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PRELIMINARY SIZING AND PERFORMANCE EVALUATION OF SUPERSONIC CRUISE AIRCRAFT

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16. Abstract

The basic processes of a method that performs sizing operations on a baseline aircraft and determines their subsequent effects on aerodynamics, propulsion, weights, and mission performance are described. The input requirements of the associated computer program are defined and its output listings explained. Results obtained by applying the method to an advanced supersonic technology concept are discussed. These results include the effects of wing loading, thrust-to-weight ratio, and technology improvements on range performance, and possible gains in both range and payload capability that become available through growth versions of the baseline aircraft. In addition, the results from an in-depth contractual study that confirm the range gain predicted for a particular wing loading, thrust-to-weight ratio combination are also included.

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SUMMARY

A procedure that allows rapid, preliminary, evaluations of the effects of size changes on the characteristics and performance capability of supersonic cruise aircraft has been developed into a numerical computer program. The program performs operations on a baseline aircraft. Sizing options include changes in wing and engine size, gross weight, and number of passengers. During operations, the aircraft is sized, new aerodynamic, propulsion, and weight characteristics are determined, and a mission profile, including a reserve segment, is flown. For a given gross weight and payload, the aircraft's range, or its "thumbprint" can be found; or the gross weight can be found if range and payload are given.

The procedure has been applied to an advanced supersonic technology aircraft concept, the AST-100, and wing and engine size changes were found that potentially allow significant improvements in range or gross weight. This result was confirmed by an in-depth contractual study of the altered aircraft. Results from applications of the various options, and a description of program processes, are contained herein.

INTRODUCTION

An aircraft design is a grand compromise between many interacting variables, but whether or not the final compromise is near optimum depends, to a large extent, on the scope of design options covered during earlier design phases. With advancing technology, comprehensive preliminary design studies become even more important, yet detailed evaluation of each of the many design options is so expensive, in terms of manpower, cost, and elapsed time, that many potentially attractive possibilities may never be explored.

Extended coverage of many design options is possible, however, if rapid, economic, preliminary analysis of aircraft sizing and performance can be made. This capability offers several advantages. First, the preferred component sizing of an aircraft can be identified while considering all operational restrictions; second, growth versions of the aircraft, in terms of gross weight or passenger complement, can be evaluated simultaneously with the basic design; third, technology advances in structures, aerodynamics, propulsion, and systems can be realistically evaluated when their interactions are entered into the design compromises; and last, but probably most important, promising design options can be identified to provide a rational basis for detailed design team studies.

A computer program has been developed to provide this capability for use in the Vehicle Integration Branch of the Aeronautical Systems Division at Langley. The application of the program to an advanced supersonic cruise aircraft design is covered in the main text of this paper. The effects of trade-offs between wing loading and thrust-to-weight ratio on range performance is discussed and the program's application to design optimization is illustrated. Additional topics include a limited coverage of the effects of technology advances and the range capability of growth versions of the aircraft. A general description of processes used in the program is given in Appendix A, and input definitions and a description of output listings in Appendix B. For identification purposes, the program is called ASP - (A)ircraft, (S)izing, and (P)erformance program.

SYMBOLS

BF	Breguet factor, V(L/D)/SFC
C	centigrade
C_{DO}	minimum drag coefficient
D	drag
F_N	fuselage fineness ratio, length/maximum diameter
g	gravitational acceleration
GAL	gallon
H	altitude
L	lift
L/D	lift-drag ratio
M	Mach number
PAS	number of passengers
R	range
SFC	specific fuel consumption
t	time
T	thrust

T_{MAX}	maximum available thrust at a given altitude and Mach number
T/W	thrust to weight ratio, installed sea level thrust/aircraft gross weight
V	velocity
W	weight
W/S	wing loading, aircraft gross weight/reference area
α	angle of attack
θ	flight path angle
δ_f	flap deflection

Subscripts

BL	baseline
C	cruise
F	fuel
G	gross (as in gross weight, W_G)
MAX	maximum
N	nacelle
OPER	operating
SL	sea level

A dot over a symbol denotes its time derivative.

PRELIMINARY CONSIDERATIONS

At the present time, the ASP program (fig. 1) applies to supersonic, and particularly transport, aircraft. The program, described more fully in Appendix A, performs operations on a baseline aircraft for which detailed information already exists. Within the program, the baseline aircraft is sized according to optional input values of wing loading, thrust-to-weight ratio, number of passengers, and gross weight. Aerodynamic, propulsion, and weight characteristics of the sized aircraft are subsequently determined. Then a mission profile, including a reserve fuel leg, is flown to find the aircraft's range capability. Controlled, repetitive passes through these operations follow to satisfy one of three major input options: (1) the "thumbprint," a map of constant range contours as a function of wing loading and thrust-to-weight ratio; (2) the range for a given gross weight and payload; or (3) the gross weight for a given range and payload.

To illustrate the capabilities of the program, results from a preliminary sizing analysis of the AST-100 configuration, the baseline aircraft (fig. 2), are considered. Based on advanced supersonic technology, this aircraft concept cruises at a Mach number of 2.62 and carries 292 passengers over a range of about 4,000 nautical miles on a hot day (standard plus 8°C). Its takeoff gross weight is 718,000 pounds; its wing loading, 72 psf; and its engine, an in-house, advanced single spool, nonafterburning JP-4 fueled, turbojet with variable geometry turbine features. The engine is sized (T/W = .367) to meet takeoff noise restrictions and is larger than required from cruise considerations. A detailed description of the aircraft and its characteristics is reported in reference 1.

RESULTS AND DISCUSSION

Wing and Engine Sizing

A diagram useful in aircraft sizing studies, the thumbprint pinpoints the aircraft's wing and engine size for best range capability. The version used herein consists of constant range contours on a grid of thrust-to-weight ratio and wing loading, but a grid of maximum sea level engine airflow and wing area could be used equally as well. Also superimposed on this grid is a fuel limit contour along with contours of operational constraints. These generally include takeoff speed and field length, approach speeds, minimum thrust margins during climb and cruise, and takeoff noise. To provide this information, the program sizes and determines the characteristics of aircraft having various combinations of wing loading and thrust-to-weight ratio; then, from these results it develops the thumbprint. The results leading to the thumbprint are discussed in detail because they demonstrate program capabilities. Takeoff noise constraints, however, will not be shown. These are determined in a separate program.

In developing the thumbprint, the aircraft gross weight, passenger complement, and fuselage dimensions are held constant; but the wing loading is varied from 50 to 110 psf, and the thrust to weight ratio from .25 to .55 so that the baseline aircraft will occupy a median location. In comparison with the baseline aircraft, the sizing procedure gives reasonable planform arrangements at the extremes of these variables (fig. 3).

Aerodynamics.- Wing and engine size changes have a significant effect on the aircraft's minimum drag coefficient which, in turn, affects its maximum lift-to-drag ratio (fig. 4). Part of this effect is due to the "bookkeeping" scheme adopted herein in which the engine installation drag is included in the aerodynamic, rather than thrust, characteristics. C_{DO}, therefore, increases with T/W because installation drag, as well as nacelle friction drag, increases with engine size. C_{D0} decreases with decreasing W/S because both the fuselage and engine contributions decrease as the wing grows.

Weights.- The empty weight of the aircraft increase with wing and engine size (fig. 5) because of corresponding increases in structural weight and engine weight. Although mainly affected by wing size, structural weight also varies with T/W because the changing nacelle weights are included. As a result of these empty weight changes, the total fuel weight (at constant gross weight) is severely affected by both wing and engine size (fig. 6); and between the extreme wing and engine size combinations, the fuel weight varies by about 20 percent of the aircraft gross weight. Because of fuel limit restrictions, however, the aircraft with higher wing loadings may not be able to contain this fuel load. A precise definition of maximum fuel capacity is beyond the intended scope of this program. Still, some indication of the onset of fuel storage problems is required, and the fuel limit contour, included in figure 6, is intended to serve this purpose. The approximate method used to define the maximum fuel supply is discussed in Appendix A.

Takeoff and landing characteristics.- Takeoff and landing characteristics of the various aircraft are shown in figure 7. Takeoff speeds (fig. 7a), for the most part, simply respond to the larger lift that becomes available from increasing wing and flap area as wing loading decreases. T/W changes have negligible effect; aircraft with lower values simply take longer and go farther to reach the necessary velocity. Approach speeds (fig. 7b) behave similarly, but now, changes in T/W affect the results slightly because of differences in aircraft empty weight. In contrast, changing either lift (W/S) or acceleration (T/W) capability has a large effect on takeoff distances (fig. 7c).

Excess thrust.- The excess thrust available during climb and cruise is shown in figure 8 for the baseline aircraft and for aircraft with the extreme combinations of W/S and T/W. For the baseline aircraft, the minimum excess thrust during climb does not occur at transonic speeds, but rather when the aircraft reaches the cruise Mach number of 2.62. The excess thrust continues to drop as the aircraft climbs to optimum cruise altitude[1] at constant M and it reaches its minimum value at the end of cruise. Changing W/S or T/W does not affect this general trend. However, for W/S = 110 psf and T/W = .55, the aircraft is already at its best altitude for cruise when it reaches the cruise Mach number, but for W/S = 50 psf and T/W = .30, the aircraft has insufficient thrust to climb to its optimum cruise altitude. Instead, it seeks a lower altitude where a cruise at maximum power is possible. These departures from the nominal flight path are found to occur for many of the sized aircraft.

Minimum thrust margins for climb are shown in figure 9a. These thrust margins increase with engine size as expected, but at constant T/W, the reason for the nonlinear variation with wing loading is not as obvious. As indicated in figure 8, all of the minimum thrust margins during climb occur at the same altitude (57,700 ft.) and Mach number (2.62). At constant T/W, the maximum

[1] The optimum cruise altitude is found by a search, at constant Mach number, for the altitude where the Breguet factor, V(L/D)/SFC, is a maximum.

thrust available, T_{MAX}, is therefore constant. Under these conditions, the thrust margin should normally diminish with decreasing W/S because the drag increases as the wing grows; but at high W/S, induced drag increments are produced by the higher lift coefficients required by the smaller wings, and these induced drag increments decrease with W/S. These opposing effects cause a minimum drag (or thrust margin peak) to occur in the variation with W/S.

Behaving in a somewhat similar manner, the minimum thrust margins in cruise (fig. 9b) are generally lower than climb values; and at low T/W and W/S values, the thrust margin vanishes.

Cruise conditions.- Marginal thrust has a strong effect on the optimum cruise altitude and conditions at the start of cruise. The results for engine throttling, T/T_{MAX}, and altitude (figs. 10a and 10b) show clearly where marginal thrust conditions exist. As the thrust required for cruise approaches the maximum thrust available ($T/T_{MAX} \rightarrow 1$), aircraft with wing loadings of 80 and less at the lower thrust-to-weight ratios cannot attain their best cruise altitudes. This imposes severe limitations on cruise efficiency, especially for large wing/small engine combinations, where drastic reductions in L/D, from $(L/D)_{MAX}$, and high SFC associated with full power operation must prevail (figs. 10c and 10d).

Overall Mission Results

Fuel.- The fuel used during the various legs of the mission is shown in figure 11. Climb fuel decreases sharply as T/W increases (fig. 11a) because of the improved acceleration rates that become available. Reserve fuel requirements (fig. 11), however, increase with T/W because of increasing missed approach allowances (a function of takeoff fuel flow) and increasing SFC at cruise (due to reduced power requirements) during hold and diversion to the alternate airport. Conversely, reserve fuel requirements become less as wing size increases because the trip fuel allowance decreases and the larger wings improve cruise efficiency during the alternate airport and holding phases. Because of opposing trends in the total fuel (fig. 6), and the climb and reserve fuel, the fuel available for cruise becomes a maximum at different W/S-T/W combinations (fig. 11b).

Time and range.- Time and range results follow similar trends wherein small engines produce excessive climb times and ranges (fig. 12a), and maximums again occur in the cruise values (fig. 12b). Larger wings yield slower and longer descents (fig. 12c), but at large wing-small engine combinations, marginal thrust effects cause small, additional penalties in lower than normal descent ranges. Total trip time and range results (fig. 12d), show range and time peaks that do not occur at the same W/S-T/W combinations as those for the cruise values. This difference occurs because of the influence of increasing range and time with decreasing T/W during climb and descent.

Thumbprint.- All of the foregoing results are used to develop the thumbprint (fig. 13). The constant range contours pinpoint the best range at a wing loading of 110 psf and a thrust-to-weight ratio of .25. Because of the operational constraints, however, this aircraft and aircraft with many other W/S-T/W combinations are not acceptable. Neglecting the fuel limit and approach speeds, useable combinations are located in the quadrant bounded by a 200-knot takeoff speed, and a 10 percent thrust margin during cruise. The best combination then occurs at W/S = 85 psf and T/W = .31. It provides a range increment in excess of 400 nautical miles over the baseline aircraft.

Detailed design study.- Because this range increment was sufficiently attractive, the Advanced Aircraft Technology Group of the Vought Corporation, Hampton Technical Center, Hampton, Virginia, made a detailed study of the aircraft with this W/S-T/W combination. This aircraft, designated AST-102, was identical to the one sized herein, except for the inboard wing portions where wing thickness ratio had to be increased to gain additional fuel capacity and to allow for landing gear storage. The results of this study provide the opportunity to evaluate the capability of ASP. Comparisons of group weight results are, therefore, included in Table 1, and mission performance results in Table 2. Despite small detailed differences, the general agreement of the results is good. The comparison supports the implication that a large improvement in the AST-100 configuration can be obtained through wing and engine size changes and demonstrates the utility of the program for directing design improvements.

Instead of the range increment, noted above, this improvement could be reflected in a reduced aircraft gross weight (by about 62000 lbs.) to meet the 4000 nautical mile range requirement. Of course, either of these improvements can be realized only if some means other than engine oversizing can be used to meet takeoff noise retrictions. Coannular noise alleviation of variable-cycle engines now being studied (ref. 2) should substantially reduce the degree of engine oversizing that was necessary to meet noise requirements in the AST-100 study (ref. 1).

Sensitivity Results

Subsonic cruise segments.- The previous mission profile did not contain outbound or inbound, subsonic cruise options. Either, or both, of these segments may be required to avoid overland sonic booms. For the baseline aircraft, subsonic cruise legs reduce total range capability (fig. 14) because of lower cruise efficiency at subsonic speeds. With a 600 nautical mile, inbound subsonic cruise, the thumbprint (fig. 15) indicates range decrements for all W/S-T/W combinations; but the best combination - W/S = 85 psf, T/W = .31 - remains unchanged.

Transonic drag increases.- The effects of inaccuracies in the transonic drag were examined by applying transonic drag increases to the AST-100 aircraft with different engine sizes over a Mach number range from .9 to 1.4. The results (fig. 16) indicate that for the baseline engine, T/W = .367, large drag increases can be tolerated without appreciable range penalty. This leeway exists because the engine, which is oversized to meet takeoff noise limits, has sufficient excess thrust to overcome these drag increases with only slight increases in climb fuel; but as marginal thrust capability (with smaller engines) is approached, transonic drag increments will greatly increase climb time and fuel, and total range reductions can become intolerable.

Technology improvements.- The sensitivity of the range and gross weight of the AST-100 to changes in engine weight, specific fuel consumption, drag and structural weight, were also determined. The drag and SFC changes were applied over the entire mission profile. The results for constant gross weight (fig. 17a) and constant range (fig. 17b) indicate that drag and SFC are most sentitive, but these are followed closely by structural weight. Engine weight changes are not as significant because the baseline engine weight is a small percentage of gross weight.

Passenger and gross weight changes.- Different seating arrangements, to some extent, affect the aircraft's range performance because the resulting changes in fuselage length and fineness ratio alter the drag and structural weight. This effect is illustrated in figure 18 where gross weight required to produce a range of 4000 nautical miles with various numbers of passengers in different seating arrangements are shown, together with accompanying changes in fuselage length and fineness ratio. Preferred seating changes from 4 to 5 rows abreast at about the 250-300 passenger level, but the 6-abreast seating is not competitive because of high fuselage drag.

With the preferred number of rows abreast and with the wing loading and thrust-to-weight ratio held constant at baseline values, the total range available as gross weight and number of passengers change is shown in figure 19a. Over this matrix, because of the restriction of constant W/S and T/W, the size of both the wing and engine increase with gross weight. For a constant number of passengers, however, the weight of these components grows more slowly than the gross weight; and since the payload is constant, the fuel occupies a greater proportion of the aircraft's total weight as gross weight increases. For a constant passenger load, range improves with gross weight because the fuel mass fraction increases and L/D increases with increasing wing size.

If the payload mass fraction is held constant, however, the range tends to become constant at higher gross weights. This occurs because as the gross weight and passenger load increase along these contours, the increase in fuselage, wing, and engine weight result in a net loss in fuel mass fraction, but this is compensated for by aerodynamic and propulsion benefits that accrue with increasing wing and engine size. On the other hand, at the lowest gross weights, range decreases rapidly as a result of marginal thrust and the inability to operate near conditions of optimum cruise efficiency. Changes in W/S and T/W can improve the range-payload fraction relationship, but the general trend with gross weight and passenger level is the same (fig. 19b).

Energy considerations.- From energy considerations, additional fuel and increases in wing and engine size is not an efficient means for obtaining higher range capability at constant passenger level. The penalty (fig. 20) for carrying this additional weight results in poorer fuel utilization as gross weight increases. Apparently, the most efficient approach, from the fuel usage standpoint, is a low range, high passenger aircraft that makes intermediate stops to cover a given range. This approach, however, cannot be carried to extremely low ranges because at the low gross weights involved (at constant passenger level), fuel usage degrades again since most, or all, of the decreasing fuel supply is used during the climb segment. Although these results are interesting, fuel utilization, of course, is not necessarily the prime factor that affects the ultimate design. Other factors include economics and trip time considerations, and passenger preference for nonstop flights.

As a final remark, it should be noted that the results shown in figures 19 and 20 are primarily intended to demonstrate applications of the sizing and performance program. The subjects of range-payload and energy efficiency require a much broader coverage of variables including off-design missions before the trends reported here can be considered firm.

CONCLUDING REMARKS

A procedure has been developed to allow rapid, but preliminary, sizing and performance evaluations of baseline supersonic cruise aircraft. Sizing options include the wing (and control surfaces), engine, passenger complement, and gross weight. Applications to an advanced supersonic technology aircraft concept indicate that, if the takeoff noise requirements can be met by other means than engine oversizing, appreciable improvements in range, or gross weight, are available through wing and engine size changes. The confirmation of this result by an in-depth contractural study of the appropriately sized aircraft lends confidence in the ability of the program to direct design improvements.

APPENDIX A

AIRCRAFT SIZING AND PERFORMANCE PROGRAM

The basis of the program is set forth in this section through brief discussions of the procedures used in the major program elements. These include component sizing, propulsion, aerodynamics, weights, mission analysis, and major options. Before proceeding, it should be noted that, while the components of the sized aircraft have different relative positions than those of the baseline aircraft, these adjusted locations are not established by a weight and balance analysis. Also, although the program operates on input, trimmed aerodynamic data, no corrections are made to account for the trim changes that can result from component sizing.

COMPONENT SIZING

The baseline aircraft configuration requires geometric definition in sufficient detail to allow input in the zero-lift wave drag program format described in reference 3. To simplify drag calculations and passenger packaging, the input fuselage is approximated by an equivalent body of revolution consisting of identical fore- and afterbodies of Sears-Haack profile (ref. 4) and a cylindrical midsection. This midsection contains the passengers, doors, galleys, lavatories, and cargo, with space reserved for wing carry-through structure and landing gear (fig. 21). Variables that effect the length and diameter of the midsection are the seat width and pitch, aisle width, number of seats abreast, number of passengers, number and width of doors, galleys, and lavatories, and the cargo volume. These are optional input variables, and for this report, the seat width was 20 inches; the seat pitch, 34 inches; and the aisle width, 18 inches. The 7.3 foot wide door-galley-lavatory complex served at least 75 passengers. The cargo volume was taken as 4.5 cubic feet per passenger, plus 344 cubic feet for bulk cargo. The cargo was assumed to be stored in cargo containers which, according to calculations of typical cases, occupy 70 percent of the available volume. Normally, the cargo is located beneath the passenger compartment; however, if insufficient space is available, the excess cargo is stored in a full-depth section behind the passenger compartment with the midsection length increased accordingly.

In application, the midsection length and diameter are first calculated for the passenger requirements of the baseline aircraft. Then, from the length of the baseline aircraft fuselage, the length of the fore- and afterbodies and the fuselage fineness ratio are determined. If the number of passengers or the number of seats abreast for the sized aircraft differ from baseline values, the appropriate midsection length and diameter are calculated and the new fuselage length determined from this midsection length and the baseline fore- and afterbody lengths.

From the inputs for the baseline wing and control surfaces, definitive geometric properties are selected and then normalized by a representative wing dimension. During sizing, these surfaces are altered in a geometrically similar manner, and their size is a function of these nondimensional properties and wing loading. Surface locations on the fuselage are established by keeping their plan-area centroids at the same percent body length stations as baseline values. These positions are accepted so that program operations can continue only if no overlap of wing, horizontal tail, and/or canard occurs, and only if these surfaces can be contained within the fuselage length.

Engine nacelle length, L_N, and diameter, D_N, are sized by the installed, sea-level, static thrust, T_{SL}, in the following manner,

$$L_N = L_{N,BL} \, (T_{SL}/T_{SL,BL})^{N_L}$$

$$D_N = D_{N,BL} \, (T_{SL}/T_{SL,BL})^{.5}$$

where the subscript BL refers to baseline values and T_{SL}, of course, varies with the input thrust-to-weight ratio, T/W. The exponent N_L, which varies with engine concept, is an input; the value used herein was .438. Engine positions are established by maintaining the baseline lengthwise distances between wing trailing edge and engine exhaust plane, and by keeping the spanwise pod-to-pod, and pod-to-fuselage clearances constant percentages of the wing span.

For an approximate indication of the maximum fuel capacity of the sized aircraft, the fuel is assumed to be stored only in the exposed wing and in a small fuselage tank aft of the passenger compartment. The maximum wing-fuel volume, V_{F_W}, is given by

$$V_{F_W}/V_{W,EXP} = K_A + K_B \, V_{W,EXP}$$

where $V_{W,EXP}$ is the total volume of the exposed wing, K_A, a constant determined from baseline values of maximum wing-fuel volume, and $K_B = 7.16 \times 10^{-6}$, which was derived from wing-fuel volume studies performed by the Vought Corporation, Hampton Technical Center, Hampton, Virginia. The maximum fuel capacity is then found from V_{F_W} and the baseline body-fuel volume. Since it is comparatively small, the body-fuel volume is not altered during sizing.

PROPULSION

Detailed engine data (typical of company engine decks) must be generated prior to input. This data provides the baseline values for nacelle dimensions, installed engine gross thrust, ram drag, and fuel flow, and if they are not included in the gross thrust values, the installation drag items - spillage, bleed, bypass, and boattail drag. The gross thrust, ram drag, and fuel flow inputs contain the maximum augmented and/or nonaugmented values as functions of altitude and Mach number, and also part-power values as functions of Mach number alone. Gross thrust and ram drag are internally converted to net thrust, for either the maximum augmented or nonaugmented case (an input choice); after which the maximum net thrust, T_{MAX}, at each altitude and Mach number, the sea level static thrust T_{SL}, and the static pressure, P_A, yield values of the parameter, $T_{MAX}/T_{SL}/P_A$. Interpolated values of this parameter then provide the sized maximum thrust at any altitude and Mach number as a function of thrust-to-weight ratio and gross weight by

$$T = (T_{MAX}/T_{SL}/P_A)\ P_A(T/W)W_G$$

Maximum power fuel flows are given by

$$\dot{W}_{F_{MAX}} = \dot{W}_{F_{MAX,BL}}\ (T_{SL}/T_{SL,BL})$$

Part power net thrusts and fuel flows at each Mach number are normalized by corresponding maximum power values so that sized, part-power fuel flows can be obtained from

$$\dot{W}_F = (\dot{W}_F/\dot{W}_{F_{MAX}})\ \dot{W}_{F_{MAX}}$$

where $$(\dot{W}_F/\dot{W}_{F_{MAX}}) = F(T/T_{MAX}, M)$$

Engine installation drag items, input as a function of Mach number, are assumed to vary with engine size in proportion to the sea level static thrust.

AERODYNAMICS

The baseline aerodynamic inputs include the trimmed takeoff lift and drag coefficients with and without ground effects as functions of angle of attack and flap deflections, and both high speed trimmed lift-drag polars and zero-lift drag items as functions of Mach numbers. At each Mach number, the high speed polar data are solved to determine the minimum drag coefficient, C_{DO}, the drag due to lift factor, C_D/C_L^2, and the lift coefficient at minimum drag, C_{LO}. Total drag coefficients are then conveniently obtained as a function of lift coefficient, C_L, by the parabolic polar,

$$C_D = C_{DO} + (C_D/C_L^2)(C_L - C_L)^2$$

It is assumed that component size charges have no effect on C_D/C_L^2 and C_{LO}. Sized aircraft polars, therefore, have the same shapes as the baseline, but their drag coefficients differ because of sizing effects on C_{DO}.

The drag items that contribute to C_{DO} are wave drag, C_{DW}, friction drag, C_F, roughness drag, $C_{D,R}$, engine installation drag $C_{D,IN}$, air-conditioning drag, $C_{D,AC}$, and minimum induced drag, $C_{D,L}$. All but the last are assumed to be affected by sizing. The drag coefficients for roughness, air-conditioning, and engine installation vary with sizing by

$$C_{D,R} = (C_{D,R})_{BL} \; (S_{WET}/S_{REF})/(S_{WET}/S_{REF})_{BL}$$

$$C_{D,AC} = (C_{D,AC})_{BL} \; (N_{PAS}/S_{REF})/(N_{PAS}/S_{REF})_{BL}$$

$$C_{D,IN} = (C_{D,IN})_{BL} \; (T_{S,L}/S_{REF})/(T_{S,L}/S_{REF})_{BL}$$

where S_{WET} is the total aircraft wetted area; N_{PAS}, the number of passengers; $T_{S,L}$, the static sea level thrust; and S_{REF}, the aircraft reference area.

