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COMPUTER SIZING OF FIGHTER AIRCRAFT

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SUMMARY

The computer sizing technique has been applied to a number of military mission profiles. Performance data can be determined for all segments of the selected profile, which typically include takeoff, climb, cruise, loiter, reserve and landing segments. Options are available for detailed calculation of combat performance and energy-maneuverability characteristics. Configuration changes, such as external fuel tank drop and weapon expenditure, can be included in the mission. In the sizing mode, aircraft gross weight, wing loading, and thrust-to-weight ratio are varied automatically to determine which combinations meet the design mission radius. The resulting performance data can be used to create a "thumbprint plot." This plot is useful in determining the configuration size that best satisfies the mission and performance requirements. The sizing mode can also be used to perform parametric studies such as sensitivity of gross weight to alternate design conditions.

INTRODUCTION

In the preliminary design of a fighter aircraft, many possibilities must be examined in order to identify optimal configurations. Computers provide a fast and inexpensive method of performing these tasks. Certain aspects of the design process, such as performance analysis, can be assembled in a computer program. The computer then can perform very rapid repetitive calculations, varying certain parameters until an optimum combination of these parameters has been identified.

Reference 1 describes the development of a computer technique for determining the mission radius and maneuverability characteristics of fighter aircraft. This technique was applicable primarily to point designs. The computer program described in the reference 1 has been modified to include a number of new capabilities. One of these is an automated preliminary sizing option. In this mode, starting with a well defined baseline configuration, the program will automatically determine the combinations of aircraft gross weight, wing loading (W/S), and thrust-to-weight ratio (T/W) that meet a required mission radius. For each of these combinations, additional performance items, such as takeoff and landing field length and maneuverability characteristics are determined. This data is used to create a "thumbprint" plot. This plot is used, in turn, to determine the configuration size in terms of Takeoff Gross Weight (TOGW), W/S, and T/W that best meets all the mission performance constraints. This method permits rapid identification of an optimum configuration size.

The purpose of this paper is to describe the performance program and the development of the new sizing capability. Included are descriptions of the military mission profiles the program can represent and the methods used to calculate the performance data. The use of the sizing technique to define an optimum configuration size and the determination of additional performance data for the sized configuration is also described. The discussion is illustrated through examples taken from a conceptual design study performed at the NASA Langley Research Center.

Reference 1 provides a detailed description of the methods and assumptions used in the fighter mission performance program. The logic in that program forms the core of the new sizing option; therefore, some details of the performance program will be presented before the sizing logic is described.

SYMBOLS

ESF	engine sizing factor
h	altitude
M	Mach number
Maximum power	engine maximum augmented power setting
Military power	engine maximum nonaugmented power setting
S	wing area
T/W	aircraft thrust-weight ratio
TOGW	takeoff gross weight
W/S	aircraft wing loading

DESCRIPTION OF THE PROGRAM

All military missions have similar segments such as takeoff climb, cruise, and reserves. This fact led to adapting a modular approach to computing the mission performance. In this approach, each mission module is an executive routine that controls the calculation of the performance data for the segments of the profile it represents. This performance data is calculated in other specialized modules which represent particular segments. If the performance in a segment is known to be sensitive to aircraft weight, that segment module will automatically calculate the performance for a series of weights that might be encountered during the mission. The performance as a function of weight is stored and later interpolated in the mission module based on the actual weight during a particular segment. In this way, as the segment weight changes while the inbound and outbound mission radii are being balanced, the performance data does not have to be recomputed.

In the following sections, the segment modules are described. Where performance examples are provided, they are taken from the conceptual design for a supersonic cruise fighter studied at the Langley Research Center. This concept is a blended wing body design incorporating advanced aerodynamics and engines.

Segment Data Modules

Takeoff.- Takeoff performance is determined using a method similar to that described in reference 2. The program of that reference has been simplifed and adapted to this program. The technique employed involves a stepwise iteration technique to solve the airplane equations of motion during the takeoff roll. The takeoff distance and velocity are determined during this calculation. Takeoff performance can include the effects of high-lift devices, vectored thrust, gear drag, ground proximity, and hot-day conditions.

In addition to calculating the takeoff distance, this module also determines the takeoff fuel allowance. This allowance may be specified in one of two ways. The first is a fixed weight of fuel or a fraction of the takeoff gross weight. The second consists of a specified number of minutes of engine operation at one or two power settings corresponding to maximum nonaugmented and maximum augmented power. A set of program inputs identifies the option to use and specifies the requirements. For the design used as an example herein, the fuel allowance consists of 2 minutes at maximum nonaugmented power plus 1 minute at maximum augmented power.

Climb Segment.- Climb and acceleration performance is computed along a specified Mach number/altitude climb path. This path is developed outside of the program and is selected to provide optimum climb performance within the constraints of the mission and airframe limitations. The performance along this climb path is determined by an approximate solution to the airplane equations of motion developed in references 3 and 4. The solution involves an iterative procedure to determine the change in weight corresponding to the fuel burned between two successive points on the climb profile. Once the weight change is balanced, the corresponding range and time increments are determined. This climb and acceleration phase continues until the cruise Mach number is reached. The iterative climb procedure then continues until the start-of-cruise altitude is reached. This altitude is determined by solving the Brequet range equation (ref. 3) for the weight change associated with a specified range. The program computes the Brequet factor for each altitude step and selects the altitude which results in the lowest total fuel consumption from the start of climb to the end of cruise. This method produces a saving in climb fuel for short-range missions, and it is almost equivalent to the method of cruise at best Brequet factor for long-range missions.

Cruise Segment.- The important parameters for the cruise segment are computed during the search for the start of cruise altitude. Once this altitude is determined, the corresponding cruise parameters are known. The cruise segments are calculated using the Brequet range equation. The Brequet factor is based on the weight at start of cruise. For long-range cruise segments, the Brequet factor is an average of the values at the start and end of cruise. For missions which carry external stores or fuel tanks, the program automatically calculates an increment in the Brequet factor corresponding to the drag penalty of these items. If the stores are expended or the tanks dropped, the appropriate increment is added to the cruise Brequet factor to reflect the change in performance due to this configuration change.

Combat Segment.- Military missions include a wide variety of specifications for the combat fuel allowance. One of the important features of this program is the number options available to handle this variety of allowances. These options are:

Specific energy: In this option, the combat fuel allowance is the amount of fuel required to raise the aircraft's specific energy by a required amount.

