NASA CR 132382

AIRLINE RETURN-ON-INVESTMENT MODEL FOR TECHNOLOGY EVALUATION

FINAL REPORT

May 1974

Submitted to
National Aeronautics and Space Administration
LANGLEY RESEARCH CENTER
Hampton, Virginia

Prepared Under
Contract NAS1-11343

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SECTION 1

INTRODUCTION

This report presents the derivation, description, and operating instructions for a computer program which measures the economic value of advanced technology features applied to long range commercial passenger aircraft. The program consists of three modules; an airplane sizing routine, a direct operating cost routine, and an airline return-on-investment routine. These modules are linked (as shown in Figure 1-1) such that they may be operated sequentially or individually, with one routine generating the input for the next or with the option of externally specifying the input for either of the economic routines.

The program, labeled TEKVAL, was written by General Dynamics/Convair under NASA/LRC Contract No. NAS1-11343. The concept for TEKVAL grew out of Convair's participation in the Advanced Transport Technology (ATT) studies, also sponsored by NASA/LRC, in 1971-72. That study examined the potential benefits to commercial transports of supercritical aerodynamics, advanced propulsion with reduced noise, composite structure, and active control systems combined with reduced static stability. Configurations were optimized for maximum return-on-investment to an airline operating a fleet of such airplanes over a selected route structure; an intermediate step required the computation of direct operating cost as a function of distance for each configuration.

During the course of the ATT study, a very simple airplane sizing technique was developed, based on the Brequet range equation. For this contract, that sizing technique has been greatly expanded and combined with the formerly separate DOC and ROI programs to produce TEKVAL. The derivation of TEKVAL draws heavily on ATT study results to derive factors which reflect the impact of the above mentioned advanced technologies as an integral feature of this program.

The computer output of the SIZE routine consists of two pages. The first page lists the principal input specifications followed by derived dimensions and geometry and aerodynamic and performance parameters. The second page is a weight statement.

The DOC module also provides two pages of output. The first is a detailed breakout of labor and material manufacturing costs corresponding to the above weights statement. The second page is a detailed listing of the various elements of the ATA direct operating costs formula computed as a function of distance. In the DOC program, the user has the option of an alternate summary cost equation referenced to AMPR weight; when utilizing this option, the first output page is replaced by a summary cost statement at the head of the DOC output.

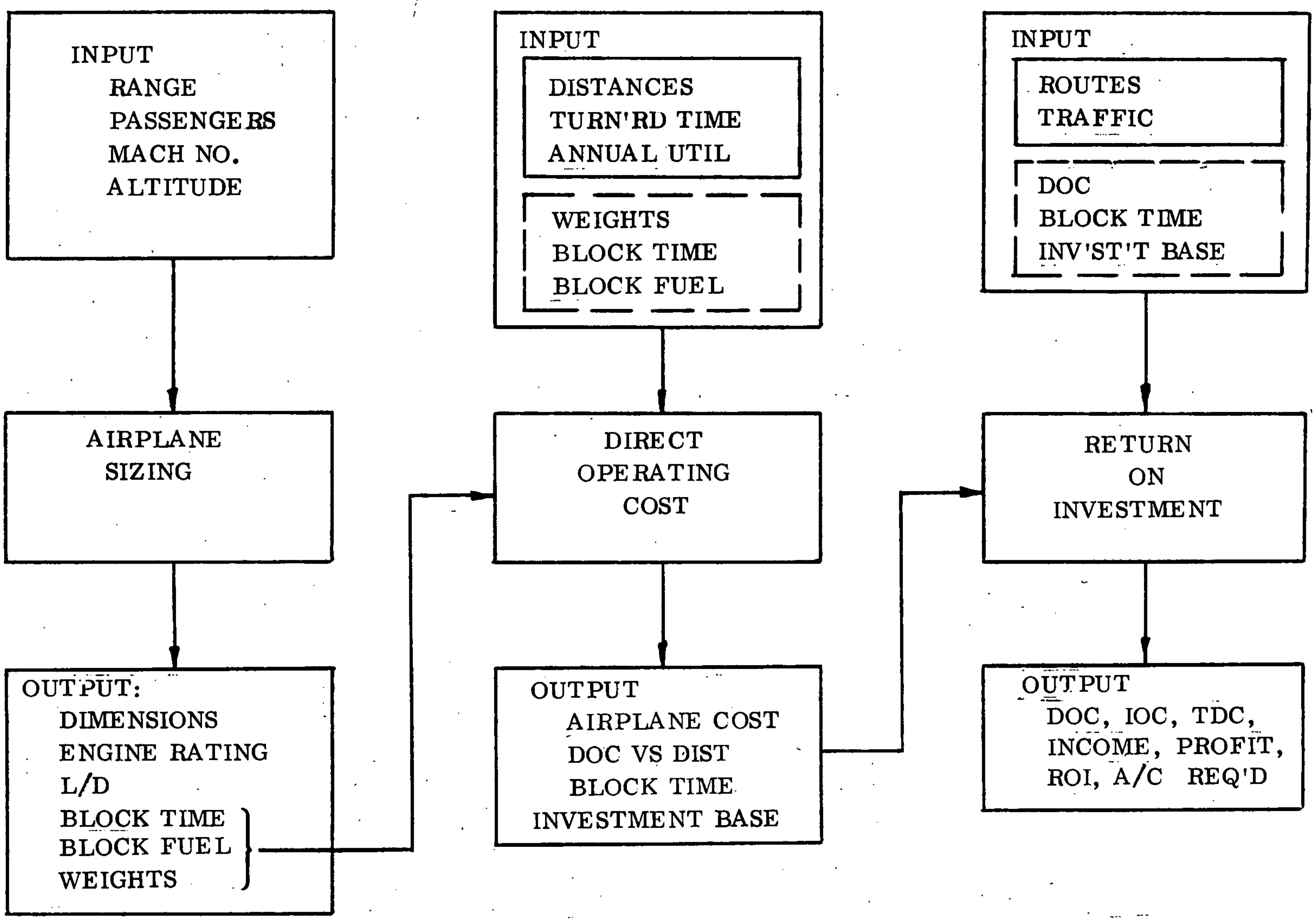

Figure 1-1. TEKVAL Program Flow

The first page of output from the ROI section repeats a number of input constants, a few basic airplane design parameters, and a listing of block time, and includes DOC and passenger fares as functions of distance. The next page(s) shows a breakout of passenger traffic, load factor, operating costs, income, profit, and ROI for each city-pair of the input set of operating routes. This breakout is followed by a total system summary of the same parameters. At the option of the user, the individual city pair listings may be suppressed.

It should be noted that program input and output utilize the English system of units. However, for the purposes of this report all dimensions, including those associated with input and output parameters will be shown in terms of the scientific international system of units with the English equivalent in parenthesis.

SECTION 2

ANALYTIC DERIVATION

2.1 AIRPLANE SIZING TECHNIQUE

The airplane sizing technique is based on an inverse solution of the Brequet range equation. Airplane takeoff gross weight is derived as a function of payload weight and cruise conditions. Airplanes are sized for that corner of the range-payload curve (Figure 2-1) where maximum fuel capacity is required to carry the full passenger payload over the design range, constrained by a maximum takeoff weight limit. The assumed flight profile is shown in Figure 2-2. The airplane cruises at constant Mach number, continually increasing altitude to remain at the optimum lift-to-drag (L/D) ratio. Engines are sized to provide the necessary cruise thrust-to-weight ratio (T/W = D/L) at the initial cruise point. Takeoff performance is not computed; however, static thrust-to-weight provides a useful indication of expected field lengths via reference to existing commercial aircraft performance.

The Brequet range equation is written as

$$R = \frac{V_t (L/D)}{c'} \ln (W_o/W_1) \tag{1}$$

with

R = Range km (nm)

V_t = True airspeed km/hr (kt)

L/D = Lift-to-drag ratio

c' = Thrust specific fuel consumption kg/N-hr (lbm/lb-hr)

W_o = Initial cruise gross weight kg (lb)

W_1 = Final cruise gross weight kg (lb).

This equation, derived in most basic aerodynamics texts, is applicable only to cruise flight, the difference between W_o and W_1 being the weight of fuel used in flying the distance, R. In order to compute gross takeoff weight (GW), equation (1) is solved for the initial cruise weight, W_o, to which is added takeoff and climb fuel weights ($W_{f_{to}}$ and $W_{f_{cl}}$, respectively):

$$GW = W_1 \cdot \exp\left[\frac{Rc'}{V_t (L/D)}\right] + W_{f_{to}} + W_{f_{cl}} . \tag{2}$$

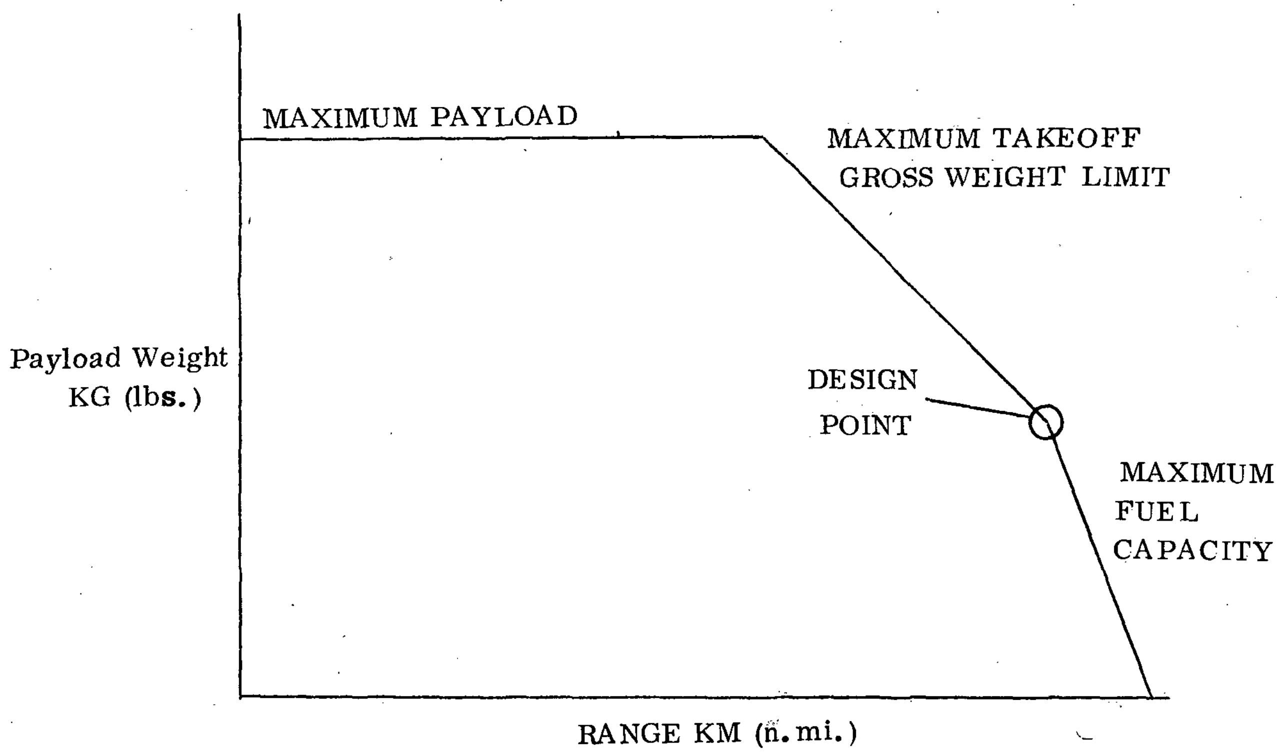

Figure 2-1. Range - Payload Design Point

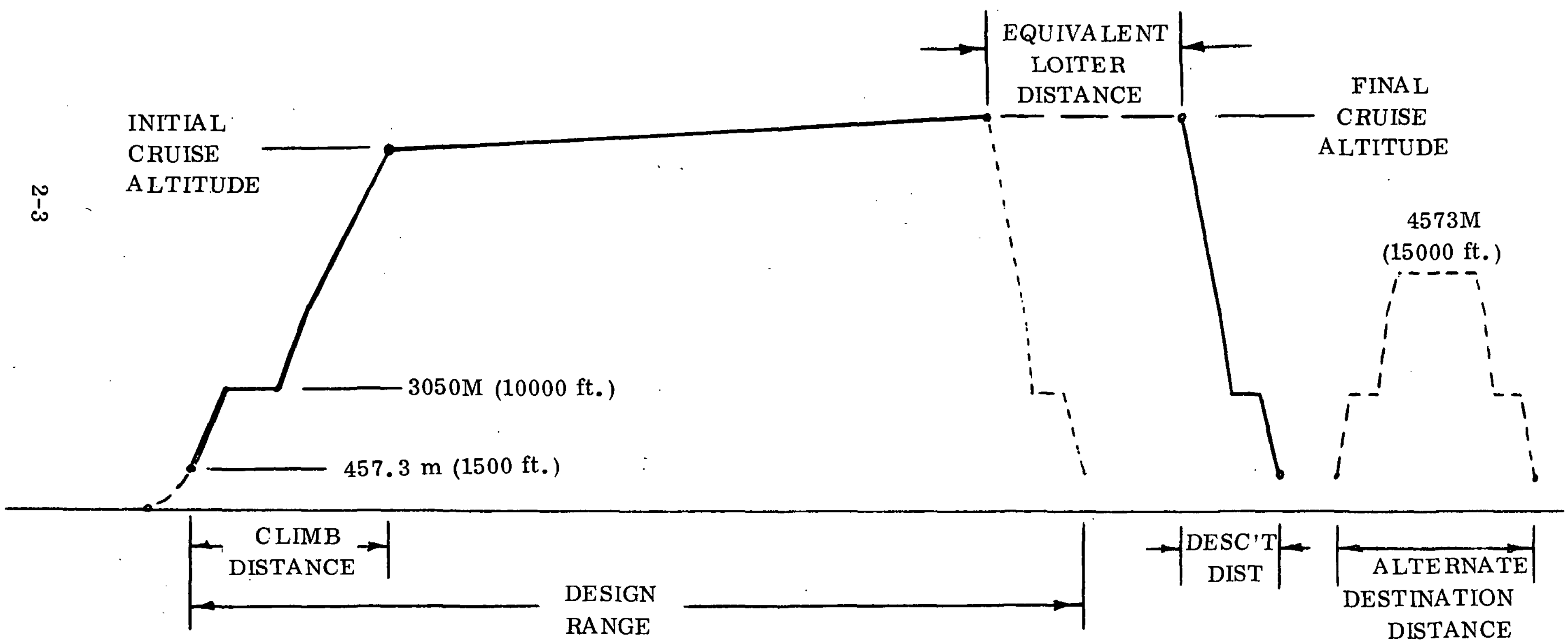

Figure 2-2. Design Flight Profile

The range, R, is the design range less climb and descent distances. The final cruise weight, W_1, is the sum of operating weight empty, payload, and reserve and descent fuel weights.

The program employs an empirical expression to generate an initial estimate of takeoff gross weight. A fuselage layout is derived from payload capacity and seating dimensions specified to the program. An airplane empty weight is computed from a large set of empirical relationships, using engines scaled to a given static thrust/weight ratio. Climb and descent performance are computed to give these distance and fuel increments. Finally, a takeoff gross weight is extracted via equation (2). A single iteration is employed for improved wing and engine sizing, and subsystem weight computations. The computation procedure is illustrated in Figure 2-3, which also constitutes a computer flow chart. The numbered paragraphs which follow correspond to the like numbered boxes in Figure 2-3. In general, simple geometric computations have not been listed in this derivation. Reference to the computer program listing and dictionary will clarify these operations.

1. Fuselage Layout — The sizing process begins by generating a fuselage layout to enclose the required seating arrangement (see Figure 2-4). Floor dimensions of the coach section are determined first to set fuselage diameter; external diameter is made 10 percent greater than floor width to allow for wall thickness and lost space. First class section length is determined and one diameter is added to the length of these two sections to account for galley, wardrobe and lavatory space.

   The sum of these three sections make up the straight portion of the fuselage. The cockpit and tailcone areas are referred to as tapered sections; their combined length is estimated as a specified number of fuselage diameters. For area ruled fuselages, the length of the straight section is increased by 25 percent and an extra 1/3 diameter is added to the length of the tapered sections: both of these constants were derived by reference to ATT study configuration layouts. The several equations used in this section are merely arithmetic manipulations of geometric input data concerning seating dimensions and arrangements. They can easily be followed by reference to the program listing and definition of terms. The principal output values of this section are:

   D_{fus} = Fuselage external diameter m (ft)

   L_{st} = Length of constant diameter section m (ft)

   L_{tpr} = Length of tapered nose and tail sections m (ft).

2. Initial Gross Weight Estimate — Empirical expressions were derived relating gross weight/payload weight ratio to design range (R) and Mach number for several potential technology combinations. The basic equation for gross weight/payload weight ratio is:

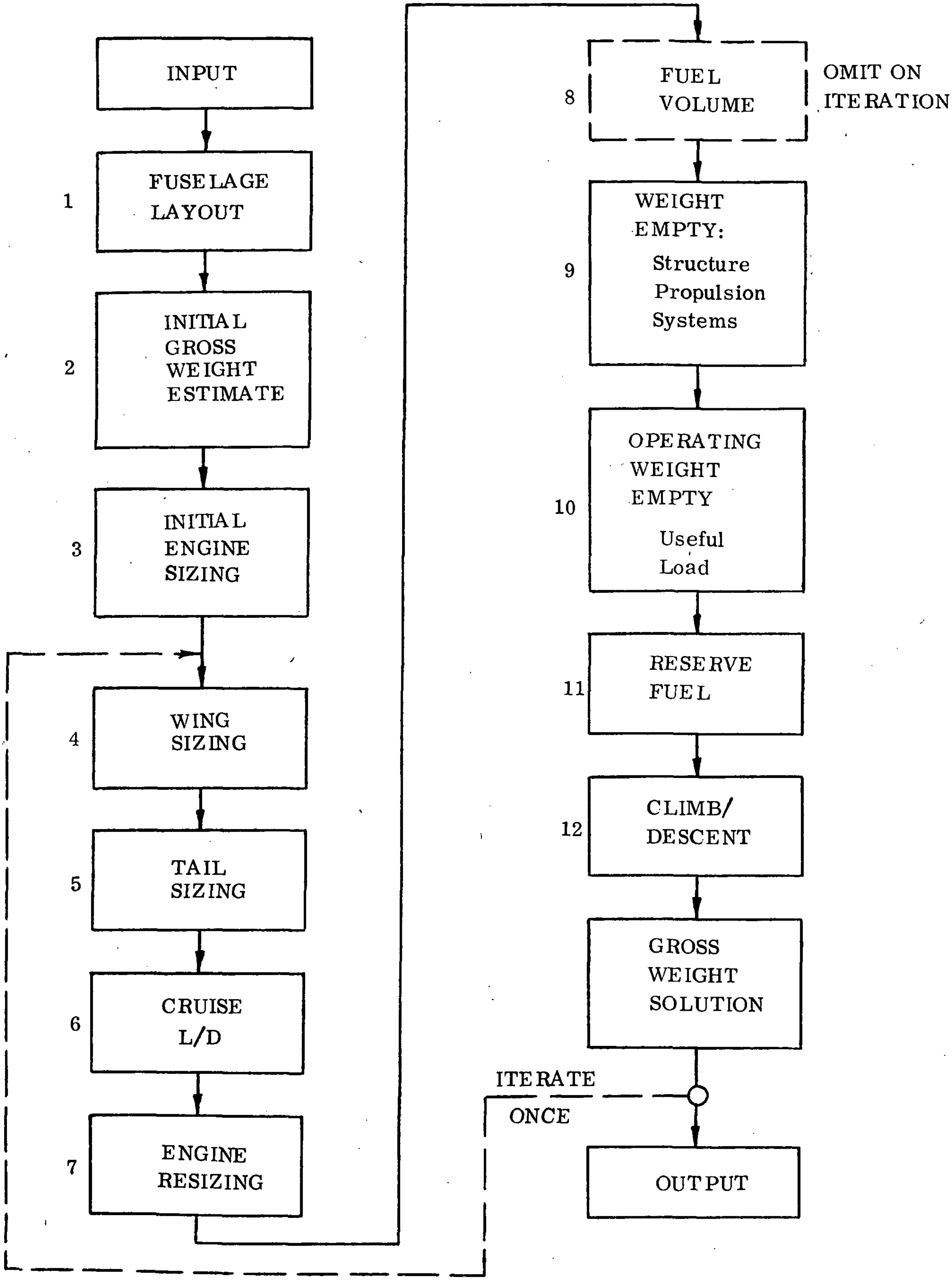

Figure 2-3. Sequence of Operations

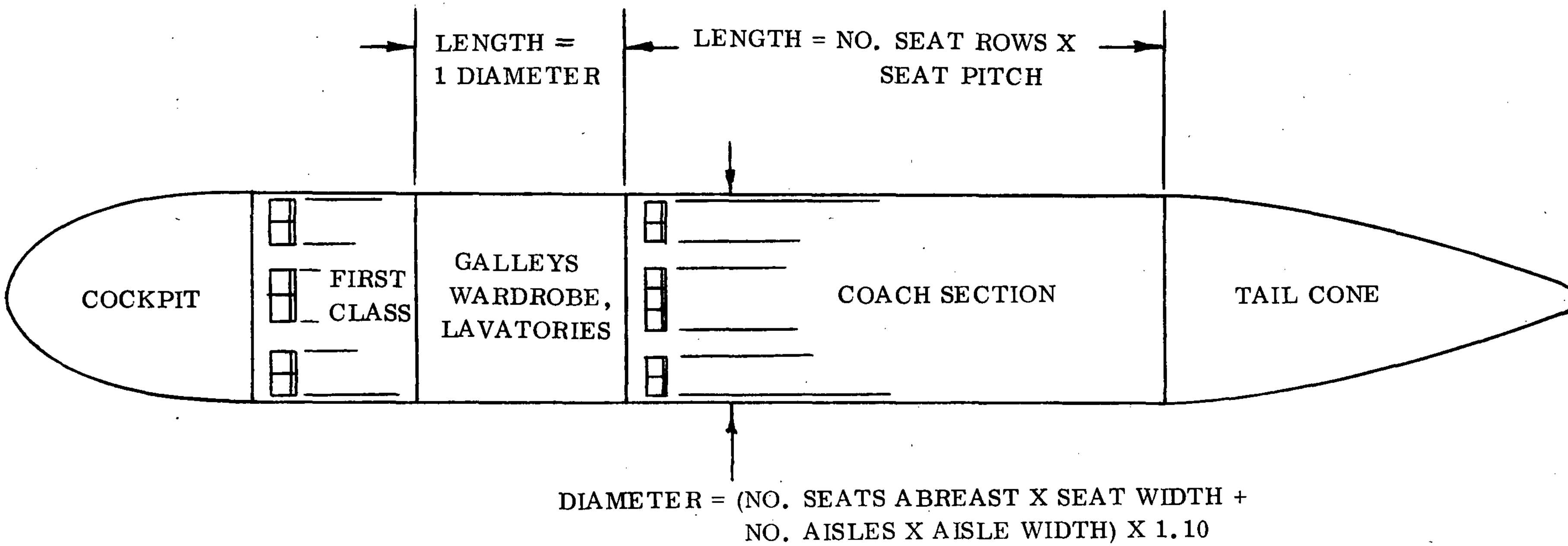

Figure 2-4. Fuselage Layout

$$GW/W_{pl} = (3 + 1.3\ R/1000)\, k_{tech}. \qquad (3)$$

For design Mach numbers (M) greater than 0.9, equation (3) is multiplied by the factor $\left[1 + 20\ (M - 0.9)^2\right]$. Aerodynamic and structural technology is reflected in the factor k_{tech} which has the following set of values:

Aerodynamics	Conventional	Supercritical
Structure		
Light Alloy	1.1	1.0
Composite	1.0	0.9

3. Initial Engine Sizing — Representative baseline engine performance must be provided to the model in the form of tables of net thrust and specific fuel consumption vs. Mach number and altitude. Also required are the engine sea level static thrust rating, basic weight, and nacelle diameter. All of these values pertain to an engine of a particular size. The program computes an engine scale factor by which all engine performance, weight, and dimensions are scaled up or down to match the thrust required at the design condition.

