$$X = X0 + X1(N) + X2(N)^2$$

$$Q0 = 2604.2 - 2.1694X + .0010915X^2 - (1.1119E-7)X^3 + (3.662E-12)X^4$$

$$Q1 = -175.73 + .22601X - (7.5225E-5)X^2 + (7.7018E-9)X^3 - (2.5437E-13)X^4$$

$$Q2 = 2.8549 - .0040102X + (1.2832E-6)X^2 - (1.3234E-10)X^3 + (4.3908E-15)X^4$$

$$Q = Q0 + Q1(P) + Q2(P)^2$$

$$S0 = -400.79 + 1.5801Q - (2.0254E-4)Q^2 + (2.4111E-8)Q^3 - (8.6737E-13)Q^4$$

$$S1 = 16.196 - .024333Q + (9.3484E-6)Q^2 - (1.2594E-9)Q^3 + (4.7522E-14)Q^4$$

$$S2 = -.14758 + (2.359E-4)Q - (1.037E-7)Q^2 + (1.6016E-11)Q^3 - (6.3195E-16)Q^4$$

$$S = S0 + S1(R) + S2(R)^2$$

MAXIMUM RANGE CRUISE TIME AND SPEED AT CONSTANT ALTITUDE PROGRAM

$$B0 = -1 + (5.0794E-3)H - (1.3968E-3)H^2 + (8.254E-5)H^3 - (1.2698E-6)H^4$$

$$B1 = .05 + .0015159H + (1.123E-4)H^2 - (3.4921E-6)H^3$$
$$+ (7.9365E-8)H^4$$

$$N = B0 + B1(G)$$

$$B0 = .47803 + .0013417D + (6.2287E-6)D^2 - (1.6261E-8)D^3$$
$$+ (1.6438E-11)D^4$$

$$B1 = .08217 + (4.1209E-4)D - (4.5577E-6)D^2 + (1.6777E-8)D^3$$
$$- (2.001E-11)D^4$$

$$B2 = (4.2143E-4) - (9.4397E-5)D + (1.2646E-6)D^2 - (4.8537E-9)D^3$$
$$+ (5.7222E-12)D^4$$

$$B3 = -(6.6767E-4) + (8.4671E-6)D - (1.0501E-7)D^2 + (3.6382E-10)D^3$$
$$- (3.7828E-13)D^4$$

$$M = B0 + B1(N) + B2(N)^2 + B3(N)^3$$

$$M1 = M - [(60-T)(2)(M)/1200]$$

$$V = (710)(M1 - .14) + 100 - E$$

$$T1 = D1/V$$

FUEL REQUIRED FOR MAXIMUM RANGE CRUISE AT CONSTANT ALTITUDE PROGRAM

$$B0 = 4.54 - .16444A + .0033932A^2 - (1.0283E-4)A^3 + (1.926E-6)A^4$$
$$- (1.3757E-8)A^5$$

$$B1 = (3.22E-9) - (3.6664E-3)A + (8.9338E-4)A^2 - (5.5939E-5)A^3$$
$$+ (1.4593E-6)A^4 - (1.3281E-8)A^5$$

$$B2 = (6E-4) + (1.1203E-4)A - (2.3358E-5)A^2 + (1.4536E-6)A^3$$
$$- (3.7144E-8)A^4 + (3.3334E-10)A^5$$

$$N = B0 + B1(G) + B2(G)^2$$

$$B0 = -(2.5399E-3)D + (9.7299E-5)D^2 - (2.3516E-7)D^3 + (1.4251E-10)D^4$$

$$B1 = 2 + (4.2388E-3)D + (1.2326E-5)D^2 - (1.0298E-7)D^3 + (1.7277E-10)D^4$$

$$L = B0 + B1(N)$$

$$F = L/V$$

$$R = (F)(T)/60$$

MAXIMUM RANGE CLIMB AIRSPEED SCHEDULE

$$S = 405.56 - .79075D + .0011382D^2 - (4.1018E-7)D^3$$

$$M = .86 - (2.1634E-3)D + (7.6582E-5)D^2 - (1.1344E-6)D^3 + (7.2125E-9)D^4 - (2.3035E-11)D^5 + (3.6588E-14)D^6 - (2.3062E-17)D^7$$