Specified Mach Number, Altitude, and Power Setting: Here, the combat allowance is the amount of fuel required to operate the aircraft's engine at a specified Mach number, altitude, and power setting for a required number of minutes.

Acceleration: The combat fuel allowance in this option consists of the fuel required to accelerate the aircraft between two Mach numbers at a specified altitude. Acceleration performance is computed using an iteration technique similar to that of the climb segment.

Maneuver: This option provides for the calculation of the fuel required to execute sustained turn maneuvers. Two separate maneuvers may be included in the combat allowance. Each may take place at a different combination of Mach number and altitude and consist of a different number of turns.

Combinations of these combat allowances are possible. There are also options to control the aircraft weight at which the combat performance is computed. For the example in this report, the combat allowance included three sustained turns at a Mach number of 2.0 and an altitude of 40,000 feet.

Loiter Segment.- Loiter is defined as steady flight at a fixed altitude for a specified period of time. The loiter module determines the Mach number for minimum fuel flow at the specified altitude. The loiter segment fuel is that fuel flow multiplied by the required loiter time. Loiter segments can be included as part of the main mission or as part of the reserve segment. The mission for the concept in this report includes loiter in the reserve segment.

Dash Segment.- A dash or low level penetration is essentially flight at a constant Mach number and altitude. These flight conditions are specified in the mission requirements. The dash segment module computes the aircraft's specific range factor corresponding to these conditions. The mission module uses this parameter to determine the fuel used during a dash of the required length. It should be noted that both the loiter fuel flow and the dash specific range factor are very strong functions of aircraft weight. When this segment data is interpolated by the mission module, an average segment weight is used.

Descent Segment.- There are two options for this segment. The first consists of specified increments for range, weight, and time during the descent. The second option uses a stepwise iteration technique, similar to that of the climb segment, to determine these increments as the aircraft flies a fixed Mach number/altitude descent path. The example in this report uses the second option to descend from the cruise Mach number and altitude to M = .85 at sea level.

Reserve Segment.- The reserve fuel allowance for a military mission may be specified in a number of ways. For this reason, there are six options for the reserve segment. These are listed in Table 1 which is self explanatory. These options may be combined in any order required by a mission definition. For the example, a loiter time of 20 minutes at M = .4 at sea level (Option 5) is specified.

Landing Segment.- The principal output of the landing segment module is the landing ground-roll distance. A combination time and velocity step iteration scheme is used to solve the airplane equations of motion as the aircraft slows from the touchdown velocity to a stop. The touchdown velocity is determined from the approach conditions by balancing the equation of motion along a constant angle glide from the obstacle. The landing performance can include effects of approach velocity, glide slope angle, thrust reversing, braking, and lift spoiling devices. The concept studied in this report includes a thrust reverser so as to attain a landing roll of less than 1000 feet.

MISSION PROFILE MODULES

The program contains five different mission modules, each representing a different military mission (Table 2). The mission modules use the previously described segment modules to assemble the appropriate mission segments and to determine the maximum mission radius or range. All radius type missions are balanced; i.e., the total outbound radius equals the total inbound radius. For each mission module, a description of the special features and options of the profile, a schematic diagram, and a table describing the mission segments will be given.

All of the missions, with the exception of the long-range penetration mission (Profile 4), have similar logic to control external fuel tank drop. If tanks are carried, they are dropped when empty during the outbound cruise segment. There are two possible exceptions to this. If the takeoff and climb segments use more fuel than carried externally, the tanks are dropped at the start of cruise. Alternately, if there is fuel remaining in the tanks at the end of the cruise segment, this excess fuel is dropped along with the tanks. The program output provides an indication of this condition. The tanks can also be retained until the end of the mission.

In addition to computing the overall mission performance, each module controls the calculation of two special performance items. The first of these is the time and fuel required for a level acceleration following a required Mach number schedule. The second item involves maneuverability parameters. For a required combination of Mach number, altitude, and power setting, the program will compute the aircraft's maximum instantaneous specific power and maximum sustained load factor and turn rate. These parameters are important in comparing performance of fighter designs. Certain acceleration and maneuver performance is usually part of the mission specifications.

Mission Profile 1 - Air Superiority/Interdiction

The first mission module represents an air superiority or interdiction profile and includes a low-level dash segment. This profile is shown schematically in Table 3. Normally, both the cruise and dash radii are balanced independently. There is an option in this module for eliminating the return dash and starting the climb to return cruise altitude immediately following the combat segment.

Mission Profile 2 - Fleet Air Defense/Fighter Escort

The second mission module is perhaps the most flexible in that it can actually represent three different missions. The profile shown in Table 4 includes all of the possible segments. A fighter escort mission would include a low-altitude combat and a return climb segment. A loiter segment at the combat station is a primary feature of a fleet air defense mission. An intercept profile would have a combat segment at the end of the outbound cruise.

A new capability being developed for this module will allow the return cruise segment to be performed at a Mach number different from the outbound cruise. This will be useful for missions which require that only the outbound segment be supersonic. This capability is being evaluated as an option for all radius mission modules.

Mission Profile 3 - Supersonic Penetration

The third mission module represents a supersonic penetration profile. It features two range segments, a subsonic cruise followed by a supersonic high-altitude cruise. The profile is shown schematically in Table 5 together with the descriptions of its segments. The climb to supersonic cruise altitude is treated by logic that calculates the intercept of a Mach number-altitude climb schedule, and then proceeds in the same manner as for the initial climb segment.

Mission Profile 4 - Long Range Penetration

The fourth mission module represents a long-range penetration profile. The profile is depicted in Table 6 together with descriptions of the segments. The dash segments can be conducted at different speeds and altitudes. This module is unique in that it permits the simulation of air-to-air refueling. The program determines the optimum fuel transfer range considering the basing requirements of both tanker and receiver. External fuel tanks, if carried, are retained until the end of the mission.

Mission Profile 5 - Long-Range Cruise

The fifth mission profile represents a long-range cruise or ferry mission. Table 7 shows this profile schematically and describes the mission segments.

SIZING LOGIC

The previous sections have described the performance prediction methods employed by the program. The new sizing option is a method of repeating these calculations for various combinations of aircraft TOGW, W/S and T/W in such a way as to provide information that will aid in identifying an optimum size for a configuration. The logic for this new option has been added to all the mission modules except the long-range penetration mission (Profile 4).