   An initial estimate of engine scale (ES) is made so as to give a static thrust-to-weight ratio as specified by input. Engine weight and nacelle diameter are scaled via the relations

$$D/D_o = (ES)^{0.5} \qquad (4)$$

   and

$$W/W_o = (ES)^{1.11} \qquad (5)$$

   where D_o and W_o are the diameter and weight values for the 1.0 scale engine. These relationships should hold over an engine scale range of 0.5 - 2.0; beyond this range a different baseline engine should be selected.

4. Wing Sizing — Wing area is computed from gross weight and wing loading. Wing dimensions of span, root and tip chords, and mean aerodynamic chord (m.a.c.) are computed from area and specified aspect ratio and taper ratio (see program listing). Wing sweep angle is given at the 1/4 m.a.c. and is translated to the leading edge for use in computing wing thickness ratios. For conventional and supercritical airfoils, thickness/chord ratio (t/c) is related to design Mach number and leading edge sweep angle (Λ_{le}) by the expressions

$$\text{conventional: } t/c = 0.802 - M\,(\cos\Lambda_{le})^{0.6775} \quad (6)$$

and

$$\text{supercritical: } t/c = 0.896 - M\,(\cos\Lambda_{le})^{0.6775}. \quad (7)$$

5. Tail Sizing — The longitudinal locations of wing and tail surface m.a.c.'s are given as fractions of total fuselage length. From these, tail arm lengths are determined. The tail volume coefficients of Figure 2-5 are then employed to compute horizontal and vertical tail exposed areas. In the case of a fin-mounted engine such as on the McDonnell-Douglas DC-10, vertical tail area is reduced by the projected area of the nacelle. Because of its relative length, the diameter of a fin-mounted nacelle is approximately 20 percent greater than a podded wing — or fuselage-mounted installation. This factor and a nacelle length/diameter ratio are combined to compute nacelle projected.

6. Initial Cruise Lift/Drag Ratio (L/D) — This parameter is required for subsequent engine sizing; it also represents a good measure of the aerodynamic efficiency of the total airplane and is included in the output listing. Cruise L/D is computed as the mathematically equivalent ratio of lift/drag coefficients (C_ℓ/C_d).

Lift coefficient (C_ℓ) at initial cruise weight is first estimated by the equation

$$C_\ell = 0.95\ (W/S)/1481\ \delta\ M^2 \quad (8)$$

where

W/S = Design takeoff wing loading N/m^2 (lb/ft^2)

and δ = Atmospheric pressure ratio at initial cruise altitude.

The factor 0.95 is inserted as an estimate of the ratio of gross weights at initial cruise and takeoff conditions. For the second program iteration, this factor is modified by the results of the first pass. A table of pressure ratio vs. altitude yields the value of δ for the inputted initial cruise altitude.

The drag coefficient (C_d) at initial cruise conditions is measured by the expression

$$C_d = C_{fe}\ (A/S_w) \quad (9)$$

with

C_{fe} = Equivalent skin friction coefficient (input)

Horizontal:

Without active control system: $V_h = 0.75$

With active control system: $V_h = 0.60$

Vertical:

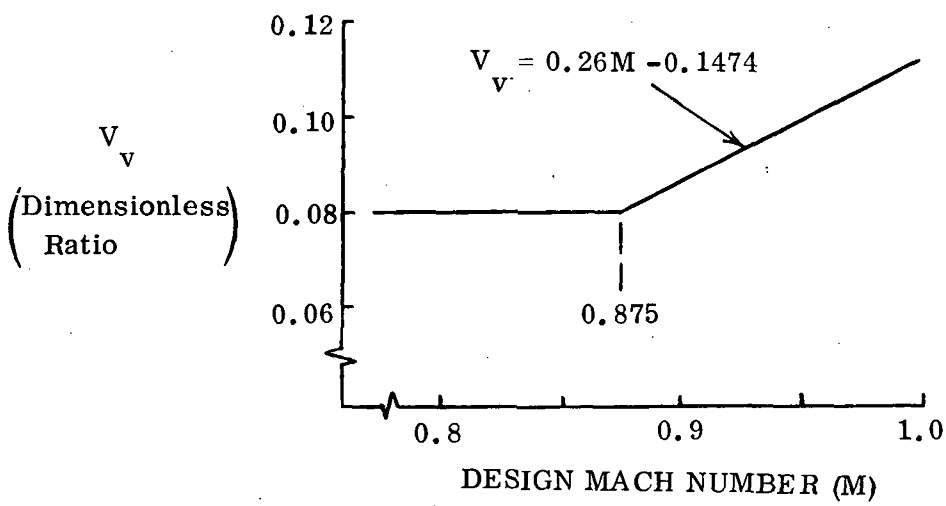

Figure 2-5. Tail Volume Coefficients.

A = Total airplane wetted area m^2 (ft^2)

and S_w = Wing area m^2 (ft^2).

Total airplane wetted area is the sum of the surface areas of the fuselage, wing, tail, and nacelles and pylons. Fuselage gross wetted area (A_{fus}) is approximated by

$$A_{fus} = \pi D_{fus} (L_{st} + 0.7 L_{tpr}) \qquad (10)$$

where fuselage dimensional parameters were specified early. Wing root fairings, or gloves, cover an appreciable portion of the fuselage side surfaces; these masked areas must be subtracted from gross area to prevent an overestimate of airplane drag. The cross-sectional area of an airfoil shape (A_{cs}) can be estimated by

$$A_{cs} = 0.7\ c^2\ (t/c)$$

where c is the airfoil chord and t its thickness. Figure 2-6 illustrates the geometric terms employed in defining wing glove dimensions. The wing root is assumed to intersect the fuselage in a plane canted 20 degrees as shown. The lateral distance from the airplane centerline to this intersection is labelled $y_{g\ell}$ and is expressed as

$$y_{g\ell} = (D_{fus}/2) \mathrm{Cos}\ (20°)$$

$$= 0.47\ D_{fus}\ .$$

The ratio of the root chord of the glove (u in Figure 2-6) to the theoretical wing chord computed at $y_{g\ell}$ (v in Figure 2-6) is termed $c_{g\ell}$, and is inputted to the program. With the wing chord, v, computed from available geometric parameters. Net fuselage wetted area can now be obtained as the gross area, from equation (10), less the glove cross sectional areas:

$$A_{cs} = (2)(0.7)\ v^2\ (t/c)\ c_{g\ell}\ / \mathrm{Cos}\ (20°)$$

$$= 1.49\ v^2\ (t/c)\ c_{g\ell}\ . \qquad (11)$$

Cross sectional areas of the tail surfaces are neglected.

For wetted area computations, the wing is divided into inboard and outboard sections, with the break coming where the glove intersects the straight leading and trailing edges, as seen in Figure 2-6. The lateral location of the break point is

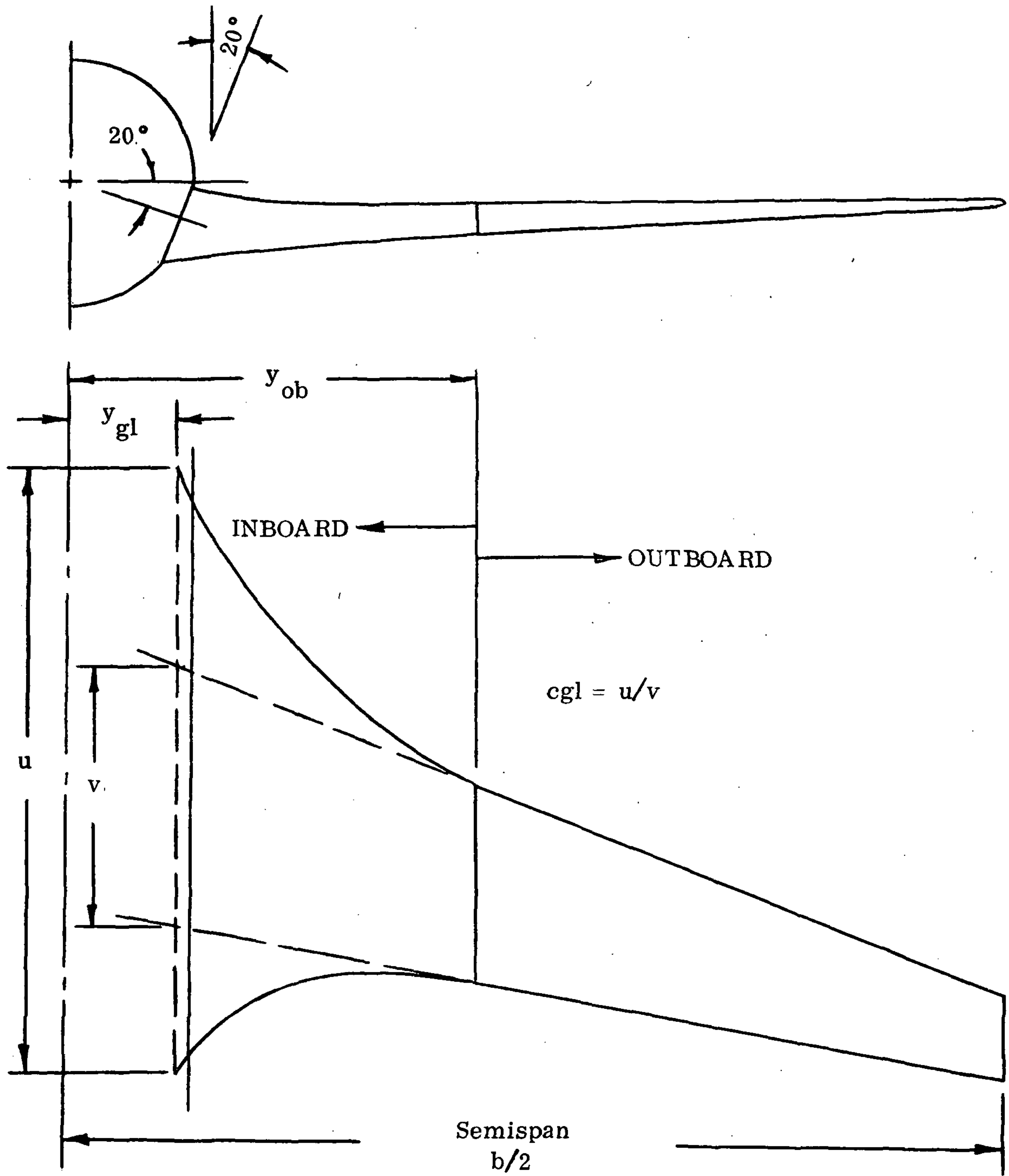

Figure 2-6. Wing Fillet Geometry for Wetted Area Determination

input as a fraction of the wing semispan. For the outboard section, wetted area (A_{ob}) is figured as

$$A_{ob} = c_{sw} S_{ob} \tag{12}$$

where

c_{sw} = Ratio of wing wetted area/planform area (input)

S_{ob} = Planform area of outboard wing sections m^2 (ft^2).

A value of 2.02 is recommended for c_{sw}. For the inboard section, equation (12) is modified by an expression involving c_{gl}:

$$A_{ib} = c_{sw} S_{ib} \left[1 - 0.043 (c_{gl} - 1)\right] \tag{13}$$

with

A_{ib} = Wetted area of inboard wing sections including gloves m^2 (ft^2)

S_{ib} = Theoretical planform area of inboard wing sections from $y_{g\ell}$ to y_{ab} in Figure 2-6 m^2 (ft^2).

Tail surface wetted areas are computed via equation (12), using the same input value of c_{sw}.

Nacelle length/diameter ratio, $(L/D)_{nac}$ (input), and previously computed diameter D_{nac} are combined to compute a cylindrical nacelle wetted area. A 20 percent increment is added to account for pylons, giving the complete expression

$$A_{nac} = 1.2 \pi D_{nac}^2 (L/D)_{nac} . \tag{14}$$

Equation (14) applies only to podded engine installations. For a fin-mounted engine, with its relatively long nacelle and increased diameter,

$$A_{nac} = 1.44 \pi D_{nac}^2 (L/D)_{nac-fin} . \tag{15}$$

A separate $(L/D)_{nac-fin}$ is input for this configuration.

Total wetted area is the sum of the above components.

7. Engine Resizing — Having computed L/D at initial cruise conditions, engine size is rescaled to give T/W = D/L. Required cruise thrust per engine is computed at weight W_o. The cruise thrust for the full-scale engine at initial cruise Mach and altitude is extracted from the appropriate table. Engine scale is recomputed as the ratio of these two thrust values. Engine weight and nacelle diameter are adjusted to the new scale factor, as are wetted area and L/D.

8. Fuel Volume —An initial estimate of total fuel quantity is required to determine fuel subsystem weights. In the Brequet formula, equation (1), the difference between W_o and W_1 is the weight of cruise fuel W_{fcr}. Range factor (RF) is the label applied to the ratio $V_t\,(L/D)/c'$. Equation (1) can be manipulated to produce the expression

$$W_{fcr}/W_o = 1 - \exp(-R/RF). \qquad (16)$$

An empirically derived increment of 0.1 is added to this expression to account for climb, descent and reserve fuel. Total fuel weight (W_{ftot}) is then obtained from

$$W_{ftot} = 0.95\ GW\left[1.1 - \exp(-R/RF)\right] \qquad (17)$$

where GW is still the current estimate of takeoff gross weight.

Dividing (17) by fuel density then yields fuel total quantity in gallons.

Total design range is inserted for R in evaluating equation (16). The range factor, RF, is computed at initial cruise conditions; L/D is already available, and c' is obtained via a table look-up. True airspeed (V_t) is computed from the relation

$$V_t = V_e/\sqrt{\sigma}$$

$$= M\,(V_e/M)/\sqrt{\sigma} \qquad (18)$$

where

V_e = Equivalent airspeed km/hr (kt)

and σ = Atmospheric density ratio.

This form was chosen for convenience for all V_t vs. M computations to minimize data storage requirements (it is used repeatedly in the climb and descent segments); the parameters V_e/M and $\sqrt{\sigma}$ are both obtained from tables as functions of altitude.

This entire fuel volume estimation step is omitted in the iterative pass.

9. Weight Empty — A series of empirical weight estimating relationships for structure, propulsion, and subsystems and equipment were derived from data on a large number of existing commercial transports. These equations are listed in Table 2-1.

The impact of several advanced technology features (area ruling, composite structure, active control systems, and supercritical aerodynamics) is accounted for by modifying factors applied to the basic equations. A series of three control factors are input to define which advanced technologies are to be employed. At this point, only the body (W_b) and wing (W_w) structural weights are affected:

$$\text{Body:} \quad W_b = W_b \, (1 - 0.016 \, K_{AR}) \, (1 - 0.2 \, K_{MATL}) \, (1 - 0.01 \, K_{ACS}) \qquad (19)$$

where

K_{AR} = Fuselage area ruling factor (0 = without, 1 = with)

K_{MATL} = Construction material factor (0 = light alloy, 1 = composites)

K_{ACS} = Active control system factor (0 = without, 1 = with).

The above three factors are input constants.

$$\text{Wing:} \quad W_w = W_w \cdot R_{MACH} \cdot R_{MATL} \cdot R_{ACS} \qquad (20)$$

For $M > 0.85$, $R_{MACH} = 1 + 0.7 \, (M - 0.85)$.

For $K_{MATL} = 1$, $R_{MATL} = 0.885 - 0.00255 \, (b/\cos \Lambda_{c/2})/t_r$.

For $K_{ACS} = 1$ and $K_{MATL} = 0$, $R_{ACS} = 0.871$.

For $K_{ACS} = 1$ and $K_{MATL} = 1$, $R_{ACS} = 0.912$.

The three R-factors are internally computed. If $M < 0.85$ or K_{MATL} or K_{ACS} are zero, the corresponding R-factors are set equal to 1.0.

The summation of all items listed in Table 2-1 yields weight empty (WE).

10. Operating Weight Empty — The addition of useful load to WE gives OWE. Useful load weights consists of four items computed from the following equations:

Table 2-1. Weight Estimating Relationships
(Output in Pounds)

Structure

Body: $W_b = \left[(0.2712 \cdot GW \cdot ULF)^{0.3} L_f^{0.9} D_f^{1.05}\right]$

Wing: $W_w = 0.306 \left[GW \cdot ULF \cdot S_w \cdot \left(b/\cos \Lambda_{c/2}\right) / 1000 \ (t/c)\ C_{root}\right]^{0.62}$

Tail: $W_{h,v} = 12.8 \cdot S_{h,v}^{0.9}$ ($S_{h,v}$ = exposed area)

Nacelle: $W_{nac}(ea) = 3846 \cdot ES - 977$

Ldg Gear: $W_{\ell g} = 0.046 \cdot GW$

Propulsion

Engine: $W_{eng}(ea) = W_{eng_1} \cdot ES^{1.11}$

Engine/Nacelle Sound Proofing (if employed):

$W_{sp}(ea) = 0.035 \cdot RATING - 460$

Starting: $W_{st} = 0.35 \cdot W_{eng}^{0.65}$

Controls: $W_{ec} = 120 \cdot \left[\left(L_f + b/\cos \Lambda_{c/2}\right) N_{eng}/100\right]^{0.294}$

Water Injection Provisions (if employed):

$W_{wi}(ea) = 3.41 \times 10^{-3} \cdot RATING$

Fuel System:

Pumps: $W_p = 1.1 \times 10^{-3} \cdot RATING \left(1.75\ N_{eng} + 0.266\ N_{eng}^2\right)$

Distribution: $W_{dist} = 0.24 \cdot N_{eng} \sqrt{RATING} + 0.62\ Q^{0.7}$

Table 2-1 (Cont'd)

Venting: $W_v = 3.48 \times 10^{-3} \cdot N_{eng} \cdot \text{RATING}$

Control: $W_{fc} = 1.116 \cdot Q^{0.5}$

Refueling: $W_{rf} = 4.9 \cdot Q^{0.33}$

Dump: $W_{dmp} = 0.159 \cdot Q^{0.65}$

Sealant: $W_{s\ell} = 0.282 \cdot Q^{0.75}$

<u>Systems and Equipment</u>

Surface Controls: $W_{sc} = 340 + 0.95\,(S_w + S_h + S_v)$

Instruments: $W_{inst} = 2.68 \times 10^{-3} \cdot GW + 165$

Hydraulics:
$$W_{hyd} = 0.48 \left[0.45\,(S_w + S_h + S_v)^{1.3125} + \left(L_f + b/\cos \Lambda_{c/2}\right)^{1.0612} \right]^{0.849}$$

Avionics: $W_{avi} = 1.3 \cdot WAVI$

Electrical:
$$W_{elec} = 62.8 \left(\Sigma W_{fuel\ sys} - W_{s\ell} + W_{avi}\right)^{0.473} + 2 \cdot PAX$$

Air Conditioning: $W_{ac} = 300 + 35 \left[D_f \cdot (\text{No. Seat Rows})\right]^{0.72}$

Anti-Ice: $W_{ai} = 6.25 \cdot \left(b/\cos \Lambda_{c/2}\right)^{0.95}$

Auxiliary Gear: $W_{aux} = 0.011\,(GW \times 10^{-3})^{1.55}$

Furnishings: $W_{frn} = 40 \cdot PAX^{1.185} + 1625$

APU (if present): $W_{apu} = 29.2 \cdot PAX^{0.7}$

Crew: $W_{cr} = N_{cr} \cdot W_{crew} + N_{stew} \cdot W_{stew}$ (21)

where

W_{cr} = Crew weight kg (lb)

N_{cr} = Number in cockpit crew

W_{crew} = Weight of crew member kg (lb)

N_{stew} = Number of stewardesses

W_{stew} = Weight of stewardesses kg (lb).

The weights of crew members and stewardesses are input values, as is the number of flight crew members. The number of stewardesses required is computed as a function of the number of passengers in coach and first class sections. In first class, there is one stewardess for each 20 passengers; in coach, one for each 40 passengers.

Equipment: $W_{eq} = 100 + 30 \cdot PAX$ (22)

Oil: $W_{oil} = 14.06 \cdot N_{eng}$ (23)

Unusable Fuel: $W_{uf} = 0.025 \cdot S_w$ (24)

In the above three equations

W_{eq} = Passenger equipment weight kg (lb)

PAX = Total number of passenger seats (input)

W_{oil} = Weight of engine oil kg (lb)

N_{eng} = Number of engines (input)

W_{eng} = Weight of scaled engine kg (lb)

W_{uf} = Weight of unusable fuel kg (lb)

S_w = Wing area m^2 (ft^2).

11. Reserve Fuel — FAA regulations define reserve fuel requirements sufficient for a holding period at the end of cruise plus diversion to an alternate destination. The holding period and distance to alternate vary for domestic and international service; these two parameters are therefore defined by input to the model.

Reserve fuel for hold at end of cruise is computed by adding the equivalent distance to design range. Diversion to an alternate airfield presumably occurs following a normal descent; reserve fuel requirements thus include climb to and cruise at some intermediate altitude. An altitude of 4573 m (15,000 ft) is built into the model.

Alternate field reserve fuel requirements are computed in the following manner. Since the total fuel supply would be exhausted at the end of this leg, airplane gross weight at that point is just OWE plus payload. The climb/descent routine described in the following section determines fuel and distance for the descent from 4573 m (15,000 ft), giving gross weight at the end of the alternate cruise leg. This weight is increased by 5 percent as an estimate of gross weight at the start of the diversion.

Climb fuel and distance to 4573 m (15,000 ft) are computed from this weight. Climb and descent distances are subtracted from the required alternate field distance to yield the necessary cruise distance.

