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THESIS

EFFECTS OF WIND ON THE AIRCRAFT OPTIMUM CRUISE PERFORMANCE AND FLIGHT PERFORMANCE ADVISORY SYSTEMS FOR F-4E AND F-5E AIRCRAFT

by

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June 1982

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Effects of Wind on the Aircraft Optimum Cruise Performance and Flight Performance Advisory Systems for F-4E and F-5E Aircraft

by

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ABSTRACT

One of several fuel-saving operational concepts being investigated is the application of state-of-the-art hand-held calculators to serve as Flight Performance Advisory Systems (FPAS). The principal function of a FPAS is to advise the pilot, based on the aircraft drag configuration, and gross weight, of the optimum flight performance parameters such as altitude and airspeed. The research reported herein is the development of the mathematical relationships for the effects of the wind on the aircraft optimum cruise performance. This thesis also describes the operating procedure of a Hewlett-Packard HP-41CV hand-held calculator programmed to serve as an F-4E and F-5E Flight Performance Advisory System. The objective of the FPAS is to recommend optimal flight profiles to achieve maximum fuel conservation. Because of the constraints imposed by HP-41CV memory size, the F-4E FPAS is comprised of three programs, and the F-5E FPAS is comprised of a single program.

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I. INTRODUCTION

The total fuel cost for U.S. Navy aircraft alone in 1980 was $1 billion and is forecast to continue to rise as the supply of natural petroleum diminishes and the price per barrel increases. OPNAVINST 4100.5A of 9 May 1978 set the goal for aircraft energy consumption as "5 percent reduction in fossil fuel energy consumption per flight hour by the end of 1985, using 1975 as baseline".

Accordingly, the Naval Air Development Center (NADC) has been investigating candidate fuel savings modifications and operational concepts for a variety of naval aircraft. The goal of this investigation, undertaken as part of the Naval Material Command sponsored Navy Aircraft Fuel Conservation (NAFC) program, is to identify, develop, and incorporate selected aircraft modifications and/or operational concepts aimed at increasing aircraft energy efficiency (reducing fuel consumption per flight hour). One of several operational concepts being addressed by NADC is the use of hand-held calculators as a Flight Performance Advisory System (FPAS). The principal function of the FPAS is to advise the pilot of the altitude and the airspeed combination that will yield maximum flight efficiency in terms of fuel consumption. At present, such information is manually derived by tedious manipulation of NATOPS or Flight Manual charts thereby discouraging frequent in-flight optimization. It is expected that F-4E and F-5E FPAS will simplify the task of in-flight optimization, resulting in increased frequency of usage and improved accuracy.

The HP-41CV hand-held calculator [Ref. 1] was selected because of its relatively low cost and incorporation of the latest hand-held calculator technology including alphanumeric display and large random access memory (RAM). In addition, this calculator can be configured with a read-only memory (ROM) providing increased memory capability.

While sophisticated on-board computers used by the commercial airlines resulted in reported fuel-savings on the order of 4%-8% [Ref. 2: pp. 7] it is recognized that the military fighter community is unlikely to realize such high fuel-savings. However, it is believed that simple, low cost FPAS, such as a hand-held calculator, could assist the fighter pilot to achieve fuel-savings on the order of 1%-2% [Ref. 2: pp. 7]. The research on FPAS reported herein was undertaken in conjunction with an investigation and the development of mathematical relationships that can be used to obtain optimum aircraft ground specific range when flying with a head wind or tail wind. More specifically, a means is developed for computing best ground specific range (BGSR) for an aircraft operating in wind conditions and computing the best range Mach number (BRMN) under wind conditions.

II. TECHNICAL DISCUSSION - REGRESSION PROCEDURE

Formulas used in the FPAS programs were developed from the charts in the performance section of the F-4E and F-5E Dash 1 Flight Manual [Refs. 3 and 4]. A multiple linear regression was performed on data points selected from the appropriate Flight Manual charts.

The form of the linear regression is:

$$Y = \sum_{i=1}^{n} a_i X_i \tag{2-1}$$

Where a_i are constants and X_i are independent variables. The X_i can be powers of the independent variables; for example X_i could be DC squared where DC is drag count. Hence the regression uses a multivariable high order polynomial which allows numerous combinations of the independent variables (gross weight, drag count, temperature, etc.) to be used to form the regression.

The library programs available at the Naval Postgraduage School on the IBM 370/3033 computer system were used. The program used was MINITAB which was developed by Pond Laboratory at the Pennsylvania State University [Ref. 5: pp. 66]. Data are input in the form of independent and dependent variables for each point selected from a curve in the Flight Manual charts. Products of the independent variables and powers thereof can be defined in the program and used in the regression.

The first criterion used in selecting the best regression is the R-squared value. The definition of R-squared is given in [Ref. 5: pp. 72]. The R-squared value is a measure of how well the regression equation fits the data, with 100% indicating a perfect fit. As R-squared values approaches unity the regression has minimal error. The second criterion is the comparison between the actual dependent variable value and the value predicted from the regression formula. The final decision was made by assessing actual residual which equals predicted value subtracted from observed value.

III. EFFECTS OF WIND ON THE AIRCRAFT OPTIMUM CRUISE PERFORMANCE

A. INTRODUCTION

U.S. Naval Air Development Center was investigating several candidate fuel-saving aircraft modifications and operational concepts for the aircraft. In supporting the Navy Aircraft Fuel Conservation (NAFC) Program, Professor Allen E. Fuhs developed mathematical models for the wind effects on the aircraft optimum cruise performance [Ref. 6]. All the equations and algebra were lengthy, and the mathematical model was limited to a first order analysis.

Here, in this thesis, a mathematical model was developed with second order analysis. Once the functional relationships between the aircraft specific range with no wind and flight velocity are known, the best range Mach number and ground specific range with wind can be determined with this model.

The functional relationships of the aircraft specific range with or without wind and true airspeed can be found by computer program 'BICSAC' [Ref. 2: pp. 8], which was developed by Naval Air Development Center. Input data consists of tables containing lift coefficients, engine thrust vs. fuel flow, and drag counts. All of these data vary from aircraft to aircraft. The method used to calculate the effects of the wind on the aircraft specific range using probabilistic approach [Ref. 2], which was developed by Naval Air Development Center, was reasonable. However, mathematical models of the wind effect on the aircraft specific range was sought; the models highlight the important aircraft parameters influencing ground specific range.

Here the mathematical models of the wind effects on the aircraft specific range are derived and are used to calculate an example for a specific aircraft.

B. DERIVATION OF THE EQUATIONS

The equations were derived as follows: Specific Range is defined as NM/lbs. fuel:

$$SR = 0.592 \left(\frac{V}{W_f}\right) \tag{3-1}$$

where V is velocity in ft./sec. and W_f is fuel flow rate in pounds per second. The constant 0.592 converts ft./sec. to knots. Fuel flow rate (W_f) is multiplication of SFC and thrust:

$$W_f = (SFC)F \tag{3-2}$$

where F is thrust in pounds. The thrust is equal to drag in level flight profile and can be represented as follows:

$$F = D = \frac{W}{(L/D)} \tag{3-3}$$

where D is drag, W is aircraft gross weight in pounds, and L/D is lift/drag ratio. The effect of wind on ground specific range to be derived. Specific Range is defined as follows:

$$SR = \frac{V(L/D)}{(SFC)W} \tag{3-4}$$

where V is true airspeed in ft./sec., L/D is the lift/drag ratio for the aircraft, SFC is specific fuel consumption, and W is aircraft weight in pounds. Specific range, SR, is applicable only in the absence of wind. When the aircraft flys in a wind of velocity, V, the specific range becomes the ground specific range GSR which is

$$GSR = \frac{V_g(L/D)}{(SFC)W} = \left(\frac{V_g}{V}\right)SR \tag{3-5}$$

Where V_g is aircraft velocity relative to the ground. Specific range is a function of true airspeed and has a maximum value at the peak of the SR versus velocity curve. L/D and SFC are needed as functions of V.

1. Aerodynamics

Drag Coefficient is comprised of parasite drag and induced drag.

$$C_D = C_{D_0} + C_{D_i} \tag{3-6}$$

where C_{D_0} is defined as the drag coefficient without stores or lift. C_{D_i} is induced drag and is defined as follows:

$$C_{D_i} = \frac{\partial C_D}{\partial C_L^2} C_L^2 \tag{3-7}$$

Lift/drag ratio can be represented as follows:

$$\frac{C_L}{C_D} = \left[\frac{C_{D_0}}{C_L} + \frac{\partial C_D}{\partial C_L^2} C_L\right]^{-1} \tag{3-8}$$

Equation (3-4) indicates that a large value of L/D is desireable for large SR; to find the maximum L/D take the partial derivative of (C_L/C_D) with respect to C_L which gives the following relation:

$$\frac{\partial}{\partial C_L}\left(\frac{C_D}{C_L}\right) = \left[- \frac{C_{D_0}}{C_L^2} + \frac{\partial C_D}{\partial C_L^2}\right] \qquad (3\text{-}9)$$

See Figure 1 which is a plot of L/D versus lift coefficient. As shown, the peak of the L/D curve is designated (L/D)*. Since $C_D = 2C_{D_0}$ at maximum L/D, the equation of (L/D)* is as follows:

$$(L/D)^* = \left[4 \frac{\partial C_D}{\partial C_L^2} C_{D_0}\right]^{-\frac{1}{2}} \qquad (3\text{-}10)$$

An equation for C_L^*, which is the value of lift coefficient for (L/D)*, is useful for fitting aircraft data. Using equation (3-9)

$$\frac{\partial C_L^2}{\partial C_D} = \left[2\ (L/D)^*\ C_L^*\right] \qquad (3\text{-}11)$$

Combining equations (3-10) and (3-11) yields

$$C_L^{*2} = \left[C_{D_0} \frac{\partial C_L^2}{\partial C_D}\right] \qquad (3\text{-}12)$$

One can calculate L/D versus lift coefficient combining the equations (3-8), (3-11), and (3-12). Equations (3-11) and (3-12) help select the parameters C_{D_0}. When the aircraft is in cruising flight, the aircraft weight is equal to aircraft lift:

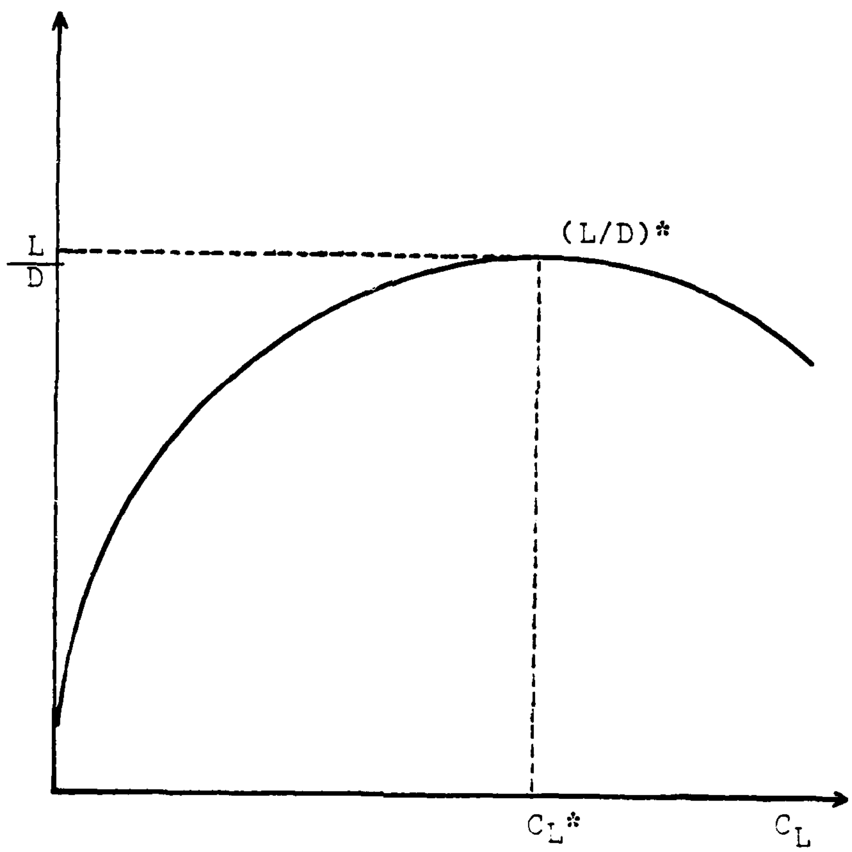


Figure 1. L/D Versus Lift Coefficient

$$L = W = \left[\frac{\rho V^2 C_L S}{2}\right] \quad (3\text{-}13)$$

where ρ is density at altitude in slug/ft^3 and S is wing area in ft^2. Thus, the lift coefficient becomes:

$$C_L = \frac{(2W)}{(\rho V^2 S)} \quad (3\text{-}14)$$

Equations (3-8) and (3-14) can be combined giving L/D as a function of aircraft flight velocity

$$L/D = \left[\frac{\rho V^2 S C_{D_0}}{2W} + \left(\frac{\partial C_{D_0}}{\partial C_L^2}\right)\left(\frac{2W}{\rho V^2 S}\right)\right]^{-1} \quad (3\text{-}15)$$

Equation (3-15) can be inserted into equation (3-4). The goal is to express SR as a function of flight velocity. The only other term which is not expressed as a function of V in equation (3-4) is SFC. SFC is a complicated function of throttle setting, flight velocity, and altitude. Typical curves of SFC are given in the USAF Grey Book [Ref. 6]. In this thesis, curves of SR as a function of V are used. The curves are from [Ref. 2].

2. Wind Equations

Ground specific range is a function of ground speed and specific range which has been defined in the previous section. (See Figure 2 for the geometry of the velocity triangle.) Ground speed is a function of wind velocity, aircraft velocity, and the angle θ is measured from the

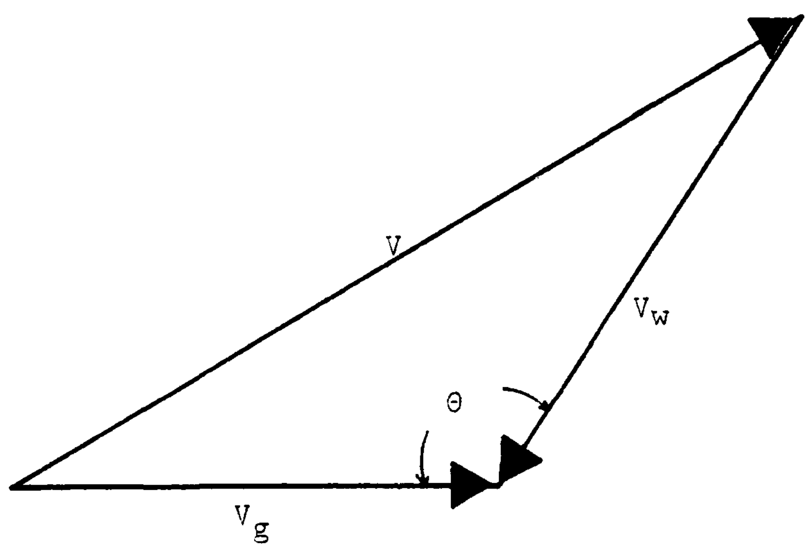


Figure 2. Figure for True Airspeed, Wind Velocity, and Ground Speed

wind velocity vector to the vector for aircraft velocity relative to the ground. From the cosine law, ground velocity can be computed as follows:

$$V_g = V_W \cos\theta \pm \{V^2 - V_W^2 (1 - \cos^2\theta)\}^{\frac{1}{2}} \tag{3-16}$$

The algebraic sign must be selected in equation (3-16). A choice has been made that when θ is 0 degrees, the wind is a tail wind. If it is 180°, then cosθ is -1, and it is a head wind. The ground speed becomes $V-V_W$. Divide equation (3-16) by V to give the following relationship.

$$U_g = \frac{V_g}{V} = \frac{V_W}{V} \cos\theta + \left\{1 - \frac{V_W^2}{V^2} (1 - \cos^2\theta)\right\}^{\frac{1}{2}} \tag{3-17}$$

Substitution of equation (3-17) into (3-5) gives GSR as a function of velocity as follows:

$$GSR = \left[\frac{V(L/D)}{SFC \cdot W}\right] \left[\left\{1 - \frac{V_W^2}{V^2} (1 - \cos^2\theta)\right\}^{\frac{1}{2}} + \frac{V_W}{V} \cos\theta\right]\Bigg\} \tag{3-18}$$

Take the partial derivative of GSR with respect to velocity in order to find the velocity for maximum GSR. In order to make the equation simple, take the natural logarithm for equation (3-18)

$$\ln(GSR) = \ln(SR) + \ln\left(\frac{V_g}{V}\right) \tag{3-19}$$

The derivative of the Equation (3-19) is

$$\left[\frac{1}{GSR}\frac{\partial GSR}{\partial V}\right] = \left\{\left[\frac{1}{SR}\frac{\partial SR}{\partial V}\right] + \left(\frac{V}{V_g}\right)\left[\frac{\partial(V_g/V)}{\partial V}\right]\right\} \tag{3-20}$$

The basic equation for finding maximum GSR becomes

$$\left[\frac{1}{SR}\frac{\partial SR}{\partial V}\right] = \left\{-\left(\frac{V}{V_g}\right)\left[\frac{\partial(V_g/V)}{\partial V}\right]\right\} \tag{3-21}$$

Substitution of equation (3-17) into the right hand side of equation (3-21) gives

$$\left[\frac{V}{V_g}\frac{\partial(V_g/V)}{\partial V}\right] = \left(\frac{-1}{V}\right)\left[\frac{\left\{-\left(\frac{V_W}{V}\right)^2(1-\cos^2\theta) + \frac{V_W}{V}\cos\theta\left[1-\frac{V_W^2}{V^2}(1-\cos^2\theta)\right]^{\frac{1}{2}}\right\}}{\left\{\left[1-\frac{V_W^2}{V^2}(1-\cos^2\theta)\right]\left[\left\{1-\frac{V_W^2}{V^2}(1-\cos^2\theta)\right\}^{\frac{1}{2}} + \frac{V_W}{V}\cos\theta\right]\right\}}\right] \tag{3-22}$$

The approach will be to use curves for a specific aircraft for evaluation of the left hand side of equation (3-21). Equation (3-22) can be used for the right hand side of equation (3-21).

3. Second Order Analysis

The first order analysis for finding the best range Mach number and the magnitude of GSR has been accomplished. See the Notes for AE 3001 Aircraft Energy Conservation [Ref. 6]. A second order analysis is accomplished in this section. Define U_g as ground speed divided by true airspeed, i.e., $U_g = V_g/V$; also define $U_W = V_W/V$. Define ε^* as $(V^*-V_0)/V_0$ and $GSR=SR\cdot U_g$ where V_0 is the velocity for maximum specific range with no wind, and V^* is the velocity for maximum specific range with wind. SR can be expanded in a Taylor series about V_0 as follows:

$$SR(V) = SR(V_0) + \left(\frac{\partial SR}{\partial V}\right)(V-V_0) + \left(\frac{\partial^2 SR}{\partial V^2}\right)\frac{(V-V_0)^2}{2} \tag{3-23}$$

The second term ($\partial SR/\partial V$) becomes zero when velocity is V_0 since $\partial SR/\partial V$ is evaluated at the peak of the SR curve where the derivative of SR with respect to V is zero. The graphical illustration can be found in Figure 3. In Figure 4 one uses straight line for first order solution. One assumes ab and cb are straight lines. An equation is needed for the curve passing through points a and b in Figure 4. Define F(V) as follows:

$$F(V) = \left(\frac{1}{SR}\right) \left(\frac{\partial SR}{\partial V}\right)$$

Note that $F(V_0) = 0$. Then F(V) can be represented by a Taylor series expansion about V_0 as follows:

$$F(V) = F(V_0) + \left(\frac{dF}{dV}\right) (V-V_0) + \left(\frac{d^2F}{dV^2}\right) \frac{(V-V_0)^2}{2} \tag{3-24}$$

In this series representation of the F(V), dF/dV can be expressed in terms of SR by

$$dF/dV = - \left(\frac{1}{SR^2}\right) \left(\frac{dSR}{dV}\right)^2 + \left(\frac{1}{SR}\right) \left(\frac{d^2SR}{dV^2}\right) \tag{3-25}$$

The first term in equation (3-25) is also zero at V_0 for the same reason as mentioned above. Therefore, equation (3-24) can be rewritten using equation (3-25) as follows:

$$F(V) = \left(\frac{1}{SR}\right) \left(\frac{\partial^2 SR}{\partial V^2}\right) \quad (V-V_0) \tag{3-26}$$

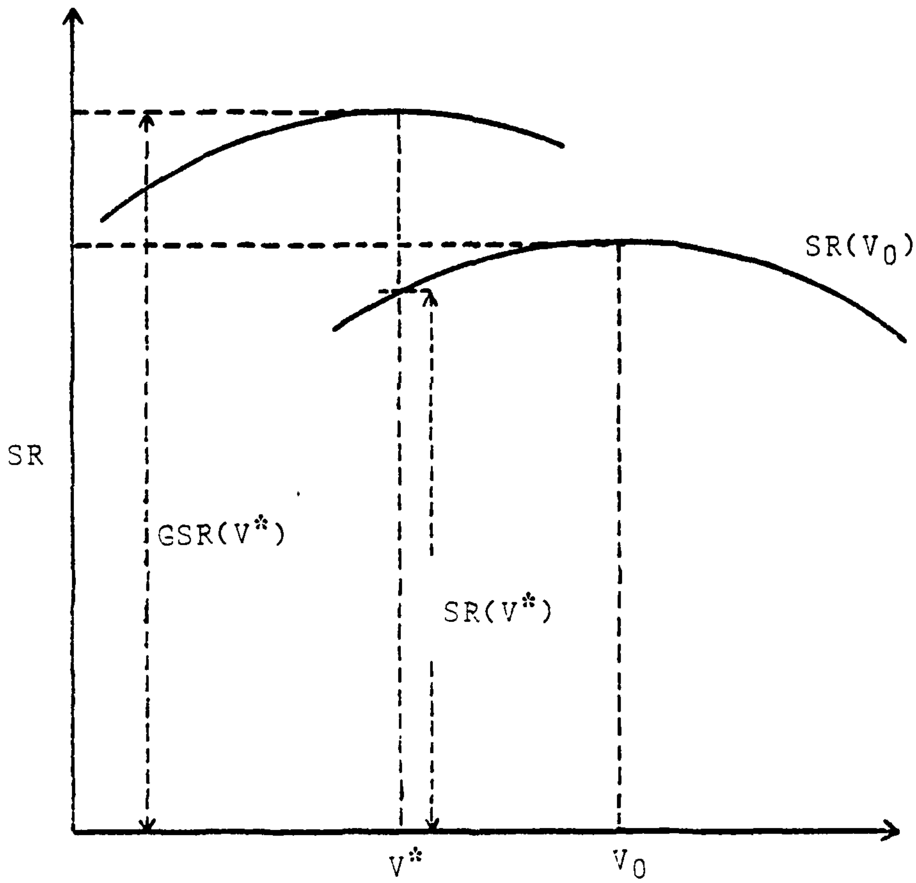


Figure 3. Specific Range Versus Velocity

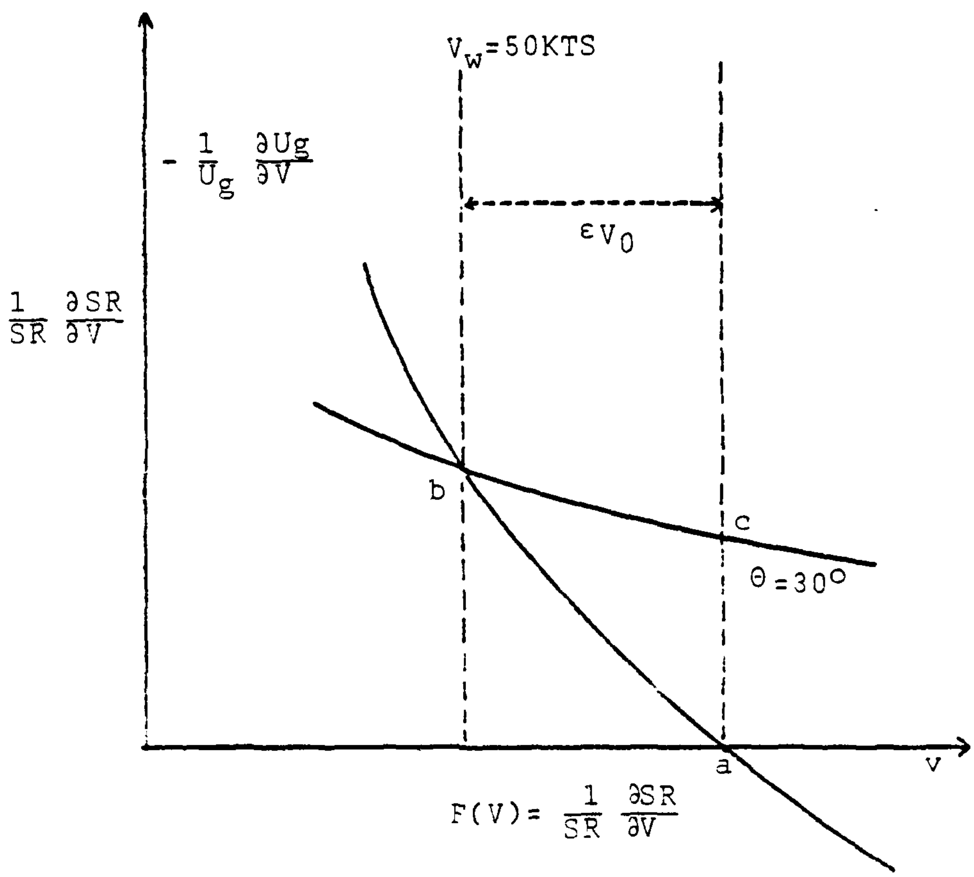


Figure 4. SR Versus Velocity

Replacing $V-V_0$ with εV_0 gives

$$F(V) = \left(\frac{1}{SR}\right) \left(\frac{\partial^2 SR}{\partial V^2}\right) \quad \varepsilon V_0 \tag{3-27}$$

Equation (3-27) is appropriate for a first order analysis. An equation for the straight line passing through d and e in Figure 5 can be obtained by expanding equation (3-17) about V_0. Recall $V=V_0\ (1+\varepsilon)$ where ε is much less than unity. Define $U_{W_0} = (V_W/V_0)$, which is much less than unity, also, when compared to unity, second order analysis retains terms like ε, U_{W_0}, ε^2, εU_{W_0}, and $U^2_{W_0}$, but discards the higher order terms like ε^3, $U^3_{W_0}$ etc. which are much less than unity. Then,

$$U_W \cos\theta = \left(\frac{V_W}{V_0(1+\varepsilon)}\right) \cos\theta = U_{W_0} \cos\theta\ (1-\varepsilon) \tag{3-28}$$

and, $(1-U_W^2\ (1-\cos^2\theta))^{\frac{1}{2}}$ can be expanded using binomial expansion as follows:

$$1 - \left(\frac{1}{2}\right) U_W^2\ (1-\cos^2\theta) - \left(\frac{1}{8}\right) U_W^4\ (1-\cos^2\theta)^2 + \ldots\ldots \tag{3-29}$$

The term $(1/V)$ is the same as $(1/(V_0\ (1+\varepsilon))$, and this can be expanded using binomial expansion as follows:

$$\frac{1}{V_0}\ (1-\varepsilon + \varepsilon^2 + \ldots\ldots\ldots\ldots\ldots).$$

Neglect terms of order higher than second. Then the term U_W becomes $U_{W_0}(1-2\varepsilon+\varepsilon^2)$. Equation (3-22) can be written as follows:

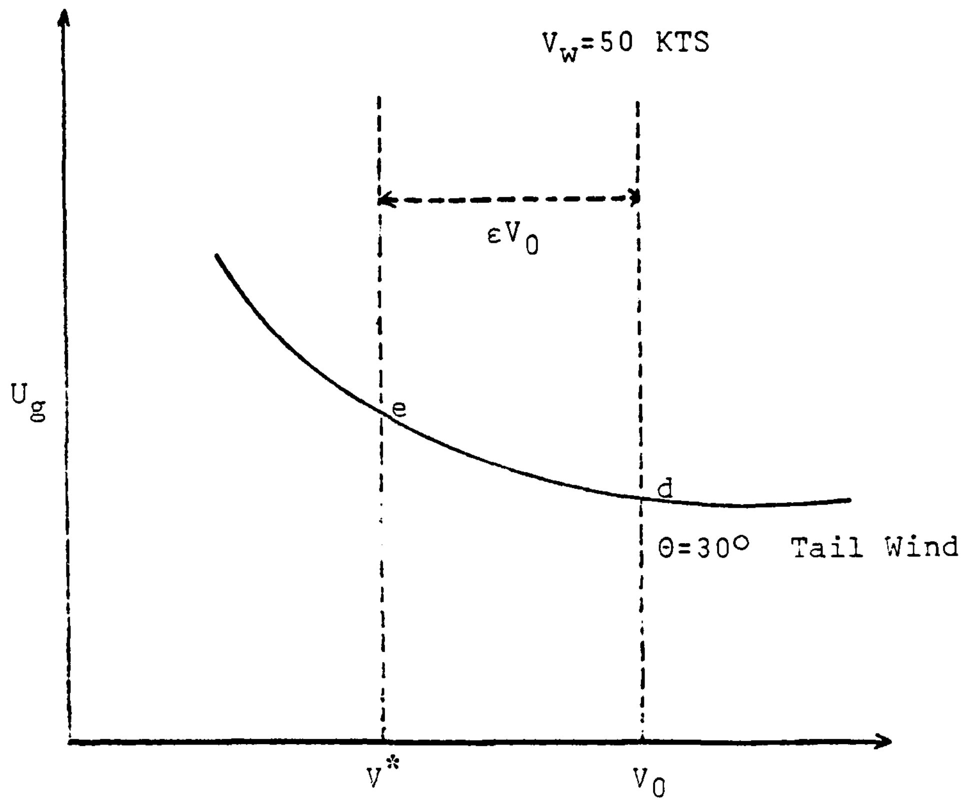


Figure 5. U_g Versus Velocity

$$\left[\frac{V}{V_g}\frac{\partial(V_g/V)}{\partial V}\right] = \left\{(-\frac{1}{V_0})\ (1-\varepsilon+\varepsilon^2)\ \cdot\right. \tag{3-30}$$

$$\left.\frac{\left[\left\{1-\frac{1}{2}U_{W_0}^2(1-2\varepsilon+\varepsilon^2)(1-\cos^2\theta)\right\}\left\{U_{W_0}\cos\theta(1-\varepsilon)\right\}-\left\{U_{W_0}^2(1-2\varepsilon+\varepsilon^2)(1-\cos^2\theta)\right\}\right]}{\left[\left\{1-\frac{1}{2}U_{W_0}^2(1-2\varepsilon+\varepsilon^2)(1-\cos^2\theta)\right\}\left\{U_{W_0}\cos\theta(1-\varepsilon)\right\}+\left\{\frac{U_{W_0}^2}{2}(1-2\varepsilon+\varepsilon^2)(1-\cos^2\theta)\right\}\right]}\right\}$$

In the expression above, terms above third order can be neglected and equation (3-22) can be simplified as follows:

$$\left[\frac{1}{U_g}\left(\frac{\partial U_g}{\partial V}\right)\right] = \left(\frac{-1}{V_0}\right)\frac{\left[U_{W_0}\cos\theta - 2\varepsilon\cdot U_{W_0}\cdot\cos\theta - U_{W_0}^2(1-\cos^2\theta)\right]}{\left[1+U_{W_0}\cos\theta - \varepsilon\,U_{W_0}\cos\theta - U_{W_0}^2 + U_{W_0}^2\cos\theta\right]} \tag{3-31}$$

In order to continue the reduction of equation (3-31) to second order, $U_W\cos\theta - \varepsilon U_W\cos\theta - U_W^2 + U_W^2\cos\theta$ is assumed to be X. The term $(1/(1+X))$ can be expanded using binomial expansion

$$\left(\frac{1}{(1+X)}\right) = 1-X+X^2-X^3+\ldots\ldots\ldots\ldots$$

$$\left(\frac{1}{(1+X)}\right) = 1-U_{W_0}\cos\theta+\varepsilon U_{W_0}\cos\theta+U_{W_0}^2-U_{W_0}^2\cos^2\theta+U_{W_0}^2\cos^2\theta$$

Then, equation (3-31) can be rewritten in the following simplified form.

$$\left[\frac{1}{U_g}\frac{\partial U_g}{\partial V}\right] = \left[-\frac{1}{SR}\right]\left[\frac{\partial SR}{\partial V}\right] = \left[-\frac{1}{V_W}\right]\left[U_{W_0}\cos\theta - 2\varepsilon\,U_{W_0}\cos\theta - U_{W_0}^2\right] \tag{3-32}$$

Equation (3-32) is a valid second order representation of the term involving the derivative of U_g. From equation (3-25), d^2F/dV^2 at $V=V_0$ can be evaluated

$$\frac{d^2F}{dV^2} = \left\{ \frac{d}{dV} \left[- \frac{1}{SR^2} \left(\frac{dSR}{dV}\right)^2 \right] + \frac{d}{dV} \left\{ \frac{1}{SR} \; \frac{d^2SR}{dV^2} \right\} \right\} \tag{3-33}$$

Equation (3-33) becomes

$$\frac{d^2F}{dV^2} = \left[- \left(\frac{1}{SR^2}\right) \left(\frac{d^2SR}{dV^2}\right) \left(\frac{dSR}{dV}\right) + \left(\frac{1}{SR}\right) \left(\frac{d^3SR}{dV^3}\right) \right] \tag{3-34}$$

The first term drops out since (1/SR)(dSR/dV) is zero when evaluated at V_0.

Finally, equation (3-33) becomes

$$\left[\frac{d^2F}{dV^2}\right]_{\text{at } V=V_0} = \left[\frac{1}{SR}\right] \left[\frac{d^3SR}{dV^3}\right] \tag{3-35}$$

Therefore, substituting equations (3-25) and (3-35) into equation (3-24) gives

$$F(V) = \left\{ \left(\frac{1}{SR}\right) \left(\frac{\partial SR}{\partial V}\right)_{V_0} + (V^* - V_0) \left(\frac{1}{SR}\right) \left(\frac{\partial^2 SR}{\partial V^2}\right) + \frac{1}{SR} \quad \frac{\partial SR}{\partial V^3} \quad \frac{(V-V_0)^2}{2} \right\} \tag{3-36}$$

The first term of equation (3-36) drops out since $\partial SR/\partial V$ is zero when $V=V_0$. Thus equation (3-36) can be simplified as

$$\left[\left(\frac{1}{SR}\right) \left(\frac{\partial SR}{\partial V}\right)\right] = \left\{ \varepsilon V_0 \left(\frac{1}{SR}\right) \left(\frac{\partial^2 SR}{\partial V^2}\right) + \left(\frac{\varepsilon^2 V_0^2}{2SR}\right) \left(\frac{\partial^3 SR}{\partial V^3}\right) \right\} \tag{3-37}$$

From equation (3-21), which is valid at V*, equation (3-37) and equation (3-32), the following relationships are obtained:

$$\left[\frac{1}{SR}\,\frac{\partial SR}{\partial V}\right] = \left[\ \frac{1}{V_0}\left\{U_{W_0}\cos\theta\ -2\varepsilon\ U_{W_0}\cos\theta\ -\ U_{W_0}^2\right\}\right] \tag{3-38a}$$

and

$$\left[\frac{1}{SR}\,\frac{\partial SR}{\partial V}\right] = \left[\varepsilon V_0\ \left(\frac{1}{SR}\right)\ \left(\frac{\partial^2 SR}{\partial V^2}\right)\ +\ \left(\frac{\varepsilon^2 V_0^{\ 2}}{2}\right)\ \left(\frac{1}{SR}\right)\ \left(\frac{\partial^3 SR}{\partial V^3}\right)\right] \tag{3-38b}$$

In order to solve equation (3-29) for ε, $(\partial^2 SR/\partial V^2)$ and $(\partial^3 SR/\partial V^3)$ should be determined first of all. Several methods can be used to find the derivatives of SR with respect to velocity. The aerodynamic analysis along with an analysis for SFC is a method of determining the SR function with respect to velocity. However, in this thesis graphical data of SR as function of velocity for A-7E aircraft is used as one example. One can find the SR versus V chart in Herskovitz [Ref. 2: pp. 15]. Also, one can read the SR value with respect to aircraft velocity. Then the second and third derivatives of SR with respect to velocity can be determined as follows:

$$\frac{d^2 SR}{dV^2}\ \cong\ \left[\ \frac{f(x+2h)\ +\ 2f(x+h)\ +\ f(x)}{h^2}\ \right] \tag{3-39}$$

The equation above can be rewritten as follows:

$$\frac{\partial^2 SR}{\partial V^2}\ \doteq\ \left[\ \frac{SR_3\ -\ 2SR_2\ +\ SR_1}{(\Delta V)^2}\ \right] \tag{3-40}$$

Also

$$\frac{\partial^3 SR}{\partial V^3} = \left[\frac{SR_4 - 3SR_3 + 3SR_2 + SR_1}{(\Delta V)^3} \right] \tag{3-41}$$

Equation (3-38) can be solved for ε as indicated below. Define some constants for convenience.

$$\left.\begin{aligned} a &= \left[\frac{V_0{}^3}{2SR}\right] \left[\frac{\partial^3 SR}{\partial V^3}\right] \\ b &= \left[\left(\frac{V_0{}^2}{SR}\right) \left(\frac{\partial^2 SR}{\partial V^2}\right) + (2U_{W_0} \cos\theta) \right] \\ c &= \left[U^2_{W_0} - U_{W_0} \cos\theta \right] \end{aligned}\right\} \tag{3-42}$$

Then equation (3-38) becomes:

$$a\varepsilon^2 + b\varepsilon + c = 0 \tag{3-43}$$

The roots are as follows:

$$\varepsilon = \left[- \frac{b}{2a} \pm \left(\frac{1}{2a}\right) (b^2 - 4ac)^{\frac{1}{2}}\right] \tag{3-44}$$

The square root can be expanded with the binomial expansion. Then the roots become as follows:

$$\varepsilon_1 = - \left(\frac{c}{b}\right) \left(1 - \frac{ac}{b^2}\right) \tag{3-45}$$

$$\varepsilon_2 = \left(\frac{b}{a}\right) \left(-1 + \frac{(ac)}{b} + \frac{(a^2c^2)}{b^4}\right) \tag{3-46}$$

The sign of ε should flip when θ changes from 0° to 180°. When θ is zero degree, the wind is a tail wind. The aircraft should fly at a slower speed, and the sign of ε is minus. When θ is 180°, the wind is a head wind, and the aircraft should fly at a faster speed. The sign of ε is positive.

From the beginning of Section 3., the GSR and V* are defined as follows:

$$GSR = SR(U_g) \tag{3-47}$$

$$V^* = V_0(1+\varepsilon^*) \tag{3-48}$$

where ε should be ε_1, since ε_2 is a number bigger than unity. If ε is bigger than unity, it is not physically reasonable. From equations (3-17) and (3-23), GSR can be written as follows:

$$GSR(V^*) = \left\{ \left[SR(V_0) + \frac{\varepsilon^2 V_0{}^2}{2} \frac{\partial^2 SR}{\partial V^2} \right] \left[1 + U_{W_0}(1-\varepsilon)\cos\theta - \frac{1}{2} U_{W_0}^2 (1-\cos^2\theta) \right] \right\} \tag{3-49}$$

Rearranging equation (3-49), GSR equation can be rearranged as

$$GSR(V^*) = SR(V_0) \left[1 + U_{W_0}(1-\varepsilon)\cos\theta - \frac{1}{2} U_{W_0}^2 (1-\cos^2\theta) + \frac{\varepsilon^2 V_0{}^2}{2SR} \frac{\partial^2 SR}{\partial V^2} \right] \tag{3-50}$$

Sample calculations of ε^*, GSR, and V* using computer program are shown in Appendix A and B. The aircraft in the sample problem is the A-7E, with the following inputs: altitude 35,000 ft., drag count 50, and wind velocity 50 knots which is changing directions from head wind to tail wind. The ground specific range can be found in the Technical Publications [Ref. 2: pp. 17].

A computer program for a sample problem is included in Appendix A. The values of Specific Range in the program were taken from GSR versus velocity chart in Herskovitz [Ref. 2: pp. 17]. The solutions of the example problems are included in Appendix B. See Figures B.1, B.2, and B.3 for graphical results.

IV. F-4E FPAS PROGRAM

A. INTRODUCTION

The U.S. Naval Development Center (NAVAIRDEVCEN) has been investigating several candidate fuel-saving modifications and operational concepts for Naval aircraft including the A-7E, F-4J, P-3C, and S-3A. One of several fuel-saving operational concepts being investigated is the application of state-of-the-art hand-held calculators to serve as Flight Performance Advisory System using an HP-41CV hand-held programmable calculator [Ref. 7]. The principal function of the FPAS would be to advise aircraft personnel of the flight conditions (speed and altitude) yielding maximum flight efficiency measured in terms of specific range. At present, such information is manually derived using charts in the Flight Manuals. Repeated utilization of these charts while in flight is not practical. It is expected that a computerized FPAS will simplify the task of planning for fuel efficient flight.

While the Aircraft Fuel Conservation Project is examining a broad range of FPAS options, including a microprocessor to supplement aircraft data processing equipment, the hand-held calculator option was selected as an interim solution because it offers immediate availability at a relatively low cost. The HP-41CV hand-held programmable calculator was selected because it represents the latest technology including alphanumeric display and 2200 bytes of random access memory (RAM). A programmable module of 8000 bytes of read only memory (ROM) is also available. Recently Hewlett-Packard developed new memory module which can add 1666 or more extended bytes of memory to the HP-41CV calculator.

The purpose of this part of the thesis is to document the program and operational features of the F-4E/HP-41CV FPAS and F-5E/HP-41CV FPAS. While the features of the program documented in this thesis are by no means final, a foundation is formed for future development of military aircraft in-flight software.

A description of the F-4E and F-5E programs written for the HP-41CV calculator is contained in Chapters 4 and 5. The contents of Chapters 4 and 5 include a general overview of the entire program and the methodology used to generate the equations from the F-4E Flight Manual [Ref. 3], and from the F-5E Flight Manuals [Ref. 4], and a listing of program input/ output parameters and the equations used for each program mode. An annotated listing of the F-4E and F-5E FPAS program is contained in Appendix D. A program User's Guide is contained in Chapter 6. Several illustrative examples of F-4E and F-5E FPAS Program utilization are described in Chapter 8.

B. F-4E PROGRAM DESCRIPTION

The F-4E FPAS program is comprised of the following three subprograms:

(1) Optimum cruise;

(2) Bingo program; and

(3) Maximum endurance and descent.

The optimum cruise program provides the aircrew with best cruise speed, altitude, and specific range for given aircraft gross weight and drag count. The optimum cruise program consists of pre-flight and in-flight modes. The former is used by the aircrew for mission profile planning. The latter mode is exercised after takeoff using actual aircraft weight, drag count, and outside temperature.

The Bingo program provides the aircrew with fuel and distance required to climb to the optimum altitude; further, the Bingo program yields distance and fuel required to descend from optimum cruise altitude to desired altitude. This program also provides the aircrew with optimum cruise altitude, airspeed, fuel, and distance required to fly with minimum fuel consumption. The Bingo program is not only useful for the energy conservation but is also helpful for flight safety. The Bingo program is developed when the optimum cruise altitude is too high for short range missions. The method for finding the peak altitude of Bingo flight profile is provided in the Bingo program description.

The maximum endurance program was separated from the previous program because the previous programs exceed the memory of HP-41CV. However, the maximum endurance and descent programs are useful for loiter flight.

1. Climb and Descent Mode Descriptions

The data used in climb mode is based on climb speed of 350 KIAS with military thrust climb until interception of optimum cruise altitude. When optimum Mach number and cruise altitude are attained the optimum conditions are maintained on the cruise leg.

The data used in descent mode is based on descent airspeed of 300 KIAS with power set at 80% RPM and speed brakes retracted.

2. Optimum Cruise Program

a. Program Input/Output Parameters

The following is a listing of the applicable common input/output parameters for each of the three F-4E programs and the F-5E program. The symbol, definition, and units used for each input/output parameters are shown as follows:

DC	=	Drag count
BW	=	Base weight (lbs)
SW	=	Store weight (lbs)
FW	=	Fuel weight (lbs)
TW	=	Tail wind components (kts)
ALT	=	Present altitude (ft)
TEMP	=	Present temperature (centigrade)
GW	=	Gross weight (lbs)
EW	=	Effective weight (lbs)
SDT	=	Standard day temperature
BRMN	=	Best range Mach number
BRTAS	=	Best range true airspeed (kts)
BRGS	=	Best range ground speed (kts)
BRFF	=	Best range fuel flow (lbs/hr)
BRALT	=	Best range altitude (ft)
NBRALT	=	Next FAA best range altitude in feet, since FAA best range altitude is not always assigned to the aircraft in Instrument Flight Rule conditions. Thus one has to have alternative best range altitude.
NFW	=	Fuel weight at which to initiate climb (lbs)
CEILING	=	Because of aircraft configration limitation, the operator has reached his maximum altitude (ft).

Other parameters which are not specified in the above list are listed in each program description.

b. Performance Equations

This section briefly discusses the methodology used in deriving the equations for the F-4E FPAS program. The discussion of the performance equations is followed by a listing of the equations for the optimum cruise program.

The equations for the F-4E FPAS program were obtained through regression and graphical analysis techniques. Regression analysis employed linear regressions of polynomials to curve fit the Flight Manual performance data for the F-4E. Sufficiently accurate curve fit for data from the Flight Manual could not be obtained using regression analysis in every case. Consequently other methods or variations of regression equations were applied. Alternate methods include piecewise curve fits over partitioned parameter intervals.

Most of the equations were derived using the package of Minitab with IBM-370 [Ref. 5: pp. 66]. Multiple regression techniques were employed.

For optimum cruise, which is a curve fit to the curves from the Flight Manual, equations were first derived for a standard day and zero wind condition and later adjusted to accommodate the effects of non-standard temperature upon air density and speed of sound and a "Rule of Thumb" performance head wind correction. The equation of head wind correction was derived by Naval Air Development Center, Warminster, PA [Ref. 7: pp. 4].

c. The Nature of the Temperature Variations

Implicit in the computation of best range altitude is a value for air density. The Flight Manual data assumes a standard atmosphere model. Thus, the first step in FPAS is to compute BRALT according to the Flight Manual data. This altitude is translated to an equivalent "density altitude" using an equation derived from ideal gas laws.