Friction Drag

The component skin friction coefficients are computed by the reference temperature method (ref. 5) using the turbulent flow constants given in reference 6, and the Prandtl-Schlichting formulation for incompressible, average skin friction (ref. 7). An input emissivity (herein taken as .8) is required for the iterative solution for wall temperature. While the fuselage and engine nacelles are treated as flat plates with corresponding total wetted areas and lengths, the wing and control surfaces are treated as a summation of strips with the strip mean aerodynamic chord serving as the local characteristic length. All surfaces are assumed to be at zero angle of attack. To allow for the variation, with component sizing, of more accurate baseline skin friction inputs, the aircraft total skin friction coefficients obtained from component summations are not used in their absolute sense. They are used, however, to increment baseline values by

$$C_F = C_{F,BL} \; (\overline{C_F}/\overline{C_{F,BL}})$$

where $C_{F,BL}$ is the baseline input, and $\overline{C_F}$ and $\overline{C_{F,BL}}$ are internally calculated values for the sized and baseline aircraft. During application, the sized aircraft skin friction coefficients are also corrected for the Mach number and altitude variations required by the mission flight schedule.

Wave Drag

Because of prohibitively long computing times, it was clearly beyond the intended scope of this program to include any of the available methods for finding component sizing effects on the wave drag. An approximate, but quick and simple, approach was therefore adopted. Like the skin friction, the results are used to increment baseline wave drag inputs. The approach treats the aircraft as a collection of isolated components, all exposed to free-stream conditions with component interference effects ignored. Since the wing and control surfaces vary in a geometrically similar manner and the aircraft reference area, S_{REF}, varies accordingly, the wave drag coefficients for these components are assumed to remain constant with changes in component size. Fuselage wave drag coefficients, however, do change with fuselage size. As mentioned previously, the fuselage is composed of identical fore- and afterbodies connected by a cylindrical midsection, and the fore- and afterbody are assumed to be the only contributors to fuselage wave drag. For these sections, a Sears-Haack profile was chosen which allows the fuselage wave drag coefficient to be obtained by (ref. 8)

$$C_{DW,F} = 24V\ (S_{MAX}/S_{REF})/L^3$$

where V, L, and S_{MAX} are total volume, length, and maximum cross-sectional area of the fore- and afterbody combination. For engine size changes, the wave drag coefficient of the nacelles is held constant and equal to the baseline values. These were precomputed, as a function of Mach number, using an isolated nacelle and the method of reference 2. Then, with other wing sizes, the nacelle wave drag coefficient, $C_{DW,N}$, is given by

$$C_{DW,N} = (C_{DW,N})_{BL}\ S_{REF,BL}/S_{REF}$$

With these assumptions, the wave drag for the sized aircraft is obtained simply from

$$C_{DW} = (C_{DW})_{BL} + C_{DW,F} - (C_{DW,F})_{BL} + C_{DW,N} - (C_{DW,N})_{BL}$$

Where $(C_{DW})_{BL}$ is the input wave drag coefficient for the baseline aircraft, and $C_{DW,F}$ and $(C_{DW,F})_{BL}$, the internally calculated fuselage wave drag coefficients for the sized, and baseline, aircraft respectively.

To evaluate this simple approach, its results are compared with results from the zero-lift wave drag program (ref. 2) in figure 22 for a range of wing loading and thrust-to-weight ratio variations on the baseline AST-100 configuration. Over the bulk of this matrix, the two methods agree within one to two drag counts, with the discrepancy approaching five counts at the extremes. For the most part, the effects of these discrepancies on total aircraft range (fig. 23) were found to be small; and, since the trends with wing loading and thrust-to-weight ratio are realistically predicted, the simple approach was accepted as adequate for most applications. If desired, however, this approach can be bypassed and provisions are made for an input matrix of precalculated wave drag coefficients.

WEIGHTS

The weight inputs for the baseline aircraft require detailed listings of component structural weights, propulsion system weights, system and equipment weights, and crew and passenger related weights. These inputs are used to determine constants of proportionality which are subsequently combined with appropriate sizing parameters to obtain the weight breakdown for the sized aircraft. In most cases these weights replace, rather than increment, the baseline weights.

The wing weight is found from

$$W_W = K_1 + K_2 X$$

where

$$X = K_3 \left[(F_L W_G)^{K_4} (b)^{K_5} \gamma (1 - W_R/W_G)^{K_6} (1 + \lambda)^{K_7} \right] / (t/c)^{K_8}$$

and

$$\lambda = 1 + K_9 (\bar{\Lambda})^{K_{10}}$$

in which F_L is the load factor; W_G, the gross weight; b, the wing span; $\bar{\Lambda}$, the average of the leading and trailing edge sweep angles; W_R, the wing weight relief items, including wing fuel, and landing gear, engine, and nacelle weights; λ, the wingtip chord to root chord ratio; and t/c, the average wing thickness to chord ratio. The equation was obtained from a proprietary industry study; the constants, K_N, therefore, are unidentified. Calculated for both the baseline wing and sized wing, these weight results are used to increment the baseline wing weight.

The fuselage weight is assumed to be proportional to the quantity, $(F_L W_G F_{SWET})^{.6}$, wherein F_{SWET} is the fuselage wetted area. This relation was taken from a Vought Corporation equation used in the AST-100 study (ref. 1).

For other structural weight items, control surface weights are proportional to their wetted areas, and the landing gear weight is proportional to aircraft gross weight.

The weights of the major items in the propulsion system - engines, nacelles, thrust reversers, and noise suppressors - are given by equations of the form

$$W_I = W_{I,BL} (T_{SL}/T_{SL,BL})^{N_W}$$

Subscript i refers to the item in question and N_W is the engine weight sizing input (present value, 1.08). Because of their generally small values, the remaining miscellaneous weight items in the propulsive system are held constant and equal to baseline values.

Items in the systems and equipment weights, and crew and passenger related weights, are again found from simple proportional equations. Surface control and hydraulic system weights are proportional to total surface control area; electrical, instrumentation, avionics, and auxiliary power weights, to aircraft gross weight; furnishings and equipment, air conditioning, passenger service, cargo and cargo containers, passengers and baggage weights, to the number of passengers; flight and cabin crew weights, to the number of crew members; and unusable fuel weight, to total fuel weight. Fuel weight, of course, is the difference between aircraft gross weight and the sum of all weight items.

MISSION PERFORMANCE

When the aerodynamic, propulsion, and usable fuel characteristics are known, a mission analysis for the sized aircraft is made to determine its range performance. The mission profile includes the following legs: takeoff, climb to outbound subsonic cruise, subsonic cruise, climb to supersonic cruise, supersonic cruise, descent to inbound subsonic cruise, subsonic cruise, descent to Mach number .5, and reserves. The inbound and/or outbound subsonic cruise legs can be deleted. At the present time, no attempt is made to optimize climb paths for sized aircraft, which follow instead, the specified altitude-Mach number schedule for the baseline aircraft.

Starting from zero velocity with maximum power and with takeoff aerodynamics including ground effects, the ground run is found from an iterative solution which uses specified values of aircraft rotational speed, takeoff angle-of-attack, and flap deflection to find the velocity for start of rotation that allows the takeoff angle-of-attack to be reached at the takeoff velocity, V_{TO} , for lift-weight equivalence. The aircraft then begins its climb holding the takeoff angle-of-attack constant. After "lift-off" the takeoff aerodynamics are corrected for landing gear retraction, over a specified time interval, and for the diminishing influence of the ground effect, over a specified altitude interval. These corrections are assumed to be linear over their respective intervals. As an approximation to an "engine out" contingency, the takeoff field length is assumed to be 15 percent greater than the horizontal distance covered when the aircraft attains a 35 feet altitude. After this point, the aircraft continues its climb at constant angle-of-attack until an input climb gradient is reached. This gradient is maintained, by angle-of-attack changes, until the aircraft reaches an altitude of 700 feet. Up to this point, rather than following a specified H(M) schedule, the aircraft is generating the H-M profile that results from the influence of its aerodynamic and maximum power characteristics on the three degree of freedom, differential equations of motion

$$\frac{1}{g}\dot{V} = (T\cos\alpha - D)/W - \sin\theta$$

$$\frac{V}{g}\dot{\theta} = (T\sin\alpha + L)/W - \cos\theta\left[1 - \frac{V^2}{g(R_E+H)}\right]$$

$$\dot{H} = V\sin\alpha$$

$$\dot{R} = V\cos\alpha$$

$$\dot{W} = -\dot{W}_F$$

which are solved by numerical integration.

After the Mach number for the 700 feet altitude is determined and included in the baseline H(M) schedule, the aircraft follows this adjusted profile up to the supersonic cruise Mach number unless an outbound subsonic cruise leg is to be flown. In this event, the aircraft climbs the same adjusted profile until it reaches the specified subsonic cruise Mach number, than searches (at constant M) for the altitude with the best cruise Breguet factor, V(L/D)/SFC , with engines throttled. The cruise leg, at constant lift coefficient, is then performed for a specified cruise range. Following this subsonic cruise phase, the aircraft accelerates at constant altitude until it intersects the input H(M) profile, which it follows thereafter to the supersonic cruise Mach number. An altitude search, at constant M, is then made to find the best Breguet factor for the start of cruise, under throttled conditions. The climb fuel can then be determined.

Since the fuel available for supersonic cruise and descent is the remainder after climb and reserve fuel are allotted, the reserve fuel requirements are now determined. The reserves include a trip fuel allowance (7 percent), and fuel for a missed approach (2 minutes of takeoff fuel flow), a flight to an alternate airport (260 nautical miles), and a hold at constant altitude (30 minutes at 15,000 feet). The reserve solution, which is an iterative one as the weight at the end of descent is unknown at this time, starts with an initial assumption of total reserve fuel weight, $W_{F,R}$. For the trip fuel allowance, the trip fuel is

$$W_{F,T} = W_F - W_{F,R} - W_{F,TAXI} - W_{F,UN}$$

Where W_F is the total fuel weight, $W_{F,TAXI}$, the taxi fuel weight taken as .005 W_G, and $W_{F,UN}$ the unusable fuel weight. For the alternate airport requirement, the aircraft starts at a Mach number of .5 and at a weight given by

$$W = W_G - W_F + W_{F,R} + W_{F,UN}$$

and flies a linear H-M climb path under maximum power and a 260 nautical mile cruise with engines throttled, at various Mach number-altitude combinations, to search for the combination that requires least fuel. Assuming no weight change, the aircraft then descends to 15,000 feet and a Mach number of .5 and by a Mach number search in a similar fashion, finds the holding fuel requirement. The sum of all reserve fuel items updates the total reserve fuel and the process is repeated until initial guess and final value agree within .1 percent.

The total fuel available for cruise and descent is now known, and these legs are solved by iterating on descent fuel weight. During the cruise leg, the aircraft flies at constant C_L until cruise fuel (the difference between available fuel and assumed descent fuel) is exhausted. The aircraft then decelerates at constant altitude and increasing C_L until it reaches an $(L/D)_{MAX}$ condition, which is then maintained for the remainder of the descent to a Mach number of .5 . Two exceptions to this routine can occur - when the thrust available is insufficient to negotiate the climbing, constant C_L cruise, and when the inbound subsonic cruise option is selected. If the thrust problem is encountered, the aircraft departs from its normal cruise pattern and follows a path dictated by its maximum thrust capability. This is still a climbing cruise, but it occurs at a lower rate and produces a lower range than at the preferable constant C_L cruise. If inbound subsonic cruise occurs, the descent stops at a specified Mach number and the aircraft again searches for the altitude that gives the best Brequet factor. A constant C_L cruise is then performed over a preselected range requirement, after which the aircraft continues on the remaining portion of its descent leg. The initial and final values of descent fuel are now compared and the process repeats from the start of cruise until they are within .1 percent.

After the descent, the approach speed is computed using the takeoff aerodynamics without ground affect, but with landing gear extended, and for the aircraft weight with trip fuel expended. Certain necessary parameters, such as glide slope, angle of attack, and flap deflection, must be specified.

From brake release to start of cruise, the acceleration is continually monitored, and if at any point the acceleration becomes less than .001g, the mission is aborted. The aircraft is then reentered in an earlier procedure where the engine size is increased by a thrust-to-weight ratio increment, the aerodynamic, propulsion, and weight characteristics updated, and the available fuel determined so that a new try at the mission profile can be attempted. For successful missions, the climb and cruise minimum thrust margins are determined. Climb thrust margin is defined as the minimum value of $(T_{MAX}/D - 1)$ that occurs during the ascent to supersonic cruise Mach number, with the cruise thrust margin similarly defined during the cruise leg.

All segments of the mission, except as previously noted during takeoff, use simplified differential equations of motion (ref. 9). These simplifications are based on the following assumptions: the time derivative of the flight path angle is zero, the angle of attack and flight path angle are small, and the aircraft's altitude is negligibly small compared to the earth's radius. The resulting equations for the climb segment (where weight is changing) require

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a specified flight path, H(M) . Over path interval points 1 and 2, the weight change is given by

$$\ln (W_2/W_1) = -\overline{SFC}/g \left[\frac{V_2 - V_1 + g\ (DH/DV)\ \ln (V_2/V_1)}{(1 - \bar{D}/\bar{T})}\right]$$

for velocity changes, and by

$$\ln (W_2/W_1) = -\overline{SFC}/V \left(\frac{H_2 - H_1}{1 - \bar{D}/\bar{T}}\right)$$

for constant velocity. DH/DV is the climb path slope, and the barred quantities represent effective values over the interval. Because small Mach number intervals (.1) were used, however, effective values were taken as numerical averages of interval point values. Time and range changes over the interval are

$$t_2 - t_1 = (W_2 - W_1)/\bar{\dot{W}}_f$$

$$R_2 - R_1 = \left(\frac{V_1 + V_2}{2}\right) (t_2 - t_1)$$

where $\bar{\dot{W}}_f$ is the average fuel flow over the interval.

During descent, the weight change over the interval is assumed to be zero and time changes are given by

$$t_2 - t_1 = \frac{W_1}{g} \left[\frac{V_2 - V_1 + g\ (DH/DV)\ \ln (V_2/V_1)}{(\bar{T} - \bar{D})}\right]$$

for changing velocity, and by

$$t_2 - t_1 = \frac{W}{V} \left(\frac{H_2 - H_1}{\bar{T} - \bar{D}}\right)$$

for constant velocity. Again, numerical averages are used for the barred quantities, and the altitude at point 2 for $(L/D)_{MAX}$ is found by assuming $W_2 = W_1$. W_2 is subsequently incremented by

$$W_2 - W_1 = \bar{\dot{W}}_f\ (t_2 - t_1)$$

In cruise, the governing equation is

$$R_2 - R_1 = \overline{BF} \ln \left[1/(1 - W_F/W_1)\right]$$

where $\overline{BF}$ is the numerical average of the Brequet factor, $\dfrac{V\ L/D}{SFC\ (1 - \frac{V^2}{gRE})}$,

which varies over the computing interval because of the constant C_L or maximum thrust condition, and W_F is the interval fuel weight. During outbound or inbound subsonic cruise, the interval is the entire cruise leg, whereas in supersonic cruise, the interval is sized by fuel weight increments obtained from the available cruise fuel and a specified number of intervals.

As a test of its accuracy, this mission performance routine and a more elaborate analysis in which the full equations of motion were numerically integrated, were both applied to the flight profile of the AST-100 configuration without outbound or inbound subsonic cruise legs. The results of the two methods are in excellent agreement (fig. 24).

OPTIONS

Through selective inputs the program can be controlled to perform several options. The major ones fall into three general categories: the single aircraft case, which finds the range for a given gross weight and payload; the thumbprint case, which provides constant range contours for a thrust-to-weight ratio-wing loading matrix at constant gross weight and payload; and the given range case, which yields the gross weight that provides this range with a given payload.

In the single aircraft case, inputs in any, or all, of the parameters, W_G, W/S, T/W, or number of passengers will produce a single path through the program and yield the range, mission profile, weights, and other selected characteristics of the aircraft sized to these conditions. Input technology improvements in percent for any, or all, areas of structural weight, engine weight, total systems and equipment weight, empty weight, specific fuel consumption, and drag will cause the characteristics of the sized aircraft to reflect the effects of these improvements. In addition, the effects of changes in transonic drag can be determined from input percentage changes in drag, and the Mach number inte~~rval over~~ which these changes are to be effective.

When the thumbprint option is selected, additional inputs of wing loading and thrust-to-weight ratio (7 values of each), and input restrictions on takeoff field length, climb and cruise minimum thrust margins, and takeoff and approach speeds are also required. Successive paths through the program are then made for each WS-T/S combination. During these paths, matrices of total range, takeoff field length, minimum thrust margins during climb and cruise, takeoff and approach speeds, and total fuel fraction are built up as functions of wing loading and thrust to weight ratio. Interpolations within these matrices are then made, after all 49 passes are completed, to find the thrust-to-weight ratio - wing loading combinations that correspond to appropriate contours for range and the operational constraints.

During the given range case, multiple passes are again made through the program, but this time at different gross weights, until the range attained brackets the input range requirement. The desired gross weight is then found from interpolation and a final pass through the program is made to confirm the result.

APPENDIX B

PROGRAM INPUT AND OUTPUT

Input Definitions

The program is coded in FORTRAN Extended (ref. 10) and the required input segments and their order of occurrence are as follows:

Sized Aircraft Identification
$ START
Baseline Aircraft Identification
Baseline Aircraft Geometry
$ AIN
$ CLMPR0
$ ENIN
Basline Engine Identification
Baseline Engine Characteristics
$ WTIN

Identifications are single cards with an 80-column field available. Segments labeled START, AIN, CLMPR0, ENIN, and WTIN are inputs in the NAMELIST format (ref. 9) and the variables they contain may be listed in any order. Definitions of these variables follow, and default values, where they exist, are enclosed in parenthesis. The parenthesis beside the variables define arrays and the included numbers indicate their maximum size.

Sizing and routing options are conveyed in the START segment which includes:

IPPRNT	an integer controlling preliminary output; 1 causes printing, 0 deletes printing. (1)

In all but one of the routing options which follow, a value of 1 activates the option, a value of 0 suppresses it.

I0NEAC	the single aircraft option; it produces one pass through the program and finds the range for a set of design conditions. (0)
ITHUM	this parameter provides the "thumbprint." (0)
GRANGE	set equal to a given range in nautical miles, this parameter will cause a search for the gross weight that provides this range for a set of sizing parameters. An initial guess at the gross weight through the parameter WGDES may shorten computing time for this option. (0.)

IDI	this option activates repeated passes through the program to determine the effects of transonic drag increases. (0)
ITW0	this option causes repeated passes through the program to find the effect of varying thrust-to-weight ratio at constant wing loading. Wing loading is entered in W0SDES, the thrust-to-weight ratios (a maximum of 7 values), in T0WTB.
IWS0	this option is similar to the one above, but now wing loading varies at constant thrust-to-weight ratio. Wing loadings are entered in W0STB (7 values, maximum), and the thrust-to-weight ratio, in T0WDES.

When applying these options, all but the one chosen must be defaulted.

Sizing options include:

WGDES	design gross weight, lb. (0.)
W0SDES	design wing loading, psf (0.)
T0WDES	design thrust-to-weight ratio (0.)
NPDES	number of design engine pods (0)
NENDES	number of design engines (0.)
IPASDES	number of design passengers (0)

NOTE: By default, baseline values are inserted in the above design parameters.

SW	seat width, inches (20)
SP	seat pitch, inches (34.)
STSAB	number of seats abreast, an integer; 0 provides the baseline value (0)
WILE	aisle width, inches (18.)
IPPDGL	number of passengers per door-galley-lavatory complex, an integer (75)
DW	door width, feet (2.3)
GHW	galley-lavatory width, feet (5.)
TP	passenger cabin wall thickness, inches (4.)

The following technology improvement parameters are expressed in percent; positive values are improvements.

DCDI	drag (0.)
DEGW	engine weight (0.)
DEW	empty weight (0.)
DSFC	specific fuel consumption (0.)
DSE	systems and equipment weight (0.)
DSTW	structural weight (0.)

Mission profile options include:

ZMCR	supersonic cruise Mach number
MAXP0W	an integer controlling engine thrust; use 1 for augmented, 0 , for nonaugmented (1)
DELTCG	standard day temperature increment, in deg.C (0)
EM	surface emissivity (.8)
GRALFA	ground run angle of attack, deg. (0.)
T0DELF	takeoff flap deflection, deg. (20.)
T0ALFA	takeoff angle of attack, deg. (8.)
T0CLGR	takeoff climb gradient, percent (6.8)
DTGRUP	time for landing gear retraction, sec. (10.)
HN0GE	altitude for disappearance of aerodynamic in-ground effect, ft. (wing span)
H0BS	takeoff obstacle altitude, ft. (35.)
ALFD0T	aircraft rotational speed during takeoff, deg/sec (3.)
APDELF	approach flap deflection, deg. (20.)
APALFA	approach angle of attack, deg. (8.)
APGS	approach glide slope, deg. (-3.)
NCRP	number of computing intervals during supersonic cruise, an integer (10)
IDSP	number of computing intervals during descent, an integer (6)

DSFF	descent fuel flow parameter, expressed in terms of fuel flow at maximum power (.0667)
DSTHR	descent thrust parameter, in terms of maximum power (0.)
SSRNGC	outbound subsonic cruise range (0.)
ZMSBC	outbound subsonic cruise Mach number (0.)
SSRNGD	inbound subsonic cruise range (0.)
ZMSBD	inbound subsonic cruise Mach number (0.)
RMAFA	missed approach fuel allowance, in minutes of takeoff fuel flow (2.)
TPFA	trip fuel allowance, in percent of trip fuel (7.)
AAD	distance to alternate airport, nautical miles (260.)
THLD	hold time, minutes (30.)
HHLD	hold altitude, feet (15,000.)

With the "thumbprint" option specified, ITHUM = 1 , the following parameters are also required:

W0STB(7)	a one-dimensional array containing, in decreasing order, the thumbprint wing loadings in psf, seven values must be specified
T0WTB(7)	a one-dimensional array containing, in increasing order, the thumbprint thrust-to-weight ratios, seven values must be specified
TT0FL(5)	a one-dimensional array containing takeoff field length restrictions in feet; one value is required. (10,500.)
IT0FL	the number of points in the above array, an integer. (1)
TCLTP(5)	a one-dimensional array containing minimum thrust margin restrictions during climb, in terms of $(T_{MAX}/D) - 1$; one value is required. (.2)
ICLTP	the number of points in the above array, an integer. (1)
TCRTP(5)	a one-dimensional array containing minimum thrust margin restrictions during supersonic cruise; same terms as above, one value required. (.1)
ICRTP	the number of points in the above array, an inter. (1)

The transonic drag increase option, IDI = 1, must also include:

DIL0	the lowest value for drag increase, in percent
DIHI	the highest value for drag increase, in percent
DDI	the value by which drag increases are incremented, in percent. (5)
TIML	the lowest Mach number at which drag increases are applied
TIMH	the highest Mach number at which drag increases are applied
IVCDT0	set equal to 1 for increases in all drag items. (0)
IVCDW	set equal to 1 for increases in wave drag only. (0)
IVCDF	set equal to 1 for increases in friction drag only. (0)
IVCDBL	set equal to 1 for increases in engine installation drag. (0)

If the internal wave drag computations are to be replaced by a set of precalculated wave drag coefficients, the following parameters are required.

INWD	this parameter must be set equal to 1 to use input wave drag coefficients. (0)
WDCTB(7,7,2)	a three-dimensional array containing the input wave drag coefficients at various thrust-to-weight ratio, wing loading, and Mach number combinations. The first dimension corresponds to T/W, the second, to W/S, and the third to Mach number. Since only two Mach numbers are available, the inputs should include one at low transonic speeds and the other at supersonic cruise. For intermediate Mach numbers, the program interpolates between these extremes.
WDT0W (7)	a one-dimensional array containing corresponding values of thrust-to-weight ratio
WDW0S (7)	a similar array containing corresponding values of wing loading, in psf
WDZM (2)	a similar array containing corresponding values of Mach number
NT0W	the number of points in the WDT0W array

NW0S	the number of points in the NDW0S array
NMCH	the number of points in the WDZM array

This concludes the definition of variables in the START segment.

The baseline aircraft identification and geometry are input in the zero-lift wave drag program format described in the Appendix of reference 2.

The next segment, labeled AIN, contains the baseline aircraft aerodynamic inputs. Either trimmed or untrimmed angles of attack and lift-drag polars may be input. The program does not correct for sizing effects on trim changes. The takeoff aerodynamic input parameters that include ground effects are:

TALPT0G(15,4)	a two-dimensional array of angle of attack, α, values for various flap deflections
TCLT0G(15,4)	a similar array for lift coefficients, C_L
TCDT0G(15,4)	the array for drag coefficients, C_D
NT0G	the number of α, C_L, and C_D, points for each flap deflection, the first dimension of the above arrays.

The takeoff parameters that do not include ground effects are:

TALPHT0(15,4)	angle of attack array
TCLT0(15,4)	lift coefficient array
TCDT0(15,4)	drag coefficient array
NT0P	the number of a α, C_L and C_D points for each flap deflection in the above three arrays
NFD	the number of flap deflections in all of the above arrays, the second dimension
TFSET(4)	a one-dimensional array for the flap deflections, in degrees
DCDLG	landing gear drag coefficient

The high speed lift-drag polars (preferable trimmed), and zero-lift drag items are input in the following parameters.