Range factor is computed at design Mach number at 4573 m (15,000 ft); the method for computing L/D at off-design conditions is described in the following section. An inversion of equation (1) is employed to give the ratio of gross weights at beginning and end of the alternate cruise leg:

$$W_o/W_1 = \exp(D_{cr}/RF) \text{ with } D_{cr} = \text{cruise distance km (nm)}.$$

Cruise fuel for this leg is then simply

$$W_{falt} = W(W_o/W_1 - 1) \quad (25)$$

where W is the gross weight upon arrival at 4573 m (15,000 feet). Total reserve fuel requirement for the alternate field diversion is the sum of W_{falt} plus climb and descent fuel. This total is added to OWE and payload to give the true gross weight at the end of the descent to the primary destination.

12. Climb and Descent — The method selected for computing climb or descent flight path angle, γ, is the simple expression

$$\operatorname{Tan} \gamma = T/W - D/L \quad (26)$$

which ignores any longitudinal acceleration effects during climb. The same expression is valid for computing level flight acceleration during the climb schedule, which simplifies programming.

The climb/descent schedule employed in the program is shown in Figure 2-7. The climb to 3050 m (10,000 ft) is flown at a constant 130 m/sec (250 knots) equivalent airspeed per current federal regulations. The airplane accelerates to maximum climb speed, $V_{c\ell}$ (input in kt EAS), at 3050 m (10,000 ft) and climbs at constant equivalent airspeed to the altitude at which design Mach number is encountered. The remainder of the climb is at constant Mach.

Gross weight at the start of climb is takeoff weight (GW) less takeoff fuel (W_{fto}), which is given by the empirical relation

$$W_{fto} = 0.0152 \cdot N_{eng} \cdot \text{RATING} \qquad (27)$$

where N_{eng} is the number of engines and RATING is the sea level static thrust of the scaled engine. For those instances where water injection is used to reduce nitrous oxide omissions during takeoff, the weight of water expended is also subtracted from GW. This weight is also a function of engine thrust:

$$W_{H_2O} = 0.012075 \cdot N_{eng} \cdot \text{RATING}. \qquad (28)$$

Climb distance increments, ΔD, are derived from the relation

$$\Delta D = \Delta H/\tan\gamma \qquad (29)$$

where ΔH is the altitude increment for a given leg and Tan γ is an average of the values computed at the end points of the leg. Elapsed time is given by

$$\Delta T = \Delta D/V_t \qquad (30)$$

and the weight of fuel consumed by

$$\Delta W_f = \Delta T \cdot F_n \cdot c' \qquad (31)$$

where V_t is true airspeed, F_n is net engine thrust, and c' is specific fuel consumption. All three are average values for the leg.

To compute flight path angle, engine thrust and fuel consumption are interpolated from input tables. To obtain D/L, lift coefficient is given by

$$C_\ell = W/q\,S_w \qquad (32)$$

where W is the current gross weight and q is dynamic pressure N/m^2 (lb/ft^2).

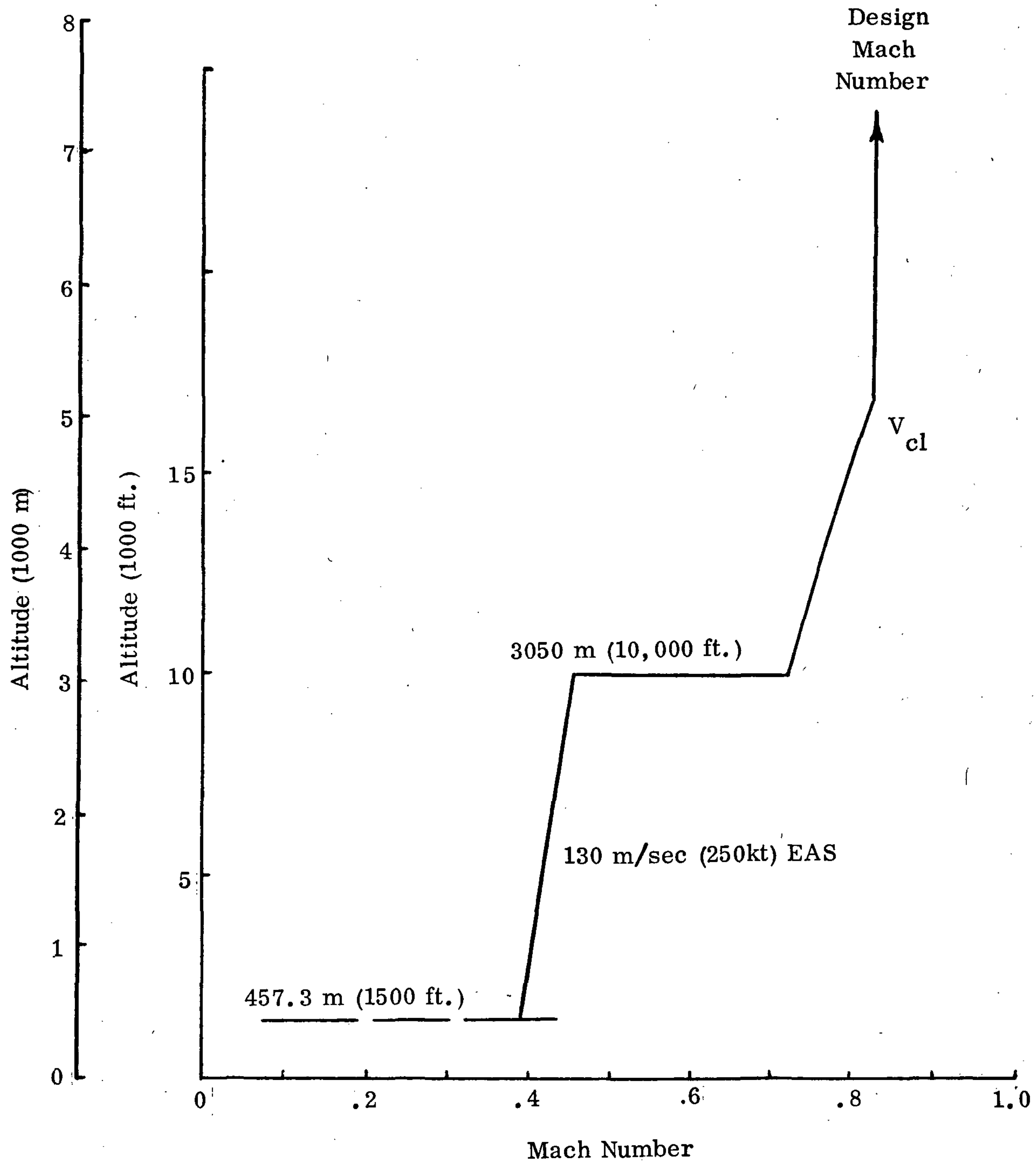

Figure 2-7. Climb and Descent Schedule

At 130 m/sec (250 kt) EAS, $q = 10{,}150\ N/m^2$ ($212\ lb/ft^2$). At 3050 m (10,000 ft), $q\ (lb/ft^2) = 3.392 \times 10^{-3}\ V_{C\ell}^2$. These two values suffice until the constant Mach climb segment is reached; thereafter,

$$q = 1481 \cdot \delta \cdot M^2 \tag{33}$$

with all parameters previously defined.

Drag coefficient is derived as a function of incremental Mach (ΔM) below critical Mach. Figure 2-8 shows the curves employed. For supercritical airfoils, critical Mach number is independent of lift coefficient; increments in parasitic and induced drag coefficients (ΔC_{d_o} and ΔC_{d_i}) are obtained directly from tables representing these curves. For conventional airfoils, critical Mach number varies inversely with lift coefficient. For reasonable values of C_ℓ, incremental induced drag coefficient, ΔC_{d_i} can be considered independent of this effect. To derive the increment in parasitic drag coefficient, ΔC_{d_o}, the increase in critical Mach number (ΔM_c) for the current C_ℓ is computed. The ΔC_{d_o} table is then entered at (ΔM_c) and at ($\Delta M_c + \Delta M$). The difference in these two values interpolated from the table is the required ΔC_{d_o}. Total drag coefficient C_d is then:

$$C_d = C_{d_o} + \Delta C_{d_o} + C_\ell^2/\pi\, AR\, e + \Delta C_{d_i} \tag{34}$$

Wing aspect ratio, AR, and Oswald efficiency factor, e, are input values.

Returning to the main climb/descent routine, the climb from 457.3 to 3050 meters (1500 to 10,000 feet) is computed as a single increment, first at constant weight and again with C_ℓ corrected for the computed change in gross weight. A similar technique is employed for the level acceleration leg. The climb at constant $V_{C\ell}$ is broken into increments by Mach number since drag coefficient changes rapidly during this leg. The Mach number increment used is an input variable, with a recommended value of 0.05. Each increment is computed at constant weight with no iteration. The constant Mach climb is likewise broken into incremental altitude steps because of rapidly changing q. The altitude increment is also under external control with a recommended value of 1524 meters (5,000 feet).

Descents are computed as climbs, but using idle thrust rather than climb thrust. Entering weight for the routine is actually the weight at the end of the descent, with fuel being added back in as the descent is computed backwards, starting at 457.3 m. (1500 ft) up to final cruise altitude. Commercial airplanes normally perform cruise step climbs, as fuel is burned off, for reasons of air traffic control. The Breguet equation theoretically presumes a continuous climb to maintain constant L/D during cruise. The model follows this assumption and computes a final cruise altitude which gives the same cruise L/D at the final cruise weight, W_1. Constant L/D implies constant C_ℓ, and since M is also constant, final cruise

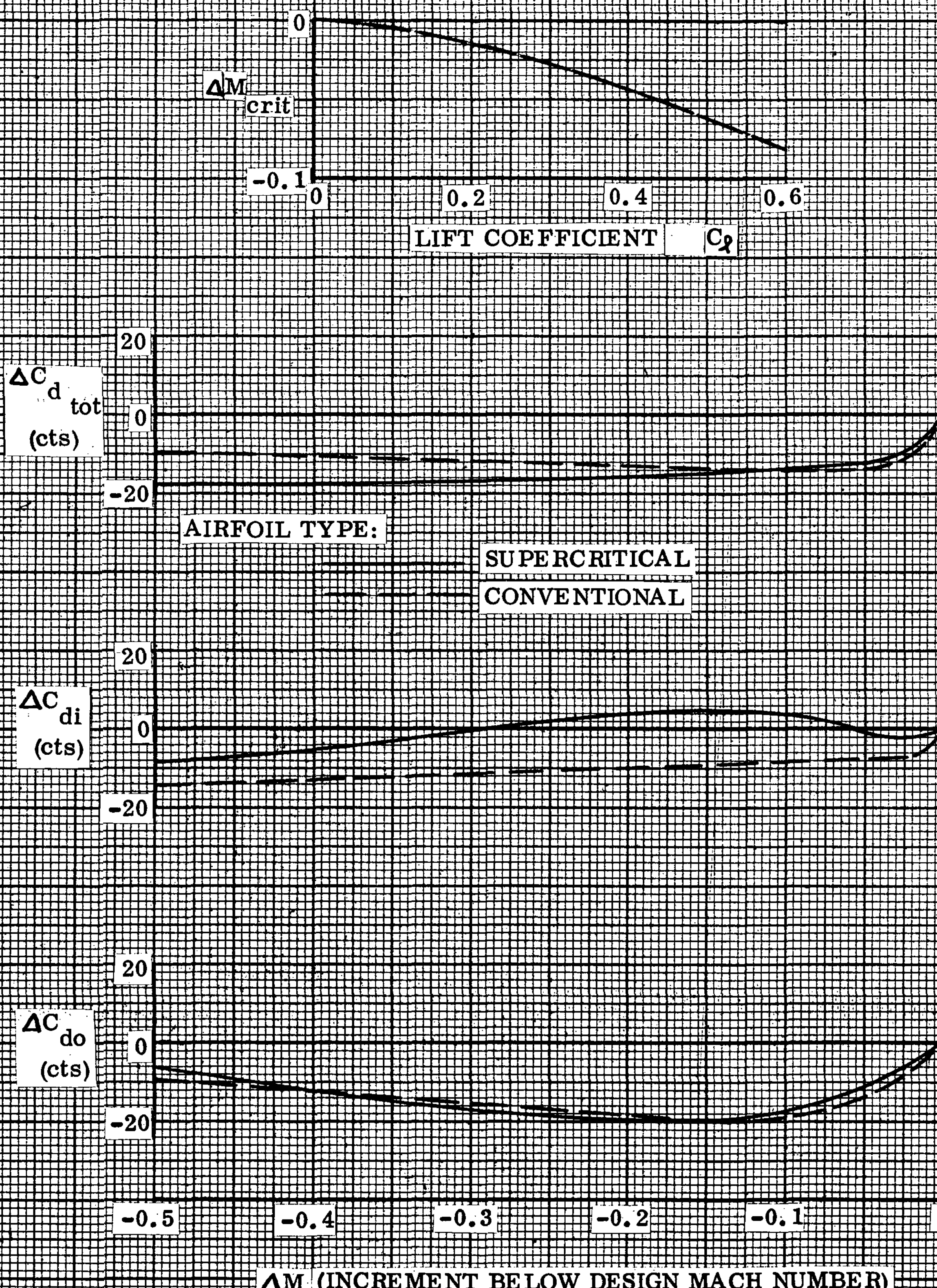

Figure 2-8. Compressibility Drag Increments.

altitude can be obtained from the table of altitude vs. V_e/M. At initial cruise conditions (subscript o)

$$V_{e_o}^{\ 2} = 2W_o/\rho_o C_\ell S_w .$$

At end of cruise (subscript 1), only the weight has changed, therefore

$$V_{e_1}^{\ 2} = 2W_1/\rho_o C_\ell S_w .$$

By looking up the value of V_e/M at initial cruise altitude,

$$(V_e/M)_1 = (V_e/M)_o \sqrt{W_1/W_o} . \tag{35}$$

Final cruise altitude is then a function of $(V_e/M)_1$, obtained from the table.

13. Gross Weight Solution — All of the prerequisite pieces are now available for a gross weight solution. The weight ratio W_o/W_1 is obtained from

$$W_o/W_1 = \exp\ (D_{cr}/RF) \tag{36}$$

where RF is an average range factor for initial and final cruise conditions and D_{cr} is cruise distance, given by

$$D_{cr} = R - D_{c\ell} - D_{des} + D_{res} \tag{37}$$

where $D_{c\ell}$ is total climb distance and D_{des} is total descent distance. All distance computations are in units of nautical miles. The term, D_{res}, is the distance equivalent of the reserve fuel loiter time requirement plus a 6 minute allowance for air maneuver. The final cruise weight W_1 is known as the weight at the beginning of the descent. Initial cruise weight is then available from equation (36) and gross weight at start of takeoff, GW, is given by

$$GW = W_o + W_{fcl} + W_{fto} + W_{H_2O} . \tag{38}$$

The portion of cruise fuel corresponding to D_{res} is computed from

$$W_{fres} = W_1 \left[\exp\ (D_{res}/RF) - 1\right] . \tag{39}$$

Total fuel capacity is computed by summation of the various increments for climb, descent, cruise, and reserves.

A single program iteration is performed beginning at step 4 , but omitting step 8.

14. Output — Block fuel and block time computations are performed for output presentation and for use in the DOC and ROI routines which follow. Block time, T_{bl}, is given in hours by

$$T_{bl} = T_{cl} + T_{cr} + T_{des} + 0.1 \quad (40)$$

where T_{cl} and T_{des} are the computed climb and descent time, the 0.1 hour constant is air maneuver time, and cruise time (T_{cr}) is the quotient of cruise distance and average true airspeed. At design range, block fuel, W_{bfl}, is just total fuel minus reserves.

The DOC and ROI routines must determine block time and block fuel as functions of distance flown. For this purpose, slope-intercept parameters are computed for each of these functions as shown below.

Block time

Slope: $T_{bs} = T_{cr}/D_{cr}$ hr/km (hr/nm) (41)

Intercept: $T_{bi} = T_{bl} - R \cdot T_{bs}$ hr (42)

Block fuel

Slope: $F_{bs} = W_{fcr}/D_{cr}$ kg/km (lb/nm) (43)

Intercept: $F_{bi} = W_{fbl} - R \cdot F_{bs}$ kg (lb) (44)

where

T = Time (hr)

D = Distance km (nm)

W_f = Fuel weight kg (lb)

and subscripts

cr = Cruise

bl = Block

A complete sample output is included in Section 5.

2.2 DOC (DIRECT OPERATING COST)

The basic function of the DOC module is to translate aircraft characteristics into generalized economic dimensions. This is accomplished by a series of equations (cost estimating relationships or CERs) which are responsive to design characteristics, performance, and operating rules. The first major step is calculation of aircraft flyaway cost.

Flyaway Cost

Flyaway cost is computed at either of two levels, dependent on availability of design definition. The first level computes airframe cost according to the formula

$$\text{Cost Airframe} = \text{WAF}\left(\frac{98}{\text{PQ}^{0.135}} + \frac{5500}{\text{PQ}}\right)\left(\frac{200,000}{\text{WAF}}\right)^{0.2}$$

where

WAF	=	Airframe weight kg (lb)
PQ	=	Production quantity
98	=	Nominal \$98/pound recurring production cost at unit #1 (\$44.5/kg)
0.135	=	Learning curve exponent
5500	=	Nominal \$5500/lb development cost (\$2500/kg)
0.2	=	Cost/size scaling exponents
200,000	=	Nominal airframe reference weight in pounds (90909 kg).

Engine costs are input directly or computed as a function of thrust. Avionics costs are input directly. Total flyaway cost is the sum of airframe, engines, and avionics costs.

When functional weights and cost coefficients are available, airframe costs are computed in 24 functional elements by labor and material as follows:

Cost of Airframe Element = Labor Cost + Material Cost

$$\text{Labor Cost} = \left(\frac{\text{PQ}}{\text{PR}}\right)^{\text{MLL}} \cdot \text{WSUB} \cdot \text{C MLH} \cdot (\text{CRCS})^{\text{CLSAL}} \cdot \text{CLRHW}$$

where

PQ	=	Production quantity actual
PR	=	Production quantity reference
MLL	=	Labor learning exponent

WSUB = Subsystem weight kg (lb)

CMLH = Cost per labor hour — manufacturing $/hr

CRCS = Reference weight kg (lb)

CLSAL = Labor size scaling exponent

CLRHW = Hours per pound at reference weight hr/kg (hr/lb)

$$\text{Cost of Mat'l} = \left(\frac{PQ}{PR}\right)^{MML} \cdot WSUB \cdot MCF \cdot (CRCS)^{CMSAL} \cdot CMRCW$$

where

MML = Material quantity learning factor

MCF = Material unit cost at reference weight $/kg ($/lb)

CMSAL = Material size scaling exponent

CMRCW = Material unit cost at reference weight $/kg ($/lb)

MLL — Labor Learning Exponent

In the labor cost equation, the exponent MLL is used to adjust from one production quantity to another along a cost reduction or learning curve. This approximation is intended for use between 100 units and 2000 units, and is not as accurate as rigorous learning curves applied back to the first production unit. Figure 2.2-1 shows exponents approximating various learning curves from unit 100 to unit 500 — the principal region of interest. For the general case, a labor curve of 80% is recommended. This corresponds to a value at MLL = 0.680.

CLSAL — Labor Sizing Scaling Exponent

For either a given component (e.g., a wing) or for a total airframe, there is significant cost/size scaling. That is, as design size is increased, cost per unit of weight is decreased. Figure 2.2-2 shows transport cost vs. weight. Figure 2.2-3 shows horizontal stabilizer hours as a function of weight. In these two examples, the size scaling exponents are both 0.8.

For labor only, the following size scaling exponents have been developed on prior programs:

1.	Total Airframe	0.82
2.	Primary Structure — Wing, Fuselage, Empennage	0.80
3.	Electrical, Pneumatic, Hydraulic	0.85
4.	Final Assembly and Checkout	0.70

MML — Material Quantity Learning Factor

Provision is made in the model for use of a material quantity cost reduction curve where the analyst has cost/quantity data for material. This "learning" is much less than labor cost/quantity reduction and in the absence of detailed data, a 98% curve (MML = 0.96) is suggested as being typical.

CMSAL — Material Size Scaling Exponent

This factor is available for use where detailed cost data is available on material as a function of airframe or component size. With typical, light alloy construction, this factor is very close to 1.0; however, with composite materials, special skin gages, or specially tailored alloys, scaling may be required. For some applications requiring highly specialized machinery or if a critical fraction of some resource is required, it might take on a value greater than one.

Sustaining tooling and engineering are computed as percentages of initial tooling and engineering. Assembly, integration, and profit are computed as percentages. Initial tooling and engineering are pro-rated and added to establish total airframe cost. The sample run and listing contains the equations and a set of input values representative of a conventional large transport aircraft.

Direct Operating Costs

Direct operating costs are computed according to the 1967 ATA formula, with cost factors updated to 1971 rates. Cost factors requiring updating for the effects of inflation are as follows:

CREW = Crew cost constant $/hr — 1971 Value $180

CDLH = Maintenance direct labor $/hr - 1971 Value $5

CFT = Fuel cost $/metric ton — 1971 Value $32.60/metric ton ($15/1000 lb)

Costs are computed for the various distance specified in DNM(I) — up to 20 separate distances. Times are computed from parasitic time (taxi, takeoff, air maneuver) identified as TBI (block time intercept from synthesis) and TBS (block time slope from synthesis). Block fuel is obtained from the synthesis and adjusted for fuel used in air delay (AD) and ground delay (GD), if any. Speeds, times, and block fuel are calculated for each DNM(I).

Aircraft utilization is calculated in an approximation of the ATA formula as follows:

$$U = ANHR \cdot TBTR/(TURNT + TBTR)$$

where

U = Annual utilization block hours

ANHR = Idealized utilization (4800 hr/yr)

TBTR = Block time for a given flight hr

TURNT = Ground turnaround time at gate (typically 0.50 hours)

Figure 2-9 shows resulting annual block utilization.

The ATA equations are then used to calculate Direct Operating Costs expressed in dollars per nautical mile for the following elements (see listing for equations).

CCT = Crew cost

CFOT = Cost of fuel and oil

CINST = Cost of (hull) insurance

CAFLT = Cost of airframe and misc. labor (maintenance)

CAFMT = Cost of airframe and misc. material (maintenance)

CCELT = Cost of engine labor (maintenance)

CCEMT = Cost of engine material (maintenance)

CDEPT = Cost of depreciation, including depreciation of spare parts

CAMBT = Cost of applied maintenance burden

These elements are then printed out for each DNM(I) as shown on the sample format.

2.3 ROI MODULE (RETURN-ON-INVESTMENT)

Direct operating cost is an abstract measure of an airplane's economic efficiency flying an arbitrary distance. ROI attempts to relate economic efficiency to actual city pairs, actual traffic levels, and reasonable fare yields. In addition to the direct costs, the indirect costs of passenger services, aircraft handling, and administration are included in the calculations.

The basic return-on-investment percentage is defined as that interest rate on a fixed dollar investment (e.g., a bank savings account) which will yield equal financial benefit over the investment period to the investment being analyzed.