Correction of BRALT for Non-standard Atmospheric Temperature. As indicated in the previous section, a correction is made to BRALT when the ambient temperature does not equal the value for the standard temperature. Assume the pressure in the atmosphere as a function of altitude equals that for the standard atmosphere. When the ambient temperature differs from standard temperature, the flight altitude is adjusted so that the ambient density equals the standard density at altitude, BRALT.

Define h_1 as BRALT; define h_2 as the corrected altitude. One wants

$$\rho_a(h_2) = \rho_s(h_1) \tag{4-1}$$

Where $\rho_a(h_2)$ is the actual density at altitude h_2 and $\rho_s(h_1)$ is the density for a standard atmosphere at altitude h_1 or BRALT. The density $\rho_a(h_2)$ can be expanded in a Taylor's series as

$$\rho_a(h_2) = \rho_a(h_1) + \left(\frac{d\rho}{dh}\right)_{h_1} (h_2 - h_1) = \rho_s(h_1) \tag{4-2}$$

Manipulation of equation (4-2) and introduction of the perfect gas law yields

$$\frac{d\rho}{dh}\ (h_2 - h_1) = \rho_s(h_1) - \rho_a(h_2) = \left(\frac{P_s}{R}\right)\left(\frac{1}{T_s} - \frac{1}{T_a}\right) \tag{4-3}$$

The equation for static equillibrium in the atmosphere is

$$\frac{dP}{dh} = - \rho g \tag{4-4}$$

where P is pressure and g is the acceleration of gravity. To use equation (4-2), one needs a formula for $d\rho/dh$. From differentiation of the perfect gas law

$$\frac{dP}{dh} = RT \frac{d\rho}{dh} + \rho R \frac{dT}{dh} \tag{4-5}$$

Combining equations (4-4) and (4-5) yields

$$\left(\frac{d\rho}{dh}\right)_{h_1} = - \frac{\rho_s}{T_s} \left(\frac{g}{R} + \frac{dT}{dh}\right) \tag{4-6}$$

Finally equations (4-3) and (4-6) can be combined to give an expression for the corrected altitude

$$h_2 = h_1 - \left\{ \frac{T_s}{T_a} \quad \frac{(T_a - T_s)}{(\frac{g}{R} + \frac{dT}{dh})} \right\} \tag{4-7}$$

In subsequent discussion, h_2 will be identified as BRALT. If one assumes that $T_s \approx T_a$ and that the atmosphere is isothermal, i.e., $dT/dh = 0$, then equation (4-7) reduces to

$$h_2 = h_1 - \frac{R}{g} (T_a - T_s) \tag{4-8}$$

As one would expect, when T_a is greater than T_s, then the BRALT is lower than that value for flight in a standard atmosphere. The report by FAAC [Ref. 1], discusses the correction of BRALT for altitude in Appendix F of the report. The formula derived by FAAC is equivalent to equation (4-8). Comparison of the derivation above with that of FAAC indicates FAAC did not state the correct assumptions involved in the altitude adjustment.

d. Equations for Optimum Cruise Program

Optimum cruise, which is defined by the Flight Manual for F-4E aircraft [Ref. 3], is the maximum value of specific range. Specific range is the nautical miles flown per pound of fuel consumed. Assuming both engines of F-4E are operating, three charts from the Flight Manual are relevant to determination of optimum cruise conditions. The three charts are reproduced here as Figure 6. The small insert in Figure 6 shows that the curves are entered with drag index. Hence, drag index is one of the independent variables. From the bottom curve in Figure 6, the best range Mach number, BRMN, is obtained. The bottom curve has been regressed yielding the equation

$$BRMN = .86672 + 3.228DC^2 - .000010812DC^3 \tag{4-9}$$

For the wind correction, the true airspeed, BRTAS, is needed. BRTAS is obtained from Mach number using speed of sound as shown in equation (4-10) below

$$BRTAS = BRMN \cdot 38.98 \cdot \sqrt{(TEMP + 273.16)} \tag{4-10}$$

According to [Ref. 1: pp. 5], the correction for tail wind is

$$BRTAS = BRTAS - 0.25(TW) \tag{4-11}$$

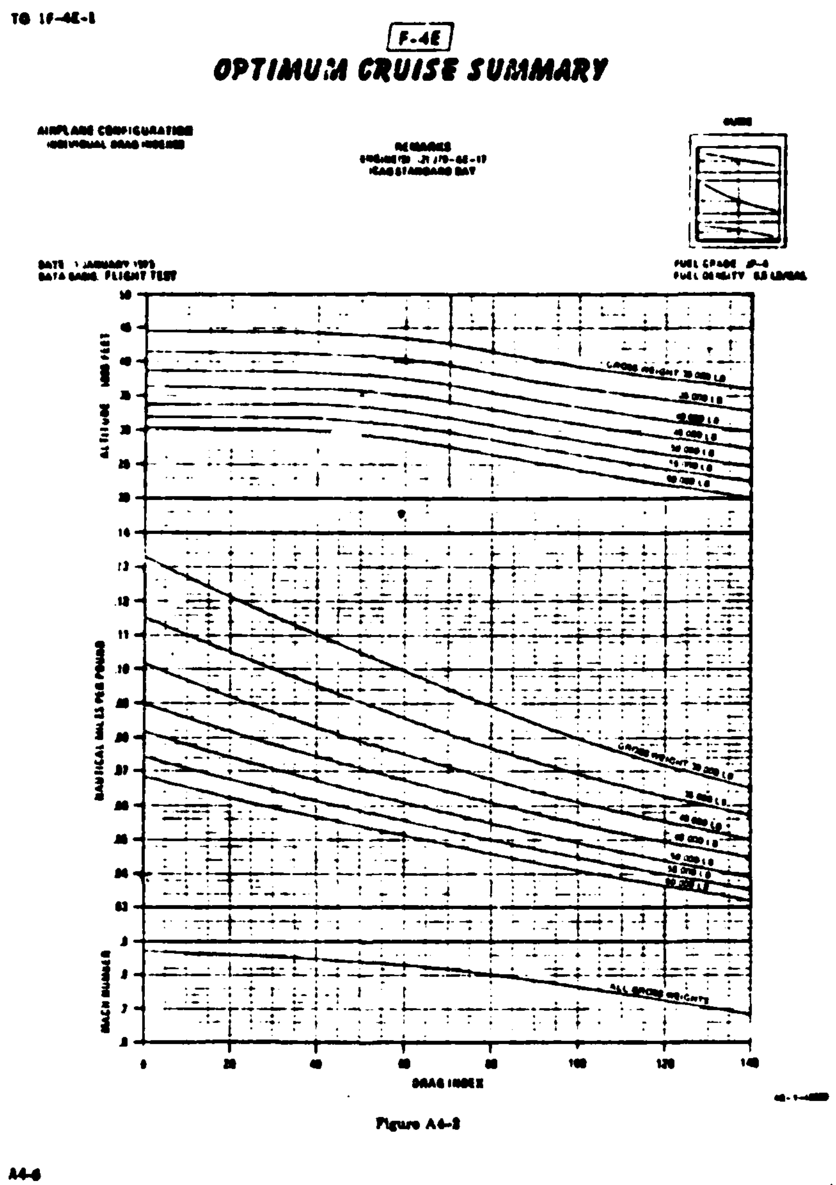


Figure 6. F-4E Optimum Cruise Summary

At this point, one should note that Chapter 3 of this thesis derived an equation equivalent to equation (4-11). See equation (3-48). The empirical value of 0.25 given in equation (4-11) can be calculated from knowledge of specific range, SR; the second derivative of SR with respect to airspeed, $\partial^2 SR/\partial V^2$; the optimum flight velocity with no wind V_0; and the wind velocity V_W. For the A-7E aircraft the constant multiplying wind velocity was found to be -0.19. This value is a slightly less than the value of equation (4-11). The equation of Best Range Ground Speed becomes

$$BRGS = TW + BRTAS \tag{4-12}$$

which is a simple algebraic combination of tail wind and true airspeed. Continuing with the charts in Figure 7, the middle set of curves give specific range as a function of drag index and gross weight. The equation which generates these curves is

$$\begin{aligned} SR = {} & .3467 - .011423GW - .0010658DC + .00017361GW^2 - .000001143DC^2 \\ & - 1.01941 \cdot 10^{-6}GW^3 + 4.026908 \cdot 10^{-8}DC^3 - 1.48918 \cdot 10^{-10}DC^4 \\ & + 9.065261 \cdot 10^{-18}(GW)^4(DC)^4 - 1.36419 \cdot 10^{-13}(GW)^3(DC)^3 \\ & + .000014286(GW)(DC) \end{aligned} \tag{4-13}$$

Note that SR is a function of drag index and gross weight.

The top curve in Figure 7 is best range altitude, BRALT, as a function of drag index and gross weight. The equation which is used in the HP-41CV to generate BRALT is

$$\begin{aligned} BRALT = {} & 72.771 + .0142DC - 1.2681GW - .0000831DC + .012909GW^2 \\ & - .000011726DC^3 - .00006205GW^3 + 5.952454 \cdot 10^{-8}DC^4 \end{aligned} \tag{4-14}$$

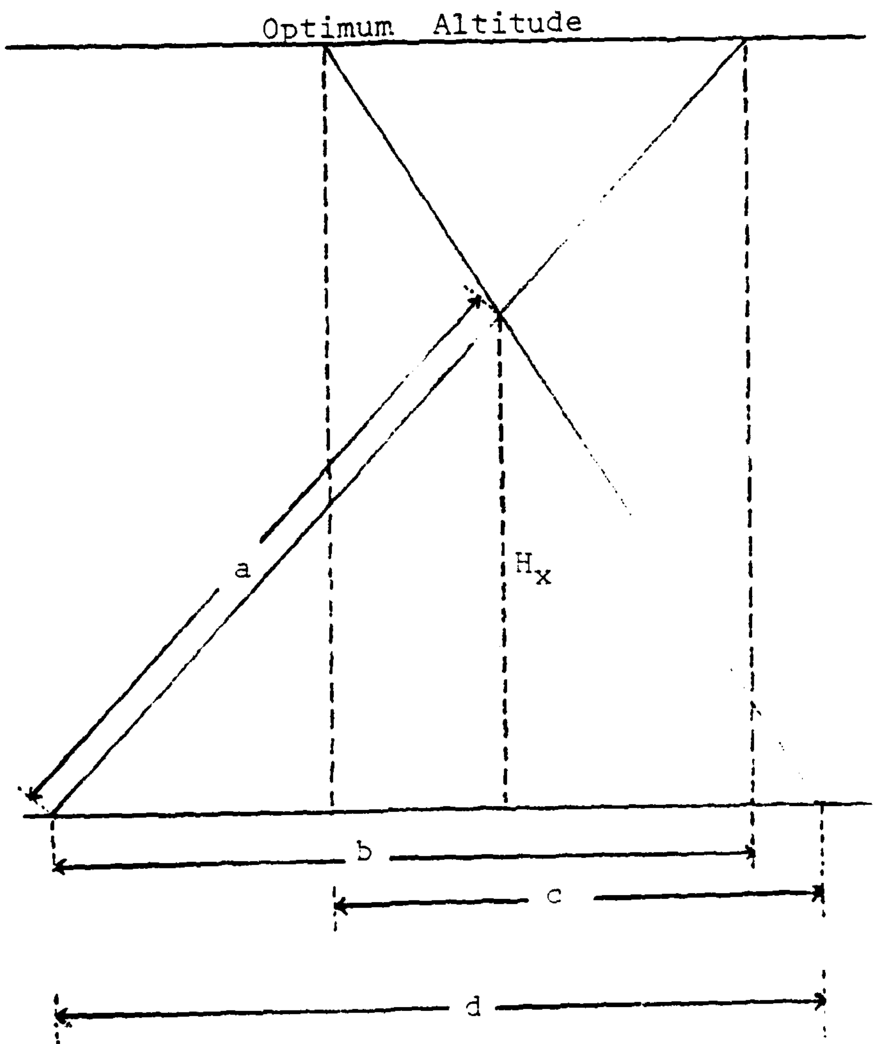


Figure 7. Method for Determining The Peak Altitude (HX)for the Bingo Program

In Section B.1 above, a correction to BRALT was derived. Below 36,000 feet the temperature of standard atmosphere varies with altitude and is given by - 0.0019812·(ALT). Using the formula for standard temperature and the results of secion B.2. the corrected BRALT for altitude less than 36,000 feet is

$$BRALT = -.0019812(ALT) + 15 - TEMP \cdot 96.103 + ALT \tag{4-15}$$

Best range altitude corrected for above 36,000 feet is

$$BRALT = (-56.5 - TEMP) \cdot 96.103 + ALT \tag{4-16}$$

According to [Ref. 1], the temperature in standard atmosphere below the altitude of 36,000 feet is

$$SDT = -.0019812(ALT) + 15 \tag{4-17}$$

and the temperature for a standard atmosphere above the altitude 36,000 feet is

$$SDT = -56.5 \tag{4-18}$$

In many cases, most of the flight altitude is restricted with Federal Aviation Agency regulations under Instrument Flight Rules or Visual Flight Rules [Ref. 1: pp. 7]. When the aircraft heading is east and flying condition is IFR, the aircraft must maintain even altitude in thousands of feet. When the aircraft heading is west and flying condition is IFR, the aircraft must maintain odd altitude in thousands of feet.

When the flying condition is VFR and with FAA flight restriction, an aircraft which is flying heading east must keep even altitude in thousands of feet plus 500 feet and an aircraft which is flying heading west must keep odd altitude in thousands of feet plus 500 feet.

When the flying condition is IFR, the aircrew is not able to fly at an arbitrary altitude. The altitude will be assigned by ground radar controller. In that case, aircrew can ask the controller for specific altitude which he wants to maintain. In that case, the aircrew should know the Next FAA Best Range Altitude. The Next FAA Best Range Altitude is FAA Best Range Altitude plus 2000 feet; that is

$$\text{NBRALT} = \text{FAA BRALT} + 2000 \text{ ft} \tag{4-19}$$

Fuel weight at which to initiate his climb to Next FAA Best Range Altitude is gross weight minus effective weight which is base weight plus store weight, that is

$$\text{NFW} = \text{GW} - \text{EW} \tag{4-20}$$

$$\text{EW} = \text{BW} + \text{SW} \tag{4-21}$$

where the gross weight is given in equation (4-22). Equation (4-22) is derived from [Ref. 7],

$$\text{GW} = \frac{\{(.9005 - (1.814\text{E} - 05\text{NBRALTP} + .4656\text{DC} - .000103\text{DC} - .3957)\}^{\frac{1}{2}}}{(9.072 \cdot 10^{-6})} \tag{4-22}$$

where Next Best Range Altitude NBRALTP is defined as follows:

$$\text{NBRALTP} = \text{NBRALT} - 96.103(\text{TEMP-SDT}) \tag{4-23}$$

3. Bingo Program

a. Program Input/Output Parameters

The program input/output parameters are as follows:

GWDP = Gross weight at the descent point

FCR = Cruise fuel

GWSL = Given sea level gross weight

FCL = Derived climb fuel

HOPT = Optimum altitude

HX = Altitude to climb to and descent from; HX may or may not be HOPT.

b. Bingo Program Description

This section discusses the actual logic of the program and methodology used. The program consists primarily of three parts. The first part is the climb mode, the second part is the cruise mode, and the third part is the descent mode. The term "Bingo" is defined here as any optimum maximum climb, cruise, and descent that begins and ends at sea level. Bingo program is useful for most F-4E missions including interceptions, interdictions, close air support, cross country training flight, and actual emergency bingo situations. Figure 7 shows the geometry of determining the peak altitude of the Bingo program. After the program is initialized, the crew may enter drag count, initial climb altitude, desired altitude, fuel weight, store weight, gross weight, etc., and be provided with the optimum altitude, fuel required, and descent point for a given Bingo distance. In addition, all of the parameters required on the jet card, which provides the aircrew with the performance data, are available from the data key.

Several assumptions were made in executing the Bingo program. First, the distance to climb and descend from sea level to optimum altitude must be determined. The total distance, when compared to the input Bingo distance, determines whether the aircraft can reach the optimum altitude before descent must begin. If not, the lower "crossing altitude" must be determined. The derivation of the crossing altitude is shown in Figure 7. Note that any descent distance was computed prior to cruise fuel (if any) being calculated. Since aircraft weight is required at the descent point for computation, and cruise fuel is not known, a nominal cruise fuel as a function of Bingo distance is assumed. The gross weight at begin-descent point cannot be calculated explicitly, and an iteration procedure is not feasible for the HP-41CV. See Figure 7 for the method for determining the peak altitude (HX) of the Bingo program.

HOPT = optimum altitude (1000 ft.)

b = climb distance (nm)

c = descent distance (nm)

d = desired flight distance (nm)

HX = altitude to climb to and descent from

$$K = \frac{(6.076116 \text{ ft.} \times 10^3)}{1 \text{ nm}}$$

$$\tan\theta = \frac{HOPT}{(Kb)}$$

$$\tan\phi = \frac{HOPT}{(Kc)}$$

$$\psi = 180^\circ - \theta - \phi$$

From the law of sines

$$a = \frac{(d \cdot \sin\phi)}{\sin\psi}$$

and

$$HX = K \cdot a \cdot \sin\theta$$

Given sea level gross weight (GWSL), the gross weight at the descent point (GWDP) is then:

$$GWDP = GWSL - FCL - FCR \qquad (4\text{-}24)$$

where FCL is the derived fuel which is required to climb.

A climb distance of 68 NM, descent distance of 49 NM, and fuel use of 14.7 lbs/NM is assumed for average gross weights and optimum altitudes. These data came from average configuration of F-4E used in flight training[1]. Then the FCR (estimated cruise fuel) equation is as follows:

$$FCR = (\text{Bingo distance} - 117\ \text{NM})\ 14.7\ \text{lbs/NM} \qquad (4\text{-}25)$$

The results are considered accurate enough for these profiles since descent fuel and distance are not sensitive enough to gross weight variations to significantly affect the total results.

It can be shown that for high speed jet aircraft, the influence of wind on Best Range Mach Number is essentially negligible for head and tail wind components up to 10% of the aircraft velocity. However, these

---

[1] Aircraft average GW = 40000 lbs., DC = 80. Descent Speed 300 IAS, 80% RPM, speed brake retracted.

components have been accounted for in the computation of Best Range Mach Number and Ground Specific Range using the same equation as the optimum cruise program.

c. Climb and Descent Mode Descriptions

Climb and descent mode is derived from Technical Order-1 F-4E performance chart [Ref. 3: pp. A3-12], see Figures 8 and 9. Use military power and maintain 350 KIAS for climb. For descent mode, set throttle 80% RPM and maintain speed at 300 KIAS with speed brake in.

d. Program Input/Output Parameters

The program input/output parameters are as follows:

GW = gross weight (lbs)

ALT = altitude (ft)

DC = drag count

DT = temperature deviations from standard temperatures (deg)

FF = fuel flow (lbs/hour)

DIST = distance (nm)

DISTCL = distance required to climb from sea level to desired altitude.

TEMPD = temperature corrections for DISTCL

HWIND = head wind corrections for climb performance

TWIND = tail wind corrections for climb performance

DDIST = distance required to descent from optimum altitude to desired altitude.

e. Equations of Bingo Program

The equation for fuel required to climb to optimum cruse altitude is defined by the Flight Manual for F-4E aircraft [Ref. 3: pp. A3-12]. The performance chart for fuel required to climb is based on

TO 1F-4E-1

F-4E

FUEL REQUIRED TO CLIMB

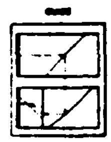
350 KIAS-MILITARY THRUST

AIRPLANE CONFIGURATION
INDIVIDUAL DRAG INDEXES

REMARKS
ENGINE(S): (2)J79-GE-17

NOTE

DATA BASED ON 350-KNOT CLIMB UNTIL
INTERCEPTION OF OPTIMUM CRUISE MACH/
TAS. THEN MAINTAIN CRUISE MACH TO
CRUISE ALTITUDE. REFER TO PART 6
TO OBTAIN CRUISE ALTITUDES.



DATE: 1 JANUARY 1973
DATA BASIS: FLIGHT TEST

FUEL GRADE: JP-4
FUEL DENSITY: 6.5 LB/GAL

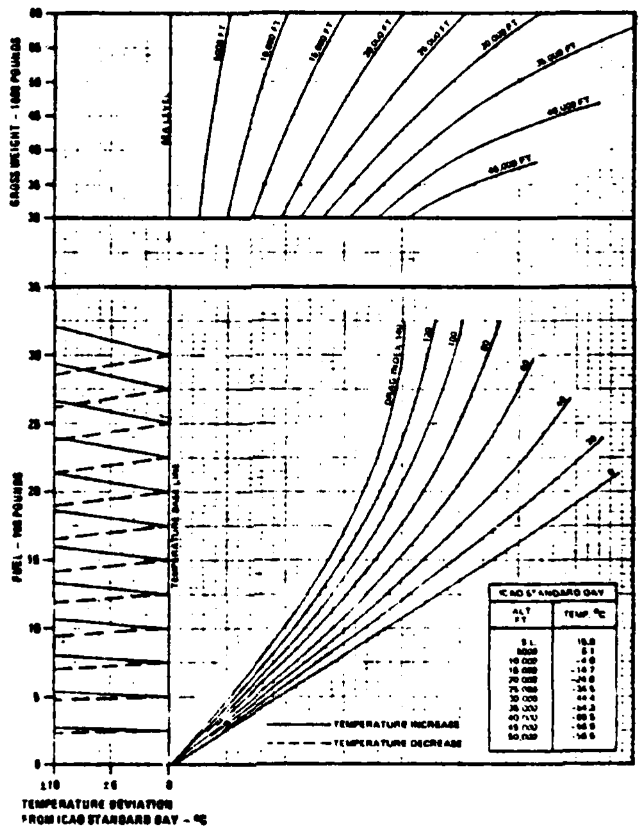


Figure A3-3 (Sheet 2 of 3)

Figure 8. F-4E Fuel Required To Climb

F-4E

DISTANCE REQUIRED TO CLIMB

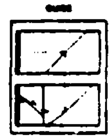
350 KIAS-MILITARY THRUST

AIRPLANE CONFIGURATION
INDIVIDUAL DRAG INDEXES

REMARKS
ENGINE(S): (2)J79-GE-17

NOTE

DATA BASED ON 350-KNOT CLIMB UNTIL INTERCEPTION OF OPTIMUM CRUISE MACH/TAS, THEN MAINTAIN CRUISE MACH TO CRUISE ALTITUDE. REFER TO PART 4 TO OBTAIN CRUISE ALTITUDES.



DATE: 1 JANUARY 1973
DATA BASIS: FLIGHT TEST

FUEL GRADE: JP-4
FUEL DENSITY: 6.5 LB/GAL

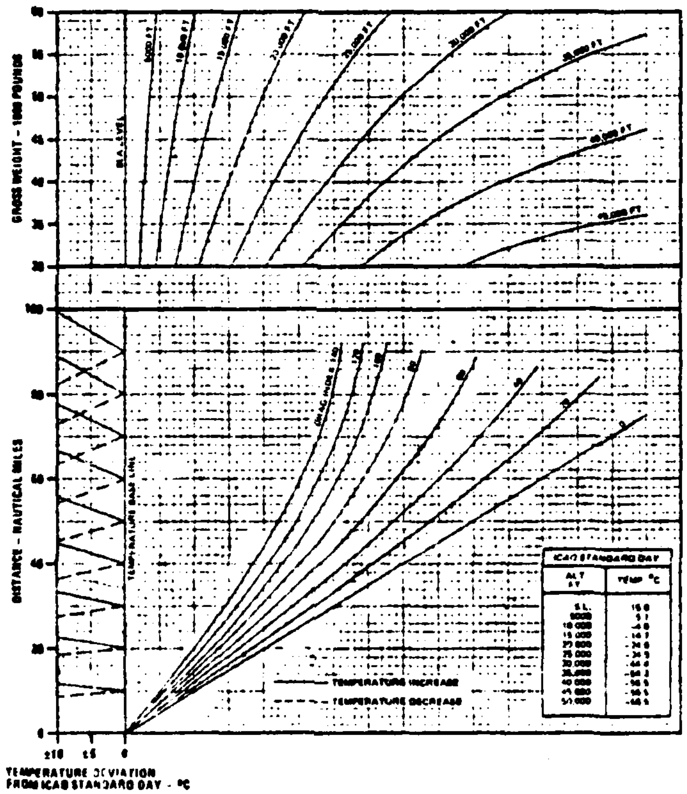


Figure A3-3 (Sheet 3 of 3)

Figure 9. F-4E Distance Required To Climb

climb speed 350 KIAS with military thrust. The data is based on 350 KIAS climb until interception of optimum cruise Mach/TAS and then maintaining cruise Mach to cruise altitude. All the data are based on flight test. The reproduced performance chart is in Figure 8. To use the fuel-required-to-climb chart, enter the charts with the initial climb gross weight. Project horizontally to the right and intersect the assigned cruise altitude, or the optimum cruise altitude for the computed drag index. Project vertically downward to intersect the applicable drag index line, and then project horizontally to the left to the temperature variation base line. Parallel the applicable guideline to intersect a vertical grid line corresponding to the degree of deviation between forecast flight temperature and standard ICAO dat temperature. From this point continue horizontally to the left to read the planning data. The equation for the fuel required to climb used the gross weight in thousands of pounds and altitude in kilofeet as inputs. For example, GW = 45,000 lbs is 45 as an input. The equation for fuel required to climb is

$$\begin{aligned} FRTCL = {} & 20.56 + .012GW - 1.8627ALT - .2119DC - .0097GW^2 + 0.04926ALT^2 \\ & + .0003097DC^2 - .0012384ALT^3 + .000002118DC^3 + .000001194GW^4 \\ & + .000013231ALT^4 - 1.62933 \cdot 10^{-8}DC^4 + .029079(GW)(ALT) \\ & + .0051266(ALT)(DC) + .0029517(GW)(DC) \end{aligned} \qquad (4\text{-}26)$$

The performance chart for fuel required to climb has four independent variables. For the accuracy of the equation, one variable was separated from equation (4-26). The separated equation from the equation (4-26) is the temperature correction for fuel required to climb. The equation is

$$TEMPF = -.183 + .12523DT + 1.0498FF - .002144FF^2 \quad (4\text{-}27)$$

The equation for distance required to climb to optimum altitude from sea level to desired altitude is regressed from the Flight Manual performance chart which is reproduced and incorporated in Figure 9. In Figure 9 the data are based on the 350 KIAS climb speed until intersection of optimum cruise altitude and then maintaining cruise Mach number at the cruise altitude. The original data are based on flight tests. The method to find the distance required to climb is the same as the method to use the fuel required to climb chart [Ref. 3: pp. A3-13]. The regressed equation is

$$\begin{aligned} DISTCL = {} & 57.5 + 1.537GW - 8.47ALT - .4076DC - .04814GW^2 + .1712ALT^2 \\ & + .000112DC^2 - .0013675ALT^3 - .0000813DC^3 + .000003133GW^4 \\ & + 4.87 \cdot 10^{-8}DC^4 + .09144(GW)(ALT) + .011657(ALT)(DC) \\ & + .006917(GW)(DC) + .000003973(GW)^2(ALT)^2 \\ & + .0000010795(ALT)^2(DC)^2 \qquad (4\text{-}28) \end{aligned}$$

The equation for distance required to climb has four independent variables. For the same reason as for equation (4-27), the equation of temperature correction is separated from the original equation for better accuracy. The equation of temperature correction for distance required to climb is

$$TEMPD = 4.32 + .6257DT + .712DST + .00658DIST^2 - .0000411DIST^3 \quad (4\text{-}29)$$

The equation of fuel required for descent is derived from the performance chart in the Flight Manual. The performance chart is reproduced in Figure 10. The data on the performance chart are based on descent at 300

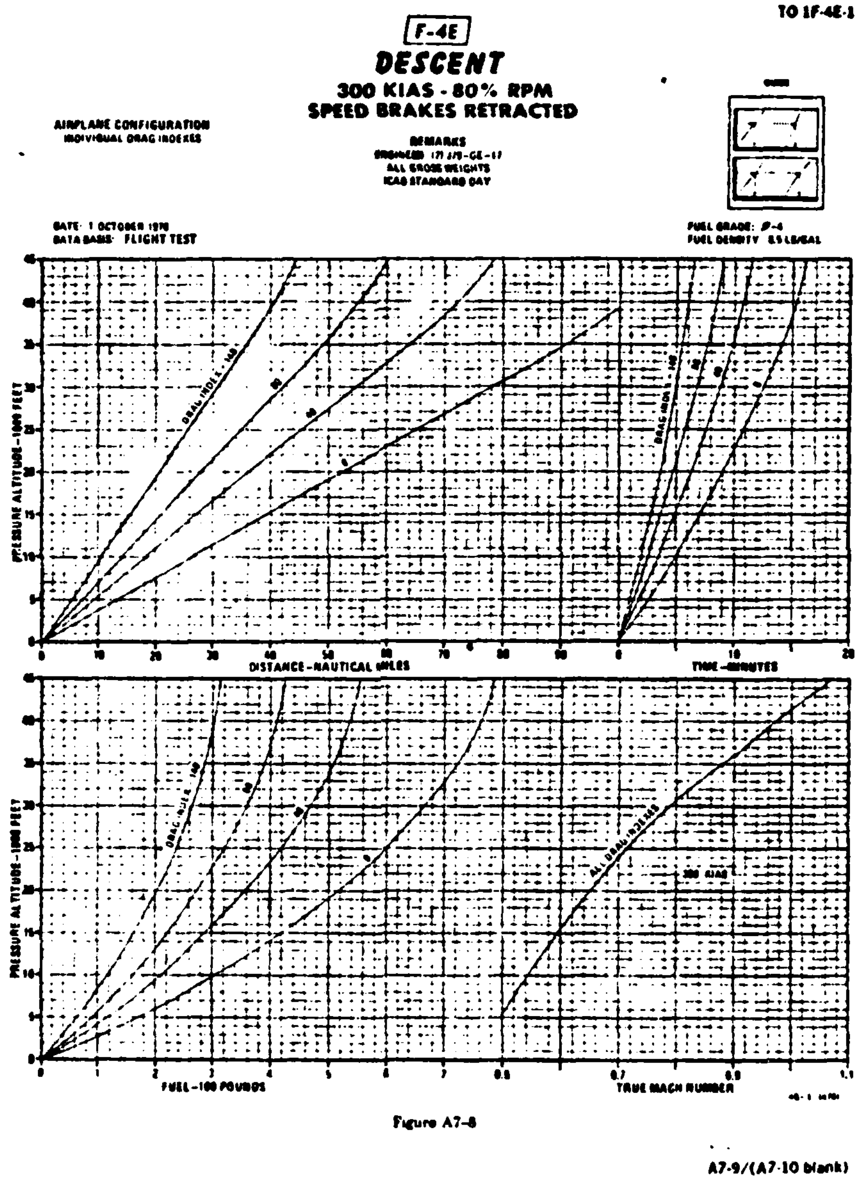


Figure 10. F-4E Descent

KIAS until intersection of desired altitude using 80% RPM with the speed brake retracted. The chart showing fuel required to descend is comprised of two independent variables and one dependent variable. The independent variables are altitude in thousands of feet and drag count. The dependent variable is fuel required to descent from given altitude to sea level. Using the performance chart, the method for determining the fuel required to descend is as follows: enter the upper plot of the fuel required to descent chart at the cruising flight level, project horizontally to the right to intersect both drag reflectors at the applicable computed drag index. From the first intersection, project vertically downward to intersect and read the distance. The equation for fuel required to descend is

$$\begin{aligned} DSFL = {} & 1.5092 + .2063ALT - .059534DC - .000681ALT^2 + .00057143DC^2 \\ & - .0000178ALT^3 - 1.76596 \cdot 10^{-6}DC^3 - 2.25922 \cdot 10^{-7}(ALTDC)^2 \\ & + 2.612572 \cdot 10^{-11}(ALT)^3(DC)^3 \end{aligned} \qquad (4\text{-}30)$$

The equation for distance required to descend from optimum altitude to desired altitude is derived from the performance chart of F-4E Flight Manual. The performance chart is also reproduced in Figure 10. The data on the performance chart are based on the flight test using 80% RPM with descent speed 300 KIAS. The equation of distance required to descend from optimum altitude to desired altitude is comprised of two independent variables and one dependent variable. The two independent variables are Drag Count and Pressure Altitude. The dependent variable is fuel in units of 100 pounds. The equation for distance required to descend from optimum altitude to sea level is

$$DDIST = -1.895 + 3.228ALT - .20426DC - .0473ALT^2 + .0033984DC^2$$
$$+ .00148ALT^3 - .000011666DC^3 - .00001797ALT^4$$
$$- .016636(ALT)\cdot(DC) + 9.093 \cdot (ALT)^2(DC)^2 \qquad (4\text{-}31)$$

The equations for cruise mode are the same as equations (4-9) to (4-18) as in the Optimum Cruise program.

4. Maximum Endurance and Descent Programs

The Maximum Endurance and Descent Programs are separated from the previous program since the programs are worthwhile to use in flight but exceed memory size. The Maximum Endurance Program provides the aircrew with maximum endurance altitude and maximum endurance airspeed for given bank angle and fuel weight.

The Descent Program provides the aircrew with distance and fuel required to descend from any altitude to assigned altitude.

a. Program Input/Output Parameters

The program input/output parameters for the Maximum Endurance and Descent Programs are:

DC = drag count

BW = base weight (lbs)

SW = store weight (lbs)

FW = fuel weight (lbs)

GW = gross weight (lbs)

EW = empty weight (lbs)

BANK ANGLE = bank angle (degrees)

ENDALT = endurance altitude (ft)

TMN	=	true Mach number
FF	=	fuel flow (lbs/hr)
EFGW	=	effective gross weight (lbs).

b. Descent Mode Descriptions

Descent mode is derived from Technical Order-1 F-4E-1 performance charts [Ref. 3]: to derive the charts, set throttle 80% RPM and maintain 300 KIAS with speed brake retracted.

c. Equations of Maximum Endurance and Descent Program

The equation for maximum endurance altitude is derived from the performance chart of the Flight Manual which is reproduced in Figure 11. The data in the performance chart are based on flight tests. Enter the altitude and bank angle chart with the average gross weight. If bank angles are to be considered, follow the gross weight curve until it intersects the bank angle to be used, then horizontally to the right to obtain effective gross weight. From this point proceed horizontally to the right and intersect the computed drag index. Reflect downward and read the optimum endurance altitude. The equation for maximum endurance altitude is comprised of four independent variables and one dependent variable. The independent variables are aircraft bank angle, gross weight, effective gross weight, and drag count. The gross weight and effective gross weight should be in thousands of pounds. The dependent variable is maximum endurance altitude in thousands of feet. The equation of maximum endurance altitude is

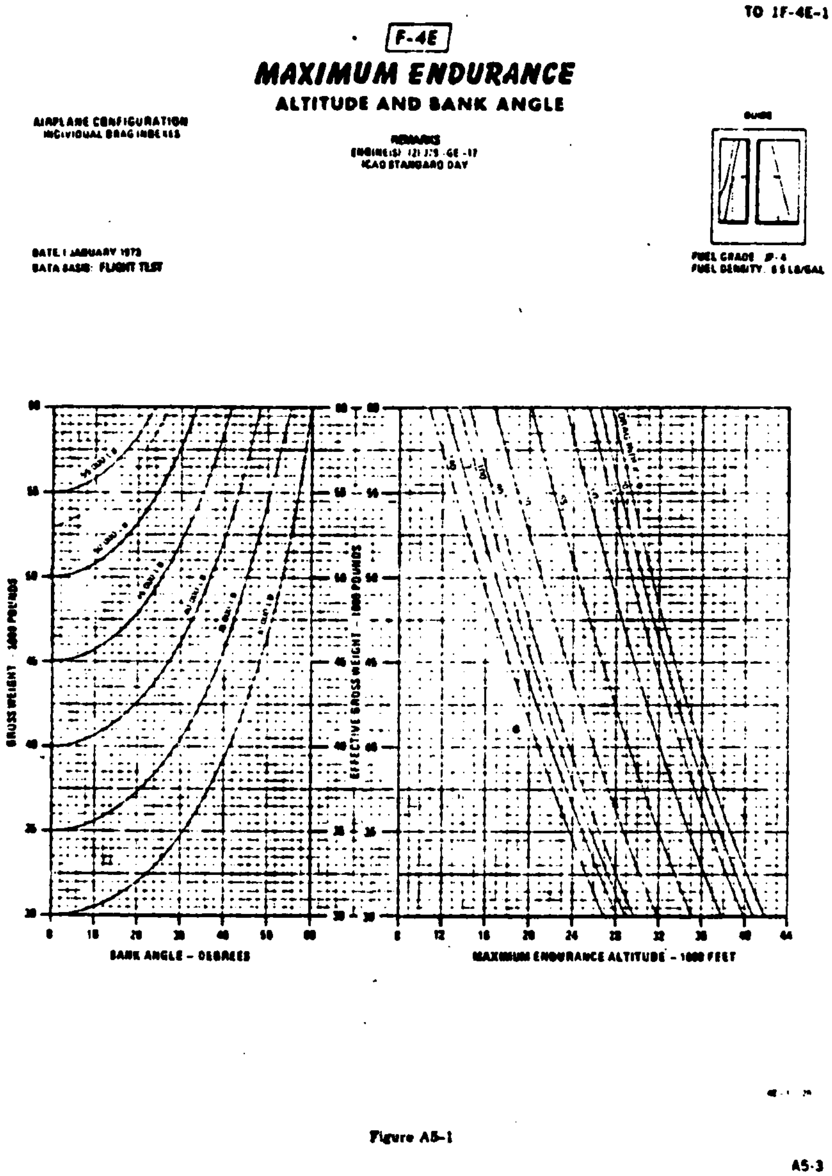


Figure 11. F-4E Maximum Endurance (Altitude and Bank Angle)

$$MEA = 61.95 + .13765DC - .751EGW - .006776DC^2 + .00126EGW^2 + .00005181DC^3 + .0000266EGW^3 - 1.08325 \cdot 10^{-7}DC^4 + .000368(DC)(EGW) - 8.53165 \cdot 10^{-8}(DC)^2(EGW)^2 \quad (4\text{-}32)$$

The equation of maximum endurance true Mach number is derived from the performance chart of Flight Manual which is reproduced in Figure 12. The charts are based on flight test data. The method to determine the maximum endurance Mach number is: enter the Mach number plots with the effective gross weight and proceed horizontally to intersect the optimum endurance altitude. Then descend downward and intersect the computed drag index and horizontally to read the Mach number. The equation is comprised of three independent variables and one dependent variable. The independent variables are effective gross weight in thousands of pounds, drag index, and altitude in thousands of feet. The dependent variable is true Mach number. The equation of Maximum Endurance True Mach number is divided into two equations. One equation is only for drag index from 0 to 80. The other equation is for drag index from 80 to 140. The first equation for Maximum Endurance True Mach number is:

$$METM = -.5945 + .04362EGW + .01661ALT + .0013355DC - .0005554EGW^2 - .0002691ALT^2 - .000018519DC^2 + 6.365632 \cdot 10^{-12}(EGW)^2 \cdot (ALT)^2 \cdot (DC)^2 - 3.9841 \cdot 10^{-17}(EGW)^3(ALT)^3(DC)^3 + .000016965(ALT)^3 + 3.738059 \cdot 10^{-8}EGW^4 - 2.72362 \cdot 10^{-7}(ALT)^4 - .00011123(EGW)(ALT) - .00003831(ALT)(DC) - .000015098(EGW)(DC) \quad (4\text{-}33)$$

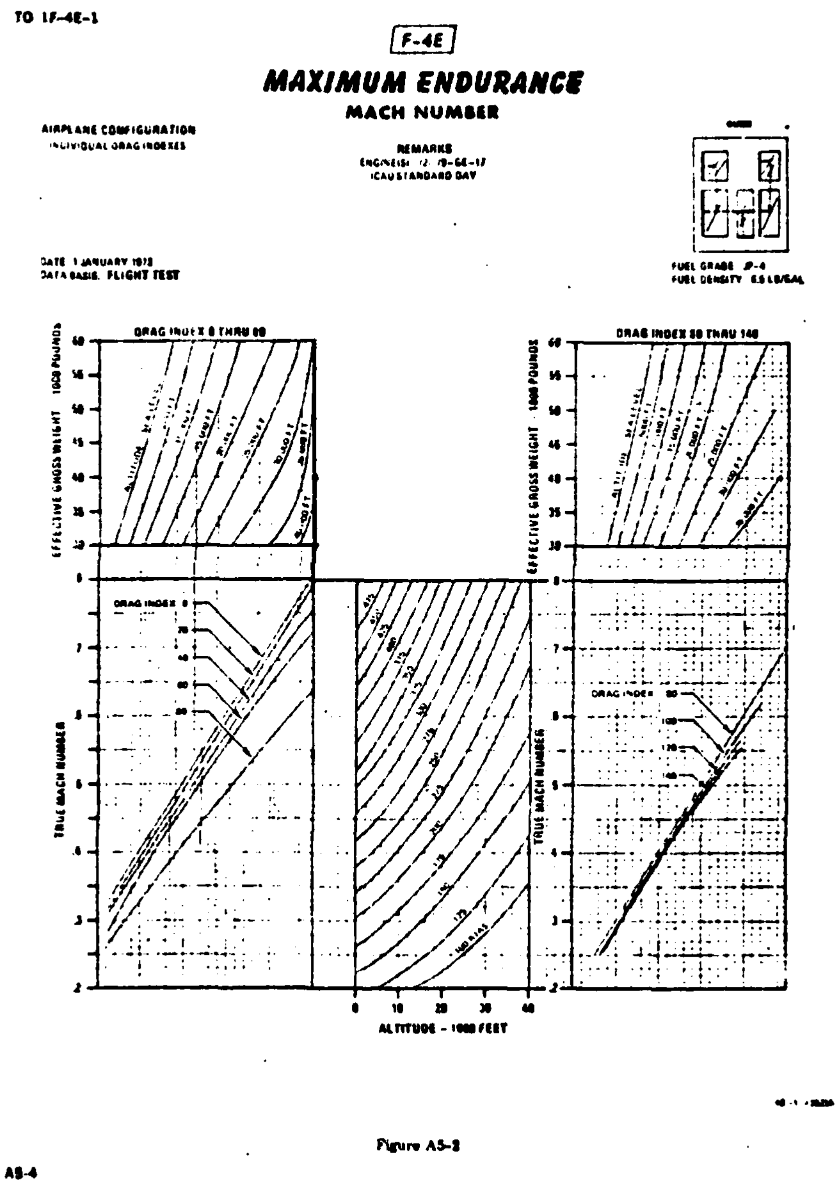


Figure 12. F-4E Maximum Endurance(Mach Number)

The other equation for Maximum Endurance True Mach number, which is for drag count from 80 to 140, is:

$$
\begin{aligned}
METM1 = {} & .1055 + .01407EGW - .007708ALT - .001032DC - .000178EGW^2 \\
& + .00088779ALT^2 + .0000083DC^2 - .000015405ALT^3 \\
& + 1.8173 \cdot 10^{-8}EGW^4 - 4.55763 \cdot 10^{-11}DC^4 + .0000641(EGW)(ALT) \\
& - .000011756(ALT)(DC) - .00001374(EGW)(DC) \qquad (4\text{-}34)
\end{aligned}
$$

The equation of maximum endurance fuel flow is derived from the performance chart of Flight Manual which is reproduced in Figures 13 and 14. The data in the performance chart are based on flight tests. According to the performance chart, total fuel flow is directly proportional to temperature change. The method for determining the maximum endurance fuel flow is illustrated in Figure 14. Enter the fuel flow plots with the effective gross weight, proceed horizontally to intersect optimum endurance altitude. Reflect downward to the computed drag index and then horizontally to read total fuel flow. The equation of the maximum endurance fuel flow is comprised of three independent variables and one dependent variable. The independent variables are effective gross weight in thousands of pounds, pressure altitude in thousands of feet, and drag index. The dependent variable is total fuel flow in thousands of pounds. The equation of maximum endurance fuel flow is divided into three equations. One is for drag count from 0 to 80 and for both high and low altitude. The other is for drag count from 80 to 140 and altitudes above 15,000 feet. The third equation is for drag count from 80 to 140 and altitudes below 15,000 feet. The first equation for maximum endurance fuel flow is:

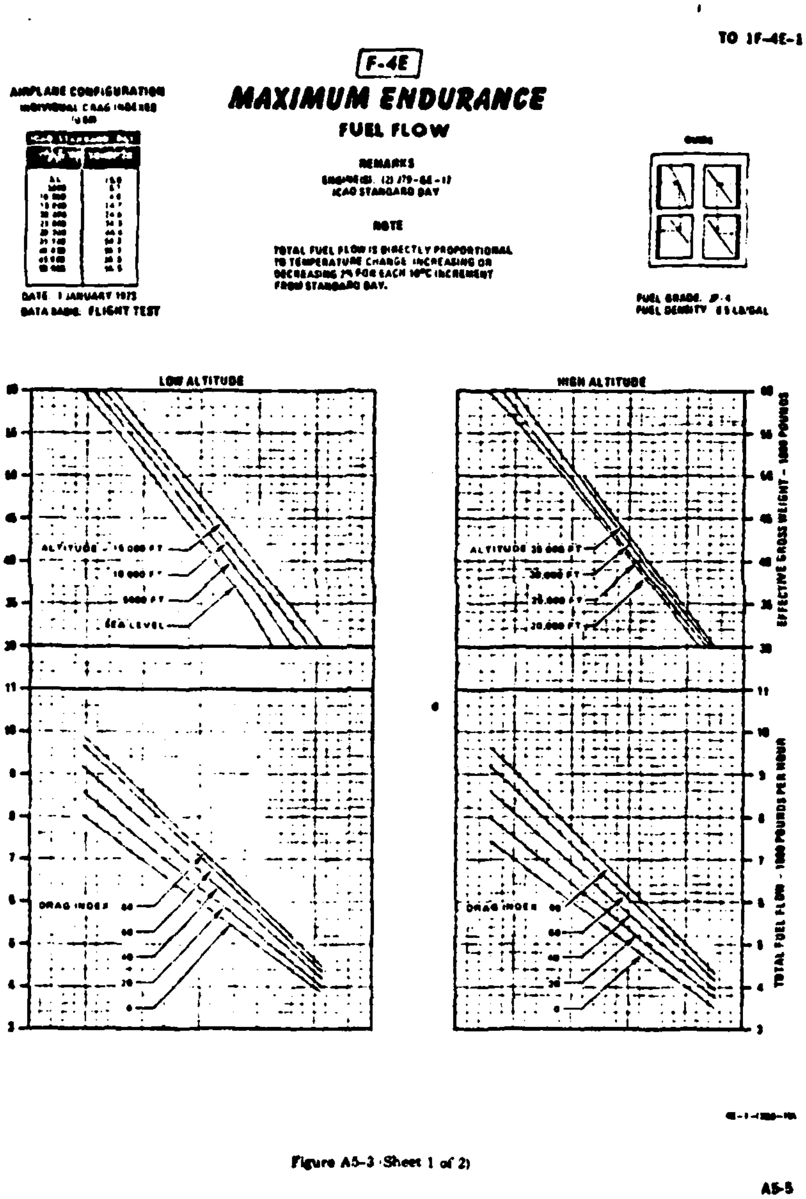


Figure 13. F-4E Maximum Endurance(Fuel Flow, Drag Count 0-80)

