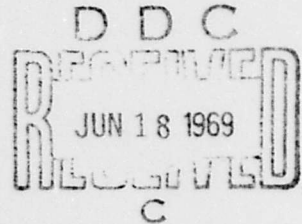


AD 688482

MEMORANDUM  
RM-5948-PR  
APRIL 1969

AIRCRAFT COMBAT  
RADIUS CALCULATION PROCEDURE FOR  
VARIOUS MISSION PROFILES AND  
EXTERNAL-STORE CONFIGURATIONS

C. M. Weber



PREPARED FOR:  
UNITED STATES AIR FORCE PROJECT RAND

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This research is supported by the United States Air Force under Project RAND--Contract No. F11620-67-C-0045--monitored by the Directorate of Operational Requirements and Development Plans, Deputy Chief of Staff, Research and Development, Hq USAF. Views or conclusions contained in this study should not be interpreted as representing the official opinion or policy of the United States Air Force.

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PREFACE

This Memorandum presents an extension and revision of the radius-calculation procedure described in RM-5280-PR, *A Procedure for Calculating the Combat Radius of Aircraft Carrying External Stores*, May 1967. The present procedure provides greater flexibility and improved accuracy, with some increase in complexity. However, from the users' point of view, the relative simplicity of the previous method can be recovered by adjusting inputs, while retaining some improvement in flexibility and accuracy.

A wider choice in cruise conditions is now available, and the effect on radius of non-distance-gaining fuel allowances is computed more accurately.

SUMMARY

This Memorandum describes a procedure for calculating the radius capability of a particular aircraft when different mission profiles, using different combinations of altitude and speed, and various external loadings are prescribed. Although designed specifically for a ground-attack mission, the procedure may be adapted for other missions as well.

The computer program described allows for variation in the disposition of empty fuel tanks and also for targetbound refueling. In the target area, combat and loiter time may be varied.

The program now being used on JOSS<sup>\*</sup> is presented along with a sample set of calculations and an explanation of the equations used in the procedure.

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<sup>\*</sup>JOSS is the trademark and service mark of The RAND Corporation for its computer program and services using that program.

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LIST OF SYMBOLS

- A = empirical constant used to account for the effect of external-store drag on cruise efficiency
- a = K, used as expedient in JOSS procedure
- B = alternate symbol for aircraft target weight
- b = J, used as expedient in JOSS procedure
- C = time at combat power setting, min
- c<sub>1</sub> = input used to select combat condition
- c<sub>3</sub> = input used to select reserve fuel
- c<sub>4</sub>, c<sub>5</sub>, c<sub>6</sub> = inputs used to select tank disposition
- c<sub>10</sub> = used to select MIL-C-5011A or AFRDQ fuel allowances
- D = fuel flow rate at combat power setting, lb/min
- d = A, used as expedient in JOSS procedure
- E<sub>1,2</sub> = inputs used to determine loiter fuel flow (see Appendix)
- e = weight of usable external fuel actually loaded, lb
- e = base of natural logarithms = 2.71828...
- F = ratio of the weight of empty external fuel tank plus unusable fuel to the weight of usable fuel in full tanks
- f = calculated total fuel weight, lb
- $\bar{f}$  = "drag area" (drag/dynamic pressure), used in determining the effects of external-store drag on aircraft performance
- G = aircraft weight at end of second leg (target weight), lb
- g = value of K modified to account for external-store drag, expedient in JOSS procedure
- H = weight of fuel transferred for refueled missions, lb
- h<sub>1,2,3,4</sub> = cruise altitude indicator, corresponding to legs 1,2,3,4
- h<sub>10</sub> = loiter altitude in target area, ft/1000
- h<sub>11</sub> = combat (target) altitude, ft/1000
- I = internal fuel capacity, lb
- J = empirical constant used in conjunction with K to express cruise efficiency (n mi/lb of fuel) in terms of aircraft weight
- j = intermediate distance calculation in JOSS procedure

- K = empirical constant used in conjunction with J to express cruise efficiency (n mi/lb of fuel) in terms of aircraft weight
- k = intermediate distance calculation in JOSS procedure
- L = time at loiter power setting, min
- l = input used to select weapon type
- l = JOSS notation for l
- log = natural logarithm (base e)
- M = aircraft weight without usable fuel, stores, or suspension equipment, lb
- $m_{1,2,3,4}$  = cruise speed indicator, corresponding to legs 1,2,3,4
- n = number of weapons
- $\emptyset$  = drag index of all pylons
- o = JOSS notation for  $\emptyset$
- o = drag index of external ordnance
- $P_1$  = ratio of aircraft effective weight at start of cruise to weight before climb
- $P_2$  = input used to select mission profile
- $P_{11}$  = same as  $P_1$ , applied to climb from target altitude to cruise altitude
- p = distance flown with external fuel, n mi
- Q = rack weight per unit of ordnance, lb
- q = intermediate distance calculation used in JOSS procedure
- R = fixed amount of reserve fuel, lb
- r = aircraft weight after loiter fuel has been consumed, lb
- $S_{1,2,3,4}$  = leg distances in mission profile, n mi
- s = drag index of suspension equipment
- T = weight of aircraft without fuel and external tanks, lb
- t = average drag index of external fuel tanks
- U = drag index of weapon racks per unit of ordnance
- u = weight of one unit of ordnance, lb
- V = fuel allowance for warm-up, taxi, and takeoff, lb
- v = weight of all pylons, lb
- W = maximum allowable takeoff weight, lb
- $w_i$  = aircraft weight at specific mission profile points (see Fig. 1), lb

- X = weight loss in target area, lb
- x = external fuel capacity, lb
- y = drag index of one unit of ordnance
- $Z_2$  = conversion factor between flight manual drag index DI and added drag area  $\Delta\bar{f}$  ( $\Delta\bar{f} = Z_2 \cdot DI$ )
- $Z_3$  = input used to select refueling distance
- $Z_{10}$  = input used to select inputs for specified aircraft
- := = a standard ALGOL symbol meaning "is to be replaced by" (equivalent to a JOSS "Set" statement)

SUBSCRIPT

- i = used to denote mission leg number



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## I. INTRODUCTION

Over the years, RAND has conducted many studies involving estimates of aircraft range or radius performance. The procedures used have varied in complexity, depending upon the kind of result desired as well as upon the kind of input data available. Most of these studies have involved continuously varying ("rubberized") airframes and engines. The method described in this study, on the other hand, was designed for use with a particular aircraft having known climb and cruise performance, fuel consumption, drag, etc., the primary goal being to determine the radius capability of the aircraft for different kinds of missions and with various kinds of external loads, using the simplest possible procedure that still gives acceptably accurate results. This method provides a simple framework wherein certain parts can be made more complex if detailed performance data are available or, in the absence of adequate information, reasonable estimates of input values can be made, based on experience with similar aircraft.

The calculation procedure (HARD-3) described in this study is a completely revised version of an earlier method (HARD-1) presented in Ref. 1. The new method provides greater flexibility and accuracy; its most significant difference is the use of one basic range equation (see p. 11) for cruise at any selected combination of speed and altitude.

In any generalized procedure, the idiosyncracies of individual aircraft cannot all be accounted for without sacrificing time and simplicity. For example, the use of fixed range-free allowances, specified flight conditions, and average weights and fuel flows may penalize or benefit one aircraft with respect to another. However, the results obtained by using the present procedure compare favorably with estimates made by using the mission-planning procedures described in military flight manuals.

The calculation method and the mission profiles available are described in Section II, which also presents a brief outline of the programmed calculation procedure. Section III describes the method of

determining the inputs needed for the calculation, and Section IV provides a detailed description of the calculation procedure.

The JOSS<sup>\*</sup> program as it is now being used is given in the Appendix, along with a sample set of calculations using the F-4E as an example. At present, this program has not been adapted at RAND for use with any computing system other than JOSS, nor is such adaptation planned.

---

\* JOSS is an on-line, time-shared computer system developed at RAND. JOSS is the trademark and service mark of The RAND Corporation for its computer program and services using that program.

## II. DESCRIPTION OF THE METHOD

### MISSION PROFILE

Figure 1 shows a generalized mission profile and aircraft weight breakdown. The four legs of the mission are denoted by  $S_1$  through  $S_4$ . External fuel tanks may be carried for the entire mission, dropped at the target, or dropped when empty. If tanks are dropped when empty, the program presented here estimates an average fuel-tank drag for the entire distance until final tank drop.

The actual distance-gaining part of the flight starts over the point of origin at the beginning of cruise\* with a theoretical weight,  $w_4$ , and ends over the destination at the end of the mission with the final weight,  $w_{10}$ . As presently designed, the program assumes that all suspension equipment (racks and pylons) is retained throughout the entire flight, but other assumptions could be accommodated by adjusting the inputs. The fuel allowances used in the calculation of weights  $w_4$  and  $w_{10}$  are discussed in Section III.

For the selected aircraft, values of cruise speed and altitude must be input for each leg of the mission. The values that may be used are encoded in the part of the program containing the aircraft inputs and are made available to the user when the calculation procedure is initiated. (See Appendix.)

The procedure is based on the stipulation that legs 2 and 3 are equal in distance ( $S_2 = S_3$ ) but may be flown at different speeds and altitudes. Since distances for the first and fourth legs ( $S_1$  and  $S_4$ ) may be different, the flight need not terminate at the point of origin. The procedure finally results in the calculation of the distance from the base to the end of the second leg.

In determining the value of weight loss in the target area, X, end of leg 2, it is assumed that loiter occurs first, the payload is dropped, then combat takes place.

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\*See Section III for the method used to account for climb fuel and distance.

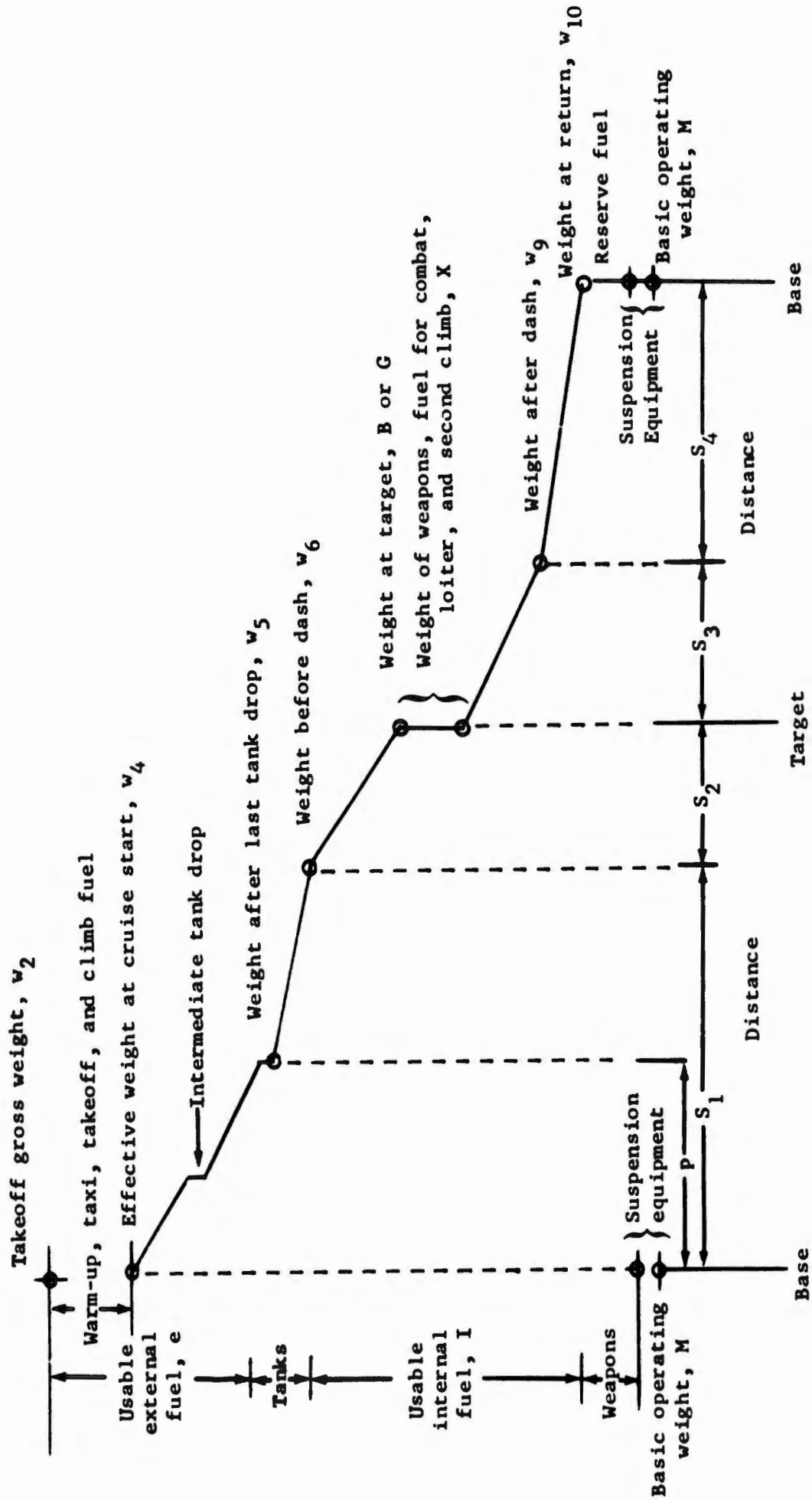


Fig. 1--Mission profile and weight breakdown

Combat and loiter may occur at any altitude in the target area (after the second leg).