For an airplane, the investment period is the depreciable lifetime. The formula is

$$ROIF = R \cdot (1 + R)^{YRS} / ((1 + R)^{YRS} - 1)$$

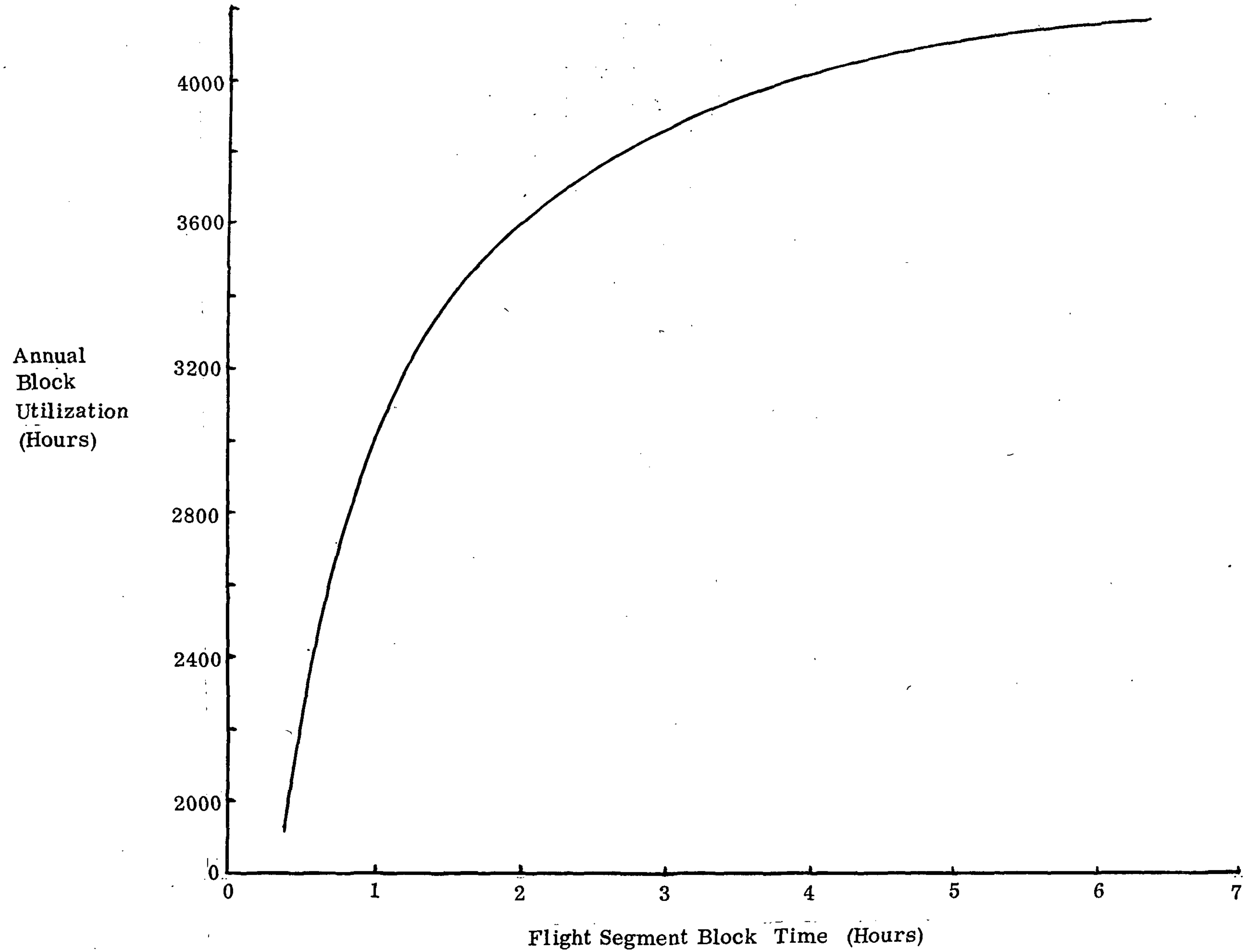

Figure 2-9. Annual Utilization

ROIF = ROI percentage

R = Annual percentage of profit on investment

YRS = Years of investment term.

An iterative solution is done by computer yielding an answer within a prespecified error specified by EPSA (typically 0.001). The iteration proceeds by a stepping factor in the iteration specified by DELR, typically 0.05.

To obtain R, the annual percentage of profit, it is necessary to calculate the following:

1. Flights per day by city pair to handle input traffic
2. DOC by city pair
3. IOC by city pair
4. Income by city pair
5. Net income after taxes
6. Aircraft required and total investment

Flights per day per city pair are computed by establishing a minimum frequency, a maximum permissible average load factor, and dividing traffic (input) by capacity. Number of flights are rounded to next higher integer, giving resulting load factors below maximum specified load factor. Referring to the sample printout, it is seen that low traffic city pairs are constrained by the minimum frequency and have low load factors. City pairs with greater activity, say 10 or 20 flights per day approach the maximum specified load factor — in this case 55%.

DOCs are computed for the specified city pair distances by interpolation from DOCs at arbitrary distances calculated in the previous section. IOCs are calculated as follows, based on the Lockheed IOC methodology.

Ramp Service and Landing Fee \$3.02 per metric ton (\$1.37 per 1000 lb) gross weight per landing	Z (1)
Passenger Service Cost — \$0.0047 per RPM	Z (2)
Reservations, Sales, and Passenger Handling — \$9/passenger hour	Z (3)
Stewardess Expense — \$15.03/Stewardess Block Hour (No. of Stewardesses from Synthesis)	Z (4)
Meal Cost = \$0.90 + \$0.45/Passenger Block Hour	Z (5)

$$\text{Administrative Cost Factor} = 0.091 \cdot \sum_{1}^{5} \text{IOC Costs} \qquad Z\ (6)$$

All of the above are in 1971 dollars and are subject to inflation, except the administrative override.

Traffic data for each of up to 200 city pair is entered as:

City Pair
Distance — See input format
Pass./Day

Income by city pair is calculated from a fare formula as follows:

For each passenger $7 (FARE I)

Plus $0.0346/km ($0.0644/nm) (FARES)

This was derived empirically for 1971 by taking actual trunk airline income and RPM, and as such, accounts for cargo, mix of first class and coach passengers, and dilutions in the form of special and promotional fares. Fares must be adjusted for inflation, and the user is cautioned to look at actual yields, not published fare schedules, to develop realistic income levels. Typical yields are about 85% of published regular coach fares.

Net income after taxes is computed by taking total income less DOC, less IOC times 52%. This is then defined as net profit. The total aircraft required are summed from fractional requirements by city pair.

This is done on the assumption that schedules can be arranged to utilize airplanes within the constraints of the empirical utilization formula, which was presumably developed from actual data. For each aircraft required, investment is equal to flyaway cost plus engine and airframe spares. Total investment is obtained by multiplying investment base per airplane (XIB) by fleet size. Total investment is compared to system net profit to obtain system Return-on-Investment.

Table 2.2 presents a summary of terms used in the analytic derivation described in Section 2 of this report. Both the scientific international and the English system of units are presented; however, the actual program utilizes the English system of units exclusively.

Table 2.2 Summary of Terms

A	Total airplane wetted area m^2 (ft^2)
A_{cs}	Airfoil cross sectional area m^2 (ft^2)
A_{fus}	Fuselage gross wetted area m^2 (ft^2)
A_{ib}	Wing inboard portion wetted area m^2 (ft^2)
A_{nac}	Nacelle wetted area m^2 (ft^2)
ANHR	Idealized utilization 4800 hr/yr
A_{ob}	Wing outboard portion wetted area m^2 (ft^2)
AR	Aspect ratio (dimensionless)
b	Wing span m (ft)
c	Wing chord m (ft)
c'	Specific fuel consumption kg/N-hr (lbm/lb-hr)
CAFLT	Cost of airframe maintenance labor $
CAFMT	Cost of airframe maintenance material $
CAMBT	Cost of applied maintenance burden $
CCELT	Cost of engine maintenance labor $
CCEMT	Cost of engine maintenance material $
CCT	Crew cost $
CDEPT	Cost of depreciation including spares $
CDLH	Maintenance direct cost per hour $/hr
C_{fe}	Equivalent skinfriction coefficient (dimensionless)

CFOT	Cost of fuel and oil $
CFT	Fuel cost $/metric ton ($/1000 lb.)
cgl	Ratio of glove root chord to theroretical wing chord (dimensionless)
CINST	Cost of (hull) insurance $
C_l	Lift coefficient (dimensionless)
CLRHW	Hours per pound at reference weight
CLSAL	Labor size scaling exponent (dimensionless)
C_d	Total drag coefficient (dimensionless)
C_{di}	Induced drag cœfficient (dimensionless)
C_{do}	Parasetic drag coefficient (dimensionless)
CMLH	Manufacturing cost per labor hour $/hr
CMRCW	Material unit cost of reference weight $/kg ($/lb.)
CMSAL	Material size scaling exponent (dimensionless)
CRCS	Reference weight kg (lb)
CREW	Crew cost per hour $/hr
C_{root}	Wing root chord m(ft)
c_{sw}	Ratio wing wetted area to planform area (dimensionless)
D	Scaled engine nacelle diameter m (ft)
D_o	Nacelle diameter of 1.0 engine m (ft)
$D_{c\ell}$	Total climb distance km (nm)
D_{cr}	Total cruise distance km (nm)
D_{des}	Total descent distance km (nm)

D_{fus}	Fuselage external diameter m (ft)
DOC	Direct Operating Cost $
D_{nac}	Nacelle diameter m (ft)
D_{res}	Total reserve distance km (nm)
e	Oswald efficiency factor (dimensionless)
EAS	Equivalent airspeed km/hr (kf)
ES	Engine scale factor (dimensionless)
F_{br}	
F_n	Net engine thrust N (lb.)
GW	Gross weight kg (lb)
K_{acs}	Active control system factor (dimensionless)
K_{ar}	Fuselage area ruling factor (dimensionless)
KEAS	Knots equivalent airspeed (kt)
K_{matl}	Construction material factor (dimensionless)
K_{tech}	Aerodynamic and structural technology factor (dimensionless)
L/D	Optimum lift to drag ratio (dimensionless)
$(L/D)_{nac}$	Nacelle length to diameter ratio (dimensionless)
$(L/D)_{nac-fin}$	Fin mounted nacelle length to diameter ratio (dimensionless)
L_{st}	Length of fuselage straight section m (ft)
L_{tpr}	Length of fuselage tapered nose and tail section m (ft)
m. a. c.	Mean aerodynamic chord m (ft)
M	Freestream Mach number (dimensionless)

M_c	Critical Mach number (dimensionless)
MCF	Material unit cost at reference weight \$/kg (\$/lb)
MLL	Labor learning exponent (dimensionless)
MML	Material quantity learning factor (dimensionless)
N_{cr}	Number of cockpit crew (dimensionless)
N_{eng}	Number of engines (dimensionless)
N_{stew}	Number of stewardesses (dimensionless)
OWE	Basic operating (empty) weight kg (lb.)
PAX	Total number of passenger seats (dimensionless)
PQ	Actual production quantity (dimensionless)
PR	Reference production quantity (dimensionless)
g	Dynamic pressure N/m^2 ($lb./ft^2$)
R	Annual percentage of profit on investment (dimensionless)
R	Range km (nm)
RATING	Sea level static thrust of scaled engine N (lb.)
RF	Range factor km (nm)
ROI	Return on investment (dimensionless)
ROIF	Return on investment percentage (dimensionless)
RPM	Revenue passenger miles km (nm)
S_h	Horizontal tail exposed area m^2 (ft^2)
S_{ib}	Wing inboard portion planform area m^2 (ft^2)
S_{ob}	Wing outboard portion planform area m^2 (ft^2)
S_v	Vertical tail exposed area m^2 (ft^2)
S_w	Wing area m^2 (ft^2)

TBTR	Block time for a given flight (hr.)
t/c	Airfoil thickness to chord ratio (dimensionless)
t_r	Wing thickness at the root m (ft)
TURNT	Ground turnaround time at gate (hr)
T/W	Cruise thrust to weight ratio (dimensionless)
u	Glove root chord m (ft)
U	Annual utilization (hr)
v	Basic wing root chord m (ft)
V_e	Equivalent airspeed km/hr (kt)
V_h	Horizontal tail volume coefficient (dimensionless)
V_t	Time airspeed km/hr (kt)
V_v	Vertical tail volume coefficient (dimensionless)
W	Current gross weight kg (lb.)
W_o	Initial cruise gross weight kg (lb.)
W_1	Final cruise gross weight kg (lb.)
W_{ac}	Air conditioning system weight kg (lb.)
WAF	Airframe weight kg (lb.)
W_{ai}	Anti-icing system weight kg (lb.)
W_{apu}	Auxiliary power unit system weight kg (lb.)
W_{aux}	Auxiliary gear weight kg (lb.)
W_{avi}	Avionics system weight kg (lb.)
WAVI	Weight of avionics kg (lb.)

W_b	Fuselage structural weight kg (lb.)
W_{bfl}	Block fuel weight kg (lb.)
W_{cr}	Crew weight kg (lb.)
W_{crew}	Weight of a crew member kg (lb.)
W_{dist}	Fuel system distribution system weight kg (lb.)
W_{dmp}	Fuel system dumping system weight kg (lb.)
WE	Weight empty kg (lb.)
W_{ec}	Engine controls weight kg (lb.)
W_{elec}	Electrical system weight kg (lb.)
W_{eng}	Individual engine weight kg (lb.)
W_{engl}	Individual scaled engine weight kg (lb.)
W_{eg}	Passenger equipment weight kg (lb.)
W_{falt}	Cruise fuel weight for alternate cruise leg kg (lb.)
W_{fc}	Fuel system controls weight kg (lb.)
W_{fcl}	Climb fuel weight kg (lb.)
W_{fcr}	Cruise fuel weight kg (lb.)
W_{fres}	Fuel weight corresponding to reserve distance kg (lb.)
W_{frn}	Furhishings weight kg (lb.)
W_{fto}	Takeoff fuel weight kg (lb.)
W_{flot}	Total fuel weight kg (lb.)
W_h	Horizontal tail structural weight kg (lb.)
W_{h20}	Water injection system fluid weight kg (lb.)
W_{hyd}	Hydraulic system weight kg (lb.)

W_{inst}	Instrument weight	kg (lb.)
$W_{\ell g}$	Landing gear weight	kg (lb.)
W_{oil}	Engine oil weight	kg (lb.)
W_{nac}	Nacelle weight	kg (lb.)
W_{p}	Fuel system pump weight	kg (lb.)
W_{pl}	Payload weight	kg (lb.)
W_{rf}	Fuel system refueling system weight	kg (lb.)
W/S	Design takeoff wing loading	N/m^2 (lb/ft^2)
W_{sc}	Surface control system weight	kg (lb.)
W_{sl}	Fuel system sealant weight	kg (lb.)
W_{sp}	Engine/nacelle soundproofing weight	kg (lb.)
W_{st}	Engine starting system weight	kg (lb.)
W_{stew}	Stewardesses weight	kg (lb.)
WSUB	Subsystem weight	kg (lb.)
W_{uf}	Unusable fuel weight	kg (lb.)
W_{v}	Fuel system vent system weight	kg (lb.)
W_{v}	Vertical tail structural weight	kg (lb.)
W_{w}	Wing structural weight	kg (lb.)
W_{wi}	Engine water injection system weight	kg (lb.)
XIB	Investment base per airplane	$
Y_{gl}	Location of wing root/fuselage intersection	m (ft.)
YRS	Years of investment term	(yr.)

γ Climb or descent flight path angle (degrees)

δ Atmospheric pressure ratio at initial cruise altitude (dimensionless)

ΔD Climb distance increment km (nm)

ΔH Climb altitutde increment m (ft.)

ΔT Climb time increment (hr)

$\Lambda_{c/2}$ Wing 50% chord sweep (degrees)

Λ_{LE} Wing leading edge sweep (degrees)

ρ_o Atmospheric density at initial cruise altitude kg/m^3 (lb/ft^3)

σ Atmospheric pressure ratio at a given altitude (dimensionless)

SECTION 3

COMPUTER PROGRAM

3.1 PROGRAM ORGANIZATION

The TEKVAL computer program is configured for maximum flexibility of operation. Each of the main program sections (SIZE, DOC, and ROI) may be operated independently with external input, or they may be operated sequentially (SIZE-DOC-ROI or DOC-ROI) with the output of one section providing partial input for subsequent sections.

Program operation is controlled by a 3-digit binary control word labeled KEY. Figure 3-1 illustrates the TEKVAL program organization and the function of the control word. The three digits control the execution of each of the main program modules, the first digit for SIZE, the second for DOC, and the third for ROI. A one calls for module execution while a zero signals omission of that module. To operate all three modules sequentially, a value of KEY = 111 is used. A value such as KEY = 010 calls for execution of the DOC module only.

The value of KEY is read at the beginning of the main program. A branch is then made to the appropriate module within the main program. Following execution of each module, the value of KEY is reduced by an appropriate power of 10, effectively eliminating the leading digit. If the succeeding digit so indicates, the next module is executed. If the succeeding digit is a zero, the program reverts to the beginning for a new value of KEY.

Each of the main program modules has its own input and output subroutines. The NAMELIST format is utilized for all input, including the control word KEY. A complete input deck is obviously required for execution of the first module of a given run. For sequential operation of subsequent modules, only partial input decks are required but there must be a separate NAMELIST deck for each module to be executed on every run. Complete input requirements and data communication between modules are described below.

3.2 DESCRIPTION OF SUBROUTINES

Figures 3-2 through 3-4 show the subroutines called by each of the main program modules and how they are interlinked. All input and output subroutines are straightforward and need no further clarification. The principle function of each of the remaining subroutines is described herein.