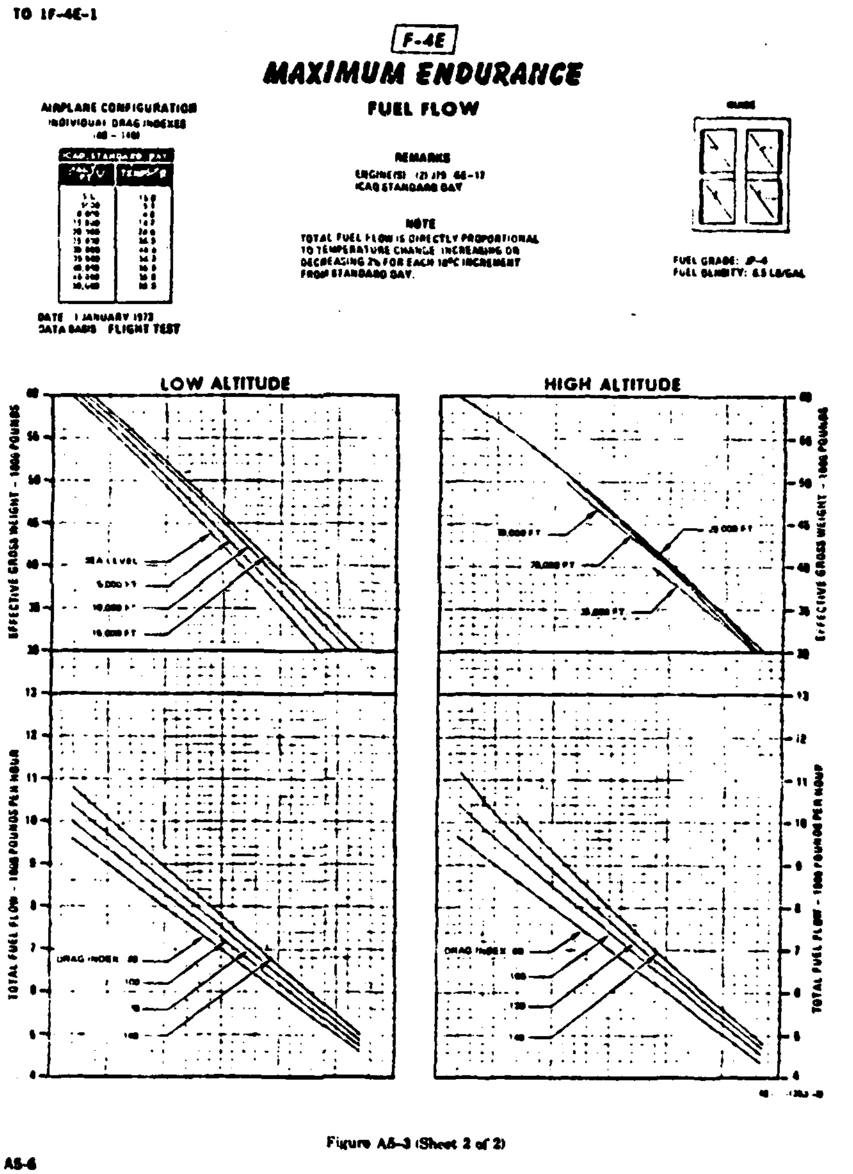


Figure 14. F-4E Maximum Endurance (Fuel Flow, Drag Count 80-140)

$$MEFF1 = -.2901 + .15044EGW - .022618ALT + .023143DC - .0001789EGW^2$$
$$- .000011ALT^2 - .00007903DC^2 + 1.27822 \cdot 10^{-10}(EGW)^2(ALT)^2(DC)^2$$
$$- .000007566(EGW)(ALT)(DC) - 4.94287 \cdot 10^{-16}(EGW)^3(ALT)^3(DC)^3 \tag{4-35}$$

The second equation for maximum endurance fuel flow is

$$MEFF2 = -.8749 + .161209EGW - .037546ALT + .013263DC$$
$$+ .00000267(EGW)(ALT)(DC) - 1.58386 \cdot 10^{-10}$$
$$(EGW)^2(ALT)^2(DC)^2 + 2.206628 \cdot 10^{-15}(EGW)^3(ALT)^3(DC)^3$$
$$- 8.18252 \cdot 10^{-21}(EGW)^4(ALT)^4(DC)^4 \qquad (4\text{-}36$$

The third equation for maximum endurance fuel flow is:

$$MEFF3 = 3.5516 + .06342EGW - .21834ALT + .013415DC$$
$$- .00006319DC^2 + .000013187(EGW)(ALT)(DC) \tag{4-37}$$

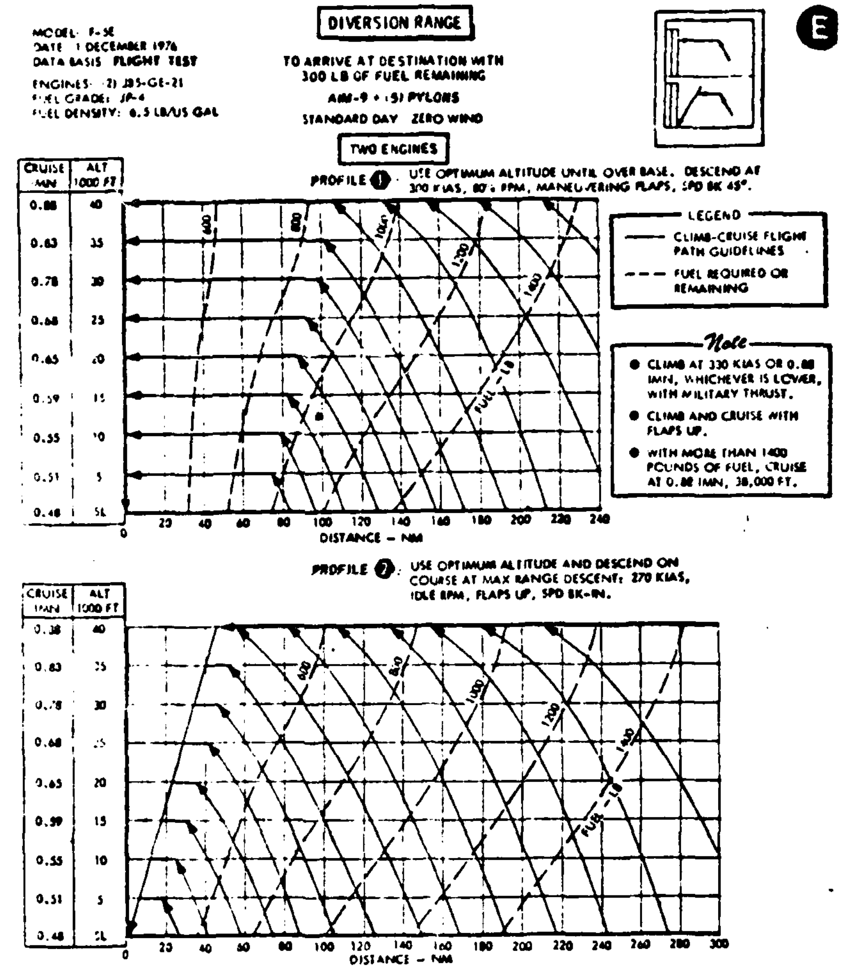
The equations for the descent program are the same as the equations for descent used in the Bingo program. The equations for descent used in the maximum endurance and descent progras are equations (4-30) and (4-31).

V. F-5E PROGRAM

A. F-5E PROGRAM DESCRIPTION

The F-5E aircraft does not have a computer; consequently, the aircrew cannot determine the wind conditions in flight. Lack of Central Air Data Computer means that wind corrections cannot be applied in F-5E program, since the aircrew do not have means to correct for wind during the flight.

Most of the aircrew of the F-5E wanted to have a method to determine diversion range without using the Flight Manual in flight. The F-5E is a single-seat fighter, so the pilot does not have time to consult the Flight Manual in flight. The best way to use the diversion chart is to memorize salient features for the typical flight. Keeping track of the performance data during the flight is too difficult. The HP-41CV program provides the aircrew with altitude, Mach number, and specific range for best range cruise, and, also provides the aircrew with diversion range, diversion speed, minimum fuel required from given point to required destinations. In the diversion mode, single-engine performance is available as well as dual-engine performance. Diversion range with both engines operating is programmed to arrive at the destination with 300 lbs. of fuel remaining using the Profile-2 method in the Flight Manual. Profile-2 method for both engines operating is described in the performance chart of the Flight Manual which is reproduced in Figure 15. Special care should be taken about base weather condition, since the fuel remaining is not sufficient for flying to an alternate base. The data of



PROFILE 1: FUEL IS INCLUDED FOR CLIMB TO OPTIMUM ALTITUDE AND PENETRATION DESCENT AT DESTINATION. NO DISTANCE CREDIT FOR DESCENT TO DESTINATION.

PROFILE 2: FUEL IS INCLUDED FOR CLIMB TO OPTIMUM ALTITUDE AND MAXIMUM RANGE DESCENT TO DESTINATION. RANGE INCLUDES DISTANCE FOR ON-COURSE DESCENT TO DESTINATION.

F-5 1-58991C

FA4-10 (Sheet 1).

Figure 15. F-5E Diversion Range (Two Engines)

this program are based on a standard day with zero wind. The configuration of the aircraft is assumed to be 2 AIM-9 with 5 pylons. The single engine diversion program uses basically the same conditions as for the diversion range program with both engines operating. The single engine diversion range program is based on the data of a single engine without using after-burner. The configuration of the aircraft with single engine diversion range program is assumed to be 2 AIM-9 with 5 pylons. The Profile-2 method was applied in the single engine diversion range program. The single engine Profile-2 method is described in Figure 16.

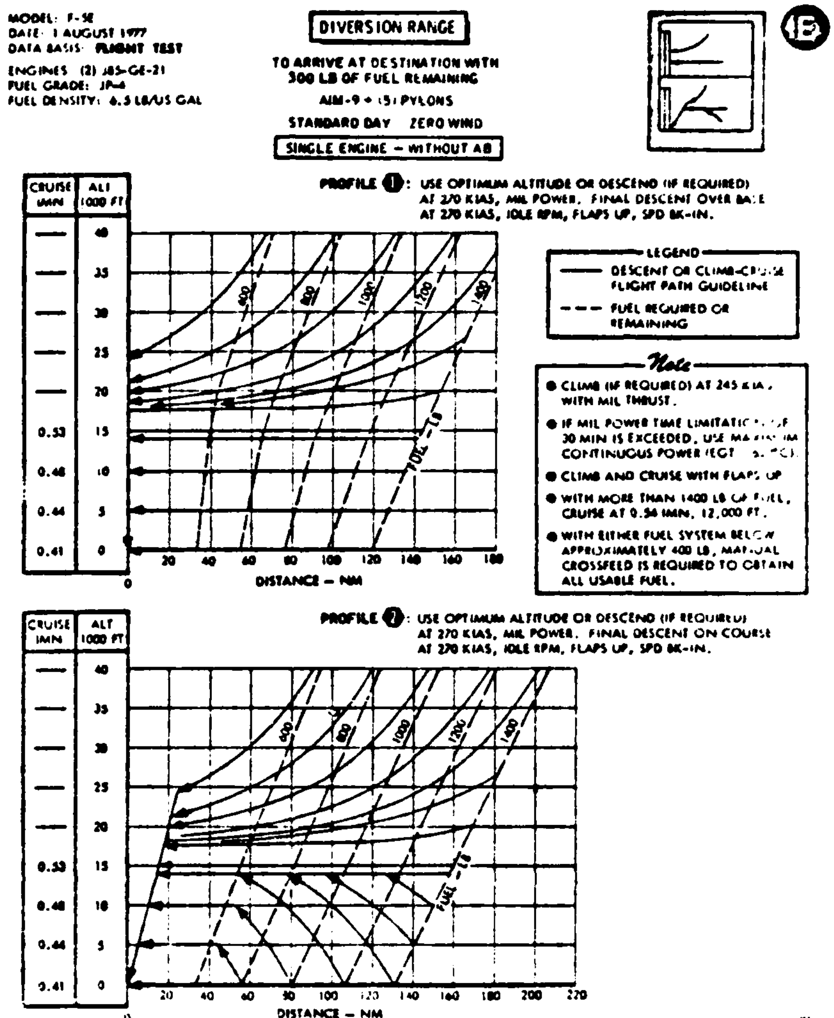
B. CLIMB AND DESCENT METHOD USED IN F-5E PROGRAM

1. Optimum Cruise for Short Range Mission

The climb method assumed for an optimum cruise mission in the program is military thrust climb. Descent distance computed for optimum cruise mode was programmed with the assumptions of using power idle, maintaining descent air speed of 270 KIAS with speed brake in and flaps up.

2. Diversion Range for Both Engines

Climb and descent procedure in this mode is as follows: Climb with maintaining airspeed 330 KIAS or Mach 0.88 IMN, whichever is lower using military thrust. Cruise with flaps up. With more than 1400 lbs. of fuel, cruise at Mach 0.88 IMN and at 38,000 ft. Fuel is included for climb to optimum altitude and maximum range descent to destination. Diversion range includes distance for on-course descent to destination. Use optimum altitude and descent on-course at maximum range descent using 270 KIAS with power IDLE and flaps up with speed brake in.



PROFILE 1. FUEL IS INCLUDED FOR DESCENT TO OPTIMUM ALTITUDE AND DESCENT AT DESTINATION. NO DISTANCE CREDIT FOR DESCENT TO DESTINATION.

PROFILE 2 FUEL IS INCLUDED FOR CLIMB OR DESCENT TO OPTIMUM ALTITUDE AND MAXIMUM RANGE DESCENT TO DESTINATION; RANGE INCLUDES DISTANCE FOR ON-COURSE DESCENT TO DESTINATION.

FA4-10 (Sheet 3).

Figure 16. F-5E Diversion Range (One Engine)

3. Diversion Range for Single Engine

Climb and descent procedure in this mode is described here in accordance with the F-5E Flight Manual. If the flying condition permits, use the following climb and descent procedure: Climb at 245 KIAS with military thrust. If the time limitation of military power (30 minutes) is exceeded, then use maximum continuous power with maintaining the exhaust gas temperature at 650 degree centigrade. Climb and cruise with flaps up. With more than 1400 lbs. of fuel, cruise at 0.54 IMN and maintain altitude at 12,000 ft. With either fuel system below approximately 400 lbs., manual crossfeed is required to obtain all usable fuel. Use optimum altitude or descent (if required) at 270 KIAS with military power. Final descent is on course at 270 KIAS and IDLE RPM with flaps up and speed brake in. Fuel is included for climb or descent to optimum altitude and maximum range descent to destination. The range for a single engine diversion includes distance for on-going descent to destination.

C. PROGRAM INPUT/OUTPUT PARAMETERS

The input and output parameters are essentially the same as F-4E input and output parameters.

DS	= Optimum cruise distance for short range missions (nm)
DC	= Drag count
GW	= Gross weight (lbs)
ALT	= Altitude (ft)
AW	= Average gross weight (lbs)
DIST	= Distance required to go (nm)
IA	= Initial altitude (ft)

FALT = Final altitude (ft)

OCA = Optimum cruise altitude (ft).

D. EQUATIONS FOR F-5E PROGRAM

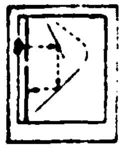
The equations for F-5E program are based on the flight test data which are in the performance data chart of F-5E Flight Manual [Ref. 4: pp. A4-6]. Optimum cruise for short range missions, which is defined by the Flight Manual for F-5E aircraft [Ref. 4: pp. 9], is the maximum value of specific range for short range mission. A flight to a maximum range of 250 nautical miles is defined as the short range mission in the Flight Manual [Ref. 4: pp. A4-6]. Specific range is the nautical miles flown per pound of fuel consumed. Assuming both engines of F-5E are operating, three charts are relevant to determination of optimum cruise conditions. The three charts are reproduced here as Figures 17, 18, and 19. For a short range mission, the cruise altitude may optimize at a lower altitude than is required for a long range mission. The optimum cruise altitude for the short range missions chart, which is reproduced in Figure 17, presents the cruise altitude for short range mission as a function of climb-cruise-descent distance. If the intersection of the drag index and mission range distance plot falls outside the dashed "Use-optimum-cruise-altitude" line, obtain optimum cruise altitude from charts FA4-2 or FA4-3 in the Flight Manual [Ref. 4: pp. A4-10, 11]. To use the chart enter the chart with drag index, proceed right to the desired mission range distance, and then down to the start climb gross weight. From this point, proceed left to read pressure altitude for cruise. The equation of optimum cruise altitude for short range missions consists of three independent variables and one dependent variable. The three independent

MODEL: F-5E,T
DATE: 1 MARCH 1976
DATA BASIS: ESTIMATED

ENGINES: (2) J85-GE-21
FUEL GRADE: JP-4
FUEL DENSITY: 6.5 LB/US GAL

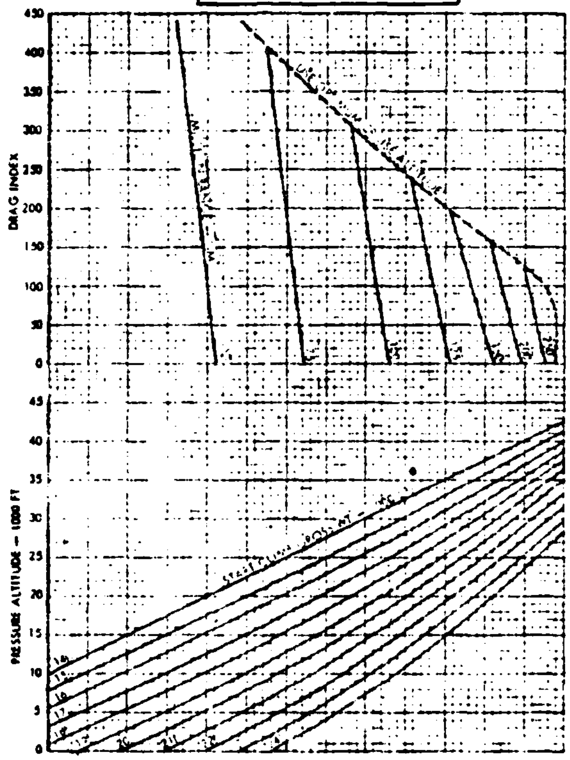
OPTIMUM CRUISE ALTITUDE FOR SHORT-RANGE MISSIONS (FLAPS UP)

STANDARD DAY



CONDITIONS

- MILITARY THRUST CLIMB.
- LONG-RANGE CRUISE IMN.
- PENETRATION DESCENT ON COURSE WITH SPEED BRAKE OUT.



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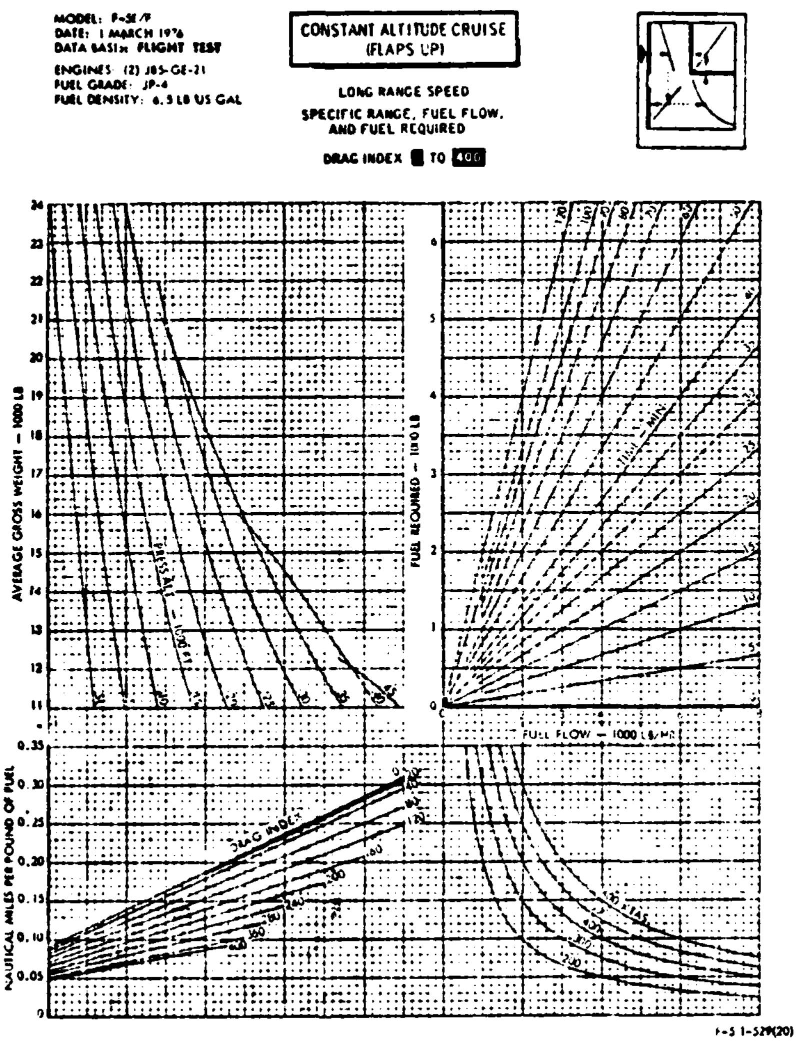
FA4-1.

Figure 17. F-5E Optimum Cruise Altitude for short Range Missions



FA4-6 (Sheet 2).

Figure 18. F-5E Constant Altitude Cruise (Specific Range)

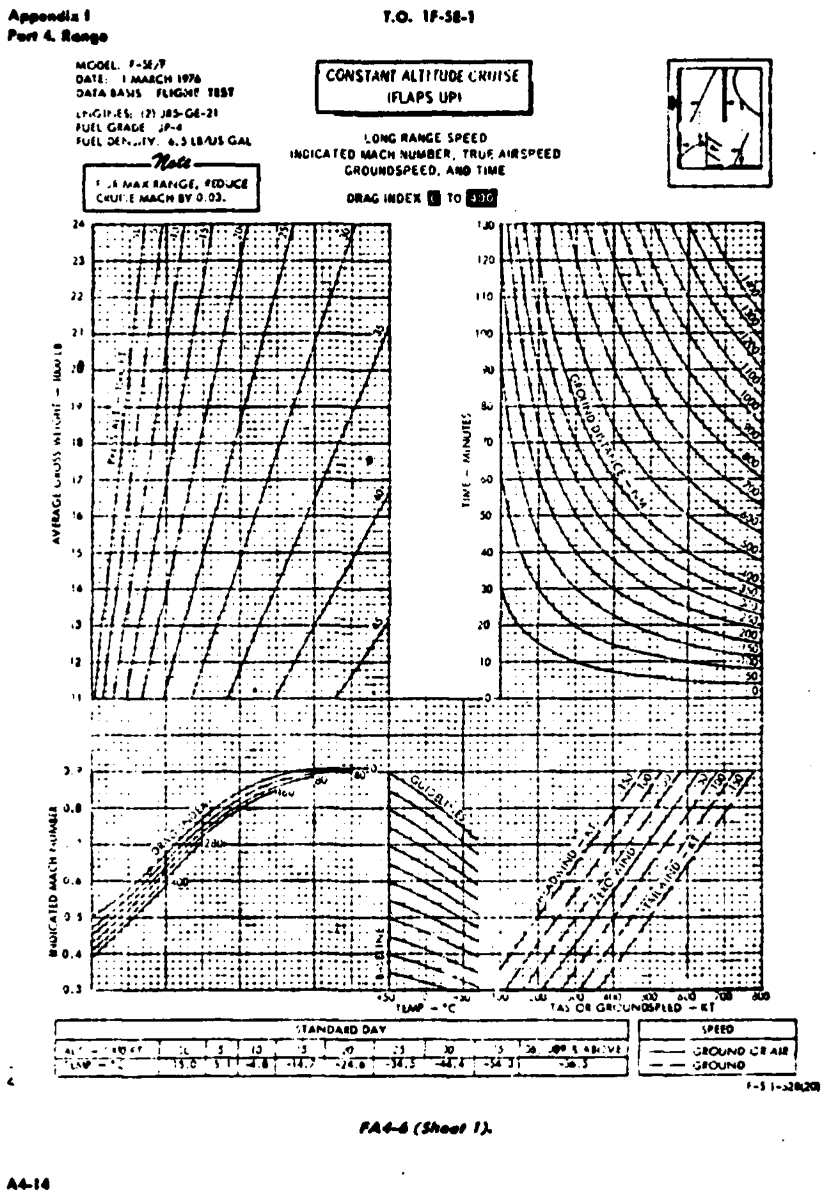


Figure 19. F-5E Constant Altitude Cruise
(Indicated Mach Number)

variables are drag index, mission range in nautical miles, and start-climb gross weight in thousand pounds. The dependent variable is pressure altitude in thousand feet. The optimum cruise altitude for short-range missions is:

$$
\begin{aligned}
OCA = {} & 45.456 - .000212DC - .02316DS - 2.13493GW - .00004554DC^2 \\
& + .0023214DS^2 - .00627GW^2 + 1.604969 \cdot 10^{-7}DC^3 \\
& - 1.24904E - 05DS^3 - .0007469GW^3 - 6.75362 \cdot 10^{-11}DC^4 \\
& - .00004143(DC)(DS) + .006857(DS)(GW) - 3.04712 \cdot 10^{-12} \\
& \quad (DC)^2(DS)^2(GW)^2 + 8.193166 \cdot 10^{-19}(DC)^3(DS)^3(GW)^3 \\
& + 8.962771 \cdot 10^{-15}(DC)^3(DS)^3 - 2.43198 \cdot 10^{-11}(DS)^3(GW)^3 \\
& - 2.45711 \cdot 10^{-13}DC^5 + 6.334016 \cdot 10^{-11}DS^5 \\
& + 4.868 \cdot 10^{-7}GW^5
\end{aligned}
\tag{5-1}
$$

The equation for indicated Mach number for optimum cruise range is derived from the flight performance chart in F-5E Flight Manual which is reproduced in Figure 19. The flight performance chart provides optimum indicated cruise Mach number as a function of average gross weight, pressure altitude, and drag index. The data on the performance chart are based on flight tests. The method to determine the indicated Mach number is as follows: enter the chart of Figure 19 with average gross weight in thousands of pounds, proceed right to the cruise pressure altitude, down to drag index, then left and read optimum indicated Mach number. The independent variables of the Optimum Cruise Indicated Mach Number are average gross weight in thousands of pounds, pressure altitude in thousands of feet, and drag count. The dependent variable is Optimum Cruise

$$
\begin{aligned}
OSR = {} & .17836 - .00333(AGW) + .0037629(ALT) - .00031305(DC) \\
& - .000126(AGW)^2 + .00005315(ALT)^2 - 1.06144 \cdot 10^{-6}(DC)^2 \\
& + 4.528377 \cdot 10^{-9}(ALT)^3 + 2.314 \cdot 10^{-7}(AGW)^4 - 3.15477 \cdot 10^{-8}(ALT)^4 \\
& - 4.55793 \cdot 10^{-12}(DC)^4 + 4.368255 \cdot 10^{-10}(ALT)^5 - .00007685(AGW) \\
& \cdot (ALT) + 1.496 \cdot 10^{-5}(AGW)(DC) - 5.5628 \cdot 10^{-6}(ALT)(DC) \\
& - 7.73637 \cdot 10^{-8}(AGW)^2(ALT)^2 - 5.81959 \cdot 10^{-10}(AGW)^2(ALT)^2 \\
& + 7.246215 \cdot 10^{-11}(ALT)^2(DC)^2 \qquad (5\text{-}3)
\end{aligned}
$$

The equation for diversion range is derived from the diversion range chart in the F-5E Flight Manual which is reproduced in Figures 15 and 16. Each diversion range chart provides the maximum range obtainable for two optional return profiles with from 600 to 1400 pounds of available fuel remaining. The range pertains to an aircraft with AIM-9 missiles and five pylons and is based on 300 pounds of fuel remaining for approach and landing after descent is completed. A climb speed schedule and recommended long range cruise indicated Mach number are included in the F-5E program. The Profile-2 of both engine and single engine is chosen in the F-5E program. The Profile-2 is defined in Figures 15 and 16. If there is insufficient fuel for Profile-1, Profile-2 is recommended. The chart may be entered at the initial altitude with either the fuel on board or with the distance to be flown (to determine the fuel required). To determine range, enter the profile chart with initial altitude, move horizontally right to the pounds of fuel remaining curve, and then vertically down to read the air distance. To determine the optimum cruise altitude for two engine operation, start at this intersection and move up parallel to the nearest climb path guide line to intersect the nearest

Indicated Mach Number. The equation for Optimum Cruise Indicated Mach Number is:

$$\begin{aligned}
OCIMN = {} & .496 - 05152AGW - .00448ALT - .0022606DC + .0010828AGW^2 \\
& - .0001844ALT^2 + 1.0873 \cdot 10^{-5}DC^2 - 1.82326 \cdot 10^{-8}DC^3 \\
& - 1.72218 \cdot 10^{-7}AGW^4 + 6.746013 \cdot 10^{-8}ALT^4 + .0033928(AGW)(ALT) \\
& + 1.2486 \cdot 10^{-5}(ALT)(DC) - 2.19486 \cdot 10^{-6}(AGW)^2(ALT)^2 \\
& - 5.77016 \cdot 10^{-10}(ALT)^2(DC)^2 - 7.82001 \cdot 10^{-8}(AGW)(ALT)(DC) \\
& - 4.10904 \cdot 10^{-18}(AGW^3(ALT)^3(DC)^3 \qquad (5\text{-}2)
\end{aligned}$$

The equation for optimum cruise is derived from the performance chart in the Flight Manual which is reproduced in Figure 18. The performance chart in Figure 18 provides specific range (nautical miles-per-pound of fuel) as a function of average gross weight, pressure altitude, and drag count. The constant altitude cruise chart in Figure 18 must be used for mission planning when optimum range capability is desired. Enter the constant altitude cruise chart in Figure 18 with average gross weight, move right to cruise altitude and down to drag index. Move left and read nautical miles-per-pound of fuel (specific range). The three independent variables of the regressed equation are average gross weight in thousands of pounds, pressure altitude in thousands of feet, and drag index. The independent variable is nautical miles-per-pound of fuel. The equation of specific range (nautical miles-per-pound of fuel) is:

optimum cruise altitude. To determine optimum cruise altitude for single-engine operation, start at the intersection and move up or down parallel to the nearest guideline to intersect the nearest optimum cruise altitude. Single-engine operation may require either up or down movement, depending upon initial altitude. The equation for fuel required for diversion range for both engines operating is derived from the diversion range chart in Figure 15. The equation of fuel required for diversion range with both engines operating is comprised of two independent variables and one dependent variable. The two independent variables are distance in nautical miles and initial altitude in thousands of feet. The dependent variable of fuel required is in pounds. The equation for fuel required for diversion range (both engines operating) is:

$$\begin{aligned} FD = {} & 269.01 - 11.919IA + 11.866DIST + .0364IA\ .0661DST^2 \\ & - .00167IA^3 + .00021275DIST^3 + .0000579IA^4 \\ & - .004439(IA)(DIST) - 7.81164 \cdot 10^{-10}DIST^5 \end{aligned} \qquad (5\text{-}4)$$

The equation of optimum cruise altitude for diversion range is derived from the same chart as used for the derivation of equation (5-4). The equation of optimum cruise altitude for diversion range is comprised of two independent variables and one dependent variable. The two independent variables are initial altitude in thousands of feet and distance from present position to desired point in nautical miles. The method for determining optimum cruise altitude for diversion range is described in the previous paragraph. The equation for Optimum Cruise Altitude for diversion range (both engines operating) is:

$$
\begin{aligned}
OALT = {} & .214 + .9098IA + .06382DIST + .00146IA^2 + .004511DIST^2 \\
& - .0000117IA^3 - .00002477DIST^3 - .000001142IA^4 \\
& + 2.426804 \cdot 10^{-8}DIST^4 \cdot .0059984(IA)(DIST)
\end{aligned} \quad (5\text{-}5)
$$

The equation of optimum cruise indicated Mach number for diversion range for both engines operating is derived from the diversion range chart in Figure 15. The optimum cruise Mach number for diversion range is the Mach number to be maintained during the cruising. The equation has only one independent variable and one dependent variable. The independent variable is optimum cruise altitude in thousands of feet and the dependent variable is indicated Mach number. The equation of optimum cruise indicated Mach number for diversion range (both engines operating) is:

$$
DRMN = .57567 - .007383ALT + .0006679ALT^2 - .00000733ALT^3 \quad (5\text{-}6)
$$

The chart of diversion range for single engine without afterburner has two profiles. Profile-2 is chosen in the F-5E program. The chart may be entered at the initial altitude with either the fuel on board (to determine range available) or with the distance to be flown (to determine the fuel required). To determine range, enter the appropriate profile chart with initial altitude, move horizontally right to the pounds-of-fuel remaining curve, and then vertically down to read the air distance. To determine the optimum cruise altitude for single engine operation, start at the intersection and move up or down parallel to the nearest guide line to intersect the nearest optimum cruise altitude. Single engine operation may require either up or down movement depending upon initial altitude. Maximum range can be obtained only by climb or descent to optimum altitude. If the intersection plot of the initial altitude and fuel remaining curve coincides with the optimum cruise altitude, remain at that altitude for cruise. To determine the fuel required for a given distance to return to base, enter the chart with initial altitude, and move horizontally right to a point of intersection with the distance to base. At this point, read the fuel required, then proceed parallel to the nearest climb or descent path guideline to determine the optimum cruise altitude. The equation for single engine fuel required for diversion range is derived from diversion range chart for single engine which is reproduced in Figure 16. The equation consists of two independent variables and one dependent variable. The independent variables are initial altitude in thousands of feet and distance from given point to destination in nautical miles. The dependent variable is fuel required in pounds for single engine diversion range without using afterburner. The equation is:

$$\begin{aligned} SFD = {} & 287.26 + 9.55469DIST - 10.862IA - .01335DIST^2 \\ & + .1838IA^2 + .00004175DIST^3 - .00314IA^4 \\ & - .06098(DIST)(IA) + .000002731(DIST)^2(IA)^2 \end{aligned} \tag{5-7}$$

The equation for single engine optimum cruise altitude for diversion range is derived from the same chart as the chart for equation (5-7). The method to use the diversion range chart for single engine without afterburner is described in the previous paragraph. The equation for single engine optimum cruise altitude for diversion range without afterburner has two independent variables and one dependent variable. The independent variables are initial altitude in thousands of feet and distance from a point to destination in nautical miles. The dependent variable is single engine optimum cruise altitude for diversion range in thousands of feet. The single engine optimum cruise altitude for diversion range is:

$$\begin{aligned} SOALT = & - 3.9211 + .43701DIST - .49916IA - .0033565DIST^2 \\ & + .058596IA^2 + 8.214 \cdot 10^{-6}DIST^3 \\ & - .00124676IA^3 + 1.09364IA^4 \end{aligned} \quad (5\text{-}8)$$

The equation for single engine indicated Mach number for diversion range is derived from the same chart as the chart for equation (5-7) which is reproduced in Figure 16. Optimum cruise indicated Mach number in the chart is given in the column next to the altitude scale. The equation is comprised of one independent variable and one dependent variable. The independent variable is final altitude in thousands of feet. The final altitude is the optimum cruise altitude that must be maintained throughout the diversion range profile. The equation for indicated Mach number for diversion range with single engine without afterburner is:

$$\begin{aligned} SDRMN = & .46766 - .01597(FALT) + .002464(FALT)^2 \\ & - .00007455(FALT)^3 - 1.44238 \cdot 10^{-9}(FALT)^5 \end{aligned} \quad (5\text{-}9)$$

The equation for descent point from optimum cruise altitude to sea level is derived from the same chart as used for equation (5-4). The range to begin the maximum range descent to base is determined by reading the air distance at the intersection of the optimum cruise altitude line with the descent line. The equation has one independent variable and one dependent variable. The independent variable is cruise altitude and the dependent variable is the range at which to begin the maximum range descent. The equation for begin descent point from optimum cruise altitude is:

$$DRDSPT = \left(\frac{45}{40}\right) \frac{ALT}{1000} \tag{5-10}$$

The equation of single engine descent point for diversion range is derived from the same chart as the chart for equation (5-7). The range at which to begin the maximum range descent to base is determined by reading the air distance at the intersection of the cruise altitude line with the descent line. The independent variables of the equation is cruise altitude and the dependent variable of the equation is the range at which to begin the maximum range descent. The equation of single engine diversion range descent point is:

$$SRDSPT = \frac{ALT}{1000} \tag{5-11}$$

The equation for distance required from optimum cruise altitude to sea level is derived from the penetration chart in Flight Manual which is reproduced in Figure 20. The configuration of descent used in the chart is speed brake with maneuvering flaps. Descent speed schedule is 300 KIAS. The method to use the chart is as follows: enter the chart of Figure 20 at initial descent pressure altitude and proceed up to the value of drag index configuration. Interpolation is required for values between drag index curves on the graph. Next, read the distance. The independent variable is altitude and the dependent variable is the distance required to descend from cruise altitude to sea level. The equation is:

$$DIST = (-.00164DC + 1.3111)ALT \tag{5-12}$$

Appendix I
Part 6. Descent

T.O. 1F-5E-1

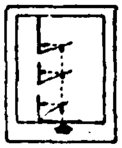
MODEL: F-5E/F
DATE: 1 AUGUST 1976
DATA BASIS: FLIGHT TEST

ENGINES: (2) J85-GE-21
FUEL GRADE: JP-4
FUEL DENSITY: 6.5 LB/US GAL

PENETRATION DESCENT

80% RPM

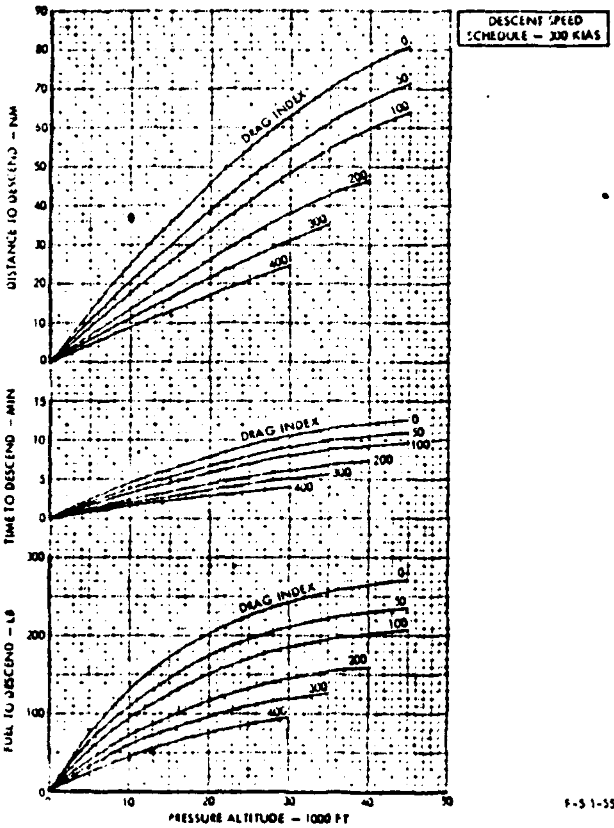
SPEED BRAKE IN   MANEUVERING FLAPS



STANDARD DAY

DRAG INDEX 0 TO 400

ALL GROSS WEIGHTS



F-5 1-553(20)

FA6-2.

A6-4

Figure 20. F-5E Pentration Descent

VI. F-4E USER'S GUIDE

A. CRUISING PROGRAM

1. Loading the Program

The following procedure is used to load the program:

(1) Plug the card reader into the HP-4CV. Be certain the calculator is OFF.

(2) Clear the memory by pressing the (ON) key while holding the error (←) key depressed.

(3) Execute the size function using size 022 as the input.

(4) Assign the START, PFT, and IFT, modes to their respective keys as shown in Figures 21, 22, and 23. This must be done by executing an ASN function for each mode, keying in the alpha labels, and pressing the designated keys.

(5) Put the calculator into USER mode by pressing the (USER) key. The word "USER" should appear in the lower left corner of the display window.

(6) Read the 19 sides of magnetic cards into the card reader.

(7) Execute the PACK function after all cards have been read in.

2. Executing the Optimum Cruise Program for F-4E

On the initial run-through program, the operator is assumed to be on the ground level prior to takeoff; therefore, initial flight information must be input.

a. Start Mode

(1) Pressing the key labeled "START" puts the program in initial mode.

(2) Once in the START mode the operator will be prompted for inputs of drag count, base weight, (F-4E aircraft weight), store weight (total), and fuel weight.

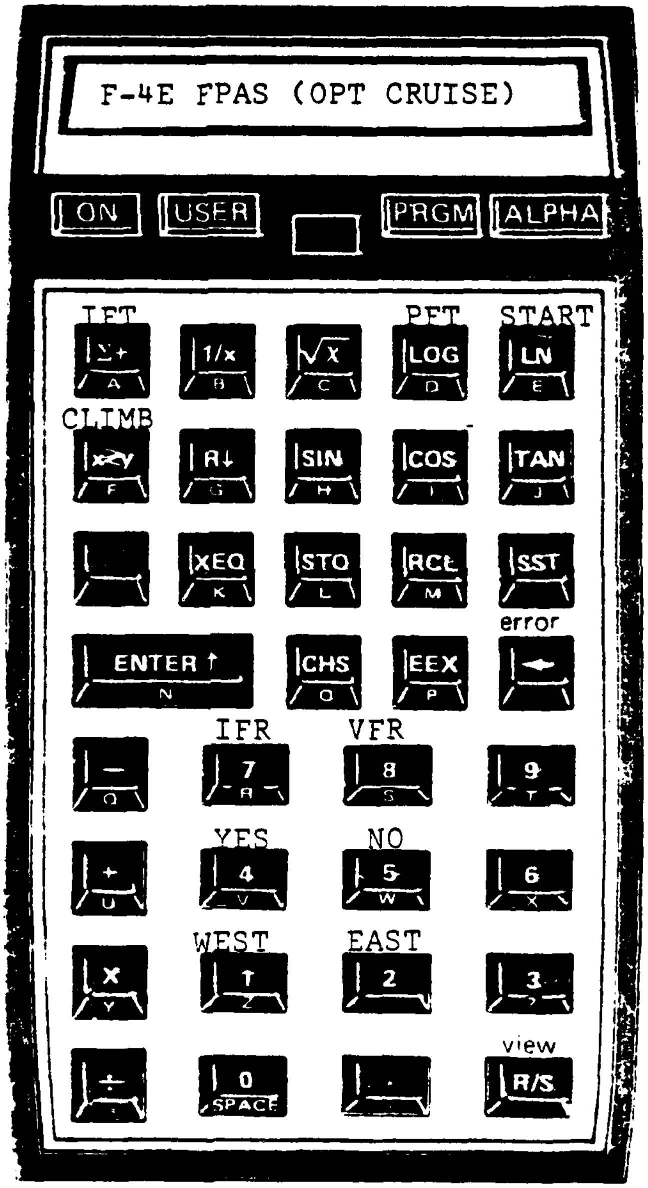


Figure 21. HP-41CV Keyboard Functions for Optimum Cruise Program

(3) Whenever a prompt for or display of data occurs, the "R/S" button must be pressed in order to instruct the program to continue execution. The "R/S" button must be pressed after the data has been keyed in or after the display has been viewed.

(4) The program will display the values of drag count and gross weight after the data has been input in order to verify the values have been correct.

(5) The next press of "R/S" leads to a prompt for a "YES" or "NO" according to whether or not the operator will be subject to FAA flight restrictions. The "YES" and "NO" input buttons are provided on the calculator and labeled on the overlay face: furthermore, the calculator prompts for the answer:

> Input a "4" or a "5" in the display window upon choosing a "YES" or "NO" input, respectively.

(6) Another depression of the "R/S" key prompts the operator for the next mode desired.

b. Option of FAA or START Key

If the operator wishes to change aircraft configuration, START buttons enables him to do so.

(1) Pressing the FAA key enables the operator to re-input either a "YES" or a "NO" to the FAA prompt. Pressing the "R/S" key after the input returns the prompt for mode selection.

(2) Pressing the "START" button enables the operator to change any or all of the drag counts, store weight, and fuel weight.

If one or more of the values are to remain the same, the previous value must be input again. The values of drag count and gross weight will be displayed as in the start mode for verification. The next press of "R/S" returns the prompt for mode selection.

c. Preflight Mode (PFT)

Next, the PFT mode may be selected in order to obtain initial cruise performance data.

(1) Pressing the PFT key puts the program in pre-flight mode.

(2) The PFT mode has two paths depending on whether or not the operator is subject to FAA flight restrictions:

(a) If the operator is not subject to FAA flight restrictions, he will be first prompted for the standard day temperature. Upon pressing the "R/S" key, he will be prompted for the temperature at the altitude displayed to the right of the window. If the operator desires the standard temperature, he need only to press the "R/S" key again, otherwise the temperature key must be pressed. This input of temperature results in the display of the computed best range altitude and Mach number. A prompt for and input of the tail wind components (positive for tail wind and negative for head wind) results in the display of the best range data, true airspeed, ground airspeed, and fuel flow. Pressing the "R/S" key returns the program to the prompt for mode selection.

(b) If the operator is subject to FAA flight restrictions he will have the standard day temperature displayed as in the path described above. The operator will be prompted to input the temperature and will also be prompted to input either an "EAST" or a "WEST" for the heading prompt and either "IFR" or "VFR" for the type of flight clearance. Input keys for each of these data are provided on the calculator overlay face and in the computer program. A "1" or a "2" displayed in the window corresponding to a "EAST" or a "WEST" input respectively, while a "7" or an "8" displayed corresponds to an "IFR" or a "VFR" input, respectively. All of the input values for the program executions are in the program. One can identify the differences of input values and can select the correct value. Once these inputs have been keyed into the program, the computer will compute and display the FAA best range altitude and true Mach number, prompt for the head component, and display the best range data for true airspeed, ground speed, and fuel flow. Pressing the "R/S" key returns the program to the prompt for mode selection.

Once the operator has reached his initial cruise altitude, he may choose any mode available in the program.

d. In-Flight Mode (IFT)

If the operator wishes to update his best range altitude he must choose the IFT mode.

(1) Pressing the IFT key puts the program into in-flight program mode.