CLT(15,15)	a two-dimensional array of lift coefficients for various Mach numbers

CDPT(15,15)	a two dimensional array of drag coefficients for various Mach numbers
NAI	the number of lift and drag coefficients at each Mach number, the first dimension of the above arrays, NAI points must be input for each Mach number
NAJ	the number Mach numbers at which the lift and drag coefficients are provided; the second dimension of the above arrays
MAER0T(15)	a one-dimensional array of Mach numbers corresponding to the above arrays
THAR0(15)	a one-dimensional array of the altitudes, in feet, at which the above high speed lift-drag polars were determined

The following are one-dimensional arrays of zero-lift drag coefficients; they contain values that correspond to the Mach numbers given in MAEROT.

CDW(15)	wave drag coefficient
CDF(15)	friction drag coefficient
CDRUF(15)	surface roughness drag coefficient
CDXT(15)	air-conditioning drag coefficient
CDBL(15)	engine installation drag coefficient
CDZT(15)	the sum of CDXT and CDBL. If CDZT values are known, but CDBL values are not, CDBL inputs are not required
INACBL	an integer, for which 1 indicates that CDXT and CDBL values are included in the total drag coefficients, CDPT; a value of 0 indicates they are not included
REFA	reference area, square feet

The CLMPRO segment contains the baseline aircraft climb schedule.

HASNT(10)	a one-dimensional array of climb altitudes, in feet
ZMASNT(10)	a similar array for the climb Mach numbers
ICLPR	the number of points in these arrays

The next segment, ENIN, contains information on the engine that is to be used during aircraft sizing. Although this engine is referred to as the baseline engine, it is not necessary that this engine be the same as the one installed when the aerodynamic, and weight characteristics of the baseline aircraft were defined. The contents of ENIN are:

DINRE	pod inlet diameter, ft.
DMAXRE	pod maximum diameter, ft.
DEXRE	pod diameter at the nozzle exhaust plane, ft.
ZLERE	pod length from inlet to exhaust plane, ft.
NENR	the number of baseline engines
NP0DSR	the number of baseline engine pods
ESEXP	the pod length sizing exponent (.438)
EWEXP	the engine weight sizing exponent (1.08)
D0QINT1(15)	a one-dimensional array containing the sum of engine installation drags at augmented power, divided by dynamic pressure, for a range of Mach numbers
D0QINT2(15)	a similar array for nonaugmented power
D0QMT(15)	a similar array containing the Mach numbers corresponding to the above arrays
NBDP	the number of points in the above arrays
INBL	an integer for which a value of 1 indicates that installation drag items are included in gross thrust values; a value of 0 indicates they are not included
T0WREF	the installed sea level thrust to aircraft gross weight ratio for the input engine and baseline aircraft combination
WGREF	the gross weight of the baseline aircraft used in determining T0WREF
WENG	weight of all engines, lb.
WNAC	weight of all nacelles, lb.
WTR	thrust reverser weight for all engines, lb. (NOTE: other thrust-scalable propulsion system weights - like noise suppressors - can be included here.)
WPLM	propulsion plumbing systems weight, lb.

WMIS	miscellaneous propulsion system weight, lb.
WAREF	engine sea level air flow, per engine, in lb/sec

The following array is required only if corrections are to be made to the wave drag for differences in baseline engine concept or size.

TPCDW (15)	a one-dimensional array containing the baseline engine nacelle wave drag coefficients (computed for one isolated nacelle and based on baseline aircraft reference area). Coefficients must correspond to the Mach numbers given in the MAERØT array.

The next input deck is comprised of three groups of cards that contain the baseline engine characteristics. The first card of the deck is used to identify the engine, the next card group provides full power characteristics, and the last group contains part power values. The full power cards contain the Mach number, altitide, gross thrust, ram drag, and fuel flow. The arrangement on each card is as follows.

Column	Description
1-5	Mach number
6-15	altitude, ft.
21-30	gross thrust, lb.
31-40	ram drag, lb.
41-50	fuel flow, lb/hr

Cards are stacked by increasing altitude (at constant Mach number), then by increasing Mach number. A maximum of 15 values for both altitude and Mach number are allowed. At least two altitudes at each Mach number are required. For each Mach number-altitude combination, the program expects to read two cards. The first of these contains nonaugmented power values, the second, augmented values. If the information for one of these is not available, then the available one must be entered in duplicate at each Mach number - altitude combination. The end of the maximum power card group is indicated by two successive cards, each containing the characters 9. in columns 1 and 2.

The cards in the part power group contain the same variables, and input in the same format, as the full power values. Cards are stacked by increasing power (at constant Mach number), then, again, by increasing Mach number. A maximum of 15 part power settings and a maximum of 10 Mach numbers are allowed. In contrast to the full power card group, the part power group must contain only one card for each part power-Mach number combination. The last card of this group completes the engine input requirements and the end is indicated on this card with characters 9. located in columns 1 and 2.

Before leaving the engine inputs, note that it is not necessary to have the baseline engine size identical to the engine size that produces the gross thrust characteristics included in the full-power data group. Instead, the baseline engine can be sized prior to input, and the results reflected by entries to the appropriate variables in segment ENIN.

The final input group WTIN, contains the detailed weights for the baseline aircraft. The default value for all variables is 0. Except where noted, input weights are in pounds.

Structural weights are:

WFUS	fuselage
WWT	wing
WCAN	canard
WHT	horizontal tail
WVT	vertical tail (sum of all)
WLG	landing gear

System and equipment weights are:

WSC	surface controls
FLAREA	total wing flap area, sq. ft.
WAP	auxiliary power
WINST	instruments
WHY	hydraulics
WEL	electrical
WAV	avionics
WFEQ	furnishings and equipment
WAC	air conditioning
WAI	anti-icing

Operating weight variables are:

WFCR	flight crew and their baggage
IFCR	number of flight crew members (an integer)
WCCR	passenger cabin crew and their baggage

ICCR	number of cabin crew members (an integer)
WUSF	unusable fuel
WEN0	engine oil
WPS	passenger service
WCC	cargo containers
WPAS	passenger weight
IPASR	number of passengers (an integer)
STSABR	number of seats abreast, baseline value
WPB	passenger baggage
WCAR	cargo

Other variables required are:

C1 through C8	Constants to be used in wing weight equation
WFWREF	wing maximum fuel load, lb.
WFBREF	body maximum fuel load, lb.
ZMCRR	supersonic cruise Mach number for baseline aircraft

If the baseline engine-nacelle combination entered in segment ENIN is different in either size or concept from the basic one used to generate the baseline aerodynamic and weight inputs, the following inputs for the basic engine-nacelle combination are also required.

DIN1	pod inlet diameter, ft.
DMAX1	pod maximum diameter, ft.
DEX1	pod diameter at nozzle exhaust plane, ft.
ZLE1	pod length from inlet to exhaust plane, ft.
WENGR	weight of all engines, lb.
WNACR	weight of all nacelles, lb.
WTRR	thrust reverser weight for all engines, lb.
WMISR	miscellaneous propulsion system weight, lb.
WPLMR	propulsion plumbing system weight, lb.

The following array also applies to the basic engine - nacelle combination, but inputs are required only if a corresponding entry is made for TPCDW in segment ENIN.

TPCDWR(15)	a one-dimensional array containing the nacelle wave drag coefficients (computed for one isolated pod and based on aircraft reference area). Coefficients must correspond to the Mach numbers given in the MAER0T array.

This completes the input requirements.

TABULATED OUTPUT

Three types of output listings are available. These include a preliminary output, sized aircraft output, and a thumbprint output.

Preliminary output.- This printout, which is optional and obtained by setting IPPRNT = 1 in input segment START, contains a listing of the input values for all variables in all input segments. In addition, the baseline engine characteristics, converted to program parameters, are listed after the input values of these characteristics are printed.

Sized aircraft output.- This printout contains the results for each aircraft treated, and a typical listing for the single aircraft option (I0NEAC = 1) is given in tables 3 through 7.

The initial listing (table 3) provides information appropriate to subsequent output, and includes the baseline aircraft and engine identifications, the routing option chosen, and whether or not fuselage packaging occurs.

The next listing contains the mission analysis results (table 4) for the aircraft having the chosen design parameters and takeoff conditions. Although not shown in its entirety, the listing includes all segments of the mission profile with the start (or end) of each segment called out at its appropriate location.

Overall sizing and performance results are listed as shown in table 5. In addition to the aircraft's identity by the controlling design parameters, the initial listing (table 5a) includes its total range, its energy efficiency parameter, its engine airflow characteristics at sea level, the number of seats available (NSEATS), and the number of seats abreast (NSTS). The technology improvements that have been applied are listed next, followed by, if necessary, cautionary notes indicating that the aircraft's fuel load limit has been exceeded, or, that because of insufficient thrust capability, the aircraft may not be cruising at its optimum altitude. A partial listing of aircraft weights, normalized by takeoff gross weight, are given next; and these include, reading across the page, the dry weight, operating weight, empty weight, total systems and equipment weight, total propulsion system weight, and structural weight; then, the fuselage, wing, canard, horizontal tail, total vertical tail, engine, and payload weights; and finally, unit weights, in pounds per square foot of wetted area, for the fuselage, wing, wing minimum gage, and fuel tank. Geometric listings are then given for the fuselage, and wing volumes along with the fuel distribution in portions of gross takeoff weight.

The overall sizing and performance listing also includes (in table 5b) the takeoff and approach results; the minimum thrust margins encountered during climb and cruise, along with the Mach numbers at which they occur; a breakdown of range, trip times, and fuel usage for the various legs of the mission; and (in table 5c) the conditions at the start of the various cruise legs, plus a breakdown of the fuel required for, and the conditions at the start of, the various reserve segments.

Aerodynamic output, shown in table 5d, includes the drag coefficients due to wave (CDW), friction (CDF), roughness (CDRUF), bleed (CDBL), air conditioning (CDAC), the induced drag at minimum drag (CDLM); the total minimum drag coefficient (CDO), the drag due to lift factor (DDLF), the lift coefficient at minimum drag (CLO), the maximum lift to drag ration (L/D)M, and the maximum lift to drag ratio excluding bleed and air conditioning drag (L/D)MA.

The last listings in the sized aircraft output are the complete weight statement, table 6, followed by the aircraft geometric details, a portion of which is included in table 7.

All of the above listings in tables 3 through 8 are printed only for the single aircraft option (I0NEAC = 1) and for the final pass through the given range-given payload option (GRANGE > 0.). During the options where a number of aircraft are sized in repeated passes through the program, only the output in table 5 is printed for each aircraft.

Thumbprint output.- This printout begins with a listing of the quantities for various W/S - T/W combinations from which the thumbprint is determined. A typical listing is shown in table 8 for total ranges and takeoff field lengths. Similar listings are also provided for climb and cruise minimum thrust margins, takeoff and approach speeds, and total fuel (normalized by takeoff gross weight). Typical output required to construct the thumbprint is shown in table 9 where the interpolated W/S - T/W combinations (or the reference area - engine airflow combinations) for constant range contours are given. Combinations of these variables are also provided to define the restrictive operational contours including takeoff field length, climb and cruise minimum thrust margins, takeoff and approach speeds, and fuel limit.

Diagnostic Output

When a problem is encountered during program operations, an informative message and values of appropriate variables are printed to indicate the nature of the problem. The areas in which these diagnostic messages will occur and subsequent program response are described in the following paragraphs.

Wing too large.- During sizing, if the wing overlaps the canard and/or the horizontal tail surfaces, or extends beyond the limits of the fuselage, a message indicating this problem and the current values of wing loading, W/S, thrust to weight ratio, T/W, and gross takeoff weight, W_G, are printed. In the thumbprint option, the program will then pass to the next thrust to weight ratio in the T0WTB array; in the GRANGE option, the program will continue with a higher gross takeoff weight; in all other options, program operations will cease.

Insufficient fuel.- If the empty weight approaches, or exceeds, the gross takeoff weight during sizing, a message indicating an insufficient fuel condition and the current values of W/S, T/W and W_G are printed. Program response is the same as in the "large wing" problem described above.

No cruise fuel.- If all the fuel is used during climb and reserve legs, an appropriate message and the current values of T/W, W/S, W_G and the cruise fuel weight, WFC, are printed. Program response is the same as above.

No acceleration.- If the aircraft cannot accelerate during takeoff or climb, a message indicating the portion of the mission where the problem is encountered and the corresponding values of acceleration, T/W, W/S, Mach number, and altitude are printed. For all routing options, the program then increments the thrust to weight ratio (by a value of .02) and reverts to an earlier routine where the effects of this change can be included.

Insufficient part-power data.- If the thrust to weight ratio is too high, or if the engine part power inputs are limited, the cruise throttling parameter, T/T_{MAX}, will be lower than available values. When this problem occurs, program operations stop and an informative message along with the current values of T/W, W/S, Mach number, altitude, T/T_{MAX}, and the minimum throttling parameter available, $(T/T_{MAX})_{MIN}$, are printed.

The storage requirement for the program is about 100,000 (octal) words. On a CDC-CYBER 173 computer, the run time for a single aircraft case is about 25 seconds; for a thumbprint, about 13 minutes; and for a given range and payload, about 1 minute.

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TABLE 1 GROUP WEIGHT COMPARISON

AST- 102
WG = 718,000 lb.

ITEM	VOUGHT CORP.	ASP
Wing, W/WG	0.1080	0.1030
Horizontal tail	.0065	.0056
Vertical tail	.0079	.0070
Fuselage	.0730	.0730
Landing gear	.0380	.0380
Nacelles	.0196	.0195
TOTAL STRUCTURE	.2530	.2461
Engines	.0587	.0603
Misc. systems	.0025	.0025
Fuel system	.0080	.0081
TOTAL PROPULSION	.0692	.0708
Surface controls	.0132	.0111
Instruments	.0047	.0047
Hydraulics	.0078	.0066
Electrical	.0070	.0070
Avonics	.0037	.0037
Furn. and equip.	.0350	.0350
Air conditioning	.0114	.0114
Anti-icing	.0003	.0003
TOTAL SYSTEMS AND EQUIPMENT	.0831	.0799
Crew and baggage	.0032	.0032
Unuseable fuel	.0031	.0035
Passenger service	.0123	.0123
Cargo containers	.0041	.0041
Passengers and baggage	.0850	.0850
ZERO FUEL WEIGHT	.5130	.5058
MISSION FUEL	.4870	.4942

TABLE 2 MISSION PERFORMANCE COMPARISON

AST-102

	VOUGHT CORP.			ASP		
BLOCK SEGMENT	W_F/W_G	TIME,MIN	RANGE,n.mi.	W_F/W_G	TIME,MIN	RANGE,n.mi.
Taxi and climb	.115	30	471	.116	32	492
Cruise	.279	149	3792	.281	147	3760
Descent	.004	20	200	.004	23	263
Total	.398	199	4463	.401	200	4517
RESERVE SEGMENT,W_F/W_G						
7% trip fuel		.028			.029	
Missed approach		.010			.011	
Alt. airport		.032			.034	
30 min. hold		.019			.019	
Total		.089			.093	
INITIAL CRUISE CONDITIONS						
Altitude, ft.		59,000			59,526	
L/D		8.88			8.77	
SFC,lb/hr/lb		1.358			1.360	

TABLE 3.- TABULATED OUTPUT- GENERAL INFORMATION FOR SIZED AIRCRAFT.

```
                   AIRCRAFT I.D.

             AST-100


                   ENGINE I.D.

          AST-JP-2  ENGINE  STD+8C,   CWA=712 LB/SEC,  FOR AST-100,102

         NO. OF ENGINES,     4     NO. OF ENGINE PODS,     4


         AIRCRAFT DESIGNED FOR GIVEN WEIGHT AND PAYLOAD

             WG=  718000.0     PASSENGERS,       292

         OUTPUT FOR ONE AIRCRAFT ONLY (INPUT DESIGN)

         NO FUSELAGE PACKAGING(IPASDES=IPASR)
```

TABLE 4.- TABULATED OUTPUT- MISSION ANALYSIS RESULTS.

```
               W/S=  72.02 PSF   T/W=  .367     IPAS=  292     WG=  718000.0 LB

    TAKEOFF CONDITIONS

        T/TMAX,   1.000     ALPHA,   8.000 DEG

        FLAP DEFL,  20.000 DEG     CLIMB GRADIENT,0/0   6.800


        M          ALT,FT         Q,PSF          W/WG       RANGE,NM        TIME,SEC       FPA,DEG     DV/DT,GS     ALPHA,DEG
        CL           CD            L/D           SFC         BF,NM           L,LBS         D,LBS        T,LBS       TMAX,LBS
                   TMAX/D

      0.0000        0.0000        0.0000        .9950        0.0000         0.0000        0.0000        .3688        8.0000
      0.0000        0.0000        0.0000       1.0117        0.0000         0.0000        0.0000  263506.0000   263505.0000
                    0.0000


       .2553        0.0000       96.5409        .9923         .6085        25.6528        0.0000        .3189        1.0000
       .2810         .0350        8.0377       1.0847     1265.6193    270439.0433    33646.1735  260842.6360   260842.6360
                    7.7525


       .2740        0.0000      111.2266        .9920         .7398        28.3195        0.0000        .1823        8.0000
       .6250         .1180        5.2984       1.0904      892.8794    693011.1371   130796.2558  260647.2309   260647.2309
                    1.9928


       .2957       34.6200      129.3433        .9914        1.0158        33.5070        2.9154        .1083        8.0000
       .6041         .1120        5.3956       1.0972      974.9939    778997.4725   144375.1650  260194.0611   260194.0611
                    1.8022

TOFL=     7097.98272
```

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TABLE 5.- TABULATED OUTPUT- OVERALL SIZING AND PERFORMANCE RESULTS.

(a) Part 1

```
                  W/S=  72.02 PSF    T/W=  .367      IPAS=  292      WG=  718000.0 LB     M.CRUISE=  2.62

RANGE.TOT.NM=  3993.3      BTU/PAS/NM=  4119.5      ENG AIRFLOW.SL.LB/SFC=   712.0      NSEATS=  292      NSTS.AB=     5


                        TECHNOLOGY PERCENTAGE IMPROVEMENTS FOR THIS AIRCRAFT ARE

          DSTW=   0.00      DSFC=   0.00      DCD=   0.00      DEGW=   0.00      DSF=   0.00      DEW=   0.00


                                    WEIGHT FRACTIONS

      WDRY/WG           WOP/WG           WEMP/WG          WSEQ/WG          WPPS/WG          WSTR/WG
      WFUS/WG           WWNG/WG          WCAN/WG           WHT/WG           WVT/WG           WEN/WG              WPL/WG
        UB               UWW              UWWM             UWFT



        .54388           .45888           .43496           .08310           .08295           .26891
        .07299           .11966          0.00000           .00663           .00821           .07242              .08500
       5.38364          3.90648          2.24160          0.00000

FUSELAGE VARIABLES,    FN=  27.319      LENGTH=  315.00 FT      RADIUS.MAX=    5.765 FT

WING VOLUMES.CU. FT.---TOTAL.     26503.20081      EXPOSED.     20019.58198      FUEL.      7770.05348

FUEL DISTRUBUTION.WF/WG---WING.MAX.     .52616      WING.REQUIRED.     .42316      FUSELAGE.     .03621
```

TABLE 5.- CONTINUED.

(b) Part 2

```
REF,AREA,SQ FT,     9969.00000     BASELINE REF,AREA,SQ FT,     9969.00000

    TAKEOFF AND APPROACH VARIABLES

FLAP DELF,TO,  20.0 DEG    ALPHA,TO,   8.0 DEG    T.O. CLIMB GRADIENT,   6.8 0/0    V,TO,  183.76 KN
FLAP DEFL,AP,  20.0 DEG    ALPHA,AP,   9.5 DEG    APPROACH GLIDE SLOPE,   3.0 DEG   V,AP,  148.85 KN

TAKEOFF FIELD LENGTH,FT.     7097.98272




MINIMUM THRUST MARGINS---CLIMB,    M=  2.62    (TMAX/D-1)MIN=   .43
                         CRUISE,   M=  2.62    (TMAX/D-1)MIN=   .21




RANGES,NM

R,ASCENT,TOT=      344.28578     R,DESCENT,TOT=      269.49033     R,CRUISE=    3379.47785
R,SSC,OB=        0.00000         R,SSC,IB=        0.00000          R,TOTAL=    3993.25395
R,ASCENT=      344.28578         R,DESCENT=      269.49033

TRIP TIMES,MIN

T,ASCENT,TOT=       22.81928     T,DESCENT,TOT=       23.76426     T,CRUISE=     132.37398
T,SSC,OB=        0.00000         T,SSC,IB=        0.00000          T,TOTAL=     178.95752
T,ASCENT=       22.81928         T,DESCENT=       23.76426

FUEL FRACTIONS,WF/WG

ASCENT,TOT,           .09355     DESCENT,TOT,           .00473     CRUISE,           .25641
SSC,OB,         0.00000          SSC,IB,         0.00000           MISSION,           .45612
ASCENT,           .09355         DESCENT,           .00473         UNUSEABLE,           .00325
RESERVES,TOTAL,           .09643 TAXI,           .00500            TOTAL           .45937

MAXIMUM FUEL LOAD,           .56237
```

TABLE 5.- CONTINUED.

(c) Part 3

```
          CONDITIONS AT START OF CRUISE LEGS

OUTBOUND SUBSONIC CRUISE LEG


M.         0.00000                        Q.        0.00000 PSF                 ALT.        0.00000 FT
T/TMAX.         0.00000                   SFC.        0.00000 LB/HR/LB
L/D.         0.00000                      BREGUET FACTOR.         0.00000 NM


MAIN CRUISE LEG


M.         2.62000                        Q.      651.53929 PSF                 ALT.    62256.11111 FT
T/TMAX.              .82725               SFC.        1.35475 LB/HR/LB
L/D.         8.95920                      BREGUET FACTOR.    10221.30379 NM


(L/D)MAX.         9.05276                 (L/D)MAX.ABS.        9.42537


INBOUND SUBSONIC CRUISE LEG


M.         0.00000                        Q.        0.00000 PSF                 ALT.        0.00000 FT
T/TMAX.         0.00000                   SFC.        0.00000 LB/HR/LB
L/D.         0.00000                      BREGUET FACTOR.         0.00000 NM


                   FUEL RESERVE INFO

MISSED APPROACH ALLOWANCE (  2.0 MINUTES OF TAKEOFF FUEL FLOW).  WF/WG=          .01295

TRIP FUEL ALLOWANCE (  7.0 PERCENT OF TRIP FUEL).  WF/WG=          .02485

ALTERNATE AIRPORT ( 260.0 N.M.)

     M.          .65000           ALT.    17500.00000 FT          L/D.        13.48574
     T/TMAX.          .19705      SFC.          .97994 LB/HP/LB   WF/WG.          .03756

HOLD ( 30.0 MIN. AT 15000.0 FT.)

     M.          .55000           ALT.    15000.00000 FT          L/D.        13.96457
     T/TMAX.          .17468      SFC.          .97699 LB/HP/LB   WF/WG.          .02108
```

TABLE 5.- CONCLUDED.

(d) Part 4

```
                                              AERODYNAMICS


                                (VALUES CORRESPOND TO INPUT MACH-ALTITUDE SCHEDULE)
   M        ALT       CDW        CDF        CDRUF       CDBL       COAC       CDLM       CDO        DDLF       CLO       (L/D)M     (L/D)MA


  0.00        0.   0.00000     .00556     .00025     .00058     .00023     .00231     .00893     .38432     .07861     14.007     15.018
   .60     7286.   0.00000     .00560     .00025     .00058     .00023     .00231     .00897     .38432     .07861     13.961     14.963
   .80    22429.   0.00000     .00587     .00025     .00077     .00025     .00211     .00925     .40289     .08369     13.884     15.137
   .95    30806.   0.00000     .00584     .00025     .00125     .00026     .00311     .01071     .46125     .09771     13.016     14.637
  1.05    32417.    .00259     .00571     .00059     .00228     .00027     .00182     .01325     .53378     .10167     10.914     12.891
  1.20    34833.    .00306     .00526     .00059     .00185     .00028     .00315     .01419     .57231     .09305      9.722     11.006
  1.40    38056.    .00241     .00533    0.00000     .00121     .00030     .00353     .01278     .58617     .08151      9.790     10.755
  1.80    44500.    .00225     .00495    0.00000     .00060     .00034     .00228     .01041     .60735     .06074      9.847     10.533
  2.20    50944.    .00211     .00460    0.00000     .00062     .00038     .00154     .00925     .65370     .04657      9.423     10.195
  2.62    57711.    .00205     .00406     .00024     .00041     .00007     .00142     .00825     .79870     .04145      9.153      9.549
VALUES AT START OF CRUISE

  2.62    62256.    .00205     .00421     .00024     .00041     .00007     .00142     .00840     .79870     .04145      9.053      9.425
```

TABLE 6.- TABULATED OUTPUT- WEIGHT STATEMENT.