Before any sizing is done, a well-defined baseline configuration must be developed. The program does not synthesize any aerodynamic, propulsion, or weight data. This information must be contained in a detailed set of program inputs that is developed by configuration specialists. Another requirement for the sizing process is an array of values for wing loading and thrust-weight ratio that represent a range of combinations applicable to the configuration and mission being studied. With these inputs, the automatic sizing process can proceed. The program selects the first combination of W/S and T/W, and based on an initial estimate of takeoff gross weight, defines the configuration size as follows. TOGW and W/S are used to compute a wing area (S). The wing area is used to scale the drag coefficients of external stores and tanks (if carried). TOGW and T/W define an engine sizing factor (ESF), which is used to scale the propulsion data.

The values of TOGW, S, and ESF are then used to determine the aircraft operating empty weight (OEW) and available mission fuel. All of this information is used by the mission module to determine the maximum mission radius. This calculated radius is compared with the required radius. If a difference exists, a new estimate of TOGW is made and the process is repeated until the calculated and required radii are equal. Figure 1 shows the results of a sizing iteration. In this case, despite a very low initial guess for TOGW, only five iterations were needed to meet the required radius. The figure also shows how the first two estimates of TOGW are used to interpolate for the next value of TOGW. The aircraft is now sized for the design mission radius and its performance data is stored by the program for later use. The program then repeats the sizing process for the remaining combinations of W/S and T/W. The resulting program output is the size and performance data for a 25-element "matrix" of airplanes.

CONFIGURATION STUDY

The data generated by the above process is well suited for developing a "thumbprint plot" or performance map. The thumbprint plot takes a number of forms. Figure 2 shows a sample thumbprint for a conceptual configuration developed at Langley. The required mission is summarized in Table 8. The figure shows contours of constant gross weight on a grid of aircraft thrust-weight ratio and wing loading. Curves representing performance constraints are also shown. These constraints correspond to the performance requirements listed in Table 8. All of the aircraft above the constraint curves meet the design mission radius, and meet or exceed the performance requirements. The design point aircraft is the one with the minimum gross weight that meets all the mission requirements. This aircraft is indicated on the figure. It has a thrust to weight ratio of 1.05, a wing loading of 66.5, and a gross weight of 46,800 pounds.

Caution must be used if the design point varies far from the original baseline. The program does not generate new aerodynamics that reflect changes in the relative size of the wing, engines, and fuselage. If the design point is far from the baseline, a new baseline should be developed and the sizing process should be repeated.

The size and performance data generated during the sizing process can be used to investigate various trends. As an example, figure 3 shows the effect of thrust-weight ratio on takeoff gross weight for an aircraft with a fixed wing loading. This plot can be viewed as a vertical cross section through the thumbprint plot. Alternately, the sizing process can be repeated to establish trends due to changing mission requirements. This is demonstrated by figure 4 which shows the effect of required mission radius on takeoff gross weight.

Modern fighter aircraft are often called upon to perform dual roles, and it may be that there are two required missions for a particular configuration. A new capability currently being developed for this program will permit sizing a configuration for one mission and then computing the attainable radius on a second mission. The required radius for the second mission can then be plotted as a constraint curve on the performance map of the first mission. This is illustrated in figure 5 for the configuration of this report. The primary mission is the same as the one described previously. The secondary mission is a supersonic penetration mission (Profile 3). The mission groundrules are listed in Table 9. The performance requirements are the same as the primary mission. Fuel is carried in external tanks which are dropped when empty. The payload is dropped at the combat station. The 1000 nautical-mile radius constraint line is shown on the figure together with the performance constraints for the primary mission. In this particular case, the new constraint did not result in a change of the design point; however, the requirements of the second mission could force a change in the design point.

CONCLUDING REMARKS

A computer program has been developed for use in the preliminary sizing and performance analysis of fighter aircraft. The program can be used to identify the aircraft size in terms of takeoff gross weight, wing loading, and thrust-weight ratio that best satisfies a set of military mission requirements. The program can also be used to develop trend data and perform sensitivity studies.

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3. Perkins, Cortland D.; and Hage, Robert E.: Airplane Performance Stability and Control. John Wiley & Sons, Inc., c 1949, Chapter 4.

4. Jackson, Charlie M., Jr.: Estimation of Flight Performance with Closed Form Approximations to the Equations of Motion. NASA TR R-228, 1966.

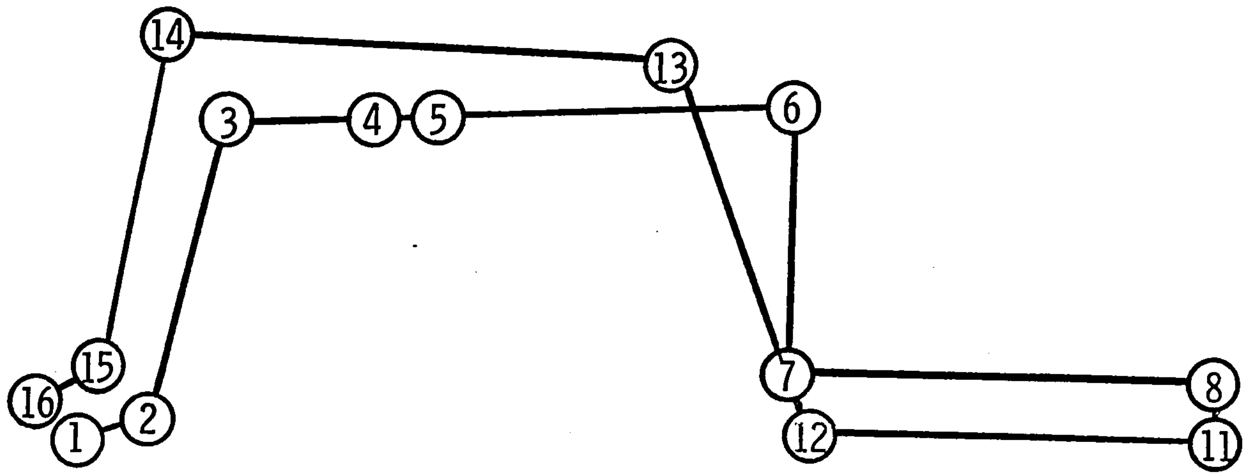
TABLE I.- RESERVE SEGMENT OPTIONS

OPTION	DESCRIPTION
1	Fixed weight of fuel
2	Fraction of internal fuel
3	Fraction of total fuel
4	Fraction of takeoff gross weight
5	Loiter at best loiter Mach number for a specified altitude and time
6	Time interval at military power plus time interval at maximum power