(2) As in the PFT mode, there are two paths of program execution depending on whether or not the operator is subject to FAA flight restrictions:

(a) If the operator is not subject to FAA flight restructions, he will first be prompted for his current fuel weight. Following the display of the standard day temperature, the rest of the mode is identical to the path of the PFT mode. The best range conditions displayed will be the most fuel efficient altitude based upon the present fuel status of the F-4E and the measured temperature and wind data. Pressing the "R/S" key returns the prompt for mode selection.

(b) If the operator is subject to FAA restrictions, he will be prompted to input his fuel weight and his present altitude respectively. The standard day temperatures will be displayed on the display window. Upon the prompt for temperature, the STD (Standard Day Temperature) or another temperature may be input as described in the PFT mode, and best range Mach number will be displayed. A prompt for and input of the tail wind components results in the display of the best range data for true airspeed, ground speed, and fuel flow. Pressing the "R/S" key results in the display of the next FAA best range altitude change and the corresponding fuel weight at which to initiate his climb. If the word "CEILING" was displayed, the operator has reached the maximum operating altitude for his operating aircraft configuration. No further stepping of the altitude will be done after this point. Pressing the "R/S" key returns the prompt for mode selection.

B. BINGO PROGRAM

1. Loading the Program

This program applies to the HP-4CV without extended memory. However, with the extended memory module, follow the same procedure as described in this section.

(1) While pressing the error key (←), turn on the calculator and release the error key.

(2) Execute SIZE function using size 032 as the input.

(3) Place the calculator in "USER" mode and begin reading in the cards.

(4) If you failed to read in the program with "USER" mode, then assign the DATA and BINGO modes as described in Figure 22. This must be done by executing an ASN function for each mode, keying in the alpha labels, and pressing the designated keys.

2. Executing the Bingo Program

a. Initialization

To begin the flight planning, and to initialize the FPAS for a mission, the program is first set up with mission configuration. To initialize, key (SHIFT) which is assigned to (ε+) key. Then enter values based on the cues displayed:

(1) TOGW? = Input the take-off gross weight in pounds.

(2) STOREWT? = Input the weight of all ordnance stores in pounds.

(3) FUELWT? = Input the total fuel on-board in pounds.

(4) DC? = Input the total drag count.

"INIT O.K" signifies that initialization is complete and options may be selected.

b. Bingo Options

Bingo is defined here as a military climb, best range cruise, and descent flight profile from sea level to optimum cruise altitude and back to sea level. This option provides the minimum necessary information to execute an optimum Bingo profile as well as all of the data necessary for the jet card when used for flight training. Press Bingo which is assigned to ($\sqrt{x}$).

(1) DISTANCE? = Input the total distance in nautical miles to go.

(2) FUELWT? = Input the current weight of the fuel onboard in pounds.

(3) DELTMP? = Input the sea level outside air temperature in centigrade.

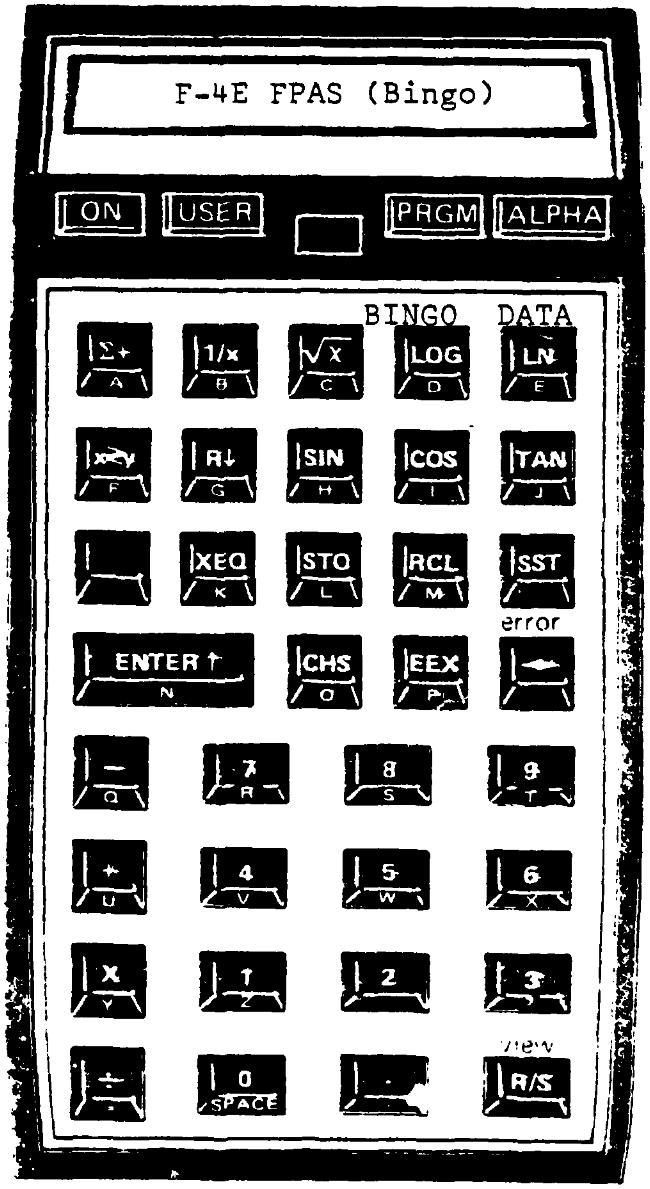


Figure 22. HP-41CV Keyboard Functions for Bingo Program

(4) HEAD WIND? = Input the velocity of the head wind components in knots (tail wind is negative).

The calculator will not display results for several minutes to compute the Bingo profile. It will then display the necessary informations as follows:

(1) LEVEL DIST = Distance required to maintain level flight between the climb and descent envelope.

(2) MN = Indicated Mach number at level flight altitude.

(3) TAS = True airspeed of the given Mach number.

(4) GRSP = Ground airspeed of the given true airspeed.

(5) CRTIME = Time required for cruising.

(6) CRUSFUEL = Fuel required for cruising mode when the total distance is greater than the distance from climb to descent.

(7) CRFUEL = Fuel required to cruise at level flight altitude when the total distance to fly is less than the distance from climb to descent.

(8) CLBDST = The distance required to climb to the optimum cruise altitude in feet.

(9) CLFUEL = Fuel required to climb from given altitude to desired altitude in pounds.

(10) OPTFL = Best range optimum cruise altitude in feet.

(11) DESPT = Begin descent point from optimum altitude to desired altitude in nautical miles.

(12) DESFUL = Fuel required to descent from optimum altitude to desired altitude.

(13) TOTFUEL = Total fuel required from climb, cruise, and for descent.

(14) No CRUISE LEG = This indicates that your selected distance was too short to allow a complete climb to the optimum altitude. In this case the optimum flight level displayed is the altitude to which you should climb and then begin your descent.

(15) CRDIST = Distance required to cruise at level flight altitude when the total distance to fly is less than the distance from climb to descent.

C. MAXIMUM ENDURANCE AND DESCENT PROGRAM

1. Loading the Program

(1) Plug-in the card reader and equivalent four memory modules into the HP-41C. For HP-41CV only plug-in the card reader.

(2) Clear the memory by pressing the (ON) key while holding the error (←) key pressed.

(3) Execute the SIZE function using size 021 as the input.

(4) Assign the DATA, END, and DES modes to their respective keys (see Figure 23). This must be done by executing an ASN function for each mode, keying in the alpha labels, and pressing the designated keys. If the calculator is in the USER mode when the calculator is reading the program, then all the functions are automatically assigned to the key as in Figure 23.

(5) Put the calculator in USER mode by pressing the (USER) key. The word "USER" should appear in the lower left corner of the display window.

(6) Read the 18 sides of magnetic cards into the card reader.

(7) Execute the PACK function after all cards have been read in.

2. Executing the Program

a. Endurance Mode

(1) Pressing the END key puts the program into the Endurance mode.

(2) The Endurance mode prompts for inputs for fuel weight and bank angle, then computes and displays the endurance altitude, fuel flow, and true Mach number. Pressing the "R/S" key returns the prompt for mode selection.

b. Descent Mode

(1) Pressing the "DES" key puts the program into the descent mode.

(2) In the program, the operator will be prompted for drag count, his initial altitude, and his desired final altitude.

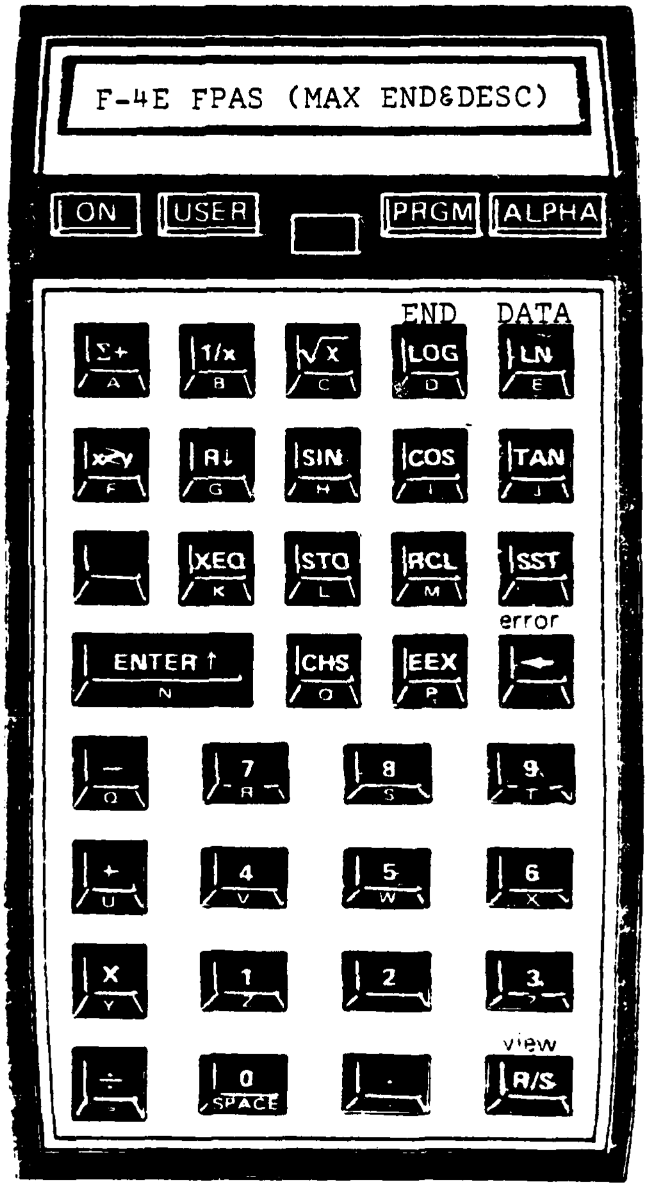


Figure 23. HP-41CV Keyboard Functions For Maxendurance And Descent Program

(3) After inputting the data, the program will display the distance that will be traveled in descending and fuel that will be used during descent.

(4) Whenever a prompt for or a display of data occurs, the "R/S" button must be pressed in order to instruct the program to continue execution. The "R/S" key must be pressed after the data has been keyed in or after the display has been viewed.

(5) Pressing the "R/S" key then returns the program to the beginning of the program execution.

VII. F-5E USER'S GUIDE

A. LOADING THE PROGRAM

(1) Plug-in the card reader for HP-41CV and equivalent to four memory modules into the HP-41C.

(2) Clear the memory by pressing the (ON) key while holding the error (←) key depressed.

(3) Execute the SIZE function using size 013 as the input.

(4) Turn on the "USER" key before reading the card into the card reader. Then the calculator will automatically assign the function as shown in Figure 24. If you missed turning on the "USER" key before reading the card into the calculator, then assign the DT, DR, and DISP modes to their respective keys as in Figure 24. This must be done by executing an ASN function for each mode, keying in the alpha labels, and pressing the designated keys.

(5) Read the 19 sides of magnetic cards into the card reader.

(6) Execute the PACK function after all cards have been read in. PACK function could be done easily by pressing the (GTO) and then pressing the (.) key two times.

B. EXECUTING THE PROGRAM

On the initial run of the program, the operator is assumed to be on the ground level prior to take off. Therefore, initial flight information must be input; however, if you have all the aircraft performance data with you on the performance card then you can use the program during the flight.

1. DATA Mode

Pressing the key labeled "DATA" puts the program into the data mode. Once you are in the DATA mode, the operator will be prompted for inputs of drag count and average gross weight (lbs). Select any mode you want.

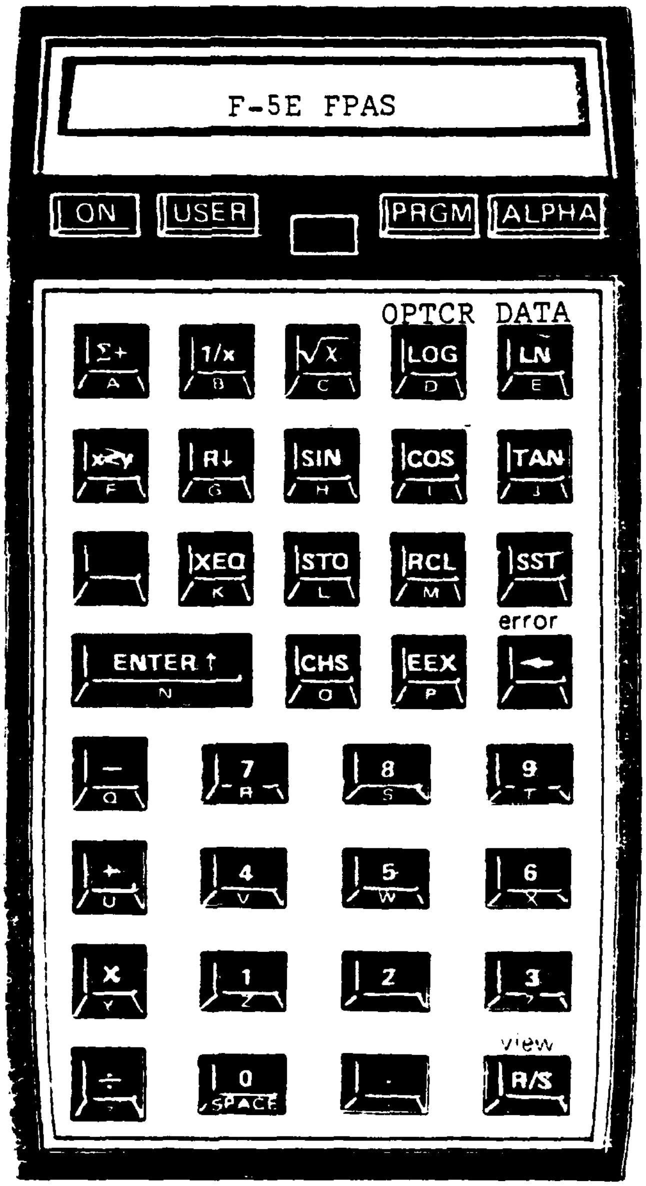


Figure 24. HP-41CV Keyboard Functions For F-5E Program

2. <u>Optimum Cruise (Short Range Mission) Mode</u>

Pressing the "OPT CR" key, Figure 21, puts the program into optimum cruise for short range mission mode. The operator is prompted for the following inputs:

CLGW? = Gross weight when you want to start climbing.

DIST? = The distance from your base to the destination.

Press the "R/S" key after each input. Then the calculator computes and displays the following data:

OPCALT = Optimum cruise altitude for short range mission.

MN = Optimum cruise IMN for optimum cruise altitude.

Then the calculator again prompts for input as follows:

DITG? = This asks you what is the distance from your position to destination?

Then you can read the following displays:

DSCND AT ____ = begin descent at ____nm from destination.

N/FUEL=______ = specific range i.e., nautical miles per pounds of fuel.

CR FUEL=_____ = fuel required for cruise from given point to begin descent point. This display does not include the fuel required for descent.

3. <u>Diversion Range Mode</u>

The calculator will prompt you to input data as follows:

F>1400? HIT 1 = If fuel remaining is more than 1400 lbs, then press 1.

If you depress 1 then the display shows as follows:

S12M54D38M88	=	If you have both engines operating then maintain altitude 38,000 ft. and Mach number .88 or if you have a single engine operating then maintain altitude 12,000 ft. and Mach number 0.54.

If you have fuel less than 1,400 lbs. then press any numerical number you want except 1. For example, 2 or 5 or any number you want except 1. If you pressed the arbitrary number except 1, then the calculator will prompt you for the following input:

DIST?	=	What is your total distance from your position to destination?
IALT?	=	What is your present altitude you are flying now?
NO,ENG?	=	Do you have two engines in operation or one engine in operation?

If you have both engines operating then press 2 or if you have one engine flame out and only one engine operating then press 1. Then the calculator will display the following data:

ALT = _____	=	Optimum cruise altitude for recovery to destination.
MN = ______	=	Best range IMN at optimum altitude.
FUEL = ____	=	Minimum fuel required to the diversion range profile with remaining fuel 300 lbs. at destination.
DESPT = ___	=	Begin descent point from optimum altitude to the destination.

VIII. ILLUSTRATIVE EXAMPLES FOR THE F-4E AND F-5E FPAS PROGRAM

The following examples will illustrate various manner in which the F-4E and F-5E FPAS programs can be used to conserve fuel.

A. F-4E FPAS ILLUSTRATIVE EXAMPLES

1. Optimum Cruise Program Example

Prior to filing a flight plan, it is desired to determine the most fuel efficient cruise altitude and airspeed for a take-off configuration with drag count 50, base weight 30,000 pounds, fuel 17,000 pounds, and 5,000 pounds of stores. For illustration purposes, we will assume that the tail wind is 20 kts., and temperature at given altitude is 20° centigrade below the standard air temperature. This example execution of the program will show how to use the optimum cruise program.

a. Data Mode

DISPLAY	INPUTS	COMMENTS
DC?	50	Enter drag count
BW?	30,000	Enter base weight (lbs)
FW?	17,000	Enter fuel weight (lbs)
DC=50		
GW=47050		
FAA?OK4NO=5	4	Depends on flight restrictions.
MODE?		What mode do you want?

b. Pre-Flight Mode

Press (LOG) key, PFT mode is assigned to (LOG) key.

DISPLAY	INPUTS	COMMENTS
SDT=54		Standard temperature at best range altitude.
TMP?AT34629	-74	Enter temperature deviations from standard air temperature.
HDG E?W?E=1W=2	1	Enter heading east=1, west=2.
I,VFR?I=7V=8	7	Enter IFT=7, VFR=8.
FAABRALT36000.		Best range altitude with FAA flight restrictions.
BRMN=0.840		Best range Mach number at best range altitude.
TW?	20	How much tail wind? Tail wind is 20 KTS.
BRTAS=467		Best range airspeed at best range altitude.
BRGS=487		Best range ground airspeed.
SR=7.E-2		Specific range (NM/lbs-fuel)
MODE?		Select another mode.

c. Climb Mode

This mode gives you the information of fuel required to climb and distance required to climb. Press (X≷Y) key which is assigned to the climb mode.

DISPLAY	INPUT	COMMENTS
FW?	15,000	Present fuel weight.
INITALT?	1,000	Start climb altitude.
FIN ALT?	30,000	Desired altitude.

DEL TEMP?	0	Deviation of temperature from standard day temperature.
DIST=49		Distance required to climb from altitude 1,000 to 30,000 ft.
FUEL=2,133		Fuel required to climb from altitude 1,000 to 30,000 ft.

2. Bingo Program Example

The following sample mission problem is presented to exercise all functions of the Bingo program to acquaint the user with the utility of the program.

a. Mission

The F-4E is to fly a high-low-high interdiction mission, including low level ingress to a weapons delivery, return to base with Bingo to the alternate airfield.

b. Flight Planning

Load the FPAS in accordance with the User's Guide. You can use this program for pre-flight mission planning or for performance reference during the flight. Select the "USER" mode. Press the (LN) key which is assigned to the DATA mode.

DISPLAY	INPUT	COMMENTS
TOGW?	45,000	
STOREWT?	5,000	
FUELWT?	15,000	
DC?	40	
INIT OK		Initial done.
MODE?		Select mode. Press (LOG) BINGO button.
DISTANCE?	200	

DISPLAY	INPUT	COMMENTS
FUELWT?	15,000	
DELTMP?	0	
HEAD WIND?	0	
CLBDIST=69		Required climb distance.
CLFUEL=2142		Fuel required to climb.
OPTFL=36,030		Best range altitude.
MACH=0.840		Best range Mach number.
TAS=470		True airspeed.
RSP=470		Ground airspeed.
CRTIME=8.29		Cruise time.
CRUSFUEL=875		Fuel required for cruising.
CRDIST=65		Distance required for cruising.
DESPT=66		Begin descent point.
DESFUL=525		Fuel required for descent.
TOTFUEL=3,543		Total fuel required.

3. Maximum Endurance and Descent Program Example

The Maximum Endurance and Descent Program consists of maximum endurance and descent mode. The DATA mode is assigned to the (Σ+) key and the Endurance mode is assigned to the (LN) key. The descent mode is assigned to the (LOG) key. First press the (Σ+) key.

DISPLAY	INPUT	COMMENTS
DC?60		
BW?	35,000	Input base weight.

DISPLAY	INPUT	COMMENTS
STWT?	8,000	Input store weight.
FW?	14,000	Input present fuel weight.
DC=60		Shows the drag count.
GW=57,000		Total gross weight.

If you want to select the Endurance mode, press the (LN) key with is assigned to the Endurance mode.

DISPLAY	INPUT	COMMENTS
BANK<?	20	Bank angle in degrees.
ENDALT=21,500		Best endurance altitude.
FF=8,749		Fuel flow at maximum endurance altitude.
ENDTMN=0.703		Maximum endurance true Mach number at maximum endurance altitude.
OK?		Are those data reasonable?

If you want to select the descent mode, press the (LOG) key which is assigned to the descent mode.

DISPLAY	INPUT	COMMENTS
INALT?	30,000	Initial descent altitude from maximum endurance altitude to desired altitude.
FINALT?	10.000	Desired descent altitude.
IAS=300		Descent speed 300 KIAS.
DIST=32		Descent distance from 30,000 ft. to 10,000 ft.
DESFUEL=261		Fuel required to descent from altitude 30,000 ft. to 10,000 ft.
OK?		Are those data acceptable to you?

B. F-5E FPAS ILLUSTRATIVE EXAMPLE

The following sample mission problem is presented to exercise all functions of the Bingo program to acquaint the user with the utility of the program. One can use this program as pre-flight mission planning for optimum altitude for short range missions. However, the diversion range for dual engine and single engine could be used during the flight.

(1) First press the DATA key which is assigned to the (Σ+) key.

DISPLAY	INPUT	COMMENTS
DI?	60	
AVGW?	15,000	Input average gross weight.
MODE?		Select a mode.

(2) Press the Optimum Cruise key which is assigned to the (LOG) key.

DISPLAY	INPUT	COMMENTS
CLGW?	17,000	Input start climb gross weight.
DIST?	200	Input the mission range.
OPCALT=34,555		Optimum cruse altitude.
MN=0.84		Best range Mach number at best range altitude.

(3) After you take off and reach the best range altitude, find the distance from your position to target using any navigation aids such as Tactical Air Navigation or Inertial Naviation systems. Then proceed as follows:

DISPLAY	INPUT	COMMENTS
DITG?	150	Input distance from your position to target.
DESCND AT 41.9		Begin descent from 41.9 NM from target.

DISPLAY	INPUT	COMMENTS
N/FUEL=0.20		Nautical mile per pound of fuel.
CR FUEL=537		Fuel required from present position to begin descent point.

(4) Press the Diversion Range key using the (LN) key. This mode gives dual engine and single engine diversion range information as follows:

DISPLAY	INPUT	COMMENTS
F>1400?HIT1		If the remaining fuel is greater than 1,400 lbs.
S12M54D38M88		If it is single engine, maintain altitude 12,000 ft. and Mach number 0.54.
		If both engines are available then maintain altitude 38,000 ft. and Mach Number 0.88.

(5) If your fuel on-board is less than 1,400 lbs., then enter any number except 1.

DISPLAY	INPUT	COMMENTS
F>1400?HIT1	2	If fuel is less than 1,400 lbs.
DIST?	200	Input distance from your present position to base.
IALT?	2,000	Initial altitude for climb.
NO,ENG?	1	For single engine enter 1
	(1 or 2)	For dual engines enter 2.
ALT=14,000		Diversion altitude.
MN=0.52		Best range Mach number.
FUEL=1971		Minimum fuel required from present position to destination.
DESPT=14		Begin descent point from destination.

(6) If you want to see the inputs of the computations, again press the DISPLAY key which is assigned to the (X≷Y) key.

IX. CONCLUSIONS

As part of the U.S. Navy Aircraft Fuel C·nservation Program, the use of Computerized Flight Performance Advisory Systems (FPAS) by the aircrew was conceived as a potentially cost-effective fuel-saving operational concept.

In Chapter III, equations were given for the best range Mach number. BRMN, and the ground specific range, GSR, were derived as a function of wind velocity V_W and wind direction, θ. A second order analysis was developed in which the derivatives of specific range, SR, with respect to flight velocity, V, play an important role.

The results of sample calculations for ε, GSR, and V^* using the second order analysis of Chapter III were reasonable when compared with the results computed by Naval Air Development Center [Ref. 2].

The mathematical relationships developed in this thesis can be utilized by any aircraft whenever the functional relationship between specific range and velocity is known. The specific range and velocity curve can be determined without difficulty [Ref. 2: pp. 9]. It is ·e-commended that a controlled experiment be set up to evaluate in-flight accuracy and relevancy of the results of the equations reported herein.

The accuracy of the Flight Performance Advisory System methodology has been verified against the F-4E and F-5E Flight Manuals [Ref. 3 and 4].

The Flight Performance Advisory System programs developed can be readily utilized in both preflight and in-flight environments. The FPAS program developed in this theses are intended as a convenient, reliable augmentation to the F-4E and F-5E Flight Manuals. The computer programs for HP-41CV do not replace the manual, but rather make its performance data more accessible and usable.

APPENDIX A
COMPUTER PROGRAM FOR WIND ANALYSIS

```
C
C
C     ****************************************************
C     *                                                  *
C     *  COMPUTER PROGRAM FOR SAMPLE CALCULATION FOR A-7E *
C     *                                                  *
C     ****************************************************
C
C     -------------
C     WIND ANALYSIS
C     -------------
C
C
      REAL V0,SR,D3SR,A,B,C,D2SR,UW0,SR1,SR2,SR3,SR4,DELV(3),EPS1
     *,EPS2,USR(36),THETA(36),EPS(36),UU(36),VSTAR(36)
      INTEGER J,L,I,K
      M=1
      V0=400.
      SR=.235
      SR1=.222
      SR2=.235
      SR3=.23
      SR4=.209
      D2SR=(SR3-2.*SR2+SR1)/50.**2
      D3SR=(SR4-3.*SR3+3.*SR2-SR1)/50.**3
C
C     -----------------
C     CHANGING WINDSPEED
C     -----------------
C
C
      DO 30 L=1,3
         IF (L.EQ.1) I=10
         IF (L.EQ.2) I=5
         IF (L.EQ.3) I=1
         DELV(L)=FLOAT(I)*10.
         UW0=DELV(L)/V0
         DO 20 J=1,36
            THETA(J)=1.*FLOAT(J)*3.141592/18.
            A=V0**3*D3SR/(2.*SR)
            B=(V0**2*D2SR/SR)+2.*UW0*COS(THETA(J))
            C=UW0**2-UW0*COS(THETA(J))
            EPS1=(-C/B)*(1.-(A*C/B**2))
            EPS2=(B/A)*(-1.+(A*C/B**2)+((A**2*C**2)/B**4))
            WRITE(6,*)DELV(L),EPS1,EPS2
```

```
            IF (ABS(EPS1).GT.ABS(EPS2)) GO TO 30
                EPS(J)=EPS1
                GO TO 40
   30           CONTINUE
                EPS(J)=EPS2
   40        CONTINUE
          GS(J)=1.+ON0*(1.-EPS(J))*COS(THETA(J))-.5*N0**2*(1.-(COS(THET
     A(J)))**2)
          GSR(J)=(SR2+(EPS(J))**2+2*SR*.5)*G0(J)
          VSTAR(J)=V0*(1+EPS(J))
       WRITE(1,*)THETA(J),EPS(J),GSR(J),VSTAR(J)
       WRITE(6,*)THETA(J),EPS(J),GSR(J),VSTAR(J)
   20 CONTINUE
C
C   -----------------
C   PLOT  EPS VS THETA
C   -----------------
C
C
       DO 100 K=1,36
          IF ((FLOAT(K).LT.9.).OR.(FLOAT(K).GT.27.))EPS(K)=-EPS(K)
  100 CONTINUE
       WRITE(6,600)
       WRITE(6,550)VELV(1)
  550 FORMAT(10X,'WIND VELOCITY=',F5.1)
  600 FORMAT('1',/,10X,'THETA VS EPS')
       IF (I.GT.1) M=2
          IF(I.EQ.1) M=5
       CALL PLOTT(THETA,EPS,36,M)
       WRITE(6,700)
       WRITE(6,550)VELV(1)
  700 FORMAT('1',/,10X,'THETA VS GSR')
       CALL PLOTT(THETA,GSR,36,M)
       WRITE(6,800)
  800 FORMAT('1',/,10X,'VSTAR VS THETA')
       CALL PLOTT(THETA,VSTAR,36,M)
       I=I+1
   10 CONTINUE
       STOP
       END
        ************************************************************
        *                                                          *
        *        PROGRAM FOR PLOT EPSILON,VS, AND GSR              *
        *                                                          *
        ************************************************************
//PLT  JOB  (1260,0556),'LT. JACKY WU',CLASS=A                     PP 00010
```

```
      CALL SYMBOL(4.5,6.,.2,'  GSS    VS. THETA',0.,17)
      Z=Z+.2
   40 CONTINUE
      CALL PLOT(0.0,0.0,999)                                  PP 00170
      STOP                                                    PP 00210
      END                                                     PP 00220
```

APPENDIX B

DISCUSSION AND COMPUTER OUTPUTS FOR EXAMPLE OF THE WIND PROBLEM

This appendix contains sample calculations for the A-7E aircraft based on information contained in Reference 2. Specifically, the information on specific range as a function of aircraft velocity shown in Figure 3 of Reference 2 was used in equations (3-39) to (3-41). The input parameters were:

$$V_0 = 400 \text{ kts.}$$

$$SR(V_0) = \frac{0.235 \text{ nm}}{\text{lb. fuel}}$$

Altitude = 35,000 ft.

Gross weight = 20,000 lbs

Drag count = 50.

In Figure B.1, V^* as a function of θ is presented for three wind velocities as follows: 10,50, and 100 knots. The corresponding values of U_{W_0} are 0.025, 0.125, and 0.25. The dimension of θ in Figure B.1 to Figure B.3 is radians. Both the V^* curve in Figure B.1 and the ε curve in Figure B.2 have similar shapes as one would expect from equation (3-48).

For a tail wind, i.e., for θ starting at zero and increasing to the intersection of the V^* and V_0 curves, the aircraft flies slower. Conversely for a head wind, the aircraft flies slower.

The sign of ε should flip when θ changes from 0° to 180°. When θ is 0°, the wind is a tail wind. The aircraft should fly at a slower speed,

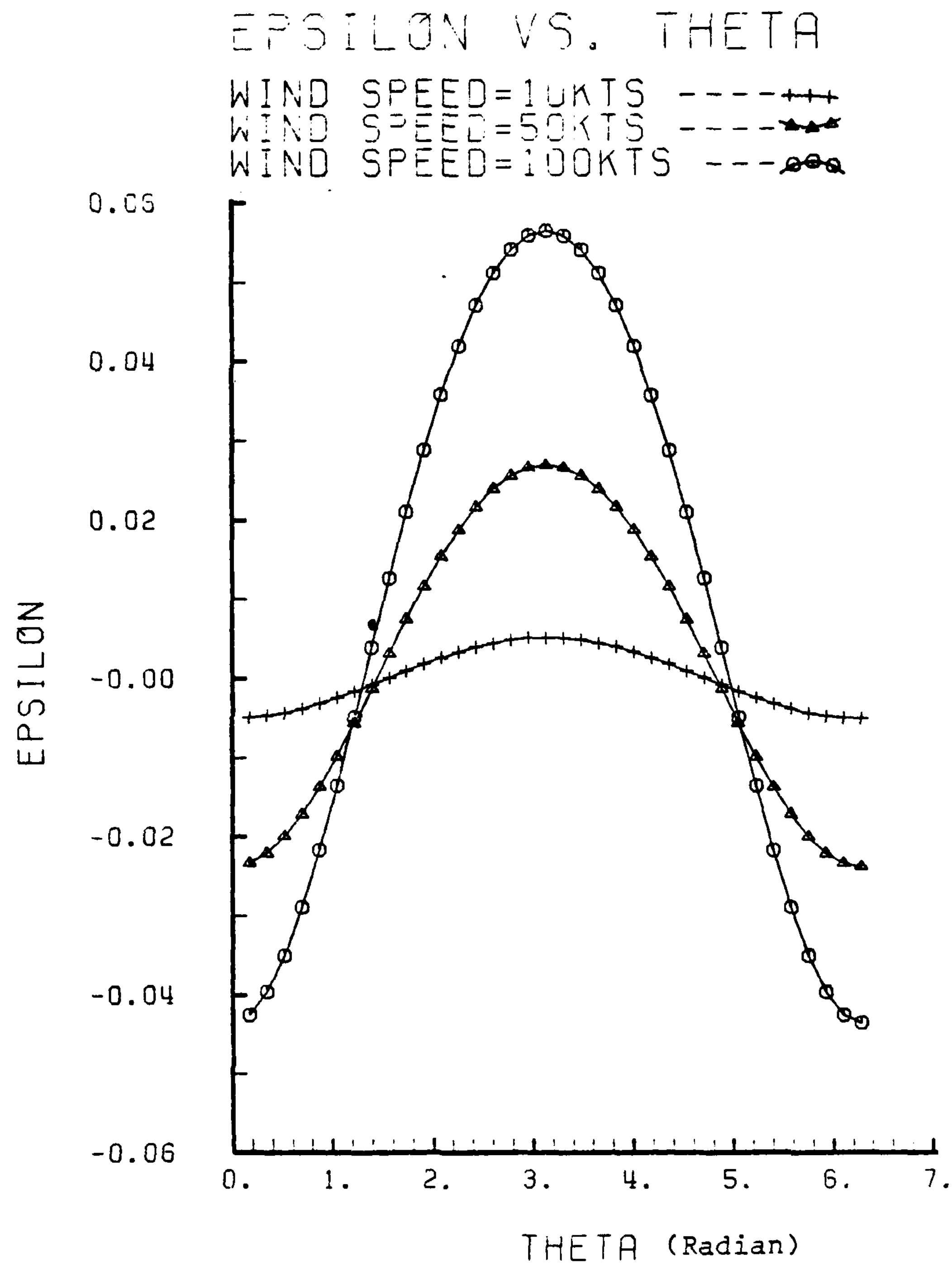


Figure B.1. ε vs. θ

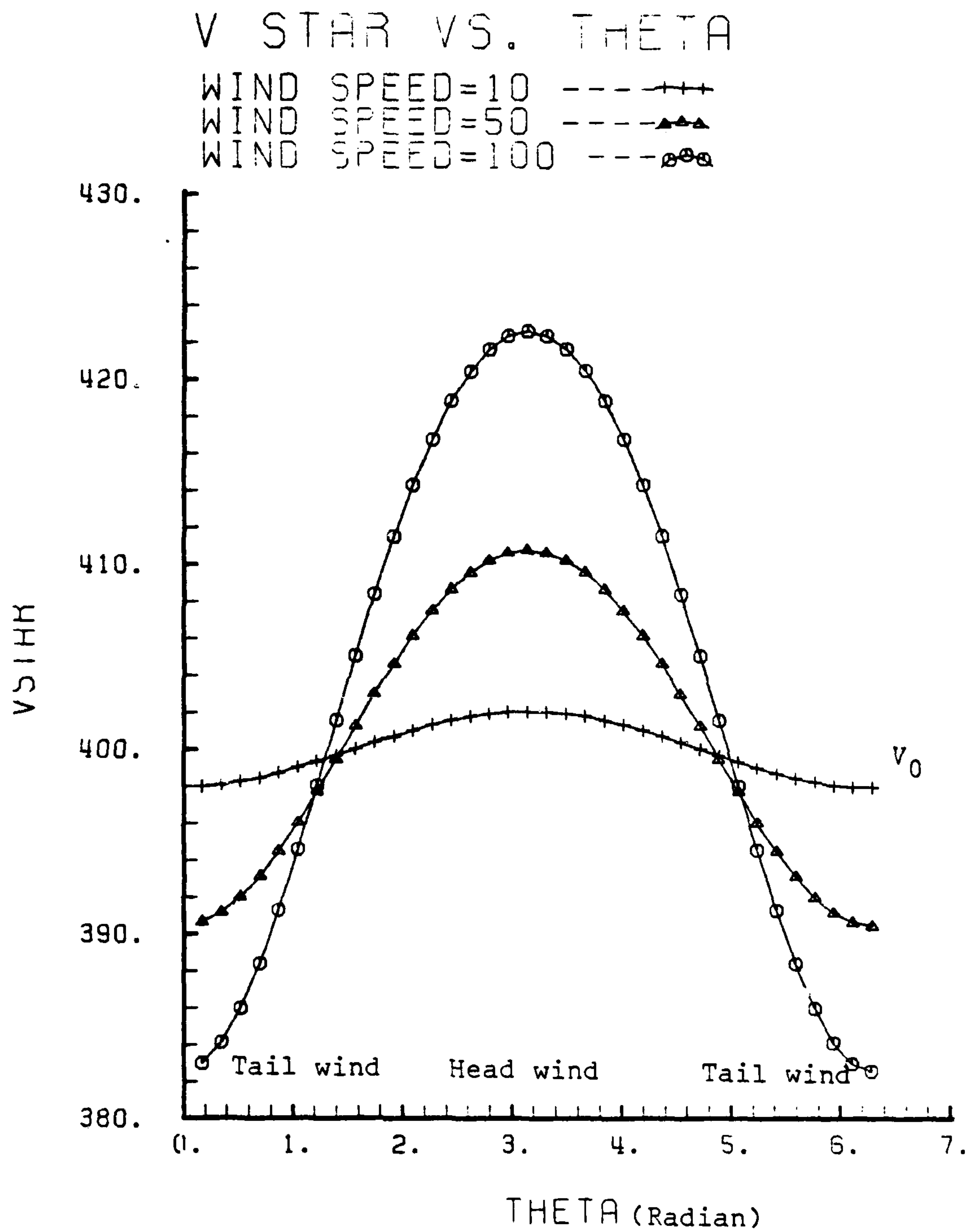


Figure B.2. V* vs. Θ

and the sign of ε is minus. When θ is 180°, the wind is a head wind, and the aircraft should fly at a slower speed. The sign of ε is positive.

The Figures B.3, B.4, and B.5 are polar plot of $|\varepsilon|$ vs. θ with the wind speed at 10 kts., 50 kts., and 100 kts., respectively. Note that as the wind speed increases from 10 kts. to 50 kts., the size of the left hand circle in Figure B.4 increases relative to the right hand circle. Also note, in Figure B.2, the V* with wind direction 1.571 Radian (90°) is approximately 405.5 kts.

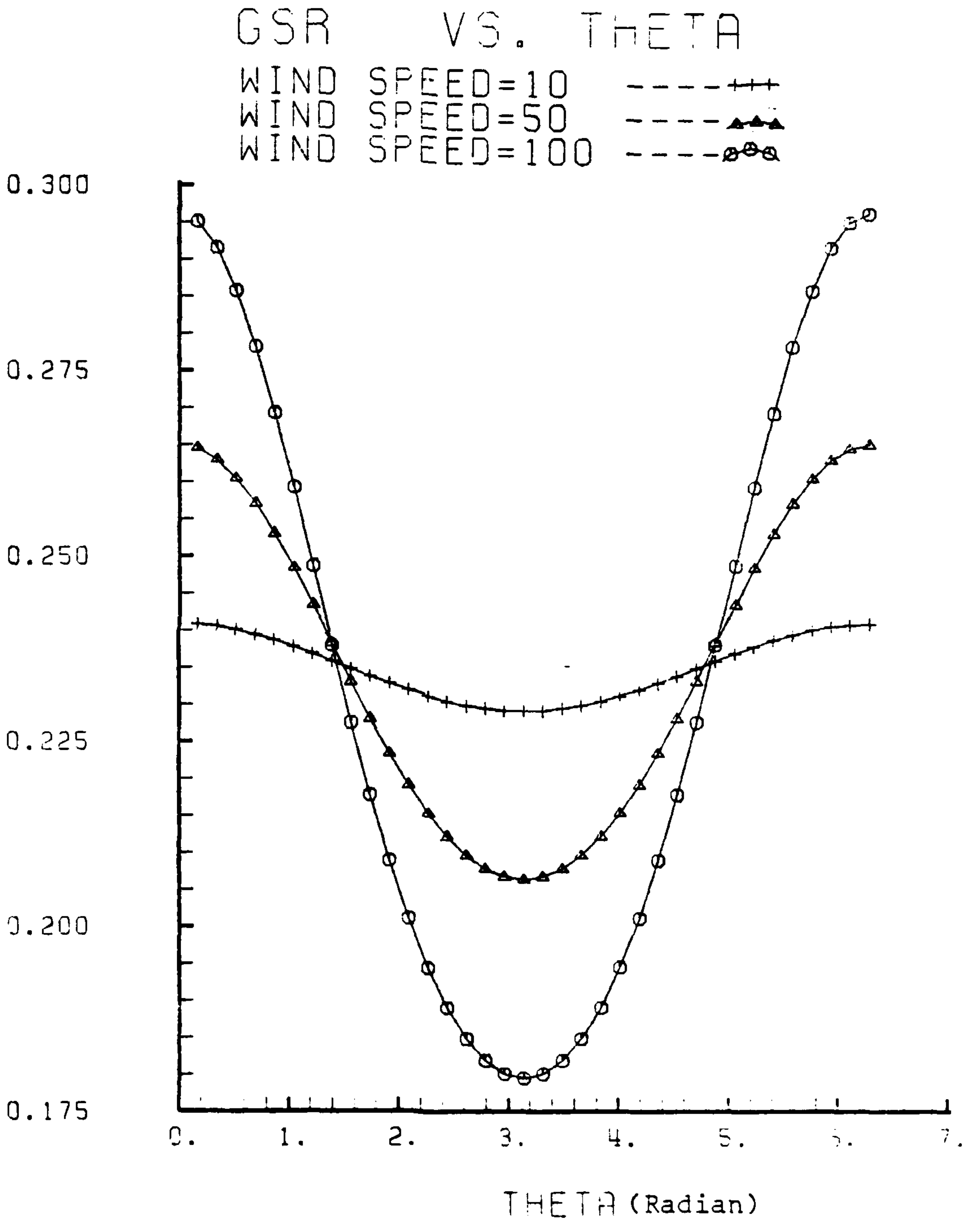


Figure B.3. GSR vs. Θ

Polar Plot of ε vs. Theta (wind 10kts)

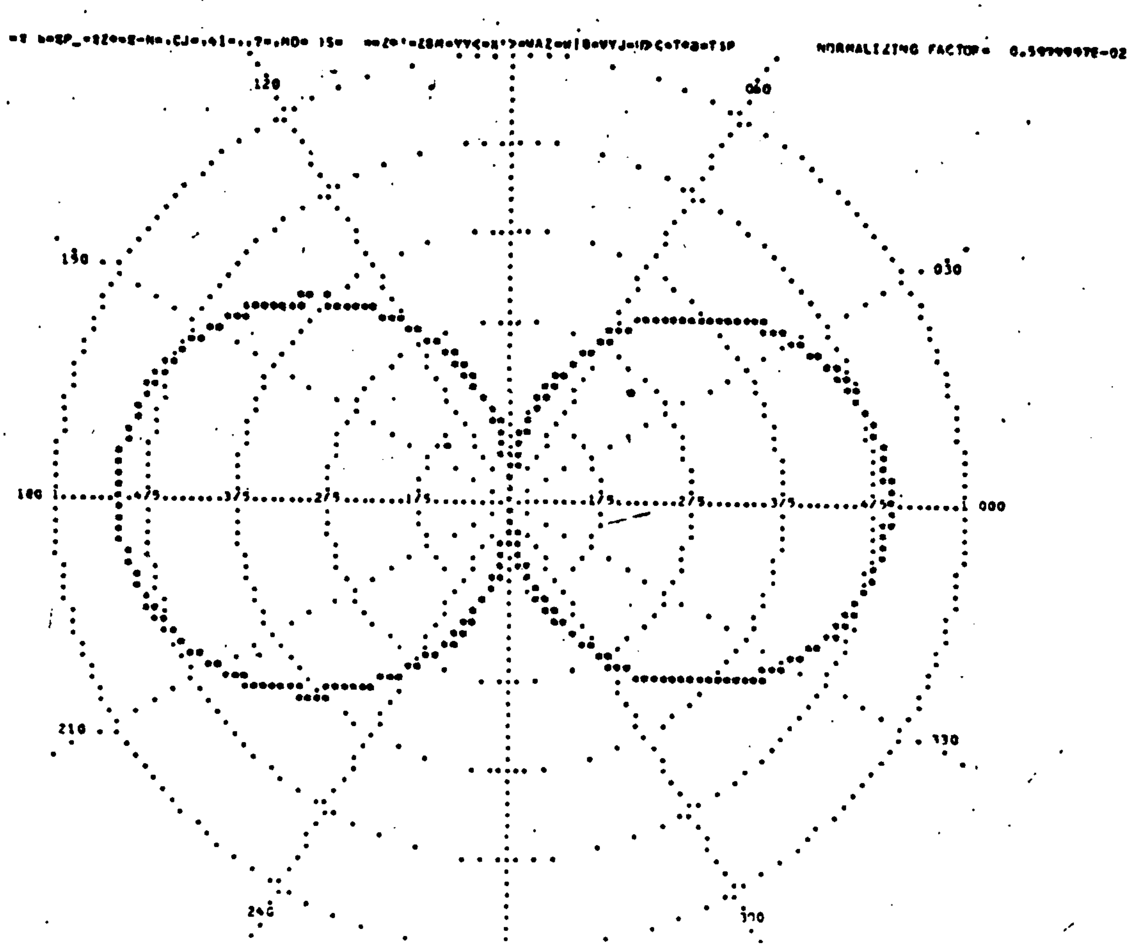


Figure 3.4. ε vs. θ (U_{W_0} = 0.025)

Polar Plot of ε vs. Theta (wind 50kts)