ITEM	W.LBS		W/W.GROSS T.O.	
WING	85914.		.1197	
HTAIL	4763.		.0066	
VTAIL	5892.		.0082	
CANARD	0.		0.0000	
FUSELAGE	52410.		.0730	
L.GEAR	27293.		.0380	
NACELLES	16803.		.0234	
TOT. STRUCTURE		193075.		.2689
ENGINES	52000.		.0724	
THRUST REV.	0.		0.0000	
MISC SYSTEMS	1780.		.0025	
FUEL SYSTEM	5781.		.0081	
TOT. PROPULSION		59561.		.0830
SURFACE CONTROLS	9405.		.0131	
AUXILIARY POWER	0.		0.0000	
INSTRUMENTS	3400.		.0047	
HYDRAULICS	5600.		.0078	
ELECTRICAL	5050.		.0070	
AVONICS	2690.		.0037	
FURN. AND EQUIP.	25111.		.0350	
AIR COND	8200.		.0114	
ANTI-ICING	210.		.0003	
TOT. SYSTEMS AND EQUIP.		59666.		.0831
EMPTY WEIGHT		312302.		.4350
FLIGHT CREW	675.		.0009	
CABIN CREW	1640.		.0023	
UNUSEABLE FUEL	2335.		.0033	
ENGINE OIL	715.		.0010	
PASSENGER SERVICE	8852.		.0123	
CARGO CONTAINERS	2960.		.0041	
OPERATING WEIGHT		329479.		.4589
PASSENGERS	48180.		.0671	
BAGGAGE	12848.		.0179	
CARGO	0.		0.0000	
ZERO FUEL WEIGHT		390507.		.5439
MISSION FUEL	327493.		.4561	
GROSS WEIGHT		718000.		1.0000

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TABLE 7.- TABULATED OUTPUT- CONFIGURATION DETAILS.

```
                                        (DIMENSIONS IN FT.SQ FT. OR CU FT)


FUSELAGE DATA

     LENGTH        315.00000     RMAX               5.765
     FN RATIO       27.31906     VOL,TOTAL        26001.9
     AREA,WET     9730.0


     FUSELAGE COORDINATES

         X            Z           R

       0.00000     0.00000     0.00000
      10.50000      .15400     1.76448
      21.00000      .23400     2.85916
      31.50000      .27150     3.72894
      42.00000      .27600     4.52811
      52.50000      .17750     5.19730
      63.00000     -.27700     5.56041
      73.50000    -1.07500     5.63823
      84.00000    -2.06000     5.63340
      94.50000    -3.11000     5.61110
     105.00000    -4.18000     5.62066
     115.50000    -5.28300     5.68810
     126.00000    -6.36000     5.79197
     136.50000    -7.41000     5.89757
     147.00000    -8.37950     5.99544
     157.50000    -9.30875     6.09255
     168.00000   -10.07400     6.14680
     178.50000   -10.69450     6.17652
     189.00000   -11.26600     6.18039
     199.50000   -11.79500     6.17794
     210.00000   -12.27000     6.10264
     220.50000   -12.65800     6.00718
     231.00000   -12.61600     5.82261
     241.50000   -12.51850     5.61806
     252.00000   -12.09200     5.27571
     262.50000   -11.65500     4.83474
```

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TABLE 8.- TABULATED OUTPUT - BASIS FOR THUMBPRINT.

```
                    WG,   718000.00000 LB     M,CRUISE,  2.620     PASSENGERS,  292

    RANGES

  W/S       T/W   RANGE      T/W   RANGE      T/W   RANGE      T/W   RANGE      T/W   RANGE      T/W   RANGE      T/W   RANGE


 110.0      .250  4561.8    .300   4726.2    .350   4472.3    .400   4156.4    .450   3894.8    .500   3587.5    .550   3285.4
 100.0      .250  4834.9    .300   4716.2    .350   4464.0    .400   4178.8    .450   3882.9    .500   3571.8    .550   3269.6
  90.0      .250  4730.8    .300   4629.4    .350   4391.7    .400   4109.1    .450   3823.1    .500   3520.6    .550   3224.2
  80.0      .250  4467.1    .300   4459.3    .350   4252.2    .400   3985.5    .450   3702.9    .500   3426.8    .550   3134.4
  70.0      .250  3925.8    .300   4180.8    .350   4010.9    .400   3 78.0    .450   3509.6    .500   3239.2    .550   2977.4
  60.0     0.000     0.0    .300   3622.3    .350   3628.9    .400   3434.3    .450   3205.3    .500   2949.6    .550   2699.1
  50.0     0.000     0.0    .300   2323.7    .350   2835.4    .400   2666.7    .450   2691.2    .500   2460.3    .550   2254.2


    TAKE OFF FIELD LENGTHS


 110.0  15898.7          12895.5          10932.5          9573.8          8532.2          7726.8          7061.3
 100.0  14541.0          11804.8          10029.6          8784.2          7858.5          7091.1          6495.3
  90.0  13210.2          10713.8           9124.3          7965.6          7152.3          6453.9          5898.8
  80.0  11876.7           9621.5           8190.4          7250.5          6417.5          5814.5          5328.2
  70.0  10493.2           8526.9           7255.2          6424.8          5706.8          5159.9          4817.7
  60.0      0.0           7428.3           6429.3          5596.8          4968.8          4620.2          4197.9
  50.0      0.0           6323.4           5456.9          4744.4          4356.2          3917.3          3576.0
```

TABLE 9.- TABULATED OUTPUT- THUMBPRINT RESULTS.

```
                         WG,   718000.00000 LB     M,CRUISE,  2.620     PASSENGERS,  292

                AIRCRAFT I.D.

          AST-100

                ENGINE I.D.

     AST-JP-2  ENGINE  STD+8C,   CWA=712 LB/SEC,  FOR AST-100,102


                     CONDITIONS FOR RANGE=  4861.755 NM

                  W/S,PSF        T/W           SREF,SQ FT    AIRFLOW,LB/SEC

                 110.00         .25000          6527.3         485.01


                     CONDITIONS FOR RANGE=  4800.000 NM

                  W/S,PSF        T/W           SREF,SQ FT    AIRFLOW,LB/SEC

                  96.65         .25000          7428.9         485.01

                 100.00         .26469          7180.0         513.52

                 110.00         .27278          6527.3         529.20
```

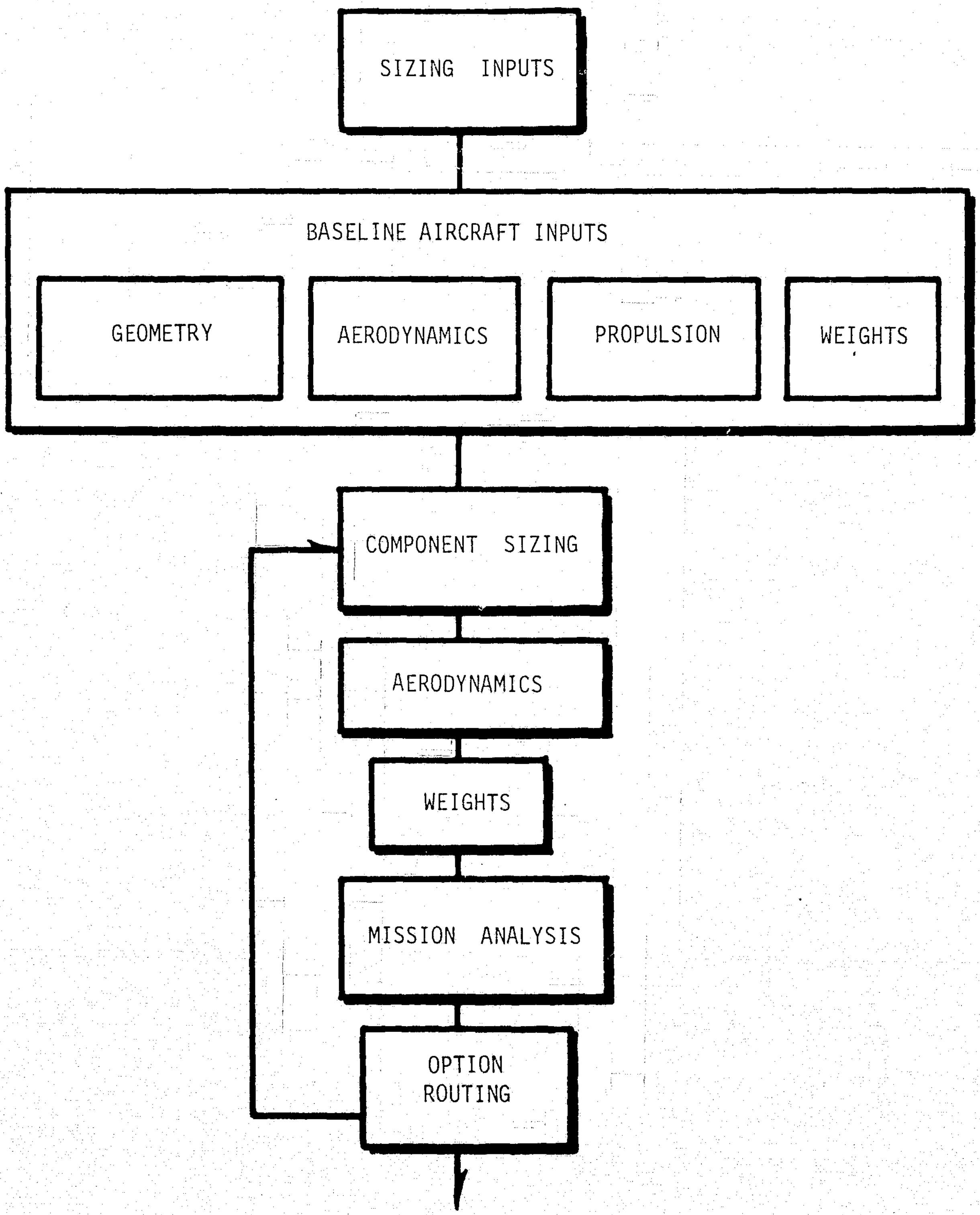


Figure 1. - Elements of the Aircraft Sizing and Performance program.

NOTE: DIMENSIONS SHOWN IN METERS WITH FEET IN PARENTHESIS EXCEPT AS NOTED

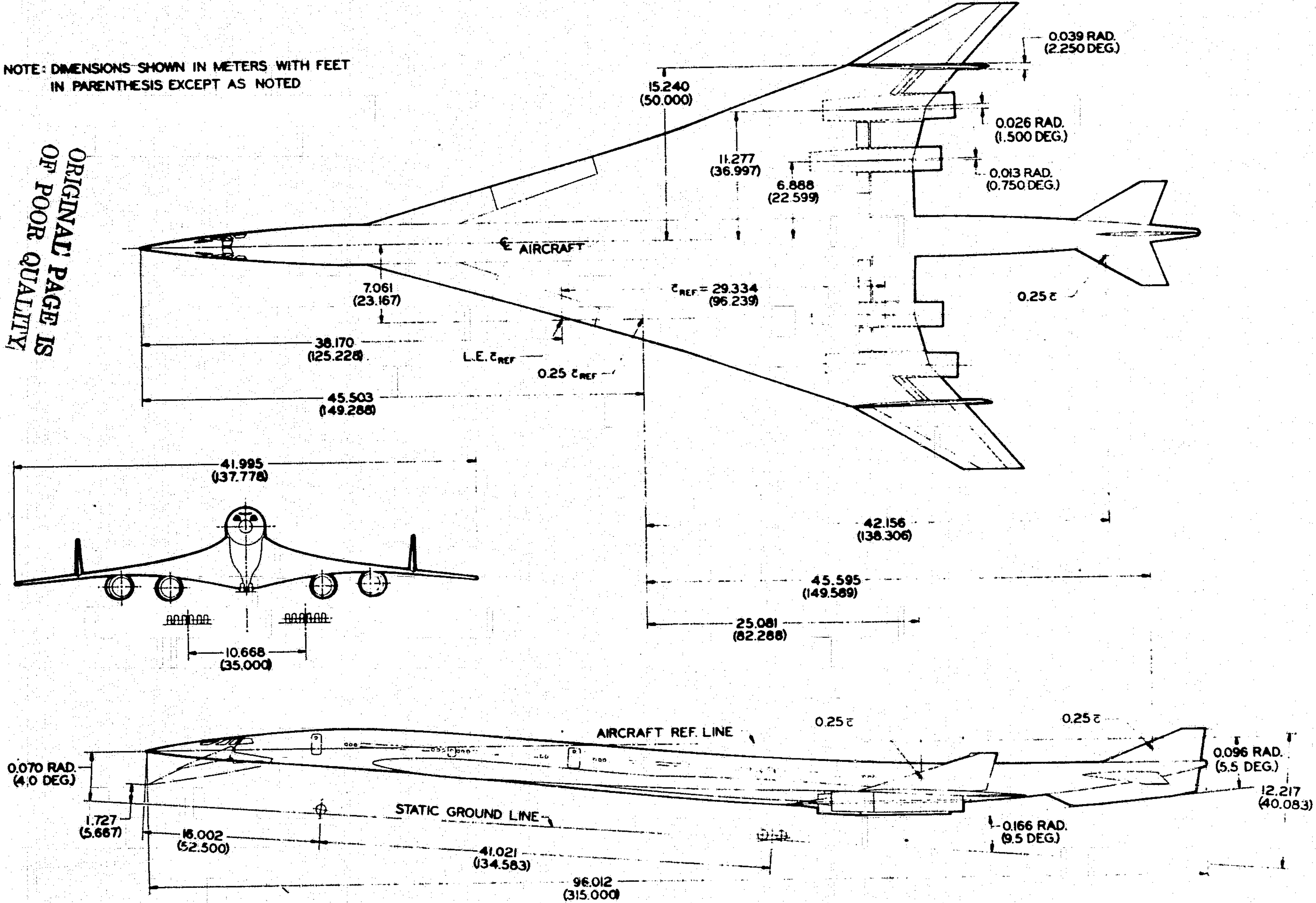
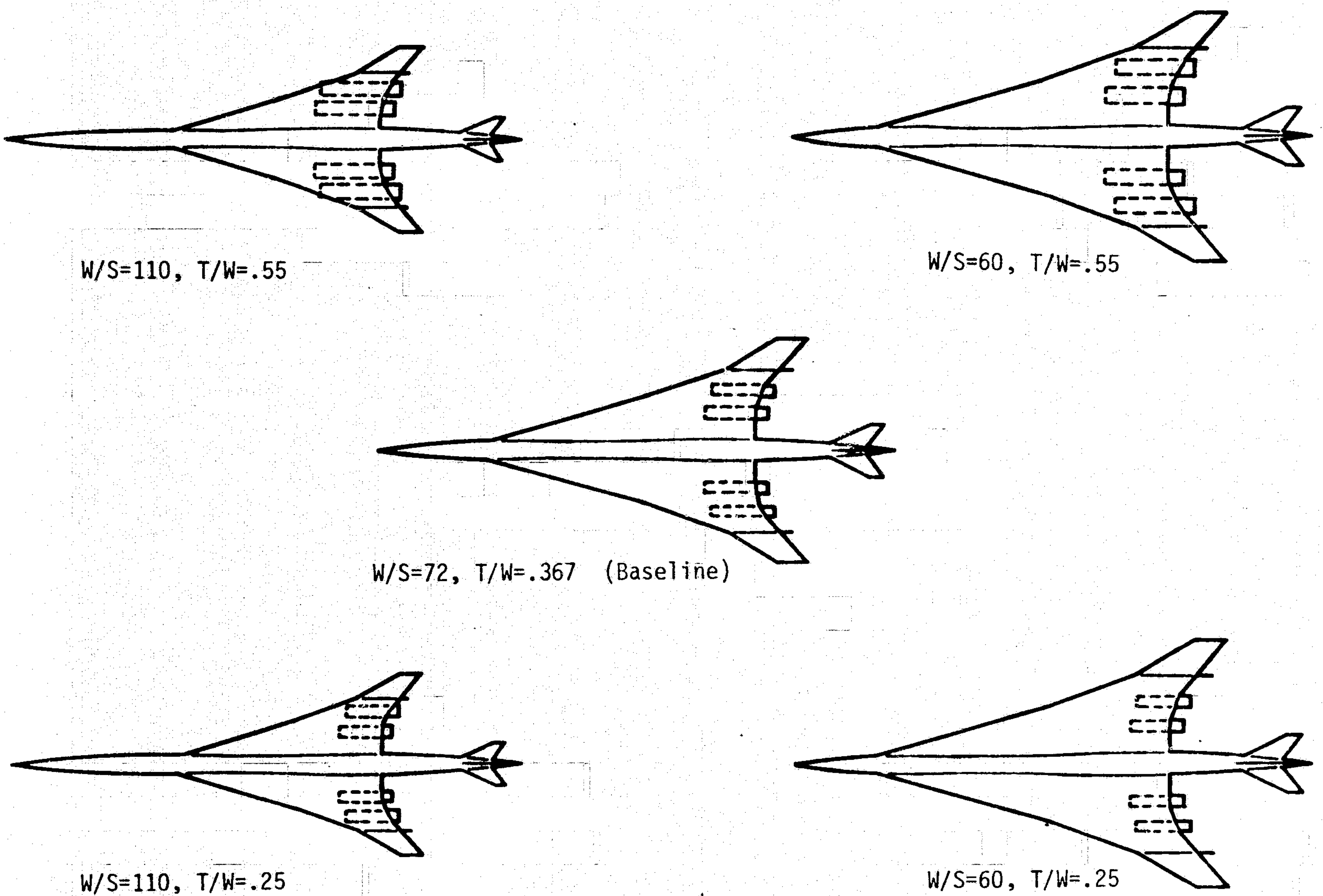


Figure 2.- Baseline aircraft, the AST-100.



W/S=110, T/W=.55

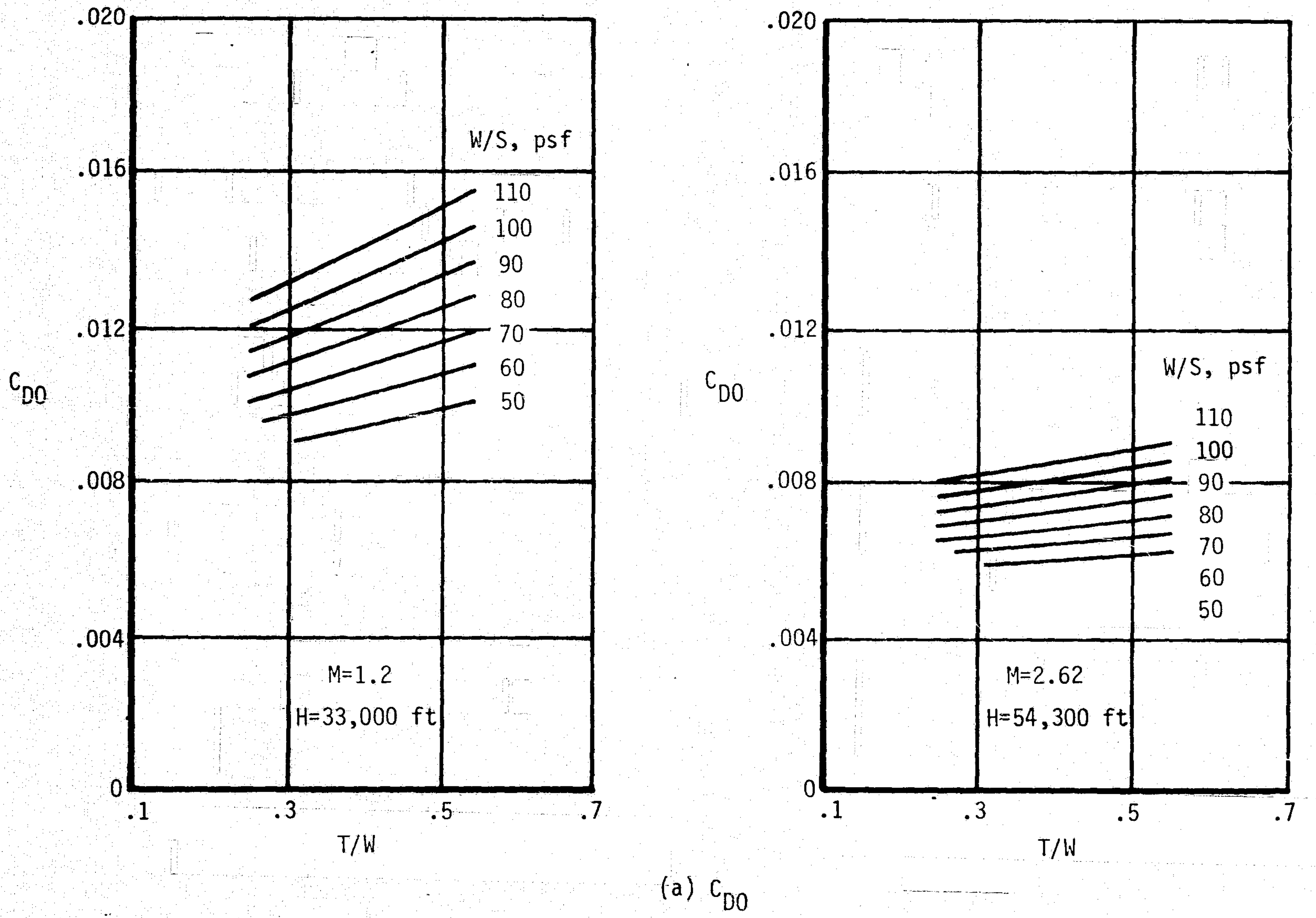
W/S=60, T/W=.55

W/S=72, T/W=.367 (Baseline)

W/S=110, T/W=.25

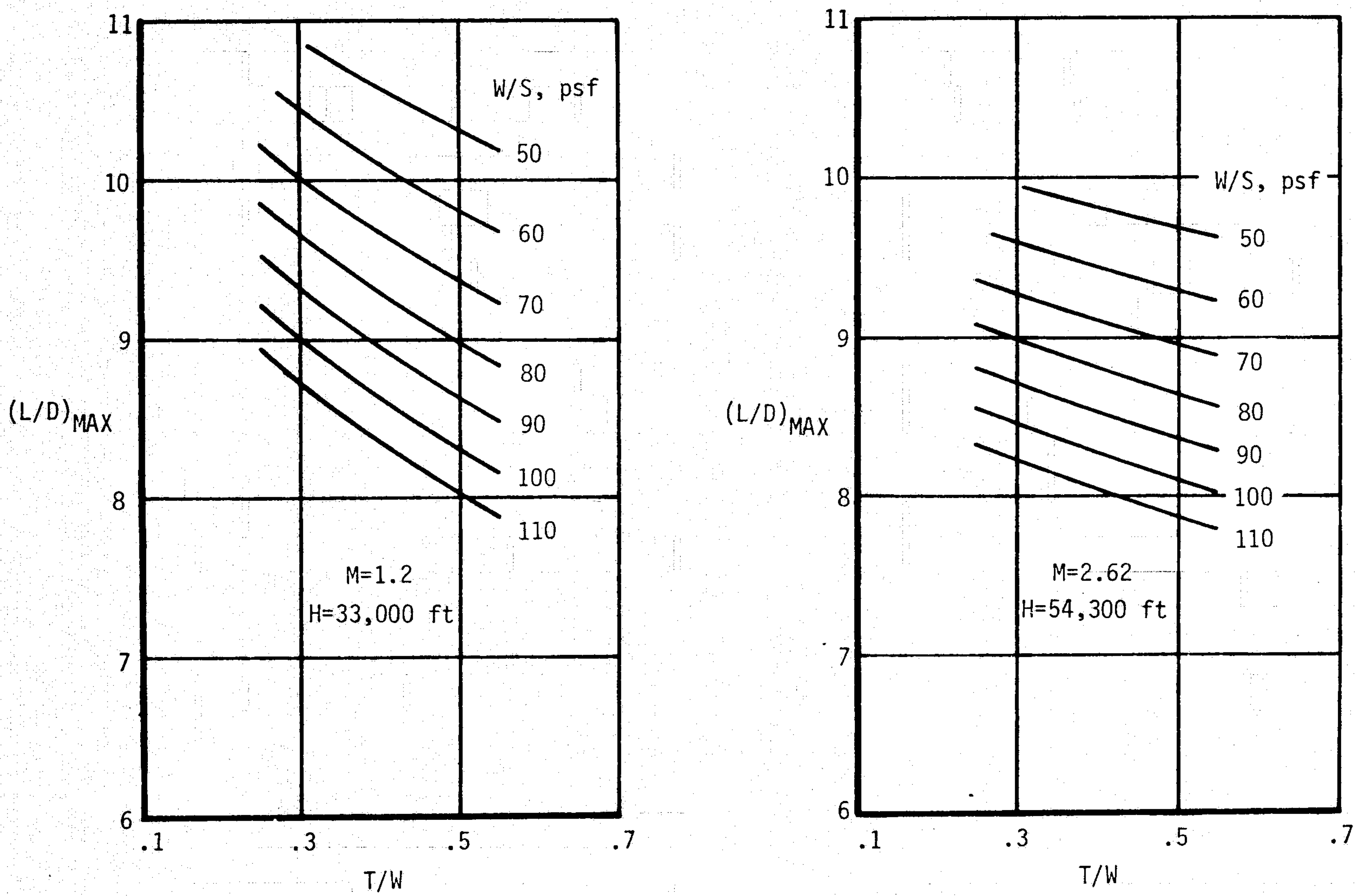
W/S=60, T/W=.25

Figure 3.- Comparison of planform arrangements.



(a) C_{DO}

Figure 4.- Sizing effects on aerodynamics.



(b) (L/D)$_{MAX}$

Figure 4.- Concluded.