TABLE II.- MISSION PROFILES

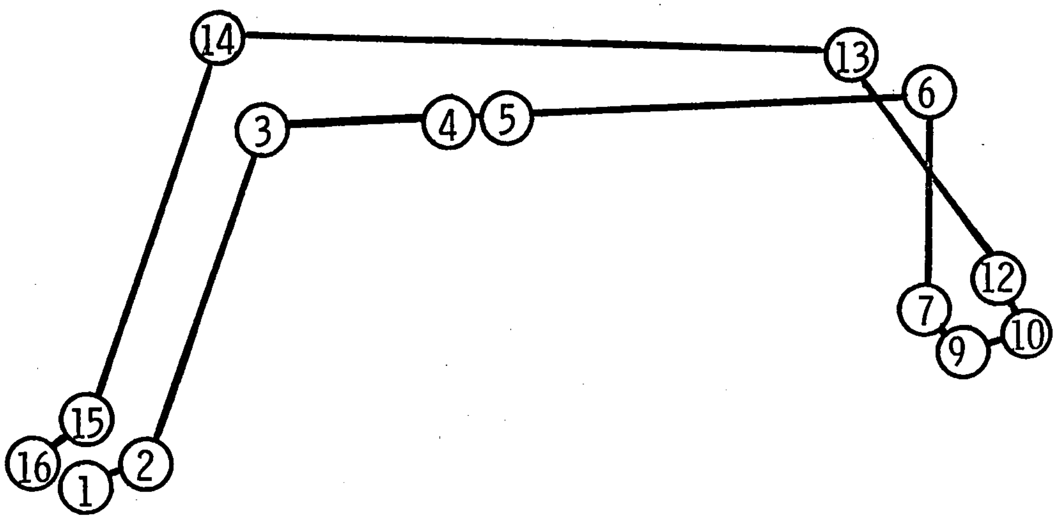
PROFILE	NAME
1	Air Superiority/Interdiction
2	Fleet Air Defense/Fighter Escort
3	Supersonic Penetration
4	Long Range Penetration
5	Long Range Cruise

TABLE III.- AIR SUPERIORITY MISSION PROFILE



PROFILE PTS.	DESCRIPTION
1-2	Takeoff fuel allowance
2-3	Accelerate and climb to start of cruise
3-4	Outbound cruise (with tanks if carried)
4-5	Drop tanks (if carried)
5-6	Continue cruise
6-7	Descend (no range credit)
7-8	Outbound dash
8-10	Weapon expended
10-11	Combat fuel allowance
11-12	Inbound dash
12-13	Accelerate and climb to cruise altitude
13-14	Return cruise
14-15	Descend (option for range credit)
15-16	Reserve fuel allowance

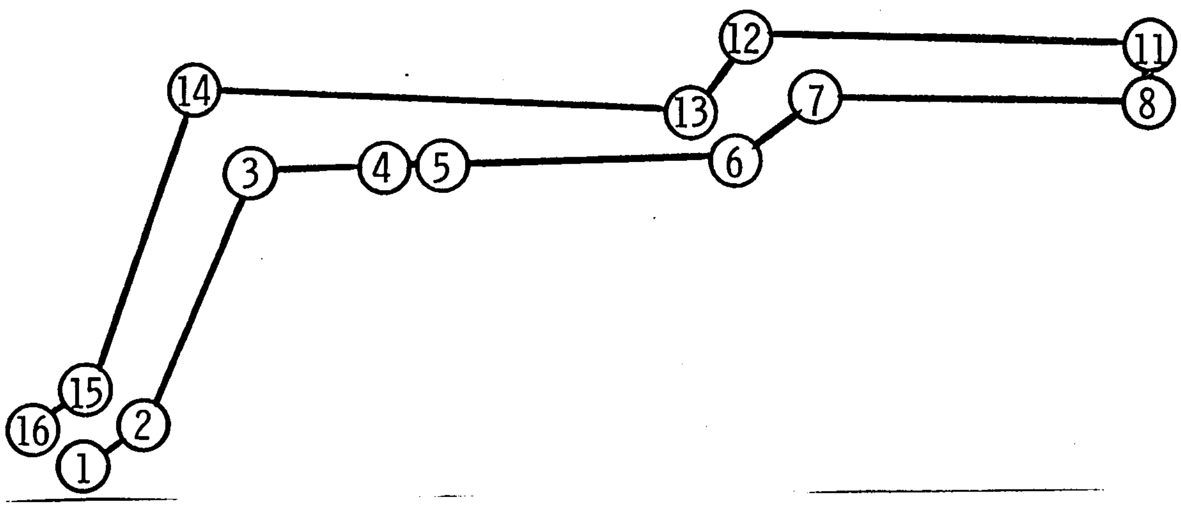
TABLE IV.- FIGHTER ESCORT MISSION PROFILE



PROFILE PTS.	DESCRIPTION
1-2	Takeoff Fuel Allowance
2-3	Accelerate and climb to start of cruise
3-4	Cruise with tanks (if carried)
4-5	Drop tanks
5-6	Continue cruise
6-7	Descend[1]
7-8	Loiter
8-10	Payload expended
11-12	Combat fuel allowance
12-13	Climb to return cruise altitude
13-14	Inbound cruise
14-15	Descend (option for range credit)
15-16	Reserve segment

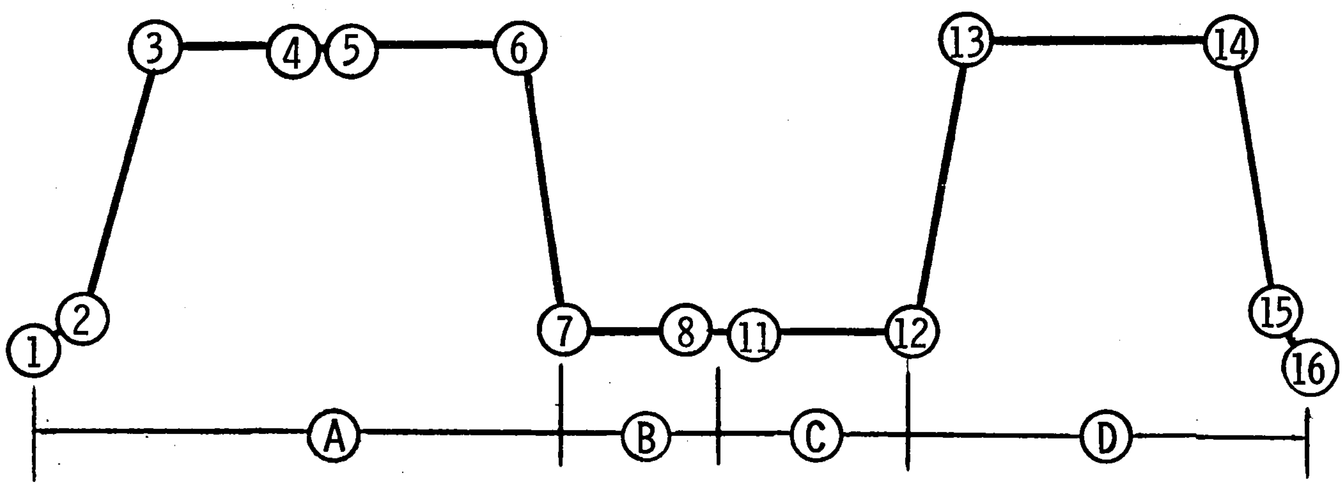
[1]Each of segments 6-13 can be excluded by mission definition