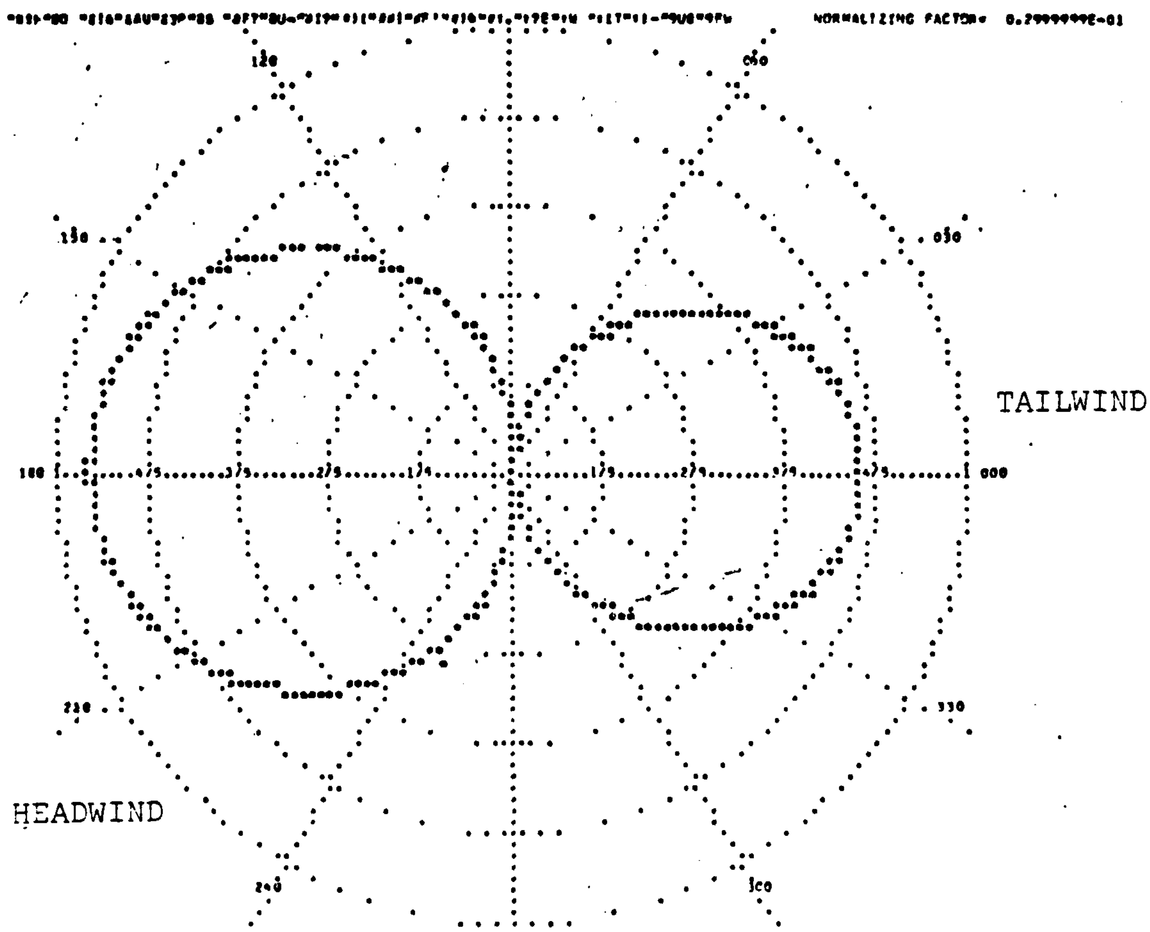


Figure B.5. ε vs. θ (U_{w_0} = 0.125)

Polar Plot of ε vs. Theta (wind 100kts)

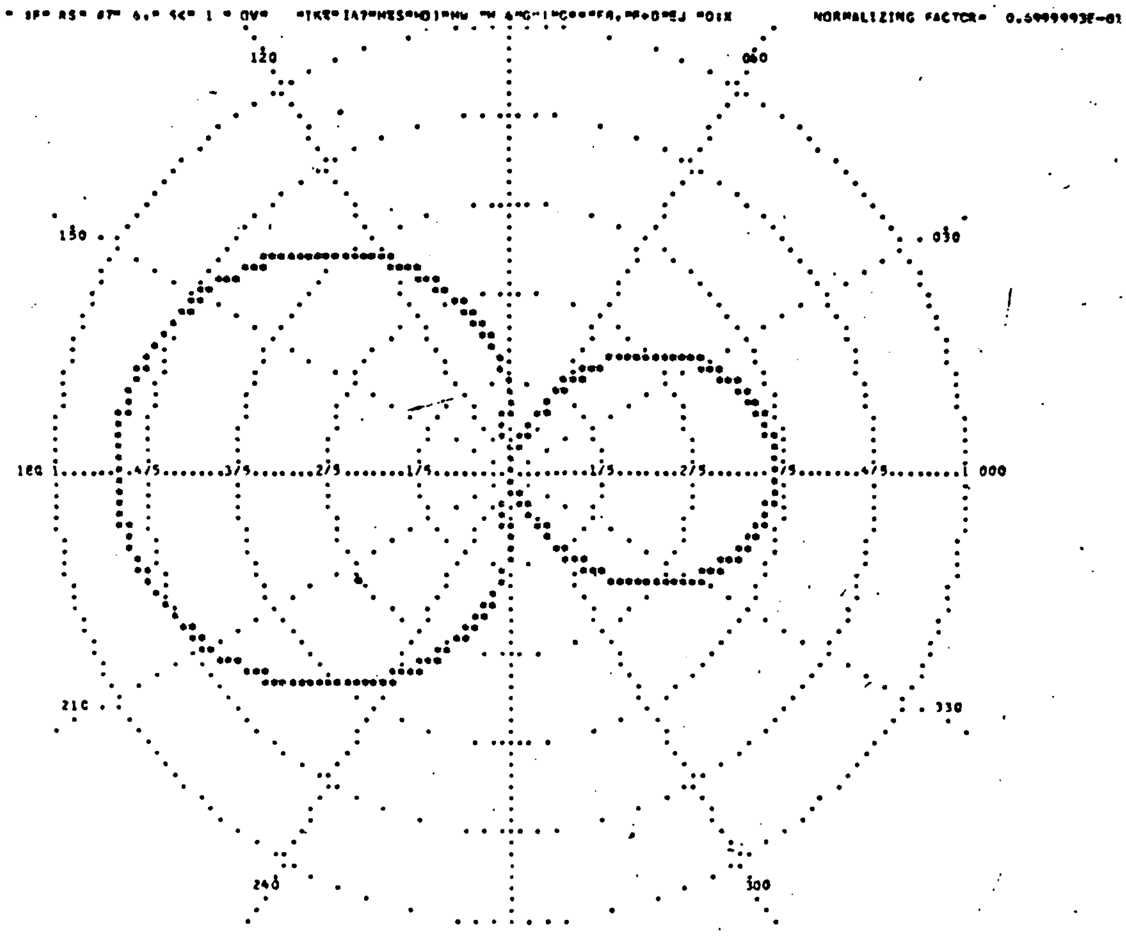
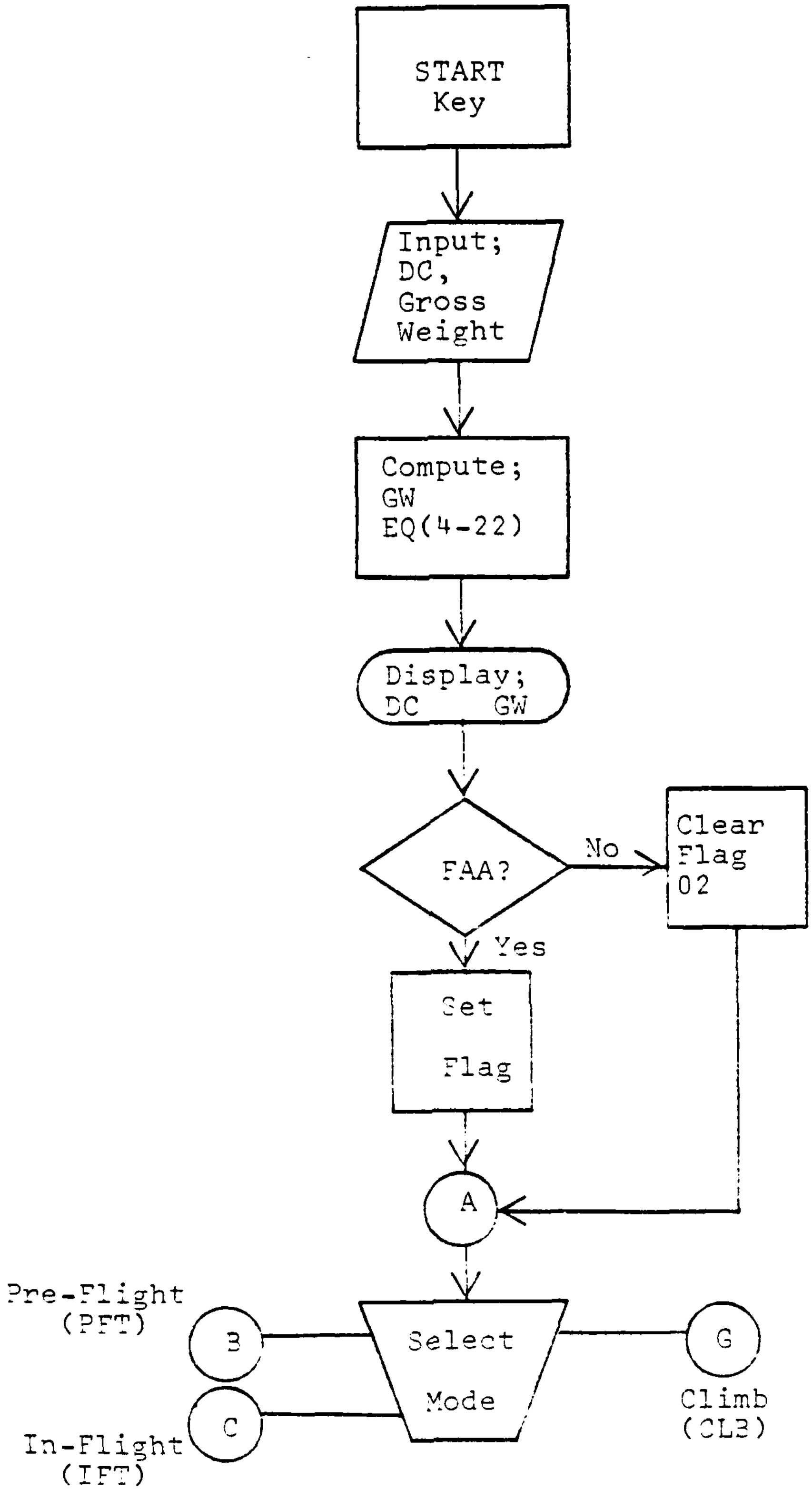


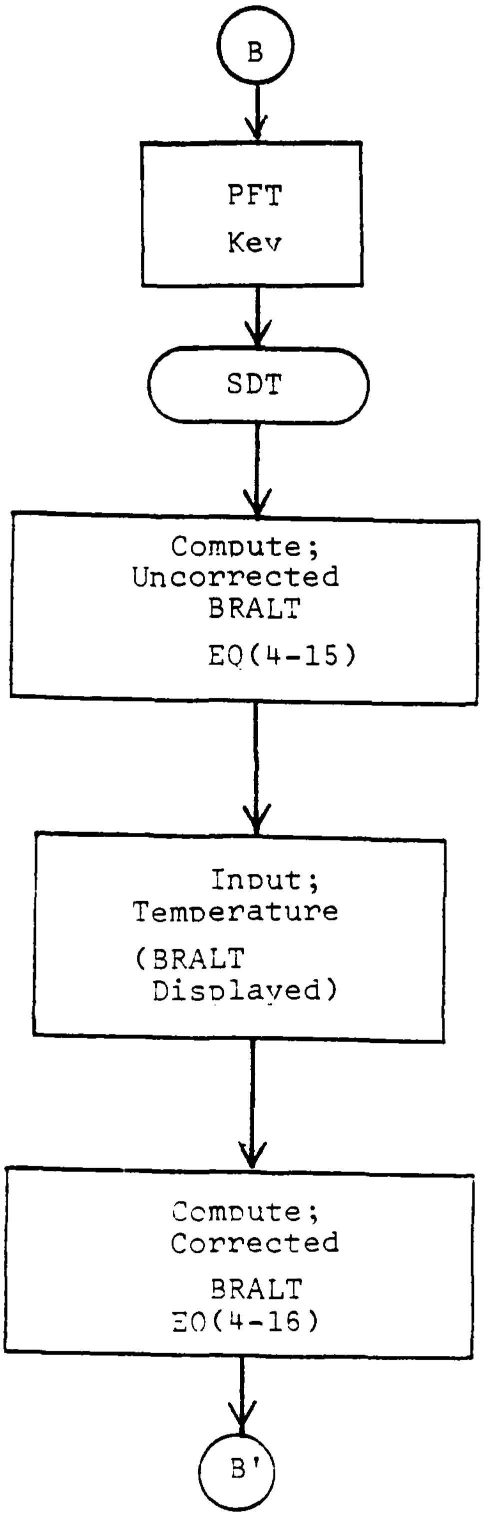
Figure B.6. ε vs. θ ($U_{w_0} = 0.25$)

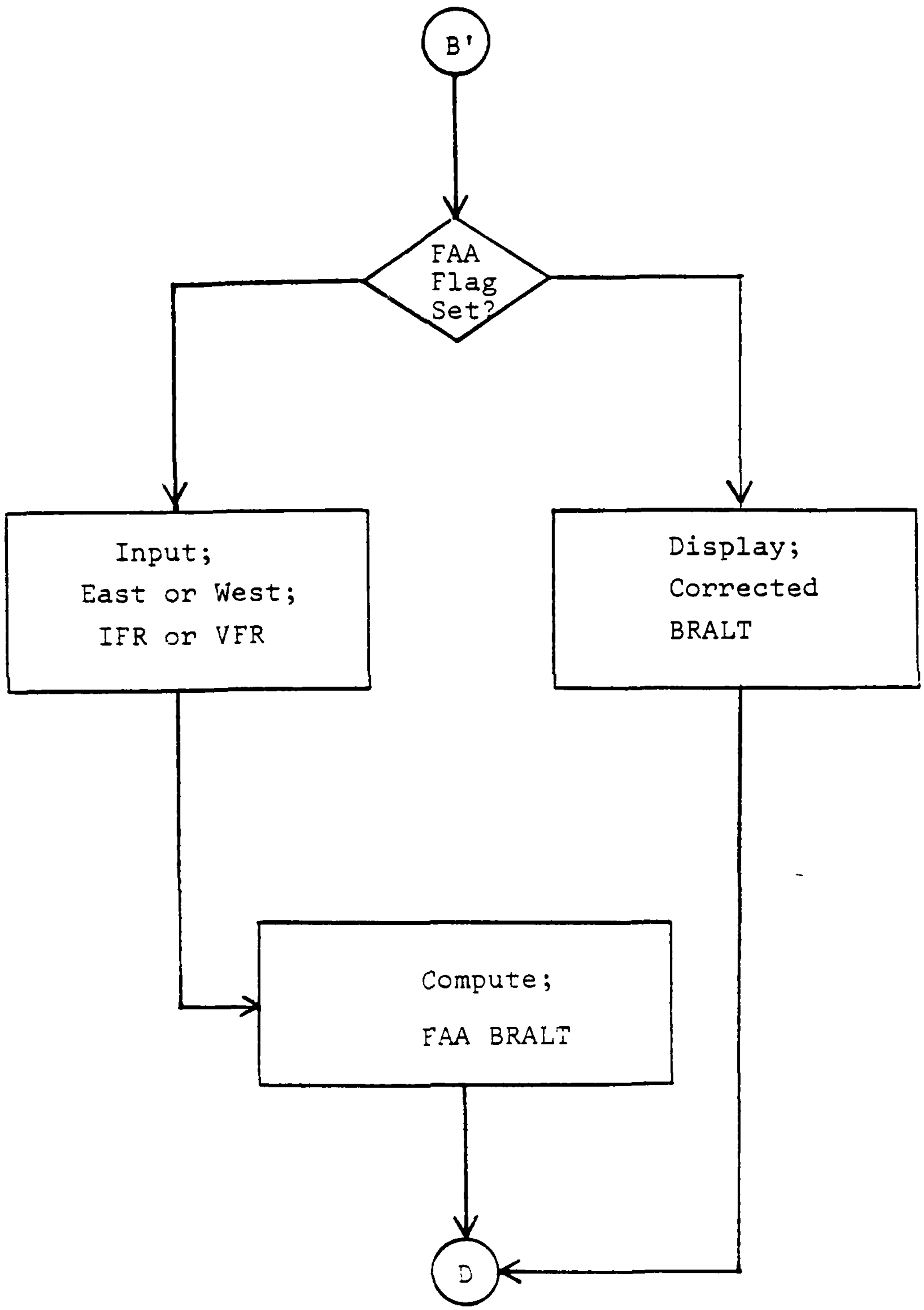
APPENDIX C

F-4E AND F-5E FPAS FLOW CHARTS

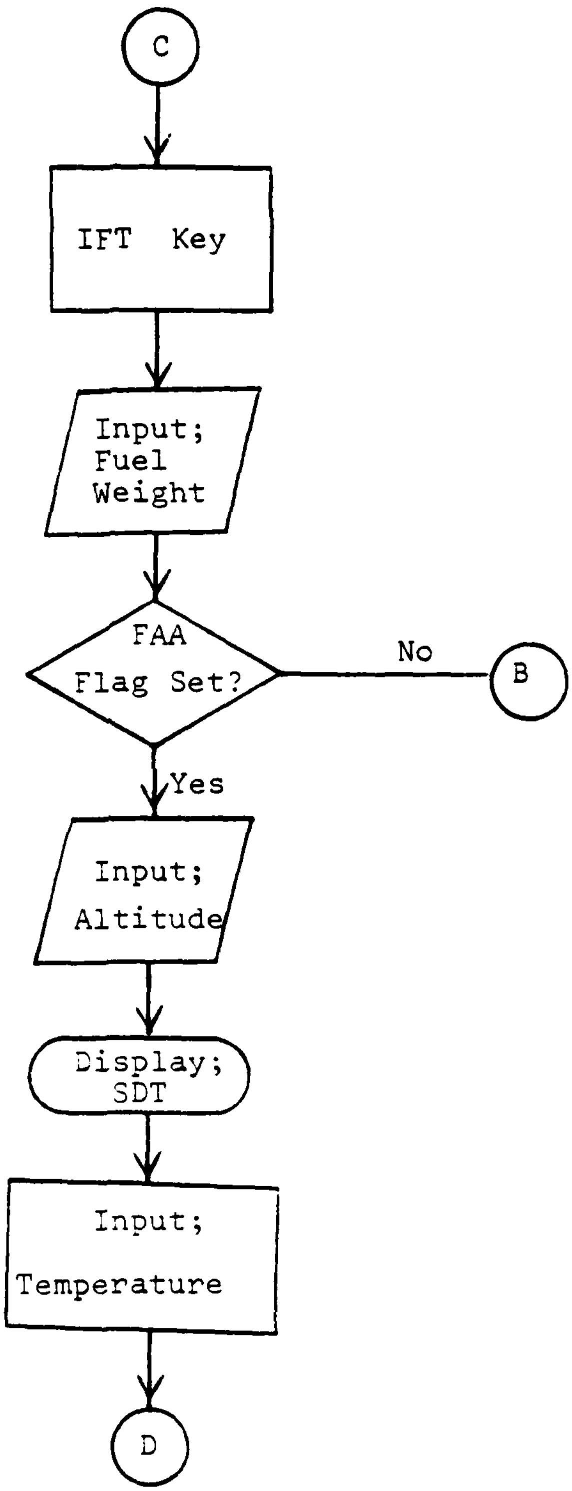
F-4E Optimum Cruise Program Flow Charts

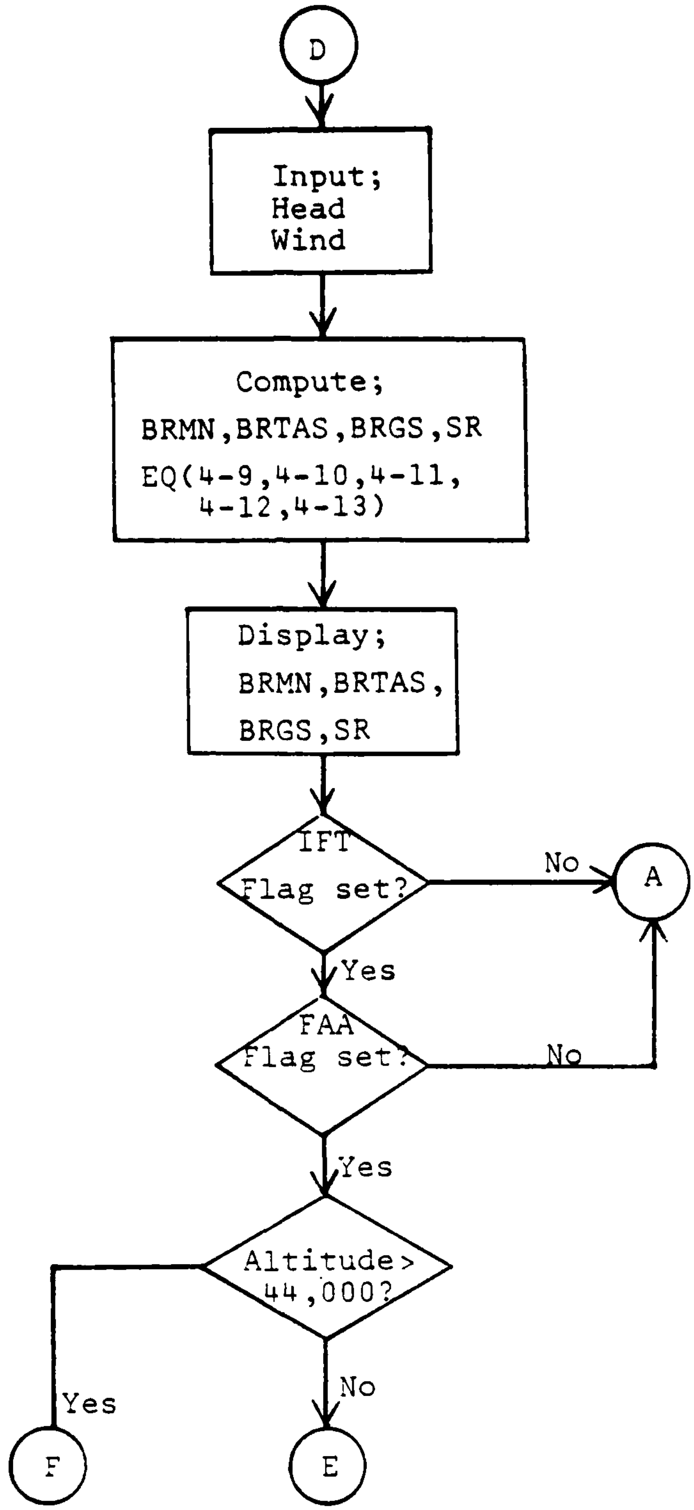


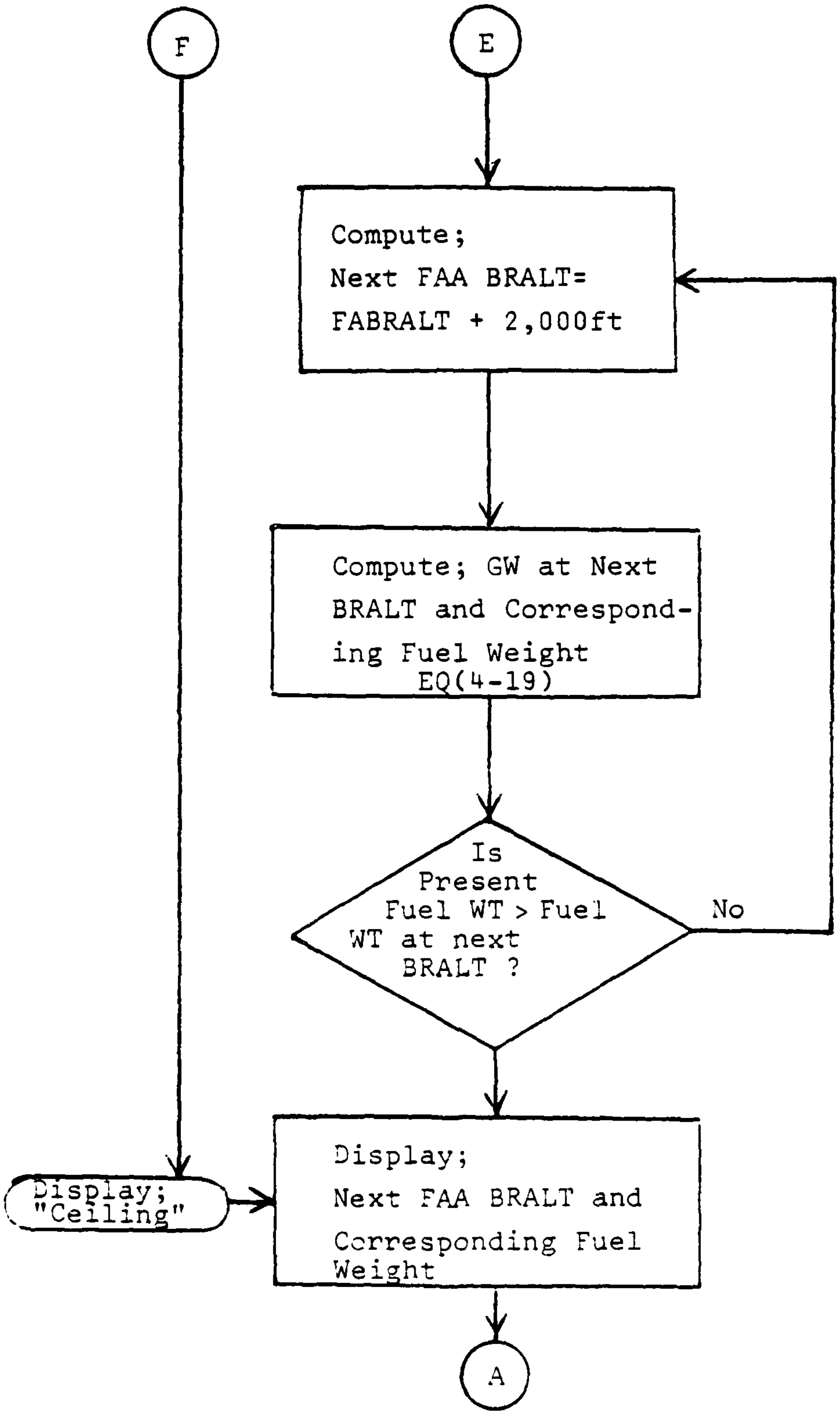

B
PFT
Kev
SDT
Compute;
Uncorrected
BRALT
EQ(4-15)
Input;
Temperature
(BRALT
Displayed)
Compute;
Corrected
BRALT
EQ(4-16)
B'

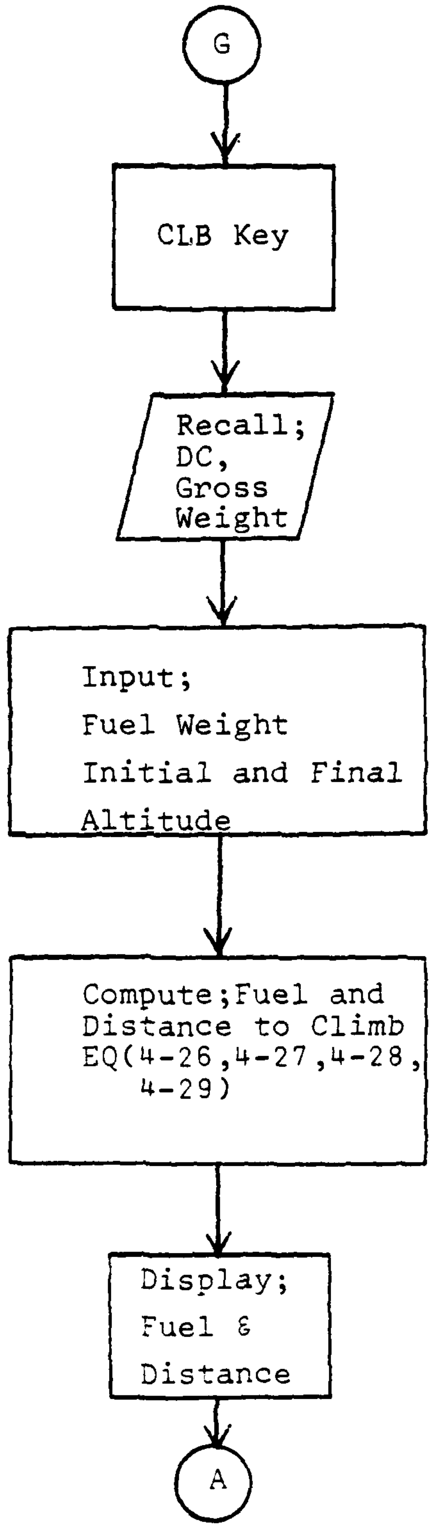


B'
FAA
Flag
Set?
Input;
East or West;
IFR or VFR
Display;
Corrected
BRALT
Compute;
FAA BRALT
D

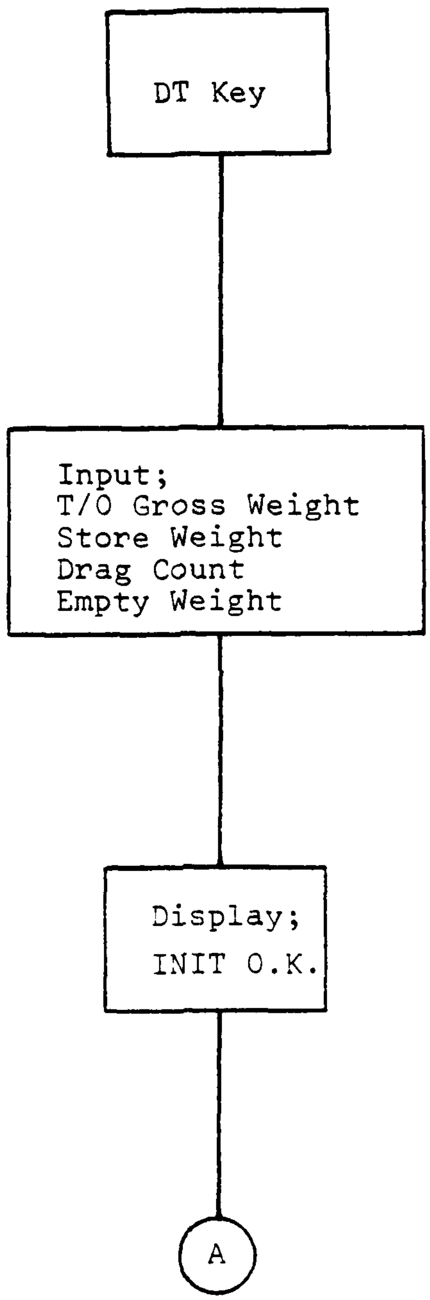

C
IFT Key
Input;
Fuel
Weight
FAA
Flag Set?
No
B
Yes
Input;
Altitude
Display;
SDT
Input;
Temperature
D

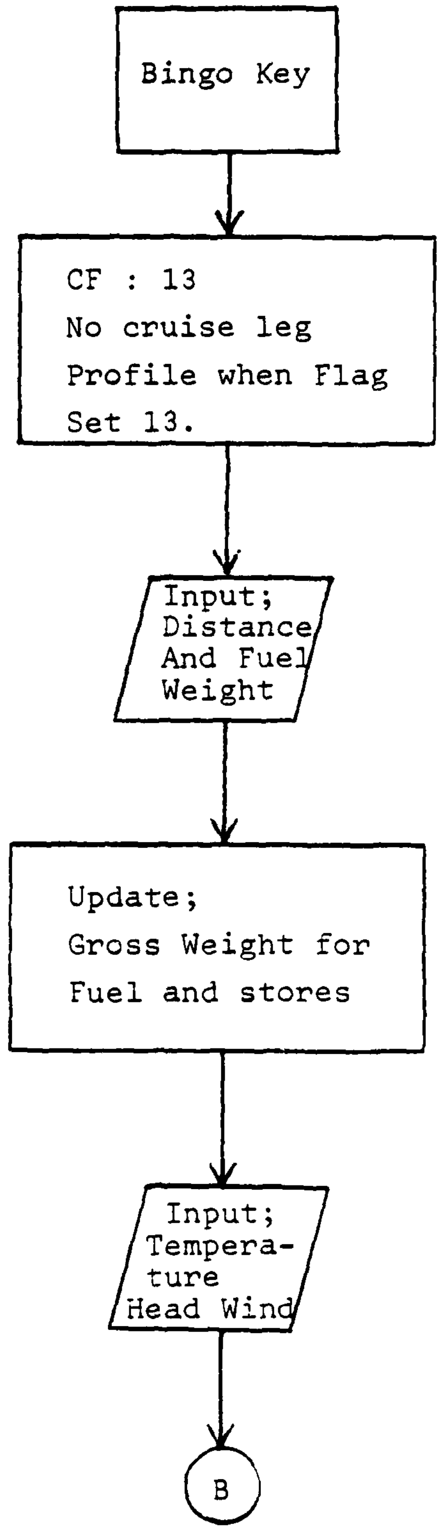

D
Input;
Head
Wind
Compute;
BRMN,BRTAS,BRGS,SR
EQ(4-9,4-10,4-11,
4-12,4-13)
Display;
BRMN,BRTAS,
BRGS,SR
IFT
Flag set?
No
A
Yes
FAA
Flag set?
No
Yes
Altitude >
44,000?
Yes
No
F
E

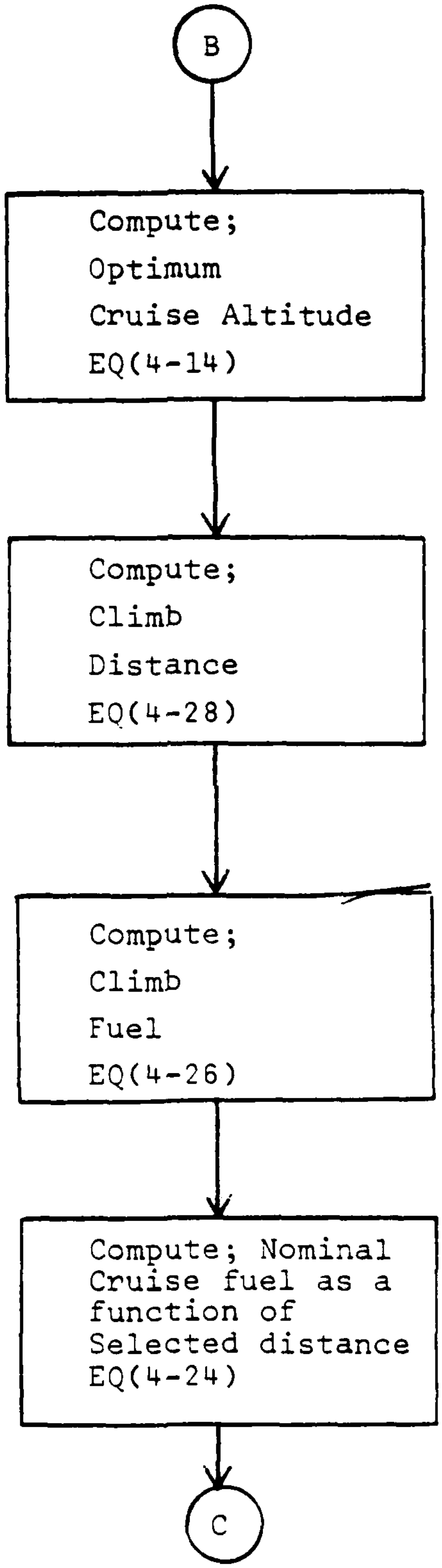

F
E
Compute;
Next FAA BRALT=
FABRALT + 2,000ft
Compute; GW at Next
BRALT and Correspond-
ing Fuel Weight
EQ(4-19)
Is
Present
Fuel WT > Fuel
WT at next
BRALT ?
No
Display;
"Ceiling"
Display;
Next FAA BRALT and
Corresponding Fuel
Weight
A

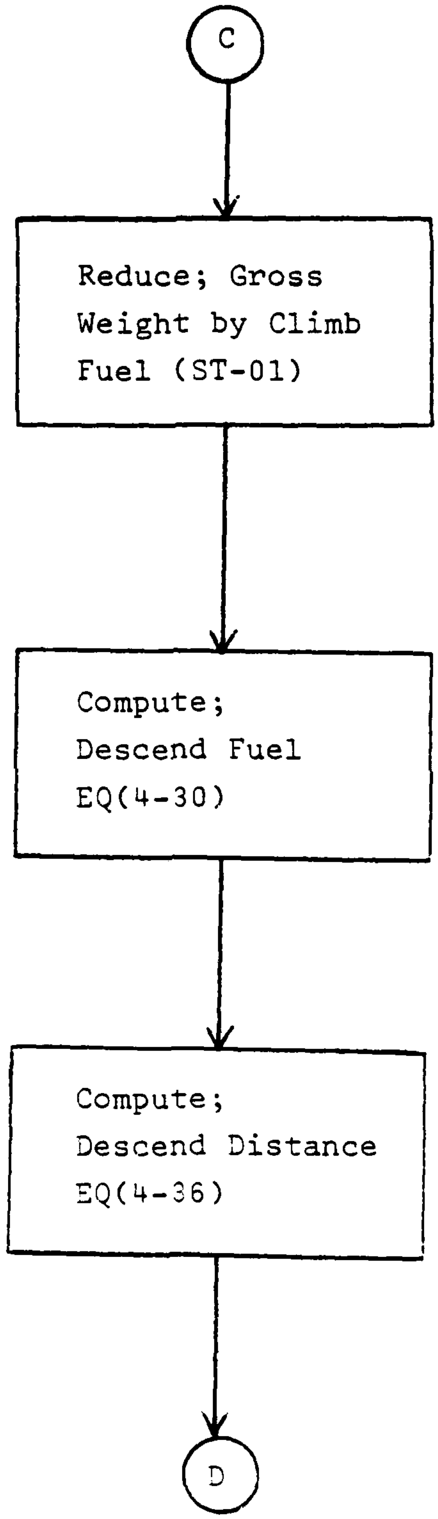

G
CLB Key
Recall;
DC,
Gross
Weight
Input;
Fuel Weight
Initial and Final
Altitude
Compute;Fuel and
Distance to Climb
EQ(4-26,4-27,4-28,
4-29)
Display;
Fuel &
Distance
A

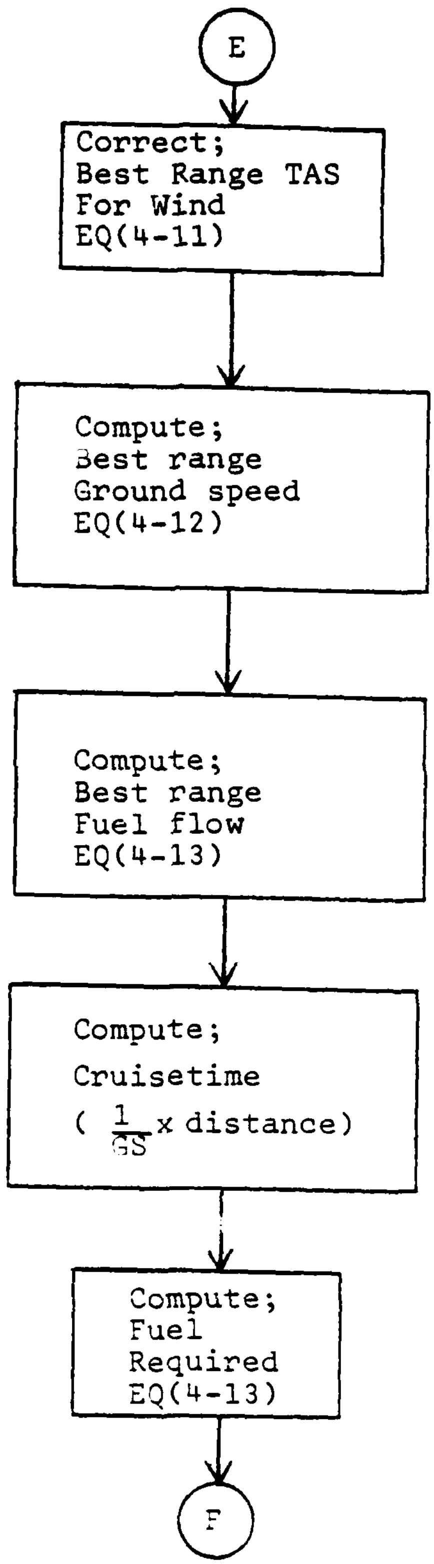
F-4E Bingo Program Flow Chart

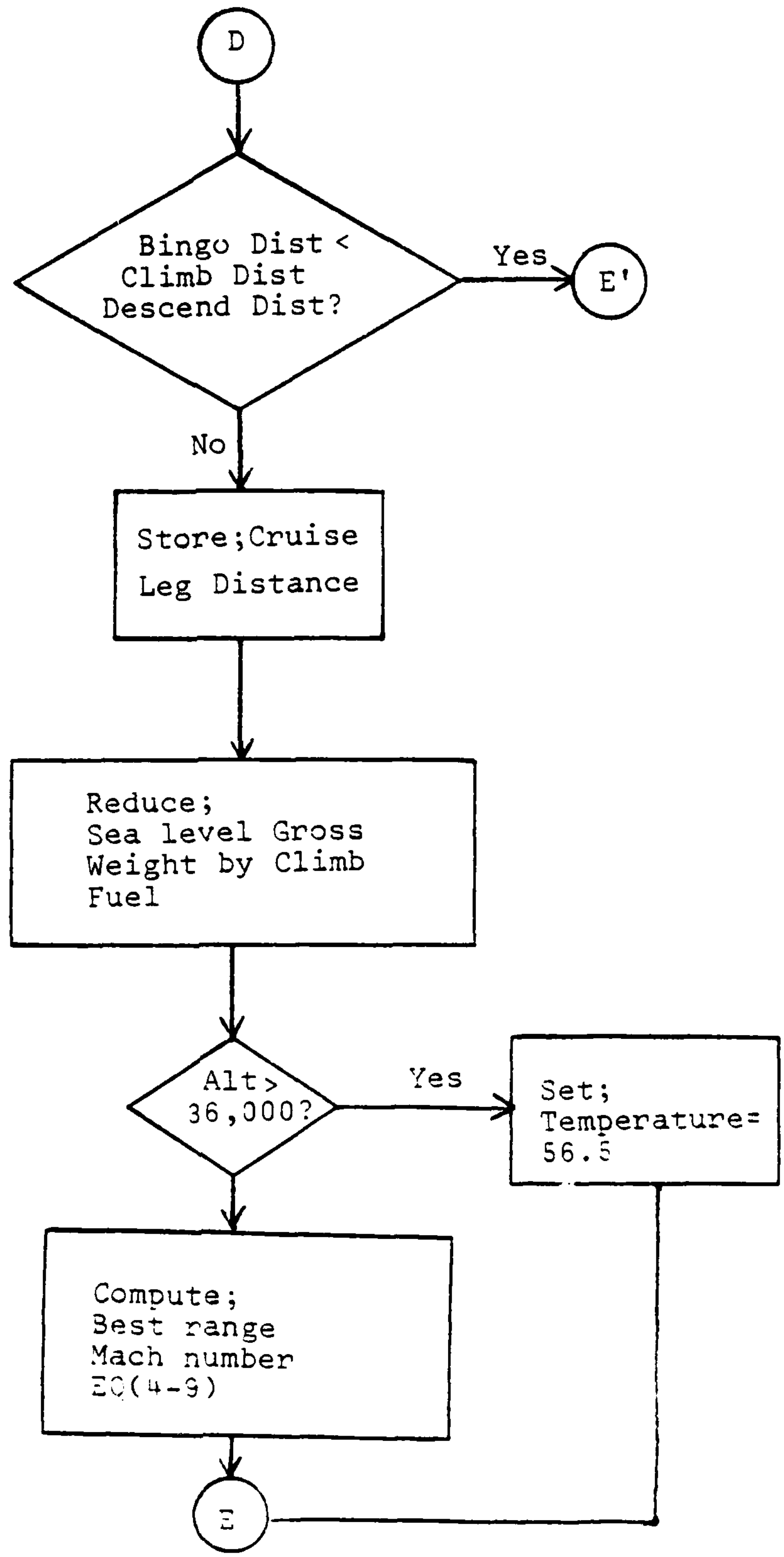


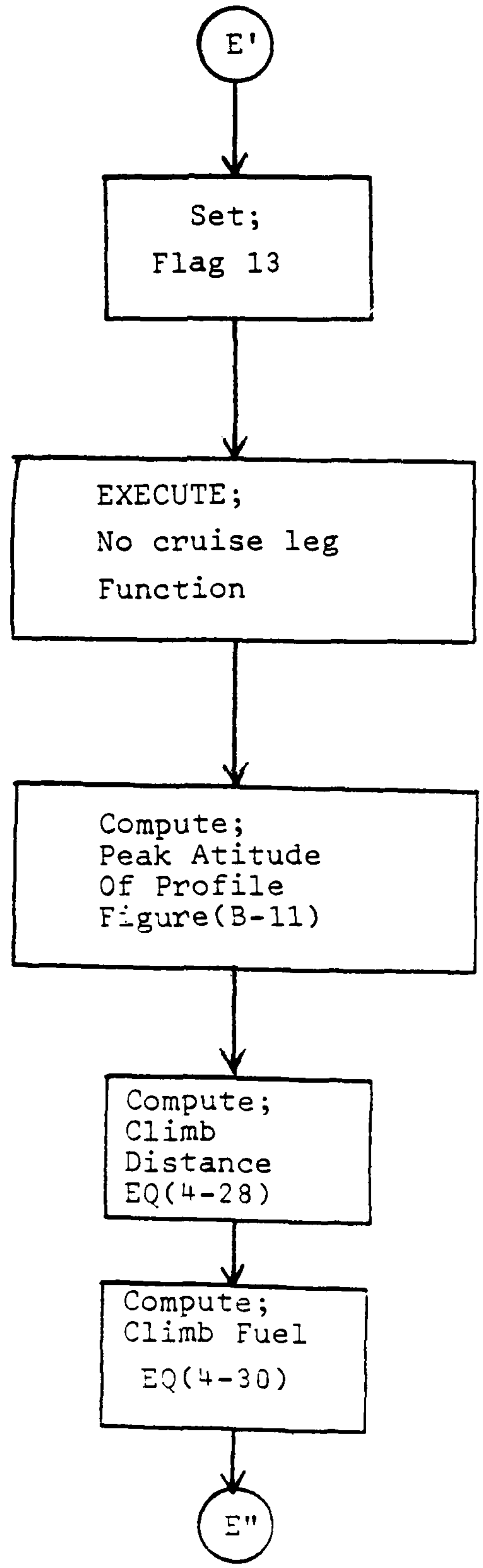

Bingo Key
CF : 13
No cruise leg
Profile when Flag
Set 13.
Input;
Distance
And Fuel
Weight
Update;
Gross Weight for
Fuel and stores
Input;
Tempera-
ture
Head Wind
B