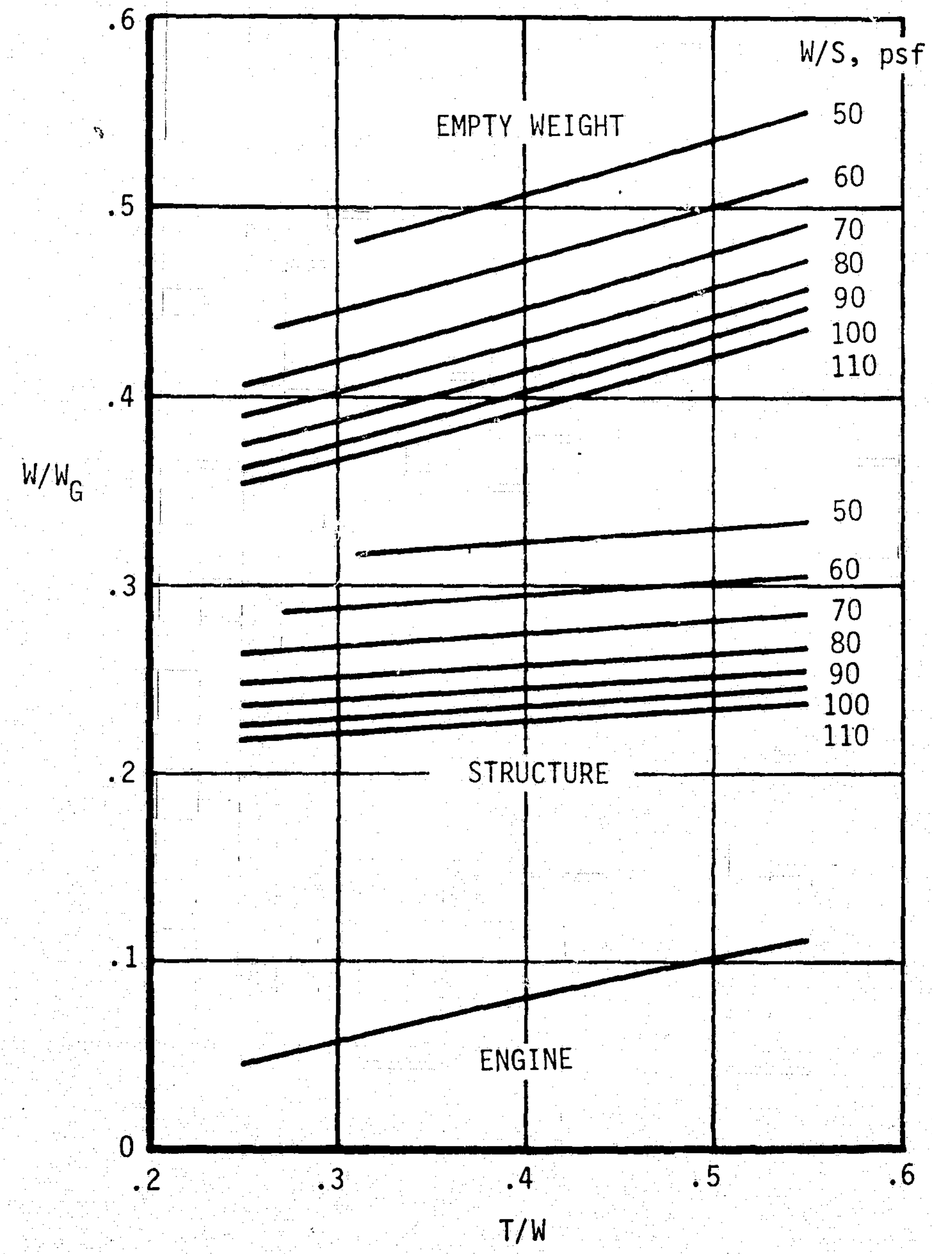


Figure 5. - Sizing effects on engine, structure, and empty weight.

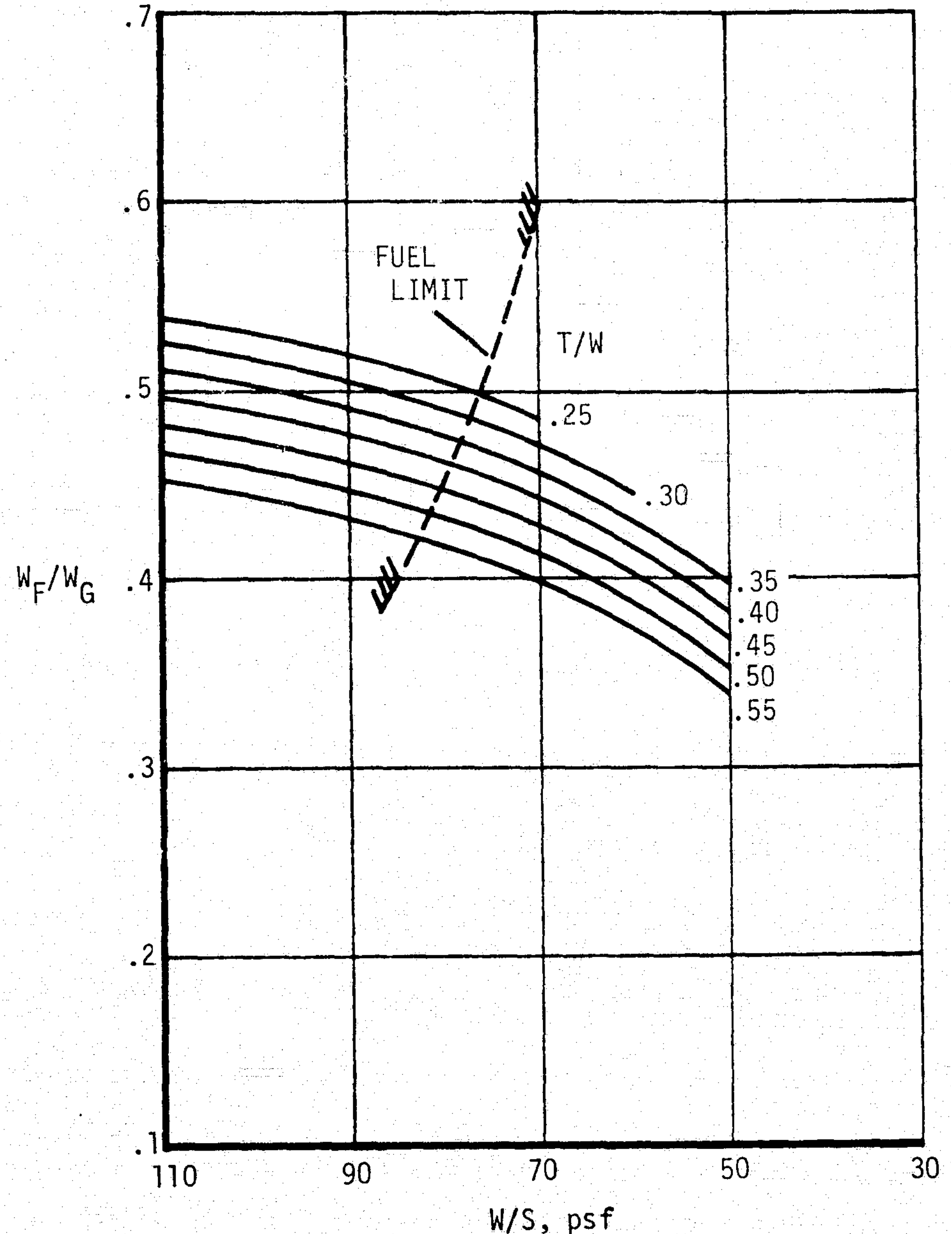
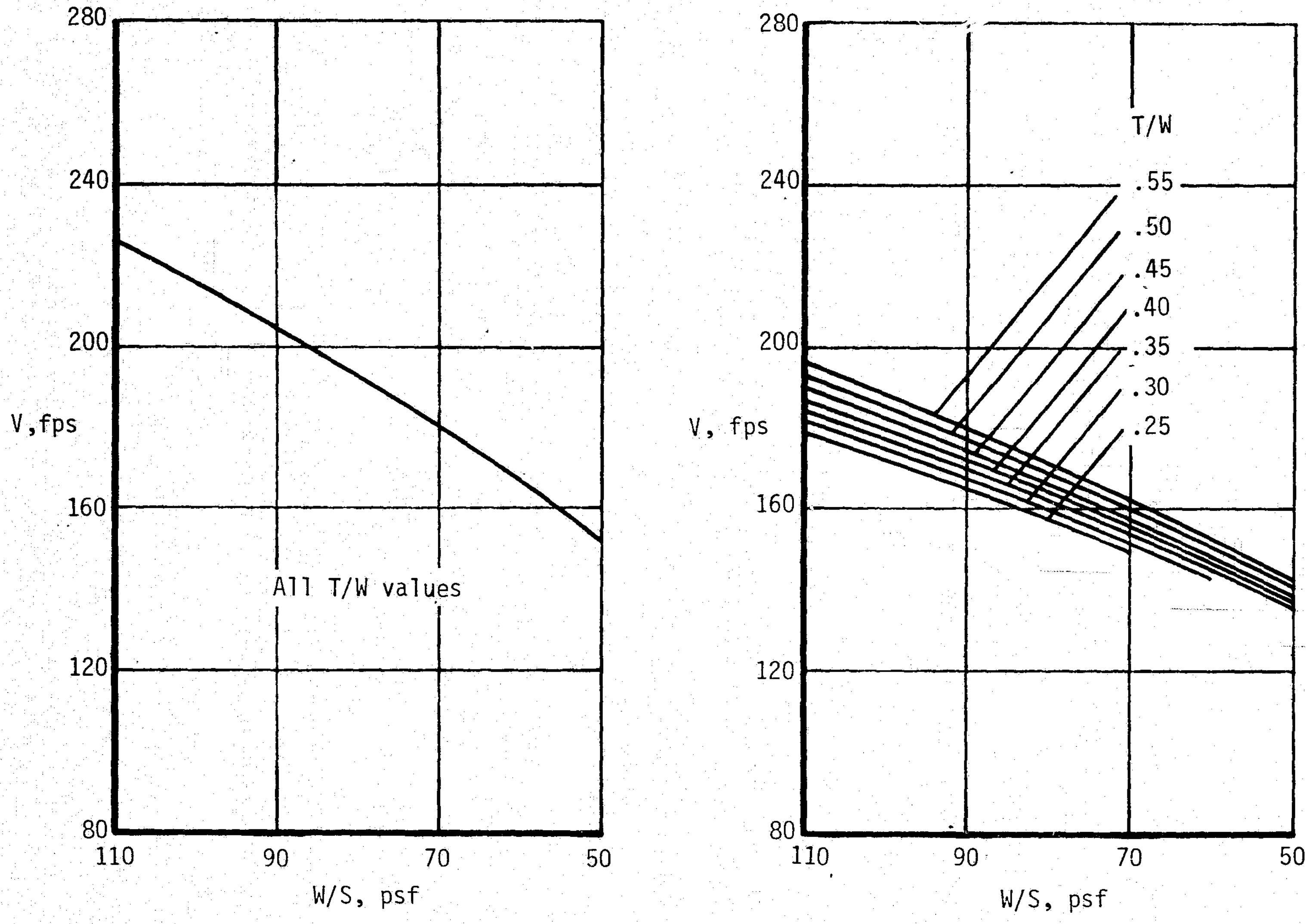


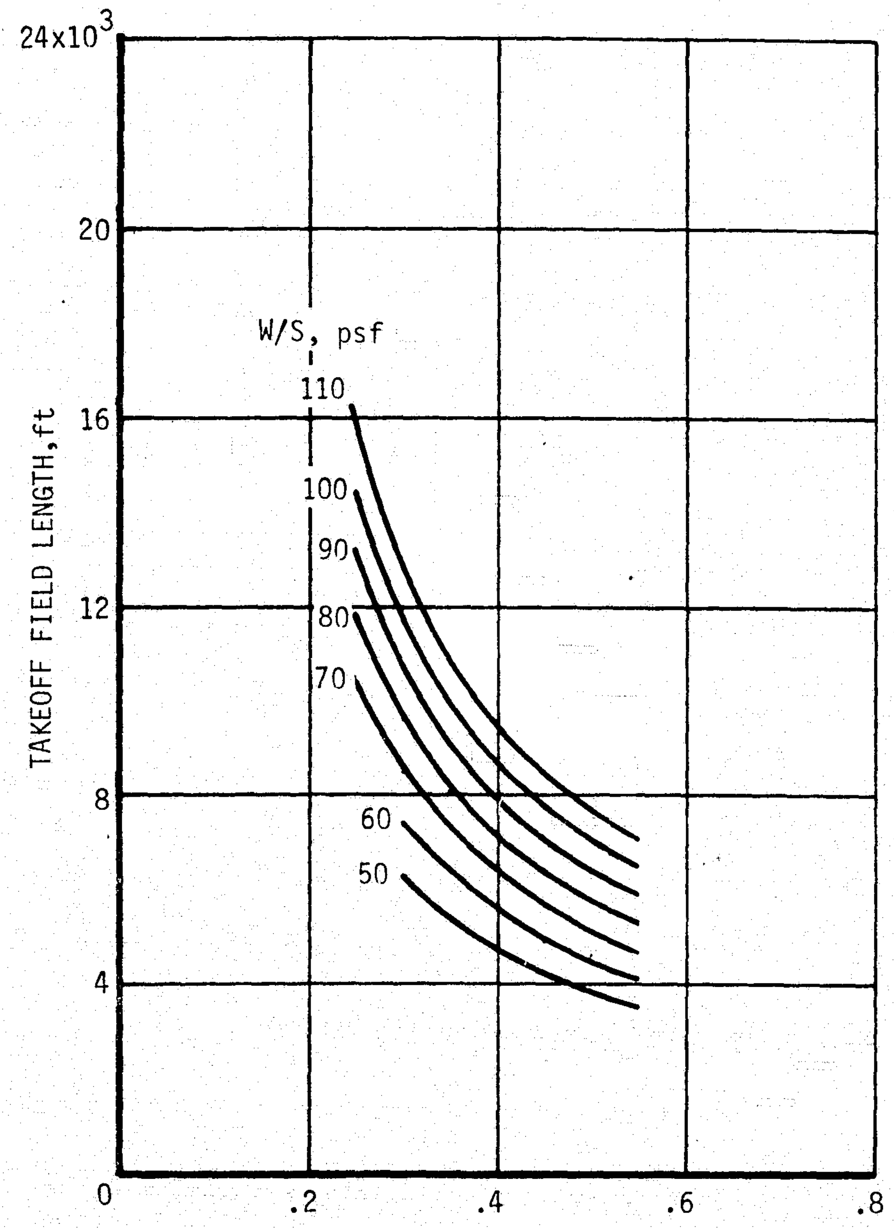
Figure 6.- Sizing effects on available fuel weight.



(a) Takeoff speed

(b) Approach speed

Figure 7.- Sizing effects on takeoff, and approach characteristics.



(c) Takeoff field lengths

Figure 7.- Concluded.

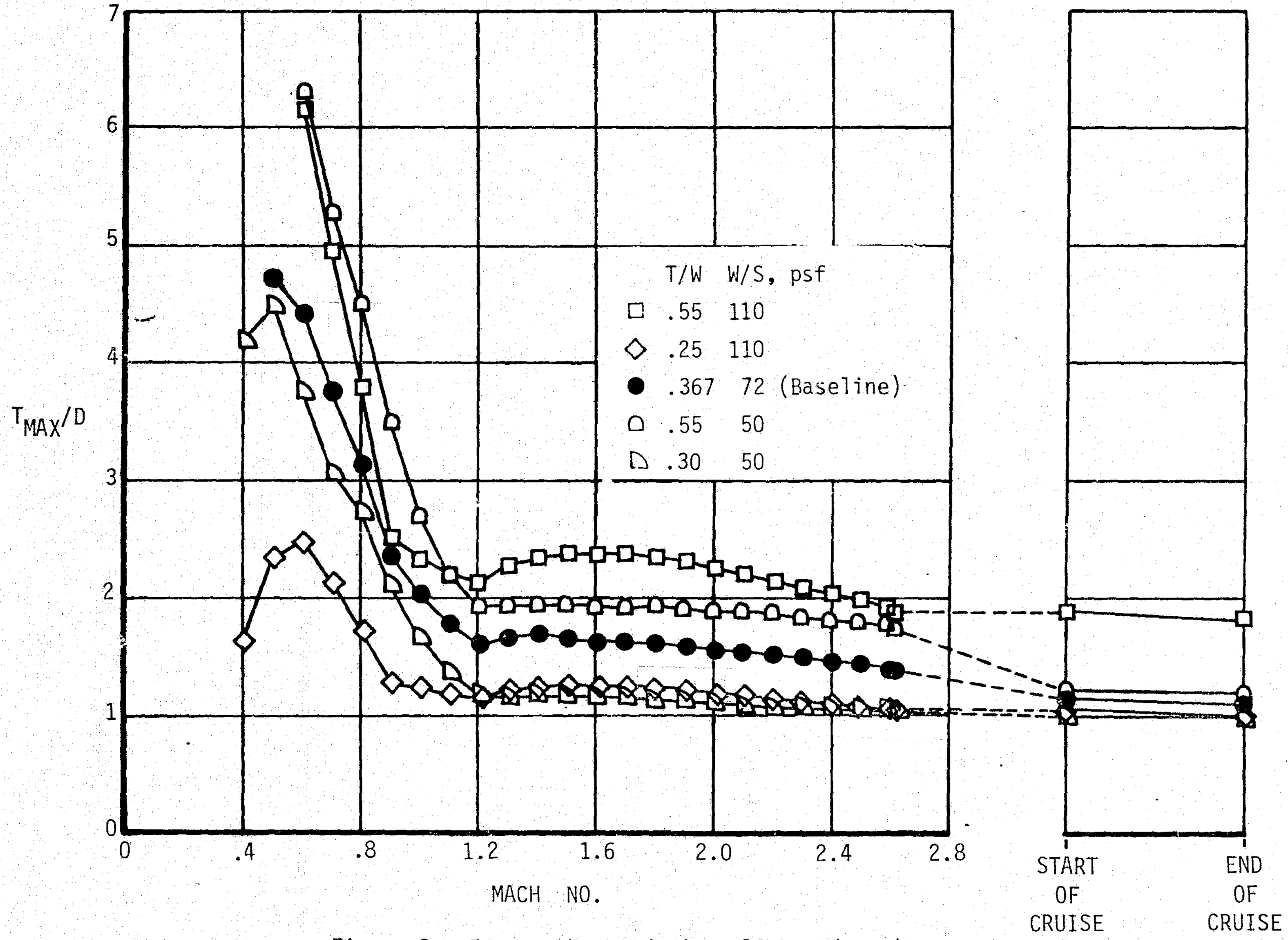
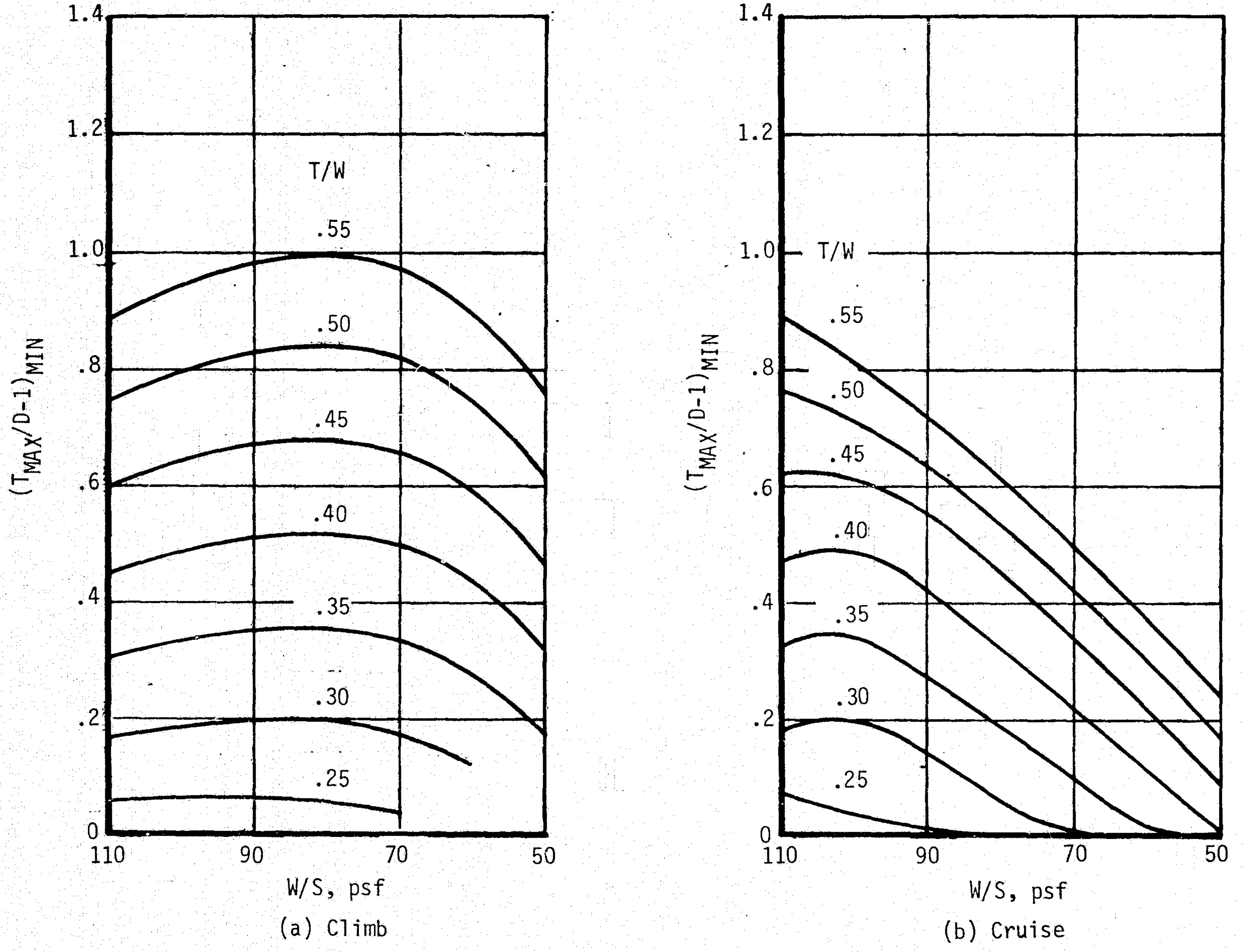


Figure 8.- Excess thrust during climb and cruise.



(a) Climb

(b) Cruise

Figure 9.- Sizing effects on minimun thrust margins.

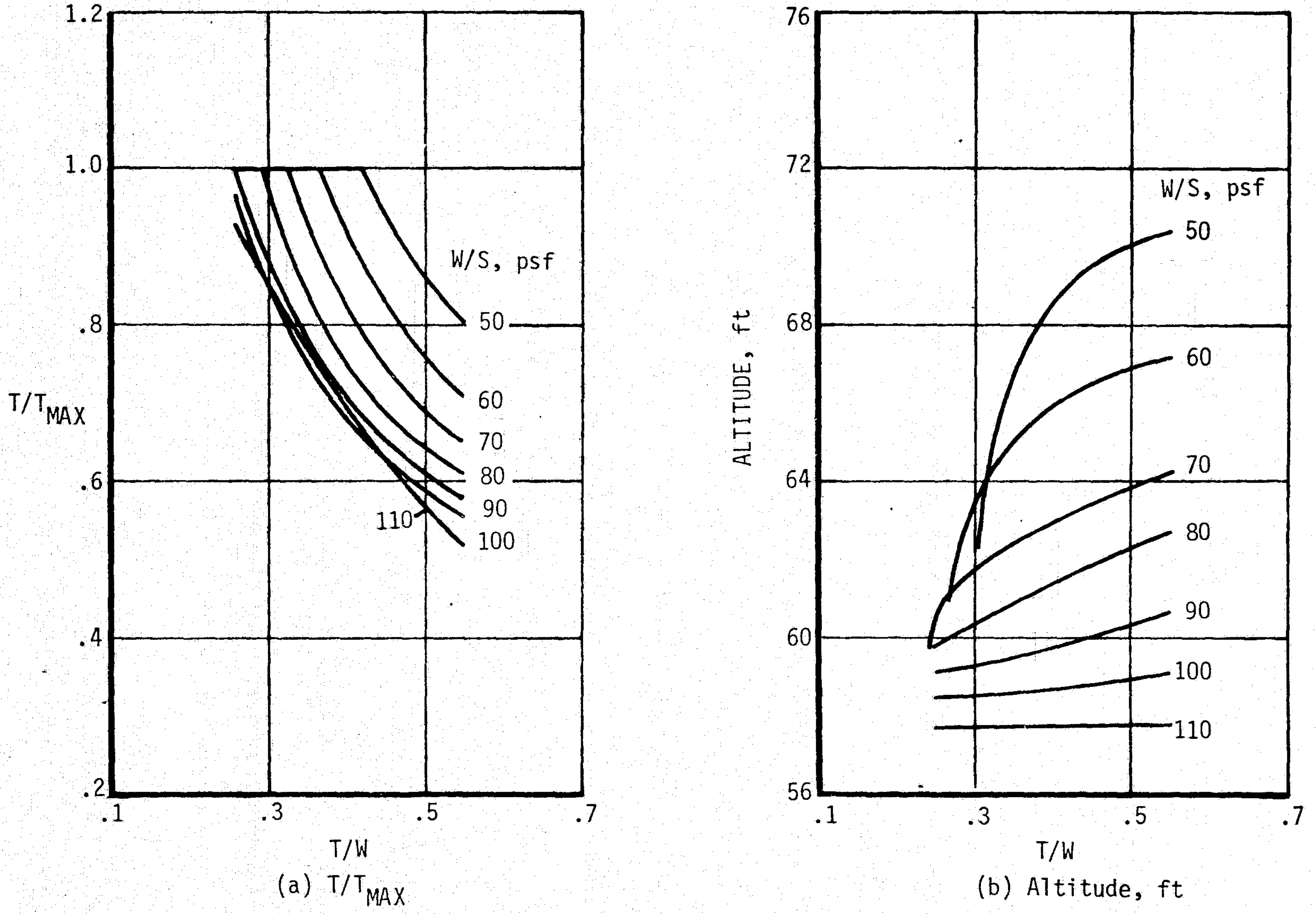
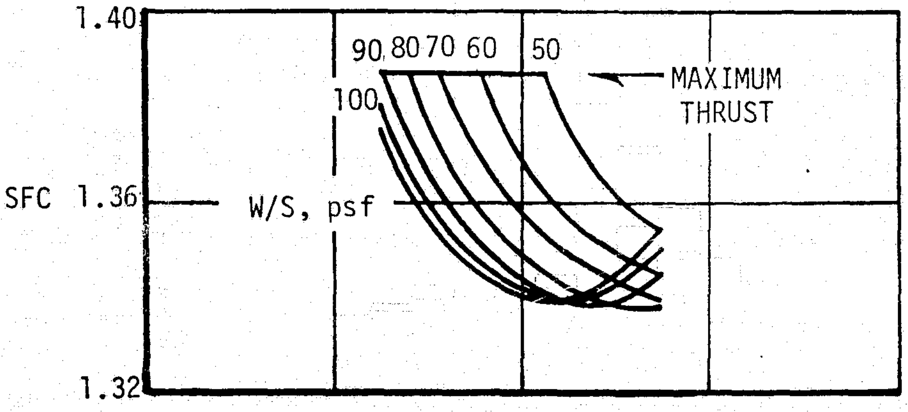
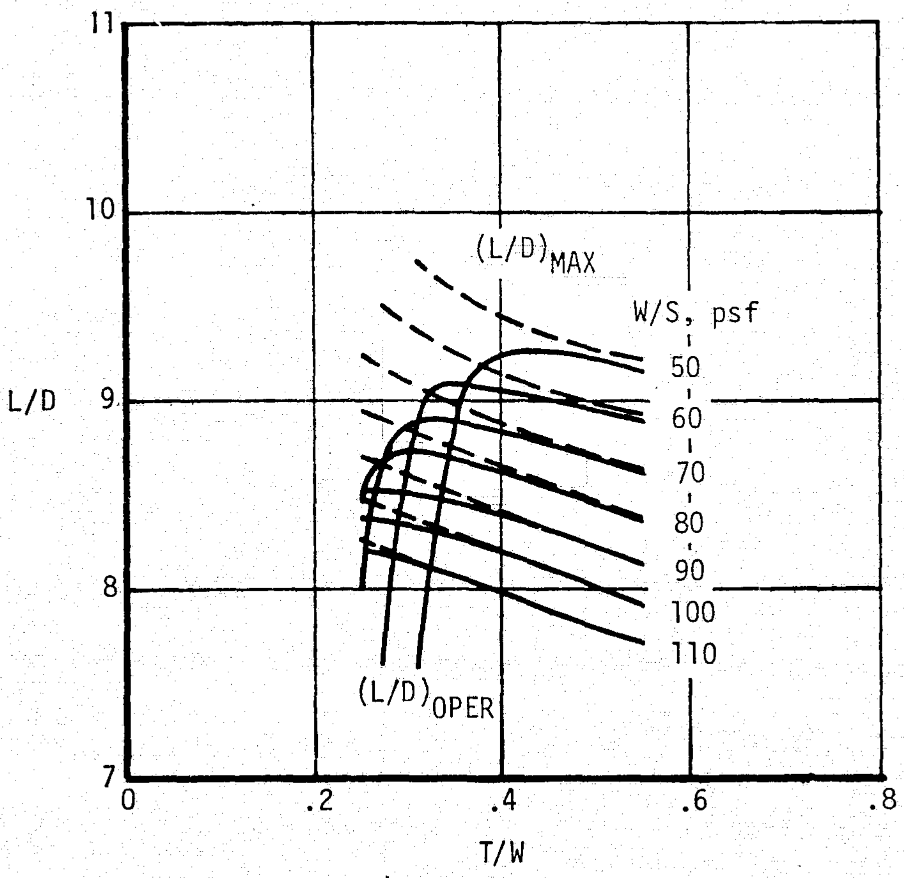


Figure 10. - Sizing effects on conditions at the start of supersonic cruise.