#### GENERAL OUTLINE OF CALCULATION PROCEDURE

Figure 2 shows a highly simplified flow diagram of the entire procedure, which may be summarized as follows:

1. Choose the desired combination of aircraft type and weapon and the rules to be used for defining the mission.
2. Determine all necessary aircraft weight and performance inputs.
3. Determine the appropriate interchange of weapons and fuel tanks as the number of weapons carried is changed.
4. Determine weights and drags for weapons, tanks, and suspension equipment.

All the above information must be provided as input data for the calculation procedure, which

1. Determines the external fuel capacity after the selected number of weapons is installed.
2. Finds the aircraft gross weight by adding all loads to the empty weight.
3. Removes enough fuel to match the maximum allowable takeoff weight (from aircraft input data) if the gross weight is greater than this maximum and finds the resulting fuel actually loaded on the aircraft.
4. Finds the drag of external weapons and fuel tanks actually loaded and calculates fuel flows and range performance corresponding to the final takeoff configuration and subsequent configurations throughout the mission.
5. Calculates the combat radius for the desired profiles.

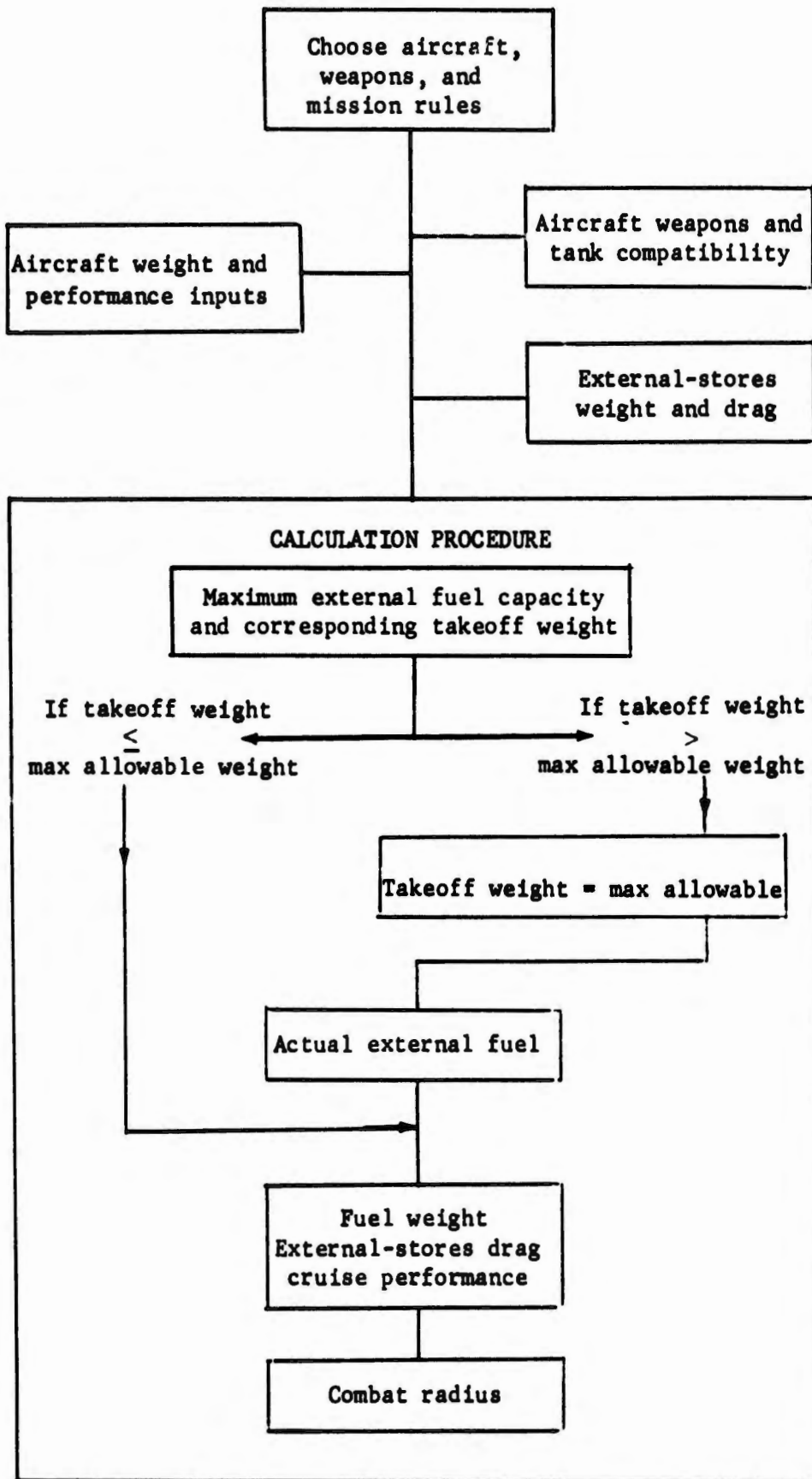


Fig. 2--Simplified diagram of calculation procedure

### III. INPUT DETERMINATION

For each aircraft, one set of inputs is needed to define the weights, basic performance characteristics, allowable store-loading combinations, and the effect of each weapon on performance; a second set is needed to specify the mission profile and fuel allowances to be considered. These two sets of inputs are described below. Their function in the calculation procedure is given in Section IV, and an example of the derivation is shown in the Appendix.

When available data are uncertain or insufficient for the amount of detail implied in the description of some of the inputs below, the input requirements may be simplified. In particular, for cruise and loiter the kinds of inputs used in the HARD-1 program<sup>(1)</sup> may be used to make satisfactory approximations. The procedures necessary to adapt these inputs to the present procedures are described in the appropriate section.

#### WEIGHT AND PERFORMANCE DATA

##### Maximum Allowable Takeoff Weight: W

The takeoff weight of an aircraft is frequently limited by factors other than fuel capacity and desired ordnance load. In many cases, runway length may be the determining factor, particularly on a hot day or when the field elevation is high. If takeoff distance is not critical, the weight may be limited by a requirement to fly at a prescribed altitude, or, ultimately, by structural strength. Whatever the cause, the limiting value of takeoff weight must be predetermined and input as a single value.

##### Basic Operating Weight: M

In general, basic operating weight includes everything except usable fuel, expended items, and suspension equipment; however, M may be modified to suit special cases, as long as proper adjustments are made to other inputs.



Internal Fuel Capacity: I

The internal fuel capacity is the total weight of usable fuel that can be carried internally. It is always loaded first, then the drag and weight of additional (external) fuel are accounted for in the computation. However, in order to stay below the maximum-gross-weight limit when relatively heavy ordnance loads are carried, the internal fuel capacity may be greater than the weight of fuel actually loaded.

Weight and Drag of External Stores

Inaccuracies in store-weight estimates usually do not have a critical effect on radius unless the maximum allowable takeoff weight has been reached, at which point a store-weight estimate that is too high will cause a reduction in the amount of fuel available for cruise. However, inaccurate drag estimates can result in more serious errors, particularly when large quantities of stores are carried. Unfortunately, the data available for store drag appear to be somewhat unreliable.

In the calculation procedures described here, drag is expressed as "drag area"  $\bar{f}$  and is equal to drag/dynamic pressure in sq ft. The "drag index" system used in the flight manuals has no consistent basis from one aircraft to another and must in each case be converted to  $\bar{f}$  for use in this program.

Suspension Equipment: s, Q, v, U, Z. It is assumed that the number of pylons remains constant (i.e., does not vary with the amount of ordnance loaded) for a given aircraft type, and hence a single value is estimated for total pylon weight (v) and drag (Z). Provision is made for varying the number of racks or other special suspension equipment as a function of the number of ordnance items loaded. Therefore, the estimated average rack weight (Q) and drag (U) per unit of ordnance are used. The total drag (s) and weight of suspension equipment are determined by

$$\text{drag} = Un + Z$$

$$\text{weight} = Qn + v$$

If the user wishes, the weight of pylons (v) can be included in the empty weight (M), and then v is set at zero. Similarly, if a full set of racks is to be carried at all times, then the total rack weight can also be included in M, making Q equal to zero.

Ordnance: u,y. In the calculation procedure, ordnance unit weight (u) is multiplied by the number carried (n) for use in determining aircraft weight and total ordnance weight dropped at the target. Ordnance unit drag (y) is the average  $\bar{f}$  of one unit mounted on the airplane and is based on the maximum-loading configuration for the specified aircraft. Flight manual drag index is determined similarly. Total ordnance drag (n·y) includes all interference factors involved in that configuration. Since the interference factors depend on the number and location of stores, it is possible for other than maximum-loading configurations to have an actual average store drag that is significantly different from that based on maximum loading. It is possible, if such a level of detail is desired, to input y as a function of the loading.

Fuel Tanks: t,F. The drag area of the fuel tanks is estimated by means of the empirical relation

$$\bar{f}(\text{tanks}) = 0.0025 x^{0.7}$$

in which the constants are based on actual values being used by industry for existing tanks and aircraft. However, this equation applies only when all initially loaded tanks are being carried. To allow for dropping tanks as they become empty, which may occur during both climb and cruise, the average drag from start of cruise to final tank drop is approximated by

$$t = 0.0013 (x - w_2 + w_4)^{0.7}$$

Fuel-tank weight is accounted for by assuming a constant ratio (F) of the weight of the empty fuel tank including unusable fuel to the weight of usable fuel in the tank.

External Fuel and Ordnance Loading

The calculation procedure assumes that only one type of weapon is loaded simultaneously with fuel tanks, which may be of different sizes. In order to account for various combinations of weapons and tanks, two tables are constructed, one representing tank capacity (x) as a function of the number of weapons carried, and the other representing actual external fuel loaded (e) as a function of tank sizes available. These relationships depend on the number of store stations, on whether multiple-bomb racks are carried, and on which stations can carry fuel. For example, assuming an aircraft has two stations (one on each wing) each capable of carrying either three weapons on a rack or a 2000-lb fuel tank, the interchange of fuel and ordnance results in the following:

Number of Weapons, n	External Fuel Capacity, x (lb)
0	4000
1 - 3	2000
4 - 6	0

In addition, after actual external fuel weight is determined, the next higher value of available tank capacity is used to account for tank drag. Assuming the option of loading tanks having either 1000- or 2000-lb capacity, the following values result:

Actual External Fuel, e (lb)	External Fuel Capacity, x (lb)
0 - 1000	1000
1000 - 2000	2000
2000 - 3000	3000
3000 - 4000	4000

Range Constants: K, J, A\*

In Ref. 1, the HARD-1 program calculated sea-level distance and high-altitude distance by separate equations. The following procedure was developed primarily for flight at any constant altitude, but also is at least as accurate for optimum-cruise flight as the original method and can be used for any cruising conditions for which performance data are available.

Starting with the basic relationship between distance S, aircraft weight w, and fuel consumption rate (mi/lb)

$$\Delta S = \frac{\text{mi}}{\text{lb}} \cdot \text{lb of fuel } (\Delta w)$$

it can be assumed that, for a conventional aircraft in cruising flight, the fuel consumption rate in mi/lb (i.e., dS/dw) varies with aircraft weight approximately by the relation:\*\*

$$\frac{dS}{dw} = -Kw^{(J-1)}$$

in which K and J are empirical constants found for a given combination of altitude and speed. Distance flown can then be represented by

$$S = \frac{K}{J} \left[ w^J(\text{initial}) - w^J(\text{final}) \right]$$

From aircraft performance data, typical aircraft weights at beginning and end of cruise are used to find K and J for specified flight conditions.

As before, a correction factor for external-store drag is applied to K such that

$$K_{\text{with stores}} = K_{\text{clean}} \cdot \exp[-A \cdot \Delta \bar{F}]$$

---

\* Note that K, J, and A are not used in the same way and do not have the same meaning as in Ref. 1.

\*\* The Breguet equation used in Ref. 1 implies that  $dS/dw = -Kw^{-1}$ .

in which A is found (as explained above for K and J) for a typical variation in added drag  $\Delta\bar{f}$ . The actual value of K is represented in the program by  $g(i,s,o,t)$ , where i identifies the leg of the mission, and s, o, and t the store configuration for that leg.

If it is more convenient to use the HARD-1-type range-factor input (designated temporarily as  $K_{H1}$ ), which is part of the Breguet equation

$$\text{range} = K_{H1} \cdot \log \left[ \frac{\text{initial weight}}{\text{final weight}} \right]$$

used for high-altitude cruise at optimum speed and altitude, the corresponding values of K and J required for HARD-3 are

$$K = K_{H1} \text{ (same as HARD-1)}$$

$$J = 0.00025 / \exp [2.18 w_2 \cdot 10^{-6}]$$

For cruise at sea level, where the HARD-1 procedure assumed cruise at constant mi per lb of fuel:

$$\text{range} = K_{SL} \cdot [\text{initial weight} - \text{final weight}]$$

the corresponding inputs for HARD-3 are

$$K = K_{SL} \text{ (same as HARD-1)}$$

$$J = 1.0$$

#### Range-Free Allowances

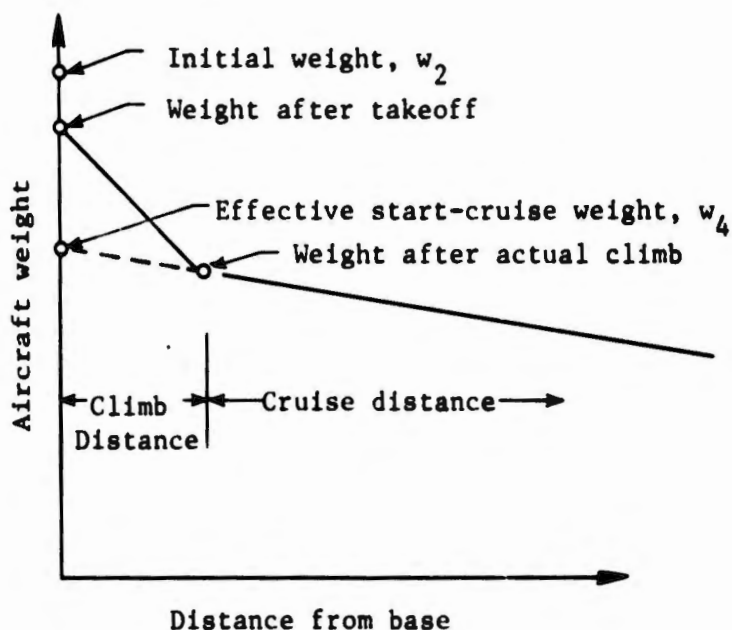
For each aircraft, the weight of fuel required for warm-up, taxi, takeoff, climb, combat, loiter, and reserve is subtracted from the total fuel to determine the fuel available for cruise.