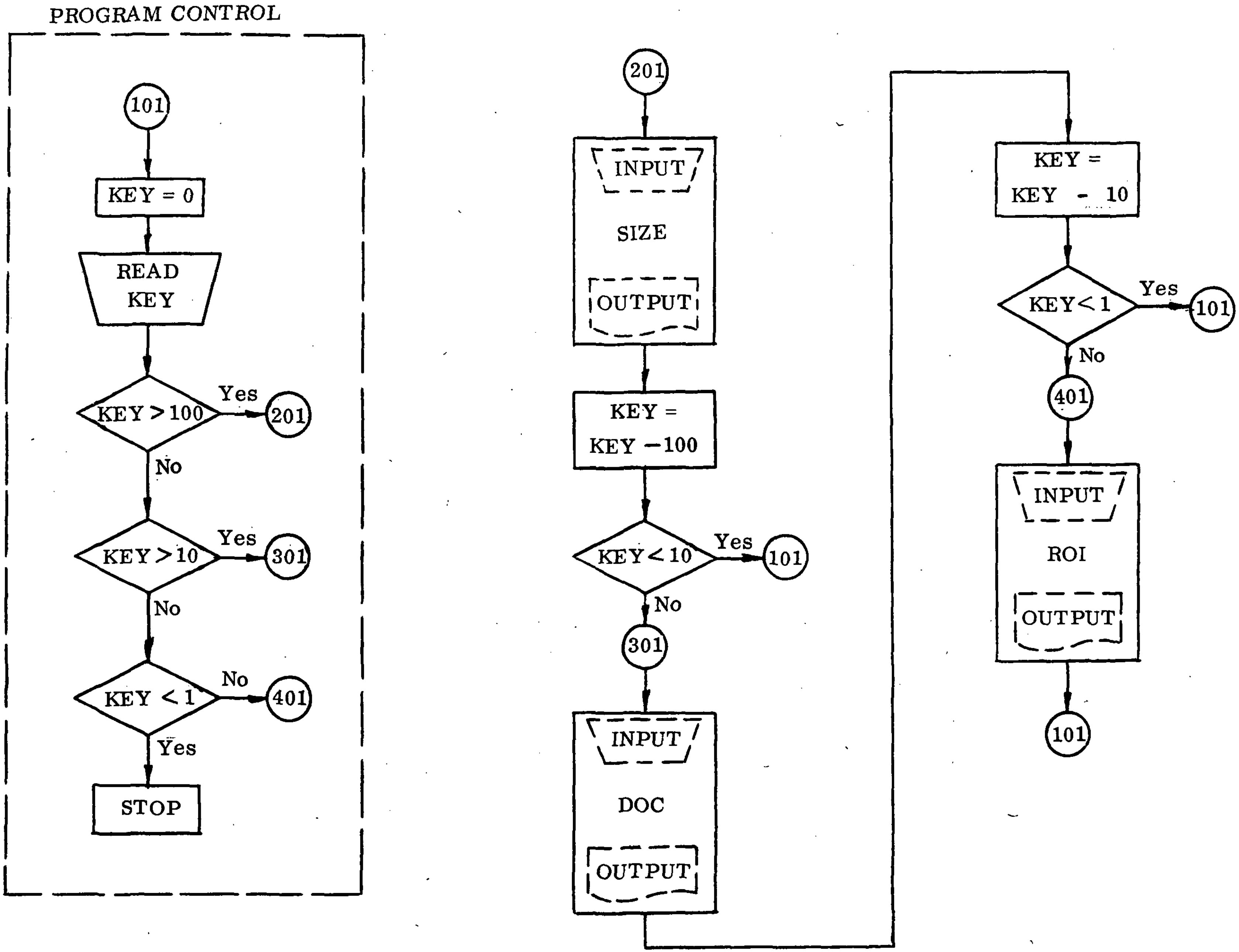

Figure 3-1. TEKVAL Program Organization

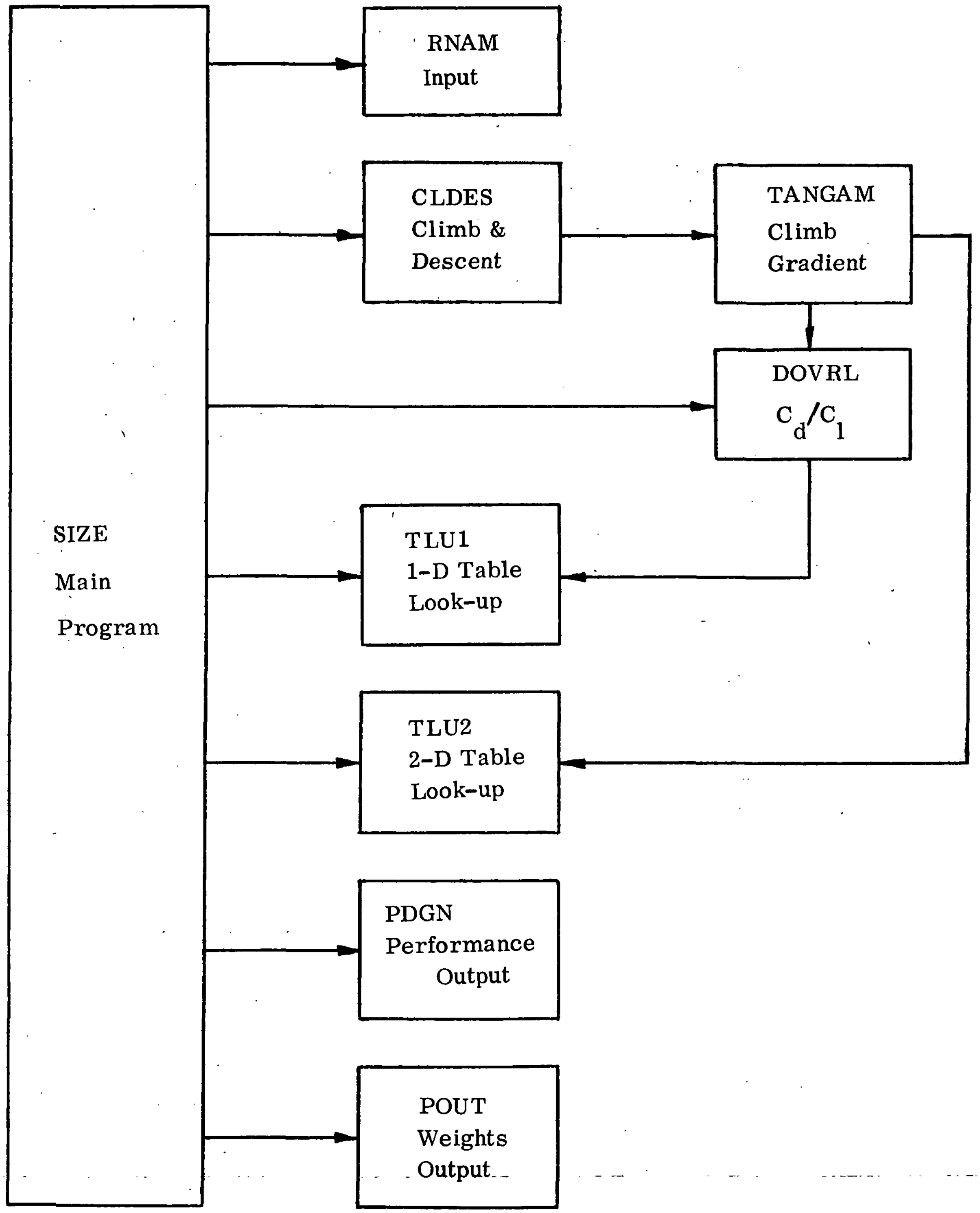

Figure 3-2. SIZE Subroutine Structure

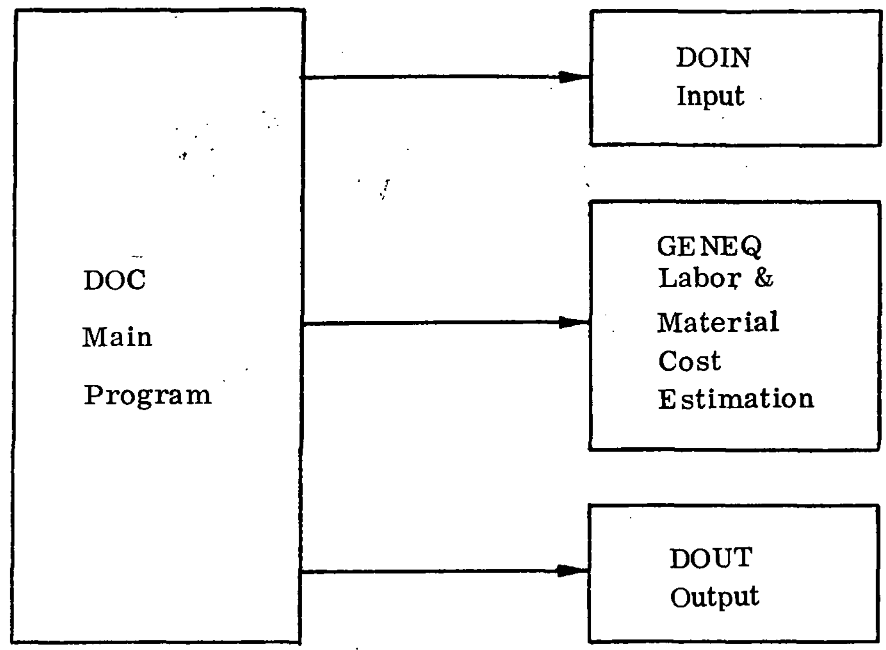

Figure 3-3. DOC Subroutine Structure

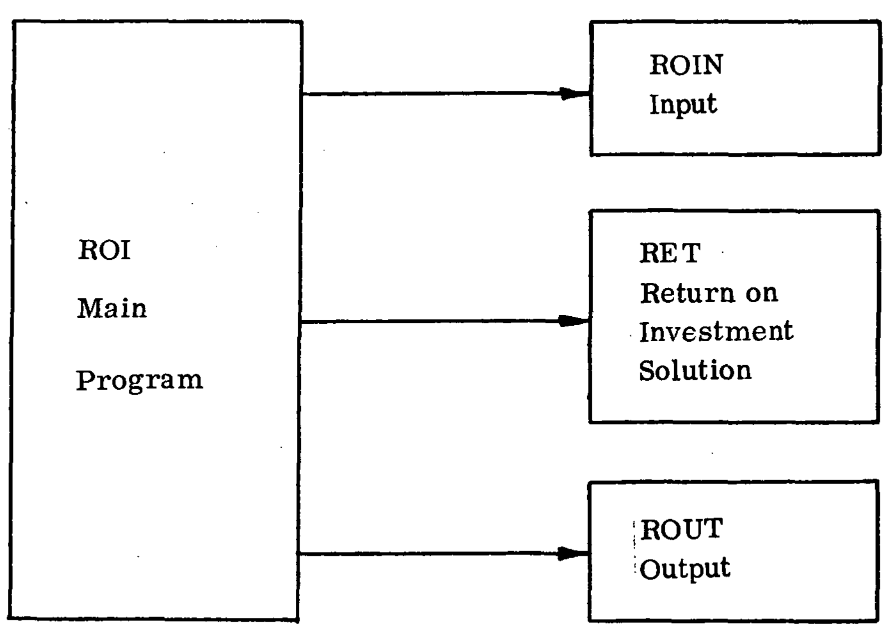

Figure 3-4. ROI Subroutine Structure

The following subroutines are employed by the SIZE module:

TLUI - A one dimensional linear interpolation table look-up routine. The call sequence lists the input value X and the locations and dimension of the X and Y vectors. The value of Y corresponding to X is returned via a call argument. If the vector dimension is exceeded during the table search, an error message "TLU1 OUT OF RANGE" is printed and the program stops.

TLU2 - A two dimensional linear interpolation table look-up routine. This routine gives Y = f (X, Z). The call sequence lists values of X and Z plus addresses for the X and Z vectors and the Y matrix, and the dimensions of the X and Z vectors. The Z indices are determined first. For each of the two Z indices, the TLU1 subroutine is utilized to determine Y = f(X). Linear interpolation on Z then gives the final value of Y. Should the Z vector dimension be exceeded, the error message "TLU2 OUT OF RANGE" is printed and the program stops.

CLDES - This subroutine computes the time, distance, and fuel required to climb or descend according to a given speed-altitude profile. The mathematical operations were described in Section 2.1. This routine performs the computations and accumulations of distance, time, and fuel increments as well as current gross weight, Mach number, dynamic pressure, true airspeed, and average values for climb gradient, specific fuel consumption, and engine thrust. It directly utilizes TLU1 for altitude related functions and frequently calls TANGAM to compute climb gradients.

TANGAM - This subroutine computes flight path gradient as the difference between T/W and D/L. Subroutine DOVRL is called to produce D/L. Subroutine TLU2 is called to obtain engine thrust and specific fuel consumption, which are then returned to CLDES via TANGAM.

DOVRL - Subroutine DOVRL computes the ratio C_d/C_ℓ as a function of Mach number for a given value of C_ℓ. The primary function of this subroutine is to back out compressibility effects from the cruise Mach number drag coefficient for the slower speeds encountered during climb and descent. The mathematical approach was described in Section 2.1.

The DOC and ROI modules each employ only one subroutine in addition to the input and output functions. Subroutine GENEQ makes use of a generalized cost equation, explained in Section 2.2, to compute labor and material costs, and their total, for a particular aircraft component or subsystem. The call arguments transfer the component weight, a reference weight, labor and material scaling exponents, and labor hours/pound and material cost/pound at the reference weight. All of these factors vary by component. A COMMON statement provides constant values for desired and reference production quantities, labor and material learning exponents, manufacturing labor rate, and material cost escalation factor.

In the ROI module, subroutine RET employs an iterative technique to compute the equivalent rate of return-on-investment equaling the profit generated by commercial airplane operations. The call sequence provides all required input: profit, number of airplanes, investment/airplane, and the time period of the operation. The mathematical technique is described in Section 2.3; because of the nature of the equations, an iterative technique is required. A trial value of ROI is used to compute what is in essence an equivalent profit for a fixed investment over a given number of years. The trial ROI is incremented in steps of DELR (arbitrary stepping increment, dimensionless) until the computed profit matches the target value within an accuracy specified by the parameter EPSA (error fraction, dimensionless). Both DELR and EPSA are input; suggested values are DELR = .05, EPSA = .001. When profit is negative, ROI is computed based on the absolute value of profit, with the negative sign attached to the result.

3.3 DICTIONARY OF VARIABLES

A dictionary of FORTRAN variables found in the program modules associated with the sizing process is presented in Table 3-1. Variables associated with the Direct Operating Cost and Return-On-Investment modules are found in Tables 3-2 and 3-3, respectively. It should be noted that the actual program input and output utilize the English system of units.

TABLE 3-1. DICTIONARY OF VARIABLES

NAME	DESCRIPTION
SIZE MODULE	
ALT	INITIAL CRUISE ALTITUDE (FT/1000)
ALTF	FINAL CRUISE ALTITUDE (FT/1000)
CDF	EQUIVALENT SKIN FRICTION COEFFICIENT
CDOMCR	CRUISE PARASITE DRAG COEFFICIENT
CGLOVE	RATIO WING GLOVE CHORD/THEO CHORD AT BODY
CHVOL	VOLUME COEFFICIENT FOR HORIZONTAL TAIL
CL	LIFT COEFFICIENT
CLCR	CRUISE LIFT COEFFICIENT
CLOCH	HORIZONTAL TAIL MAC LOCATION RATIO TO BODY LENGTH
CLOCV	VERTICAL TAIL MAC LOCATION RATIO TO BODY LENGTH
CLOCW	WING MAC LOCATION RATIO TO BODY LENGTH
CMDD	INCREMENT IN CRITICAL MACH NUMBER DUE TO CL / CL
CPAXC	FRACTION OF TOTAL SEATS IN COACH
CRMACH	DESIGN CRUISE MACH NUMBER
CSWET	RATIO WING WETTED AREA/PLANFORM AREA - RECTANGULAR SECTION
CSWPYL	RATIO PYLON/NACELLE WETTED AREAS
CTWR	INITIAL ESTIMATE OF STATIC T/W REQUIRED
CVVOL	VOLUME COEFFICIENT FOR VERTICAL TAIL
CWEF	INDUCED DRAG EFFICIENCY FACTOR
CWFRG	LATERAL EXTENT OF WING GLOVE/WING SEMI-SPAN
CWT	RATIO WO/WGTO
CWTIC	RATIO WO/WGTO ,INITIAL ESTIMATE)
DAISLE	AISLE WIDTH IN COACH (IN)
DBD	BODY DIAMETER (FT)
DBL	TOTAL BODY LENGTH (FT)
DBLC	LENGTH OF COACH SECTION (FT)
DBLST	LENGTH OF STRAIGHT BODY SECTION (FT)
DBLTPR	LENGTH OF TAPERED BODY SECTION (FT)
DBL1	LENGTH OF FIRST CLASS SECTION (FT)
DCDCV	TABLE - DRAG RISE - DELTA CDO - CONVENTIONAL (COUNTS)
DCDICV	TABLE - DRAG RISE - DELTA CDI - CONVENTIONAL (COUNTS)
DCDISC	TABLE - DRAG RISE - DELTA CDI - SUPERCRITICAL (COUNTS)
DCDSC	TABLE - DRAG RISE - DELTA CDO - SUPERCRITICAL (COUNTS)
DCL	DISTANCE - CLIMB TO INITIAL CRUISE ALTITUDE (NM)
DCR	CRUISE DISTANCE (NM)
DCRES	CLIMB DISTANCE TO 15000 FT FOR FUEL RESERVES (NM)
DDES	DISTANCE - DESCEND FROM FINAL CRUISE ALTITUDE (NM)
DDRES	DESCENT DISTANCE FROM 15000 FT FOR FUEL RESERVES (NM)
DRES2	CRUISE DISTANCE TO ALTERNATE DESTINATION (NM)
DELTAI	PRESSURE RATIO AT INITIAL CRUISE ALTITUDE
DHL	LENGTH OF HORIZONTAL TAIL ARM (FT)
DLCR	CRUISE D/L RATIO
DLNAC	LENGTH OF NACELLE (FT)
DMACH	TABLE - DRAG RISE - MACH NUMBER
DNAC	NACELLE DIAMETER(FT)
DNAC1	DIAMETER OF FULL SCALE NACELLE (FT)
DRES	DISTANCE TO ALTERNATE DESTINATION (NM)
DRES1	DISTANCE EQUIVALENT OF TRES (NM)
DSTPC	SEAT PITCH IN COACH (IN)
DSTP1	SEAT PITCH IN FIRST CLASS (IN)
DSTWC	SEAT WIDTH IN COACH (IN)
DSTW1	SEAT WIDTH IN COACH (IN)
DWB	WING SPAN (FT)

TABLE 3-1. DICTIONARY OF VARIABLES (CONT)

NAME	DESCRIPTION
DWBS	WING STRUCTURAL SPAN (FT)
DWCGL	LENGTH OF WING GLOVE CHORD (FT)
DWCOB	LENGTH OF WING CHORD AT BODY JUNCTION (FT)
DWCR	LENGTH OF WING ROOT CHORD (FT)
DWCT	LENGTH OF WING TIP CHORD (FT)
DWMAC	LENGTH OF WING MEAN AERODYNAMIC CHORD (FT)
DWTGL	THICKNESS OF WING GLOVE CHORD (FT)
DWTR	WING ROOT CHORD THICKNESS AT C/L (FT)
DVL	LENGTH OF VERTICAL TAIL ARM (FT)
ES	ENGINE SCALE
FBI	BLOCK FUEL EQUATION - INTERCEPT
FBS	BLOCK FUEL EQUATION - SLOPE
FGAM	TABLE - CRITICAL MACH INCREMENT - FACTOR
FGAMDD	FACTOR TO DETERMINE CMDD = F(WING SWEEP)
FLDENS	FUEL DENSITY (LB/GAL)
FNCL	TABLE - NET THRUST - CLIMB
FNCR	TABLE - NET THRUST - CRUISE
FNIDL	TABLE - NET THRUST - IDLE
FNMCR	FULL SCALE ENGINE NET THRUST - INITIAL CRUISE (LBS)
FNREQ	REQUIRED NET THRUST/ENGINE - INITIAL CRUISE (LBS)
FNRTG	SLST OF FULL SCALE ENGINE
FNZL	LIMIT LOAD FACTOR
FTAPER	TAPERED BODY LENGTH(DIAMETERS)
GNFR	PODDED NACELLE FINENESS RATIO
GNFRF	NACELLE FINENESS RATIO - FIN MOUNTED
GWAR	WING ASPECT RATIO
GWPL	RATIO WGTO/WPL
GWS	WING LOADING (LB/SQ FT)
GWSWP0	WING SWEEP ANGLE AT LE (DEG)
GWSWP2	WING SWEEP ANGLE AT C/2 (DEG)
GWSWP4	WING SWEEP ANGLE AT C/4 (DEG)
GWTC	WING THICKNESS/CHORD RATIO
GWTPR	WING TAPER RATIO
H	TABLE - STANDARD ATMOSPHERE - ALTITUDE (FT/1000)
HDEL	TABLE - STANDARD ATMOSPHERE - DELTA
HH	TABLE - ENGINE DATA - ALTITUDE (FT/1000)
HSIGSR	TABLE - STANDARD ATMOSPHERE - SQ RT SIGMA
KACS	FLAG FOR ACTIVE CONTROL SYSTEM (1=WITH, 0=W/O)
KAF	FLAG FOR SUPERCRITICAL AIRFOIL (1=WITH, 0=W/O)
KAPU	FLAG FOR AUXILLIARY POWER UNIT (1=WITH, 0=W/O)
KARULE	FLAG FOR BODY AREA RULING (1=WITH, 0=W/O)
KEFIN	FLAG FOR FIN MOUNTED ENGINE (1=YES, 0=NO)
KEY	PROGRAM CONTROL WORD
KMATL	FLAG FOR CONSTRUCTION MATERIAL (1=COMP, 0=ALUM)
KPSP	FLAG FOR NACELLE SOUND PROOFING (1=WITH, 0=W/O)
KRPT	FLAG FOR SIZE ITERATION LOOP
KTEST	TEST FOR ODD NUMBER OF ENGINES (+=EVEN, -=ODD)
KUPDN	FLAG FOR CLDES SUBROUTINE (1=CLIMB, 0=DESCEND)
KWI	FLAG FOR ENGINE WATER INJECTION PROVISIONS (1=WITH, 0=W/O)
NAISLE	NO. AISLES
NCREW	NO. OF FLIGHT CREW MEMBERS
NENG	NUMBER OF ENGINES
NENGPR	NO. OF PODDED ENGINES (WING OR BODY MOUNTED)
NPAXC	NO. SEATS IN COACH
NPAX1	NO. SEATS IN FIRST CLASS

TABLE 3-1. DICTIONARY OF VARIABLES (CONT)

NAME	DESCRIPTION
NROWC	NO. SEAT ROWS IN COACH
NROW1	NO. SEAT ROWS IN FIRST CLASS
NSROWC	NO. SEATS ABREAST IN COACH
NSROW1	NO. SEATS ABREAST IN FIRST CLASS
NSTEW	NO. OF STEWARDESSES
OWE	OPERATING WEIGHT EMPTY (LBS)
PAX	TOTAL NO. SEATS
PIAE	PI X ASPECT RATIO X INDUCED DRAG EFF FACTOR
Q	DYNAMIC PRESSURE (LB/SQ FT)
QFUEL	FUEL QUANTITY - TOTAL (GAL)
RACS	ACS CORRECTION FACTOR FOE WING WEIGHT
RANGE	DESIGN RANGE (NM)
RANGEF	BREGUET RANGE FACTOR
RATING	SEA LEVEL STATIC THRUST OF SCALED ENGINE (LBS)
RF	RANGE FACTOR AT 15000 FT CRUISE OR AT FINAL CRUISE
RFAVG	RANGE FACTOR - AVERAGE INITIAL AND FINAL CRUISE
RMACH	SPEED CORRECTION FACTOR FOR WING WEIGHT
RMATL	MATERIAL CORRECTION FACTOR FOR WING WEIGHT
SBW	WETTED AREA - BODY (SQ FT)
SBWCS	WING GLOVE CROSS SECTION AREA (SQ FT)
SFC	THRUST SPECIFIC FUEL CONSUMPTION (LB/LB/HR)
SFCIDL	TABLE - SPECIFIC FUEL CONSUMPTION - IDLE
SFCCL	TABLE - SPECIFIC FUEL CONSUMPTION - CLIMB
SFCCR	TABLE - SPECIFIC FUEL CONSUMPTION - CRUISE
SHEXP	EXPOSED AREA OF HORIZONTAL TAIL (SQ FT)
SNW	WETTED AREA - NACELLES (SQ FT)
SRSIG	SQUARE ROOT OF DENSITY RATIO = F(ALTITUDE)
STW	WETTED AREA - HORIZONTAL + VERTICAL TAIL (SQ FT)
SVEXP	EXPOSED AREA OF VERTICAL TAIL (SQ FT)
SW	WING AREA (SQ FT)
SWET	WETTED AREA - TOTAL AIRPLANE (SQ FT)
SWP	TABLE - CRITICAL MACH INCREMENT - WING SWEEP
SWW	WETTED AREA - WING TOTAL (SQ FT)
SWWIB	WETTED AREA - WING 2NBOARD SECTION (SQ FT)
SWWOB	WETTED AREA - WING OUTBOARD SECTION (SQ FT)
TBI	BLOCK TIME EQUATION - INTERCEPT
TBL	BLOCK TIME (HR)
TBS	BLOCK TIME EQUATION - SLOPE
TCL	TIME - CLIMB TO INITIAL CRUISE ALTITUDE (HR)
TCR	TIME - CRUISE (HR)
TDES	TIME - DESCEND FROM FINAL CRUISE ALTITUDE (HR)
TGAMC2	TAN(WING SWEEP AT C/2)
TRES	RESERVE FUEL LOITER TIME (HR)
TSTO	ENGINE SLST REQUIRED
VCL	MAX CLIMB EQUIVALENT AIRSPEED (KT)
VDIVM	TABLE - STANDARD ATMOSPHERE - VE/M
VMO	RATIO VE/M AT START OF CRUISE
VM1	RATIO VE/M AT END OF CRUISE
VOVRM	RATIO EQUIVALENT AIRSPEED/MACH NUMBER = F(ALTITUDE)
VT	WORKING VALUE - TRUE AIRSPEED (KT)
VTAVG	TRUE AIRSPEED - AVG INITIAL AND FINAL CRUISE (KT)
VTF	TRUE AIRSPEED - FINAL CRUISE (KT)
VTI	TRUE AIRSPEED - INITIAL CRUISE (KT)
WAF	AIRFRAME WEIGHT FOR DOC PROGRAM (LBS)
WCRES	RESERVE FUEL WEIGHT - ALTERNATE DESTINATION - CLIMB (LBS)

TABLE 3-1. DICTIONARY OF VARIABLES (CONT)