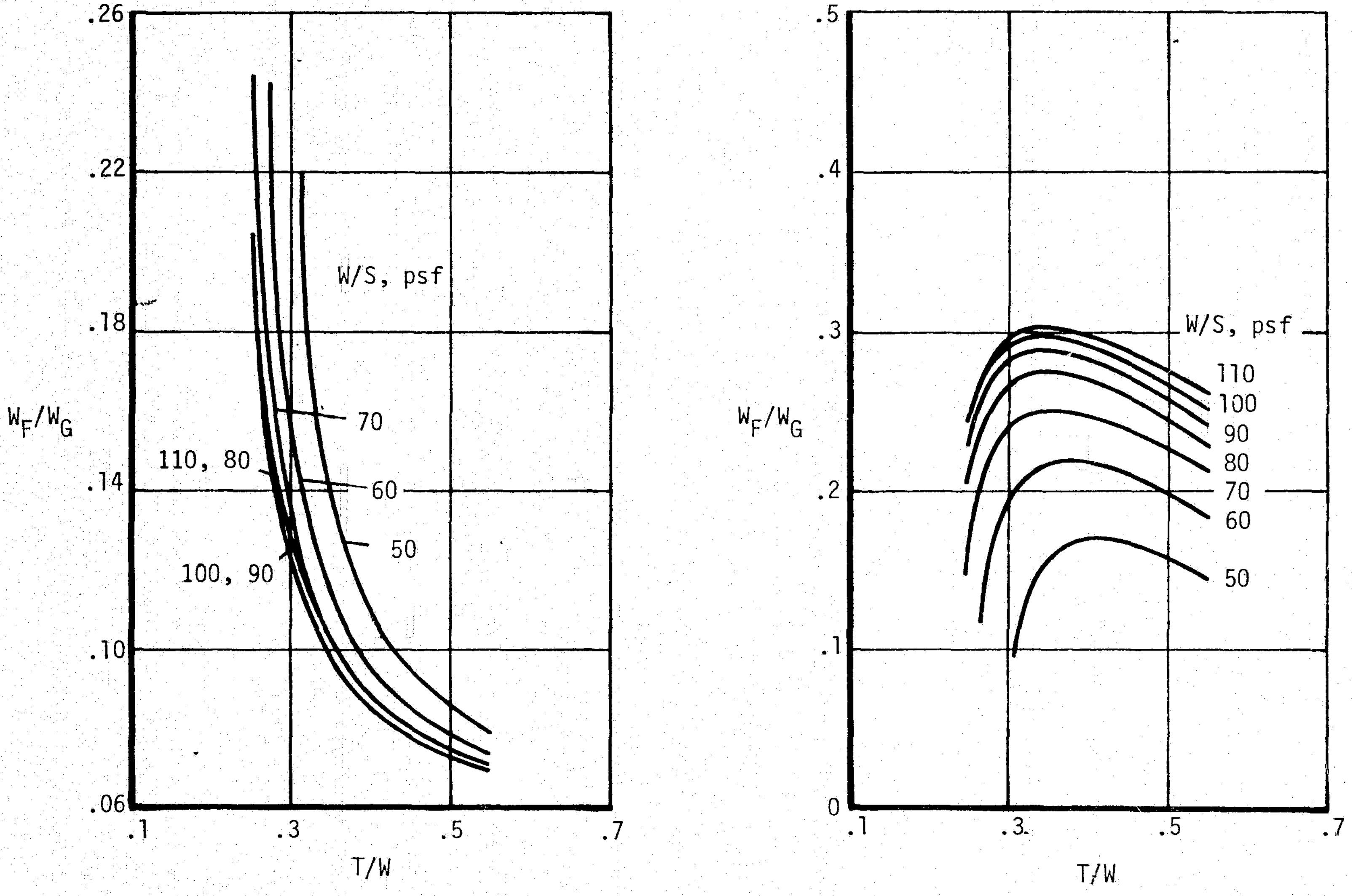


(d) Specific fuel consumption



(c) Lift-drag ratio

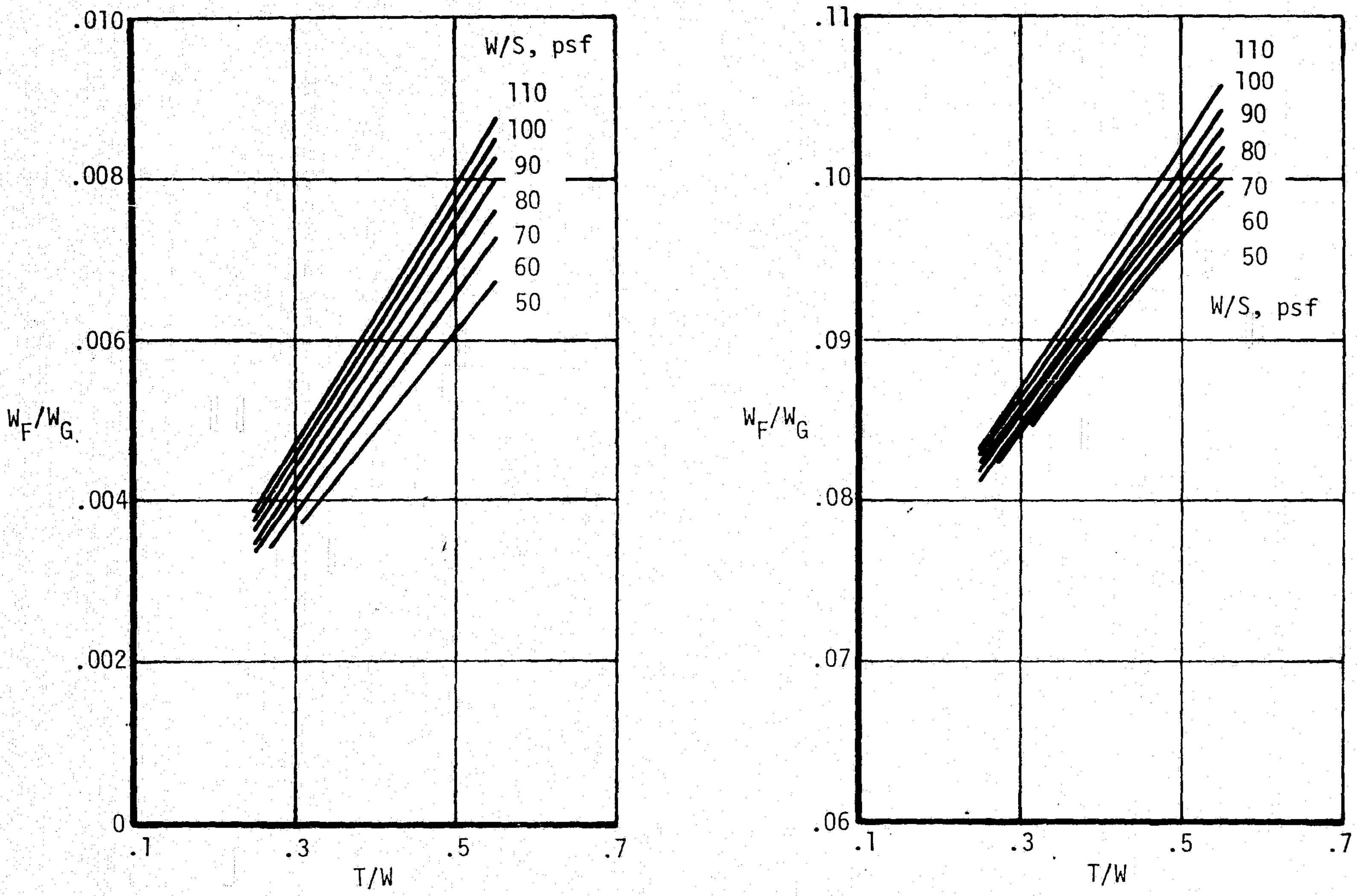
Figure 10. - Concluded.



(a) Climb

(b) Cruise

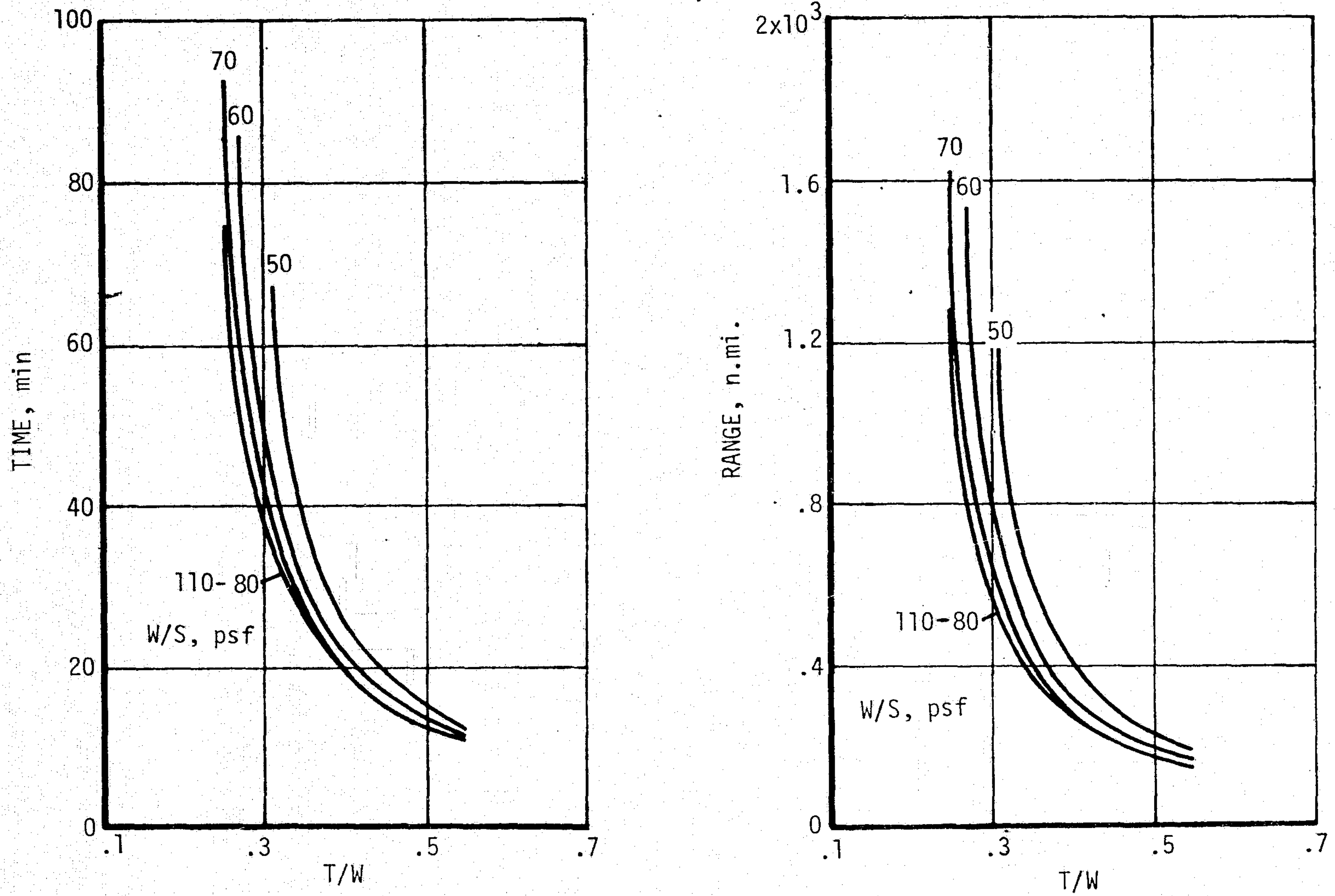
Figure 11.- Sizing effects on fuel consumption.



(c) Descent

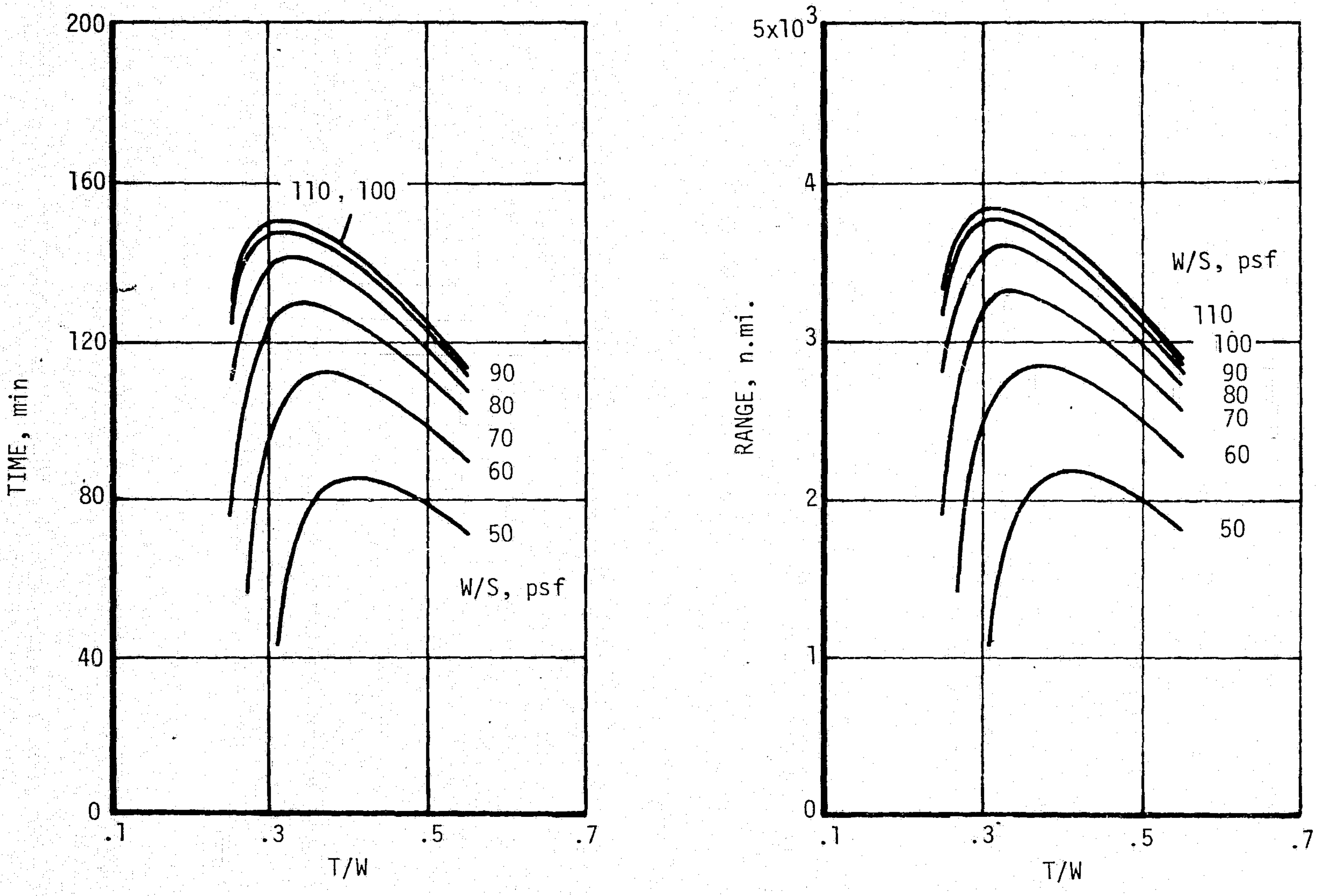
(d) Reserves

Figure 11.- Concluded.



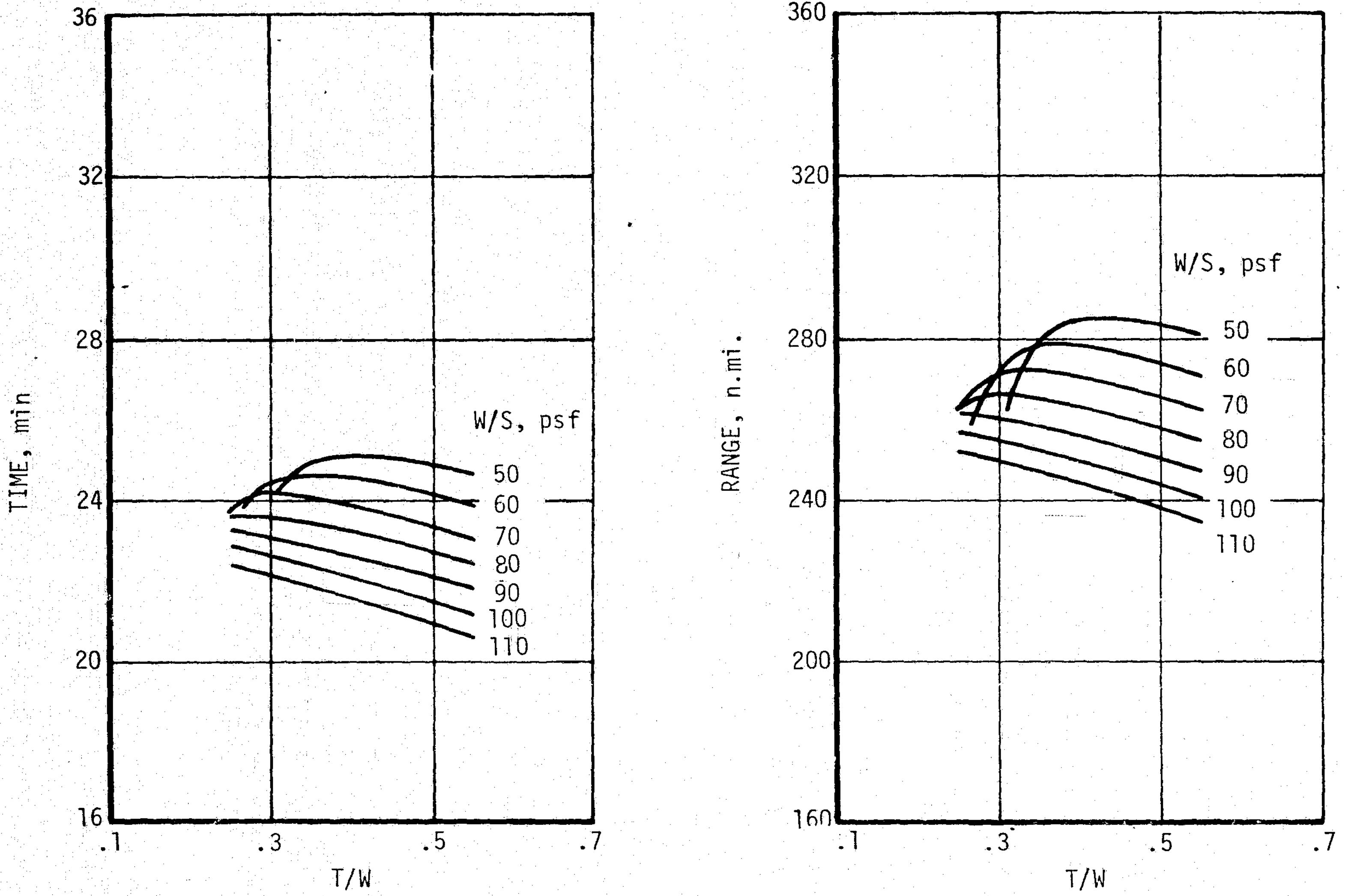
(a) Climb

Figure 12.- Sizing effects on time and range.



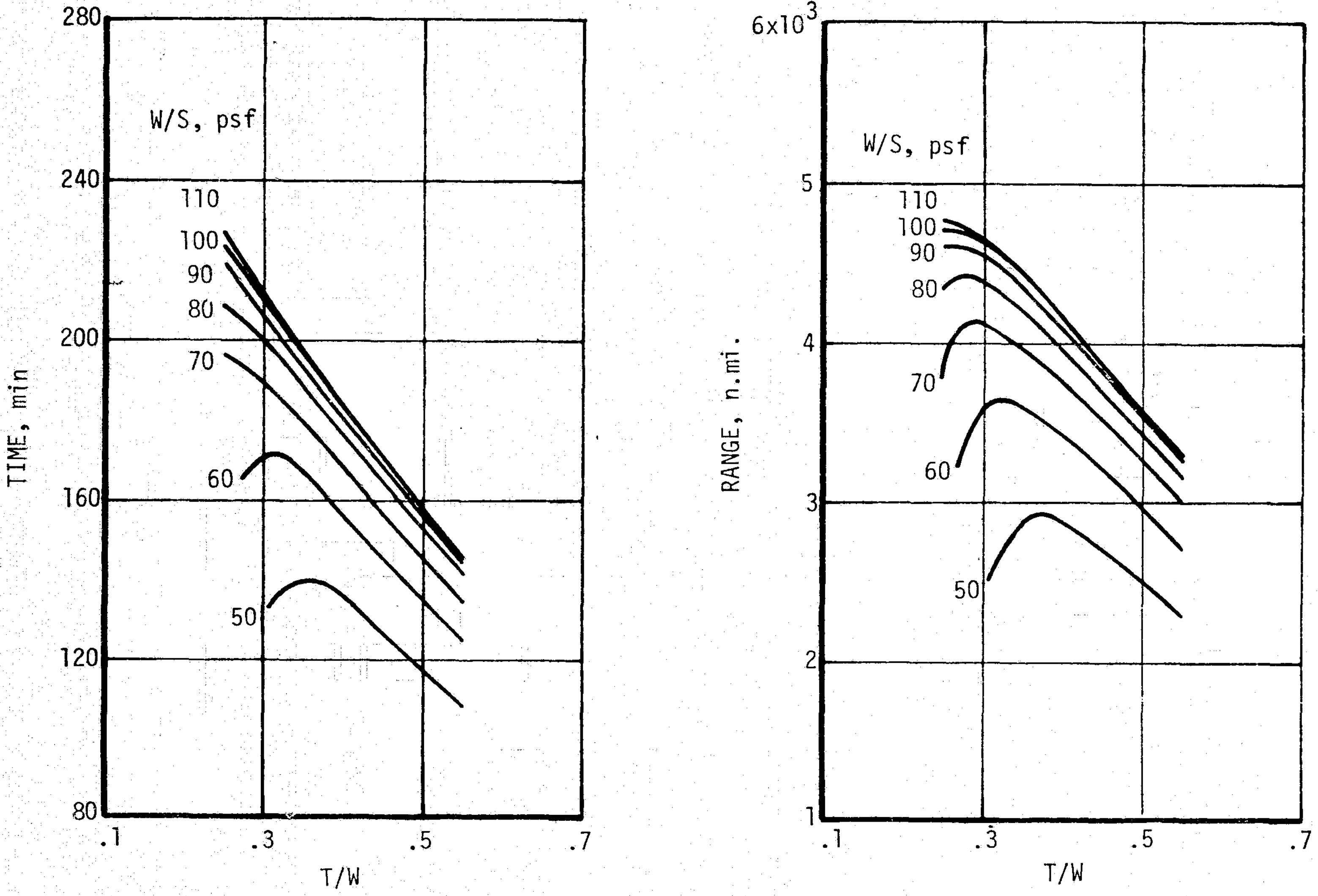
(b) Cruise

Figure 12.- Continued.