Pre-climb. Warm-up, taxi, and takeoff fuel (V) may be determined by any rules desired by the user, but is usually assumed to be equal to the fuel consumed during a specified time interval with operation at normal power, plus 1 min at maximum afterburning power (if an afterburner is used for takeoff), using fuel flows based on engine operation

under standard sea-level static conditions. The time intervals required for these allowances are usually chosen in accordance with Ref. 2. The JOSS program provided in this study also includes an energy-related estimation procedure recommended by Hq USAF (AFRDQ); it is described on p. 16.

Climb. The computation procedure uses a climb fuel allowance equal to the equivalent weight of fuel that would be needed to lift the aircraft to cruising altitude directly over the base; this allowance is derived from actual climb calculations, where available. The subtraction of takeoff and climb fuel allowances from initial gross weight results in a theoretical start-cruise weight (over the point of takeoff) which is then used in standard range equations, resulting in a cruise distance that includes the true climb distance.

In the determination of effective weight at start of cruise ( $w_4$ ), actual climb and cruise data are used (analytically or graphically) to find relationships that can best be explained pictorially. In the sketch below, the line representing cruising flight is extrapolated back to the ordinate to find  $w_4$ , as shown by the dotted line. The



input used in the calculation is then

$$P_1 = w_4/\text{weight after takeoff}$$

where  $P_1$  is found for each aircraft from available performance data.

The weight of fuel used (where applicable) for a second climb to cruise altitude after combat or loiter is determined in the same way as for the initial climb, using the post-combat configuration. The weight of fuel used in the second climb, at weight after combat, is therefore

$$(1 - P_{11})(r - C \cdot D - n \cdot u)$$

where  $r$  is the aircraft weight after loiter,  $C \cdot D$  is the weight of fuel used in combat, and  $P_{11}$  is found in the same way as  $P_1$ , but for the return configuration.

Loiter. The method used in Ref. 1 to find the fuel used during loiter has been replaced by a more accurate procedure, derived as follows:

Assume that fuel flow (weight per unit time) during loiter varies with aircraft weight by the relation:\*

$$\text{fuel flow} = \frac{dw}{dt} = -Kw^c$$

where  $K$  and  $c$  are constants determined from actual performance data.

Loiter time can be found by integrating for a weight variation from  $w_1$  to  $w_2$ :

$$\text{loiter time, } t = \left[ \frac{w_1^{1-c} - w_2^{1-c}}{K(1-c)} \right]$$

---

\*For clarity, symbols used apply only to this derivation and are defined as required.

Then aircraft weight after loiter is

$$w_2 = \left[ w_1 (1 - c) - tK(1 - c) \right]^{1/(1 - c)}$$

for a given configuration at a specified altitude. To account for the effect on fuel flow of varying altitude and added external drag, fuel flow is assumed to vary with altitude  $h$  and added drag  $\Delta\bar{f}$  as follows:

$$\text{fuel flow} = E \cdot \exp[ah] \cdot \exp[b \cdot \Delta\bar{f}]$$

where  $E$  is the fuel flow for a clean configuration at sea level, and  $a$  and  $b$  are constants determined from actual performance data.

Thus, combining the three variations (weight, altitude, drag), the overall fuel flow equation is

$$\text{fuel flow} = \left\{ E \cdot \exp[ah] \cdot \exp[b \cdot \Delta\bar{f}] \right\} \cdot \left( \frac{w}{w_1} \right)^c$$

where  $w_1$  is the aircraft weight at which  $K$  was evaluated.

In HARD-1, a single value of fuel flow  $E$  was used. To convert to present equations,

$$\text{Set } E_1 = E$$

$$\text{Set } E_2 = 0$$

or estimate weight and drag effect by:

$$\text{Set } E_2 = 1.1$$

$$\text{Set } E_1 = E_1 \cdot \exp [0.05(s + o)] / (M + 0.6I) * E_2$$

where  $M + 0.6I$  is the weight corresponding to the estimated value of  $E$ .

Combat. Combat fuel flow ( $D$ ) is estimated for average target weight at the power settings and altitudes specified for each mission



and is then multiplied in the calculation routine by the specified combat time (C) to determine the total fuel allowance for combat in the target area.

A procedure based on energy relationships rather than time is also included as an option, and is described more fully below.

Reserve. Reserve fuel is the weight of the fuel (R) used during a fixed loiter time after returning to base (Ref. 2 prescribes 20 min), plus 5 percent of the total fuel loaded:

$$\text{reserve fuel} = R + 0.05 \cdot \text{total fuel}$$

The total reserve fuel, suspension equipment, and other disposable equipment that may be carried back to the base is added to the empty weight (M) to obtain the aircraft weight ( $w_{10}$ ) over the base upon return.

The set of data described above is collected in one JOSS part\* number. An example, designated part 99, is given in the Appendix.

#### AFRDQ Fuel Allowances\*\*

Hq USAF (AFRDQ) has proposed a method of calculating combat and takeoff fuel allowances to replace the fixed-time allowances provided in MIL-C-5011A (Ref. 2). This method is based on "energy maneuverability" concepts, and, if desired, can be incorporated in the procedure.

Specific maneuver energy is defined as:

$$E_s = h + v^2/2g$$

where

h = altitude, ft

v = velocity, ft/sec

g = gravitational constant, 32.2 ft/sec<sup>2</sup>

Specific power ( $P_s$ ), which is defined as  $dE_s/dt$ , may be equated with rate of climb (in fps) at a constant velocity.

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\* A "part" in JOSS programming consists of a sequence of steps, each consisting of a common integer portion and a decimal fraction, that may be used to input values, perform calculations, or give operational commands in the order determined by the value of the decimal fraction.

\*\* For clarity in presentation, symbols used apply only to this section and are defined as they appear.

Warmup and Taxi. Pre-takeoff allowance is the weight of fuel (F) used for 2 min at military thrust for sea-level static operation.

Takeoff. Fuel weight in pounds used during takeoff up to climb speed is approximated by:

$$E_s (w_{f_1} + w_{f_2}) / P_s$$

where

- $E_s$  = 12,410 (when evaluated at sea level, Mach 0.8)
- $w_{f_1}$  = fuel flow (maximum power, sea level, static) lb/sec
- $w_{f_2}$  = fuel flow (maximum power, sea level, Mach 0.8) lb/sec
- $P_s$  = specific power at sea level, Mach 0.8, maximum power, at weight after taxiing, ft/sec

Combat. The fuel allowance for combat in the target area is the weight of fuel needed to gain a specified maneuver energy:

$$\Delta E_s \cdot w_f / P_s$$

where

- $\Delta E_s$  = (60,000 -  $h_{\text{target}}$ ) for air-ground missions
- $\Delta E_s$  = (134,000 -  $h_{\text{target}}$ ) for air-air missions
- $w_f$  = fuel flow at target altitude, lb/sec
- $P_s$  = specific power at target altitude with 50 percent fuel aboard

and where  $w_f$  and  $P_s$  are determined at:

- Mach 0.7 and military power for air-ground missions
- Mach 0.9 and maximum power for air-air missions

Derivation of Programmed Equations. For this study, only air-ground missions will be considered.

To approximate the effect of external-store drag on the fuel allowances, let

$$P_s = \frac{V}{W} [T - (D + \Delta D)]$$

where

T = thrust, lb

$\Delta D$  = added external drag, lb

D = drag of clean aircraft, lb

w = aircraft weight, lb

Rearranging and substituting  $\Delta \bar{f}/\bar{f}$  for  $\Delta D/D$ ,

$$P_s = \frac{Tv}{w} \left[ 1 - \frac{D}{T} \left( 1 + \frac{\Delta \bar{f}}{\bar{f}} \right) \right]$$

where

$\bar{f}$  = clean aircraft drag area

$\Delta \bar{f}$  = added drag area

In this study,  $P_s$  is determined from aircraft rate of climb data as follows:

From the previous equation, let

$$P_s = B \left[ 1 - A \left( 1 + \frac{\Delta \bar{f}}{\bar{f}} \right) \right] / w$$

From given climb data, constants A and B are evaluated at a typical takeoff weight by finding values of  $P_s$  (denoted temporarily as  $P_1$  and  $P_2$ ) corresponding to two drag configurations ( $\Delta \bar{f}_1$  and  $\Delta \bar{f}_2$ ).

$$A = \left( \frac{P_1}{P_2} - 1 \right) / \left[ \frac{P_1}{P_2} \left( 1 + \frac{\Delta \bar{f}_2}{\bar{f}} \right) - \left( 1 + \frac{\Delta \bar{f}_1}{\bar{f}} \right) \right]$$

$$B = P_1 w / \left[ 1 - A \left( 1 + \frac{\Delta \bar{f}_1}{\bar{f}} \right) \right]$$

For combat fuel, the ratio of fuel flow to specific power is assumed to vary with altitude by the relation:

$$\frac{w_f}{P_s} = \left( \frac{w_f}{P_s} \right)_{h=0} + Ch^2$$

and C is evaluated from known fuel flow and rate of climb data:

$$C = \left[ \left( \frac{w_f}{P_s} \right)_h - \left( \frac{w_f}{P_s} \right)_{h=0} \right] / h^2$$

When evaluated, these constants are then used in the following equations for takeoff allowance V and combat allowance D:

$$V = F + 12410 \cdot [w_{f_1} + w_{f_2}] \cdot [w_2 - F] / B / \left[ 1 - A \left( 1 + \frac{s + o + t}{\bar{f}} \right) \right]$$

$$D = 10^3 [60 - h_{11}] \left[ \frac{w_{f_3}}{P_{s_3}} + Ch_{11}^2 \right]$$

where V, D,  $h_{11}$ , s, o, t, and  $\bar{f}$  have the standard meaning used throughout the text.

#### MISSION-SPECIFICATION INPUTS\*

Before proceeding with the radius calculation, the user must select several inputs that depend upon the aircraft and stores to be used and upon the mission format. Using the program described in the Appendix, JOSS demands each of these before it starts the calculation procedure.

#### Aircraft type: $Z_{10}$

The aircraft-type input,  $Z_{10}$ , selects the part of the program that supplies the aircraft-related inputs described previously.

#### Ordnance Type and Weight: $l, u$

From part  $Z_{10}$ ,  $l$  selects the proper drag constants and fuel-ordnance interchange described above. The user must make certain that the necessary information for the specified weapon has been included in the aircraft input data.

Input  $u$  is the weight of one unit of ordnance. A standard value is put into the program automatically, but may be changed by the user.

---

\*The Appendix shows in detail how these inputs are used.

Mission Profile:  $P_2$

Input  $P_2$  selects the proper calculation procedure for the desired mission profile. Altitude and speed are chosen for each leg and may be used in any combination for which the range constants  $K, J, A$  have been determined. The second and third legs are always equal in distance; first and fourth legs may have any value. The numerical value of  $P_2$ , which selects the appropriate calculation procedure, is supplied by the user when demanded by the program as shown in the Appendix.

For mission profiles having two equal legs ( $S_2 = S_3$ ), the selection of  $P_2 = 1$  automatically sets the first ( $S_1$ ) and last ( $S_4$ ) legs equal to zero.

For profiles having four legs,  $S_1$  and  $S_4$  must be input by the user; again, second and third legs are equal in distance. Setting  $P_2 = 4$  selects this option.

Profiles having three legs are simulated by setting  $P_2 = 4$ , and using the same cruise conditions ( $h, m$ ) for the first and second legs or for the third and fourth legs, whichever is appropriate.

Cruise Speed and Altitude:  $m, h$

For each leg, speed and altitude are chosen from those values available in the aircraft inputs. Speed is indicated by a coded symbol,  $m$ ;  $h$  is a coded symbol for altitude.

Loiter Time and Altitude:  $L, h_{10}$

Any value for time  $L$  and altitude  $h_{10}$  may be specified for flight at speed for maximum endurance in the target area.

Combat Time, Power Setting, and Altitude:  $C, c_1, h_{11}$

Except when the energy-related combat allowance procedure is chosen, any value of combat time  $C$  may be specified. The constant  $c_1$  selects the fuel flow corresponding to the desired power setting and altitude from the values of  $D$  input in part  $Z_{10}$ . The following choices are typical:

$c_1$	Combat Condition
1	high altitude, maximum power
2	high altitude, military power
3	low altitude, maximum power
4	low altitude, military power

Combat altitude is also input separately as  $h_{11}$ , which is used in estimating the fuel consumed during climb back to cruising altitude after combat as well as for calculating the energy-related combat fuel allowance described on p. 17.