TAKEOFF AIRSPEED PROGRAM

$$U1 = 54.023 + (3.4787E-3)G - (1.9475E-8)G^2$$

$$U = U1 + [(26-P)/2]$$

$$V0 = -1917.1 + 61.604U - .70348U^2 + .0035661U^3 - (6.6578E-6)U^4$$

$$V1 = 76.824 - 2.4517U + .028779U^2 - (1.4753E-4)U^3 + (2.7872E-7)U^4$$

$$V2 = -.72239 + .023415U - (2.798E-4)U^2 + (1.4596E-6)U^3 - (2.807E-9)U^4$$

$$V3 = V0 + V1(R) + V2(R)^2$$

MAXIMUM REFUSAL SPEED PROGRAM

$$B0 = -43.01 + 6.761G - .35159G^2 + .0080545G^3 - (6.7769E-5)G^4$$

$$B1 = 26.312 - 3.8382G + .20326G^2 - .047022G^3 + (3.994E-5)G^4$$

$$B2 = -4.9639 + .72723G - .038721G^2 + (8.985E-4)G^3 - (7.638E-6)G^4$$

$$B3 = .30288 - .044855G - .0023921G^2 - (5.5549E-5)G^3$$
$$+ (4.7217E-7)G^4$$

$$R = B0 + B1(E) + B2(E)^2 + B3(E)^3$$

$$B0 = -11.412 + 62.185L - 9.0037L^2 + .64921L^3 - .017455L^4$$

$$B1 = -.2811 - 4.2012L + .70377L^2 - .058693L^3 + .0017461L^4$$

$$M = B0 + B1(R)$$

OPTIMUM ENDURANCE ALTITUDE PROGRAM

$$B0 = 55.333 + .073076D - (9.7836E-4)D^2 + (3.5015E-6)D^3$$
$$- (3.9782E-9)D^4$$

$$B1 = -1.1 - (8.0597E-3)D + (8.0097E-5)D^2 - (2.8836E-7)D^3$$
$$+ (3.3032E-10)D^4$$

$$B2 = (6.6667E-3) + (1.2541E-4)D - (1.4039E-6)D^2$$

$$H = B0 + B1(G) + B2(G)^2$$

CRUISE CEILING PROGRAM

$$B0 = 85.118 - .29117D + .0030434D^2 - (1.2851E-5)D^3 + (1.6621E-8)D^4$$

$$B1 = -2.7877 + .025635D - (3.3063E-4)D^2 + (1.4162E-6)D^3$$
$$- (1.8343E-9)D^4$$

$$B2 = .063327 - (8.5289E-4)D + (1.0814E-5)D^2 - (4.6514E-8)D^3$$
$$+ (6.0606E-11)D^4$$

$$B3 = -(6.0468E-4) + (9.0826E-6)D - (1.143E-7)D^2 + (4.9304E-10)D^3$$
$$- (6.4567E-13)D^4$$

$$H = B0 + (B1)G + (B2)G^2 + (B3)G^3$$

APPENDIX D

HP-9830 Programs and Lists of Variables

```
1 REM THIS PROGRAM CALCULATES THE FUEL FLOW AND LBFUEL/NAUTICAL MILE FOR AN
2 REM A-7E FLYING A LOW LEVEL MISSION AND IS DEPENDENT ON 4 VARIABLES --
3 REM GROSS WEIGHT,DRAG COUNT,MACH NUMBER, AND TEMPERATURE(CENTIGRADE)
10 PRINT "ENTER GROSS WT,DRAG CT, MACH #, AND TEMP(CENT)"
11 PRINT
12 PRINT
20 INPUT G,D,M,T
49 G=G/1000
50 M1=0.38813+0.0042981*G
54 GOSUB 800
56 I=0
58 GOSUB 600
60 S2=S
70 IF S1>S2 THEN 100
90 S=S2
95 GOTO 300
100 I=1
110 GOSUB 600
120 S3=S
130 IF S1<S3 THEN 200
140 S2=S3
150 I=I+1
160 GOSUB 600
170 GOTO 120
200 I1=(S1-S2)/(S3-S2)
210 M1=M
220 I=I-1+I1
221 I=INT(I)
222 GOSUB 600
223 S2=S
224 I=I+1
225 GOSUB 600
226 S3=S
227 S=S2+(I1*(S3-S2))
240 GOTO 300
285 PRINT
286 PRINT
300 R=S+2*(4.3732E-03+0.027743*D)*M↑2
301 R3=R
302 R1=2*INT(R/2)
304 R2=R1+2
306 J=1
308 IF J=2 THEN 311
309 R=R1
310 GOTO 319
311 R=R2
319 B0=5.6253-1.989*R+3.0252*R↑2-1.0761*R↑3+0.17675*R↑4
320 B0=B0-0.013095*R↑5+3.526E-04*R↑6
330 B1=205.3012-248.9317*R+91.66355*R↑2-15.55218*R↑3+1.224432*R↑4
340 B1=B1-0.0395333*R↑5+2.896385E-04*R↑6
350 B2=-1052.123+1231.24*R-487.4233*R↑2+91.6522*R↑3-8.662962*R↑4+0.3953974*R↑5
360 B2=B2-0.006905535*R↑6
370 B3=1680.142-1950.139*R+788.8513*R↑2-152.5733*R↑3+15.03819*R↑4
380 B3=B3-0.7274139*R↑5+0.013707*R↑6
390 B4=-864.6875+1000.443*R-408.7451*R↑2+80.08314*R↑3-8.03958*R↑4
400 B4=B4+0.3982527*R↑5-7.720617E-03*R↑6
430 N=B0+B1*M+B2*M↑2+B3*M↑3+B4*M↑4
440 IF J=2 THEN 480
450 N1=N
```

```
455 J=2
460 GOTO 311
475 R=2
480 N2=N
490 N=N1+(N2-N1)*(R3-R1)/2
500 REM       COMPLETED CALCULATION OF INTERMEDIATE # BY LINEAR INTERPOLATION
510 P=4.9746*N+7.9043E-06*N↑2
520 N4=(6.4375+0.010426*T-6.8925E-06*T↑2+4.9127E-07*T↑3)*M
530 F=(0.1*N4*P)*1000
539 F=INT(F)
540 PRINT "GROSS WT="G*1000
541 PRINT "TS="S"DC="D"M="M
542 PRINT "TEMP="T
543 PRINT "REF #="R3
544 PRINT "N="N
545 PRINT "LBFUEL/NM="P
550 PRINT "FUEL FLOW=  "F
551 PRINT
555 GOTO 10
600 B0=22.819-31.734*I+41.33*I↑2-5.0953*I↑3
610 B1=-154.98+217.51*I-261.73*I↑2+35.905*I↑3
620 B2=405.08-525.56*I+607.49*I↑2-88.737*I↑3
630 B3=-445.62+542.98*I-611.55*I↑2+92.894*I↑3
640 B4=184.78-204.42*I+225.89*I↑2-35.189*I↑3
650 S=B0+B1*M1+B2*M1↑2+B3*M1↑3+B4*M1↑4
660 RETURN
800 A0=-2.3287-0.26316*D+0.0073327*D↑2-7.513E-05*D↑3+3.5396E-07*D↑4
810 A0=A0-7.78E-10*D↑5+6.4624E-13*D↑6
820 A1=4.835+1.0956*D-0.030653*D↑2+3.1912E-04*D↑3-1.5276E-06*D↑4
830 A1=A1+3.408E-09*D↑5-2.8692E-12*D↑6
840 A2=10.284-1.0719*D+0.031094*D↑2-3.2878E-04*D↑3+1.595E-06*D↑4
850 A2=A2-3.6009E-09*D↑5+3.0634E-12*D↑6
860 S1=A0+A1*M1+A2*M1↑2
870 RETURN
880 END
```