(c) Descent

Figure 12.- Continued.



(d) Total

Figure 12.- Concluded.

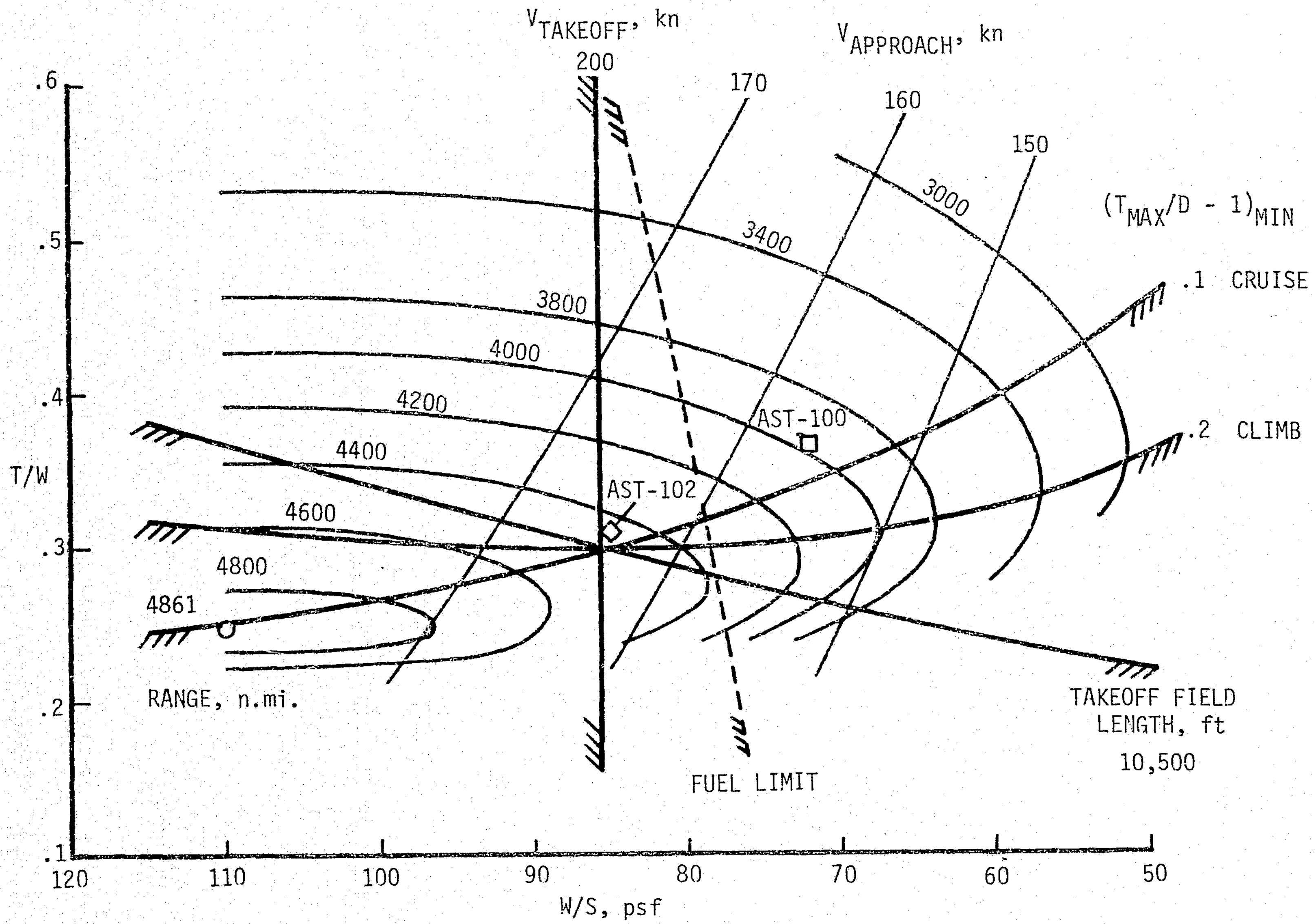


Figure 13. - Thumbprint. W_G = 718,000 lb.; M_c = 2.62; Passengers = 292; Standard + 8°C day; $\delta_f = 20°$.

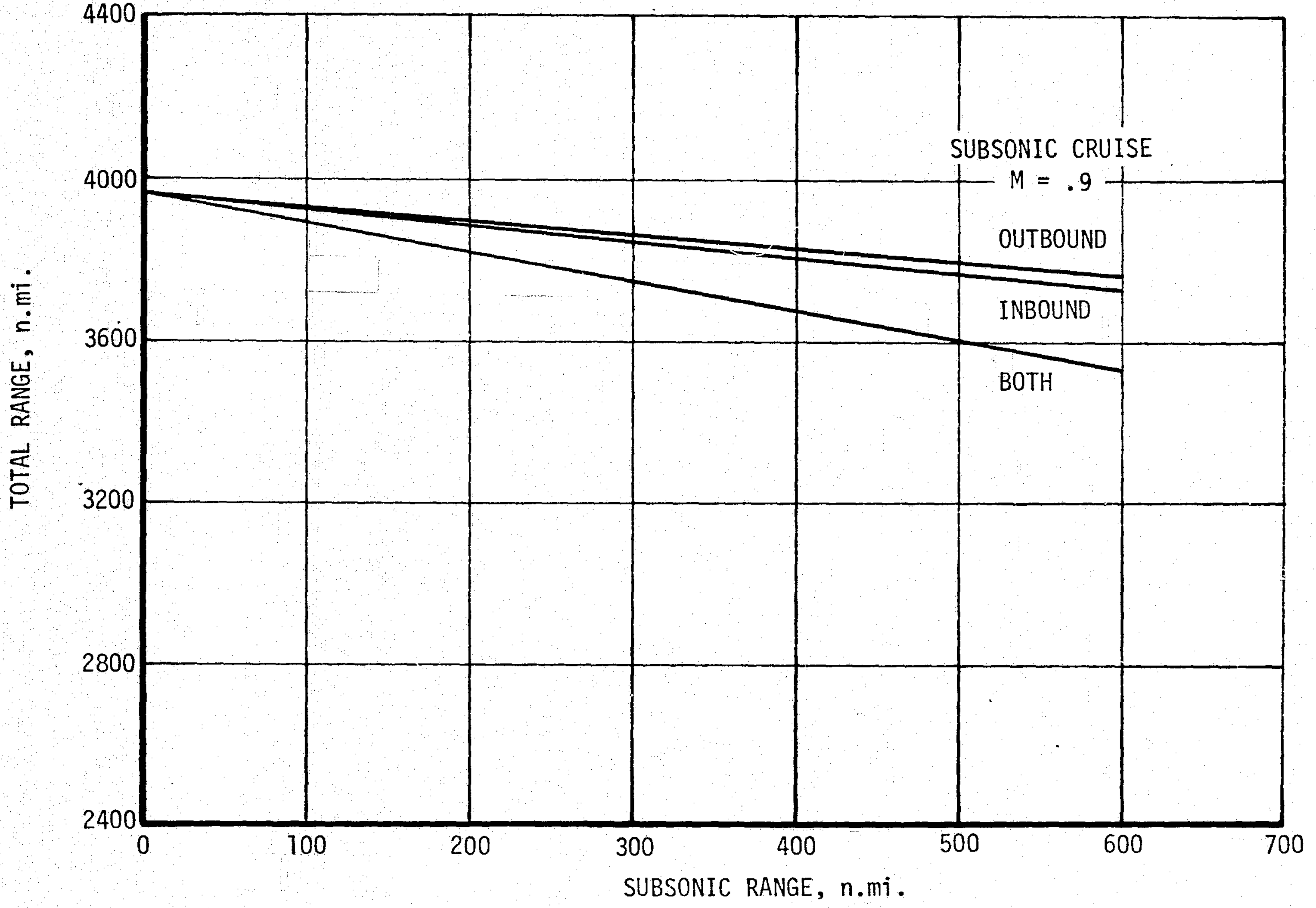


Figure 14.- Effect of outbound and inbound subsonic cruise range on total range of baseline aircraft.

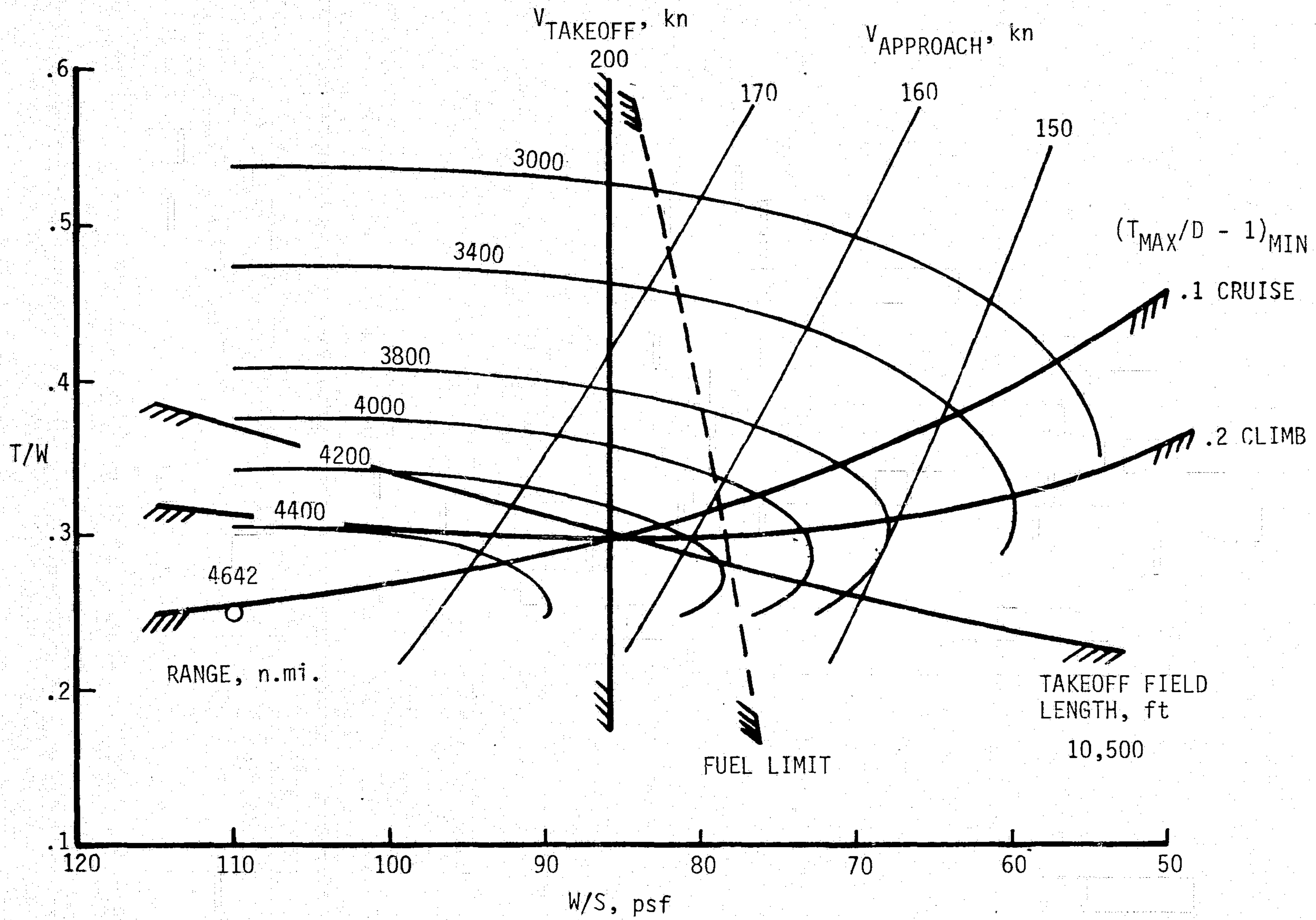


Figure 15. - Thumbprint for aircraft with 600 n.mi. inbound subsonic cruise, W_G = 718,000 lb.; M_c = 2.62; Passengers = 262; Standard + 8°C day; δ_f = 20°

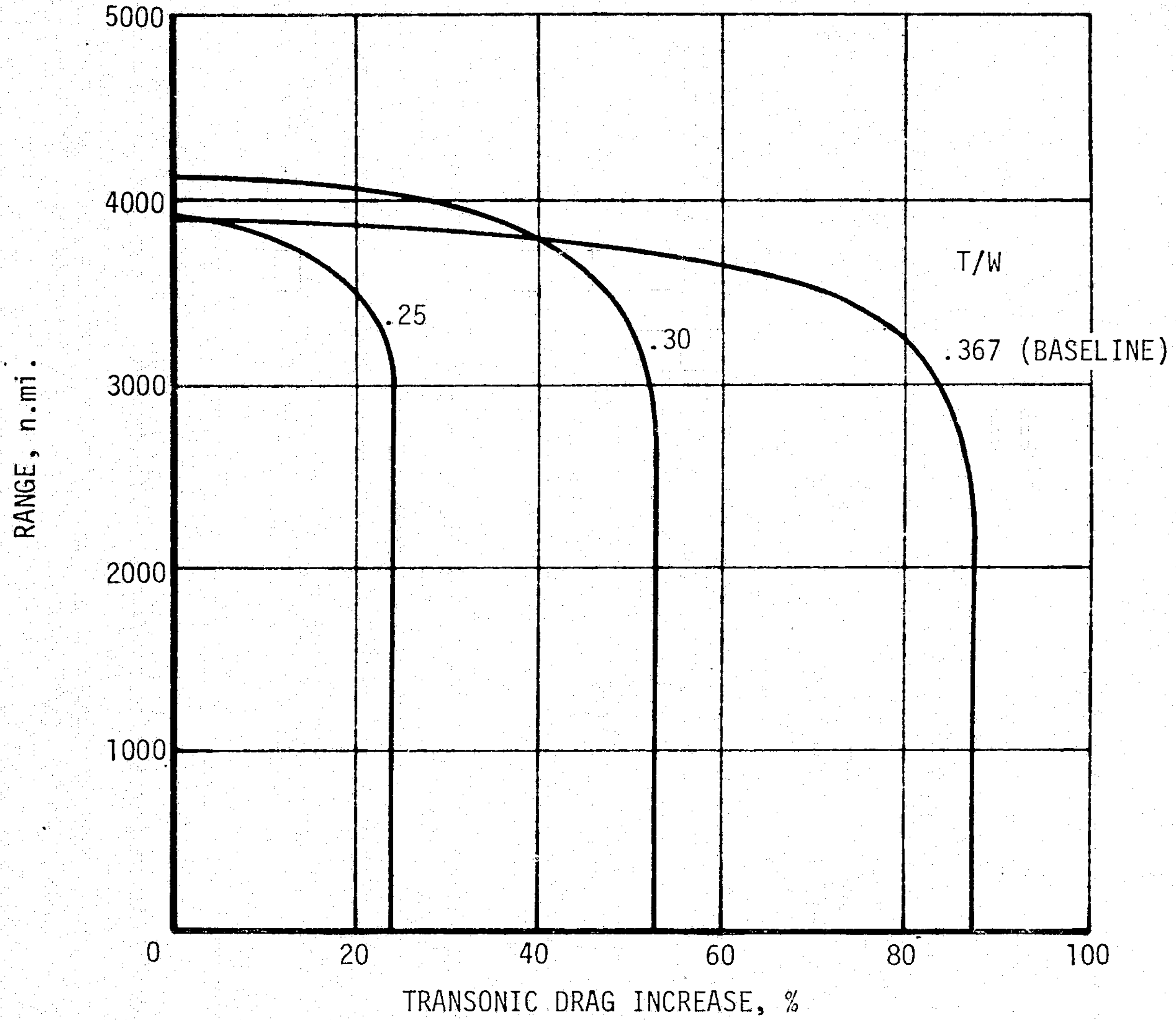
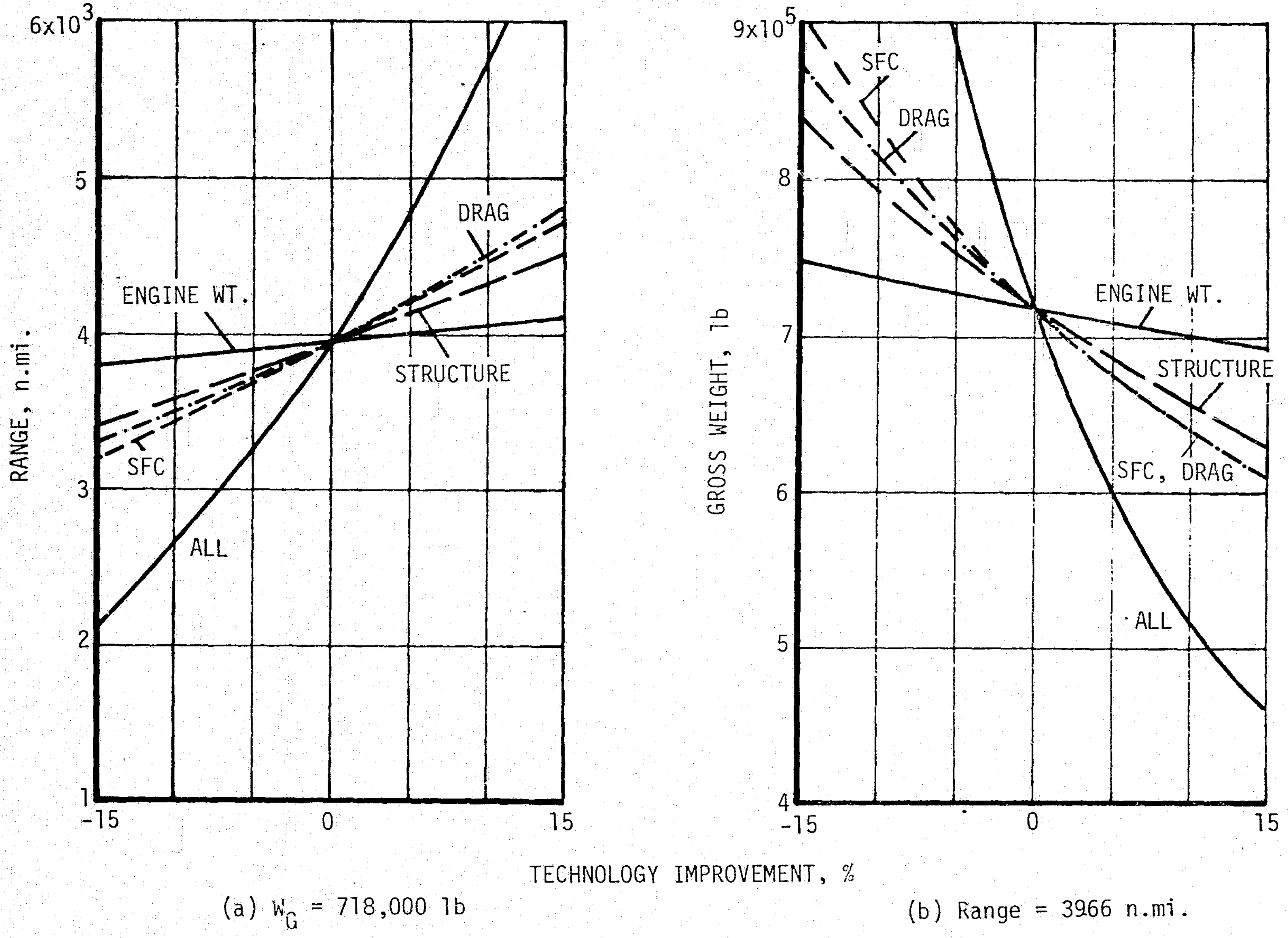


Figure 16. - Effect of transonic drag increase on total range. W_G = 718,000 lb; W/S = 72 psf; M_c = 2.62; Passengers = 292; Mach no. interval for drag increase, .9 to 1.4.



(a) W_G = 718,000 lb

(b) Range = 3966 n.mi.

Figure 17.- Technology improvements in range and gross weight for baseline aircraft.