NAME	DESCRIPTION
WCREW	WEIGHT OF FLIGHT CREW MEMBER (LBS)
WDRES	RESERVE FUEL WEIGHT - ALTERNATE DESTINATION - DESCENT (LBS)
WE	WEIGHT EMPTY (LBS)
WENG1	FULL SCALE ENGINE WEIGHT (LBS)
WFBL	BLOCK FUEL WEIGHT (LBS)
WFCL	FUEL WEIGHT - CLIMB TO INITIAL CRUISE ALTITUDE (LBS)
WFCR	FUEL WEIGHT - CRUISE (LBS)
WFDES	FUEL WEIGHT - DESCEND FROM FINAL CRUISE ALTITUDE (LBS)
WFRES	RESERVE FUEL WEIGHT - TOTAL (LBS)
WFRES1	RESERVE FUEL WEIGHT - LOITER + AIR MANEUVER (LBS)
WFRES2	RESERVE FUEL WEIGHT - ALTERNATE DESTINATION - TOTAL (LBS)
WFTOT	FUEL WEIGHT - TOTAL (LBS)
WGTO	GROSS TAKEOFF WEIGHT (LBS)
WGULT	WGTO X ULTIMATE LOAD FACTOR (LBS)
WH2O	TAKEOFF WATER INJECTION FLUID WEIGHT (LBS)
WPASS	PASSENGER WEIGHT (LBS)
WPDIST	PROPULSION SYS WEIGHT - FUEL SYS DISTRIBUTION (LBS)
WPDUMP	PROPULSION SYS WEIGHT - FUEL SYS DUMPING (LBS)
WPEC	PROPULSION SYS WEIGHT - ENGINE CONTROLS (LBS)
WPENG	PROPULSION SYS WEIGHT - ENGINES (LBS)
WPFS	PROPULSION SYS WEIGHT - FUEL SYS TOTAL (LBS)
WPL	PAYLOAD WEIGHT (LBS)
WPPUMP	PROPULSION SYS WEIGHT - FUEL SYS PUMPS (LBS)
WPREFL	PROPULSION SYS WEIGHT - FUEL SYS REFUELLING (LBS)
WPROP	PROPULSION SYS WEIGHT - TOTAL (LBS)
WPSEAL	PROPULSION SYS WEIGHT - FUEL SYS SEALING (LBS)
WPSP	PROPULSION SYS WEIGHT - NACELLE SOUND PROOFING (LBS)
WPST	PROPULSION SYS WEIGHT - STARTING SYSTEM (LBS)
WPSYSC	PROPULSION SYS WEIGHT - FUEL SYS CONTROLS (LBS)
WPVENT	PROPULSION SYS WEIGHT - FUEL SYS VENTING (LBS)
WPWI	PROPULSION SYS WEIGHT - WATER INJECTION PROVISIONS (LBS)
WRESCR	RESERVE FUEL WEIGHT - ALTERNATE DESTINATION - CRUISE (LBS)
WRTO	WEIGHT RATIO W0/W1 FROM BREGUET EQUATION
WSB	STRUCTURAL WEIGHT - BODY (LBS)
WSEAC	SYS + EQUIP WEIGHT - AIR CONDITIONING (LBS)
WSEAI	SYS + EQUIP WEIGHT - ANTI-ICE (LBS)
WSEAPU	SYS + EQUIP WEIGHT - AUX POWER UNIT (LBS)
WSEAUX	SYS + EQUIP WEIGHT - AUX GEAR (LBS)
WSEAVI	SYS + EQUIP WEIGHT - AVIONICS INSTALLATION (LBS)
WSEFRN	SYS + EQUIP WEIGHT - FURNISHINGS (LBS)
WSEHYD	SYS + EQUIP WEIGHT - HYDRAULICS + PNEUMATICS (LBS)
WSEINS	SYS + EQUIP WEIGHT - INSTRUMENTS (LBS)
WSELEC	SYS + EQUIP WEIGHT - ELECTRICAL (LBS)
WSESC	SYS + EQUIP WEIGHT - SURFACE CONTROLS (LBS)
WSH	STRUCTURAL WEIGHT - HORIZONTAL TAIL (LBS)
WSLG	STRUCTURAL WEIGHT - 6ANDING GEAR (LBS)
WSNAC	STRUCTURAL WEIGHT - NACELLES (LBS)
WSTEW	WEIGHT OF STEWARDESS (LBS)
WSTR	STRUCTURAL WEIGHT - TOTAL LBS)
WSV	STRUCTURAL WEIGHT - VERTICAL TAIL (LBS)
WSW	STRUCTURAL WEIGHT - WING (LBS)
WSYSEQ	SYS + EQUIP WEIGHT - TOTAL (LBS)
WT	WORKING VALUE - GROSS WEIGHT (LBS)
WTO	GROSS WEIGHT AT START OF CRUISE (LBS)
WTRTO	RATIO TOTAL FUEL WEIGHT/INITIAL CRUISE GROSS WEIGHT

NAME	DESCRIPTION
WTX	WORKING VALUE - GROSS WEIGHT (LBS)
WT1	GROSS WEIGHT AT END OF CRUISE (LBS)
WUL	USEFUL LOAD WEIGHT - TOTAL (LBS)
WULCR	USEFUL LOAD WEIGHT - CREW (LBS)
WULEQ	USEFUL LOAD WEIGHT - EQUIPMENT (LBS)
WULOIL	USEFUL LOAD WEIGHT - ENGINE OIL (LBS)
WULUF	USEFUL LOAD WEIGHT - UNUSABLE FUEL (LBS)
WUTO	FUEL WEIGHT - WARMUP AND TAKEOFF (LBS)
X	LIMIT WING GLOVE THICKNESS (FT)
XM	TABLE - ENGINE DATA - MACH NUMBER
XMACH	WORKING VALUE - MACH NUMBER

SUBROUTINE CLDES

ALT	WORKING VALUE - ALTITUDE (FT/1000)
ALTI	MAXIMUM CLIMB ALTITUDE (FT/1000)
CL	LIFT COEFFICIENT
DDIST	INCREMENTAL CLIMB/DESCENT DISTANCE (FT)
DIST	CUMULATIVE CLIMB/DESCENT DISTANCE (FT)
DTIME	INCREMENTAL CLIMB/DESCENT TIME (HR)
DWFL	INCREMENTAL CLIMB/DESCENT FUEL WEIGHT (LBS)
GAMAVG	AVERAGE CLIMB GRADIENT (FT)
SFCAVG	AVERAGE SPECIFIC FUEL CONSUMPTION (LB/LB/HR)
SFC1,2	SPECIFIC FUEL CONSUMPTION AT SEGMENT END POINTS (LB/LB/HR)
TGAM1,2	CLIMB GRADIENT AT SEGMENT END POINTS (FT)
THAVG	AVERAGE TOTAL NET THRUST (LBS)
THR1,2	TOTAL NET THRUST AT SEGMENT END POINTS (LBS)
TIME	CUMULATIVE CLIMB/DESCENT TIME (HR)
VCL	MAXIMUM CLIMB AIRSPEED (KEAS)
VT1,2	TRUE AIRSPEED AT SEGMENT END POINTS (KT)
WFUEL	CUMULATIVE CLIMB/DESCENT FUEL WEIGHT (LBS)
WT	CURRENT GROSS WEIGHT (LBS)
WTX	CURRENT GROSS WEIGHT ESTIMATE (LBS)
XH1,2	ALTITUDE AT SEGMENT END POINTS (FT/1000)
XMACH	WORKING VALUE - MACH NUMBER
XM1,2	MACH NUMBER AT SEGMENT END POINTS

SUBROUTINE DOVRL

CD	DRAG COEFFICIENT - TOTAL AT XMACH
CDI	DRAG COEFFICIENT - INDUCED
CDO	DRAG COEFFICIENT - PARASITE
CDOMCR	DRAG COEFFICIENT - TOTAL AT CRUISE MACH
DELCDI	COMPRESSIBILITY INCREMENT AT XMACH - CDI
DELCDO	COMPRESSIBILITY INCREMENT AT XMACH - CDO
DELM	MACH NUMBER INCREMENT BELOW CRUISE MACH NUMBER
DELMDD	CRITICAL MACH NUMBER INCREMENT DUE TO CL
DL	RATIO CD/CL AT XMACH

SUBROUTINE TANGAM

FN	NET THRUST/ENGINE AT XMACH AND ALT (LBS)
SFC	SPECIFIC FUEL CONSUMPTION AT XMACH AND ALT (LB/LB/HR)
TGAM	CLIMB GRADIENT AT XMACH AND ALT (FT)
THRUST	TOTAL NET THRUST AT XMACH AND ALT (LBS)

NAME	DESCRIPTION
SUBROUTINE TLU1	
I	INDEX VALUE FOR X-VECTOR SEARCH
N	DIMENSION OF X AND Y VECTORS
Q	INTERPOLATION FRACTION
YOUT	OUTPUT VALUE OF Y = F(X)
YVECT	ADDRESS OF Y-VECTOR
XIN	INPUT VALUE OF PARAMETER X
XVECT	ADDRESS OF X-VECTOR
SUBROUTINE TLU2	
J	INDEX VALUE FOR Z-VECTOR SEARCH
NX	DIMENSION OF X-VECTOR
NY	INDEX VALUE FOR X-VECTOR SEARCH
NZ	DIMENSION OF Z-VECTOR
Q	INTERPOLATION FRACTION FOR Z-VECTOR
XIN	INPUT VALUE OF PARAMETER X
XVECT	ADDRESS OF X-VECTOR
YMAT	ADDRESS OF Y-MATRIX (DIMENSION NX X NZ)
YOUT	OUTPUT VALUE OF Y = F(X,Z)
Y1,Y2	INTERPOLATED VALUES FROM X-VECTORS
ZIN	INPUT VALUE OF PARAMETER Z
ZVECT	ADDRESS OF Z-VECTOR

Table 3-2. Dictionary of Variables

DOC Module (DOCIN)

AD	AIR DELAY - MINUTES
AFMF	AIRFRAME MAINTENANCE COEFFICIENT
AFSP	AIRFRAME SPARES FACTOR
ANHR	IDEALIZED ANNUAL UTILIZATION HOURS
CAVI	SHIP SET COST OF AVIONICS - $
CCENG	ENGINE COST FACTOR
CDLH	COST OF MAINTENANCE DIRECT LABOR $/HOUR
CFT	COST OF FUEL - $/1000 LBS
CMLH	MANUFACTURING COST PER HOUR $
COT	COST OF OIL = $/LB
CREW	CREW COST PER HOUR
DNM	DISTANCES (UP TO 20) NAUTICAL MILES
ENGSP	ENGINE SPARES FACTOR
EQTYPE	FLAG - 0 = SUMMARY EQUATIONS, 1 = DETAILED EQUAT.
FEC	ENGINE UNIT COST
FRAD	FUEL RATE - AIR DELAY - 1000 LBS/MINUTE
FRGD	FUEL RATE - GROUND DELAY - 1000 LBS/MINUTE
GD	GROUND DELAY - MINUTES
GDMVP	GROUND MANEUVER TIME/FLIGHT-MINUTES
IEQ	FLAG - 1 = READ DOCEQ, 0 = DO NOT READ DOCEQ
IMAX	LAST DISTANCE IN DNM - INTEGER TO 20
MCF	MATERIAL ESCALATION COST FACTOR
MLL	MANUFACTURING LABOR LEARNING EXPONENT
MML	MANUFACTURING MATERIAL LEARNING EXPONENT
PQ	PRODUCTION QUANTITY - UNITS
PR	REFERENCE PRODUCTION QUANTITY
TURNT	TURNAROUND TIME (HR)
YRS	DEPRECIATION LIFETIME - YEARS

DOC Module (DOCEQ)

CEACC	MATERIAL SCALING EXPONENT - AIR-CONDITIONING
CEACL	LABOR HRS/LB AT REF WT - AIR-CONDITIONING
CEACM	MATL COST/LB AT REF WT - AIR-CONDITIONING
CEACR	REFERENCE WEIGHT FOR AIR-CONDITIONING
CEACS	LABOR SCALING EXPONENT - AIR-CONDITIONING
CEAIC	MATERIAL SCALING EXPONENT - ANTI-ICING
CEAIL	LABOR HRS/LB AT REF WT - ANTI-ICING
CEAIM	MATL COST/LB AT REF WT - ANTI-ICING
CEAIR	REFERENCE WEIGHT FOR ANTI-ICING
CEAIS	LABOR SCALING EXPONENT - ANTI-ICING
CEAPUC	MATERIAL SCALING EXPONENT - AUXILLARY POWER UNIT
CEAPUL	LABOR HRS/LB AT REF WT - AUXILLARY POWER UNIT
CEAPUM	MATL COST/LB AT REF WT - AUXILLARY POWER UNIT
CEAPUR	REFERENCE WEIGHT FOR AUXILLARY POWER UNIT

Table 3-2. Dictionary of Variables (Cont.)

CEAPUS	LABOR SCALING EXPONENT - AUXILLARY POWER UNIT
CEAUXC	MATERIAL SCALING EXPONENT - AUXILLARY GEAR
CEAUXL	LABOR HRS/LB AT REF WT - AUXILLARY GEAR
CEAUXM	MATL COST/LB AT REF WT - AUXILLARY GEAR
CEAUXR	REFERENCE WEIGHT FOR AUXILLARY GEAR
CEAUXS	LABOR SCALING EXPONENT - AUXILLARY GEAR
CEHYDC	MATERIAL SCALING EXPONENT - HYDRAULICS/PNEUMATICS
CEHYDL	LABOR HRS/LB AT REF WT - HYDRAULICS/PNEUMATICS
CEHYDM	MATL COST/LB AT REF WT - HYDRULICS/PNEUMATICS
CEHYDR	REFERENCE WEIGHT FOR HYDRAULICS/PNEUMATICS
CEHYDS	LABOR SCALING EXPONENT - HYDRAULICS/PNUMATICS
CEINC	MATERIAL SCALING EXPONENT - INSTRUMENTS
CEINL	LABOR HRS/LB AT REF WT - INTRUMENTS
CEINM	MATL COST/LB AT REF WT - INSTRUMENTS
CEINR	REFERENCE WEIGHT FOR INSTRUMENTS
CEINS	LABOR SCALING EXPONENT - INSTRUMENTS
CESCC	MATERIAL SCALING EXPONENT - SURFACE CONTROLS
CESCL	LABOR HRS/LB AT REF WT - SURFACE CONTROLS
CESCM	MATL COST/LB AT REF WT - SURFACE CONTROLS
CESCR	REFERENCE WEIGHT FOR SURFACE CONTROLS
CESCS	LABOR SCALING EXPONENT - SURFACE CONTROLS
CFURNC	MATERIAL SCALING EXPONENT - FURNISHINGS
CFURNL	LABOR HRS/LB AT REF WT - FURNISHINGS
CFURNM	MATL COST/LB AT REF WT - FURNISHINGS
CFURNR	REFERENCE WEIGHT FOR FURNISHINGS
CFURNS	LABOR SCALING EXPONENT - FURNISHINGS
CLECC	MATERIAL SCALING EXPONENT - ELECTRICAL
CLECL	LABOR HRS/LB AT REF WT - ELECTRICAL
CLECM	MATL COST/LB AT REF WT - ELECTRICAL
CLECR	REFERENCE WEIGHT FOR ELECTRICAL
CLECS	LABOR SCALING EXPONENT - ELECTRICAL
CPECC	MATERIAL SCALING EXPONENT - ENGINE CONTROLS
CPECL	LABOR HRS/LB AT REF WT - ENGINE CONTROLS
CPECM	MATL COST/LB AT REF WT - ENGINE CONTROLS
CPECR	REFERENCE WEIGHT FOR ENGINE CONTROLS
CPECS	LABOR SCALING EXPONENT - ENGINE CONTROLS
CPFSC	MATERIAL SCALING EXPONENT - FUEL SYSTEM
CPFSL	LABOR HRS/LB AT REF WT - FUEL SYSTEM
CPFSM	MATL COST/LB AT REF WT - FUEL SYSTEM
CPFSR	REFERENCE WEIGHT FOR FUEL SYSTEM
CPFSS	LABOR SCALING EXPONENT - FUEL SYSTEM
CPSPC	MATERIAL SCALING EXPONENT - SOUND PROOFING
CPSPL	LABOR HRS/LB AT REF WT - SOUND PROOFING

Table 3-2. Dictionary of Variables (Cont.)

CPSPM	MATL COST/LB AT REF WT - SOUND PROOFING
CPSPR	REFERENCE WEIGHT FOR SOUND PROOFING
CPSPS	LABOR SCALING EXPONENT - SOUND PROOFING
CPSTC	MATERIAL SCALING EXPONENT - STARTING
CPSTL	LABOR HRS/LB AT REF WT - STARTING
CPSTM	MATL COST/LB AT REF WT - STARTING
CPSTR	REFERENCE WEIGHT FOR STARTING
CPSTS	LABOR SCALING EXPONENT - STARTING
CPWIC	MATERIAL SCALING EXPONENT - WATER INJECTION
CPWIL	LABOR HRS/LB AT REF WT - WATER INJECTION
CPWIM	MATL COST/LB AT REF WT - WATER INJECTION
CPWIR	REFERENCE WEIGHT FOR WATER INJECTION
CPWIS	LABOR SCALING EXPONENT - WATER INJECTION
CSBC	MATERIAL SCALING EXPONENT - FUSELAGE
CSBL	LABOR HRS/LB AT REF WT - FUSELAGE
CSBM	MATL COST/LB AT REF WT - FUSELAGE
CSBR	REFERENCE WEIGHT FOR FUSELAGE
CSBS	LABOR SCALING EXPONENT - FUSELAGE
CSHC	MATERIAL SCALING EXPONENT - HORIZONTAL TAIL
CSHL	LABOR HRS/LB AT REF WT - HORIZONTAL TAIL
CSHM	MATL COST/LB AT REF WT - HORIZONTAL TAIL
CSHR	REFERENCE WEIGHT FOR HORIZONTAL TAIL
CSHS	LABOR SCALING EXPONENT - HORIZONTAL TAIL
CSLGC	MATERIAL SCALING EXPONENT - LANDING GEAR
CSLGL	LABOR HRS/LB AT REF WT - LANDING GEAR
CSLGM	MATL COST/LB AT REF WT - LANDING GEAR
CSLGR	REFERENCE WEIGHT FOR LANDING GEAR
CSLGS	LABOR SCALING EXPONENT - LANDING GEAR
CSNAC	MATERIAL SCALING EXPONENT - NACELLES
CSNAL	LABOR HRS/LB AT REF WT - NACELLES
CSNAM	MATL COST/LB AT REF WT - NACELLES
CSNAR	REFERENCE WEIGHT FOR NACELLES
CSNAS	LABOR SCALING EXPONENT - NACELLES
CSVC	MATERIAL SCALING EXPONENT - VERTICAL TAIL
CSVL	LABOR HRS/LB AT REF WT - VERTICAL TAIL
CSVM	MATL COST/LB AT REF WT - VERTICAL TAIL
CSVR	REFERENCE WEIGHT FOR VERTICAL TAIL
CSVS	LABOR SCALING EXPONENT - VERTICAL TAIL
CSWC	MATERIAL SCALING EXPONENT - WING
CSWL	LABOR HRS/LB AT REF WT - WING
CSWM	MATL COST/LB AT REF WT - WING
CSWR	REFERENCE WEIGHT FOR WING
CSWS	LABOR SCALING EXPONENT - WING

Table 3-3. Dictionary of Variables

ROI Module (ROIIN)

AF	SYSTEM GROWTH FACTOR BY CITY PAIR
ANHR	ANNUAL HOURS IN SERVICE
DELR	STEPPING FACTOR IN ROI ITERATION-DEC. FRACTION
EPSA	ERROR FRACTION IN ROI ITERATION-DEC. FRACTION
FAREI	FIXED CHARGE PER PASS - $
FARES	CHARGE PER PASS N MI - $
FLM	MAX. PERMITTED CITY PAIR LOAD FACTOR-DEC FRACTION
IRTE	FLAG - 1 = READ ROUTE DATA, 0 = DO NOT READ
ISUB	1 = PRINT DATA BY CITIES , 2 = PRINT SUMMARY ONLY
MINF	MINIMUM FLIGHTS / DAY
T	DAILY OPERATIONAL PERIOD (HR)
TAX	INCOME TAX RATE - DEC. FRACTION
Z(1)	SERVICE COST AND LANDING FEE/1000 LB - DOLLARS
Z(2)	PASS. SERVICE COST/MILE - DOLLARS
Z(3)	RESERV, SALES , PASS HANDLING/PASS - DOLLARS
Z(4)	STEWARDESS COST/BLOCK HOUR - DOLLARS
Z(5)	MEAL COST/PASS HOUR - DOLLARS
Z(6)	GENERAL AND ADMINISTRATIVE IOC FACTOR- PERCENT

SECTION 4

PROGRAM OPERATION AND INSTRUCTIONS

This section defines the input requirements and physical deck arrangement for each of the main program modules operated individually or in sequence.

Input is divided into data blocks for each of the main program modules and for the program control word KEY. The FORTRAN NAMELIST routine requires that each input data block be headed by a control card bearing the name assigned to that block. Table 4-1 lists the names assigned to each set of input data. In addition to the NAMELIST input deck, the ROI module requires a set of city-pair distance and traffic data in formatted style (see Section 5).

A list of input parameters required by each program module, when run independently, appears in Table 4-2. Those parameters generated by one model for sequential input to the next are indicated; these variables are then omitted from the succeeding input deck when running sequentially. Any parameter read into the program supersedes the value previously read in or computed. Once a parameter value has been read in, it maintains that value unless modified by subsequent input, therefore, it is unnecessary to repeat unchanged data for consecutive runs through the same module.

Figure 4-1 illustrates the deck setup for a sequential run of all three program modules. To run modules individually, each input deck must be preceeded by an NKEY data set as seen in Figure 4-2. The parameter COM, appearing in the input list of each module, provides for a 60 character run title to be reproduced at the head of each module output.