List of Variables for Program 1

Variable	Definition
G	Gross weight (lbs.)
D	Drag count
T	Temperature (°C)
M	Mach number
M1	Result of lower graph, Figure B1
I	Guidelines, numbered top to bottom consecutively
S	Transfer Scale calculated as function of I
S1	Transfer Scale calculated as function of D
S2	Transfer Scale calculated for upper guideline
S3	Transfer Scale calculated for lower guideline
I1	Relative Transfer Scale location between guidelines
R,R3	Reference number
R1	Even reference number below actual reference number
R2	Even reference number above actual reference number
J	Integer counter
N	Result of lower graph, Figure B3
N1	Result of lower graph, Figure B3 for R1
N2	Result of lower graph, Figure B3 for R2
N4	Result of lower graph, Figure B4
A0,B0, A1,B1	Coefficients
A2,B2, B3,B4	Coefficients
P	Pounds of fuel per nautical mile
F	Fuel flow

Program 2

```
1 REM  THIS PROGRAM CALCULATES THE TAKEOFF DISTANCE REQUIRED FOR AN A-7E
2 REM  IT IS DEPENDENT ON 9 VARIABLES --
3 REM  GROSS WEIGHT,RNWY ALTITUDE,TEMP,DRAG COUNT,RELATIVE HUMIDITY,WINDS
4 REM  RNWY SLOPE,CENTER OF GRAVITY LOCATION,FLAPS, AND DOUBLE DATUM STATUS
9 PRINT "INPUT ALT,TEMP,DC,GW"
10 INPUT A,B,D,G
11 I=50
12 L=10
13 N=1
14 P=27
20 R=25
100 B0=13.086-0.00017113*A-2.0655E-07*A↑2+3.6861E-11*A↑3
101 B0=B0-2.4156E-15*A↑4
110 B1=-0.045635-7.8931E-06*A+3.7545E-09*A↑2
111 B1=B1-9.7088E-13*A↑3+6.997E-17*A↑4
120 B2=-0.001317-8.2558E-07*A+4.0739E-10*A↑2
121 B2=B2-8.548E-14*A↑3+5.4964E-18*A↑4
130 B3=-1.9097E-05+1.3671E-08*A-9.4694E-12*A↑2+2.0434E-15*A↑3
140 B3=B3-1.4617E-19*A↑4
150 C=B0+B1*B+B2*B↑2+B3*B↑3
160 IF D=1 THEN 190
170 E=0.54178+0.65876*C
180 GOTO 200
190 E=1.9773+0.56598*C
200 G0=-4.8896E+05+8.4974E+01*G-5.7856E-03*G↑2+1.9373E-07*G↑3-3.1744E-12*G↑4
210 G0=G0+2.0446E-17*G↑5
220 G1=5.8621E+04-1.0146E+01*G+6.8807E-04*G↑2-2.292E-08*G↑3+3.7387E-13*G↑4
230 G1=G1-2.3964E-18*G↑5
240 H=G0+G1*E
250 J=0
260 IF I<40 THEN 280
270 J=(I-40)/1000
280 K=H*J+H
285 IF L=0 THEN 340
290 L0=6.7124E+01+8.9509E-01*K+2.3306E-05*K↑2-1.6254E-09*K↑3+3.3728E-14*K↑4
300 L1=-9.0995-1.0856E-02*K+2.1754E-07*K↑2-2.5327E-11*K↑3+1.197E-15*K↑4
310 L2=1.4782E-01-2.1666E-06*K+3.4274E-09*K↑2-2.7817E-13*K↑3+9.3077E-18*K↑4
320 M=L0+L1*L+L2*L↑2
330 GOTO 350
340 M=K
350 X0=4.5704E+01+9.3429E-01*M+2.2265E-05*M↑2-2.338E-09*M↑3+7.941E-14*M↑4
360 X1=7.9472+1.4914E-02*M+9.0708E-06*M↑2-7.1235E-10*M↑3+3.0684E-14*M↑4
370 X2=5.3616-8.5136E-03*M+3.5914E-06*M↑2-4.5932E-10*M↑3+1.9889E-14*M↑4
380 X=X0+X1*N+X2*N↑2
390 Q0=2.6042E+03-2.1694*X+1.0915E-03*X↑2-1.1119E-07*X↑3+3.662E-12*X↑4
400 Q1=-1.7573E+02+2.2601E-01*X-7.5225E-05*X↑2+7.7018E-09*X↑3-2.5437E-13*X↑4
410 Q2=2.8549-4.0102E-03*X+1.2832E-06*X↑2-1.3234E-10*X↑3+4.3908E-15*X↑4
420 Q=Q0+Q1*P+Q2*P↑2
430 S0=-4.0079E+02+1.5801*Q-2.0254E-04*Q↑2+2.4111E-08*Q↑3-8.6737E-13*Q↑4
440 S1=1.6196E+01-2.4333E-02*Q+9.3484E-06*Q↑2-1.2594E-09*Q↑3+4.7522E-14*Q↑4
450 S2=-1.4758E-01+2.359E-04*Q-1.037E-07*Q↑2+1.6016E-11*Q↑3-6.3195E-16*Q↑4
460 S=S0+S1*R+S2*R↑2
470 S=INT(S)
479 PRINT "            FOR"
480 PRINT "GW="G"  ALT="A"  TEMP="B"  DC="D"RH="I"HDWD="L
482 PRINT "RNWY SLP="N"%   CEN GRAV="P"FLAPS="R
483 PRINT
530 PRINT "TAKEOFF ROLL DIST="S
531 GOTO 9
532 END
```