TABLE V.- SUPERSONIC PENETRATION MISSION PROFILE



PROFILE PTS.	DESCRIPTION
1-2	Takeoff fuel allowance
2-3	Accelerate and climb to subsonic cruise altitude
3-4	Outbound cruise (with tanks if carried)
4-5	Drop tanks (if carried)
5-6	Continue cruise
6-7	Accelerate and climb to supersonic cruise altitude
7-8	Supersonic cruise
8-10	Weapon expended
10-11	Combat fuel allowance
11-12	Return cruise (supersonic)
12-13	Decelerate and descend to subsonic cruise altitude
13-14	Return cruise (subsonic)
14-15	Descend (option for range credit)
15-16	Reserve fuel allowance

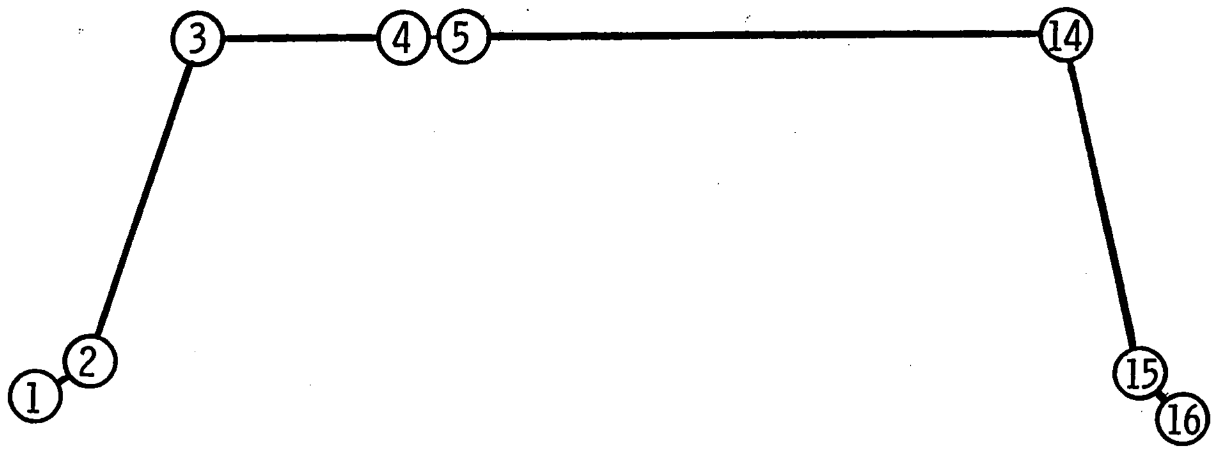
TABLE VI.- LONG-RANGE PENETRATION MISSION PROFILE



PROFILE PTS.	DESCRIPTION
1-2	Takeoff fuel allowance
2-3	Accelerate and climb to cruise altitude
3-4	Outbound cruise
4-5	Refuel
5-6	Continue cruise
6-7	Descend to dash altitude
7-8	Pre-target dash
8-11	Weapon expended
11-12	Post-target dash
12-13	Accelerate and climb to cruise altitude
13-14	Cruise
14-15	Descend (option for range credit)
15-16	Reserve fuel allowance

A, B, C and D are desired range increments

TABLE VII.- FERRY MISSION PROFILE



PROFILE PTS.	DESCRIPTION
1-2	Takeoff fuel allowance
2-3	Accelerate and climb to start of cruise
3-4	Cruise
4-5	Drop tanks[1]
5-6	Continue cruise
14-15	Descend (option for range credit)
15-16	Reserve segment

[1]Tanks may be retained until end of mission

TABLE VIII.- FIGHTER CONCEPT MISSION REQUIREMENTS

Supersonic Intercept Mission	
Takeoff Fuel Allowance:	2 minutes at military power plus 1 minute at maximum power
Cruise Mach Number:	2.0
Mission Radius:	500 nautical miles
Armament:	4 long range + 2 short range air-to-air missiles
Combat Allowance:	3 maximum power turns at Mach 2.0, 40,000 feet altitude
Transonic Acceleration:	(Mach 7 to 1.8, h = 40,000 feet) 1.25 minutes
Maximum Sustained Load Factor:	(Mach 2.0) 5g (at combat weight)
Takeoff and landing ground roll:	1000 feet
Reserves Fuel Allowance:	20 minute loiter at sea level

TABLE IX.- FIGHTER CONCEPT ALTERNATE MISSION

Supersonic Penetration Mission	
Subsonic Cruise Mach Number:	.85
Subsonic Cruise Radius:	500 nautical miles
Supersonic Cruise Mach Number:	20
Supersonic Cruise Radius:	500 nautical miles
Combat Fuel Allowance:	1.5 maximum power turns at Mach 2.0 40,000 feet altitude
External Fuel:	3 500 gallon tanks (dropped when empty)