Reserve Fuel:  $c_3$

Input  $c_3$  is used to insert or remove the 5-percent fuel term from the equation for final weight ( $w_{10}$ )

$c_3 = 0$  if reserve is a constant weight of fuel (=R)

$c_3 = 1$  if retention of the  $0.05 \cdot f$  term is desired

Fuel-Tank Disposition:  $c_4, c_5, c_6$

In order to provide the choice of either retaining or dropping tanks, the equations for  $s$ ,  $o$ , and  $t$  are modified by means of inputs  $c_4$  and  $c_6$  as follows:

If all tanks are to be carried for the entire mission, tank drag is added to suspension drag, and the equation for  $t$  gives a value of zero when  $c_4$  is set equal to 1.

In military operations, it is common procedure to carry all tanks throughout the entire mission unless an emergency necessitates jettisoning. To account for the situation where tanks are dropped in the target area, input  $c_6$  is set equal to 1, which adds tank drag to ordinance drag on the targetbound leg and provides only suspension drag on the return leg (since  $c_4 = 0$ ).

Although it is not usually of major significance, tank weight also is accounted for by using  $c_4$  and  $c_6$ , as shown later in the calculation procedure.

Another contingency considered is the case where it is planned to drop tanks when empty but, at the time of combat, some external fuel

still remains and must be dropped. Here, the drag is the same as in the case where tanks are dropped when empty ( $c_4 = 0$ ), but since the dropped fuel is not available for cruise, its weight must be accounted for. Input  $c_5$  allows this fuel to be added to the weight  $X$  disposed of in the target area.

The user makes the appropriate selection from the following:

$c_4 = 0$  if tanks are dropped at any time

$c_4 = 1$  if all tanks are retained throughout the mission

$c_5 = 1$  if some tanks still contain fuel at the target and are dropped after loiter and before combat; otherwise,  $c_5 = 0$

$c_6 = 1$  if all tanks are carried to the target and dropped before combat; otherwise,  $c_6 = 0$

### Refueling, $Z_3$

Provision is made for one targetbound refueling, which may occur over the takeoff point or at any specified distance. The aircraft is assumed to be refueled to its initial gross weight.

Input  $Z_3$  is the distance the aircraft has traveled from base on the targetbound leg when refueling occurs:

$Z_3 = 0$  if there is no refueling

$Z_3 = 1$  for refueling directly over the base

$Z_3 =$  the actual distance at which refueling occurs

#### IV. CALCULATION PROCEDURE

Although the principles remain the same, details in the calculations and some of the symbols have been changed from those in Ref. 1.

The procedure is summarized in the flow diagram shown in Fig. 3, pp. 30-31, and is described in detail below. The Appendix contains an example of the procedure as it is used in practice.

The HARD-3 program is designed to vary and mix the number of weapons and fuel tanks automatically; but, if performance is required for one specified configuration where automatic variation of the number of weapons is not required or when different types of weapons or other stores are intermixed, the procedure can be modified by bypassing any desired part of the fuel-and-weapon-allocating procedure. One possible form of this alternate procedure (designated HARD-3A) will be described.

#### VARIABLE-STORES PROGRAM (HARD-3)

The following steps explain each corresponding step in Fig. 3, which assumes that the mission rules and the necessary weight and drag information for the specified aircraft and weapon have been made available to the program:

1. The weight of external fuel ( $x$ ) for which space is available is determined for the specified number of weapons carried externally.
2. Aircraft actual takeoff weight ( $w_2$ ) is first estimated from the available fuel capacity found in step 1:

$$w_2 = T + I + e + Fx$$

where

- $e$  = external fuel (assumed equal to  $x$ ), lb
- $x$  = external fuel capacity, lb
- $F$  = ratio of tank weight to fuel capacity
- $I$  = internal fuel capacity, lb
- $T = M + n(u + Q) + v$  (used for convenience)



M = aircraft basic operating weight, lb

u = weight of one unit of ordnance, lb

Q = average rack weight per weapon, lb

v = total weight of all pylons, lb

If  $w_2$  is not greater than the maximum allowable weight W, the calculation proceeds to step 3. However, if  $w_2$  is greater than W, fuel weight must be corrected so that  $w_2 = W$ . If there is no external fuel ( $x=0$ ), internal fuel may be less than capacity I; therefore, I is recalculated to become the weight of fuel actually loaded internally. If  $x > 0$ , the external fuel capacity x and actual external fuel e must be matched properly.

First,  $w_2$  must have W as an upper limit:

$$w_2 := \min [w_2, W]$$

then, from this value of  $w_2$  and the original value of x, actual external fuel is estimated by

$$e = \max [0, w_2 - I - T - F \cdot x]$$

For this estimate of actual external fuel, the x corresponding to the number of tanks having enough capacity to contain e is determined from the aircraft-inputs part of the program (step  $Z_{10} + 0.56$ ). If this value of x is different from the original value, the difference in weight will change the value of e; therefore, this process is repeated until a proper match is obtained.

Other limitations are desirable because of the effect of required tank weight on the weight of fuel carried. To simplify this problem it is assumed that a tank is not added unless it provides a weight of fuel greater than 10 percent of the incremental tank weight. The programmed procedure is illustrated in step 2 of the flow diagram and in part 7 in the Appendix.

3. Drag area ( $\text{ft}^2$ ) of all external items is found from the following:

For fuel tanks

$$t = 0.0025 x^{0.7}$$

For suspension equipment

$$s = nU + \emptyset + c_4 t$$

For ordnance

$$o = ny + c_6 t$$

where

U = average rack drag area per weapon

$\emptyset$  = pylon drag area

y = average installed drag area of one unit of ordnance

$c_4$  = input constant used to add drag of fuel tanks to suspension equipment for return to base when tanks are retained.

$c_6$  = input constant used to include tank weight with ordnance weight when dropped in the target area.

After the above value of t has been used to find s and o, the effect on cruising fuel consumption of dropping empty tanks during cruise or climb is estimated by finding an average value of fuel tank drag:

$$t = 0.0013 (\max[0, x - w_2 + w_4])^{0.7} \quad \text{if } c_4 = 0 \text{ and } c_6 = 0$$

4. Equivalent start-cruise weight ( $w_4$ ) is found from:

$$w_4 = P_1 (w_2 - V) \quad \text{if there is no refueling } (Z_3 = 0)$$

or

$$w_4 = w_2 \quad \text{if refueled}$$

where, from aircraft inputs

$P_1$  = ratio of weight after climb to weight before climb

V = fuel for warm-up, taxi, and takeoff

5. Aircraft weight over the base at the end of the mission is

$$w_{10} = M + R + nQ + v + 0.05 fc_3 + Fxc_4$$

where

R = reserve fuel allowance from aircraft inputs, lb

$c_3$  = input constant used to include 5 percent fuel in reserves

$c_4$  = input constant used to include fuel tank weight when tanks are carried back to base

f = total fuel carried =  $w_2 - T - Fx$

6. The portion of the flight p provided by external fuel is:

$$p = \max \left[ 0, \left( K_1 / \exp[A_1(s + o + t)] \right) \left( w_4^{J_1} - (w_2 - e)^{J_1} \right) / J_1 \right]$$

where K, J, A for this and later equations are selected for the flight conditions specified for the appropriate leg of the mission, the leg being denoted by the subscript.

The weight after dropping tanks ( $w_5$ ) is

$$w_5 = w_4 - Fx \quad \text{if } p = 0$$

$$w_5 = w_2 - e - Fx \quad \text{if } p > 0$$

Since p is based on flight conditions for the first leg, if  $p > S_1$  and cruise conditions (h, m) are different for the second leg, the calculated value of p will not be the actual distance provided by external fuel. If this is the case, the actual portion of flight provided by external fuel is

$$S_1 + \frac{K_2}{\exp[A_2(s + o + t)]} \cdot \frac{w_6^{J_2} - (w_2 - e)^{J_2}}{J_2}$$

Aircraft weight ( $w_6$ ) at the start of the second leg depends on the relation between p and the length of the first leg  $S_1$ :

if  $S_1 > p$

$$w_6 = \left[ w_5^{J_1} - J_1(S_1 - p) \exp[A_1(s + o)] / K_1 \right]^{1/J_1}$$

if  $S_1 \leq p$

$$w_6 = \left[ w_4^{J_1} - J_1 S_1 \exp[A_1(s + o + t)] / K_1 \right]^{1/J_1}$$

7. Aircraft weight at the end of the third leg is found from the weight at the end of the mission  $w_{10}$ , fuel flow during the last leg, and last leg distance  $S_4$ .

$$w_9 = \left[ S_4 J_4 \exp[A_4 s] / K_4 + w_{10}^{J_4} \right]^{1/J_4}$$

8. The rest of the procedure involves iteration of aircraft target weight and distance of the second leg until the desired accuracy is attained. The procedure first estimates the target weight roughly from:

$$\text{target weight} \cong G = \sqrt{w_6 w_9}$$

9. The above estimate of  $G$  is used to obtain the approximate second-leg distance  $S_2$  from the following:

For a two-leg symmetrical profile ( $P_2 = 1$ ),

if  $p > 0$

$$S_2 = p + \frac{K_2}{\exp[A_2(s + o)]} \cdot \frac{w_5^{J_2} - G^{J_2}}{J_2}$$

if  $p = 0$

$$S_2 = \frac{K_2}{\exp[A_2(s + o)]} \cdot \frac{w_6^{J_2} - G^{J_2}}{J_2}$$

For other missions ( $P_2 = 4$ )

if  $p < S_1$

$$S_2 = \frac{K_2}{\exp[A_2(s + o)]} \cdot \frac{w_6^{J_2} - G^{J_2}}{J_2}$$

if  $p \geq S_1$

$$S_2 = \frac{K_2}{\exp[A_2(s + o)]} \cdot \frac{[w_6^{J_2} - (w_5 + Fx)^{J_2}]}{J_2} + \frac{K_2}{\exp[A_2(s + o)]} \cdot \frac{w_5^{J_2} - G^{J_2}}{J_2}$$

Using the first approximation to  $S_2$ , a closer estimate to actual target weight is made from:

if  $P_2 = 1$  (two-leg mission)

$$B = X + \left[ (S_2 + Z_3) J_3 \exp[A_3 s] / K_3 + w_9^{J_3} \right]^{1/J_3}$$

if  $P_2 = 4$

$$B = X + \left[ w_9^{J_3} + S_2 J_3 \exp[A_3 s] / K_3 \right]^{1/J_3}$$

in which X is the total weight disposed of in the target area, including loiter fuel, combat fuel, and payload, described in Section III.

This approximation for target weight B is then averaged with the first value G, a new value of  $S_2$  is found, and the process is repeated until G and B are within the desired tolerance.

Total distance to the target is then the sum of the first and second legs and the distance from the origin to the refueling point:

$$\text{distance to target} = Z_3 + S_1 + S_2$$

#### SPECIFIED CONFIGURATION PROGRAM (HARD-3A)

In addition to the mission-related inputs described previously, the following configuration data must be input when they are not included in the HARD-3 program:

1. Number of external stores expended in the target area, not including fuel tanks, n
2. Average expended weight per expended item, u

3. Average drag area\* per expended item, y
4. Total weight of all pylons, v
5. Total drag area of all pylons,  $\emptyset$
6. Average weight of all racks per expended item, Q
7. Average drag area of all racks per expended item, U
8. Total weight of fully loaded fuel tanks
9. Total usable fuel capacity, x
10. Total tank drag area
11. Usable external fuel actually loaded
12. Usable internal fuel actually loaded
13. Combat time, min
14. Loiter time, min

The procedure then continues as for HARD-3, beginning with step 4 of the calculation procedure.

All pylons and racks are assumed to be carried throughout the flight. Other nonexpended stores must be included with either pylons or racks.

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\*The drag index DI used in the flight manual must be converted to drag area by multiplying all values of DI by a conversion factor  $Z_2$ , which is provided with other aircraft inputs in part  $Z_{10}$ . The total drag area of expended items must equal  $n \cdot y$ .