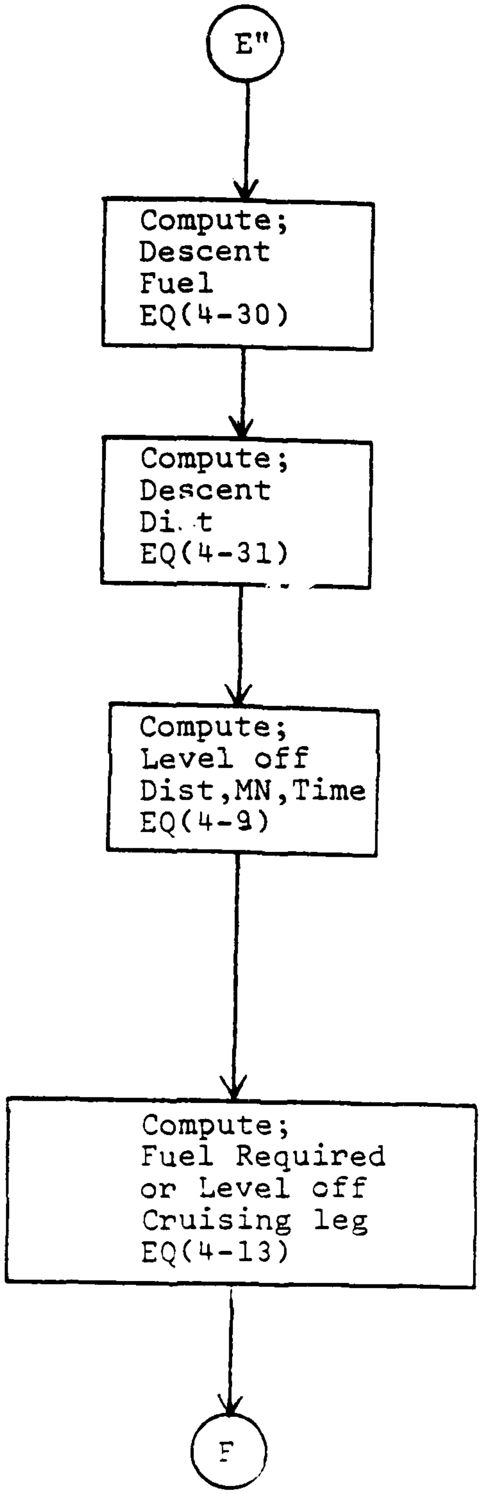

B
Compute; Optimum Cruise Altitude EQ(4-14)
Compute; Climb Distance EQ(4-28)
Compute; Climb Fuel EQ(4-26)
Compute; Nominal Cruise fuel as a function of Selected distance EQ(4-24)
C

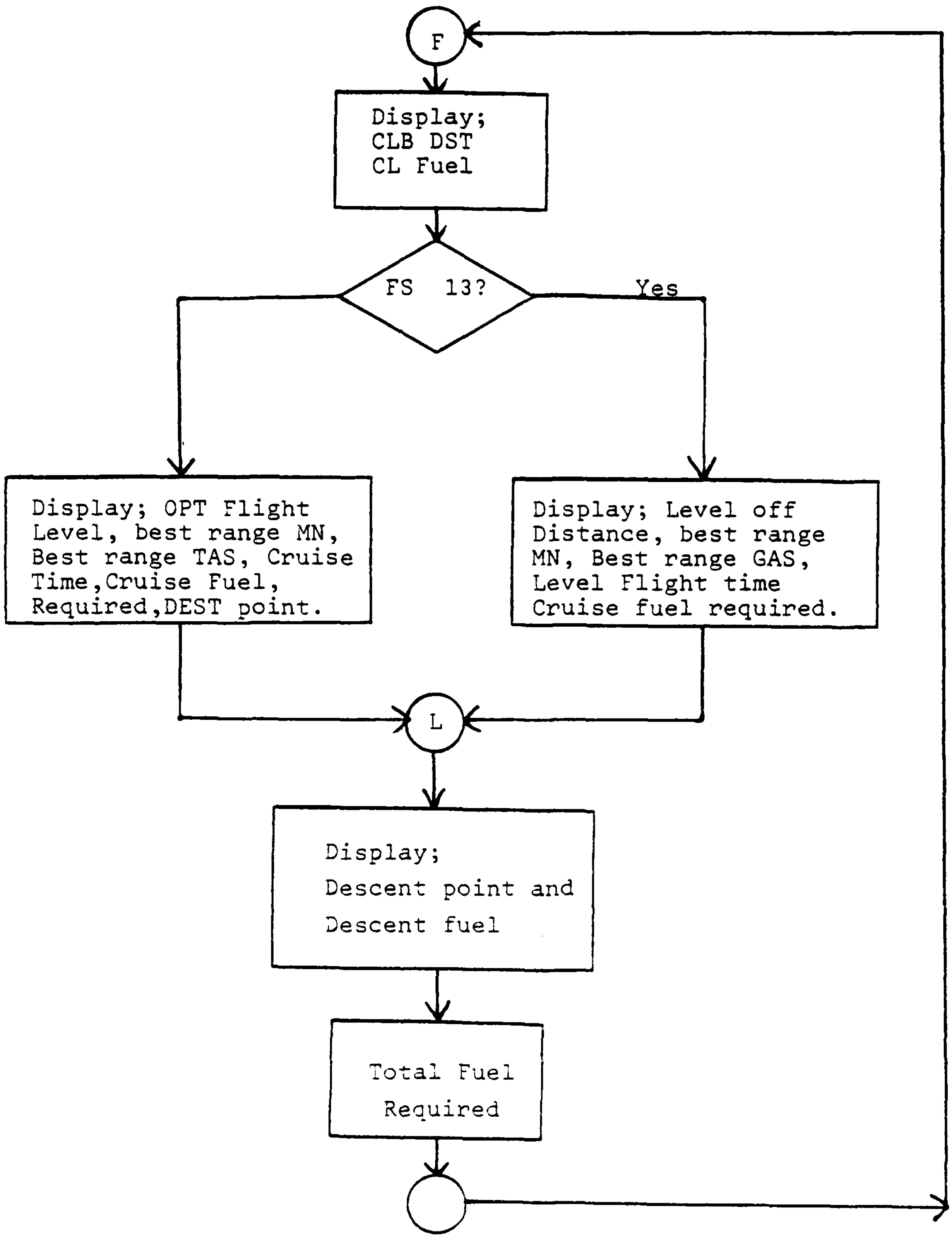

C
Reduce; Gross Weight by Climb Fuel (ST-01)
Compute; Descend Fuel EQ(4-30)
Compute; Descend Distance EQ(4-36)
D


E
Correct;
Best Range TAS
For Wind
EQ(4-11)
Compute;
Best range
Ground speed
EQ(4-12)
Compute;
Best range
Fuel flow
EQ(4-13)
Compute;
Cruisetime
($\frac{1}{GS}$ x distance)
Compute;
Fuel
Required
EQ(4-13)
F

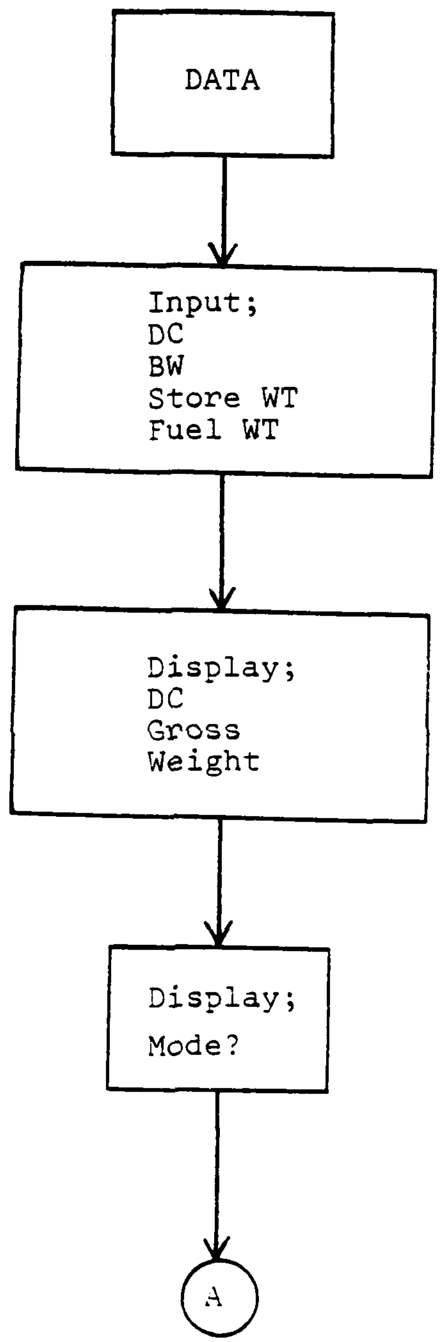

D
Bingo Dist <
Climb Dist
Descend Dist?
Yes
E'
No
Store;Cruise
Leg Distance
Reduce;
Sea level Gross
Weight by Climb
Fuel
Alt >
36,000?
Yes
Set;
Temperature=
56.5
Compute;
Best range
Mach number
EQ(4-9)
E

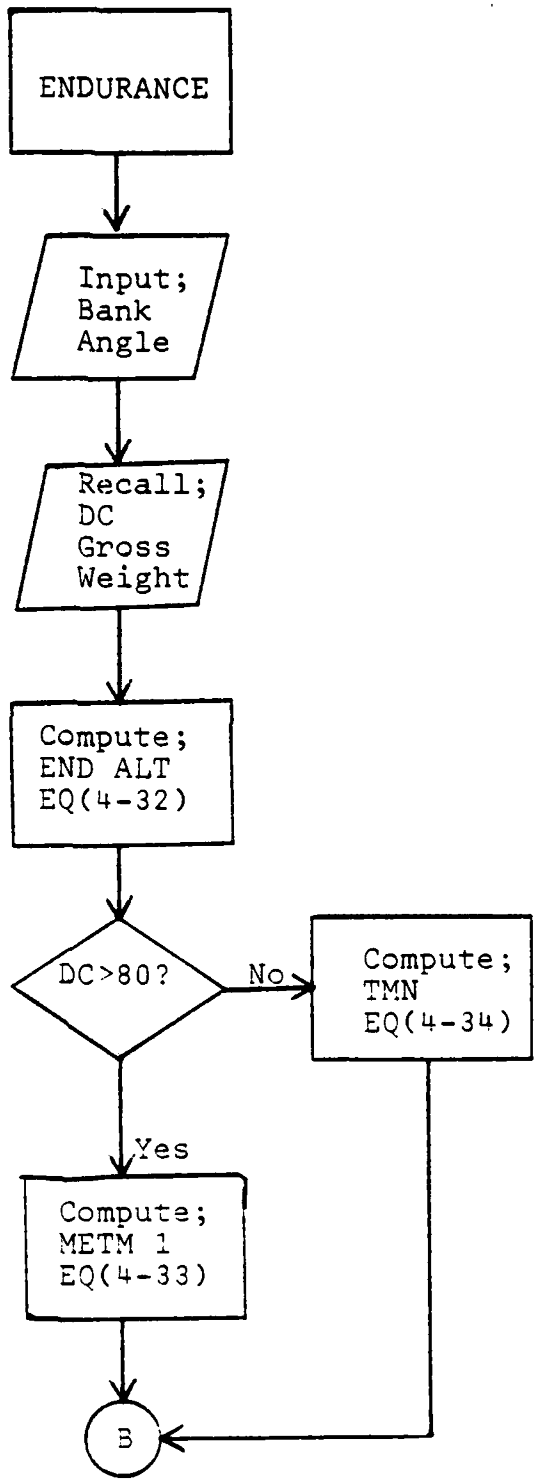

E'
Set;
Flag 13
EXECUTE;
No cruise leg
Function
Compute;
Peak Atitude
Of Profile
Figure(B-11)
Compute;
Climb
Distance
EQ(4-28)
Compute;
Climb Fuel
EQ(4-30)
E"

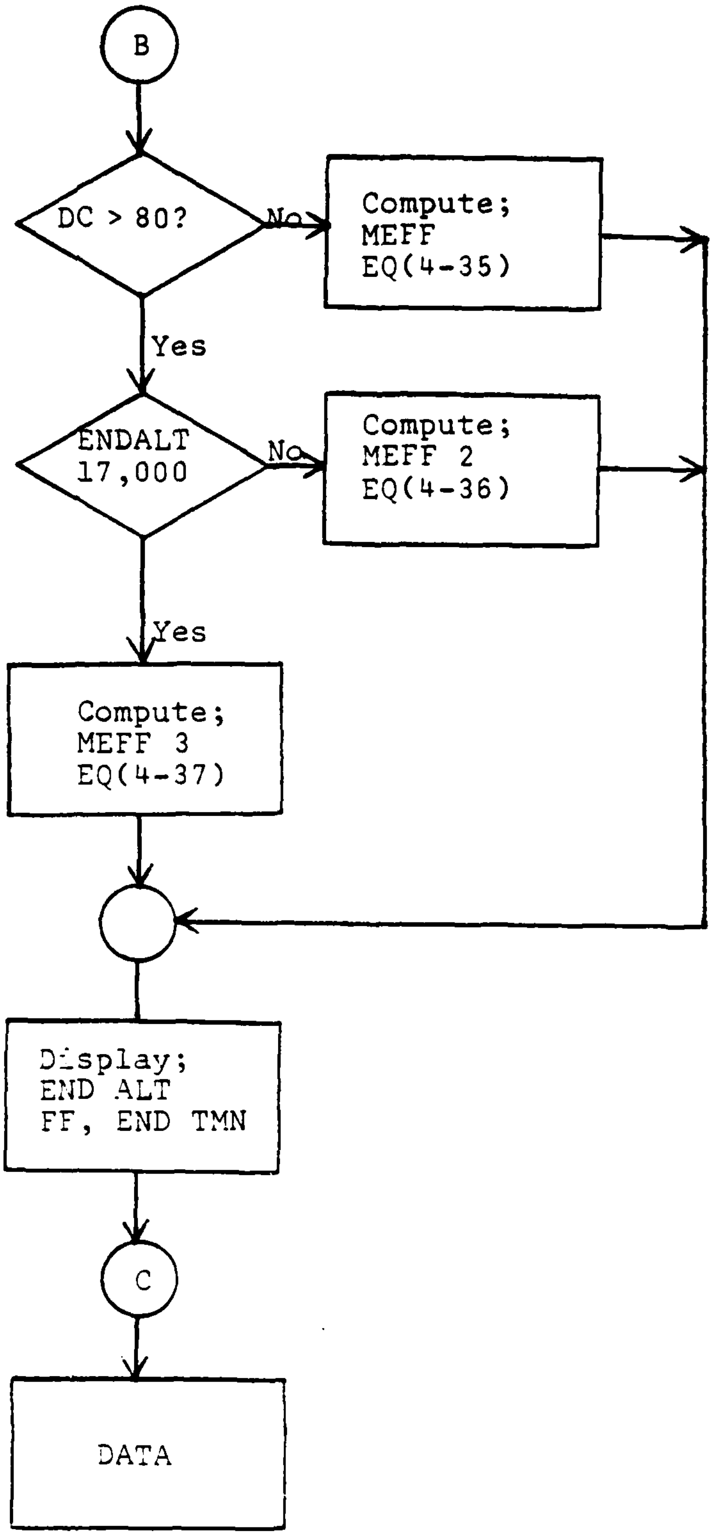

E"
Compute;
Descent
Fuel
EQ(4-30)
Compute;
Descent
Dist
EQ(4-31)
Compute;
Level off
Dist,MN,Time
EQ(4-9)
Compute;
Fuel Required
or Level off
Cruising leg
EQ(4-13)
F

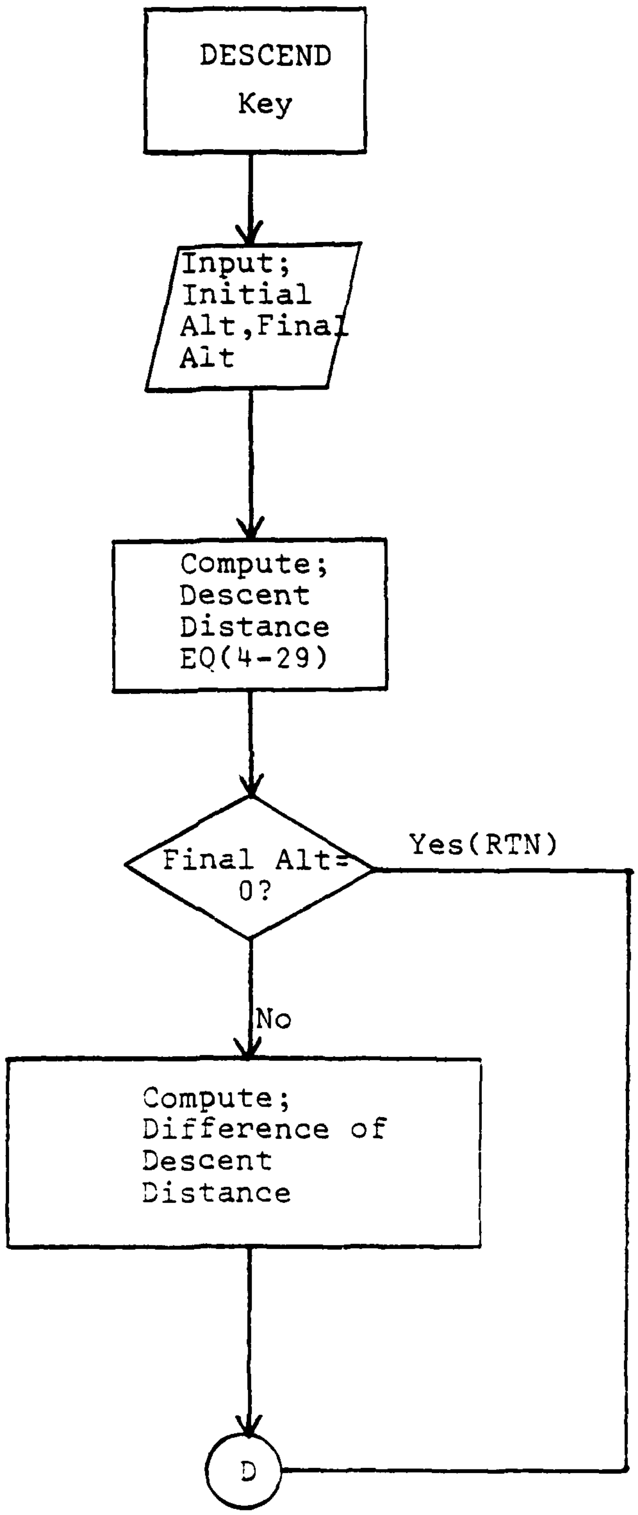

F
Display;
CLB DST
CL Fuel
FS 13?
Yes
Display; OPT Flight Level, best range MN, Best range TAS, Cruise Time,Cruise Fuel, Required,DEST point.
Display; Level off Distance, best range MN, Best range GAS, Level Flight time Cruise fuel required.
L
Display;
Descent point and
Descent fuel
Total Fuel
Required

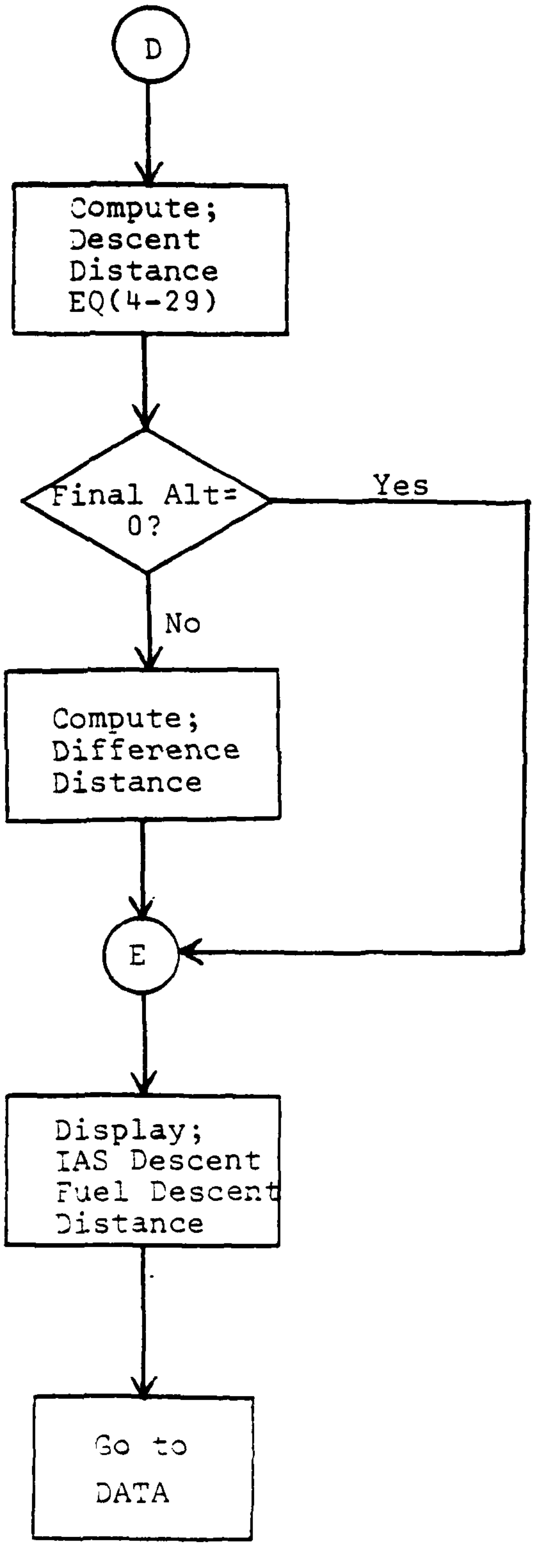
F-4E Maximum Endurance and Descent Program Flow Chart



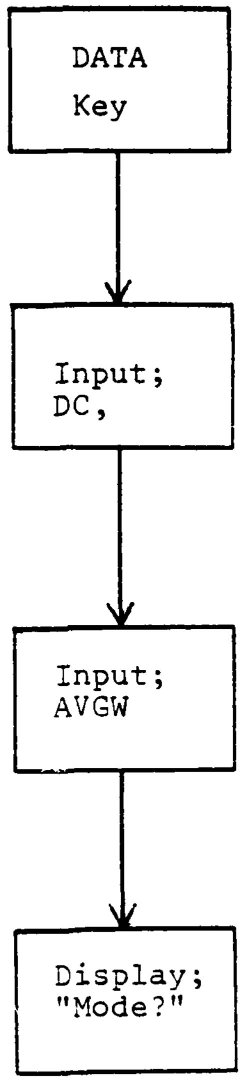

ENDURANCE
Input; Bank Angle
Recall; DC Gross Weight
Compute; END ALT EQ(4-32)
DC>80?
No
Compute; TMN EQ(4-34)
Yes
Compute; METM 1 EQ(4-33)
B

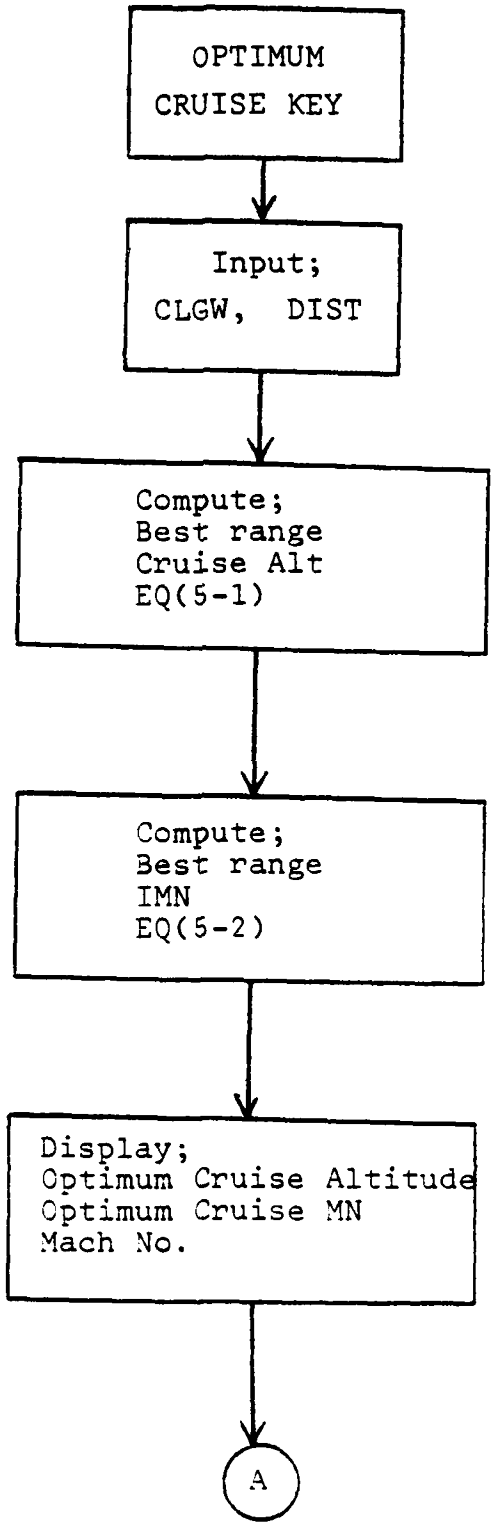

B
DC > 80?
No
Compute;
MEFF
EQ(4-35)
Yes
ENDALT
17,000
No
Compute;
MEFF 2
EQ(4-36)
Yes
Compute;
MEFF 3
EQ(4-37)
Display;
END ALT
FF, END TMN
C
DATA

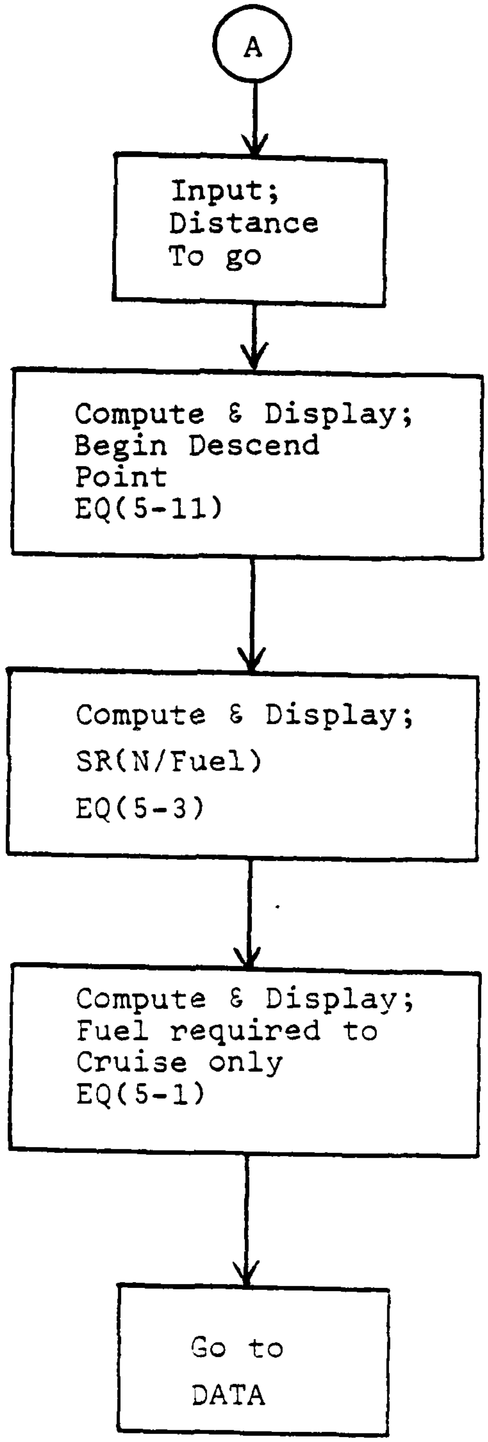

DESCEND
Key
Input;
Initial
Alt,Final
Alt
Compute;
Descent
Distance
EQ(4-29)
Final Alt=
0?
Yes(RTN)
No
Compute;
Difference of
Descent
Distance
D

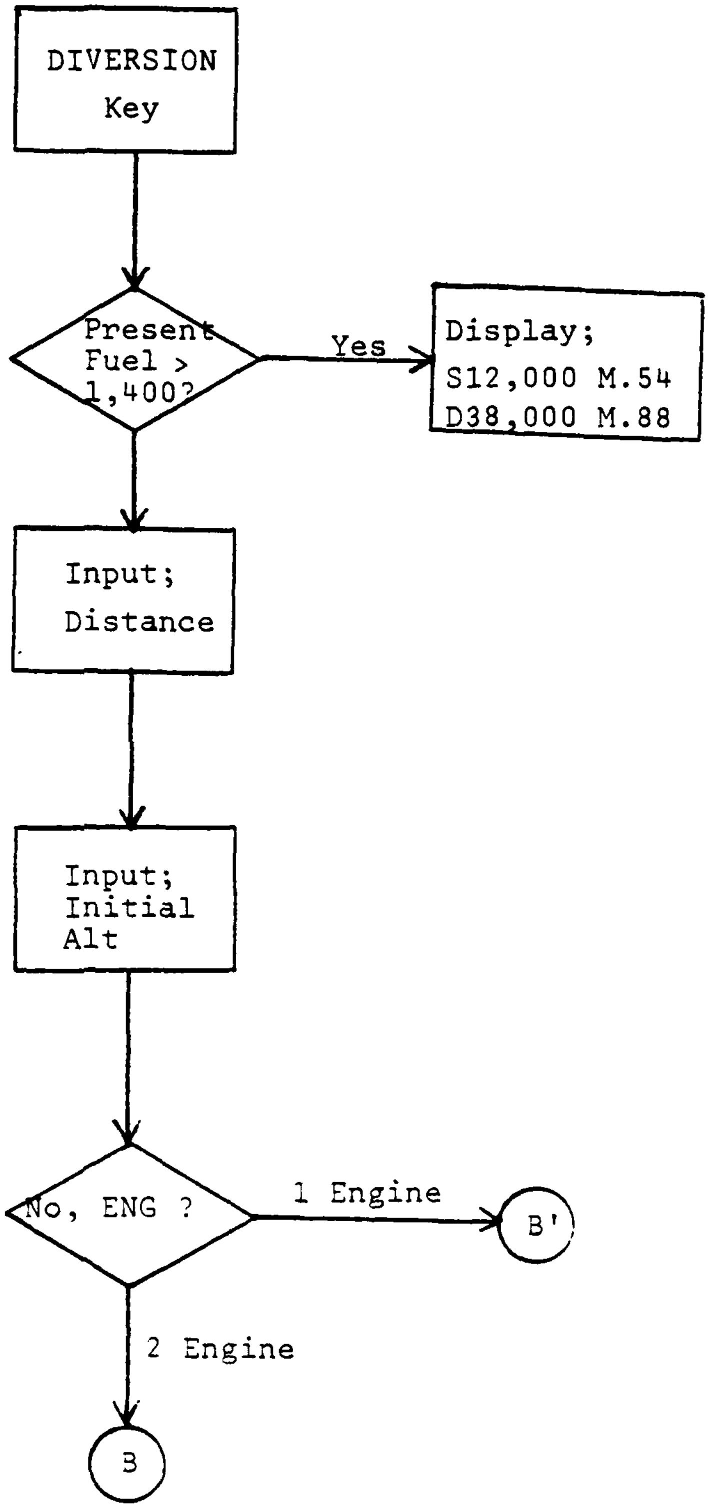

D
Compute;
Descent
Distance
EQ(4-29)
Final Alt=
0?
Yes
No
Compute;
Difference
Distance
E
Display;
IAS Descent
Fuel Descent
Distance
Go to
DATA

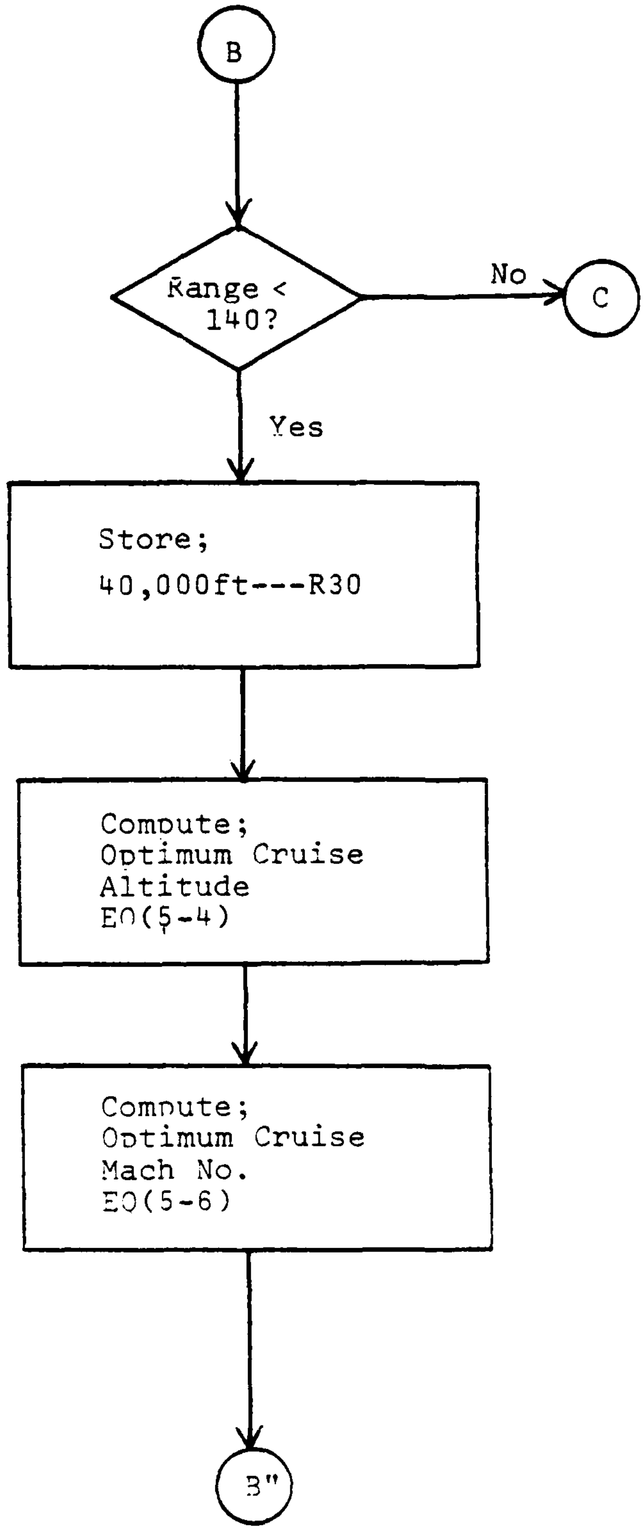
F-5E Program Flow Chart

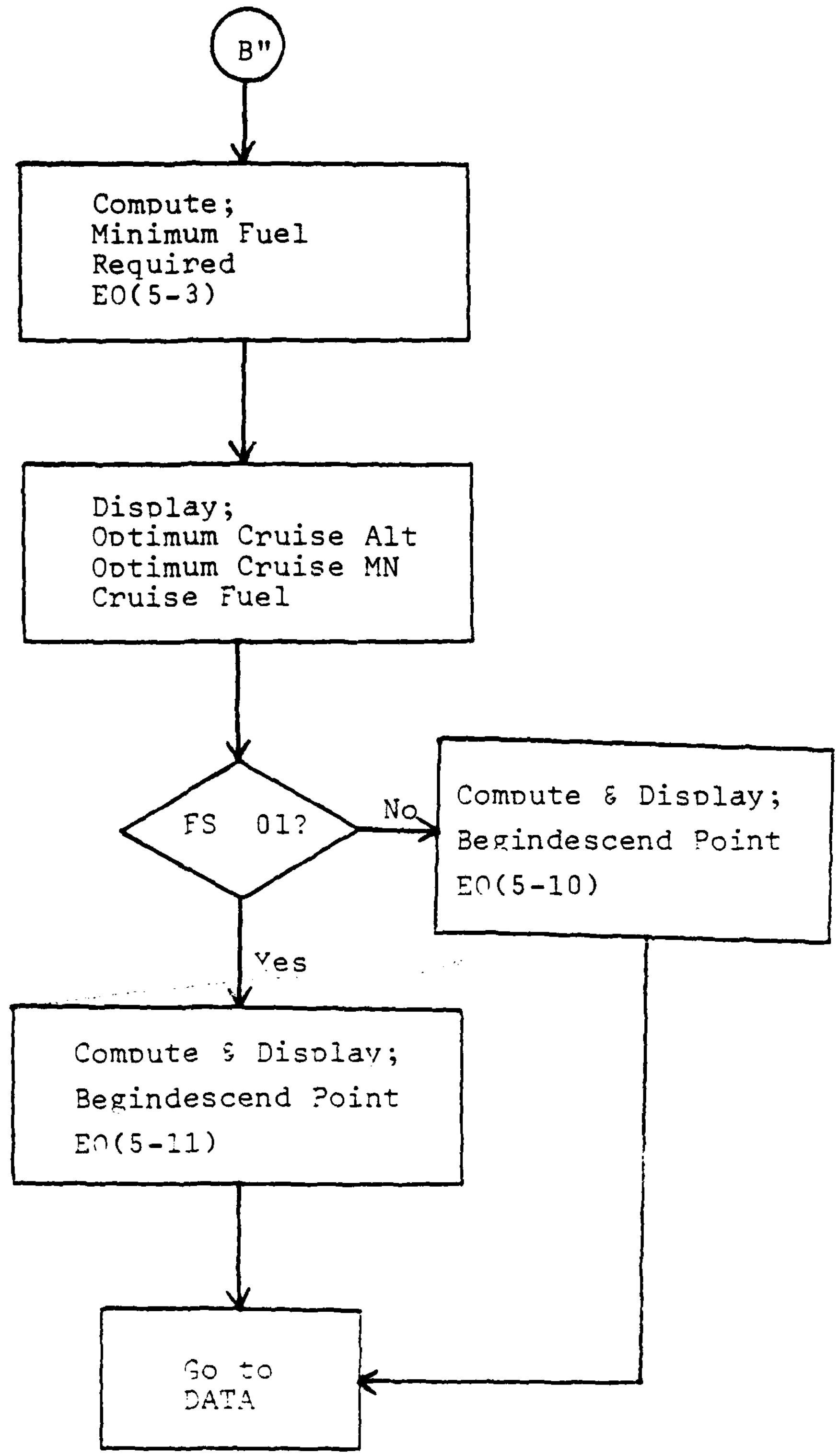


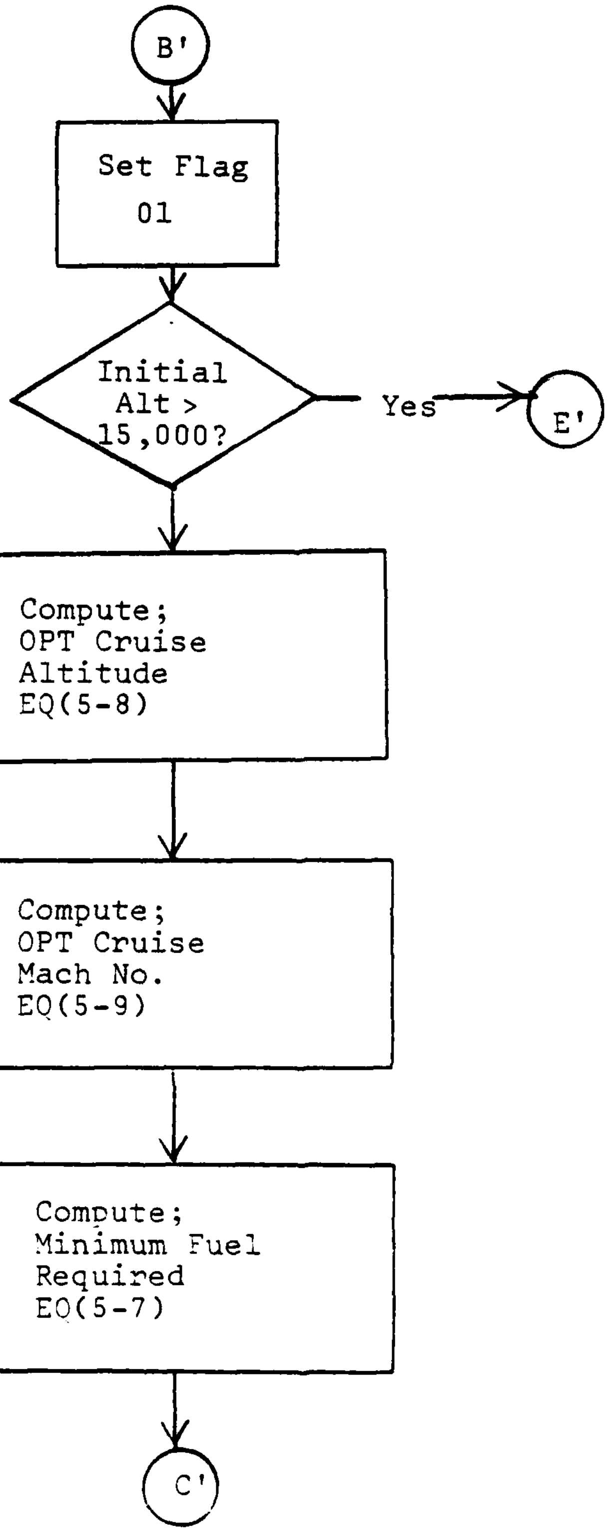

OPTIMUM
CRUISE KEY
Input;
CLGW, DIST
Compute;
Best range
Cruise Alt
EQ(5-1)
Compute;
Best range
IMN
EQ(5-2)
Display;
Optimum Cruise Altitude
Optimum Cruise MN
Mach No.
A

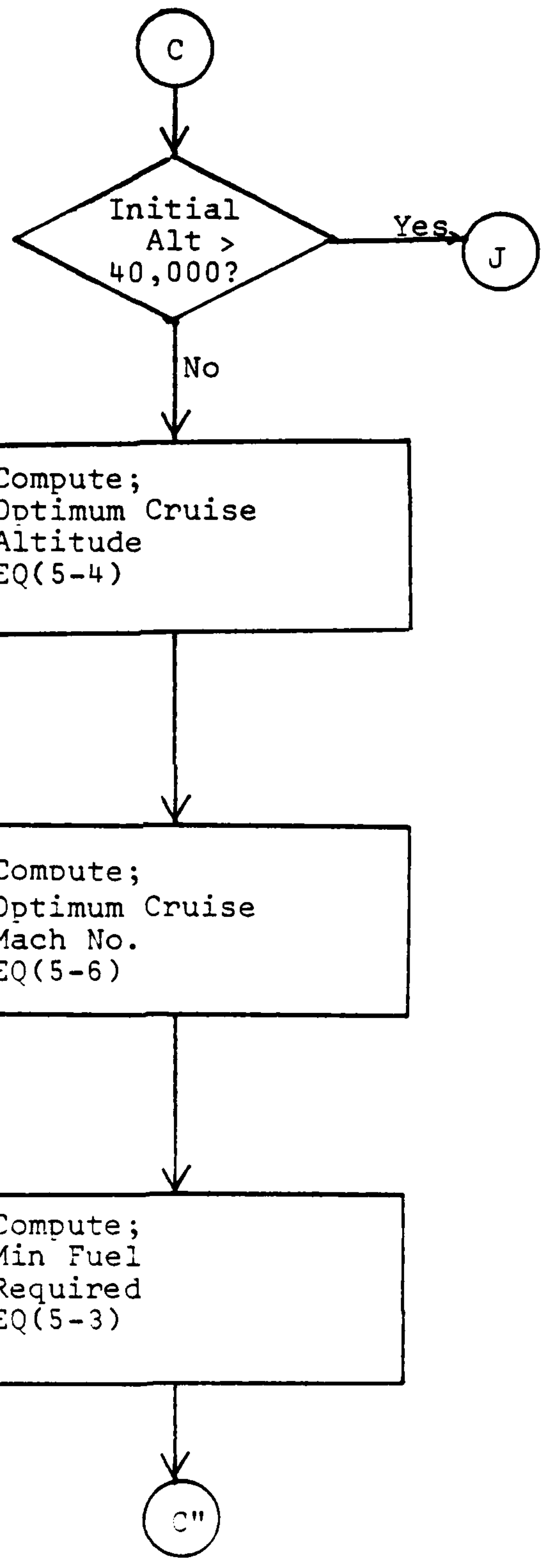

A
Input;
Distance
To go
Compute & Display;
Begin Descend
Point
EQ(5-11)
Compute & Display;
SR(N/Fuel)
EQ(5-3)
Compute & Display;
Fuel required to
Cruise only
EQ(5-1)
Go to
DATA