Table 4-1. NAMELIST Input Labels

PROGRAM ELEMENT	SUBROUTINE	INPUT LABEL
TEKVAL PROGRAM CONTROL	-	NKEY
SIZE	RNAM	SIZN
DOC	DOIN	DOCIN, DOCEQ
ROI	ROIN	ROIIN

Table 4-2. Input Requirements

SIZE

ALT	CWEF	GNFR	NCREW
CDF	CWTIC	GNFRF	NENG
CGLOVE	DAISLE	GWAR	NSTRWC
CHVOL	DHCL	GWS	PAX
CLOCH	DMCL	GWSWP4	RANGE
CLOCV	DNAC1	GWTPR	TRES
CLOCW	DRES	KACS	VCL
COM	DSTP1	KAF	WAVI
CPAXC	DSTPC	KAPU	WCREW
CRMACH	DSTW1	KARULE	WENG1
CSWET	DSTWC	KEFIN	WPASS
CSWPYL	FLDENS	KMATL	WSTEW
CTWR	FNRTG	KPSP	
CVVOL	FNZL	KWI	
CWFRG	FTAPER	NAISLE	

Tables:

H	HH	SFCCL	DMACH
HDEL	XM	SFCCR	DCDCV
MSIGSR	FNCL	SFCIDL	DCDSC
VDIVM	FNCR	SWP	DCDICV
	FNIDL	FGAM	DCDISC

DOC (*From SIZE)

DOCIN:

AD	COT	GD	PQ
AFMF	CREW	GDMVR	PR
AFSP	DNM	IEQ	*RANGE
ANHR	ENGSP	IMAX	*RATING
CAVI	EQTYPE	MCF	*TBI
CCENG	*FBI	MLL	*TRS
CDLH	*FBS	MML	TURNT
CFT	FEC	*NENG	*WAVI
CMLH	FRAD	*NSTEW	*WGTO
*COM	FRGD	*PAX	YRS

Table 4-2. Input Requirements (Cont'd)

Optional Weights Input (Computed by SIZE):

For EQTYPE = 0, WAF

For EQTYPE = 1,

WSB	WSLG	WPFS	WSEAC
WSW	WPSP	WSESC	WSEAI
WSH	WPST	WSEINS	WSEAUX
WSV	WPEC	WSEHYD	WSEAPU
WSNAC	WPWI	WSELEC	WSEFRU

DOCEQ (For EQTYPE = 1 Only):

CSBR	CSBS	CSBL	CSBC	CSBM
CSWR	CSWS	CSWL	CSWC	CSWM
CSHR	CSHS	CSHL	CSHC	CSHM
CSVR	CSVS	CSVL	CSVC	CSVM
CSNAR	CSNAS	CSNAL	CSNAC	CSNAM
CSLGR	CSLGS	CSLGL	CSLGC	CSLGM
CPSPR	CPSPS	CPSPL	CPSPC	CPSPM
CPSTR	CPSTS	CPSTL	CPSTC	CPSTM
CPECR	CPECS	CPECL	CPECC	SPECM
CPWIR	CPWIS	CPWIL	CPWIC	CPWIM
CPFSR	CPFSS	CPFSL	CPFSC	CPFSM
CESCR	CESCS	CESCL	CESCC	CESCM
CEINR	CEINS	CEINL	CEINC	CEINM
CEHYDR	CEHYDS	CEHYDL	CEHYDC	CEHYDM
CLECR	CLECS	CLECL	CLECC	CLECM
CEACR	CEACS	CEACL	CEACC	CEACM
CEAIR	CEAIS	CEAIL	CEAIC	CEAIM
CEAUXR	CEAUXS	CEAUXL	CEAUXC	CEAUXM
CEAPUR	CEAPUS	CEAPUL	CEAPUC	CEAPUM
CFURNR	CFURNS	CFURNL	CFURNC	CFURNM

Table 4-2. Input Requirements (Cont'd)

ROI (*From SIZE, + from DOC)

AF	EPSA	MINF	*+TBI
ANHR	FAREI	*+NSTEW	*+TBS
*+COM	FARES	*+PAX	+TURNT
DELR	FLM	*+RANGE	*+WGTO
+DNM	IRTE	T	+XIB
	*IMAX		
+DOC	ISUB	TAX	+YRS
			Z

Formatted City-Pair Traffic Data:

ROUTE TITLE					JMAX
NAMEI	NAME 2	D	A	P	PCTM

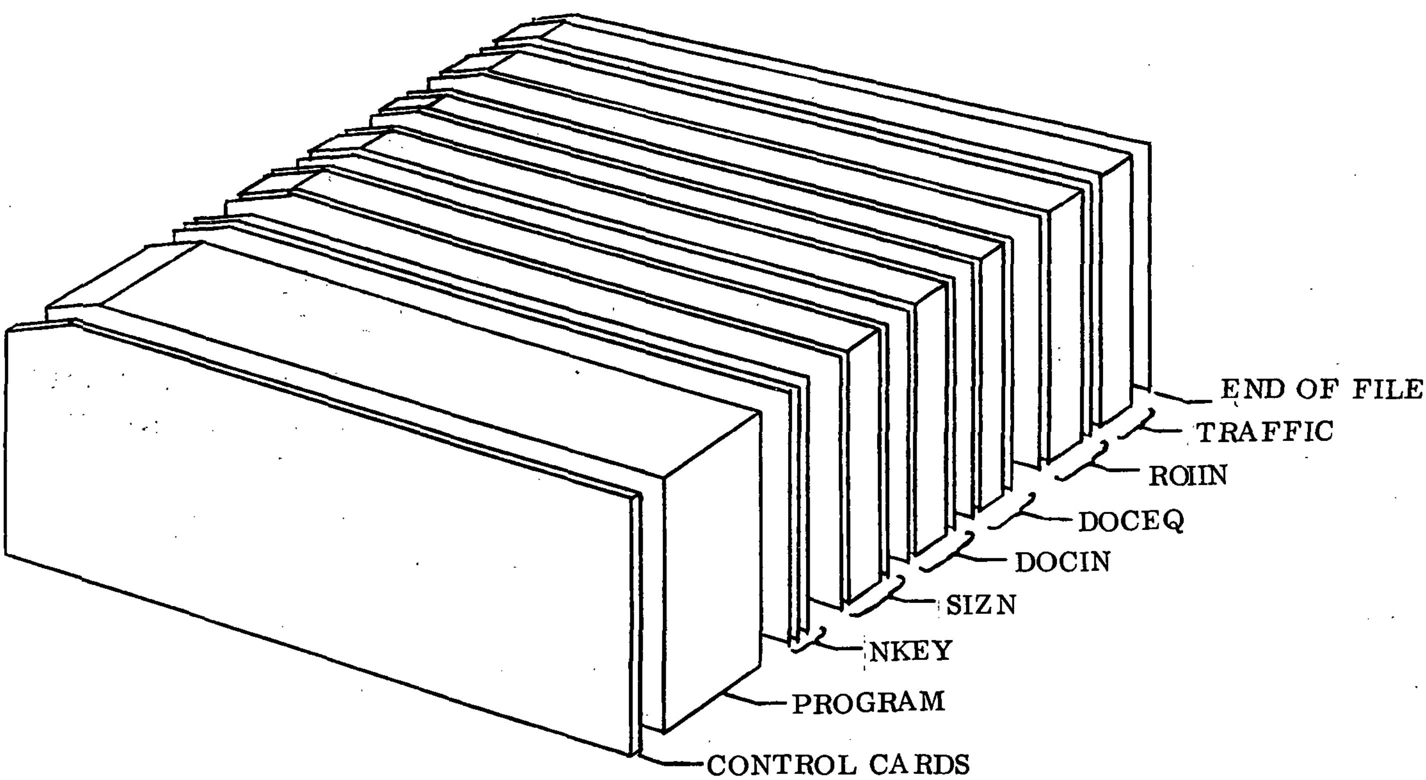

Figure 4-1. Deck Setup for Sequential Operation

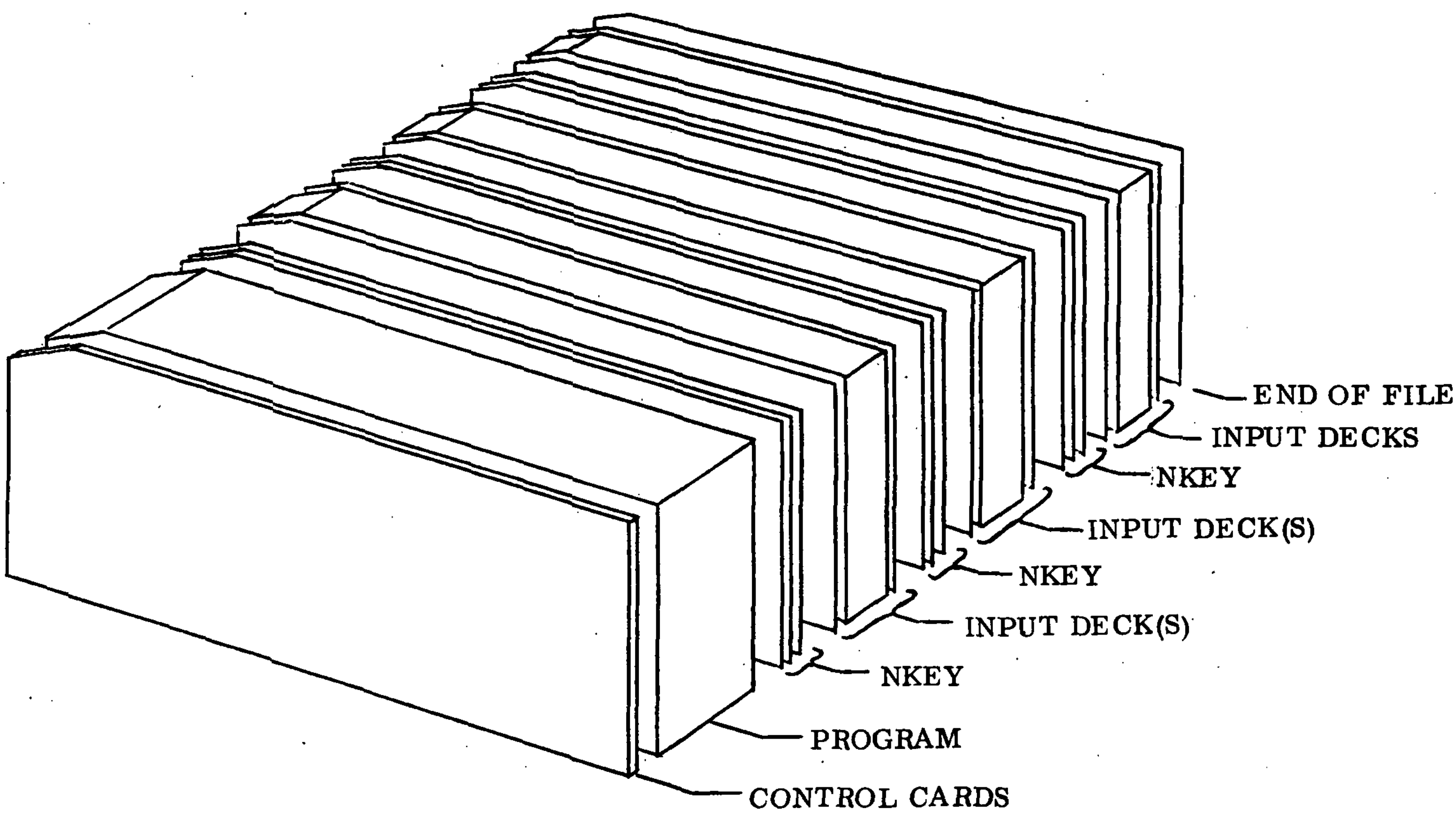

Figure 4-2. Deck Setup for Individual Module Operation

SECTION 5

SAMPLE RUN

Following is a reproduction of a sample case employing all three program modules sequentially. The airplane is designed to carry 195 passengers over a design range of 5559 km (3000 nm). Cruise speed is to be 0.9 Mach with an initial cruise altitude of 11 km (36,000 feet). The design is to employ supercritical aerodynamics, an active control system, and composite construction, but no area ruling. The power plant is the Pratt & Whitney STF-429 design utilized in the ATT study; sound proofing and water injection are included. The configuration calls for three engines in a DC-10 arrangement. Domestic fuel reserves are indicated.

DOC input consists of factors typical of domestic operation. A set of detailed cost estimation factors are included. Note that the set of distance values DNM are not restricted to constant increments but are chosen to reflect the hyperbolic shape of the DOC curve.

Input to the ROI routine lists a system limit load factor of 55 percent and a 48 percent tax rate on profit, both values being input. City-pair traffic data are not listed in the input, since they are formatted data (not reproduced by the NAMELIST routine); however, the information is reproduced in the detailed output listing when called for. Figure 5-1 defines the required input card format for traffic data.

In the 1972 Convair ATT study, 1985 city pair traffic data were projected for 156 domestic and international routes varying in length from 278 km (150 nm) to over 9265 km (5000 nm). From the 1968 CAB "Handbook of Airline Statistics," the top 100 city-pairs ranked by number of passengers and number of passenger-kilometers yielded data for a total of 128 domestic routes, including mainland-to-Hawaii. Total traffic for each route was reduced to a representative fraction for an "average" trunk airline by reference to the number of seat-kilometers operated by each trunk authorized to serve that route. Total traffic for an additional 28 U.S. - international routes was estimated from data on total seat-kilometers available, average load factors, and relative market share of the major airlines serving each route. All data were then projected to 1975, 1980, and 1985 by a uniform annual growth rate of 9 percent in revenue passenger-kilometers. A complete summary of traffic data is being provided to NASA with this model.

A representative set of 20 domestic routes was selected for the sample problem to illustrate the variation in economic return with distance and traffic level. Traffic data are two-way daily passenger totals. Peak hourly rates (see Figure 5-1) are simply daily rates divided by the arbitrary 10-hour (input) daily operational period. The requirement for peak hourly traffic data is a holdover from previous versions of the ROI module and could be deleted with proper program modification.

All NAMELIST input data are listed in the sample run as single entries per card, followed by a definitive comment. In more common usage, several parameters would be listed per card, omitting the definitions, to reduce the bulk of the input data decks.

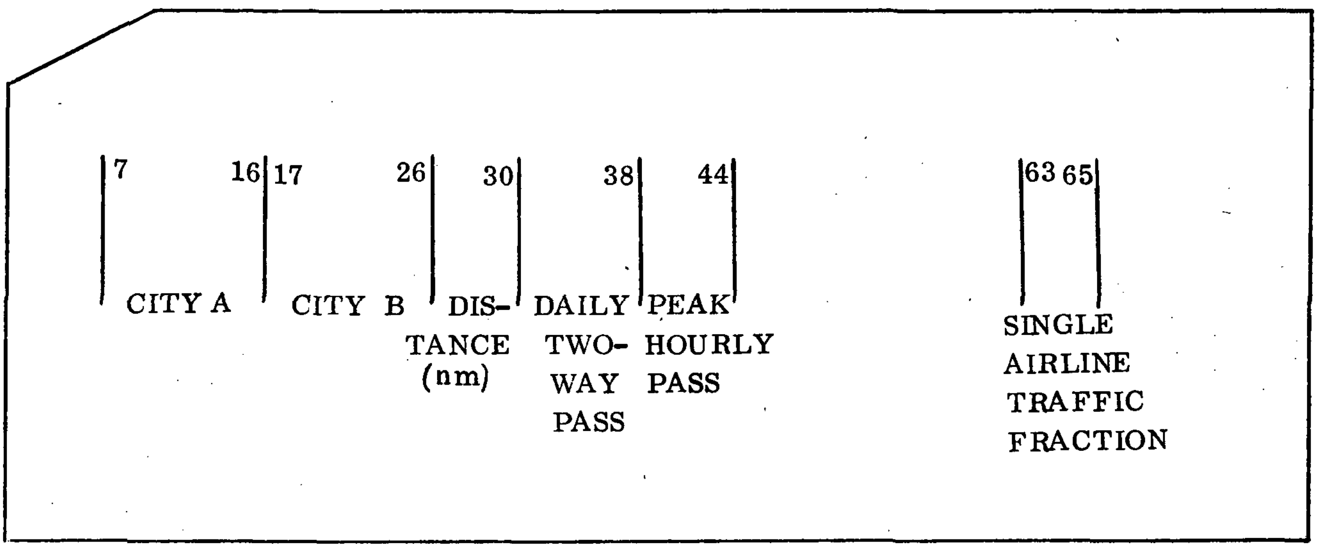

Figure 5-1. City-Pair Traffic Data Card Format

```
P$NKEY
 KEY    =111 ,
 $END

P$SIZN
 ALT    =36.       ,DEF=55H  INITIAL CRUISE ALTITUDE(FT/1000.)                     ,
 CDF    =.00270    ,DEF=55H  SKIN FRICTION COEFFICIENT                             ,
 CGLOVE=2.4        ,DEF=55H  RATIO OF WING ROOT FILLET CHORD/THEO CHORD AT FUS     ,
 CHVOL =0.60       ,DEF=55H  HORZ TAIL VOLUME COEFF                                ,
 CLOCH =0.90       ,DEF=55H  HORZ LOCATION RATIO TO BODY LENGTH                    ,
 CLOCV =0.95       ,DEF=55H  VERT LOCATION RATIO TO BODY LENGTH                    ,
 CLOCW =0.55       ,DEF=55H  WING LOCATION RATIO TO BODY LENGTH                    ,
 COM    =60H TEKVAL TEST CASE - .90 MACH  195 PASS  3000 NM                        ,
 CPAXC =.85        ,DEF=55H  PERCENTAGE OF COACH SEATS                             ,
 CRMACH=0.90       ,DEF=55H  DESIGN CRUISE MACH NO.                                ,
 CSWET =2.02       ,DEF=55H  RATIO WING WETTED AREA TO PLANFORM AREA               ,
 CSWPYL=0.2        ,DEF=55H  PYLON WETTED AREA FRACTION OF NAC WETTED AREA         ,
 CTWR  =0.275      ,DEF=55H  INITIAL STATIC T/W ESTIMATE                           ,
 CVVOL =0.0866     ,DEF=55H  VERT TAIL VOLUME COEFF                                ,
 CWEF  =0.77       ,DEF=55H  INDUCED DRAG EFFICIENCY FACTOR                        ,
 CWFRG =0.4        ,DEF=55H  LATERAL EXTENT OF WING ROOT FILLET/WING SEMI-SPAN     ,
 CWTIC =0.95       ,DEF=55H  RATIO WO/WGTO INITIAL ESTIMATE                        ,
 DAISLE=21.        ,DEF=55H  AISLE WIDTH (INCHES)                                  ,
 DHCL  =5.         ,DEF=55H  CLIMB ALT INCREMENT (FT/1000.)                        ,
 DMCL  =0.05       ,DEF=55H  CLIMB MACH INCREMENT                                  ,
 DNAC1 =7.17       ,DEF=55H  WING ENGINE NACELLE DIAM(ES=1)                        ,
 DRES  =200.       ,DEF=55H  RESERVE FUEL DISTANCE (NM)                            ,
 DSTPC =34.        ,DEF=55H  COACH CLASS SEAT PITCH(INCHES)                        ,
 DSTP1 =38.        ,DEF=55H  FIRST CLASS SEAT PITCH(INCHES)                        ,
 DSTWC =22.        ,DEF=55H  COACH SEAT WIDTH(INCHES)                              ,
 DSTW1 =25.        ,DEF=55H  FIRST CLASS SEAT WIDTH(INCHES)                        ,
 FLDENS=6.7        ,DEF=55H  FUEL DENSITY ( LB/GAL)                                ,
 FNRTG =40000.     ,DEF=55H  ENGINE STATIC THRUST RATING (ES=1)                    ,
 FNZL  =2.5        ,DEF=55H  LIMIT LOAD FACTOR                                     ,
 FTAPER=4.33       ,DEF=55H  LENGTH OF TAPERED FUSELAGE SECTIONS(DIAMETERS)        ,
 GNFR  =3.0        ,DEF=55H  NACELLE FINENESS RATIO-WING OR FUSELAGE               ,
 GNFRF =4.0        ,DEF=55H  NACELLE FINENESS RATIO-FIN                            ,
 GWAR  =9.0        ,DEF=55H  WING ASPECT RATIO                                     ,
 GWS   =125.6      ,DEF=55H  WING LOADING                                          ,
```

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GWSWP4=38.       ,DEF=55H  WING SWEEP ANGLE AT C/4                                       ,
GWTPR =0.3874    ,DEF=55H  WING TAPER RATIO                                              ,
KACS  =1         ,DEF=55H  ACTIVE CONTROL SYSTEM (0=WITHOUT, 1=WITH)                     ,
KAF   =1         ,DEF=55H  AIRFOIL TYPE (0 = CONVENTIONAL 1 = SUPERCRITICAL              ,
KAPU  =1         ,DEF=55H  APU ( 0=WITHOUT, 1 = WITH)                                    ,
KARULE=0         ,DEF=55H  AREA RULE ( 0 = STRAIGHT FUSELAGE, 1 = AREA RULED)            ,
KEFIN =1         ,DEF=55H  FIN MOUNTED ENGINE (DC-10 STYLE) (0=WITHOUT,1=WITH)           ,
KMATL =1         ,DEF=55H  CONSTRUCTION MATERIAL (0=LIGHT ALLOY,1=COMPOSITE)             ,
KPSP  =1         ,DEF=55H  ENGINE NACELLE QUIETING(0=WITHOUT,1=WITH)                     ,
KWI   =1         ,DEF=55H  WATER INJECTION ( 0 = WITHOUT, 1 = WITH)                      ,
NAISLE=2         ,DEF=55H  NO OF AISLES                                                  ,
NCREW =3         ,DEF=55H  NO    IN FLIGHT CREW                                          ,
NENG  =3         ,DEF=55H  NO OF ENGINES                                                 ,
NSROWC=7         ,DEF=55H  NO OF SEATS PER ROW IN COACH                                  ,
PAX   =195.      ,DEF=55H  NO OF PASSENGERS                                              ,
RANGE =3000.     ,DEF=55H  DESIGN RANGE (NM)                                             ,
TRES  =1.        ,DEF=55H  RESERVE FUEL TIME (HR)                                        ,
VCL   =395.      ,DEF=55H  CLIMB Q-LIMIT (KEAS)                                          ,
WAVI  =1245.     ,DEF=55H  AVIONICS BLACK BOX WEIGHTS                                    ,
WCREW =195.      ,DEF=55H  WEIGHT OF CREW MEMBER                                         ,
WENG1 =8326.     ,DEF=55H  ENG WT(ES=1) INCLUD-TR,NOZZLE,TAIL,SPIN,WATER INJECT          ,
WPASS =205.      ,DEF=55H  PASSENGER WEIGHT                                              ,
WSTEW =130.      ,DEF=55H  WEIGHT OF STEWARDESS                                          ,
HH     = 0. , 10. , 20. , 30. , 36. , 40. , 45. ,
XM     =  .3,   .4,   .5,   .6,   .7,   .8,   .9,   .95,   .98,
FNCL(1)=          24500., 23250., 22100., 20900., 19900., 19050.,
FNCL(13)=         21000., 20000., 19150., 18200., 17500., 16800., 16250.,
FNCL(25)=    0.,      0.,      0., 15100., 14750., 14450., 14300., 14250., 14200.,
FNCL(37)=    0.,      0.,      0., 11520., 11510., 11510., 11500., 11490., 11490.,
FNCL(49)=    0.,      0.,      0.,      0.,  9340.,  9490.,  9640.,  9710.,  9800.,
FNCL(61)=    0.,      0.,      0.,      0.,  7650.,  7800.,  7950.,  7950.,  7925.,
FNCL(73)=    0.,      0.,      0.,      0.,  5850.,  6000.,  6050.,  6100.,  6100.,
FNCR(1)=21700., 20400., 19300., 18100., 17200., 16300.,
FNCR(13)=18100., 17300., 16600., 15950., 15200., 14600., 14100.,
FNCR(25)=    0.,      0.,      0., 13600., 13100., 12700., 12450., 12400., 12350.,
FNCR(37)=    0.,      0.,      0., 10630., 10530., 10480., 10350., 10280., 10200.,
FNCR(49)=    0.,      0.,      0.,      0.,  8780.,  8750.,  8850.,  8820.,  8800.,
FNCR(61)=    0.,      0.,      0.,      0.,  7225.,  7200.,  7150.,  7150.,  7150.,
FNCR(73)=    0.,      0.,      0.,      0.,  5600.,  5535.,  5520.,  5500.,  5500.,
SFCCL(1)= .560,   .610,   .662,   .723,   .780,   .884,
```