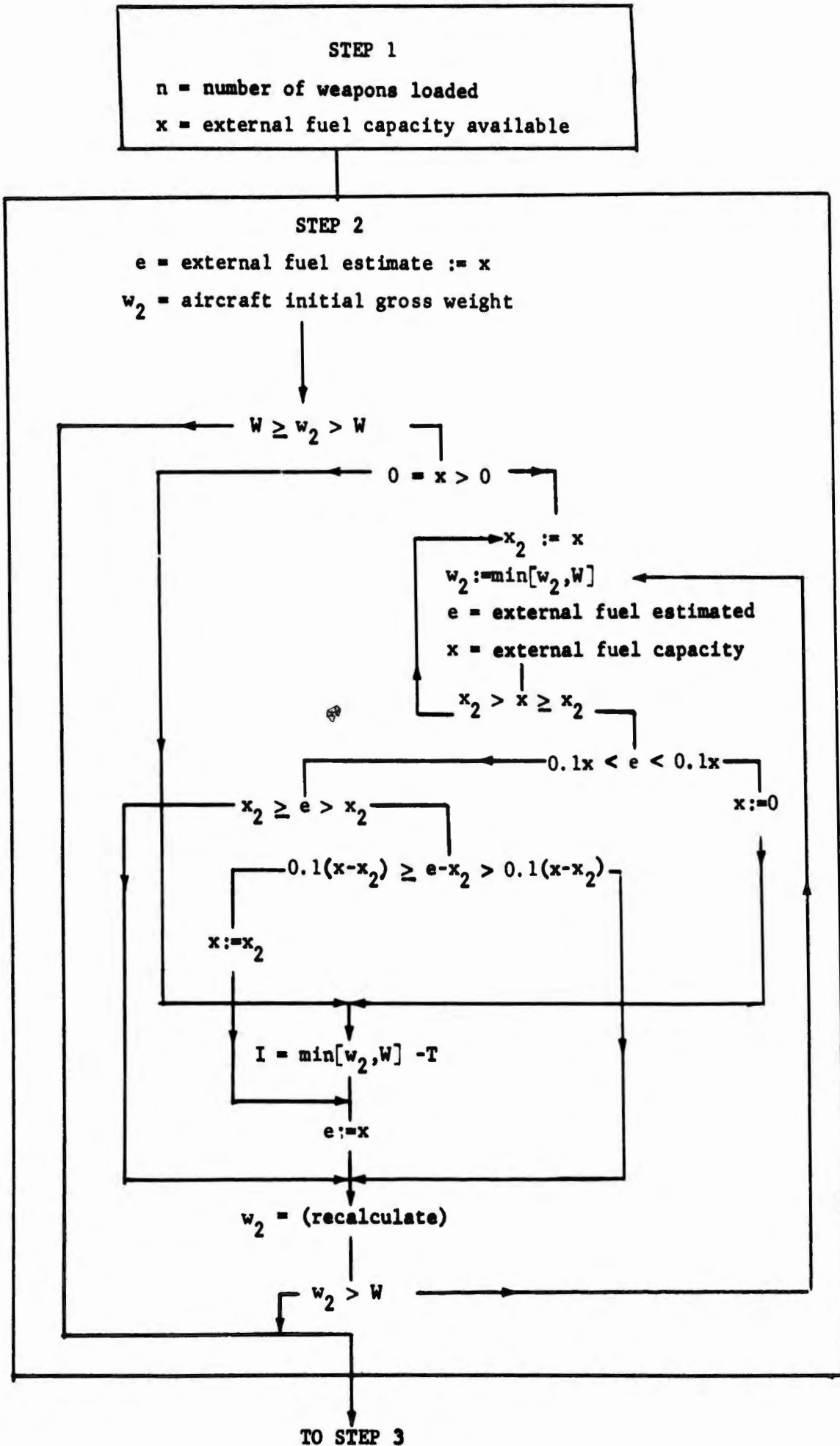


Fig. 3--Flow diagram

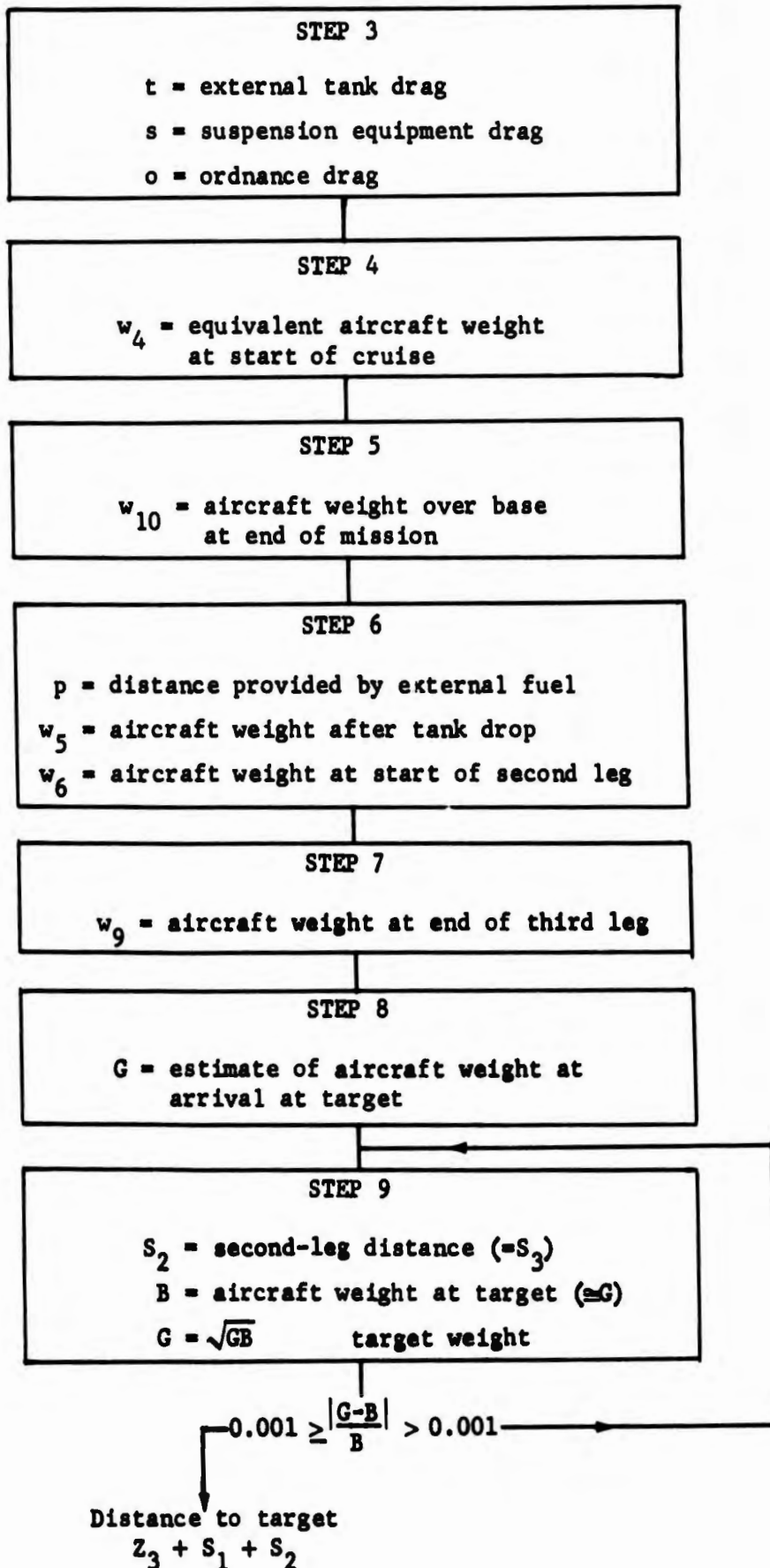


Fig. 3 (con'd)



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Appendix

A SAMPLE JOSS PROGRAM

The method described in the body of this Memorandum has been programmed for JOSS in such a way that, if the required inputs for the specified aircraft and weapon have been stored in JOSS memory, the JOSS operator need have no knowledge of any of the procedures described except for the meaning of the symbols for the mission-specification inputs.<sup>(3)</sup> The sample case included here should provide all the guidance needed to obtain the desired performance data.

For those who may want to provide their own aircraft inputs, the use of Section III and the sample F-4E input determination shown later should be sufficient.

The remaining information presented here shows the equations and the actual computation procedure described in Section IV.

Not shown are several JOSS parts that are used to call for the necessary inputs when the procedure is initiated.

SAMPLE RADIUS CALCULATION

As an example of the use of the JOSS program, combat radius of the F-4E is calculated on the following pages. After the program is recalled from its JOSS file, the command "Do part 1" starts the procedure by requesting the necessary inputs. The following conditions are specified:

- a. Weapon type and number: M117; 0, 11, 19 loaded
- b. Profile: symmetrical two-leg mission at optimum speed at sea level
- c. Fuel reserve: 5 percent of total fuel and fuel for 20 min at maximum endurance at sea level after return to base
- d. External tanks: dropped when empty
- e. Refueling: none
- f. Warm-up, takeoff, and combat fuel allowances: MIL-C-5011A<sup>(2)</sup>
- g. Combat condition: military power at sea level for 0, 5, and 10 min

h. Loiter: maximum endurance speed at sea level for 0 and 15 min  
Repeat the procedure for the same sea-level mission, but include fuel allowance for two climbs to cruise altitude. This is useful when curves are to be plotted showing the tradeoff between sea-level dash distance and total distance to the target.

Determine combat radius for flight to and from the target at optimum speed and altitude.

Determine the effect of using the AFRDQ energy-related fuel allowances for a typical case.

The JOSS operation used for this example is shown on the following pages, using actual JOSS print-out, followed by explanatory notes relating to certain steps in the procedure.

After acquiring the necessary programs, the procedure is initiated by the command "Do part 1":

Do part 1.

For automatic variation in no. of wpns (HARD-3), set Z(1)=0

For specified loading configuration (HARD-3A), set Z(1)=1

Z(1) = 0

Aircraft code no., Z(10) = 00

(see note A)

Available wpn code no. / max no. carried

82 821 117 7

24 241 19 7

wpn code no., (1) = 117

(see note B)

PROFILE LEG, i:	1	2	3	4
Leg distance, S(i):	S(1)	S(2)	S(3)	S(4)
Cruise alt/1000, h(i)	h(1)	h(2)	h(3)	h(4)
Cruise speed ind., m(i)	m(1)	m(2)	m(3)	m(4)

Payload is dropped between legs 2 and 3.

For 2-leg mission [S(2)=S(3)], set P(2)=1, otherwise, P(2)=4

P(2) = 1

(see note C)

Opt alt and speed input as 100

Normal power (NRT) input as 110

Military power (MRT) input as 120

Full AB power (MAX) input as 200

Alt-speed combinations available for cruise, (h,m)

(0,100),(5,100),(20,100),(0,120),(100,100)

h(2) = 0  
m(2) = 100  
h(3) = 0  
m(3) = 100

(see note D)

Set c(3)=1 if reserve is to include .05\*total fuel in addition to R, otherwise set c(3)=0

c(3) = 1

Set c(4)=1 if all tanks are to be carried throughout the entire mission, otherwise =0

c(4) = 0

Set c(5)=1 if tanks are dropped when empty (c(4)=0), but external fuel remaining at start of combat is discarded, otherwise =0

c(5) = 1

Set c(6)=1 [c(4)must=0] if all tanks are carried to target and dropped before combat, otherwise =0

c(6) = 0

Set Z(3)=0 if there is no refueling

Set Z(3)=1 for over-base refueling

Set Z(3)=distance from base if refueled  
Z(3) = 0

For MIL-C takeoff and combat allowances set c(10)=0  
For AFRDQ allowances, set c(10)=1 and do not input combat time  
C as noted below

c(10) = 0  
Combat: MRT h=0 set c(1)=4  
MRT h=35 2  
MAX h=0 3  
c(1) = 4

(see note E)

combat (target) altitude/1000 = h(11) = 0  
loiter alt/1000 = h(10) = 0

At this point, if combat time C (only if c(10)=0), loiter time L and no. of weapons to be carried n are input, then giving the command 'Do part Z(10)' will result in the calculation of combat radius, then any desired value may be typed out. To provide automatic variation of C,L,or n with the printout now being used, complete parts 15,16,17, as needed and then command 'Do part 10'. Other inputs may be varied in a similar manner. If different printout is desired, change steps 9.2,21.5, as necessary.

Sample procedures:

9.1 Page.

9.2 Type form 2.

9.4 Line.

10.2 Do step 9.2.

10.22 Line.

10.3 To part 16 if c(10)=1.

10.4 To part 15.

15.2 Do part 16 for C=0,5,10.

16.2 Do part 17 for L=0,10.

17.1 Line.

17.2 Do part 18 for n=0,12.

17.7 Line.

18.4 Do part Z(10).

18.5 Type C,L,n,w(2),B,f,e,P(3),S(1),S(2),Z(3)+S(1)+S(2) in form 3.

18.8 Do part 9 if S=53.

20.2 Demand P(2).

20.55 Do part 4.

20.6 To part 10.

21.2 Demand C.

21.3 Demand L.

21.4 Demand n.

21.5 Type form 2.

21.6 Do part Z(10).

21.65 Do step 18.5.

25.2 Do part 3.

25.4 To part 10.

If profile is to be changed, altitude and speed for each leg must be input again. This may be done by commanding 'Do part 20'

To change weapon only, Do part 25

Climbs to cruise altitude after takeoff and after combat are automatically included. For 3 or 4-leg missions, second climb is to  $h(4)$ . To allow for 2 climbs in the LO-LO profile command 'Do part 20', set  $P(2)=4$ ,  $S(1)=0$ ,  $S(4)=0$

(see note F)

\*The following changes are necessary to provide the desired answers:

17.1 Do part 17 for  $n=1$ .

17.2 Do part 18 for  $n=0,11,14$ .

(see note G)

Do part 10.

C	L	n	T/O WT	TGT WT	FUEL	EXT	p	S(1)	S(2)	TOT
0	0	0	56190	44896	21606	8710	323	0	424	424
0	0	11	61587	51823	17706	4810	106	0	276	276
0	0	19	62000	55683	11483	0	0	0	134	134
0	15	0	56190	45622	21606	8710	323	0	388	388
0	15	11	61587	53049	17706	4810	106	0	231	231
0	15	19	62000	57397	11483	0	0	0	83	83
5	0	0	56190	45992	21606	8710	323	0	369	369
5	0	11	61587	53048	17706	4810	106	0	231	231
5	0	19	62000	56999	11483	0	0	0	95	95
5	15	0	56190	46747	21606	8710	323	0	332	332
5	15	11	61587	54316	17706	4810	106	0	184	184
5	15	19	62000	58771	11483	0	0	0	42	42
10	0	0	56190	47271	21606	8710	323	0	307	307
10	0	11	61587	54281	17706	4810	106	0	185	185
10	0	19	62000	58322	11483	0	0	0	55	55
10	15	0	56190	47876	21606	8710	323	0	277	277
10	15	11	61587	55593	17706	4810	106	0	138	138
10	15	19	62000	60150	11483	0	0	0	1	1

\* To include fuel allowance for climb after takeoff and after combat,  
 \*a 4-leg profile is used with  $S(1)=S(4)=0$ .

to part 20.