List of Variables for Program 2

Variable	Definition
A	Runway Altitude (feet)
B	Temperature (°C)
D	Double datum status (1 indicates "with")
G	Gross weight (lbs.)
I	Relative humidity (%)
L	Headwind (kts.)
N	Runway slope (%)
P	Center of gravity (%)
R	Flap position (degrees)
C	Result of upper graph, Figure B5
E	Takeoff factor
H	Unadjusted ground roll distance, Figure B6
J	Adjustment factor due to relative humidity
K	Ground roll distance (GRD) adjusted for relative humidity
M	GRD adjusted for wind
X	GRD adjusted for runway slope
Q	GRD adjusted for the center of gravity location
S	True GRD (also adjusted for flap position)
B0,G0,L0, X0,Q0	Coefficients
B1,G1,L1, X1,Q1	Coefficients
B2,G2,L2, X2,Q2	Coefficients
B3,S0, S1,S2	Coefficients

Program 3

```
1 REM  THIS PROGRAM CALCULATES THE A-7E MAXIMUM RANGE'AIRSPEED AND
2 REM  TIME OF FLIGHT AND IS DEPENDENT ON  6 VARIABLES --
3 REM  GROSS WEIGHT,ALTITUDE,DRAG COUNT,TEMPERATURE,WINDS, AND DISTANCE
9 PRINT "INPUT GW,ALT,DC,TEMP(*C),HDWD,DISTANCE"
10 INPUT G,H,D,T,L,D1
30 G=G/1000
40 H=H/1000
50 A0=-1+5.0794E-03*H-1.3968E-03*H↑2-3.4912E-06*H↑3+7.9365E-08*H↑4
60 A1=0.05+0.0015159*H+1.123E-04*H↑2-3.4921E-06*H↑3+7.9365E-08*H↑4
70 N=A0+A1*G
80 B0=0.47803-0.0013417*D+6.2287E-06*D↑2-1.6261E-08*D↑3+1.6438E-11*D↑4
85 B1=0.08217+4.1209E-04*D-4.5577E-06*D↑2+1.6777E-08*D↑3-2.001E-11*D↑4
90 B2=4.2143E-04-9.4397E-05*D+1.2646E-06*D↑2-4.8537E-09*D↑3+5.7222E-12*D↑4
95 B3=-6.6767E-04+8.4671E-06*D-1.0501E-07*D↑2+3.6382E-10*D↑3-3.7828E-13*D↑4
100 M=B0+B1*N+B2*N↑2+B3*N↑3
110 M=M-(((60-T)*2*M)/(10*120))
120 V=710*(M-0.14)+100-L
130 T1=D1/V
135 V=INT(V)
140 PRINT
150 PRINT "FOR"
160 PRINT "GW="G"  ALT="H"  DC="D"TEMP="T"  HDWD="L"DIST="D1
161 PRINT
162 PRINT "GROUND SPEED="V"     TIME OF FLIGHT="T1
170 END
```

List of Variables for Program 3

Variable	Definition
G	Gross weight (lbs.)
H	Altitude (ft.)
D	Drag count
T	Temperature (°C)
L	Headwind (kts.)
D1	Distance to fly
N	Result of first chart, Figure B8
M	Cruise Mach number (adjusted and unadjusted for T)
V	Ground speed (kts.)
T1	Time of flight
A0,B0	Coefficients
A1,B1	Coefficients
B3	Coefficient

Program 4

```
10 REM      THIS PROGRAM CALCULATES  FUEL REQUIRED FOR MAX RANGE AT CONSTANT
11 REM  ALTITUDE FOR AN A-7E AND IS DEPENDENT ON 5 VARIABLES --
12 REM  GROSS WEIGHT,ALTITUDE,DRAG COUNT,TRUE AIRSPEED, AND TIME(MINUTES)
20 PRINT "ENTER GROSS WT,ALT,DRAG CT,TAS,TIME(MINUTES)"
21 PRINT
22 PRINT
30 INPUT G,A,D,V,T
35 PRINT "GROSS WT="G
36 PRINT "ALTITUDE="A
37 PRINT "DRAG COUNT="D
38 PRINT "TRUE AIRSPEED="V
39 PRINT "TIME OF FLIGHT="T
40 G=G/1000
50 A=A/1000
60 B0=4.54-0.16444*A+0.0033932*A↑2-1.0283E-04*A↑3+1.926E-06*A↑4-1.3757E-08*A↑5
70 B1=-3.6664E-03*A+8.9338E-04*A↑2-5.5939E-05*A↑3+1.4593E-06*A↑4-1.3281E-08*A↑5
80 B2=6E-04+1.1203E-04*A-2.3358E-05*A↑2+1.4536E-06*A↑3-3.7144E-08*A↑4
85 B2=B2+3.3334E-10*A↑5
90 N=B0+B1*G+B2*G↑2
100 A0=-2.5399E-03*D+9.7299E-05*D↑2-2.3516E-07*D↑3+1.4251E-10*D↑4
110 A1=2+4.2388E-03*D+1.2326E-05*D↑2-1.0298E-07*D↑3+1.7277E-10*D↑4
120 L=A0+A1*N
130 F=L*V
140 R=F*T/60
141 L=(INT(L*1000))/1000
142 F=INT(F)
143 R=INT(R)
147 PRINT
148 PRINT
150 PRINT "LBFUEL/NM="L"FUEL FLOW="F
155 PRINT "FUEL REQUIRED="R
156 PRINT
157 PRINT
160 GOTO 20
170 END
```