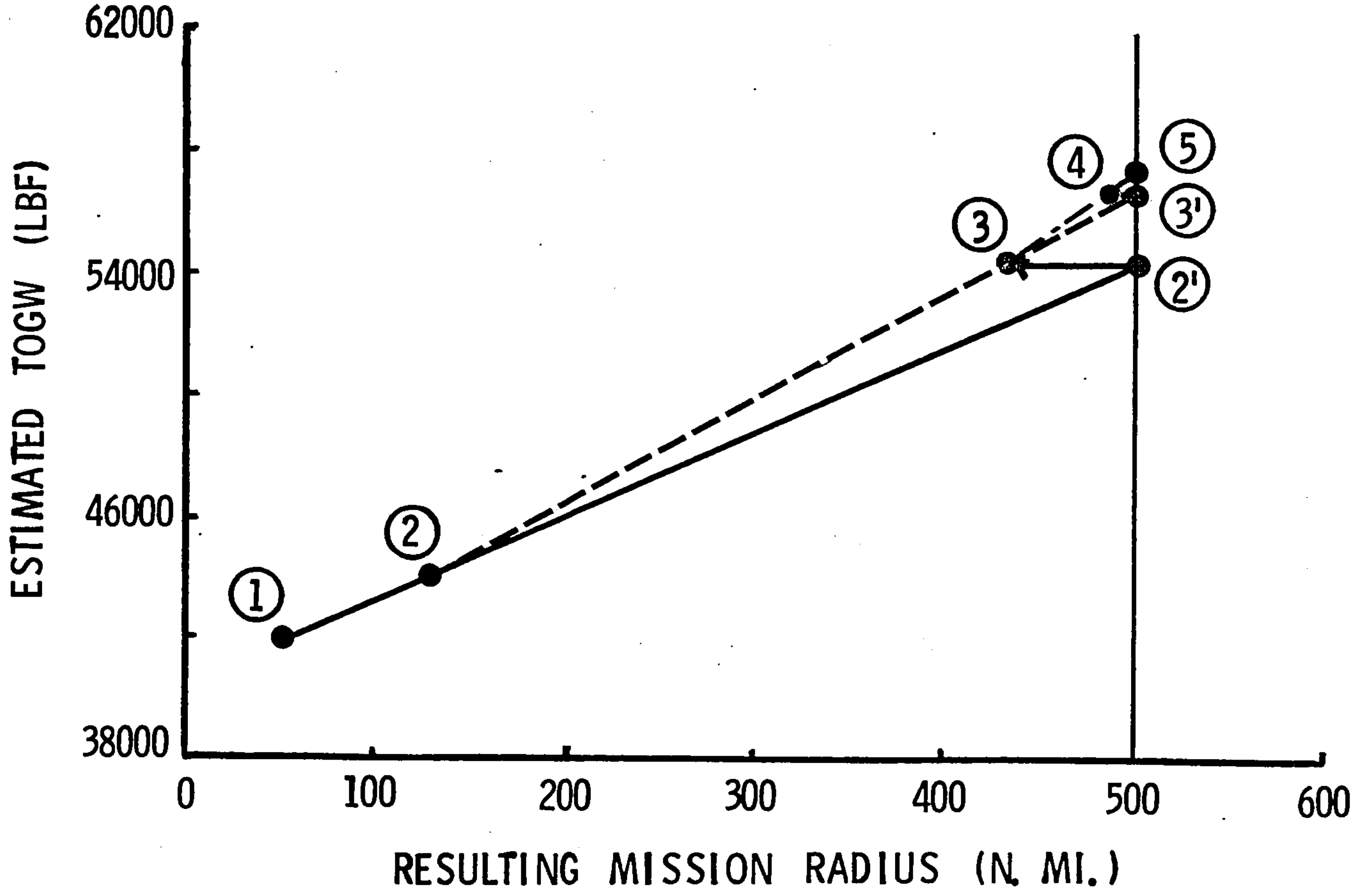


Figure 1.- Successive gross weight estimates for a sizing iteration.

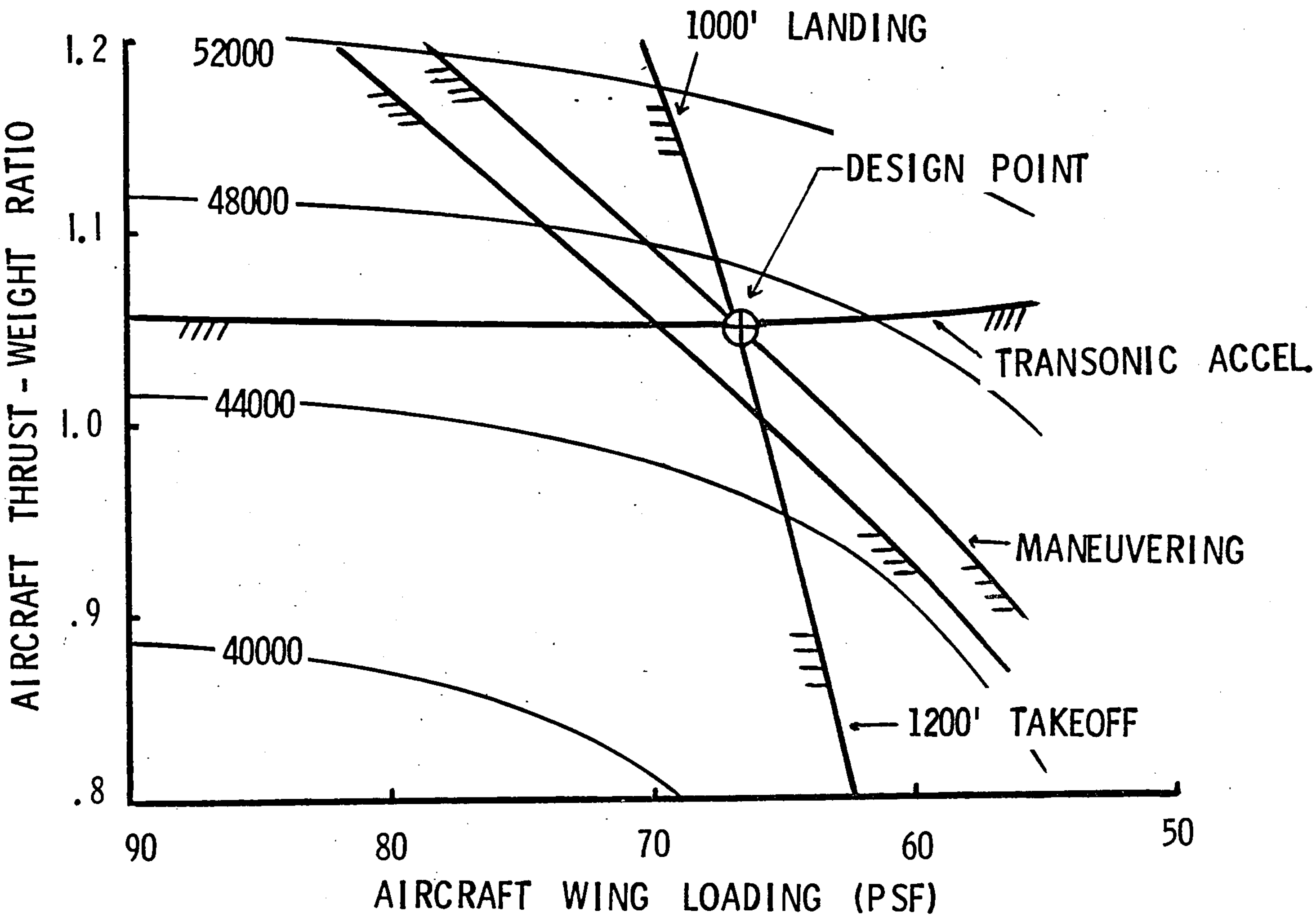


Figure 2.- Thumbprint plot for supersonic intercept mission.