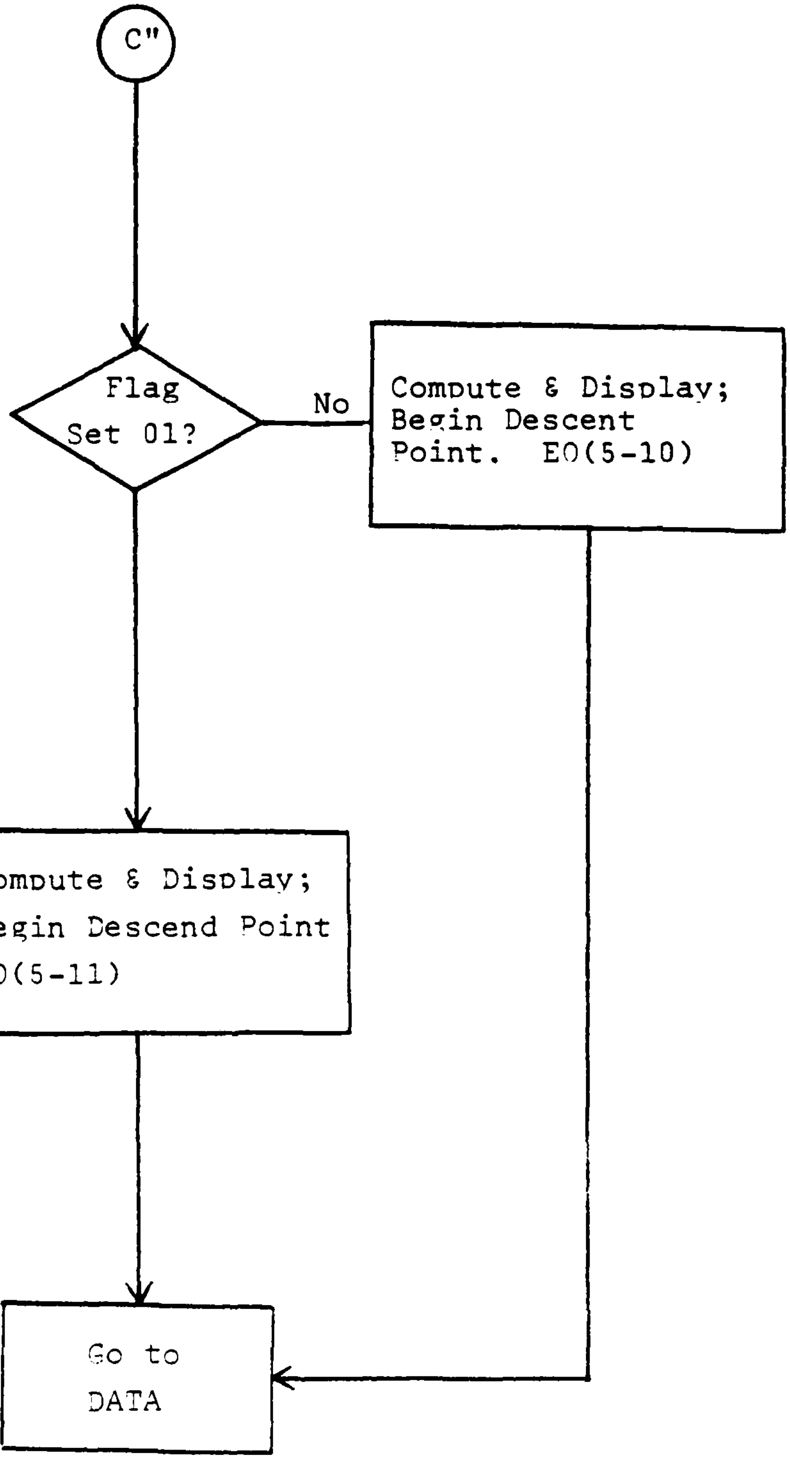

DIVERSION Key
Present Fuel > 1,400?
Yes
Display; S12,000 M.54 D38,000 M.88
Input; Distance
Input; Initial Alt
No, ENG ?
1 Engine
B'
2 Engine
B

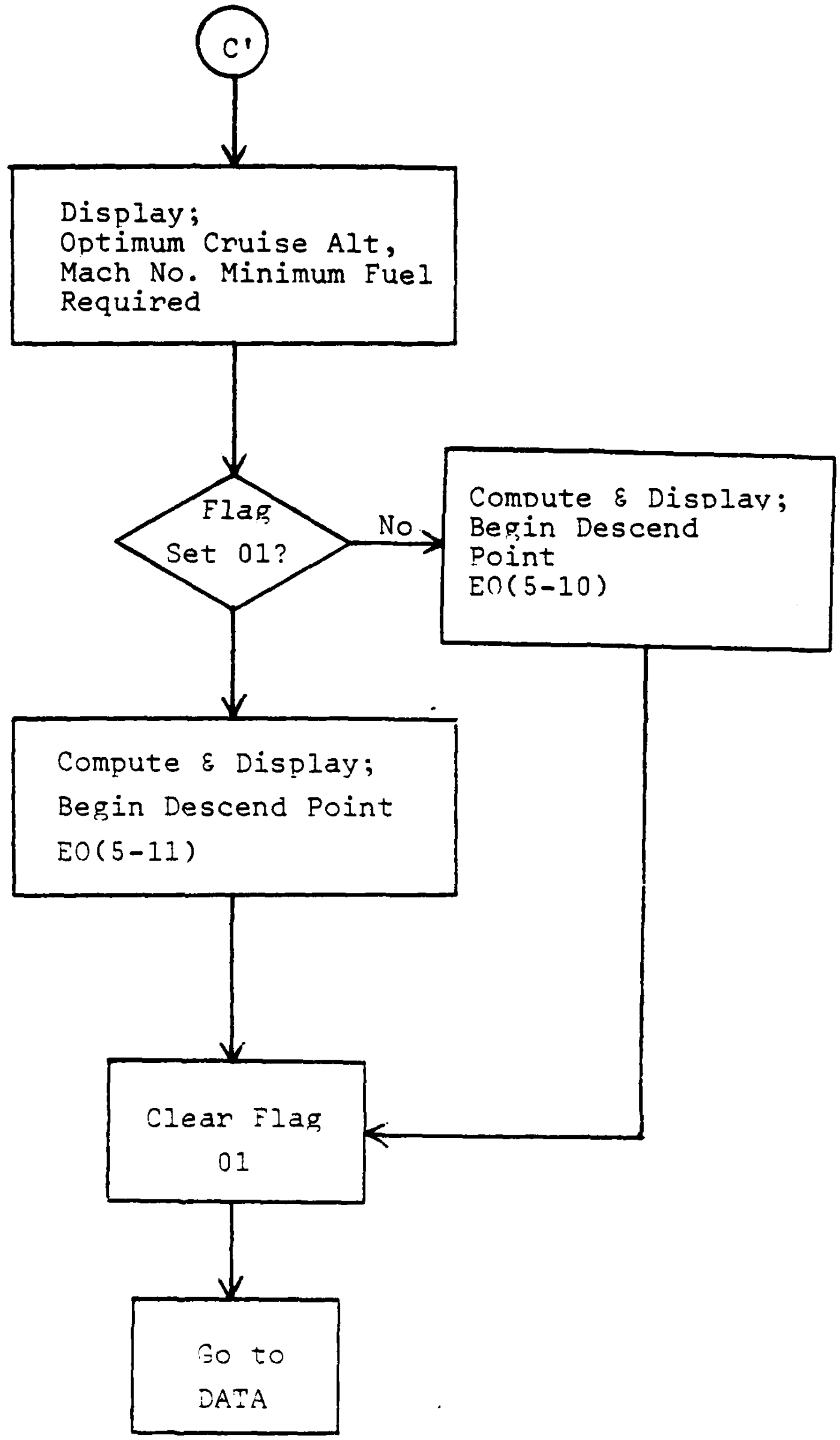

B
Range <
140?
No
C
Yes
Store;
40,000ft---R30
Compute;
Optimum Cruise
Altitude
EQ(5-4)
Compute;
Optimum Cruise
Mach No.
EQ(5-6)
B"

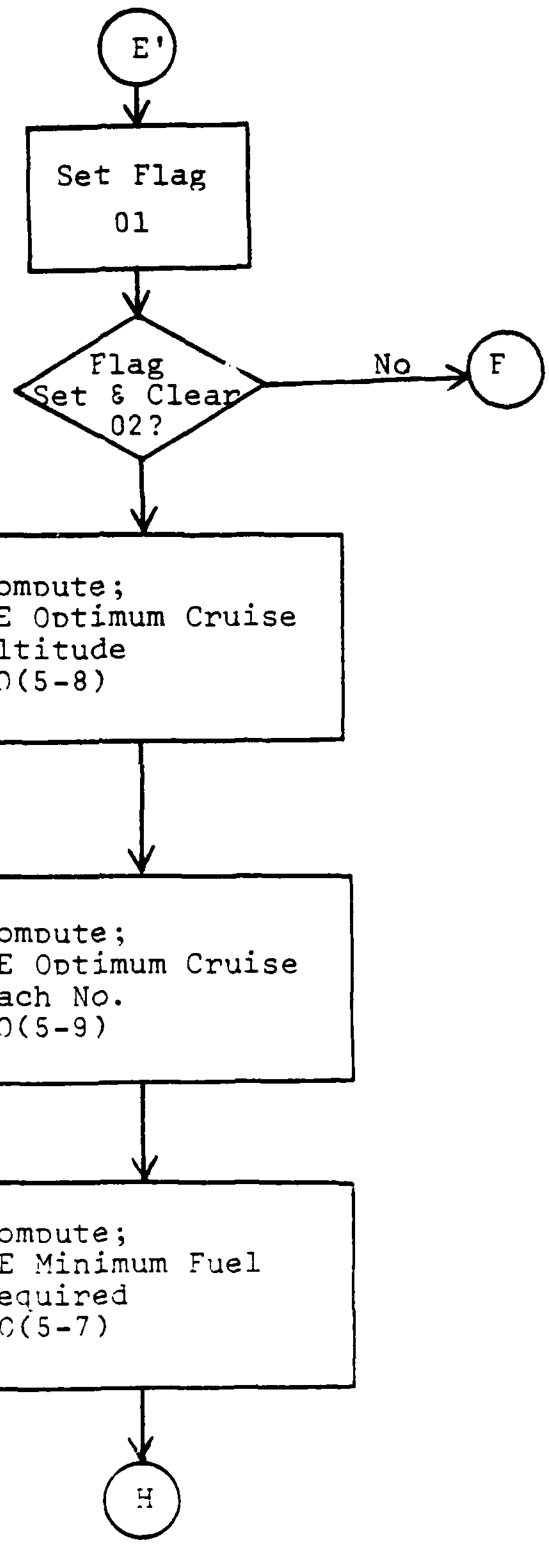

B"
Compute;
Minimum Fuel
Required
EO(5-3)
Display;
Optimum Cruise Alt
Optimum Cruise MN
Cruise Fuel
FS 01?
No
Compute & Display;
Begindescend Point
EO(5-10)
Yes
Compute & Display;
Begindescend Point
EO(5-11)
Go to
DATA

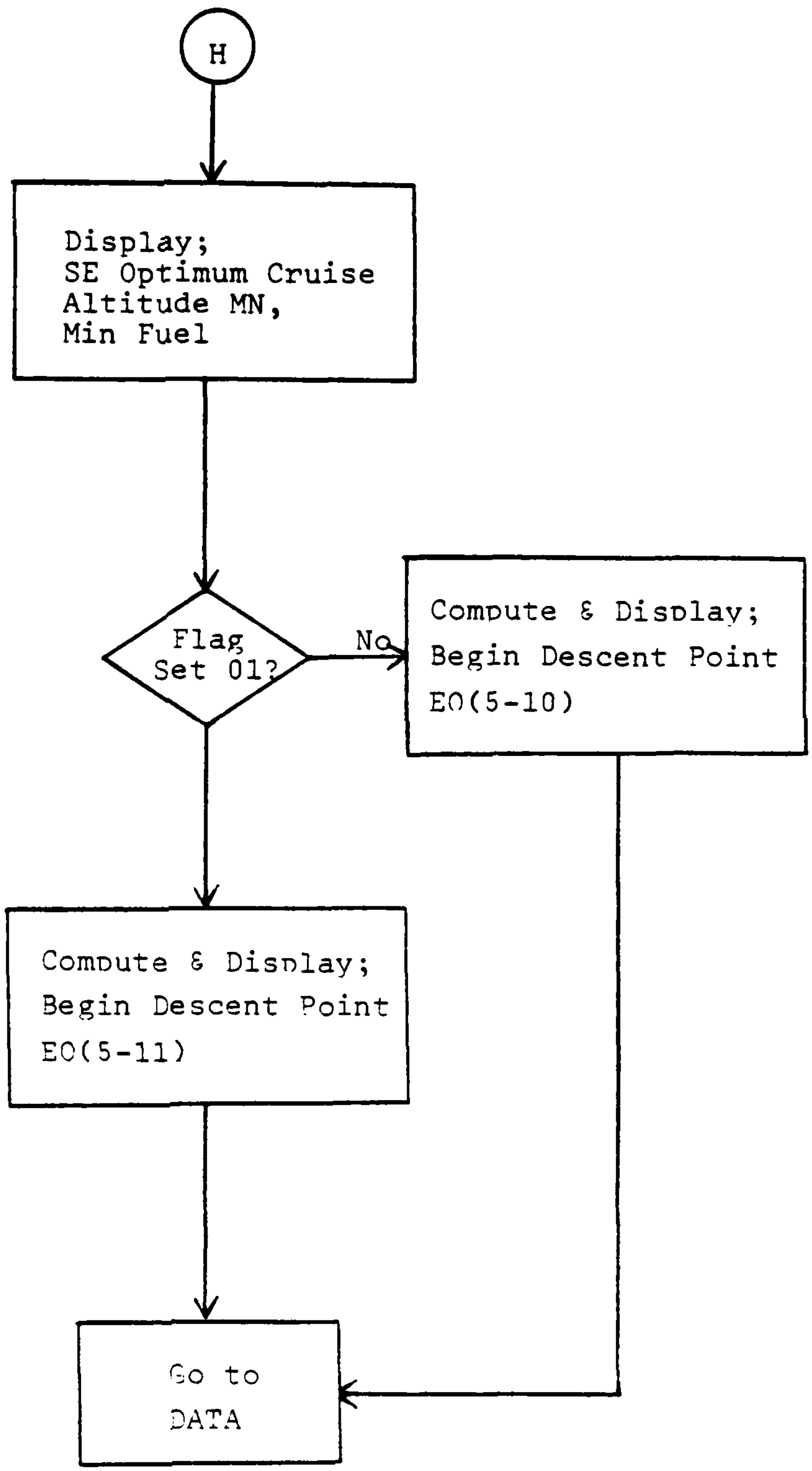

B'
Set Flag
01
Initial
Alt >
15,000?
Yes
E'
Compute;
OPT Cruise
Altitude
EQ(5-8)
Compute;
OPT Cruise
Mach No.
EQ(5-9)
Compute;
Minimum Fuel
Required
EQ(5-7)
C'

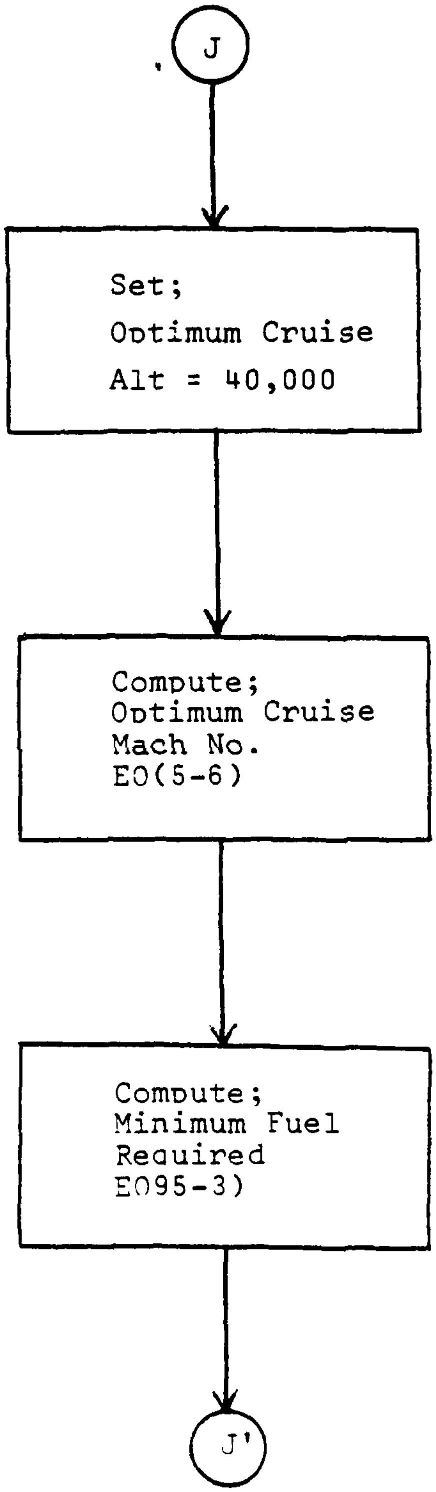

C
Initial Alt > 40,000?
Yes
J
No
Compute;
Optimum Cruise
Altitude
EQ(5-4)
Compute;
Optimum Cruise
Mach No.
EQ(5-6)
Compute;
Min Fuel
Required
EQ(5-3)
C"

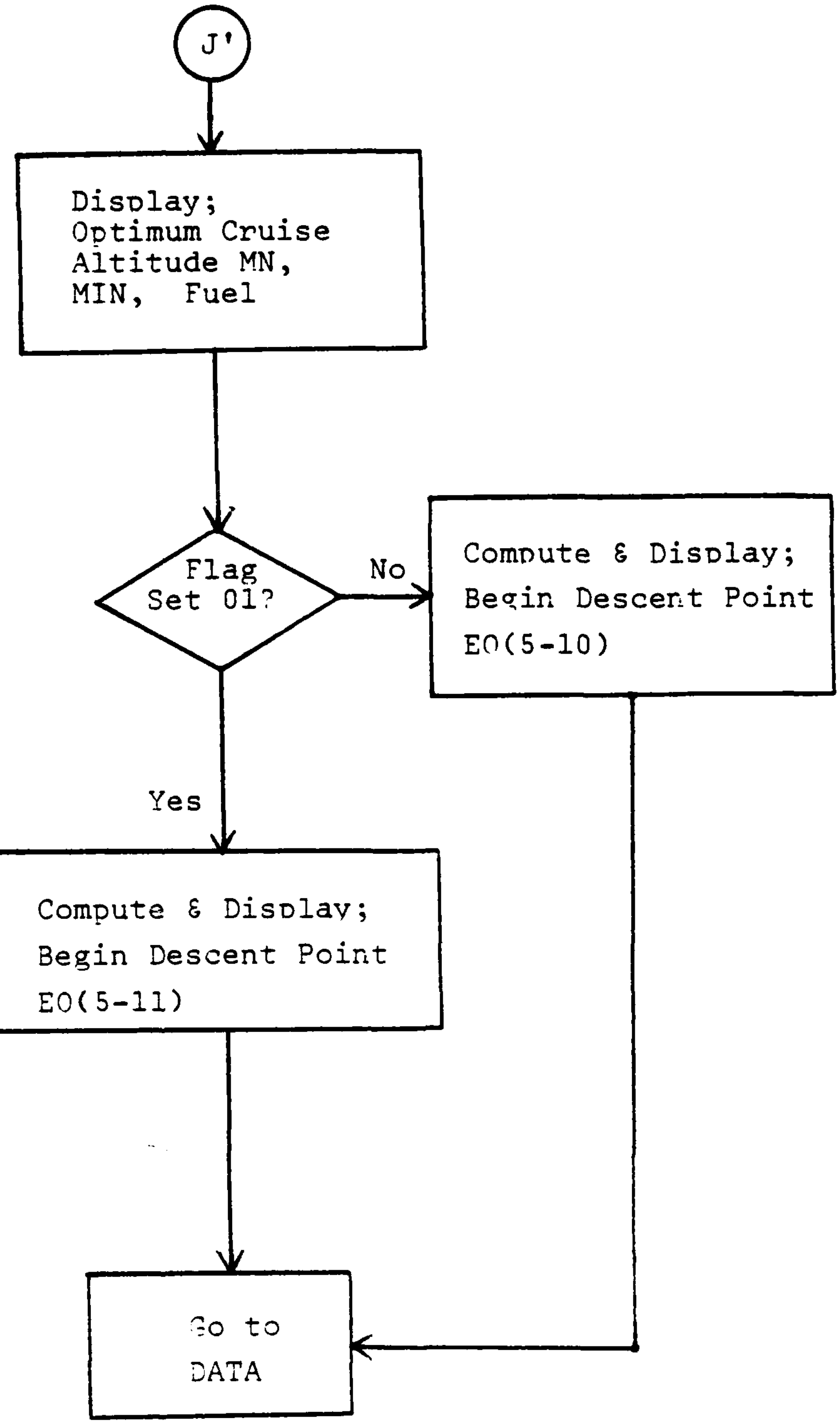

C"
Flag Set 01?
No
Compute & Display; Begin Descent Point. EO(5-10)
Compute & Display; Begin Descend Point EO(5-11)
Go to DATA


C'
Display;
Optimum Cruise Alt,
Mach No. Minimum Fuel
Required
Flag
Set 01?
No
Compute & Display;
Begin Descend
Point
EO(5-10)
Compute & Display;
Begin Descend Point
EO(5-11)
Clear Flag
01
Go to
DATA


E'
Set Flag 01
Flag Set & Clear 02?
No
F
Compute; SE Optimum Cruise Altitude EQ(5-8)
Compute; SE Optimum Cruise Mach No. EQ(5-9)
Compute; SE Minimum Fuel Required EQ(5-7)
H


H
Display;
SE Optimum Cruise
Altitude MN,
Min Fuel
Flag
Set 01?
No
Compute & Display;
Begin Descent Point
EQ(5-10)
Compute & Display;
Begin Descent Point
EQ(5-11)
Go to
DATA


J
Set;
Optimum Cruise
Alt = 40,000
Compute;
Optimum Cruise
Mach No.
EQ(5-6)
Compute;
Minimum Fuel
Required
EQ(5-3)
J'


J'
Display;
Optimum Cruise
Altitude MN,
MIN, Fuel
Flag
Set 01?
No
Compute & Display;
Begin Descent Point
EQ(5-10)
Yes
Compute & Display;
Begin Descent Point
EQ(5-11)
Go to
DATA

APPENDIX D

F-4E AND F-5E FPAS PROGRAM LISTINGS

F-4E Optimum Cruise Program Listing

Statement	Comments
01 LBL "START"	Label "Start"
02 CLRG	
03 "DC?"	Input Drag Count
04 PROMPT	
05 STO 02	
06 "BW?"	Input Base Weight
07 PROMPT	
08 ENTER↑	
09 1000	
10 /	
11 STO 04	
12 "SW?"	Input Store Weight
13 PROMPT	
14 ENTER↑	
15 1000	
16 /	
17 STO 05	
18 "FW?"	
19 PROMPT	
20 ENTER↑	
21 1000	
22 /	
23 STO 06	
24 RCL 04	
25 RCL 05	
26 +	
27 STO 07	
28 RCL 06	
29 +	
30 STO 03	
31 FIX 0	
32 "DC="	Display Drag Count
33 ARCL 02	
34 AVIEW	
35 STOP	
36 RCL 03	
37 1000	
38 *	
39 "GW="	Display Gross Weight
40 ARCL X	
41 AVIEW	
42 STOP	
43 "FAA=4 NOFAA=5"	FAA Restrictions?
44 PROMPT	
45 "FAA YES? NO?"	or No?
46 PROMPT	

Statement	Comments
47 4	
48 X=Y?	
49 GTO 10	Go to 10
50 CF 02	
51 GTO A	
52♦LBL 10	Label "10"
53 SF 02	Set FAA Flag
54 GTO A	
55♦LBL A	Label "A"
56 CF 03	
57 "MODE?"	Select Mode
58 PROMPT	
59♦LBL "PFT"	Label "PFT"
60 GTO 05	Go to 05
61♦LBL 05	
62 72.771	
63 RCL 02	
64 .0142	
65 *	
66 +	
67 RCL 03	
68 -1.2681	
69 *	
70 +	
71 RCL 02	
72 X↑2	
73 -.0000831	
74 *	
75 +	
76 RCL 03	
77 X↑2	
78 .012909	
79 *	
80 +	
81 STO 21	
82 RCL 02	
83 ENTER↑	
84 3	
85 Y↑X	
86 -.000011726	
87 *	
88 ST+ 21	
89 RCL 03	
90 ENTER↑	
91 3	
92 Y↑X	
93 -.00006265	

Statement	Comments
*	
ST+ 21	
RCL 02	
X↑2	
X↑2	
5.95454	
*	
.00000001	
*	
ST+ 21	
RCL 21	
STO 08	
GTO 77	
◆LBL 99	Subroutine "99"
36000	Altitude ≤ 36,000?
RCL 08	
X<=Y?	
GTO 20	Go to 20
-56.5	
STO 09	Altitude Above 36,000?
"SDT="	Display SDT.
ARCL 09	
AVIEW	
STOP	
RTN	
◆LBL 20	Label "20"
-.0019812	
RCL 08	
1000	
*	
*	
15	
+	
STO 09	
"STEMP<OPALT>="	Display Standard Day
ARCL 09	Temperature at Optimum
AVIEW	Cruise Altitude
STOP	
RTN	
◆LBL 77	Label "77"
XEQ 99	Execute 99
RCL 08	
STO 10	
GTO 25	Go to 25
◆LBL 25	Label "25"
FS? 02	

Statement	Comments
140 GTO 30	Go to 30
141 GTO 35	Go to 35
142♦LBL 30	Label "30"
143 "EAST=1 WST=2"	Heading East Input 1
144 PROMPT	Heading West Input 2
145 "HDG?E?W?"	
146 PROMPT	
147 1	
148 X=Y?	
149 GTO 50	Go to 50
150 CF 01	
151 GTO 51	Go to 51
152♦LBL 50	Label "50"
153 SF 01	
154 GTO 51	Go to 51
155♦LBL 51	Label "51"
156 RCL 10	
157 INT	
158 2	
159 ENTER↑	
160 MOD	
161 X=0?	
162 GTO 18	Go to 18
163 RDN	
164 FS? 01	
165 GTO 12	Go to 12
166 GTO 13	Go to 13
167♦LBL 18	Label 18
168 RDN	
169 FS? 01	
170 GTO 13	Go to 13
171 GTO 12	Go to 12
172♦LBL 13	Label "13"
173 1	
174 +	
175 1000	
176 *	
177 STO 16	
178 GTO 55	Go to 55
179♦LBL 12	Label "12"
180 1000	
181 *	
182 STO 16	
183 GTO 55	Go to 55
184♦LBL 55	Label "55"
185 "IFR=7 VFR=8"	

Statement	Comments
186 PROMPT	
187 "IFR?VFR?"	Input IFR 7
188 PROMPT	VFR 8
189 7	
190 X=Y?	
191 GTO 60	Go to 60
192 GTO 61	Go to 61
193♦LBL 60	Label "60"
194 RCL 16	
195 0	
196 +	
197 STO 16	
198 GTO 62	
199♦LBL 61	Label "61"
200 RCL 16	
201 500	
202 +	
203 STO 16	
204 GTO 62	Go to 62
205♦LBL 62	Label "62"
206 RCL 16	
207 FIX 0	
208 "FAABRALT="	Display FAA Best Range
209 ARCL X	Altitude
210 AVIEW	
211 STOP	
212 GTO 36	Go to 36
213♦LBL 35	Label "35"
214 RCL 10	
215 1000	
216 *	
217 FIX 0	
218 "BRALT="	Display Best Range Altitude
219 ARCL X	
220 AVIEW	
221 STOP	
222 GTO 36	To to 36
223♦LBL 36	Label "36"
224 .86772	
225 RCL 02	
226 -.00005	
227 *	
228 +	
229 RCL 02	
230 X↑2	
231 -.000010812	

Statement	Comments
232 *	
233 +	
234 STO 21	
235 RCL 02	
236 ENTER↑	
237 3	
238 Y↑X	
239 1.135375	
240 *	
241 .00000001	
242 *	
243 ST+ 21	
244 RCL 21	
245 STO 12	
246 FIX 3	
247 "BRMN="	Display Best Range Mach Number
248 ARCL 12	
249 PROMPT	
250 "TW?"	Input Tail Wind
251 PROMPT	
252 STO 11	
253 GTO 01	Go to 01
254♦LBL 01	Label "01"
255 .3467	Compute Best Range Fuel Flow
256 STO 21	
257 RCL 03	
258 -.011423	
259 *	
260 ST+ 21	
261 RCL 02	
262 -.0010658	
263 *	
264 ST+ 21	
265 RCL 03	
266 X↑2	
267 .00017361	
268 *	
269 ST+ 21	
270 RCL 02	
271 X↑2	
272 -.000001143	
273 *	
274 ST+ 21	
275 RCL 03	
276 ENTER↑	
277 3	
278 Y↑X	

Statement	Comments
279 -1.01941	Compute Best Range Fuel Flow
280 *	
281 .000001	
282 *	
283 ST+ 21	
284 RCL 02	
285 ENTER↑	
286 3	
287 Y↑X	
288 4.026908	
289 *	
290 .00000001	
291 *	
292 ST+ 21	
293 RCL 02	
294 X↑2	
295 X↑2	
296 -1.48918	
297 *	
298 .0000000001	
299 *	
300 ST+ 21	
301 RCL 03	
302 X↑2	
303 X↑2	
304 RCL 02	
305 X↑2	
306 X↑2	
307 *	
308 9.065261	
309 *	
310 10	
311 ENTER↑	
312 -18	
313 Y↑X	
314 *	
315 ST÷ 21	
316 RCL 03	
317 ENTER↑	
318 3	
319 Y↑X	
320 RCL 02	
321 ENTER↑	
322 3	
323 Y↑X	
324 *	

Statement	Comments
325 -1.36419	
326 *	
327 10	
328 ENTER↑	
329 -13	
330 Y↑X	
331 *	
332 ST+ 21	
333 RCL 03	
334 RCL 02	
335 *	
336 .000014286	
337 *	
338 ST+ 21	
339 RCL 21	
340 STO 14	
341 GTO 17	
342♦LBL 17	Label "17"
343 FIX 4	Compute Best Range True
344 RCL 19	Airspeed
345 273.16	
346 +	
347 SQRT	
348 38.98	
349 *	
350 RCL 12	
351 *	
352 RCL 11	
353 .25	
354 *	
355 +	
356 STO 13	
357 XEQ 21	
358 GTO 16	
359♦LBL 21	Label "21"
360 RCL 13	Compute Best Range Ground
361 RCL 11	Airspeed
362 +	
363 STO 15	
364 RTN	
365♦LBL 16	Label "16"
366 FIX 0	
367 "BRTAS="	Display Best Range True
368 ARCL 13	Airspeed
369 PROMPT	
370 "BRGS="	

Statement	Comments
371 ARCL 15	Display Best Range Ground
372 PROMPT	Speed
373 "SR="	Display Specific Range
374 ARCL 14	
375 PROMPT	
376 FS? 03	
377 GTO 90	Go to 90
378 GTO A	Go to A
379♦LBL 90	Label "90"
380 FS? 02	
381 GTO 91	Go to 91
382 GTO A	Go to A
383♦LBL 91	Label "91"
384 44000	
385 RCL 10	
386 X>Y?	
387 GTO 94	Go to 94
388 GTO 93	Go to 93
389♦LBL 93	Label "93"
390 RCL 10	
391 2	Compute Next FAA
392 +	BRALT
393 STO 10	
394 131.946	
395 RCL 10	
396 -1.1806	
397 *	
398 +	
399 RCL 02	
400 -.16622	
401 *	
402 +	
403 RCL 10	
404 X↑2	
405 -.06952	
406 *	
407 -	
408 STO 21	
409 RCL 10	
410 ENTER↑	
411 3	
412 Y↑X	
413 .0009906	
414 *	
415 ST- 21	
416 RCL 02	
417 X↑2	

Statement	Comments
418 -.0004368	
419 *	
420 ST+ 21	
421 RCL 02	
422 ENTER↑	
423 3	
424 Y↑X	
425 -.000019404	
426 *	
427 ST+ 21	
428 RCL 02	
429 ENTER↑	
430 4	
431 Y↑X	
432 1.084781	
433 *	
434 10	
435 ENTER↑	
436 -7	
437 Y↑X	
438 *	
439 ST+ 21	
440 RCL 10	
441 RCL 02	
442 *	
443 .0054296	
444 *	
445 ST+ 21	
446 RCL 21	
447 RCL 07	
448 -	
449 STO 18	
450 0	
451 X>Y?	
452 GTO 94	Go to 94
453 GTO 97	Go to 97
454♦LBL 97	Label "97"
455 RCL 18	
456 RCL 06	
457 X>Y?	
458 GTO 92	Go to 92
459 GTO 93	Go to 93
460♦LBL 94	Label "94"
461 BEEP	
462 "CEILING"	Display Ceiling Altitude
463 AVIEW	

Statement	Comments
464 STOP	
465 GTO A	Go to A
466♦LBL 92	Label "92"
467 RCL 10	
468 FIX 0	
469 1000	
470 *	
471 BEEP	
472 "NBRALT="	Display Next Best Range
473 ARCL X	Altitude
474 AVIEW	
475 STOP	
476 RCL 18	
477 1000	
478 *	
479 FIX 0	
480 "NFW="	Display NFW
481 ARCL X	
482 AVIEW	
483 STOP	
484 GTO A	
485♦LBL "IFT"	Label "IFT"
486 SF 03	
487 "FW?"	Input Fuel Weight
488 PROMPT	
489 ENTER↑	
490 1000	
491 /	
492 STO 06	
493 RCL 07	
494 +	
495 STO 03	
496 FS? 02	
497 GTO 80	Go to 80
498 GTO 85	Go to 85
499♦LBL 80	Label "80"
500 "ALT?"	Input Altitude
501 PROMPT	
502 1000	
503 /	
504 STO 10	
505 STO 08	
506 XEQ 99	
507 "TEMP?"	Input Temperature
508 PROMPT	
509 STO 19	

Statement	Comments
510 RCL 19	
511 -	
512 STO 00	
513 GTO 36	Go to 36
514♦LBL "CLB"	Label "Climb"
515 "FW?"	Input Fuel Weight
516 PROMPT	
517 1000	
518 /	
519 STO 06	
520 RCL 07	
521 +	
522 STO 03	
523 XEQ 07	Execute 07
524 XEQ 04	Execute 04
525 RCL 12	
526 FIX 0	
527 "DIST="	Display Distance Required to Climb
528 ARCL X	
529 AVIEW	
530 STOP	
531 RCL 14	
532 FIX 0	
533 100	
534 *	
535 "FUEL="	Display Fuel Required to Climb
536 ARCL X	
537 AVIEW	
538 STOP	
539 GTO A	Go to A
540♦LBL 04	Label "04"
541 RCL 18	
542 STO 08	
543 XEQ 06	Execute 06
544 STO 14	
545 0	
546 RCL 17	
547 X<=Y?	
548 RTN	
549 RCL 17	
550 STO 08	
551 XEQ 06	Execute 06
552 ST- 14	
553 RTN	
554♦LBL 06	Label "06"
555 20.56	

Statement	Comments
556 RCL 03	
557 .012	
558 *	
559 +	
560 RCL 08	
561 -1.8627	
562 *	
563 +	
564 RCL 02	
565 -.21129	
566 *	
567 +	
568 RCL 03	
569 X↑2	
570 -.00972	
571 *	
572 +	
573 RCL 08	
574 X↑2	
575 .04926	
576 *	
577 +	
578 RCL 02	
579 X↑2	
580 .0003097	
581 *	
582 +	
583 RCL 08	
584 X↑2	
585 RCL 08	
586 *	
587 -.0012384	
588 *	
589 +	
590 STO 21	
591 RCL 02	
592 ENTER↑	
593 3	
594 Y↑X	
595 .000002118	
596 *	
597 ST+ 21	
598 RCL 03	
599 X↑2	
[illegible]	
[illegible]	

Statement **Comments**

```
602 *
603 ST+ 21
604 RCL 08
605 X↑2
606 X↑2
607 .000013231
608 *
609 ST+ 21
610 RCL 02
611 X↑2
612 X↑2
613 -1.62933
614 *
615 .00000001
616 *
617 ST+ 21
618 RCL 03
619 RCL 08
620 *
621 .029079
622 *
623 ST+ 21
624 RCL 08
625 RCL 02
626 *
627 .0051266
628 *
629 ST+ 21
630 RCL 03
631 RCL 02
632 *
633 .0029517
634 *
635 ST+ 21
636 RCL 21
637 STO 13
638 -.183
639 RCL 20
640 .12523
641 *
642 +
643 RCL 13
644 1.0498
645 *
646 +
647 RCL 13
```

Statement	Comments
648 X↑2	
649 -.0021◂4	
650 *	
651 +	
652 RTN	
653♦LBL 07	Label "07"
654 "INITALT?"	Input Initial Altitude
655 PROMPT	
656 1000	
657 /	
658 STO 08	
659 STO 17	
660 "FIN ALT?"	Input Desired Final
661 PROMPT	Altitude
662 1000	
663 /	
664 STO 09	
665 STO 18	
666 STO 08	
667 XEQ 08	Execute 08
668 STO 12	
669 0	
670 RCL 17	
671 X<=Y?	
672 RTN	
673 RCL 17	
674 STO 08	
675 XEQ 08	
676 ST- 12	
677 RTN	
678♦LBL 08	Label "08"
679 57.5	Subroutine 08
680 RCL 03	
681 1.537	
682 *	
683 +	
684 RCL 08	
685 -6.47	
686 *	
687 +	
688 RCL 02	
689 -.4076	
690 *	
691 +	
692 RCL 03	
693 X↑2	

Statement	Comments
694 -.04814	
695 *	
696 +	
697 RCL 08	
698 X↑2	
699 .1712	
700 *	
701 +	
702 RCL 02	
703 X↑2	
704 .000112	
705 *	
706 +	
707 STO 21	
708 RCL 08	
709 ENTER↑	
710 3	
711 Y↑X	
712 -.0013675	
713 *	
714 ST+ 21	
715 RCL 02	
716 ENTER↑	
717 3	
718 Y↑X	
719 -.00000913	
720 *	
721 ST+ 21	
722 RCL 03	
723 X↑2	
724 X↑2	
725 .000003133	
726 *	
727 ST+ 21	
728 RCL 0[illegible]	
729 X↑[illegible]	
730 X↑2	
731 .0000[illegible]30487	
732 *	
733 [illegible]+ [illegible]	
734 RCL 0[illegible]	
735 [illegible]	
736 *	
737 -[illegible]44	
738 *	
739 ST+	

Statement	Comments
740 RCL 08	
741 RCL 02	
742 *	
743 .011657	
744 *	
745 ST+ 21	
746 RCL 03	
747 RCL 02	
748 *	
749 .006917	
750 *	
751 ST+ 21	
752 RCL 03	
753 X↑2	
754 RCL 08	
755 X↑2	
756 *	
757 .000003973	
758 *	
759 ST+ 21	
760 RCL 08	
761 X↑2	
762 RCL 02	
763 X↑2	
764 *	
765 .0000010795	
766 *	
767 ST+ 21	
768 RCL 21	
769 "DEL TEMP?"	Input Temperature Deviation
770 PROMPT	From Standard Day
771 STO 20	Temperature
772 4.32	
773 RCL 20	
774 .6257	
775 *	
776 +	
777 RCL 21	
778 .712	
779 *	
780 +	
781 RCL 21	
782 X↑2	
783 .00658	
784 *	
785 +	
786 RCL 21	

Statement	Comments
787 X↑2	
788 RCL 21	
789 *	
790 -.0000411	
791 *	
792 +	
793 RTN	
794 END	End

F-4E Maximum Endurance and Descent Program Listing

Statement	Comments
01♦LBL "DATA"	Label "Data Mode"
02 "DC?"	Input Drag Count
03 PROMPT	
04 STO 02	
05 "BW?"	Input Base Weight (lbs)
06 PROMPT	
07 1000	
08 /	
09 STO 04	
10 "STWT?"	Input Store Weight (lbs)
11 PROMPT	
12 1000	
13 /	
14 STO 05	
15 "FW?"	Input Fuel Weight (lbs)
16 PROMPT	
17 1000	
18 /	
19 STO 06	
20 RCL 05	
21 RCL 04	
22 +	
23 STO 07	
24 RCL 06	
25 +	
26 STO 03	
27 FIX 0	
28 "DC="	Display Drag Count
29 ARCL 02	
30 AVIEW	
31 STOP	
32 RCL 03	
33 1000	
34 *	
35 "GW="	Display Computed Gross Weight
36 ARCL X	
37 AVIEW	
38 STOP	
39 "MODE?"	What Mode do You Want to Select?
40 PROMPT	
41♦LBL "END"	Label "Max Endurance"
42 RCL 03	
43 "BANK∡?"	Input Bank Angle
44 PROMPT	
45 COS	
46	

Statement	Comments
47 STO 08	
48 61.72	Compute Maximum Endurance
49 RCL 02	Altitude
50 .07729	
51 *	
52 +	
53 STO 11	
54 RCL 08	
55 -.725	
56 *	
57 ST+ 11	
58 RCL 02	
59 X↑2	
60 -.0042425	
61 *	
62 ST+ 11	
63 RCL 08	
64 X↑2	
65 .00078	
66 *	
67 ST+ 11	
68 RCL 02	
69 ENTER↑	
70 3	
71 Y↑X	
72 .000021858	
73 *	
74 ST+ 11	
75 RCL 08	
76 ENTER↑	
77 3	
78 Y↑X	
79 .00003	
80 *	
81 ST+ 11	
82 RCL 02	
83 ENTER↑	
84 3	
85 Y↑X	
86 RCL 08	
87 ENTER↑	
88 3	
89 Y↑X	
90 *	
91 -4.92653	
92 *	

Statement	Comments
93 10	
94 ENTER↑	Continue to Compute Maximum Endurance Altitude
95 -12	
96 Y↑X	
97 *	
98 ST+ 11	
99 RCL 02	
100 X↑2	
101 RCL 08	
102 X↑2	
103 *	
104 -1.14143	
105 *	
106 10	
107 ENTER↑	
108 -8	
109 Y↑X	
110 *	
111 ST+ 11	
112 RCL 11	
113 STO 09	
114 GTO "TMN"	Go to 'True Mach Number'
115♦LBL "METM1"	Label "Maximum Endurance True Mach Number" Drag Count (80-140)
116 .1055	
117 STO 11	
118 .01407	
119 RCL 08	Compute Maximum Endurance True Mach Number
120 *	
121 ST+ 11	
122 RCL 09	
123 -.007708	
124 *	
125 ST+ 11	
126 -.001032	
127 RCL 02	
128 *	
129 ST+ 11	
130 RCL 08	
131 X↑2	
132 -.000178	
133 *	
134 ST+ 11	
135 RCL 09	
136 X↑2	
137 .00088779	
138 *	

Statement	Comments
139 ST+ 11	
140 RCL 02	Compute Maximum Endurance
141 X↑2	Cruise Altitude
142 .0000083	
143 *	
144 ST+ 11	
145 RCL 09	
146 ENTER↑	
147 3	
148 Y↑X	
149 -.000015405	
150 *	
151 ST+ 11	
152 RCL 08	
153 X↑2	
154 X↑2	
155 1.8173	
156 *	
157 10	
158 ENTER↑	
159 -8	
160 Y↑X	
161 *	
162 ST+ 11	
163 RCL 02	
164 X↑2	
165 X↑2	
166 -4.55763	
167 *	
168 10	
169 ENTER↑	
170 -11	
171 Y↑X	
172 *	
173 ST+ 11	
174 RCL 08	
175 RCL 09	
176 *	
177 .0000641	
178 *	
179 ST+ 11	
180 RCL 09	
181 RCL 02	
182 *	
183 -.00001756	
184 *	

Statement	Comments
185 ST+ 11	Continue to Compute
186 RCL 08	Maximum Endurance Altitude
187 RCL 02	
188 *	
189 -.00001374	
190 *	
191 ST+ 11	
192 RCL 11	
193 STO 10	
194 GTO 26	
195♦LBL 26	Label "26"
196 XEQ "MEFF"	Compute Maximum Endurance
197 BEEP	Fuel Flow
198 RCL 09	
199 1000	
200 *	
201 FIX 0	
202 "ENDALT="	Display Maximum Endurance
203 ARCL X	Altitude
204 AVIEW	
205 STOP	
206 FIX 0	
207 RCL 01	
208 1000	
209 *	
210 "FF="	Display Maximum Endurance
211 ARCL X	Fuel Flow
212 AVIEW	
213 STOP	
214 FIX 3	
215 "ENDTMN="	Display Maximum Endurance
216 ARCL 10	True Mach Number
217 AVIEW	
218 STOP	
219 "OK?"	
220 PROMPT	
221 "MODE?"	
222 PROMPT	
223♦LBL "MEFF"	Label "Maximum Endurance
224 80	Fuel Flow"
225 RCL 02	
226 X>Y?	
227 GTO "MEFF2"	Go to "Maximum Endurance
228 -.2901	Fuel Flow (low altitude
229 RCL 08	DC (80-140)
230 .15044	

Statement	Comments
231 *	
232 +	Compute Maximum Endurance
233 STO 11	Fuel Flow (DC 0-80)
234 RCL 09	
235 -.022618	
236 *	
237 ST+ 11	
238 RCL 02	
239 .023143	
240 *	
241 ST+ 11	
242 RCL 08	
243 X↑2	
244 -.0001789	
245 *	
246 ST+ 11	
247 RCL 09	
248 X↑2	
249 -.0000117	
250 *	
251 ST+ 11	
252 RCL 02	
253 X↑2	
254 -.00007903	
255 *	
256 ST+ 11	
257 RCL 08	
258 RCL 02	
259 *	
260 RCL 09	
261 *	
262 STO 00	
263 X↑2	
264 1.27822	
265 *	
266 10	
267 ENTER↑	
268 -10	
269 Y↑X	
270 *	
271 ST+ 11	
272 RCL 00	
273 -.000007566	
274 *	
275 ST+ 11	
276 RCL 00	

Statement	Comments
277 ENTER↑	
278 3	Continue to Compute
279 Y↑X	Maximum Endurance
280 -4.94287	Fuel Flow (DC 0-80)
281 *	
282 10	
283 ENTER↑	
284 -16	
285 Y↑X	
286 *	
287 ST+ 11	
288 RCL 11	
289 STO 01	
290 RTN	
291◆LBL "MEFF2"	Label "MEFF2"
292 RCL 09	
293 17	
294 X<Y?	
295 GTO "MEFF3"	Go to "MEFF3"
296 -.8749	
297 RCL 08	
298 .161209	
299 *	
300 +	
301 STO 11	
302 RCL 09	
303 -.037546	
304 *	
305 ST+ 11	
306 RCL 02	
307 .013263	
308 *	
309 ST+ 11	
310 RCL 08	
311 RCL 09	
312 *	
313 RCL 02	
314 *	
315 STO 00	
316 .00000267	
317 *	
318 ST+ 11	
319 RCL 00	
320 X↑2	
321 -1.58386	
322 *	

Statement	Comments
323 10	Compute Maximum Endurance
324 ENTER↑	Fuel Flow (Low Altitude
325 -10	DC 80-140)
326 Y↑X	
327 *	
328 ST+ 11	
329 RCL 00	
330 ENTER↑	
331 3	
332 Y↑X	
333 2.206628	
334 *	
335 10	
336 ENTER↑	
337 -15	
338 Y↑X	
339 *	
340 ST+ 11	
341 RCL 00	
342 X↑2	
343 X↑2	
344 -8.18252	
345 *	
346 10	
347 ENTER↑	
348 -21	
349 Y↑X	
350 *	
351 ST+ 11	
352 RCL 11	
353 STO 01	
354 RTN	
355♦LBL "TMN"	Label "True Mach Number
356 RCL 02	for Maximum Endurance"
357 80	
358 X<=Y?	
359 GTO "METM1"	Go to "METM1"
360 -.5945	Compute Maximum Endurance
361 STO 11	True Mach Number
362 RCL 08	
363 .04362	
364 *	
365 ST+ 11	
366 RCL 09	
367 .016611	
368 *	