List of Variables for Program 4

Variable	Definition
G	Gross weight (lbs.)
A	Altitude (ft.)
D	Drag count
V	True airspeed (kts.)
T	Time of flight (minutes)
N	Result of first chart, Figure B9
L	Pounds of fuel per nautical mile
F	Fuel flow
R	Fuel required
B0,A0	Coefficients
B1,A1	Coefficients
B2	Coefficient

Program 5

```
1 REM  THIS PROGRAM CALCULATES THE CLIMB AIRSPEED OF AN A-7E
2 REM  (INDICATED AIRSPEED BELOW 20,000')
3 REM  (MACH NUMBER ABOVE 20,000')
10 D=0
12 PRINT "CLIMB AIRSPEED SCHEDULE"
15 PRINT "DRAG CT      CLIMB AIRSPEED   CLIMB MACH"
16 PRINT "            (IAS TO 20000')  (ABOVE 20000')"
20 S=403.56-0.79075*D+0.0011382*D↑2-4.1018E-07*D↑3
21 S=INT(S)
30 M=0.86-2.1634E-03*D+7.6582E-05*D↑2-1.1344E-06*D↑3+7.2125E-09*D↑4-2.3035E-11*D
40 M=M+3.6588E-14*D↑6-2.3062E-17*D↑7
42 M=M*1000
44 M=INT(M)
46 M=M/1000
55 PRINT D,S,M
60 D=D+30
70 IF D<310 THEN 20
80 END
```

List of Variables for Program 5

Variable	Definition
D	Drag count
M	Mach number
S	Calibrated airspeed (kts.)

Program 6

```
400 REM  THIS PROGRAM CALCULATES THE TAKEOFF AIRSPEED OF AN A-7E
401 REM  UNDER VARYING  GROSS WEIGHTS, FLAP POSITIONS,
402 REM  AND CENTER OF GRAVITY LOCATIONS
498 R=20
499 P=20
500 G=20000
501 PRINT "FOR GROSS WEIGHT="G
502 PRINT
503 PRINT
504 PRINT "FLAPS            CG        TAKEOFF AIRSPEED"
530 U1=5.4023E+01+3.4787E-03*G-1.9475E-08*G↑2
540 U=U1+(26-P)/2
550 V0=-1.9171E+03+6.1604E+01*U-7.0348E-01*U↑2+3.5661E-03*U↑3-6.6578E-06*U↑4
560 V1=7.6824E+01-2.4517*U+2.8779E-02*U↑2-1.4753E-04*U↑3+2.7872E-07*U↑4
570 V2=-7.2239E-01+2.3415E-02*U-2.798E-04*U↑2+1.4596E-06*U↑3-2.807E-09*U↑4
580 V3=V0+V1*R+V2*R↑2
590 V4=INT(V3)
600 PRINT R,P,V4
610 R=R+5
620 IF R>40 THEN 630
625 GOTO 530
630 P=P+3
631 R=20
635 IF P>35 THEN 650
640 GOTO 530
650 G=G+3000
651 R=20
652 P=20
655 PRINT
656 PRINT
657 PRINT
660 PRINT "FOR GROSS WEIGHT="G
662 PRINT
663 PRINT
669 IF G>42000 THEN 710
670 GOTO 530
710 END
```

List of Variables for Program 6

Variable	Definition
R	Flap position (degrees)
P	Center of gravity (%)
G	Gross weight (lbs.)
U1	Unadjusted takeoff airspeed
U	Takeoff airspeed adjusted for center of gravity
V4	Actual takeoff airspeed (adjusted for flap position)
V0,V1, V2,V3	Coefficients

Program 7

```
1 REM  THIS PROGRAM CALCULATES THE MAXIMUM REFUSAL SPEED
2 REM  FOR AN A-7E USING ANTI-SKID
3 REM  IT  IS DEPENDENT ON 5 VARIABLES --
4 REM  GROSS WEIGHT,TEMP,RNWY LENGTH,RNWY ALTITUDE, AND DOUBLE DATUM STATUS
9 PRINT "INPUT ALT,TEMP,RNWY LTH,GW,DOUBLE DATUM"
10 INPUT A,B,L,G,D
15 G=G/1000
20 L=L/1000
70 PRINT "ALTITUDE="A
71 PRINT "TEMP="B
72 PRINT "RNWY LTH="L*1000
73 PRINT "GROSS WT="G*1000
75 PRINT "DD="D
100 B0=13.086-0.00017113*A-2.0655E-07*A↑2+3.6861E-11*A↑3
101 B0=B0-2.4156E-15*A↑4
110 B1=-0.045635-7.8931E-06*A+3.7545E-09*A↑2
111 B1=B1-9.7088E-13*A↑3+6.997E-17*A↑4
120 B2=-0.001317-8.2558E-07*A+4.0739E-10*A↑2
121 B2=B2-8.548E-14*A↑3+5.4964E-18*A↑4
130 B3=-1.9097E-05+1.3671E-08*A-9.4694E-12*A↑2+2.0434E-15*A↑3
140 B3=B3-1.4617E-19*A↑4
150 C=B0+B1*B+B2*B↑2+B3*B↑3
160 IF D=1 THEN 190
170 E=0.54178+0.65876*C
180 GOTO 200
190 E=1.9773+0.56598*C
200 B0=-43.01+6.761*G-0.35159*G↑2+0.0080545*G↑3-6.7769E-05*G↑4
210 B1=26.312-3.8382*G+0.20326*G↑2-0.0047022*G↑3+3.994E-05*G↑4
220 B2=-4.9639+0.72723*G-0.038721*G↑2+8.985E-04*G↑3-7.638E-06*G↑4
230 B3=0.30288-0.044855*G+0.0023921*G↑2-5.5549E-05*G↑3+4.7217E-07*G↑4
240 R=B0+B1*E+B2*E↑2+B3*E↑3
250 B0=-11.412+62.185*L-9.0037*L↑2+0.64921*L↑3-0.017455*L↑4
260 B1=-0.2811-4.2012*L+0.70377*L↑2-0.058693*L↑3+0.0017461*L↑4
270 M=B0+B1*R
271 M=INT(M)
272 PRINT
275 PRINT "   TAKEOFF FACTOR  ="E
276 PRINT
280 PRINT "MAX REFUSAL SPEED =  ",M
281 PRINT
290 GOTO 9
300 END
```