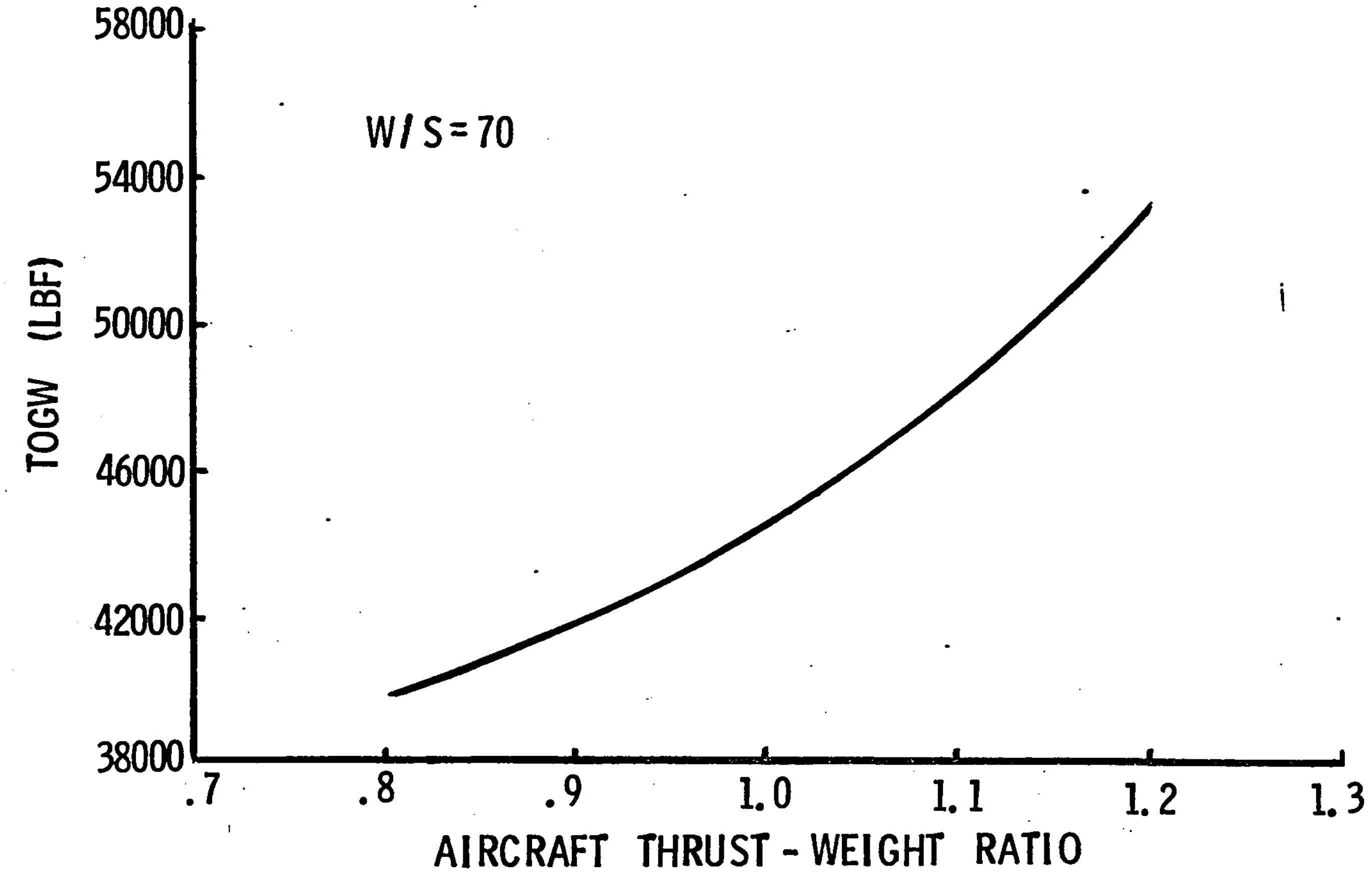


Figure 3.- Effect of thrust-weight ratio on takeoff gross weight.