$P(2) = 4$

$h(1) = 1000$

$m(1) = 1000$

$h(2) = 0$

$m(2) = 1000$

$h(3) = 0$

$m(3) = 1000$

$h(4) = 0$

$m(4) = 1000$

$S(1) = 0$

$S(4) = 0$

C	L	n	T/O WT	TGT WT	FUEL	EXT	p	S(1)	S(2)	TOT
0	0	0	56190	44867	21606	8710	281	0	384	384
0	0	11	61587	51847	17706	4810	70	0	240	240
0	0	19	62000	55754	11483	0	0	0	102	102
0	15	0	56190	45589	21606	8710	281	0	348	348
0	15	11	61587	53067	17706	4810	70	0	195	195
0	15	19	62000	57461	11483	0	0	0	51	51
5	0	0	56190	45958	21606	8710	281	0	329	329
5	0	11	61587	53066	17706	4810	70	0	195	195
5	0	19	62000	57062	11483	0	0	0	63	63
5	15	0	56190	46704	21606	8710	281	0	292	292
5	15	11	61587	54328	17706	4810	70	0	148	148
5	15	19	62000	58824	11483	0	0	0	10	10
10	0	0	56190	47188	21606	8710	281	0	269	269
10	0	11	61587	54292	17706	4810	70	0	150	150
10	0	19	62000	58379	11483	0	0	0	23	23
10	15	0	56190	47829	21606	8710	281	0	237	237
10	15	11	61587	55592	17706	4810	70	0	102	102
10	15	19	62000	60197	11483	0	0	0	-31	-31



\* To find radius of circle (r) use formula:  $r = \frac{1}{2} \sqrt{a^2 + b^2}$ ,  
#we return to part 1.

Do part 20.

$P(2) = 1$

$h(2) = 1$

$m(2) = 1$

$h(3) = 1$

$m(3) = 1$

C	L	n	T/O WT	TGT WT	FUEL	EXT	p	S(1)	S(2)	TOT
0	0	0	56190	44333	21606	8710	469	0	702	702
0	0	11	61597	51055	17706	4810	99	0	395	395
0	0	19	62000	55271	11483	0	0	0	157	157
0	15	0	56190	45053	21606	8710	469	0	636	636
0	15	11	61587	52366	17706	4810	99	0	320	320
0	15	19	62000	57197	11483	0	0	0	78	78
5	0	0	56190	45440	21606	8710	469	0	601	601
5	0	11	61587	52385	17706	4810	99	0	319	319
5	0	19	62000	56756	11483	0	0	0	96	96
5	15	0	56190	46196	21606	8710	469	0	534	534
5	15	11	61587	53765	17706	4810	99	0	243	243
5	15	19	62000	58772	11483	0	0	0	15	15
10	0	0	56190	46570	21606	8710	469	0	501	501
10	0	11	61587	53743	17706	4810	99	0	244	244
10	0	19	62000	58262	11483	0	0	0	35	35
10	15	0	56190	47371	21606	8710	469	0	432	432
10	15	11	61587	55187	17706	4810	99	0	167	167
10	15	19	62000	60369	11483	0	0	0	-47	-47

\* To substitute APPK rules for MIL-C:

e(10)=1

to part 10.

C	L	n	T/O WT	TGT WT	FUEL	EXT	p	S(1)	S(2)	TOT
1	0	0	56190	45075	21606	8710	516	0	681	681
1	0	11	61587	51757	17706	4810	116	0	372	372
1	0	19	62000	55945	11483	0	0	0	131	131
1	15	0	56190	45815	21606	8710	516	0	615	615
1	15	11	61587	53104	17706	4810	116	0	297	297
1	15	19	62000	57911	11483	0	0	0	52	52

Do part 1.

(see note H)

For automatic variation in no. of wpns (HARD-3), set Z(1)=0

For specified loading configuration (HARD-3A), set Z(1)=1

Z(1) = 1

Aircraft code no., Z(10) = 99

If loading is not listed below, set l=1

Available wpn code no. / max no. carried

82 821 117 7

24 241 19 7

wpn code no., (1) = 117

PROFILE LEG, i:	1	2	3	4
Leg distance, S(i):	S(1)	S(2)	S(3)	S(4)
Cruise alt/1000, h(i)	h(1)	h(2)	h(3)	h(4)
Cruise speed ind., m(i)	m(1)	m(2)	m(3)	m(4)

Payload is dropped between legs 2 and 3.

For 2-leg mission [S(2)=S(3)], set P(2)=1, otherwise, P(2)=4

P(2) = 1

Opt alt and speed input as 100

Normal power (NRT) input as 110

Military power (MRT) input as 120

Full AB power (MAX) input as 200

Alt-speed combinations available for cruise, (h,m)

(0,100),(5,100),(20,100),(0,120),(100,100)

h(2) = 100

m(2) = 100

h(3) = 100

m(3) = 100

Set c(3)=1 if reserve is to include .05\*total fuel in addition to R, otherwise set c(3)=0

c(3) = 1

Set c(4)=1 if all tanks are to be carried throughout the entire mission, otherwise =0

c(4) = 0

Set c(5)=1 if tanks are dropped when empty (c(4)=0), but external fuel remaining at start of combat is discarded, otherwise =0

c(5) = 1

Set c(6)=1 [c(4)must=0] if all tanks are carried to target and dropped before combat, otherwise =0

c(6) = 0

Set Z(3)=0 if there is no refueling

Set Z(3)=1 for over-base refueling  
Set Z(3)=distance from base if refueled  
Z(3) = 0

For MIL-C takeoff and combat allowances set c(10)=0  
For AFRDO allowances, set c(10)=1 and do not input combat time  
C as noted below

c(10) = 0  
Combat: MRT h=0 set c(1)=4  
MRT h=35 2  
MAX h=0 3  
c(1) = 4

combat (target) altitude/1000 = h(11) = 0  
loiter alt/1000 = h(10) = 0  
Climbs to cruise altitude after takeoff and after combat are  
automatically included. For 3 or 4-leg missions, second  
climb is to h(4). To allow for 2 climbs in the L0-L0 profile  
command 'Do part 20', set P(2)=4, S(1)=0, S(4)=0

Include drag and weight of non-expended items with pylons  
HARD-3 values may be input by setting u=u, y=y, etc.  
If flight manual Drag Index DI is used, input drag as DI\*Z(2)

no. of expended items, n = 11  
average wt per expended item, u = 615.835  
average drag per expended item, y = 101  
Total pylon wt, v = 1117.415  
total pylon drag, 0 = 1117.415  
average rack wt per expended item, 0 = 0  
average rack drag per expended item, U = 0  
Total wt of full fuel tanks = 17706  
Total usable ext fuel capacity, x = 4810  
Total tank drag, t = 101  
Actual usable ext fuel loaded, e = 4810  
Actual usable internal fuel loaded, I = 17706  
gross wt=w(2)

w(2) = 61583.5  
combat time, min, C = 0  
loiter time, min, L = 15  
if desired, input pre-climb fuel V; reserve fuel R; else V=V,R=R  
V = 0  
R = 0

C	L	n	T/O WT	TCT WT	FUEL	EXT	p	S(1)	S(2)	TOT
0	15	11	61584	51922	17706	4810	101	0	333	333

Notes for Joss Procedure

A. The code number for the selected aircraft must be supplied at this point. The F-4E is used in this example.

B. The store-identifying number  $l$  must be chosen;  $l$  is used to define store drag  $y$ , external fuel capacity  $x$ , suspension weight  $Q$ , and suspension drag  $U$ . The weapon chosen here is the M-117.

C. The symbol applicable to the desired profile must be selected. The second and third legs are always equal, but any value may be used for  $S_1$  and  $S_4$ . This example consists of cruise to and from the target at sea level at speed for best range.

D. Speed and altitude for each leg of the mission profile must be chosen.  $h$  is equal to altitude in thousands of feet,  $m$  indicates Mach number except for the conditions noted.  $h = 100$  chooses optimum altitude and  $m = 100$  chooses optimum speed. Other conditions may be used, provided the corresponding values of  $K$ ,  $J$ ,  $A$  are used as inputs.

E. The combat power setting and the altitude symbol must correspond to fuel-flow input D. In this example, fuel flow is estimated for military power at sea level at high subsonic speed.

F. At this point the appropriate steps are supplied to provide the desired sequence of calculations and the desired output.

G. The operational command is now given as shown on the following page, which provides answers for a mission with cruise at sea level.

H. As an example of the HARD-3A program, this case is approximately the same as that shown for  $C = 0$ ,  $L = 15$ ,  $n = 11$  using the HARD-3 program. The resulting combat radius is slightly different because the pylon weight and drag are handled differently.

For HARD-3A, when the program is obtained,  $Z(1)$  must be set = 1. After mission inputs have been selected as for HARD-3, the program will demand drag and weight data for the specified configuration, then proceed with the calculation as shown.

SAMPLE AIRCRAFT INPUTS

The inputs (as discussed in Section III) for each airplane are described by a program part that is acquired by evaluating  $Z_{10}$  (JOSS notation is Z(10)). For instance, for the F-4E used in the foregoing illustrative example the input data are currently stored in JOSS as part 99 (Z(10) = 99).

For the convenience of the reader, each step of the part, as it applies in general to any aircraft, is listed below before being described in detail for the F-4E. The decimal numbers refer to the JOSS notation for the aircraft part. The integer of the number, which identifies the aircraft, is omitted for brevity.

- Z(10) + .1      W = maximum allowable aircraft gross weight
- .12            M = aircraft weight without fuel and removable items
- .14            I = internal fuel capacity of usable fuel, lb
- .15            F = ratio of empty tank weight to usable fuel in tank
- .2             V = fuel used during warm-up, taxi, and takeoff
- .24             $P_1$  = ratio of effective weight after climb to weight after takeoff for cruise at optimum cruise altitude
- .25            D = fuel flow (lb/min) for the power setting corresponding to the selected value of c(1)
- .4             Q = weight of store racks not included in either v or M
- .41            v = total pylon weight
- .42            U = drag of store racks not included in  $\gamma$  or in aircraft drag
- .43             $\phi$  = total pylon drag
- .431           Z(2) = factor to convert drag index DI to drag area  $\gamma$
- .44             $\gamma$  = average drag area of store selected by  $l^*$
- .5-.53        x (function of n, l)

---

\* In the text,  $l$  and  $\phi$  (oh) are used to avoid confusion with the numerals one and zero. The actual JOSS printouts reproduced here and later in this Memorandum have not been altered because the JOSS type face clearly distinguishes letters from numbers.

- .56 x (function of e)
- .6-.623 Provide<sup>R</sup> print-out of weapons available, cruise altitude-speed combinations, combat altitude, and power settings
- .7  $P_1$  (function of first-leg altitude and configuration)
- .702 R (reserve fuel for 20-min loiter at sea level)
- .7021 V (for AFRDQ allowances)
- .7022 D (for AFRDQ allowances)
- .703 P(11) (allows for climb to third-leg altitude from combat altitude)
- .712-.84 Values of K, J, A for various combinations of cruise speed and altitude)
- .9-.92 Determines value of  $E_1$  and  $E_2$  to be used in loiter fuel calculation

One disadvantage of the HARD-3 procedures described in this Memorandum, resulting from the added versatility and accuracy, is the increase in labor involved in determining performance inputs, particularly if AFRDQ rules are used. The time involved depends, naturally, on availability of data. Flight manuals usually do not include all necessary data--a condition that could easily be remedied by the publisher. At the time of this writing, the F-4E flight manual was not available.

The data presented below for the F-4E were obtained from reports provided by the manufacturer. (4,5)

### Weights

The maximum reported loading condition results in a gross weight of 61,651 lb. For this example the maximum allowable gross weight for takeoff was chosen as 62,000 lb. The JOSS statement is:

.1 Set W = 62,000

Operational empty weight:

.12 Set M = 31,201

Internal usable fuel capacity:

.14 Set I = 12,896

Takeoff and Combat Allowances

It is convenient to find all necessary fuel flows at one time, then place them in their proper place in the program.

MIL-C-5011A Fuel Allowances. Pre-climb fuel allowance is the sum of pounds of fuel used in 5 min operation at sea level, Mach 0, at normal power, and 1 min at full afterburner. Fuel flows for these conditions are not normally provided in flight manuals. From installed-engine data:

.2 Set V = 1825

Combat fuel flow also is not provided in flight manuals in convenient form for these purposes, but, if not otherwise available, can be deduced from other data.

At a weight of approximately 40,000 lb:

Altitude (ft)	Mach Number	Fuel Flow (lb/min)	c <sub>1</sub>
35,000	1.75	1090	1
35,000	0.9	133	2
0	0.9	1650	3
0	0.9	437	4

These values are expressed in the program as:

.25 Set D = [c(1) = 1:1090; c(1) = 2:133; c(1) = 3:1650; c(1) = 4:437]

AFRDQ Fuel Allowances (see p. 16).\* Fuel flows and rates of climb are required for several conditions, and again, the flight manual is not a convenient source but can be used to make rough approximations. To estimate fuel allowances for both takeoff and combat, the following values of specific power were obtained from climb performance and fuel-flow data:

At sea level, M = 0.8, max power, w <sub>1</sub> = 55,000, Δf̄ <sub>1</sub> = 0, P <sub>s1</sub> = 633	} ft/sec
At sea level, M = 0.8, max power, w <sub>1</sub> = 55,000, Δf̄ <sub>2</sub> = 12, P <sub>s2</sub> = 327	
At sea level, M = 0.7, mil power, w <sub>2</sub> = M + 0.51 Δf̄ <sub>3</sub> = 4, P <sub>s3</sub> = 243	
At 30,000 ft, M = 0.7, mil power, w <sub>2</sub> = M + 0.51 Δf̄ <sub>3</sub> = 4, P <sub>s4</sub> = 86.7	

\* Symbols in this and the following subsections may apply only as used to determine numerical inputs for the JOSS program.