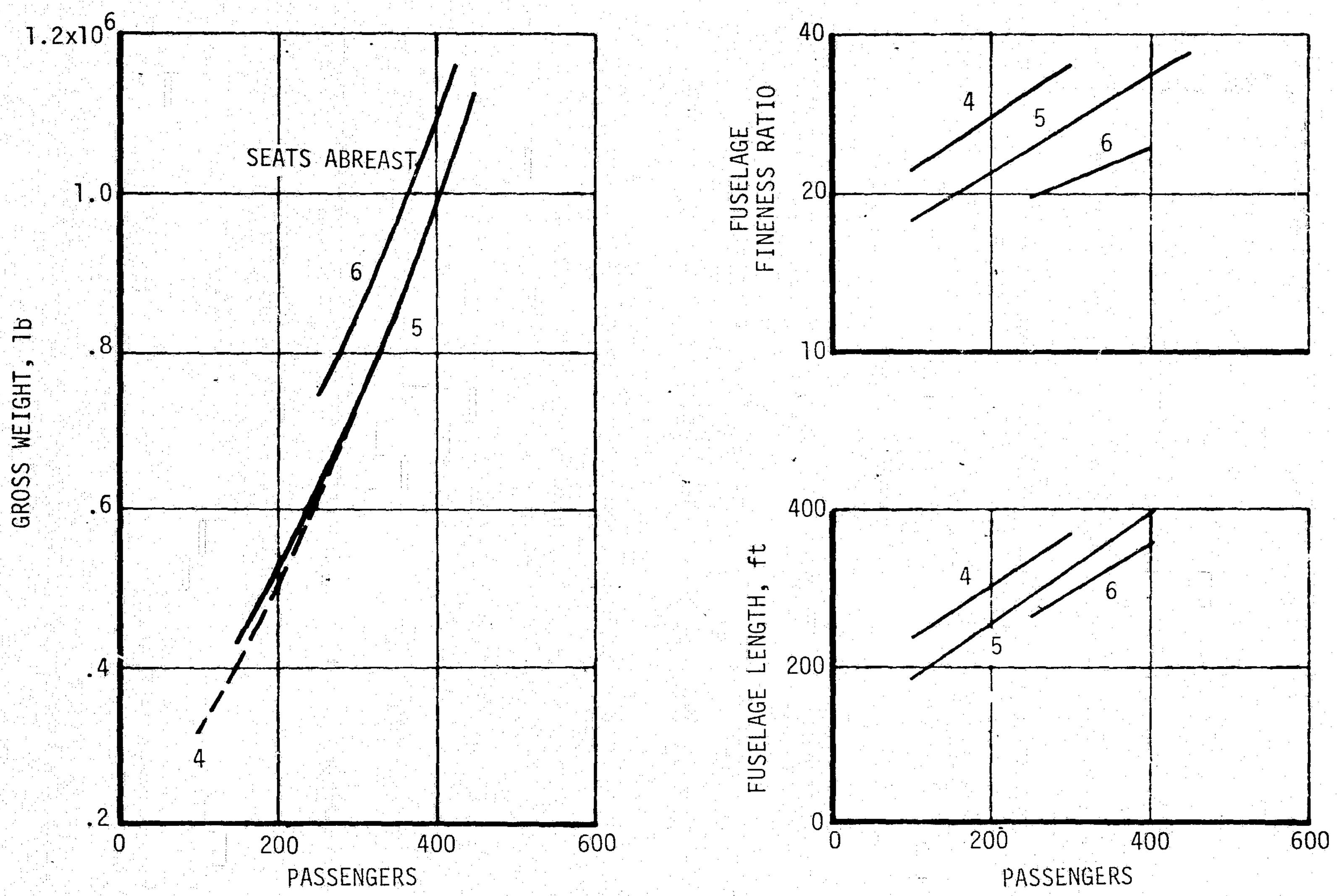
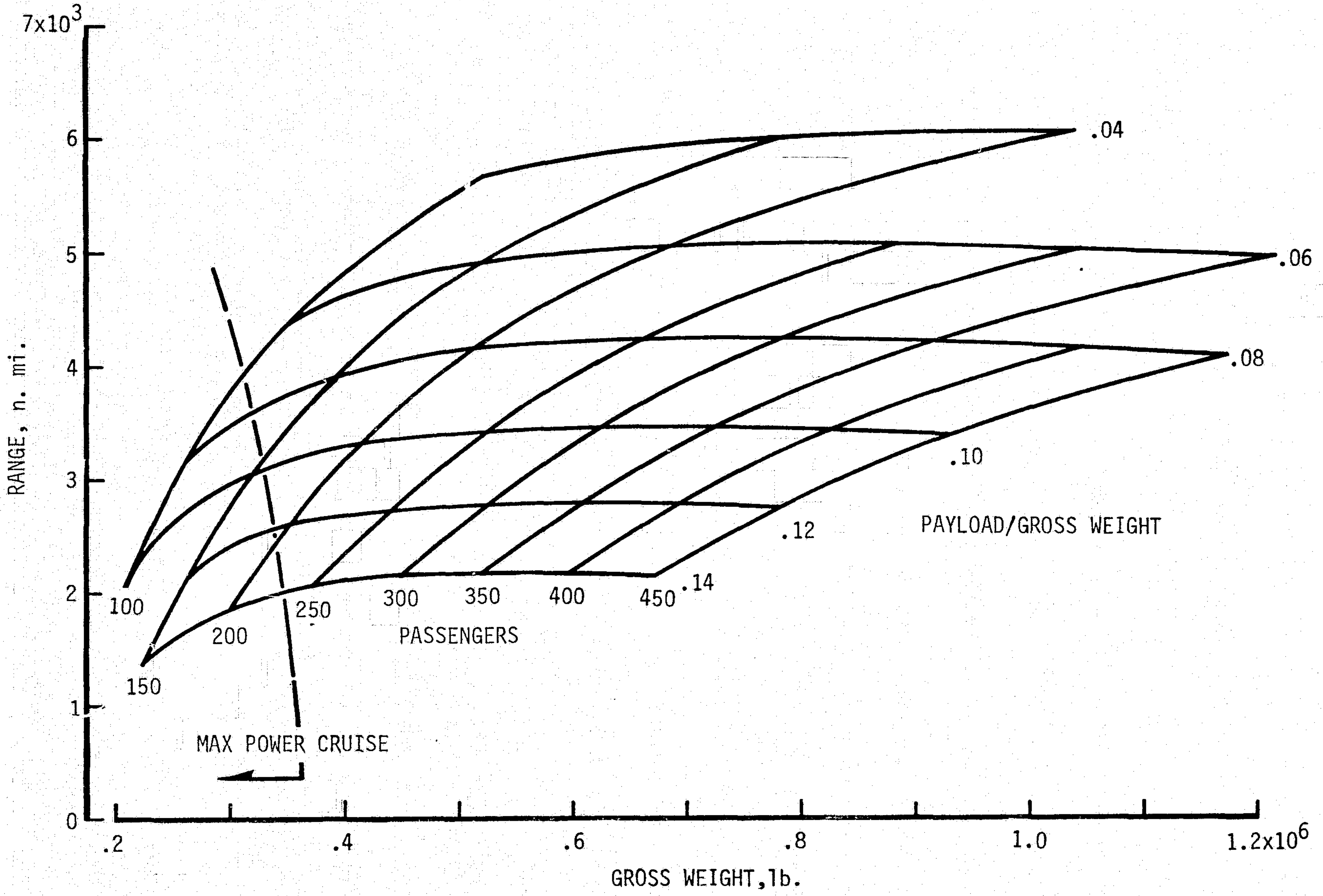
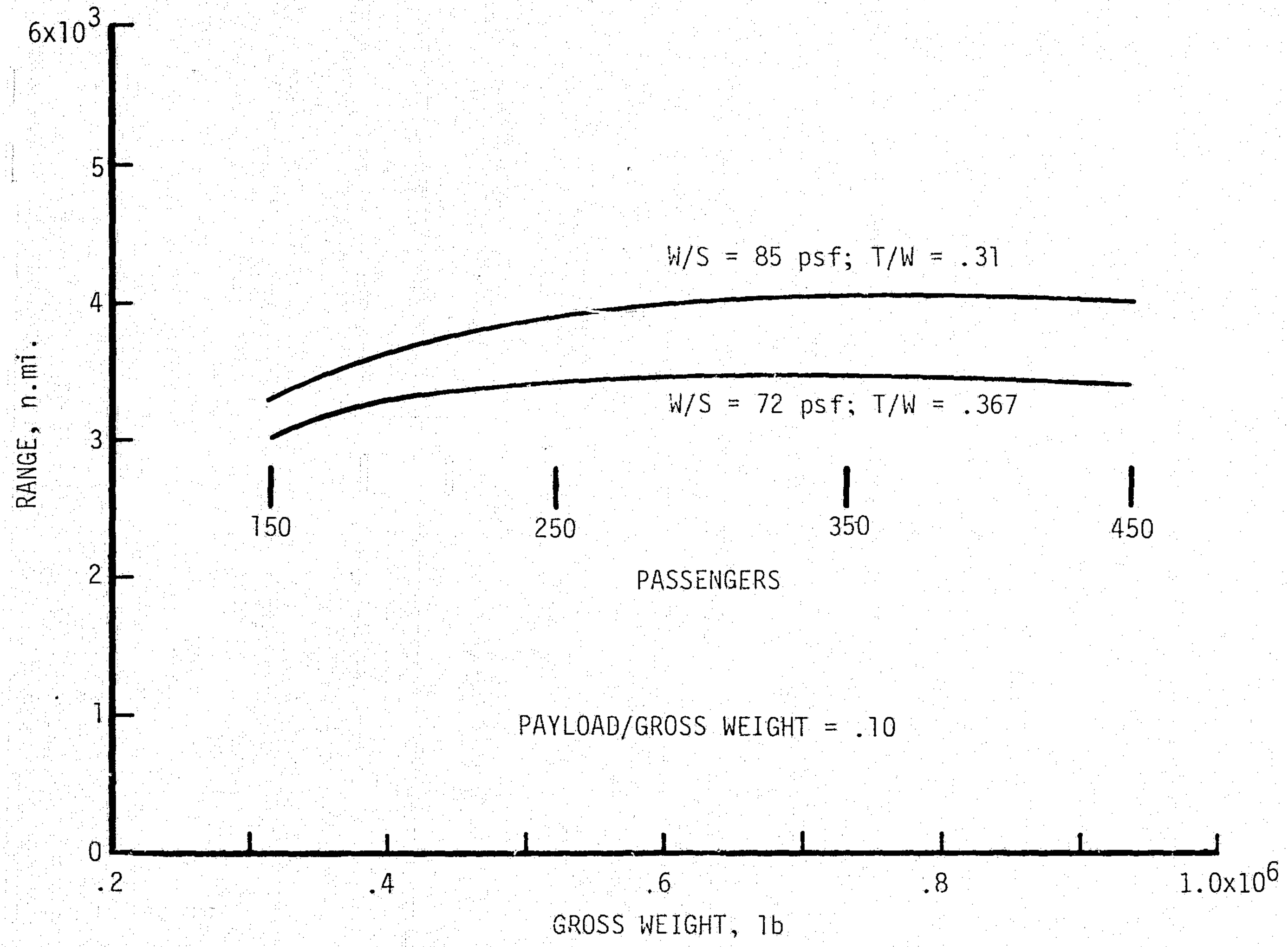


Figure 18.- Effect of abreast seating on aircraft gross weight and fuselage size for a range of 4000 n.mi. T/W = .367; W/S = 72 psf.



(a) T/W = .367; W/S = 72 psf.

Figure 19.-Range capability at various passenger and gross weight combinations.



(b) Varying W/S and T/W

Figure 19.- Concluded

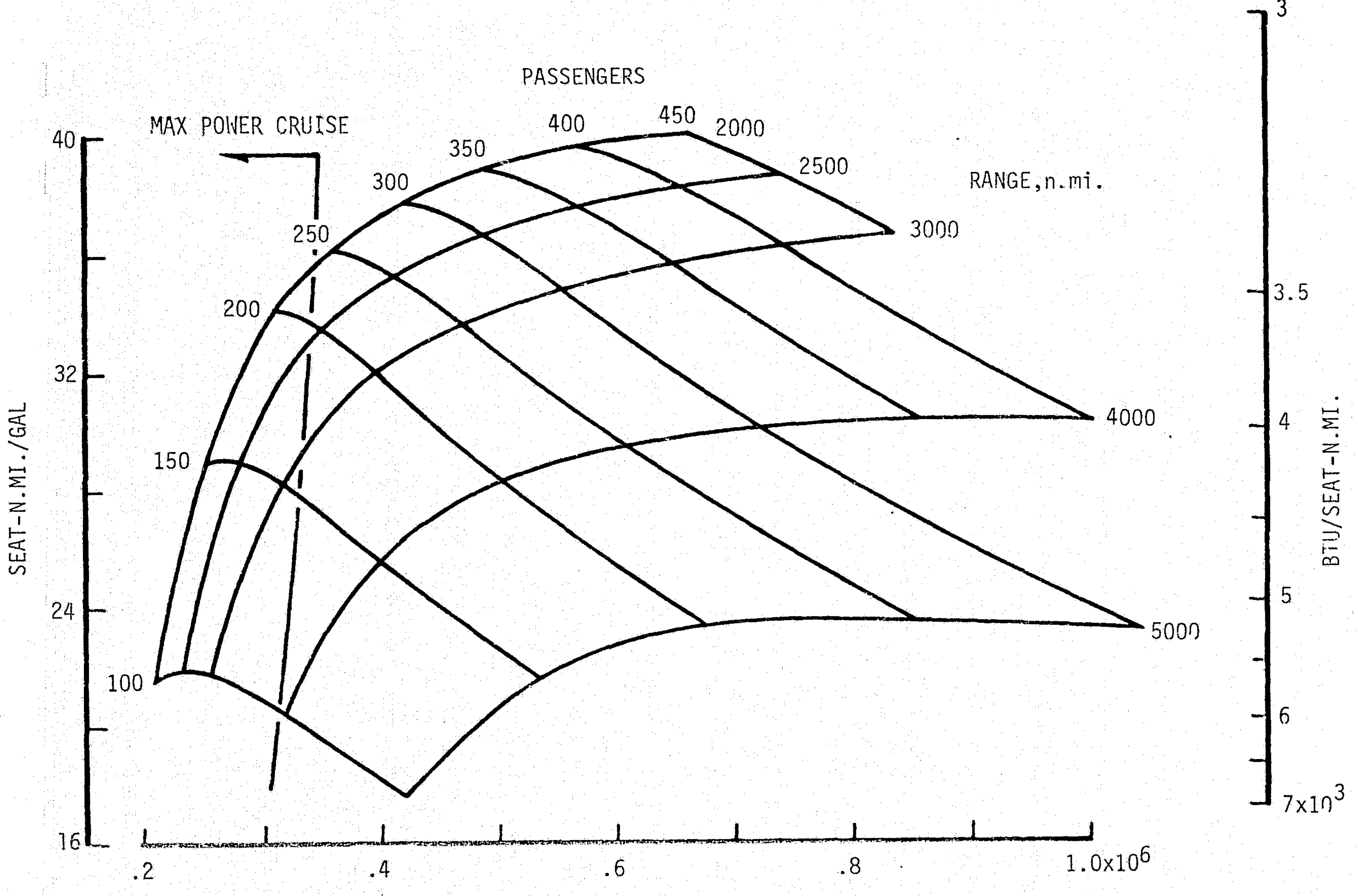


Figure 20.- Energy requirements at various passenger and gross weight combinations. $T/W = .367$; / $W/S = 72$ psf.

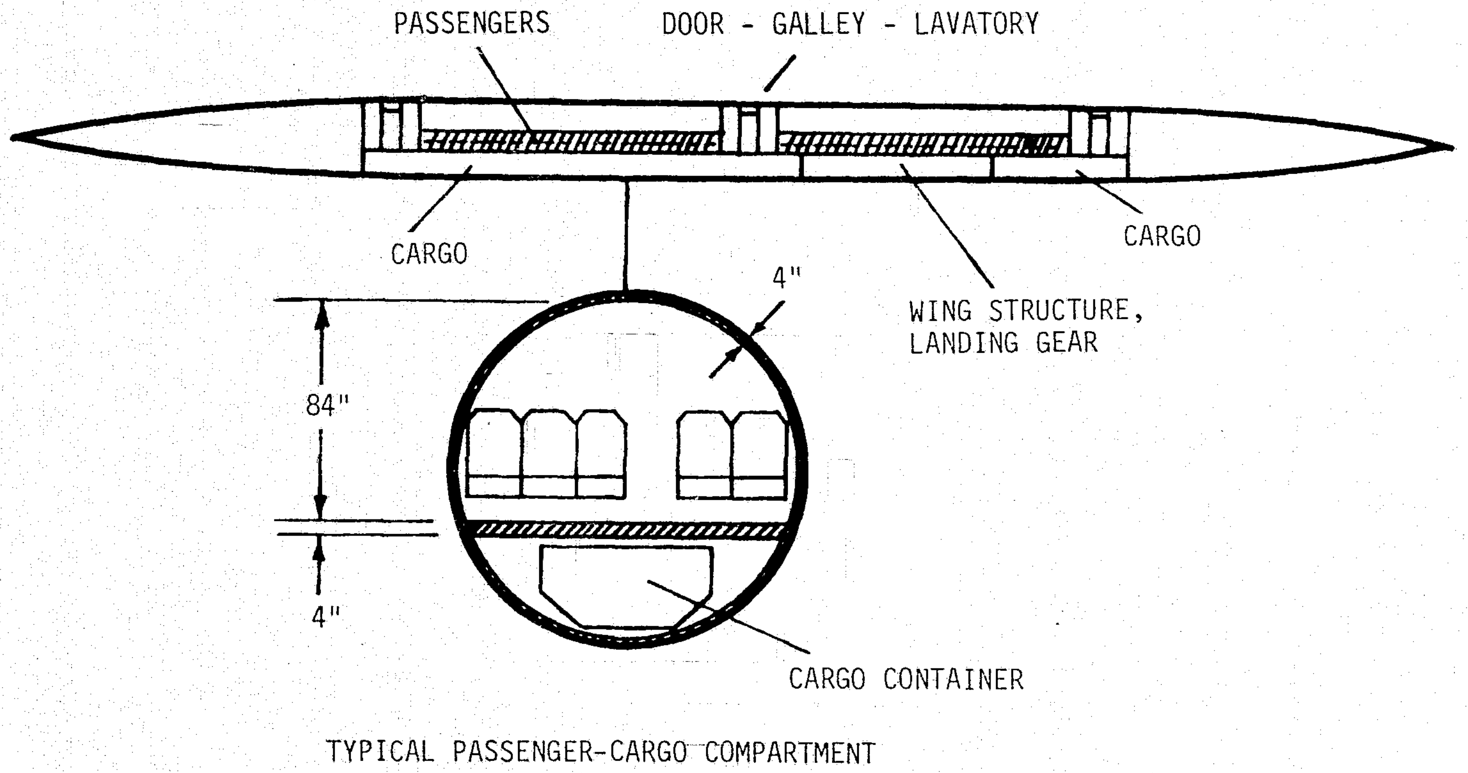
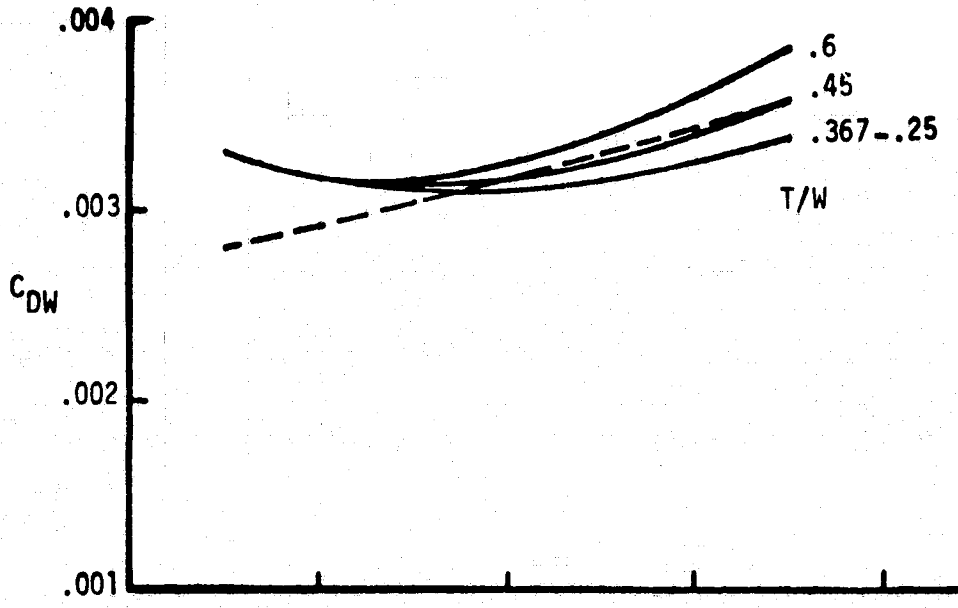
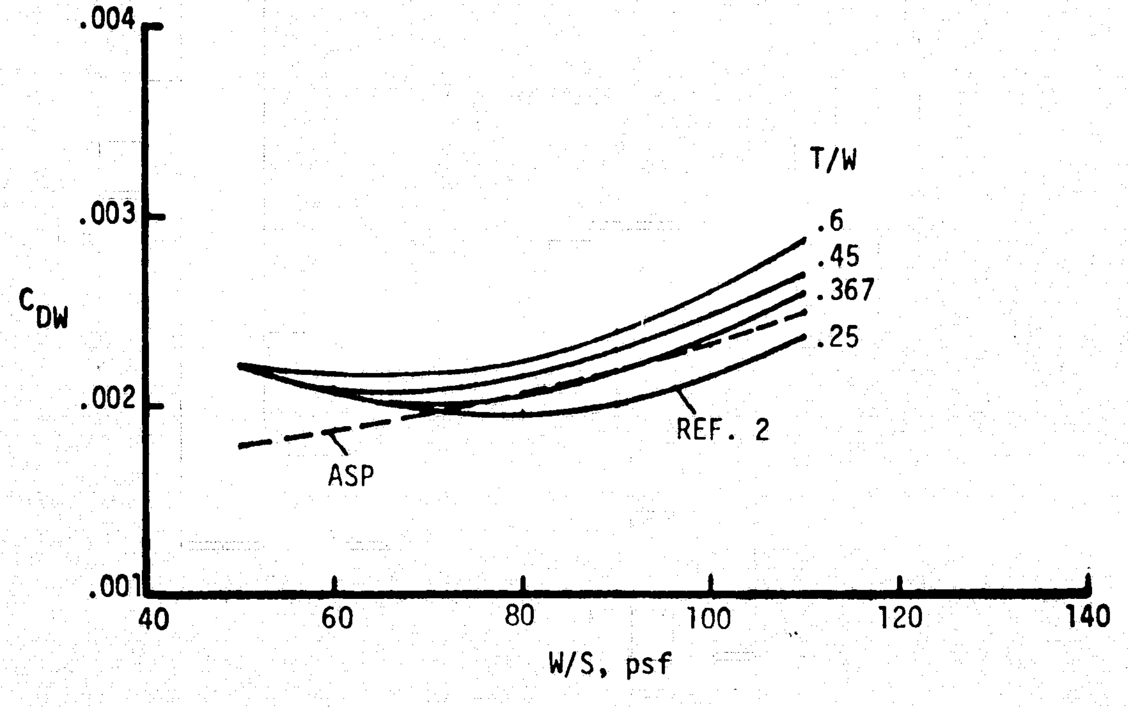


Figure 21.- Passenger compartment packaging arrangement.



(b) M = 1.2



(a) M = 2.62

Figure 22.- Comparison of wave drag results.

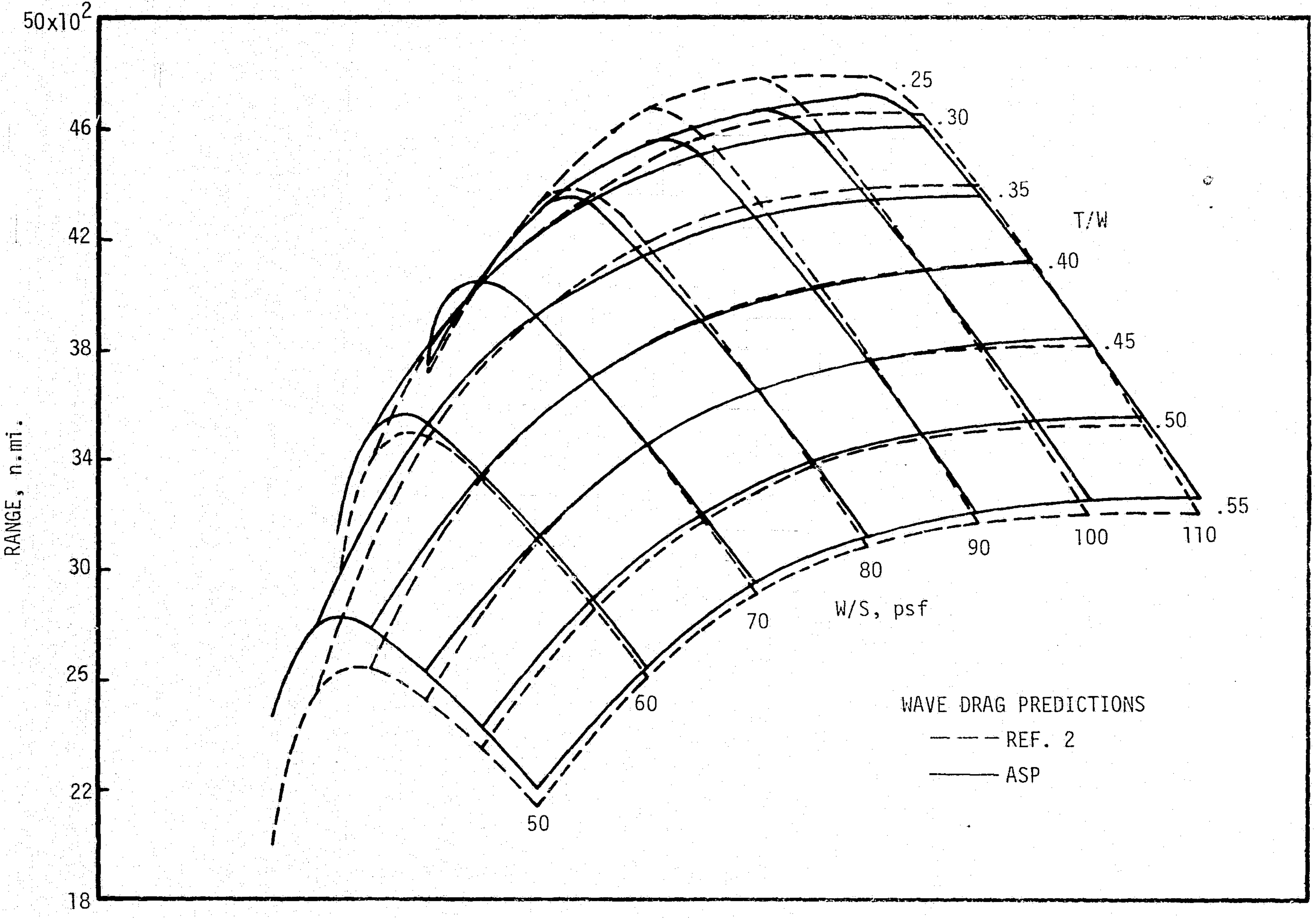


Figure 23.- Effect of differences in wave drag predictions on total range. W_G=718,000 lb; M_C=2.62; Passengers= 292.

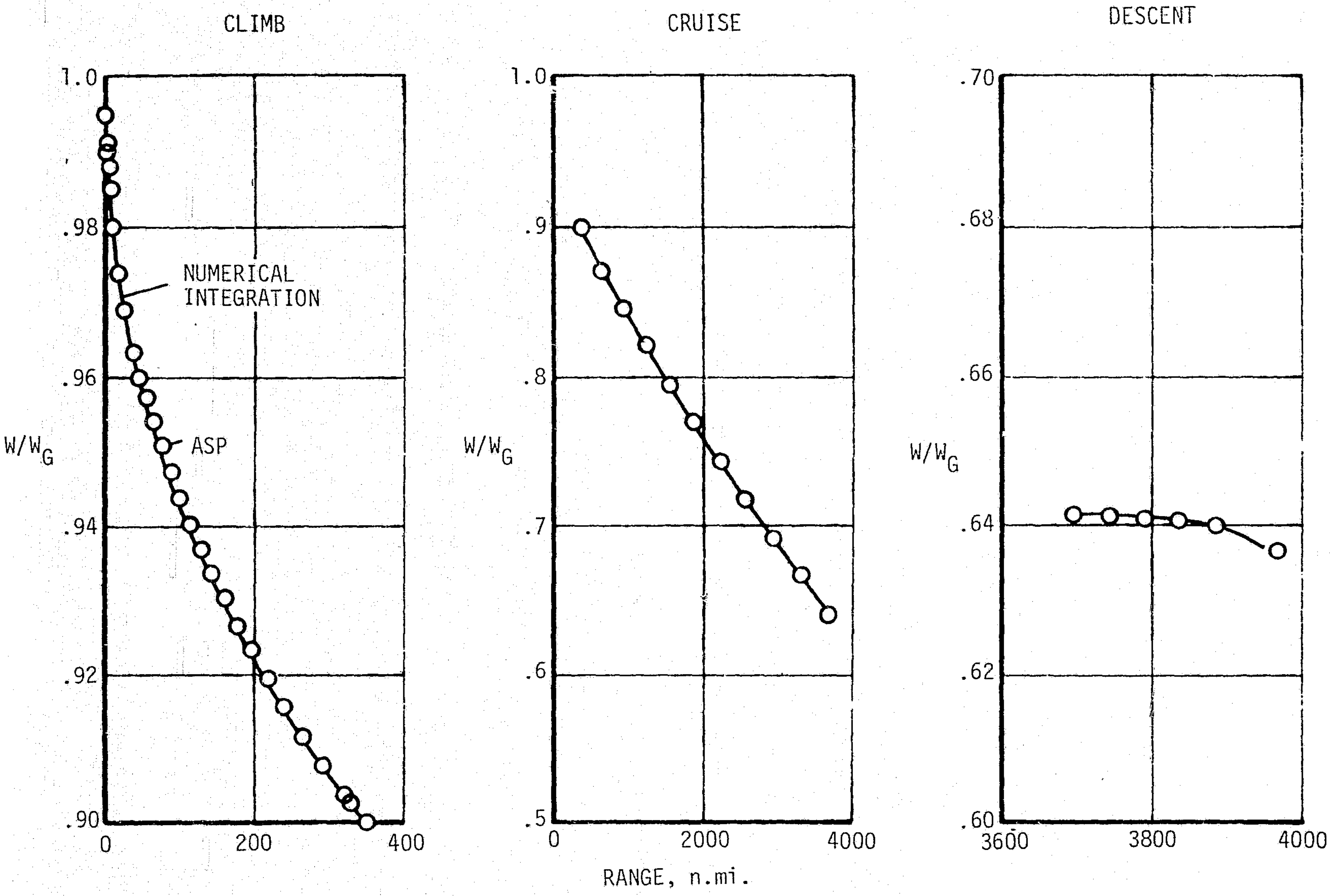


Figure 24.- Comparison of mission analysis methods.