List of Variables for Program 7

Variable	Definition
A	Runway Altitude (ft.)
B	Temperature (°C)
L	Runway length (ft.)
G	Gross weight (lbs.)
D	Double datum status (1 indicates "with")
C	Result of upper chart, Figure B5
E	Takeoff factor
R	Result of first chart, Figure B12
M	Maximum refusal speed (kts.)
B0,B1, B2,B3	Coefficients

Program 8

```
1 REM  THIS PROGRAM CALCULATES THE OPTIMUM ENDURANCE ALTITUDE
2 REM  OF AN A-7E AT VARYING GROSS WEIGHTS AND DRAG COUNTS
4 DIM B[3]
5 G=19
6 D=0
10 PRINT "OPTIMUM ENDURANCE ALT "
20 PRINT "GROSS WT    DRAG CT              OPT END ALT"
50 G=G+3
80 B[3]=55.333+0.073076*D-9.7836E-04*D↑2+3.5015E-06*D↑3-3.9782E-09*D↑4
90 B[1]=-1.1-8.0597E-03*D+8.0097E-05*D↑2-2.8836E-07*D↑3+3.3032E-10*D↑4
100 B[2]=6.6667E-03+1.2541E-04*D-1.4039E-06*D↑2+5.2032E-09*D↑3-6.0218E-12*D↑4
110 H=B[3]+B[1]*G+B[2]*G↑2
115 Z=INT(H*1000)
118 X=G*1000
119 PRINT X,D,Z
120 D=D+30
121 IF D<310 THEN 80
122 D=0
123 IF G<45 THEN 50
140 END
```

List of Variables for Program 8

Variable	Definition
G	Gross weight (lbs. times 1000)
D	Drag count
H	Optimum endurance altitude (ft.)
Z	Optimum endurance altitude (integer format)
X	Gross weight (lbs.)
B1,B2,B3	Coefficients

Program 9

```
1 REM  THIS PROGRAM CALCULATES THE CRUISE CEILING OF AN A-7E
2 REM  UNDER VARYING GROSS WEIGHTS AND DRAG COUNTS
4 DIM B[4]
5 G=19
6 D=0
10 PRINT "CRUISE CEILING"
20 PRINT "GROSS WT    DRAG CT            CRUISE CEILING"
50 G=G+3
80 B[4]=85.118-0.29117*D+0.0030434*D↑2-1.2851E-05*D↑3+1.6621E-08*D↑4
90 B[1]=-2.7877+0.025635*D-3.3063E-04*D↑2+1.4162E-06*D↑3-1.8343E-09*D↑4
100 B[2]=0.063327-8.5289E-04*D+1.0814E-05*D↑2-4.6514E-08*D↑3+6.0606E-11*D↑4
105 B[3]=-6.0468E-04+9.0826E-06*D-1.143E-07*D↑2+4.9304E-10*D↑3-6.4567E-13*D↑4
110 H=B[4]+B[1]*G+B[2]*G↑2+B[3]*G↑3
115 Z=INT(H*1000)
118 X=G*1000
119 PRINT X,D,Z
120 D=D+30
121 IF D<310 THEN 80
122 D=0
123 IF G<45 THEN 50
140 END
```

List of Variables for Program 9

Variable	Definition
G	Gross weight (lbs. times 1000)
D	Drag count
H	Cruise ceiling (ft.)
Z	Cruise ceiling (integer format)
X	Gross weight (lbs.)
B1,B2, B3,B4	Coefficients

APPENDIX E

TI-59 Programs and User Information

USER INFORMATION FOR PROGRAM 1

Program: Low Level Cruise Performance

Number of Steps: 1386

Computation Time: 90-110 seconds

STEP	ENTER	PRESS KEY	DISPLAY
1	gross weight (lbs.)	A	gross weight/1000
2	drag count	C	drag count
3	mach number	D	mach number
4	temperature (°C)	E	Transfer Scale
5	---	R/S	Unusable number
6	read in cards 3 & 4	-	---
7	drag count	C	Transfer Scale
8	mach number	D	mach number
9	temperature (°C)	E	lb.fuel/nautical mile
10	---	R/S	fuel flow