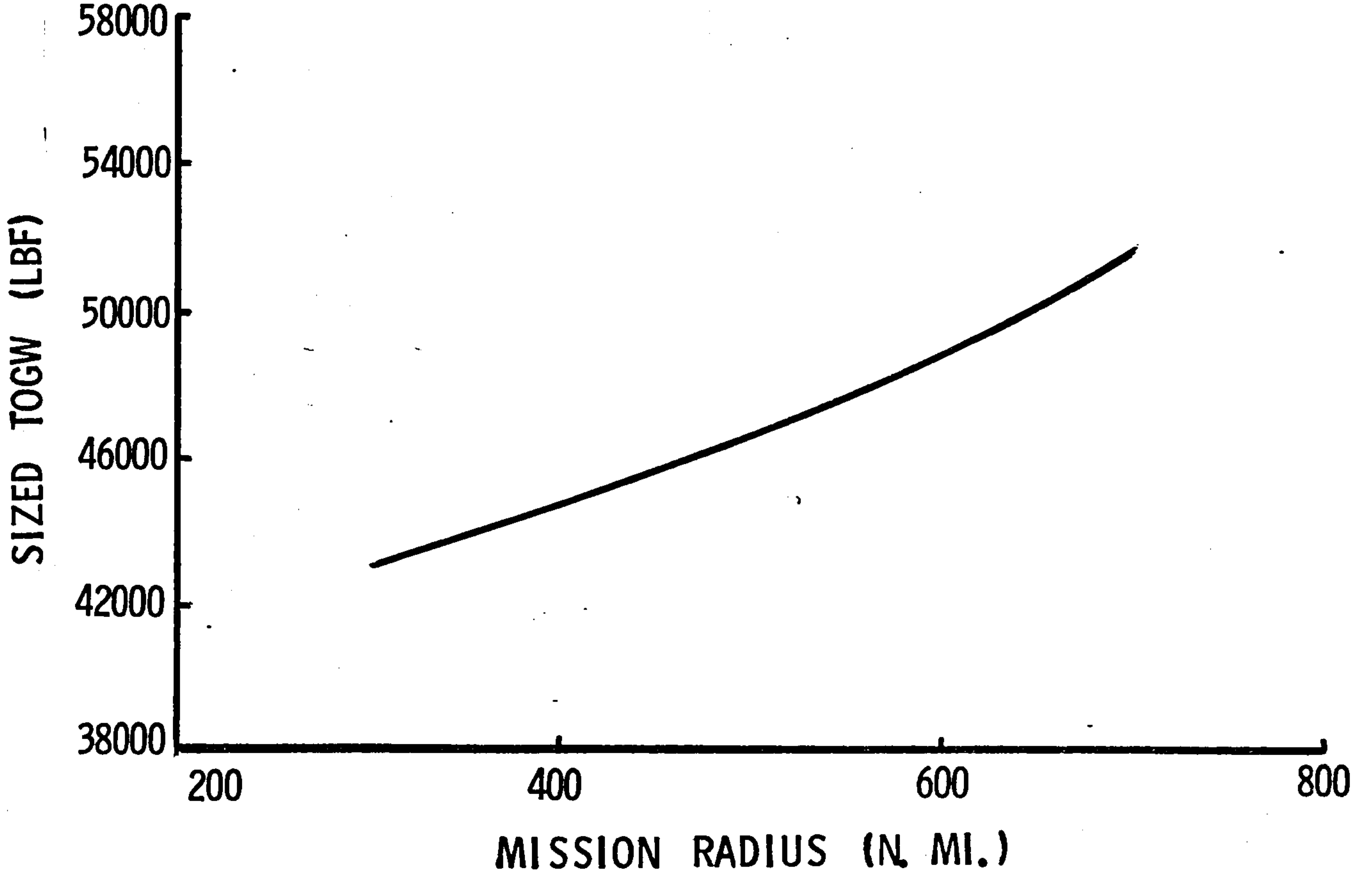


Figure 4.- Effect of required mission radius on sized takeoff gross weight.

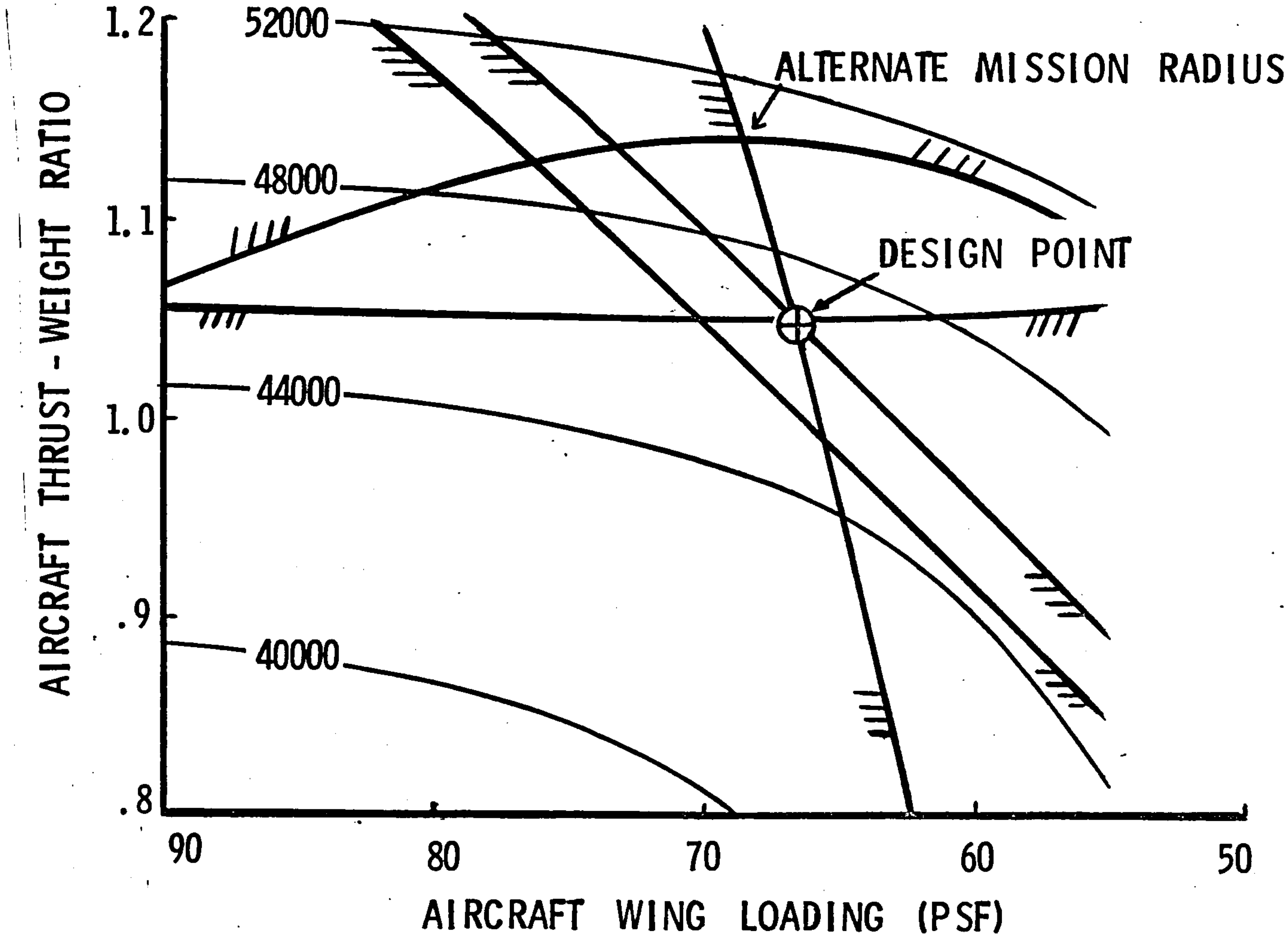


Figure 5.- Thumprint plot for supersonic penetration mission.

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16. Abstract

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