Statement	Comments
369 ST+ 11	
370 RCL 02	Continue to Compute Maximum Endurance True Mach Number
371 .0013355	
372 *	
373 ST+ 11	
374 RCL 08	
375 X↑2	
376 -.0005554	
377 *	
378 ST+ 11	
379 RCL 09	
380 X↑2	
381 -.0002691	
382 *	
383 ST+ 11	
384 RCL 02	
385 X↑2	
386 -.000018519	
387 ST+ 11	
388 RCL 09	
389 RCL 08	
390 *	
391 RCL 02	
392 *	
393 STO 00	
394 X↑2	
395 6.365632	
396 *	
397 10	
398 ENTER↑	
399 -12	
400 Y↑X	
401 *	
402 ST+ 11	
403 RCL 00	
404 ENTER↑	
405 3	
406 Y↑X	
407 -3.98411	
408 *	
409 10	
410 ENTER↑	
411 -17	
412 Y↑X	
413 *	
414 ST+ 11	

Statement	Comments
415 RCL 09	
416 ENTER↑	Continue to Compute
417 3	Maximum Endurance
418 Y↑X	True Mach Number
419 .000016956	
420 *	
421 ST+ 11	
422 RCL 08	
423 X↑2	
424 X↑2	
425 3.738059	
426 *	
427 10	
428 ENTER↑	
429 -8	
430 Y↑X	
431 *	
432 ST+ 11	
433 RCL 09	
434 X↑2	
435 X↑2	
436 -2.72362	
437 *	
438 10	
439 ENTER↑	
440 -7	
441 Y↑X	
442 *	
443 ST+ 11	
444 RCL 08	
445 RCL 09	
446 *	
447 -.00011123	
448 *	
449 ST+ 11	
450 RCL 09	
451 RCL 02	
452 *	
453 -.00003831	
454 *	
455 ST+ 11	
456 RCL 08	
457 RCL 02	
458 *	
459 -.000015098	
460 *	

Statement	Comments
461 ST+ 11	
462 RCL 11	
463 STO 10	
464 GTO 26	
465♦LBL "MEFF2"	Label "MEFF2"
466 17	
467 RCL 09	
468 X>Y?	
469 GTO "MEFF3"	Go to "MEFF3"
470 -.8749	
471 RCL 08	Compute Maximum Endurance Fuel Flow (Low Altitude DC 80-140)
472 .161209	
473 *	
474 +	
475 STO 11	
476 RCL 09	
477 -.037546	
478 *	
479 ST+ 11	
480 RCL 02	
481 .013263	
482 *	
483 ST+ 11	
484 RCL 08	
485 RCL 09	
486 *	
487 RCL 02	
488 *	
489 STO 00	
490 .00000267	
491 *	
492 ST+ 11	
493 RCL 00	
494 X↑2	
495 -1.58386	
496 *	
497 10	
498 ENTER↑	
499 -10	
500 Y↑X	
501 *	
502 ST+ 11	
503 RCL 00	
504 ENTER↑	
505 3	
506 Y↑X	

Statement	Comments
507 2.206628	Continue to Compute Maximum Endurance Fuel Flow (Low Altitude 80-140)
508 *	
509 10	
510 ENTER↑	
511 -15	
512 Y↑X	
513 *	
514 ST+ 11	
515 RCL 00	
516 X↑2	
517 X↑2	
518 -8.18252	
519 *	
520 10	
521 ENTER↑	
522 -21	
523 Y↑X	
524 *	
525 ST+ 11	
526 RCL 11	
527 STO 01	
528 GTO 26	
529♦LBL "MEFF3"	Label "MEFF3"
530 3.5516	Compute Maximum Endurance Fuel Flow (High Altitude DC 80-140)
531 RCL 08	
532 .06342	
533 *	
534 +	
535 STO 11	
536 RCL 09	
537 -.21834	
538 *	
539 ST+ 11	
540 RCL 02	
541 .013415	
542 *	
543 ST+ 11	
544 RCL 08	
545 X↑2	
546 .0010054	
547 *	
548 ST+ 11	
549 RCL 09	
550 X↑2	
551 .0031995	
552 *	

Statement	Comments
553 ST+ 11	
554 RCL 02	Continue to Compute
555 X↑2	Maximum Endurance
556 -.00006319	Fuel Flow (High Altitude
557 *	DC 80-140)
558 ST+ 11	
559 RCL 08	
560 RCL 09	
561 RCL 02	
562 *	
563 *	
564 .000013187	
565 *	
566 ST+ 11	
567 RCL 11	
568 STO 01	
569 RTN	
570◆LBL "DES"	Label "Descent"
571 XEQ 01	
572 XEQ 03	
573 XEQ 05	
574 BEEP	
575 FIX 0	
576 "IAS="	
577 ARCL 06	
578 AVIEW	
579 STOP	
580 "DIST="	Display Distance Required
581 ARCL 07	to Descent
582 AVIEW	
583 STOP	
584 RCL 08	
585 100	
586 *	
587 "DESFUEL="	Display Fuel Required to
588 ARCL X	Descend
589 AVIEW	
590 STOP	
591 "OK?"	
592 PROMPT	
593 GTO "DATA"	Go to Data
594◆LBL 01	Label "01"
595 "INALT?"	Input Initial Altitude
596 PROMPT	
597 1000	
598 /	

Statement	Comments
599 STO 04	
600 "FINALT?"	Input Desired Descent
601 PROMPT	Altitude
602 1000	
603 /	
604 STO 05	
605 RCL 04	
606 XEQ 02	
607 STO 06	
608 RTN	
609◆LBL 02	Label "02"
610 300	
611 RTN	Descent Airspeed 300 KIAS
612◆LBL 03	Label "03"
613 RCL 04	
614 XEQ 04	
615 STO 07	
616 0	
617 RCL 05	
618 X=Y?	
619 RTN	
620 XEQ 04	
621 ST- 07	
622 RTN	
623◆LBL 04	Label "04"
624 STO 09	
625 6.08363	
626 RCL 02	
627 X↑2	
628 *	
629 10	
630 ENTER↑	
631 -5	
632 Y↑X	
633 *	
634 STO 11	
635 -1.931	
636 RCL 02	
637 *	
638 .01	
639 *	
640 ST+ 11	
641 2.5337	
642 ST+ 11	
643 RCL 11	
644 RCL 09	

Statement	Comments
645 *	
646 STO 11	
647 RCL 11	
648 RTN	
649♦LBL 05	Label "05"
650 RCL 04	
651 XEQ 06	
652 STO 08	
653 0	
654 RCL 05	
655 X<=Y?	
656 RTN	
657 XEQ 06	
658 ST- 08	
659 RTN	
660♦LBL 06	Label "06"
661 STO 09	
662 1.5092	
663 RCL 09	
664 .2063	
665 *	
666 +	
667 STO 11	
668 RCL 02	
669 -.059534	
670 *	
671 ST+ 11	
672 RCL 09	
673 X↑2	
674 -.000681	
675 *	
676 ST+ 11	
677 RCL 02	
678 X↑2	
679 .00057143	
680 *	
681 ST+ 11	
682 RCL 09	
683 ENTER↑	
684 3	
685 Y↑X	
686 -.0000178	
687 *	
688 ST+ 11	
689 RCL 02	
690 ENTER↑	

Statement	Comments

```
691 3
692 Y↑X
693 -1.76596
694 *
695 .000001
696 *
697 ST+ 11
698 RCL 02
699 X↑2
700 RCL 09
701 X↑2
702 *
703 -2.25922
704 *
705 10
706 ENTER↑
707 -7
708 Y↑X
709 *
710 ST+ 11
711 RCL 09
712 ENTER↑
713 3
714 Y↑X
715 RCL 02
716 ENTER↑
717 3
718 Y↑X
719 *
720 2.612572
721 *
722 10
723 ENTER↑
724 -11
725 Y↑X
726 *
727 ST+ 11
728 RCL 11
729 RTN
730 STOP
731 RCL 08
732 .END.
```

F-4E Bingo Program Listing

Statement	Comments
01♦LBL "DT"	Label "Data"
02 FIX 0	
03 CLRG	
04 "TOGW?"	Input Take-Off Gross Weight
05 PROMPT	
06 STO 21	
07 STO 23	
08 "STOREWT?"	Input Store Weight
09 PROMPT	
10 STO 22	
11 ST- 23	
12 "FUELWT?"	Input Fuel Weight
13 PROMPT	
14 ST- 23	
15 1000	
16 ST/ 01	
17 ST/ 22	
18 ST/ 23	
19 ST/ 21	
20 "DC?"	Input Drag Count
21 PROMPT	
22 STO 02	
23 "INIT OK"	
24 PROMPT	
25 "MODE?"	Select Mode
26 PROMPT	
27 GTO "BNGO"	Go to Bingo
28♦LBL "BNGO"	Label "Bingo"
29 CF 13	
30 "DISTANCE?"	Input Distance
31 PROMPT	
32 STO 04	
33 "FUELWT?"	Input Fuel Weight
34 PROMPT	
35 XEQ 03	
36 "DELTMP?"	Input Temperature Deviation from Standard Day Temperature
37 PROMPT	
38 STO 03	
39 "HEADWIND?"	Input Head Wing Component
40 PROMPT	
41 STO 11	
42 GTO 05	Go to 05
43♦LBL 05	Label "05"
44 XEQ 21	Execute 21
45♦LBL 06	Label "06"
46 XEQ 22	Execute 22

Statement	Comments
47 XEQ 24	Execute 24
48 RCL 04	
49 117	
50 -	
51 14.7	
52 *	
53 X<0?	
54 CLX	
55 +	
56 1000	
57 /	
58 ST- 01	
59 XEQ 25	Execute 25
60 XEQ 27	Execute 27
61 RCL 06	
62 +	
63 RCL 04	
64 X<=Y?	
65 GTO 07	Go to 07
66 -	
67 CHS	
68 STO 04	
69 RCL 21	
70 RCL 05	
71 1000	
72 /	
73 -	
74 STO 01	
75 RCL 07	
76 -2	
77 *	
78 ST+ 03	
79 XEQ 13	Execute 18
80 XEQ 28	Execute 28
81 RCL 10	
82 38.98	
83 *	
84 RCL 03	
85 ENTER↑	
86 273.6	
87 +	
88 SQRT	
89 *	
90 -.25	
91 ENTER↑	
92 RCL 11	

Statement	Comments
93 CHS	
94 *	
95 +	
96 STO 09	
97 RCL 11	
98 CHS	
99 +	
100 STO 17	
101 XEQ 29	Execute 29
102 1/X	
103 STO 16	
104 1	
105 RCL 11	
106 RCL 09	
107 /	
108 +	
109 *	
110 STO 16	
111 RCL 04	
112 *	
113 STO 20	
114 RCL 04	
115 RCL 17	
116 /	
117 60	
118 *	
119 STO 18	
120 GTO 08	Go to 08
121♦LBL 07	Label "07"
122 SF 13	No Cruise Leg of
123 5	Bingo Profile
124 ST- 00	
125 0	
126 STO 20	
127 STO 18	
128 6.076116	
129 STO 24	
130 180	
131 STO 29	
132 RCL 07	
133 RCL 06	
134 /	
135 RCL 24	
136 /	
137 ATAN	
138 STO 27	

Statement	Comments
139 ST- 29	
140 RCL 07	
141 RCL 13	
142 /	
143 RCL 24	
144 /	
145 ATAN	
146 STO 28	
147 ST- 29	
148 RCL 04	
149 RCL 28	
150 SIN	
151 *	
152 RCL 29	
153 SIN	
154 /	
155 RCL 27	
156 SIN	
157 *	
158 RCL 24	
159 *	
160 STO 07	
161 RCL 21	
162 STO 01	
163 XEQ 22	Execute 22
164 XEQ 24	Execute 24
165 1000	
166 /	
167 ST- 01	
168 XEQ 25	Execute 25
169 XEQ 27	Execute 27
170♦LBL 08	Label "08"
171 FS? 13	
172 GTO 09	Go to 09
173 GTO 10	Go to 10
174♦LBL 09	Label "09"
175 RCL 06	
176 RCL 13	
177 +	
178 RCL 04	
179 X<=Y?	
180 GTO "AA"	Go to AA
181 RCL 06	
182 RCL 13	
183 +	
184 CHS	

Statement	Comments
185 RCL 04	
186 +	
187 STO 30	
188 "LEVEL DIST="	Display Level Off Distance
189 ARCL X	
190 FIX 2	
191 TONE 9	
192 AVIEW	
193 STOP	
194 XEQ 28	Execute 28
195 "MN="	Display Level Off
196 ARCL X	Cruising Mach Number
197 AVIEW	
198 STOP	
199 XEQ 29	Execute 29
200 1/X	
201 RCL 30	
202 *	
203 STO 30	
204 "CRFUEL="	Display Fuel Required
205 ARCL X	to Cruise
206 AVIEW	
207 STOP	
208 GTO 10	Go to 10
209♦LBL "AA"	Label "AA"
210 "NOCRUSELEG"	Display No Cruising Leg
211 PROMPT	
212 GTO 10	Go to 10
213♦LBL 10	Label "10"
214 GTO "DATA"	Go to Data
215♦LBL "DATA"	Label Data
216 BEEP	
217 "CLBDST="	Display Distance Required
218 ARCL 06	to Climb
219 AVIEW	
220 STOP	
221 100	
222 RCL 05	
223 *	
224 "CLFUEL="	Display Fuel Required
225 ARCL X	to Climb
226 AVIEW	
227 STOP	
228 1000	
229 RCL 07	
230 *	

Statement	Comments
231 "OPTFL="	Display Best Range
232 ARCL X	Cruising Altitude
233 AVIEW	
234 STOP	
235 FS? 13	
236 GTO 14	Go to 14
237 FIX 4	
238 "MACH="	Display Best Range Mach
239 ARCL 10	Number
240 AVIEW	
241 STOP	
242 FIX 0	
243 "TAS="	Display Best Range True
244 ARCL 09	Airspeed
245 AVIEW	
246 STOP	
247 "OAT="	Display Ambient Air
248 ARCL 03	Temperature
249 "WIND="	Display Wind
250 ARCL 11	
251 "GRSP="	Display Ground Speed
252 ARCL 17	
253 AVIEW	
254 STOP	
255 FIX 2	
256 "CRTIME="	Display Time Required to
257 ARCL 13	Cruise
258 AVIEW	
259 STOP	
260 FIX 0	
261 RCL 20	
262 "CRUSFUEL="	Display Fuel Required to
263 ARCL X	Cruise
264 AVIEW	
265 STOP	
266 "CRDIST="	Display Distance Required
267 ARCL 04	to Cruise
268 AVIEW	
269 STOP	
270•LBL 14	Label "14"
271 "DESPT="	Display Begin Descent Point
272 ARCL 13	
273 AVIEW	
274 STOP	
275 100	
276 RCL 14	

Statement	Comments
277 *	
278 "DESFUL="	Display Fuel Required to
279 ARCL X	Descent
280 AVIEW	
281 STOP	
282 RCL 20	
283 RCL 05	
284 100	
285 *	
286 +	
287 RCL 14	
288 100	
289 *	
290 +	
291 FS? 13	
292 GTO "FF"	Go to FF
293 GTO "TF"	Go to TF
294♦LBL "FF"	Label "FF"
295 RCL 30	
296 +	
297 GTO "TF"	Go to TF
298♦LBL "TF"	Label "TF"
299 "TOTFUEL="	Display Total Fuel Required
300 ARCL X	
301 AVIEW	
302 STOP	
303 FS? 13	
304 GTO 09	Go to 09
305 GTO "DATA"	Go to Data
306♦LBL H	Label "H"
307 "CURRNT ALT?"	Input Current Altitude
308 "PROMPT"	
309 1000	
310 /	
311 STO 29	
312 GTO 20	Go t0 20
313♦LBL 03	Label "03"
314 1000	
315 /	
316 STO 01	
317 RCL 22	
318 ST+ 01	
319 RCL 23	
320 ST+ 01	
321 RCL 01	
322 STO 21	

Statement	Comments
323 RTN	
324♦LBL 20	Label "20"
325 350	
326 RTN	
327♦LBL 21	Label "21"
328 72.771	
329 STO 31	
330 RCL 02	
331 .0142	
332 *	
333 ST+ 31	
334 RCL 01	
335 -1.2681	
336 *	
337 ST+ 31	
338 RCL 02	
339 X↑2	
340 -.0000831	
341 *	
342 ST+ 31	
343 RCL 01	
344 X↑2	
345 .012909	
346 *	
347 ST+ 31	
348 RCL 02	
349 ENTER↑	
350 3	
351 Y↑X	
352 -.000011726	
353 *	
354 ST+ 31	
355 RCL 01	
356 ENTER↑	
357 3	
358 Y↑X	
359 -.00006205	
360 *	
361 ST+ 31	
362 RCL 02	
363 ENTER↑	
364 4	
365 Y↑X	
366 5.95244	
367 *	
368 .00000001	

Statement	Comments
369 *	
370 ST+ 31	
371 RCL 31	
372 STO 07	
373 RTN	
374♦LBL 22	Label "22"
375 57.5	Subroutine for Climb
376 STO 31	Distance
377 RCL 01	
378 1.537	
379 *	
380 ST+ 31	
381 -8.47	
382 RCL 07	
383 *	
384 ST+ 31	
385 RCL 02	
386 -.4076	
387 *	
388 ST+ 31	
389 RCL 01	
390 X↑2	
391 -.04814	
392 *	
393 ST+ 31	
394 RCL 07	
395 X↑2	
396 .1712	
397 *	
398 ST+ 31	
399 RCL 02	
400 X↑2	
401 .000112	
402 *	
403 ST+ 31	
404 RCL 07	
405 ENTER↑	
406 3	
407 Y↑X	
408 -.0013675	
409 *	
410 ST+ 31	
411 RCL 02	
412 ENTER↑	
413 3	
414 Y↑X	

Statement	Comments
415 -.00000913	
416 *	
417 ST+ 31	
418 RCL 01	
419 X↑2	
420 X↑2	Continue to Compute
421 .000003133	Distance Required to Climb
422 *	
423 ST+ 31	
424 RCL 02	
425 X↑2	
426 X↑2	
427 .0000000487	
428 *	
429 ST+ 31	
430 RCL 01	
431 RCL 07	
432 *	
433 .09144	
434 *	
435 ST+ 31	
436 RCL 07	
437 RCL 02	
438 *	
439 .011657	
440 *	
441 ST+ 31	
442 RCL 01	
443 RCL 02	
444 *	
445 .006917	
446 *	
447 ST+ 31	
448 RCL 01	
449 RCL 07	
450 *	
451 X↑2	
452 .000003973	
453 *	
454 ST+ 31	
455 RCL 07	
456 RCL 02	
457 *	
458 X↑2	
459 .0000010795	
460 *	

Statement	Comments
461 ST+ 31	
462 RCL 31	
463 STO 06	
464 RTN	
465♦LBL 24	Label "24"
466 20.6	Subroutine for Climb Fuel
467 STO 31	
468 RCL 01	
469 .0119	
470 *	
471 ST+ 31	
472 RCL 07	
473 -1.86	
474 *	
475 ST+ 31	
476 RCL 02	
477 -.211	
478 *	
479 ST+ 31	
480 RCL 01	
481 X↑2	
482 -.0097	
483 *	
484 ST+ 31	
485 RCL 07	
486 X↑2	
487 .0493	
488 *	
489 ST+ 31	
490 RCL 02	
491 X↑2	
492 .0003	
493 *	
494 ST+ 31	
495 RCL 07	
496 ENTER↑	
497 3	
498 Y↑X	
499 -.0012	
500 *	
501 ST+ 31	
502 RCL 02	
503 ENTER↑	
504 3	
505 Y↑X	
506 .000002118	

Statement	Comments
507 *	
508 ST+ 31	
509 RCL 01	
510 ENTER↑	
511 4	
512 Y↑X	
513 .000001194	
514 *	
515 ST+ 31	
516 RCL 07	
517 ENTER↑	
518 4	
519 Y↑X	
520 .000013231	
521 *	
522 ST+ 31	
523 RCL 02	
524 ENTER↑	
525 4	
526 Y↑X	
527 -1.62933	
528 *	
529 .00000001	
530 *	
531 ST+ 31	
532 RCL 01	
533 RCL 07	
534 *	
535 .029079	
536 *	
537 ST+ 31	
538 RCL 07	
539 RCL 02	
540 *	
541 .0051266	
542 *	
543 ST+ 31	
544 RCL 01	
545 RCL 02	
546 *	
547 .0029517	
548 *	
549 ST+ 31	
550•LBL "TT"	Label "TT"
551 .1[illegible]3	
552 ENTER↑	

Statement	Comments
553 .12523	
554 RCL 00	
555 *	
556 +	
557 1.0498	
558 RCL 31	
559 *	
560 +	
561 RCL 31	
562 X↑2	
563 -.002144	
564 *	
565 +	
566 STO 05	
567 RTN	
568◆LBL 25	Label "25"
569 1.5092	Subroutine for Descent Fuel
570 STO 31	
571 .2063	
572 RCL 07	
573 *	
574 ST+ 31	
575 RCL 02	
576 -.059534	
577 *	
578 ST+ 31	
579 RCL 07	
580 X↑2	
581 -.000681	
582 *	
583 ST+ 31	
584 RCL 02	
585 X↑2	
586 .0005713	
587 *	
588 ST+ 31	
589 RCL 07	
590 ENTER↑	
591 3	
592 Y↑X	
593 -.0000178	
594 *	
595 ST+ 31	
596 RCL 02	
597 ENTER↑	
598 3	

Statement	Comments
599 Y↑X	
600 -1.76596	
601 *	
602 .000001	
603 *	
604 ST+ 31	
605 RCL 07	
606 X↑2	
607 RCL 02	
608 X↑2	
609 *	
610 -2.25922	
611 *	
612 .0000001	
613 *	
614 ST+ 31	
615 RCL 07	
616 ENTER↑	
617 3	
618 Y↑X	
619 RCL 02	
620 ENTER↑	
621 3	
622 Y↑X	
623 *	
624 2.612572	
625 *	
626 10	
627 ENTER↑	
628 -11	
629 Y↑X	
630 *	
631 ST+ 31	
632 RCL 31	
633 STO 14	
634 RTN	
635♦LBL 27	Label "27"
636 -1.895	Subroutine for Descent
637 STO 31	Distance
638 RCL 07	
639 3.228	
640 *	
641 ST+ 31	
642 RCL 02	
643 -.20426	
644 *	

Statement	Comments
645 ST+ 31	
646 RCL 07	
647 X↑2	
648 -.0473	
649 *	
650 ST+ 31	
651 RCL 02	
652 X↑2	
653 .0033984	
654 *	
655 ST+ 31	
656 RCL 07	
657 ENTER↑	
658 3	
659 Y↑X	
660 .00148	
661 *	
662 ST+ 31	
663 RCL 02	
664 ENTER↑	
665 3	
666 Y↑X	
667 -.000011666	
668 *	
669 ST+ 31	
670 RCL 07	
671 X↑2	
672 X↑2	
673 -.00001797	
674 *	
675 ST+ 31	
676 RCL 07	
677 RCL 02	
678 *	
679 -.016636	
680 *	
681 ST+ 31	
682 RCL 07	
683 RCL 02	
684 *	
685 X↑2	
686 .0000009093	
687 *	
688 ST+ 31	
689 RCL 31	
690 STO 13	

Statement	Comments
691 RTN	
692♦LBL 28	Label "28"
693 .86772	Subroutine for Best Range
694 STO 31	Mach Number
695 RCL 02	
696 -.000054	
697 *	
698 ST+ 31	
699 RCL 02	
700 X↑2	
701 -.000010812	
702 *	
703 ST+ 31	
704 RCL 02	
705 ENTER↑	
706 3	
707 Y↑X	
708 1.135375	
709 *	
710 .00000001	
711 *	
712 ST+ 31	
713 RCL 31	
714 STO 10	
715 RTN	
716♦LBL 29	Label "29"
717 .3467	
718 STO 31	
719 RCL 01	
720 -.011423	Label "26"
721 *	Subroutine for Best Range Fuel
722 ST+ 31	
723 RCL 02	
724 -.0010658	
725 *	
726 ST+ 31	
727 RCL 01	
728 X↑2	
729 .00017361	
730 *	
731 ST+ 31	
732 RCL 02	
733 X↑2	
734 -.000001143	
735 *	
736 ST+ 31	

Statement	Comments
737 RCL 01	
738 ENTER↑	Subroutine for Best Range Fuel
739 3	
740 Y↑X	
741 -1.01941	
742 *	
743 .000001	
744 *	
745 ST+ 31	
746 RCL 02	
747 ENTER↑	
748 3	
749 Y↑X	
750 4.026908	
751 *	
752 .00000001	
753 *	
754 ST+ 31	
755 RCL 02	
756 X↑2	
757 X↑2	
758 -1.48918	
759 *	
760 .0000000001	
761 *	
762 ST+ 31	
763 RCL 01	
764 X↑2	
765 X↑2	
766 RCL 02	
767 X↑2	
768 X↑2	
769 *	
770 9.065261	
771 *	
772 10	
773 ENTER↑	
774 -18	
775 Y↑X	
776 *	
777 ST+ 31	
778 RCL 01	
779 ENTER↑	
780 3	
781 Y↑X	
782 RCL 02	

Statement	Comments
783 ENTER↑	
784 3	
785 Y↑X	
786 *	
787 -1.36419	
788 *	
789 10	
790 ENTER↑	
791 -13	
792 Y↑X	
793 *	
794 ST+ 31	
795 RCL 01	
796 RCL 02	
797 *	
798 .000014286	
799 *	
800 ST+ 31	
801 RCL 31	
802 STO 15	
803 RTN	
804♦LBL 18	Label "18"
805 36.1	
806 RCL 07	Subroutine for Temperature Correction
807 X<=Y?	
808 RTN	
809 -56.5	
810 STO 03	
811 RTN	
812 END	End

F-5E Program Listing

Statement	Comments
01♦LBL "DT"	Label "Data Mode"
02 "DI?"	Input Drag Count
03 PROMPT	
04 STO 02	
05 "AVGW?"	Input Average Gross Weight
06 PROMPT	
07 1000	
08 /	
09 STO 03	
10 "MODE?"	Select Mode
11 PROMPT	
12♦LBL "O"	Label "O"
13 "CLGW?"	Optimum Cruise Mode
14 PROMPT	Input Start Climb Gross Weight
15 1000	
16 /	
17 STO 05	
18 "DIST?"	Input Distance
19 PROMPT	
20 STO 06	
21 45.456	Compute Optimum Cruise
22 RCL 02	Altitude
23 -.000212	
24 *	
25 +	
26 STO 12	
27 RCL 06	
28 -.02316	
29 *	
30 ST+ 12	
31 RCL 05	
32 -2.13493	
33 *	
34 ST+ 12	
35 RCL 02	
36 X↑2	
37 -.00004554	
38 *	
39 ST+ 12	
40 RCL 06	
41 X↑2	
42 .0023214	
43 *	
44 ST+ 12	
45 RCL 05	
46 X↑2	

Statement	Comments
47 -.00627	
48 *	Continue to Compute
49 ST+ 12	Optimum Cruise Altitude
50 RCL 02	
51 ENTER↑	
52 3	
53 Y↑X	
54 1.604969	
55 *	
56 10	
57 ENTER↑	
58 -7	
59 Y↑X	
60 *	
61 ST+ 12	
62 RCL 06	
63 ENTER↑	
64 3	
65 Y↑X	
66 -1.24904	
67 *	
68 10	
69 ENTER↑	
70 -5	
71 Y↑X	
72 *	
73 ST+ 12	
74 RCL 05	
75 ENTER↑	
76 3	
77 Y↑X	
78 -.0007469	
79 *	
80 ST+ 12	
81 RCL 02	
82 X↑2	
83 X↑2	
84 -6.75362	
85 *	
86 10	
87 ENTER↑	
88 -11	
89 Y↑X	
90 *	
91 ST+ 12	
92 RCL 02	

Statement	Comments
93 RCL 06	
94 *	Continue to Compute
95 -.00004143	Optimum Cruise Altitude
96 *	
97 ST+ 12	
98 RCL 06	
99 RCL 05	
100 *	
101 .006857	
102 *	
103 ST+ 12	
104 RCL 02	
105 RCL 06	
106 *	
107 RCL 05	
108 *	
109 STO 00	
110 X↑2	
111 -3.04712	
112 *	
113 10	
114 ENTER↑	
115 -12	
116 Y↑X	
117 *	
118 ST+ 12	
119 RCL 00	
120 ENTER↑	
121 3	
122 Y↑X	
123 8.193166	
124 *	
125 10	
126 ENTER↑	
127 -19	
128 Y↑X	
129 *	
130 ST+ 12	
131 RCL 02	
132 RCL 06	
133 *	
134 ENTER↑	
135 3	
136 Y↑X	
137 8.962771	
138 *	

Statement	Comments
139 10	Continue to Compute Optimum Cruise Altitude
140 ENTER↑	
141 -15	
142 Y↑X	
143 *	
144 ST+ 12	
145 RCL 06	
146 RCL 05	
147 *	
148 ENTER↑	
149 3	
150 Y↑X	
151 -2.43198	
152 *	
153 10	
154 ENTER↑	
155 -11	
156 Y↑X	
157 *	
158 ST+ 12	
159 RCL 02	
160 ENTER↑	
161 5	
162 Y↑X	
163 -2.45711	
164 *	
165 10	
166 ENTER↑	
167 -13	
168 Y↑X	
169 *	
170 ST+ 12	
171 RCL 06	
172 ENTER↑	
173 5	
174 Y↑X	
175 6.334016	
176 *	
177 10	
178 ENTER↑	
179 -11	
180 Y↑X	
181 *	
182 ST+ 12	
183 RCL 05	
184 ENTER↑	

Statement	Comments
185 5	
186 Y↑X	
187 .0000004868	
188 *	
189 ST+ 12	
190 RCL 12	
191 STO 01	Store 01
192◆LBL "IM"	Compute Indicated Mach Number
193 .24846	
194 RCL 03	
195 .02572	
196 *	
197 +	
198 STO 12	
199 RCL 01	
200 .0071877	
201 *	
202 ST+ 12	
203 RCL 02	
204 -.00061396	
205 *	
206 ST+ 12	
207 RCL 03	
208 X↑2	
209 -.0006696	
210 *	
211 ST+ 12	
212 RCL 01	
213 X↑2	
214 -.00032634	
215 *	
216 ST+ 12	
217 RCL 02	
218 X↑2	
219 .0000027471	
220 *	
221 ST+ 12	
222 RCL 03	
223 3	
224 Y↑X	
225 .00001034	
226 *	
227 ST+ 12	
228 RCL 01	
229 3	
230 Y↑X	

Statement	Comments
231 .000019928	
232 *	Continue to Compute Indicated Mach Number
233 ST+ 12	
234 RCL 02	
235 3	
236 Y↑X	
237 -8.57126	
238 *	
239 10	
240 ENTER↑	
241 -9	
242 Y↑X	
243 *	
244 ST+ 12	
245 RCL 01	
246 4	
247 Y↑X	
248 -2.79396	
249 *	
250 10	
251 ENTER↑	
252 -7	
253 Y↑X	
254 *	
255 ST+ 12	
256 RCL 02	
257 4	
258 Y↑X	
259 9.583365	
260 *	
261 10	
262 ENTER↑	
263 -12	
264 Y↑X	
265 *	
266 ST+ 12	
267 RCL 03	
268 RCL 01	
269 *	
270 .00017962	
271 *	
272 ST+ 12	
273 RCL 01	
274 RCL 02	
275 *	
276 .0000008431	

Statement	Comments
277 *	
278 ST+ 12	Continue to Compute
279 RCL 03	Indicated Mach Number
280 RCL 02	
281 *	
282 .000002254	
283 *	
284 ST+ 12	
285 RCL 12	
286 STO 07	
287 -.03	
288 ST+ 07	Store Register 07
289 RCL 07	
290♦LBL "NM"	Label "NM"
291 .17836	Compute Specific Range
292 RCL 03	(Nautical Miles/Pounds Fuel)
293 -.00333	
294 *	
295 +	
296 STO 12	
297 RCL 01	
298 .0037629	
299 *	
300 ST+ 12	
301 RCL 02	
302 -.00031305	
303 *	
304 ST+ 12	
305 RCL 03	
306 X↑2	
307 -.000126	
308 *	
309 ST+ 12	
310 RCL 01	
311 X↑2	
312 .00005315	
313 *	
314 ST+ 12	
315 RCL 02	
316 X↑2	
317 -1.06144	
318 *	
319 10	
320 ENTER↑	
321 -6	
322 Y↑X	

Statement	Comments
323 *	
324 ST+ 12	Continue to Compute Specific Range
325 RCL 02	
326 ENTER↑	
327 3	
328 Y↑X	
329 4.528377	
330 *	
331 10	
332 ENTER↑	
333 -9	
334 Y↑X	
335 *	
336 ST+ 12	
337 RCL 03	
338 X↑2	
339 X↑2	
340 .0000002314	
341 *	
342 ST+ 12	
343 RCL 01	
344 X↑2	
345 X↑2	
346 -3.15477	
347 *	
348 10	
349 ENTER↑	
350 -8	
351 Y↑X	
352 *	
353 ST+ 12	
354 RCL 02	
355 X↑2	
356 X↑2	
357 -4.55793	
358 *	
359 10	
360 ENTER↑	
361 -12	
362 Y↑X	
363 *	
364 ST+ 12	
365 RCL 01	
366 ENTER↑	
367 5	
368 Y↑X	

Statement	Comments
369 4.368255	
370 *	Continue to Compute Specific Range
371 10	
372 ENTER↑	
373 -10	
374 Y↑X	
375 *	
376 ST+ 12	
377 RCL 03	
378 RCL 01	
379 *	
380 -.00007685	
381 *	
382 ST+ 12	
383 RCL 03	
384 RCL 02	
385 *	
386 .00001496	
387 *	
388 ST+ 12	
389 RCL 01	
390 RCL 02	
391 *	
392 -5.5628	
393 *	
394 10	
395 ENTER↑	
396 -6	
397 Y↑X	
398 *	
399 ST+ 12	
400 RCL 03	
401 X↑2	
402 RCL 01	
403 X↑2	
404 *	
405 -7.73637	
406 *	
407 10	
408 ENTER↑	
409 -8	
410 Y↑X	
411 *	
412 ST+ 12	
413 RCL 03	
414 X↑2	

Statement	Comments
415 RCL 02	Continue to Compute
416 X↑2	Specific Range
417 *	
418 -5.81959	
419 *	
420 10	
421 ENTER↑	
422 -10	
423 Y↑X	
424 *	
425 ST+ 12	
426 RCL 01	
427 X↑2	
428 RCL 02	
429 X↑2	
430 *	
431 7.246215	
432 *	
433 10	
434 ENTER↑	
435 -11	
436 Y↑X	
437 *	
438 ST+ 12	
439 RCL 12	
440 STO 08	
441 FIX 2	
442 RCL 01	
443 1000	
444 *	
445 FIX 0	
446 "OPCALT="	Display Optimum Cruise
447 ARCL X	Altitude
448 AVIEW	
449 STOP	
450 FIX 2	
451 "MN="	Display Optimum Cruise
452 ARCL 07	Indicated Mach Number
453 AVIEW	
454 STOP	
455 "DITG?"	How Long from One's Position
456 PROMPT	to Destination?
457 STO 12	Input Distance to Fly
458 RCL 02	
459 -.00164	
460 *	

Statement	Comments
461 1.3111	Compute Begin Descending Point
462 +	
463 RCL 01	
464 *	
465 "DSCND AT"	Display Begin Descending Point
466 ARCL X	
467 AVIEW	
468 STOP	
469 CHS	
470 RCL 12	
471 +	
472 STO 12	
473 FIX 2	
474 "N/FUEL="	Display Specific Range
475 ARCL 08	(Nautical Mile Per Pount of
476 AVIEW	Fuel)
477 STOP	Compute Fuel Required to Cruise
478 RCL 12	
479 RCL 08	
480 1/X	
481 *	
482 FIX 0	
483 "CR FUEL="	Display Fuel Required to Cruise
484 ARCL X	
485 AVIEW	
486 STOP	
487 GTO "DT"	Go to Data Mode
488♦LBL "DR"	
489 "F>1400?HIT1"	Label Diversion Range
490 PROMPT	If Fuel Quantity is Greater
491 1	Than 1400 lbs. Press 1
492 X=Y?	
493 GTO 01	
494 "DIST?"	Input Distance
495 PROMPT	
496 STO 00	
497 "IALT?"	Input Initial Altitude
498 PROMPT	
499 1000	
500 /	
501 STO 01	
502 "NO.ENG?"	Both Engines in Operation or
503 PROMPT	One in Operation? Press 1 or 2.
504 1	
505 X=Y?	
506 GTO "SED"	If One Engine in Operation
	Go to SED

Statement	Comments
507 CF 01	
508 RCL 00	
509 140	
510 X<=Y?	
511 GTO 40	
512 .214	Compute Diversion Range
513 RCL 01	Cruist Altitude
514 .9089	
515 *	
516 +	
517 RCL 00	
518 .06382	
519 *	
520 +	
521 RCL 01	
522 X↑2	
523 .00146	
524 *	
525 +	
526 RCL 00	
527 X↑2	
528 .004511	
529 *	
530 +	
531 STO 12	
532 RCL 01	
533 ENTER↑	
534 3	
535 Y↑X	
536 -.0000117	
537 *	
538 ST+ 12	
539 RCL 00	
540 ENTER↑	
541 3	
542 Y↑X	
543 -.00002477	
544 *	
545 ST+ 12	
546 RCL 01	
547 X↑2	
548 X↑2	
549 -.000001142	
550 *	
551 ST+ 12	
552 RCL 00	

Statement	Comments
553 X↑2	Continue to Compute Diversion Range Cruise Altitude
554 X↑2	
555 2.426804	
556 *	
557 10	
558 ENTER↑	
559 -8	
560 Y↑X	
561 *	
562 ST+ 12	
563 RCL 01	
564 RCL 00	
565 *	
566 -.0059984	
567 *	
568 ST+ 12	
569 RCL 12	
570 40	
571 X<=Y?	
572 GTO 40	
573 RCL 12	
574 STO 03	
575 GTO "DF"	
576♦LBL 40	Label "40"
577 40	
578 STO 03	
579♦LBL "DF"	
580 269.01	Compute Fuel Required for Diversion Range
581 RCL 01	
582 -11.919	
583 *	
584 +	
585 RCL 00	
586 11.866	
587 *	
588 +	
589 RCL 01	
590 X↑2	
591 .0364	
592 *	
593 +	
594 RCL 00	
595 X↑2	
596 -.0661	
597 *	
598 +	

Statement	Comments
599 STO 12	
600 RCL 01	Continue to Compute Fuel
601 ENTER↑	Required for Diversion Range
602 3	
603 Y↑X	
604 -.00167	
605 *	
606 ST+ 12	
607 RCL 00	
608 ENTER↑	
609 3	
610 Y↑X	
611 .00021275	
612 *	
613 ST+ 12	
614 RCL 01	
615 X↑2	
616 X↑2	
617 .0000579	
618 *	
619 ST+ 12	
620 RCL 01	
621 RCL 00	
622 *	
623 -.004439	
624 *	
625 ST+ 12	
626 RCL 00	
627 ENTER↑	
628 5	
629 Y↑X	
630 -7.31164	
631 *	
632 10	
633 ENTER↑	
634 -10	
635 Y↑X	
636 *	
637 ST+ 12	
638 RCL 12	
639 STO 01	
640 .57567	
641 RCL 03	
642 -.007383	
643 *	
644 +	

Statement	Comments
645 RCL 03	
646 X↑2	Continue to Compute Fuel
647 .0006679	Required for Diversion Range
648 *	
649 +	
650 STO 12	
651 RCL 03	
652 3	
653 Y↑X	
654 -.00000733	
655 *	
656 ST+ 12	
657 RCL 12	
658 STO 07	
659 GTO "DISP"	Go to 'Display'
660•LBL "SED"	Label "Single Engine Diversion
661 SF 01	Range"
662 15	
663 RCL 01	
664 X>Y?	
665 GTO "SD1"	Go to 'SD1'
666 4.876	Compute Single Engine Cruise
667 RCL 00	Altitude for Diversion Range
668 -.4382	
669 *	
670 +	
671 RCL 01	
672 1.22133	
673 *	
674 +	
675 RCL 06	
676 X↑2	
677 .013185	
678 *	
679 +	
680 RCL 01	
681 X↑2	
682 -.00067869	
683 *	
684 +	
685 STO 12	
686 RCL 00	
687 ENTER↑	
688 3	
689 Y↑X	
690 -.00011187	

Statement	Comments
691 *	
692 ST+ 12	Continue to Compute Single
693 RCL 00	Engine Cruise Altitude for
694 ENTER↑	Single Engine Diversion Range
695 4	
696 Y↑X	
697 3.167149	
698 *	
699 10	
700 ENTER↑	
701 -7	
702 Y↑X	
703 *	
704 ST+ 12	
705 RCL 01	
706 RCL 00	
707 *	
708 -.010543	
709 *	
710 ST+ 12	
711 14	
712 RCL 12	
713 X>Y?	
714 GTO A	
715 STO 03	
716 GTO "SF"	Go to 'SF'
717♦LBL A	Label "A"
718 14	
719 STO 03	
720♦LBL "SF"	Compute Fuel Required for
721 287.62	Single Engine Diversion Range
722 RCL 00	
723 9.6549	
724 *	
725 +	
726 RCL 01	
727 -10.862	
728 *	
729 +	
730 RCL 00	
731 X↑2	
732 -.01335	
733 *	
734 +	
735 RCL 01	
736 X↑2	

Statement	Comments
737 .1838	Continue to Compute Fuel
738 *	Required for Single Engine
739 +	Diversion Range
740 STO 12	
741 RCL 00	
742 ENTER↑	
743 3	
744 Y↑X	
745 .00004175	
746 *	
747 ST+ 12	
748 RCL 01	
749 ENTER↑	
750 3	
751 Y↑X	
752 -.00314	
753 *	
754 ST+ 12	
755 -2.948	
756 ST+ 12	
757 RCL 01	
758 RCL 00	
759 *	
760 -.06098	
761 *	
762 ST+ 12	
763 RCL 00	
764 X↑2	
765 RCL 01	
766 X↑2	
767 *	
768 .000002731	
769 *	
770 ST+ 12	
771 RCL 12	
772 STO 01	
773 FS?C 02	
774 RTN	
775 GTO "SM"	
776♦LBL "SM"	Label "SM"
777 .46766	Compute Single Engine Cruise
778 RCL 03	Mach Number for Single Engine
779 -.01597	Diversion Range
780 *	
781 +	
782 RCL 03	

Statement	Comments
737 .1838	Continue to Compute Fuel Required for Single Engine Diversion Range
738 *	
739 +	
740 STO 12	
741 RCL 00	
742 ENTER↑	
743 3	
744 Y↑X	
745 .00004175	
746 *	
747 ST+ 12	
748 RCL 01	
749 ENTER↑	
750 3	
751 Y↑X	
752 -.00314	
753 *	
754 ST+ 12	
755 -2.948	
756 ST+ 12	
757 RCL 01	
758 RCL 00	
759 *	
760 -.06098	
761 *	
762 ST+ 12	
763 RCL 00	
764 X↑2	
765 RCL 01	
766 X↑2	
767 *	
768 .000002731	
769 *	
770 ST+ 12	
771 RCL 12	
772 STO 01	
773 FS?C 02	
774 RTN	
775 GTO "SM"	
776♦LBL "SM"	Label "SM"
777 .46766	Compute Single Engine Cruise Mach Number for Single Engine Diversion Range
778 RCL 03	
779 -.01597	
780 *	
781 +	
782 RCL 03	

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Statement	Comments
783 X↑2	Compute Single Engine Cruise
784 .002464	Mach Number for Single Engine
785 *	Diversion Range
786 +	
787 STO 12	
788 RCL 03	
789 ENTER↑	
790 3	
791 Y↑X	
792 -.00007455	
793 *	
794 ST+ 12	
795 RCL 03	
796 ENTER↑	
797 5	
798 Y↑X	
799 -1.44238	
800 *	
801 10	
802 ENTER↑	
803 -9	
804 Y↑X	
805 *	
806 ST+ 12	
807 RCL 12	
808 STO 07	
809 GTO "DISP"	Go to 'Display'
810♦LBL "SD1"	Compute Single Engine Cruise
811 SF 01	Altitude When Cruise Altitude
812 10.3	is More Than 15,000 ft.
813 RCL 00	
814 -.0577	
815 *	
816 +	
817 RCL 01	
818 .481	
819 *	
820 +	
821 .002494	
822 RCL 06	
823 X↑2	
824 *	
825 +	
826 RCL 01	
827 X↑2	
828 .02207	

Statement	Comments
829 *	
830 +	Continue to Compute Single Engine Cruise Altitude (Altitude Above 15,000 ft.)
831 STO 12	
832 RCL 00	
833 ENTER↑	
834 3	
835 Y↑X	
836 -.00000926	
837 *	
838 ST+ 12	
839 RCL 01	
840 X↑2	
841 X↑2	
842 -.000006418	
843 *	
844 ST+ 12	
845 RCL 00	
846 ENTER↑	
847 5	
848 Y↑X	
849 3.815037	
850 *	
851 10	
852 ENTER↑	
853 -11	
854 Y↑X	
855 *	
856 ST+ 12	
857 RCL 01	
858 RCL 00	
859 *	
860 -.011218	
861 *	
862 ST+ 12	
863 RCL 01	
864 X↑2	
865 RCL 00	
866 X↑2	
867 *	
868 .0000005161	
869 *	
870 ST+ 12	
871 RCL 12	
872 STO 03	
873 SF 02	
874 XEQ "SF"	Compute Fuel Required for Single Engine Diversion Range (Altitude Above 15,000 ft.)

Statement	Comments
875 SF 01	
876 .54	
877 STO 07	
878 SF 01	
879♦LBL "DISP"	Label "Display"
880 RCL 03	
881 1000	
882 *	
883 FIX 0	
884 "ALT="	Display Cruise Altitude
885 ARCL X	
886 AVIEW	
887 STOP	
888 FIX 2	
889 "MN="	Display Mach Number
890 ARCL 07	
891 AVIEW	
892 STOP	
893 FIX 0	
894 "FUEL="	Display Fuel Required for Diversion Range
895 ARCL 01	
896 AVIEW	
897 STOP	
898 FS? 01	
899 GTO "S1"	
900 RCL 03	
901 1.125	
902 *	
903 "DESPT="	Display Begin Descent Point
904 ARCL X	
905 AVIEW	
906 STOP	
907 GTO "DT"	Go to 'Data'
908♦LBL "S1"	
909 RCL 03	
910 "DESPT="	Display Begin Descent Point (Single Engine)
911 ARCL X	
912 AVIEW	
913 STOP	
914 CF 01	
915 GTO "DT"	Go to 'Data'
916♦LBL 01	Label "01"
917 "S12M54D38M88"	
918 PROMPT	
919 .END.	End

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