000	76	LBL
001	11	A
002	55	÷
003	01	1
004	00	0
005	00	0
006	00	0
007	95	=
008	42	STO
009	00	00
010	91	R/S
011	76	LBL
012	12	B
013	55	÷
014	01	1
015	00	0
016	00	0
017	00	0
018	95	=
019	42	STO
020	01	01
021	91	R/S
022	76	LBL
023	13	C
024	42	STO
025	02	02
026	91	R/S
027	76	LBL
028	14	D
029	42	STO
030	03	03
031	91	R/S
032	76	LBL
033	15	E
034	42	STO
035	04	04
036	53	(
037	93	.
038	03	3
039	08	8
040	08	8
041	01	1
042	03	3
043	85	+
044	93	.
045	00	0
046	00	0
047	04	4
048	02	2
049	09	9
050	08	8
051	01	1
052	65	×
053	43	RCL
054	00	00
055	95	=
056	42	STO
057	05	05
058	25	CLR
059	75	-
060	53	(
061	02	2
062	93	.
063	03	3
064	02	2
065	08	8
066	07	7
067	85	+
068	93	.
069	02	2
070	06	6
071	03	3
072	01	1
073	06	6
074	65	×
075	43	RCL
076	02	02
077	75	-
078	93	.
079	00	0
080	00	0
081	07	7
082	03	3
083	03	3
084	02	2
085	07	7
086	65	×
087	43	RCL
088	02	02
089	33	X^2
090	85	+
091	07	7
092	93	.
093	05	5
094	01	1
095	03	3
096	52	EE
097	94	+/-
098	05	5
099	65	×
100	43	RCL
101	02	02
102	45	Y^X
103	03	3
104	75	-
105	03	3
106	93	.
107	05	5
108	03	3
109	09	9
110	06	6
111	52	EE
112	94	+/-
113	07	7
114	65	×
115	43	RCL
116	02	02
117	45	Y^X
118	04	4
119	85	+
120	07	7
121	93	.
122	07	7
123	08	8
124	52	EE
125	94	+/-
126	01	1
127	00	0
128	65	×
129	43	RCL
130	02	02
131	45	Y^X
132	05	5
133	75	-
134	06	6
135	93	.
136	04	4
137	06	6
138	02	2
139	04	4
140	52	EE
141	94	+/-
142	01	1
143	03	3
144	65	×
145	43	RCL
146	02	02
147	45	Y^X
148	06	6
149	54	)

150	85	+	200	06	6	250	04	4
151	53	(	201	52	EE	251	75	-
152	04	4	202	94	+/-	252	01	1
153	93	.	203	06	6	253	93	.
154	08	8	204	65	×	254	00	0
155	03	3	205	43	RCL	255	07	7
156	05	5	206	02	02	256	01	1
157	85	+	207	45	Y^x	257	09	9
158	01	1	208	04	4	258	65	×
159	93	.	209	85	+	259	43	RCL
160	00	0	210	03	3	260	02	02
161	09	9	211	93	.	261	85	+
162	05	5	212	04	4	262	93	.
163	06	6	213	00	0	263	00	0
164	65	×	214	08	8	264	03	3
165	43	RCL	215	52	EE	265	01	1
166	02	02	216	94	+/-	266	00	0
167	75	-	217	09	9	267	09	9
168	93	.	218	65	×	268	04	4
169	00	0	219	43	RCL	269	65	×
170	03	3	220	02	02	270	43	RCL
171	00	0	221	45	Y^x	271	02	02
172	06	6	222	05	5	272	33	X^2
173	05	5	223	75	-	273	75	-
174	03	3	224	02	2	274	03	3
175	65	×	225	93	.	275	93	.
176	43	RCL	226	08	8	276	02	2
177	02	02	227	06	6	277	08	8
178	33	X^2	228	09	9	278	07	7
179	85	+	229	02	2	279	08	8
180	03	3	230	52	EE	280	52	EE
181	93	.	231	94	+/-	281	94	+/-
182	01	1	232	01	1	282	04	4
183	09	9	233	02	2	283	65	×
184	01	1	234	65	×	284	43	RCL
185	02	2	235	43	RCL	285	02	02
186	52	EE	236	02	02	286	45	Y^x
187	94	+/-	237	45	Y^x	287	03	3
188	04	4	238	06	6	288	85	+
189	65	×	239	54	)	289	01	1
190	43	RCL	240	65	×	290	93	.
191	02	02	241	43	RCL	291	05	5
192	45	Y^x	242	05	05	292	09	9
193	03	3	243	85	+	293	05	5
194	75	-	244	53	(	294	52	EE
195	01	1	245	01	1	295	94	+/-
196	93	.	246	00	0	296	06	6
197	05	5	247	93	.	297	65	×
198	02	2	248	02	2	298	43	RCL
199	07	7	249	08	8	299	02	02

Step	Code	Key
300	45	Y^X
301	04	4
302	75	-
303	03	3
304	93	.
305	06	6
306	00	0
307	00	0
308	09	9
309	52	EE
310	94	+/-
311	09	9
312	65	×
313	43	RCL
314	02	02
315	45	Y^X
316	05	5
317	85	+
318	03	3
319	93	.
320	00	0
321	06	6
322	03	3
323	04	4
324	52	EE
325	94	+/-
326	01	1
327	02	2
328	65	×
329	43	RCL
330	02	02
331	45	Y^X
332	06	6
333	54	)
334	65	×
335	43	RCL
336	05	05
337	33	X^2
338	95	=
339	42	STO
340	06	06
341	25	CLR
342	42	STO
343	07	07
344	71	SBR
345	04	04
346	43	43
347	42	STO
348	08	08
349	32	X:T
350	43	RCL
351	06	06
352	22	INV
353	77	GE
354	03	03
355	88	88
356	01	1
357	42	STO
358	07	07
359	71	SBR
360	04	04
361	43	43
362	42	STO
363	09	09
364	32	X:T
365	43	RCL
366	06	06
367	22	INV
368	77	GE
369	04	04
370	01	01
371	43	RCL
372	09	09
373	42	STO
374	08	08
375	43	RCL
376	07	07
377	85	+
378	01	1
379	95	=
380	42	STO
381	07	07
382	71	SBR
383	04	04
384	43	43
385	61	GTO
386	03	03
387	62	62
388	43	RCL
389	03	03
390	42	STO
391	05	05
392	71	SBR
393	04	04
394	43	43
395	42	STO
396	05	05
397	61	GTO
398	06	06
399	68	68
400	00	0
401	53	(
402	43	RCL
403	06	06
404	75	-
405	43	RCL
406	08	08
407	54	)
408	55	÷
409	53	(
410	43	RCL
411	09	09
412	75	-
413	43	RCL
414	08	08
415	54	)
416	95	=
417	42	STO
418	00	00
419	43	RCL
420	03	03
421	42	STO
422	05	05
423	43	RCL
424	07	07
425	75	-
426	01	1
427	85	+
428	43	RCL
429	00	00
430	95	=
431	42	STO
432	07	07
433	71	SBR
434	04	04
435	43	43
436	42	STO
437	05	05
438	61	GTO
439	06	06
440	68	68
441	00	0
442	00	0
443	02	2
444	02	2
445	93	.
446	08	8
447	01	1
448	09	9
449	75	-