At sea level, fuel used for 2 min at Mach 0 with military thrust is

$$F = 580 \text{ lb}$$

At sea level static with max power, fuel flow  $w_{f_1} = 10.2 \text{ lb/sec}$

At sea level,  $M = 0.8$  max power, fuel flow  $w_{f_2} = 15.5 \text{ lb/sec}$

At sea level,  $M = 0.7$  mil power, fuel flow  $w_{f_3} = 3.91 \text{ lb/sec}$

At 30,000 ft,  $M = 0.7$  mil power, fuel flow  $w_{f_4} = 1.37 \text{ lb/sec}$

Using the procedure described in Section III, p. 18, and the above values, the constants A, B, and C are evaluated for  $\Delta f_1 = 0$ :

$$A = \left[ \frac{P_{s_1}}{P_{s_2}} - 1 \right] / \left[ \frac{P_{s_1}}{P_{s_2}} \cdot \left( 1 + \frac{\Delta f_2}{\bar{f}} \right) - 1 \right] = 0.2725$$

$$B = P_{s_1} \cdot w_1 / [1 - A] = 4.79 \cdot (10)^7$$

$$C = \left[ \frac{w_{f_4}}{P_{s_4}} - \frac{w_{f_3}}{P_{s_3}} \right] / 900 = -3.21/10^7$$

For the above,  $\bar{f}$  (clean aircraft drag area) is estimated to be  $9.3 \text{ ft}^2$ . The JOSS input equations for V and D are then determined from the equations shown in the Appendix by substituting for A, B, C, F,  $w_{f_1}$ ,  $w_{f_2}$ ,  $P_{s_3}$  and using the input c(10) to select AFRDQ allowances

.7021 Set  $V = 580 + 0.0067 \cdot (w(2) - 580) / [1 - 0.273 \cdot (1 + (s+o+t) / 9.3)]$   
if  $c(10) = 1$

.7022 Set  $D = 10^3 [60 - h(11)] \cdot [0.01609 + (3.21 \cdot h(11)^2) / 10^7]$  if  $c(10) = 1$

Equivalent Climb Fuel  $P_1, P_{11}$ . For both the climb after takeoff and the climb after combat, the ratio of aircraft weight after climb to weight before climb,  $P_1$  and  $P_{11}$ , respectively, are determined from the general relation:

$$P = 1 - Ch(1 + D \cdot \Delta \bar{f})$$

where  $h$  = altitude/1000, ft

$\Delta\bar{f}$  = added drag area, ft<sup>2</sup>

and where the constants  $C$  and  $D$  are found from known climb performance (Section A3 of the flight manual may be used), using data at two altitudes and two drag configurations as follows:

$$\text{Let } y = \left(F - \frac{d}{c}\right)/w$$

where

$F$  = actual climb fuel

$d$  = actual climb distance

$c$  = n·mi/lb at start of cruise

$w$  = gross weight

then, with subscripts corresponding to two sets of actual data,

$$D = \left(y_1 h_1 - y_1 h_2\right) / \left(y_1 h_2 \cdot \Delta\bar{f}_2 - y_2 h_1 \cdot \Delta\bar{f}_1\right)$$

$$C = y_1/h_1 / \left(1 + D \cdot \Delta\bar{f}_1\right)$$

Using the following set of data for the F-4E at military power with  $w = 50,000$  lb and two values of drag area:

Parameter	Subscript	
	1	2
$\Delta\bar{f}$	5	12
$h$	30	20
$F$	1450	1200
$d$	43	24
$c$	0.07	0.046

Substituting these values in the previous equations:

$$y_1 = 0.0167$$

$$y_2 = 0.01357$$

$$C = 0.471/10^3$$

$$D = 0.0368$$

then the equations for the program become

$$\begin{aligned}
 .7 \text{ Set } P(1) &= 1 - 4.71/10^4 \cdot h(1) \cdot \left(1 + 0.0368 \cdot (s+o+t)\right) \text{ if } h(1) < 100 \\
 .702 \text{ Set } P(11) &= 1 - 4.7/10^4 \cdot \left[1 + 0.0368 \cdot s\right] \\
 &\cdot \max \left[0, \min[35, h(4)] - h(11)\right]
 \end{aligned}$$

For climb to optimum cruise altitude where  $h = 100$ ,  $P(1)$  is input separately and can be determined from step .7. The resulting value of  $P(1)$  is

$$.24 \text{ Set } P(1) = 0.983$$

In step .702, the value 35 in the last bracket is an estimate of maximum probable cruise altitude at average weight, used simply to prevent incorrect values if  $h(4) = 100$ .

#### Cruise Inputs

The general cruise performance equation for HARD-3 is

$$v \left( \frac{n \cdot mi}{lb} \right) = K/w^{(1-J)} / \exp[A \cdot \Delta \bar{f}]$$

where  $w$  = aircraft weight, lb

$\Delta \bar{f}$  = added drag area,  $ft^2$

$K$ ,  $J$ ,  $A$  are constants to be determined from known cruise performance at the desired speed and altitude for three values of aircraft weight and two values of added drag. The constants are determined from:

$$A = \log \left[ \frac{\gamma_3}{\gamma_1} \left( \frac{w_3}{w_1} \right)^{(1-J)} \right] / (\Delta \bar{f}_1 - \Delta \bar{f}_2)$$

$$J = 1 - \log \left( \frac{\gamma_1}{\gamma_2} \right) / \log \left( \frac{w_2}{w_1} \right)$$

$$K = \gamma_1 w_1^{(1-J)} \cdot \exp[A \cdot \Delta \bar{f}_1]$$

in which  $\gamma_1 = \text{mi/lb at } w_1 \text{ and } \Delta\bar{f}_1$   
 $\gamma_2 = \text{mi/lb at } w_2 \text{ and } \Delta\bar{f}_1$   
 $\gamma_3 = \text{mi/lb at } w_3 \text{ and } \Delta\bar{f}_2$

and where  $\Delta\bar{f}_1$  is a low value and  $\Delta\bar{f}_2$  is a high value of  $\Delta\bar{f}$ ;  $w_1$  is a low value and  $w_2$  is a high value of weight; and  $w_3$  is about midway between  $w_1$  and  $w_2$ .

These values of K, J, A are input with the appropriate subscripts for each combination of speed and altitude desired.

The following values of added drag and aircraft weight were used:

$$\begin{aligned} \Delta\bar{f}_1 &= 0 \\ \Delta\bar{f}_2 &= 10 \\ w_1 &= 35,000 \\ w_2 &= 55,000 \\ w_3 &= 45,000 \end{aligned}$$

At the selected altitude and speed (h,m) the following values were obtained:

Altitude h	Speed m	$\gamma_1$	$\gamma_2$	$\gamma_3$	K	J	A
100 <sup>a</sup>	100 <sup>a</sup>	0.125	0.08	0.059	3834	0.0126	0.0503
0	100 <sup>a</sup>	0.057	0.0495	0.036	1.494	0.688	0.0381
0	120 <sup>b</sup>	0.0225	0.0225	0.02	0.0225	1.0	0.01178
5	100 <sup>a</sup>	0.0645	0.055	0.0398	2.579	0.6475	0.0394
20	100 <sup>a</sup>	0.0932	0.073	0.0523	26.63	0.4595	0.0442

<sup>a</sup>Optimum.

<sup>b</sup>Speed corresponding to military rated thrust.

These values are shown in part 99 in steps .712 through .776.

Loiter Inputs (see p. 14)

The general formula for loiter fuel flow is

$$\text{fuel flow} = E_1 \cdot \exp[ah] \cdot \exp[b \cdot \Delta\bar{f}] \cdot [w/w_1]^c$$

where  $w$  = actual aircraft weight, lb

$w_1$  = approximate target weight, lb

$h$  = loiter altitude/1000, ft

$\Delta\bar{f}$  = added drag area, ft<sup>2</sup>

$E_1$  = fuel flow for clean aircraft at sea level at  $w = w_1, \frac{lb}{min}$

and where  $a$  and  $b$  are constants evaluated from available data as follows:

Choose aircraft weights to cover the range of interest

$w_1$  = approximate target weight

$w_2$  = low weight

$w_3$  = high weight

Choose drag configurations:

$\Delta\bar{f}_1 = 0$  (clean aircraft)

$\Delta\bar{f}_2 = \Delta\bar{f}$  approximately  $\frac{1}{2}$  of clean aircraft  $\bar{f}$

$\Delta\bar{f}_3 = \Delta\bar{f}$  approximately equal to clean aircraft  $\bar{f}$

and altitudes:

$h_1 = 0$  (sea level)

$h_2 = a$  selected high altitude

Constants  $a, b, c$  are then:

$$a = -\log[E_2/E_4]/h_2$$

$$b = \log[E_5/E_3]/\Delta\bar{f}_3$$

$$c = \log[E_7/E_6]/\log[w_3/w_2]$$

where:  $E_1$  is the fuel flow at  $w_1, h_1, \Delta\bar{f}_1$   
 $E_2$  is the fuel flow at  $w_1, h_1, \Delta\bar{f}_2$   
 $E_3$  is the fuel flow at  $w_1, h_2, \Delta\bar{f}_1$   
 $E_4$  is the fuel flow at  $w_1, h_2, \Delta\bar{f}_2$   
 $E_5$  is the fuel flow at  $w_1, h_2, \Delta\bar{f}_3$   
 $E_6$  is the fuel flow at  $w_2, h_2, \Delta\bar{f}_2$   
 $E_7$  is the fuel flow at  $w_3, h_2, \Delta\bar{f}_2$

These values of  $a, b,$  and  $c$  are then used to find the values of  $E(1)$  and  $E(2)$ , which are used later in the equation for  $r$ , aircraft weight after loiter.

$$E(2) = c$$

$$E(1) = E_1 \cdot \exp[a \cdot h(10)] \cdot \exp[b \cdot (s + o)] / w_1 * E(2)$$

The following data were obtained from curves for maximum endurance flight

$$\text{For } w_1 = \begin{cases} 45,000 \\ 45,000 \\ 45,000 \\ 45,000 \\ 45,000 \end{cases} \quad h_1 = \begin{cases} 0 \\ 0 \\ 30 \\ 30 \\ 30 \end{cases} \quad h_2 = \begin{cases} 0 \\ 6 \\ 0 \\ 0 \\ 10 \\ 6 \\ 6 \end{cases} \quad \begin{matrix} \Delta \bar{f}_1 = 0 \\ \Delta \bar{f}_2 = 6 \\ \Delta \bar{f}_1 = 0 \\ \Delta \bar{f}_2 = 0 \\ \Delta \bar{f}_1 = 10 \\ \Delta \bar{f}_2 = 6 \\ \Delta \bar{f}_2 = 6 \end{matrix} \quad \begin{matrix} E_1 = 91.7 \\ E_2 = 108.3 \\ E_3 = 80 \\ E_4 = 100 \\ E_5 = 115.5 \\ E_6 = 63.8 \\ E_7 = 115.5 \end{matrix}$$

from which

$$a = -0.002658$$

$$b = 0.03672$$

$$c = 1.1619$$

In this particular case, two fixed values of fuel flow were input along with a variation for intermediate values of altitude.

$$.9 \text{ Set } E(1) = [h(10) = 0: 91.7; h(10) = 30: 80; 91.7/\exp[0.0026 \cdot h(10)]]$$

$$.91 \text{ Set } E(2) = 1.1619$$

$$.92 \text{ Set } E(1) = E(1) \cdot \exp[0.0367 \cdot (s + o)] / 45000^* E(2)$$

At this time, fuel for the loiter portion of the reserve allowance is found. At a weight roughly equal to the empty weight plus 10 percent of internal fuel capacity, using data for two drag configurations, the resulting relation for 20 min loiter is

$$.701 \text{ Set } R = 1500 + 35 \cdot s$$

#### External Fuel-Payload Compatibility

On the F-4, outboard stations can carry a 370-gal tank and the centerline a 600-gal tank, comprising a total usable fuel load of 8710 lb. In order to provide a consistent value for pylon weight as the configuration changes, an "equivalent" weight of empty tanks plus usable fuel is found to be 545 lb. Then the average value of tank weight/fuel weight  $F$  is

$$.15 \text{ Set } F = 545/8710 = 0.063$$

The possible values of fuel capacity  $x$  are:

2405 lb when carrying one 370-gal tank

- 3900 lb when carrying one 600-gal tank
- 4810 lb when carrying two 370-gal tanks
- 6305 lb when carrying one 370-gal tank + one 600-gal tank
- 8710 lb when carrying two 370-gal tanks + one 600-gal tank

The proper value of x for the calculated value of external fuel e is then provided in the program by

.56 Set  $x = [e = 0: 0; \text{first } (n = 2405, 3900, 4810, 6305, 8710: x \geq 0)]$

The initial value of fuel capacity x is determined from the allowable loading for the specified type of store. For example, for the M-117 a total of 19 can be carried: 4 are on outboard wing stations, 3 on inboard stations, and 5 on the fuselage station. Thus fuel capacity and weapon carriage are related as follows:

Number of Weapons n	Fuel Capacity x
≤6	8710
7-10	6305
11	4810
12-14	3900
15	2405
16-19	0

This relationship is inserted in the program as:

.5 Set  $x = [n \leq 6: 8710; 7 \leq n \leq 10: 6305; 11: 4810; 12 \leq n \leq 14: 3900; 15: 2405; 0] \text{ if } l = 117$

#### Suspension Weight and Drag

Pylon weight and drag when carrying conventional weapons is:

outboard (2)      380 lb  $\Delta \bar{f} = 0.42 \text{ ft}^2$   
 inboard (2)      528 lb  $\Delta \bar{f} = 0.52 \text{ ft}^2$   
 total              1014 lb  $\Delta \bar{f} = 0.94 \text{ ft}^2$

.41 Set  $v = 1014$

If four Sparrows are carried, add 1820 to v.