450	03	3
451	01	1
452	93	.
453	07	7
454	03	3
455	05	5
456	65	×
457	43	RCL
458	07	07
459	85	+
460	04	4
461	01	1
462	93	.
463	03	3
464	03	3
465	65	×
466	43	RCL
467	07	07
468	33	X^2
469	75	-
470	05	5
471	93	.
472	00	0
473	09	9
474	05	5
475	03	3
476	65	×
477	43	RCL
478	07	07
479	45	Y^X
480	03	3
481	75	-
482	53	(
483	01	1
484	05	5
485	04	4
486	93	.
487	09	9
488	08	8
489	75	-
490	02	2
491	01	1
492	07	7
493	93	.
494	05	5
495	01	1
496	65	×
497	43	RCL
498	07	07
499	85	+
500	02	2
501	06	6
502	01	1
503	93	.
504	07	7
505	03	3
506	65	×
507	43	RCL
508	07	07
509	33	X^2
510	75	-
511	03	3
512	05	5
513	93	.
514	09	9
515	00	0
516	05	5
517	65	×
518	43	RCL
519	07	07
520	45	Y^X
521	03	3
522	54	)
523	65	×
524	43	RCL
525	05	05
526	85	+
527	53	(
528	04	4
529	00	0
530	05	5
531	93	.
532	00	0
533	08	8
534	75	-
535	05	5
536	02	2
537	05	5
538	93	.
539	05	5
540	06	6
541	65	×
542	43	RCL
543	07	07
544	85	+
545	06	6
546	00	0
547	07	7
548	93	.
549	04	4
550	09	9
551	65	×
552	43	RCL
553	07	07
554	33	X^2
555	75	-
556	08	8
557	08	8
558	93	.
559	07	7
560	03	3
561	07	7
562	65	×
563	43	RCL
564	07	07
565	45	Y^X
566	03	3
567	54	)
568	65	×
569	43	RCL
570	05	05
571	33	X^2
572	75	-
573	53	(
574	04	4
575	04	4
576	05	5
577	93	.
578	06	6
579	02	2
580	75	-
581	05	5
582	04	4
583	02	2
584	93	.
585	09	9
586	08	8
587	65	×
588	43	RCL
589	07	07
590	85	+
591	06	6
592	01	1
593	01	1
594	93	.
595	05	5
596	05	5
597	65	×
598	43	RCL
599	07	07

600	33	X^2
601	75	-
602	09	9
603	02	2
604	93	.
605	08	8
606	09	9
607	04	4
608	65	×
609	43	RCL
610	07	07
611	45	Y^X
612	03	3
613	54	)
614	65	×
615	43	RCL
616	05	05
617	45	Y^X
618	03	3
619	85	+
620	53	(
621	01	1
622	08	8
623	04	4
624	93	.
625	07	7
626	08	8
627	75	-
628	02	2
629	00	0
630	04	4
631	93	.
632	04	4
633	02	2
634	65	×
635	43	RCL
636	07	07
637	85	+
638	02	2
639	02	2
640	05	5
641	93	.
642	08	8
643	09	9
644	65	×
645	43	RCL
646	07	07
647	33	X^2
648	75	-
649	03	3
650	05	5
651	93	.
652	01	1
653	08	8
654	09	9
655	65	×
656	43	RCL
657	07	07
658	45	Y^X
659	03	3
660	54	)
661	65	×
662	43	RCL
663	05	05
664	45	Y^X
665	04	4
666	95	=
667	92	RTN
668	91	R/S
669	32	X:T
670	91	R/S
671	00	0
000	76	LBL
001	13	C
002	42	STO
003	02	02
004	32	X:T
005	42	STO
006	05	05
007	91	R/S
008	76	LBL
009	14	D
010	42	STO
011	03	03
012	91	R/S
013	76	LBL
014	15	E
015	42	STO
016	04	04
017	25	CLR
018	00	0
019	00	0
020	00	0
021	00	0
022	00	0
023	00	0
024	00	0
025	00	0
026	00	0
027	00	0
028	00	0
029	00	0
030	00	0
031	00	0
032	00	0
033	00	0
034	00	0
035	00	0
036	53	(
037	04	4
038	93	.
039	03	3
040	07	7
041	03	3
042	02	2
043	52	EE
044	94	+/-
045	03	3
046	85	+
047	93	.
048	00	0
049	02	2
050	07	7
051	07	7
052	04	4
053	03	3
054	65	×
055	43	RCL
056	02	02
057	54	)
058	65	×
059	43	RCL
060	03	03
061	33	X^2
062	95	=
063	65	×
064	02	2
065	85	+
066	43	RCL
067	05	05
068	95	=
069	42	STO
070	06	06
071	55	÷
072	02	2
073	95	=
074	59	INT
075	75	-
076	43	RCL