.43 Set  $\emptyset = 0.94$

If four Sparrows are carried, add 0.52 to  $\emptyset$ .

Rack Weight and Drag

Based on a fully loaded configuration, rack weight and drag are averaged for each weapon. The combination of MER and TER racks on the F-4 results in a total weight of 845 lb and a drag index of 3.44.

For a load of 19 units of ordnance:

$$.4 \text{ Set } Q = 845/19 = 44.5$$

$$.42 \text{ Set } U = 3.44/19 = 0.18$$

Ordnance Weight and Drag

Ordnance weight is a general input and is supplied in the general program rather than in the aircraft part.

Since the installed drag of a unit of ordnance must include store-to-rack interference and station-to-station interference, the average drag varies with aircraft type and with the particular loading. For simplification, an average value based on the fully loaded configuration is determined.

For the M117, average drag area is 0.42:

$$.54 \text{ Set } y = [1 = 117: 0.42]$$

A print-out of the final set of inputs for the F-4E is shown below.



Type part 99.

- 99.1 Set  $W=62000$ .
- 99.12 Set  $M=31201$ .
- 99.14 Set  $I=12896$ .
- 99.15 Set  $F=.063$ .
- 99.2 Set  $V=1825$ .
- 99.24 Set  $P(1)=.983$ .
- 99.25 Set  $D=[c(1)=1:1090;c(1)=2:133;c(1)=3:1650;c(1)=4:437]$ .
- 99.4 Set  $Q=[l=117:44.5;l=7:121;35.3]$ .
- 99.41 Set  $v=1014+1820$ .
- 99.42 Set  $U=[l=117:.18;l=7:.49;.143]$ .
- 99.43 Set  $O=1.46$ .
- 99.431 Set  $Z(2)=.1$ .
- 99.44 Set  $y=[l=117:.42;l=82:.11;l=821:.24;l=7:.33]$ .
- 99.45 To step 2.2 if  $Z(1)=1$ .
- 99.5 Set  $x=[n\leq 6:8710;7\leq n\leq 12:6305;13\leq n\leq 18:3900;19\leq n\leq 24:0]$ .
- 99.51 Set  $x=[n=11:4810;12\leq n\leq 14:3900;n=15:2405;n\geq 16:0;x]$  if  $l=117$ .
- 99.52 Set  $x=[3\leq n\leq 4:6305;5\leq n\leq 6:3900;n=7:0;x]$  if  $l=7$ .
- 99.55 To step 7.17 if  $Z(1)=0$ .
- 99.56 Set  $x=[e=0:0;first(x=2405,3900,4810,6305,8710:x\geq 0)]$ .
- 99.6 Type " 82 821 117 7".
- 99.602 Type " 24 241 19 7".
- 99.61 Type "(0,100),(5,100),(20,100),(0,120),(100,100)".
- 99.620 Type "Combat: MRT h=0 set c(1)=4".
- 99.621 Type " MRT h=35 2".
- 99.622 Type " MAX h=0 3".
- 99.65 To step 6.7.
- 99.7 Set  $P(1)=1-4.706/10^{*4}\cdot h(1)\cdot(1+.03676\cdot(s+o+t))$  if  $h(1)<100$ .
- 99.701 Set  $R=1500+35\cdot s$ .
- 99.702 Set  $P(11)=1-.000471\cdot(1+.037\cdot s)\cdot\max[0,\min[35,h(4)]-h(11)]$ .
- 99.7021 Set  $V=580+.0067\cdot[w(2)-580]/[1-.273\cdot(1+(s+o+t)/9.3)]$  if  $c(10)=1$ .
- 99.7022 Set  $D=1000\cdot(60-h(11))\cdot[.01609+3.21\cdot h(11)^2/10^{*7}]$  if  $c(10)=1$ .
- 99.712 Set  $K(0,100)=1.494$ .
- 99.713 Set  $J(0,100)=.688$ .
- 99.714 Set  $A(0,100)=.0381$ .
- 99.722 Set  $K(5,100)=2.579$ .
- 99.723 Set  $J(5,100)=.6475$ .
- 99.724 Set  $A(5,100)=.0394$ .
- 99.732 Set  $K(20,100)=26.63$ .
- 99.733 Set  $J(20,100)=.4595$ .
- 99.734 Set  $A(20,100)=.0442$ .
- 99.772 Set  $K(0,120)=.0225$ .
- 99.773 Set  $J(0,120)=1$ .
- 99.774 Set  $A(0,120)=.01178$ .
- 99.782 Set  $K(100,100)=3834$ .
- 99.783 Set  $J(100,100)=.0126$ .
- 99.784 Set  $A(100,100)=.0503$ .
- 99.84 To step 2.87 if  $Z(1)=1$ .
- 99.85 To step 7.466.
- 99.9 Set  $F(1)=[h(10)=0:91.7;h(10)=30:80;91.7/\exp[.0026\cdot h(10)]]$ .
- 99.91 Set  $E(2)=1.1619$ .
- 99.92 Set  $E(1)=F(1)\cdot\exp[.03672\cdot(s+o)]/45000\cdot F(2)$ .
- 99.95 To step 7.6.

COMPUTATION PROCEDURE

The equations and the calculation sequence are provided by a combination of part 7 and a set of additional formulas, which, together, correspond to the step by step procedure described in Section IV, p. 23. These are shown below as printed by JOSS for the sake of completeness. However, it is normally unnecessary for the user to be concerned with this part of the program.

Type part 7.

- 7.17 To step 7.2.
- 7.2 Set  $C=1$  if  $c(10)=1$ .
- 7.21 To step 7.462 if  $Z(1)=1$ .
- 7.22 Set  $e=x$ .
- 7.23 Set  $w(2)=T+I+e+F \cdot x$ .
- 7.25 To step 7.45 if  $W \geq w(2)$ .
- 7.254 To step 7.37 if  $x=0$ .
- 7.26 Set  $w(21)=x$ .
- 7.265 Set  $w(2)=\min[w(2), W]$ .
- 7.27 Set  $e=\max[0, w(2)-I-T-F \cdot x]$ .
- 7.3 Do step  $Z(10)+.56$ .
- 7.32 To step 7.26 if  $x < w(21)$ .
- 7.34 To step 7.44 if  $e > .1 \cdot x$  and  $w(21) < e$  and  $e-w(21) > .1 \cdot (x-w(21))$ .
- 7.35 To step 7.44 if  $w(21) \geq e > .1 \cdot x$ .
- 7.36 Set  $x=w(21)$  if  $e > .1 \cdot x$  and  $w(21) < e \leq w(21) + .1 \cdot (x-w(21))$ .
- 7.364 Set  $x=0$  if  $e < .1 \cdot x$ .
- 7.37 Set  $I=\min[w(2), W]-T$  if  $x=0$ .
- 7.42 Set  $e=x$ .
- 7.44 Do step 7.23.
- 7.442 To step 7.265 if  $w(2) > W$ .
- 7.45 Set  $f=w(2)-T-F \cdot x$ .
- 7.46 Set  $t=.0025 \cdot x^{\#} \cdot 7$ .
- 7.462 Set  $o=n \cdot y+c(6) \cdot t$ .
- 7.464 Set  $s=n \cdot U+O+c(4) \cdot t$ .
- 7.465 To step  $Z(10)+.7$ .
- 7.466 Set  $w(4)=[Z(3)=0:[w(2)-V] \cdot P(1); w(2)]$ .
- 7.467 Set  $w(10)=M+R+n \cdot O+v+c(3) \cdot .05 \cdot f+c(4) \cdot F \cdot x$ .
- 7.468 Set  $t=.0013 \cdot (\max[0, x-w(2)+w(4)])^{\#} \cdot 7$  if  $c(4)=0$  and  $c(6)=0$ .
- 7.47 Set  $x=x \cdot (1-c(4)) \cdot (1-c(6))$ .
- 7.48 Set  $w(5)=[p=0:w(4)-F \cdot x; w(2)-e-F \cdot x]$ .
- 7.49 Set  $w(6)=[w(4)^{\#}h(1)-S(1) \cdot h(1)/f(1, s, o, t)]^{\#}[1/h(1)]$ .
- 7.492 Set  $w(6)=[w(5)^{\#}h(1)-(S(1)-p) \cdot b(1)/f(1, s, o, 0)]^{\#}(1/b(1))$  if  $S(1) > p$ .
- 7.494 Set  $w(9)=[S(4) \cdot h(4)/f(4, s, 0, 0)+w(10)^{\#}h(4)]^{\#}(1/b(4))$ .
- 7.5 Set  $C=\text{sqrt}[w(6) \cdot w(9)]$ .
- 7.54 To step  $Z(10)+.9$ .
- 7.6 Set  $S(2)=[p > 0; p+k; j]$  if  $P(2)=1$ .
- 7.62 Set  $S(2)=[p < S(1); i; o+k]$  if  $P(2) \neq 1$ .
- 7.7 Set  $C=\text{sqrt}[C \cdot R]$ .
- 7.8 To step 7.6 if  $|C-B|/B > .0001$ .
- 7.85 Set  $P(3)=a(2)/\exp[d(2) \cdot (s+o+t)] \cdot [w(6)^{\#}h(2)-(w(2)-e)^{\#}h(2)]/b(2)$ .
- 7.86 Set  $P(3)=[p \leq S(1); p; S(1)+P(3)]$ .
- 7.87 To step 2.91 if  $Z(1)=1$ .

Type all formulas.

B:  $[P(2)=4; X+[w(9)*b(3)+S(2)*b(3)/f(3,s,0,0)]^{1/b(3)}; N]$   
H:  $w(2)-[w(2)*b(1)-Z(3)*b(1)/g(1,s,o,t)]^{1/b(1)}$   
N:  $X+[(S(2)+Z(3))*b(3)/f(3,s,0,0)+w(9)*b(3)]^{1/b(3)}$   
T:  $M+n*u+n*O+v$   
X:  $n*u+C*D+C-r+(1-P(11))*(r-C*D-n*u)+c(5)*\max[0, r-w(5)]$   
a(i):  $K(h(i), m(i))$   
b(i):  $J(h(i), m(i))$   
d(i):  $A(h(i), m(i))$   
g(i,s,o,t):  $a(i)/\exp[d(i)*(s+o+t)]$   
j:  $g(2,s,o,0)*[w(6)*b(2)-C*b(2)]/b(2)$   
k:  $g(2,s,o,0)*[w(5)*b(2)-C*b(2)]/h(?)$   
p:  $\max[0, f(1,s,o,t)*[w(4)*b(1)-(w(2)-e)*b(1)]]/b(1)$   
q:  $g(2,s,o,t)*[w(6)*b(2)-(w(5)+F*x)*b(2)]/b(2)$   
r:  $[C*(1-E(2))-L*(1-E(2))*E(1)]^{1/(1-E(2))}$

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## IDENT CONTROL DATA

ORIGINATING ACTIVITY

THE RAND CORPORATION

2a. REPORT SECURITY CLASSIFICATION  
UNCLASSIFIED

2b. GROUP

## REPORT TITLE

AIRCRAFT COMBAT RADIUS CALCULATION PROCEDURE FOR VARIOUS MISSION PROFILES  
AND EXTERNAL-STORE CONFIGURATIONS

## 4. AUTHOR(S) (Last name, first name, initial)

Weber, C. M.

## 5. REPORT DATE

April 1969

## 6a. TOTAL No. OF PAGES

71

## 6b. No. OF REFS.

5

## 7. CONTRACT OR GRANT No.

F44620-67-C-0045

## 8. ORIGINATOR'S REPORT No.

RM-5948-PR

## 9a. AVAILABILITY/ LIMITATION NOTICES

DDC-1

## 9b. SPONSORING AGENCY

United States Air Force  
Project RAND

## 10. ABSTRACT

An extension and revision of the HARD-1 (Handy Approximate Radius Determination) combat radius calculation procedure described in RM-5280 for aircraft carrying external stores. ✓ HARD-3 calculates the radius capability for a particular aircraft having known climb and cruise performance, fuel consumption, drag, etc. The method is somewhat more complex than HARD-1 but it provides greater flexibility and improved accuracy: a wider choice in cruise conditions is now available, and the effect on radius of non-distance-gaining fuel allowances is computed more accurately. The computer program allows for variation in the disposition of empty fuel tanks and for target-bound refueling. Although designed specifically for a ground-attack mission, the procedure may be adapted for other missions. The results compare favorably with estimates made by following the mission-planning procedures described in military flight manuals. The JOSS program is included, along with a sample set of calculations and an explanation of the equations used. The program has not been adapted at Rand for use with any computer system other than JOSS, nor is such adaptation planned.

## 11. KEY WORDS