```
SFCCL(13)=.540,   .585,   .631,   .678,   .726,   .778,   .830,
SFCCL(25)=0.  ,   0.  ,   0.  ,   .645,   .685,   .729,   .770,   .791,   .803,
SFCCL(37)=0.  ,   0.  ,   0.  ,   .636,   .671,   .699,   .735,   .750,   .766,
SFCCL(49)=0.  ,   0.  ,   0.  ,   0.  ,   .666,   .694,   .720,   .731,   .743,
SFCCL(61)=0.  ,   0.  ,   0.  ,   0.  ,   .669,   .700,   .725,   .735,   .753,
SFCCL(73)=0.  ,   0.  ,   0.  ,   0.  ,   .664,   .703,   .730,   .747,   .759,
SFCCR(1)= .552,   .615,   .676,   .739,   .803,   .880,
SFCCR(13)=.543,   .590,   .639,   .685,   .739,   .795,   .850,
SFCCR(25)=0.  ,   0.  ,   0.  ,   .643,   .687,   .737,   .775,   .795,   .810,
SFCCR(37)=0.  ,   0.  ,   0.  ,   .620,   .654,   .692,   .733,   .757,   .765,
SFCCR(49)=0.  ,   0.  ,   0.  ,   0.  ,   .655,   .680,   .715,   .732,   .741,
SFCCR(61)=0.  ,   0.  ,   0.  ,   0.  ,   .667,   .700,   .721,   .739,   .749,
SFCCR(73)=0.  ,   0.  ,   0.  ,   0.  ,   .660,   .695,   .725,   .743,   .755,
FNIDL(1)= -700., -1150., -1570., -2120., -2670., -3220.,
FNIDL(13)=-525.,  -830., -1170., -1420., -1790., -2170., -2775.,
FNIDL(25)=  0.,     0.,     0.,  -980., -1225., -1475., -1740., -1860., -1940.,
FNIDL(37)=  0.,     0.,     0.,  -700.,  -800.,  -980., -1250., -1400., -1490.,
FNIDL(49)=  0.,     0.,     0.,     0.,  -610.,  -730.,  -940., -1090., -1190.,
FNIDL(61)=  0.,     0.,     0.,     0.,  -500.,  -600.,  -760.,  -890.,  -980.,
FNIDL(73)=  0.,     0.,     0.,     0.,  -360.,  -450.,  -600.,  -700.,  -775.,
SFCIDL(1)= 2.0,   1.28,   .879,   .684,   .573,   .506,
SFCIDL(13)=1.96,   1.23,   .863,   .732,   .604,   .521,   .433,
SFCIDL(25)= 0.,    0.,     0.,    .806,   .670,   .596,   .529,   .517,   .505,
SFCIDL(37)= 0.,    0.,     0.,    .829,   .750,   .654,   .552,   .515,   .496,
SFCIDL(49)= 0.,    0.,     0.,     0.,    .804,   .727,   .607,   .541,   .512,
SFCIDL(61)= 0.,    0.,     0.,     0.,    .860,   .767,   .645,   .585,   .561,
SFCIDL(73)= 0.,    0.,     0.,     0.,    1.00,   .866,   .684,   .615,   .568,
VDIVM =   661.7,  638.1,  615.0,  592.4,  570.3,  548.7,  527.7,  507.2,
          487.2,  467.6,  448.6,  430.0,  412.0,  394.4,  377.2,
          360.6,  344.4,  328.6,  312.7,  298.7,  284.7,  271.4,
          258.6,  246.4,  234.9,
HDEL  =    1.0,   .9298,  .8637,  .8014,  .7428,  .6877,  .6360,  .5875,
          .5420,  .4994,  .4595,  .4223,  .3876,  .3552,  .3250,
          .2970,  .2709,  .2467,  .2234,  .2038,  .1851,  .1681,
          .1527,  .1387,  .1260,
HSIGSR=    1.0,   .9710,  .9424,  .9143,  .8866,  .8593,  .8326,  .8062,
          .7804,  .7549,  .7299,  .7054,  .6813,  .6576,  .6344,
          .6117,  .5893,  .5674,  .5450,  .5206,  .4962,  .4729,
          .4507,  .4295,  .4094,
H     =   0.,   2.,   4.,   6.,   8.,  10.,  12.,  14.,  16.,  18.,  20.,  22.,
          24.,  26.,  28.,  30.,  32.,  34.,  36.,  38.,  40.,  42.,  44.,  46.,
          48.,
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DMACH =  0. ,  .01,  .02,  .04,  .07,  .10,  .15,  .20,  .25,  .30,  .35,  .40,
        .45,  .50,  .60,
DCDCV =  0. , -4.0, -7.0, -12., -16., -18., -20., -18., -17.,-15.5, -14., -12.,
       -11., -9.5, -6.0,
DCDICV=  0. , -5.0, -7.0, -7.5, -8.0, -8.0, -9.0, -10.,-10.5,-11.5, -12., -13.,
      -14., -14.5, -16.,
DCDSC =  0. , -3.0, -5.0, -9.0, -14., -17., -20.,-19.5,-18.5,-17.0,-15.0, -12.,
        9.5, -6.0,  0. ,
DCDISC=  0. , -1.5, -2.0, -2.0, -2.0, -4.0, -4.5, -4.0, -2.0,  0.0, -3.0, -5.0,
       -7.0, -8.0,-10.0,
SWP   =  0. , 10.0, 15.0, 20.0, 25.0, 30.0, 35.0, 40.0, 45.0, 50.0,
FGAM  =  .5 ,  .5 , .55 , .62 , .74 , .89 ,  1.1, 1.4, 1.78, 2.26,
$END
```

COMMERCIAL TRANSPORT SIZING PROGRAM

TEKVAL TEST CASE - .90 MACH 195 PASS 3000 NM

DESIGN SPECIFICATIONS

PASSENGERS		195
COACH	165	
FIRST CLASS	30	
RANGE(NM)		3000
INITIAL CRUISE CONDITIONS		
MACH NUMBER		.900
ALTITUDE(FT)		36000
NUMBER OF ENGINES		3
MATERIAL		COMP
AIRFOIL		S/C
ACS		YES
AREA RULED FUSELAGE		NO

WING GEOMETRY	
ASPECT RATIO	9.00
TAPER RATIO	.3874
SWEEP AT C/4 (DEG)	38.00
FUEL RESERVES	
LOITER TIME (HR)	1.00
DISTANCE TO ALTERNATE (NM)	200
CRUISE EFFICIENCY AT CRUISE MACH	.770
CDF AT CRUISE MACH	.00270
WING LOADING (PSF)	125.6

DERIVED SPECIFICATIONS

GEOMETRY	
FUSELAGE	
LENGTH(FT)	161.63
DIAMETER(FT)	17.97
WING	
AREA(SQ FT)	1945.23
T/C	.142
SPAN(FT)	132.31
ROOT CHORD(FT)	21.19
TIP CHORD(FT)	8.21
M A C (FT)	15.66
TAIL (EXPOSED AREAS, SQ FT)	
HORIZONTAL	323.19
VERTICAL	178.46
NACELLES	
DIAMETER(FT)	5.31
LENGTH(FT)	15.93

PERFORMANCE	
CDOEFF AT CRUISE MACH	.01917
CRUISE CL	.4368
CRUISE L/D	15.637
ENGINE RATING-LB	21970
CLIMB	
DISTANCE (NM)	511.0
TIME (MIN)	60.2
DESCENT	
DISTANCE (NM)	75.8
TIME (MIN)	11.1
BLOCK TIME (HR)	5.96
SLOPE (HR/NM)(X1000)	1.935
INTERCEPT (HR)(X1000)	152.6
BLOCK FUEL	
SLOPE(LB/NM)	17.864
INTERCEPT(LB)	7007.6

COMMERCIAL TRANSPORT SIZING PROGRAM

TEKVAL TEST CASE - .90 MACH 195 PASS 3000 NM

WEIGHT STATEMENT

WEIGHT EMPTY				117199.6
STRUCTURE			63372.4	
FUSELAGE		26636.1		
WING		19271.0		
HORIZONTAL		1740.9		
VERTICAL		1088.2		
NACELLES		3397.4		
LDG GEAR		11238.8		
PROPULSION			15934.0	
ENGINES		12824.2		
SOUND SUPPRESSION		926.9		
STARTING		163.8		
ENGINE CONTROLS		234.5		
FUEL SYSTEM		1559.9		
PUMPS	184.7			
DISTRIBUTION	537.3			
VENTING	229.4			
CONTROLS	119.5			
REFUEL	107.1			
DUMP	69.2			
SEALING	312.6			
WATER INJECTION		224.8		
SYSTEMS AND EQUIPMENT			37893.2	
SURFACE CONTROLS		3330.7		
INSTRUMENTS		819.8		
HYDR AND PNEU		1224.0		
AVIONICS		1618.5		
ELECTRICAL		3101.7		
AIR CONDITIONING		3463.8		
AUXILIARY GEAR		55.3		
ANTI-ICE		794.3		
FURNISHINGS		22314.5		
APU		1170.6		

USEFUL LOAD			7528.1
CREW		1365.0	
UNUSABLE FUEL		48.6	
ENGINE OIL		164.5	
PASS SERVICE EQUIP		5950.0	
OPERATING WEIGHT EMPTY			124727.7
PAYLOAD			39975.0
ZERO FUEL WEIGHT			164899.0
FUEL (TOTAL)			76853.8
BLOCK		60600.2	
WARMUP AND TAKEOFF	1001.8		
CLIMB	16191.7		
CRUISE	43109.9		
DESCENT	296.7		
RESERVE		16253.6	
WATER			795.9
GROSS TAKEOFF WEIGHT			242845.4

```
P$DOCIN
 AD     = 6.      ,DEF=55H  AIR DELAY - MINUTES                                              ,
 AFMF   = 1.      ,DEF=55H  AIRFRAME MAINTENANCE COEFFICIENT                                 ,
 AFSP   = .10     ,DEF=55H  AIRFRAME SPARES FACTOR                                           ,
 ANHR   = 4500.   ,DEF=55H  IDEALIZED ANNUAL UTILIZATION HOURS                               ,
 CAVI   = 500000.,DEF=55H  SHIP SET COST OF AVIONICS - $                                    ,
 CCENG  = 5500.   ,DEF=55H  ENGINE COST FACTOR                                               ,
 CDLH   = 5.      ,DEF=55H  COST OF MAINTENANCE DIRECT LABOR $/HOUR                          ,
 CFT    = 15.     ,DEF=55H  COST OF FUEL - $/1000 LBS                                        ,
 CMLH   = 7.      ,DEF=55H  MANUFACTURING COST PER HOUR   $                                  ,
 COT    = .66     ,DEF=55H  COST OF OIL  = $/LB                                              ,
 CREW   =  160.   ,DEF=55H  CREW COST PER HOUR                                               ,
 DNM    = 0.      ,DEF=55H  DISTANCES (UP TO 20) NAUTICAL MILES                              ,
 DNM    =  100., 200., 300., 500., 700., 1000., 1500., 2000., 2500., 3000.,
 ENGSP  = .40     ,DEF=55H  ENGINE SPARES FACTOR                                             ,
 EQTYPE= 1        ,DEF=55H  FLAG - 0 = SUMMARY EQUATIONS, 1 = DETAILED EQUAT.                ,
 FEC    =  0.     ,DEF=55H  ENGINE UNIT COST                                                 ,
 FRAD   = 1.      ,DEF=55H  FUEL RATE - AIR DELAY - 1000 LBS/MINUTE                          ,
 FRGD   = 1.      ,DEF=55H  FUEL RATE - GROUND DELAY - 1000 LBS/MINUTE                       ,
 GD     = 0.      ,DEF=55H  GROUND DELAY - MINUTES                                           ,
 GDMVR  = 0.      ,DEF=55H  GROUND MANEUVER TIME/FLIGHT-MINUTES                              ,
 IEQ    = 1       ,DEF=55H  FLAG - 1 = READ DOCEQ, 0 = DO NOT READ DOCEQ                     ,
 IMAX   = 10      ,DEF=55H  NUMBER OF DNM ENTRIES - MAX OF 20                                ,
 MCF    = 1.      ,DEF=55H  MATERIAL ESCALATION COST FACTOR                                  ,
 MLL    = .8      ,DEF=55H  MANUFACTURING LABOR LEARNING EXPONENT                            ,
 MML    = .95     ,DEF=55H  MANUFACTURING MATERIAL LEARNING EXPONENT                         ,
 PQ     = 250.    ,DEF=55H  PRODUCTION QUANTITY - UNITS                                      ,
 PR     = 250.    ,DEF=55H  REFERENCE PRODUCTION QUANTITY                                    ,
 TURNT  = .5      ,DEF=55H  TURNAROUND TIME - HOURS                                          ,
 YRS    = 15.     ,DEF=55H  DEPRECIATION LIFETIME - YEARS                                    ,
 $END
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?$DOCEQ
 CSBR  = 24870. ,DEF=55H  REFERENCE WEIGHT FOR FUSELAGE                    ,
 CSWR  = 20070. ,DEF=55H  REFERENCE WEIGHT FOR WING                        ,
 CSHR  = 2450.  ,DEF=55H  REFERENCE WEIGHT FOR HORIZONTAL TAIL             ,
 CSVR  = 2000.  ,DEF=55H  REFERENCE WEIGHT FOR VERTICAL TAIL               ,
 CSNAR = 3410.  ,DEF=55H  REFERENCE WEIGHT FOR NACELLES                    ,
 CSLGR = 13000. ,DEF=55H  REFERENCE WEIGHT FOR LANDING GEAR                ,
 CPSPR = 700.   ,DEF=55H  REFERENCE WEIGHT FOR SOUND PROOFING              ,
 CPSTR = 140.   ,DEF=55H  REFERENCE WEIGHT FOR STARTING                    ,
 CPECR = 195.   ,DEF=55H  REFERENCE WEIGHT FOR ENGINE  CONTROLS            ,
 CPWIR = 260.   ,DEF=55H  REFERENCE WEIGHT FOR WATER INJECTION             ,
 CPFSR = 1.6    ,DEF=55H  REFERENCE WEIGHT FOR FUEL SYSTEM                 ,
 CESCR = 3400.  ,DEF=55H  REFERENCE WEIGHT FOR SURFACE CONTROLS            ,
 CEINR = 1740.  ,DEF=55H  REFERENCE WEIGHT FOR INSTRUMENTS                 ,
 CEHYDR= 2000.  ,DEF=55H  REFERENCE WEIGHT FOR HYDRAULICS/PNEUMATICS       ,
 CLECR = 3217.  ,DEF=55H  REFERENCE WEIGHT FOR ELECTRICAL                  ,
 CEACR = 3490.  ,DEF=55H  REFERENCE WEIGHT FOR AIR-CONDITIONING            ,
 CEAIR = 500.   ,DEF=55H  REFERENCE WEIGHT FOR ANTI-ICING                  ,
 CEAUXR= 85.    ,DEF=55H  REFERENCE WEIGHT FOR AUXILLARY GEAR              ,
 CEAPUR= 908.   ,DEF=55H  REFERENCE WEIGHT FOR AUXILLARY POWER UNIT        ,
 CFURNR= 23169. ,DEF=55H  REFERENCE WEIGHT FOR FURNISHINGS                 ,
 CSBS  = .8     ,DEF=55H  LABOR SCALING EXPONENT - FUSELAGE                ,
 CSWS  = .8     ,DEF=55H  LABOR SCALING EXPONENT - WING                    ,
 CSHS  = .8     ,DEF=55H  LABOR SCALING EXPONENT - HORIZONTAL TAIL         ,
 CSVS  = .8     ,DEF=55H  LABOR SCALING EXPONENT - VERTICAL TAIL           ,
 CSNAS = .9     ,DEF=55H  LABOR SCALING EXPONENT - NACELLES                ,
 CSLGS = 1.0    ,DEF=55H  LABOR SCALING EXPONENT - LANDING GEAR            ,
 CPSPS = 1.0    ,DEF=55H  LABOR SCALING EXPONENT - SOUND PROOFING          ,
 CPSTS = 1.0    ,DEF=55H  LABOR SCALING EXPONENT - STARTING                ,
 CPECS = 1.0    ,DEF=55H  LABOR SCALING EXPONENT - ENGINE CONTROLS         ,
 CPWIS = 1.0    ,DEF=55H  LABOR SCALING EXPONENT - WATER INJECTION         ,
 CPFSS =  .9    ,DEF=55H  LABOR SCALING EXPONENT - FUEL SYSTEM             ,
 CESCS =  .8    ,DEF=55H  LABOR SCALING EXPONENT - SURFACE CONTROLS        ,
 CEINS = 1.0    ,DEF=55H  LABOR SCALING EXPONENT - INSTRUMENTS             ,
 CEHYDS=  .9    ,DEF=55H  LABOR SCALING EXPONENT - HYDRAULICS/PNUMATICS    ,
 CLECS =  .8    ,DEF=55H  LABOR SCALING EXPONENT - ELECTRICAL              ,
 CEACS =  .8    ,DEF=55H  LABOR SCALING EXPONENT - AIR-CONDITIONING        ,
 CEAIS =  .8    ,DEF=55H  LABOR SCALING EXPONENT - ANTI-ICING              ,
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CEAUXS= 1.0      ,DEF=55H  LABOR SCALING EXPONENT - AUXILLARY GEAR                    ,
CEAPUS= 1.0      ,DEF=55H  LABOR SCALING EXPONENT - AUXILLARY POWER UNIT              ,
CFURNS= 1.0      ,DEF=55H  LABOR SCALING EXPONENT - FURNISHINGS                       ,
CSBL  = 2.3      ,DEF=55H  LABOR HRS/LB AT REF WT - FUSELAGE                          ,
CSWL  = 2.2      ,DEF=55H  LABOR HRS/LB AT REF WT - WING                              ,
CSHL  = 4.3      ,DEF=55H  LABOR HRS/LB AT REF WT - HORIZONTAL TAIL                   ,
CSVL  = 4.3      ,DEF=55H  LABOR HRS/LB AT REF WT - VERTICAL TAIL                     ,
CSNAL = 5.0      ,DEF=55H  LABOR HRS/LB AT REF WT - NACELLES                          ,
CSLGL = 0.5      ,DEF=55H  LABOR HRS/LB AT REF WT - LANDING GEAR                      ,
CPSPL = 1.0      ,DEF=55H  LABOR HRS/LB AT REF WT - SOUND PROOFING                    ,
CPSTL = 1.0      ,DEF=55H  LABOR HRS/LB AT REF WT - STARTING                          ,
CPECL = 1.0      ,DEF=55H  LABOR HRS/LB AT REF WT - ENGINE CONTROLS                   ,
CPWIL = 3.3      ,DEF=55H  LABOR HRS/LB AT REF WT - WATER INJECTION                   ,
CPFSL = 1.6      ,DEF=55H  LABOR HRS/LB AT REF WT - FUEL SYSTEM                       ,
CESCL = 7.5      ,DEF=55H  LABOR HRS/LB AT REF WT - SURFACE CONTROLS                  ,
CEINL = 0.0      ,DEF=55H  LABOR HRS/LB AT REF WT - INTRUMENTS                        ,
CEHYDL=  1.6     ,DEF=55H  LABOR HRS/LB AT REF WT - HYDRAULICS/PNEUMATICS             ,
CLECL = 3.3      ,DEF=55H  LABOR HRS/LB AT REF WT - ELECTRICAL                        ,
CEACL = 0.7      ,DEF=55H  LABOR HRS/LB AT REF WT - AIR-CONDITIONING                  ,
CEAIL = 0.7      ,DEF=55H  LABOR HRS/LB AT REF WT - ANTI-ICING                        ,
CEAUXL= 0.0      ,DEF=55H  LABOR HRS/LB AT REF WT - AUXILLARY GEAR                    ,
CEAPUL= 0.0      ,DEF=55H  LABOR HRS/LB AT REF WT - AUXILLARY POWER UNIT              ,
CFURNL= 0.7      ,DEF=55H  LABOR HRS/LB AT REF WT - FURNISHINGS                       ,
CSBC  = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - FUSELAGE                       ,
CSWC  =  .95     ,DEF=55H  MATERIAL SCALING EXPONENT - WING                           ,
CSHC  = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - HORIZONTAL TAIL                ,
CSVC  = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - VERTICAL TAIL                  ,
CSNAC = 0.95     ,DEF=55H  MATERIAL SCALING EXPONENT - NACELLES                       ,
CSLGC = 0.95     ,DEF=55H  MATERIAL SCALING EXPONENT - LANDING GEAR                   ,
CPSPC = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - SOUND PROOFING                 ,
CPSTC = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - STARTING                       ,
CPECC = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - ENGINE CONTROLS                ,
CPWIC = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - WATER INJECTION                ,
CPFSC = 0.9      ,DEF=55H  MATERIAL SCALING EXPONENT - FUEL SYSTEM                    ,
CESCC = 0.9      ,DEF=55H  MATERIAL SCALING EXPONENT - SURFACE CONTROLS               ,
CEINC = 1.0      ,DEF=55H  MATERIAL SCALING EXPONENT - INSTRUMENTS                    ,
CEHYDC= 0.8      ,DEF=55H  MATERIAL SCALING EXPONENT - HYDRAULICS/PNEUMATICS          ,
CLECC = 0.8      ,DEF=55H  MATERIAL SCALING EXPONENT - ELECTRICAL                     ,
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CEACC  = 0.9    ,DEF=55H  MATERIAL SCALING EXPONENT - AIR-CONDITIONING         ,
CEAIC  = 0.9    ,DEF=55H  MATERIAL SCALING EXPONENT - ANTI-ICING               ,
CEAUXC= 1.0     ,DEF=55H  MATERIAL SCALING EXPONENT - AUXILLARY GEAR           ,
CEAPUC= 1.0     ,DEF=55H  MATERIAL SCALING EXPONENT - AUXILLARY POWER UNIT     ,
CFURNC= 1.0     ,DEF=55H  MATERIAL SCALING EXPONENT - FURNISHINGS              ,
CSBM   = 19.    ,DEF=55H  MATL COST/LB AT REF WT - FUSELAGE                    ,
CSWM   = 18.    ,DEF=55H  MATL COST/LB AT REF WT - WING                        ,
CSHM   = 20.    ,DEF=55H  MATL COST/LB AT REF WT - HORIZONTAL TAIL             ,
CSVM   = 20.    ,DEF=55H  MATL COST/LB AT REF WT - VERTICAL TAIL               ,
CSNAM  = 13.    ,DEF=55H  MATL COST/LB AT REF WT - NACELLES                    ,
CSLGM  = 19.    ,DEF=55H  MATL COST/LB AT REF WT - LANDING GEAR                ,
CPSPM  = 10.    ,DEF=55H  MATL COST/LB AT REF WT - SOUND PROOFING              ,
CPSTM  = 76.    ,DEF=55H  MATL COST/LB AT REF WT - STARTING                    ,
CPECM  = 72.    ,DEF=55H  MATL COST/LB AT REF WT - ENGINE CONTROLS             ,
CPWIM  = 75.    ,DEF=55H  MATL COST/LB AT REF WT - WATER INJECTION             ,
CPFSM  = 54.    ,DEF=55H  MATL COST/LB AT REF WT - FUEL SYSTEM                 ,
CESCM  = 23.    ,DEF=55H  MATL COST/LB AT REF WT - SURFACE CONTROLS            ,
CEINM  = 300.   ,DEF=55H  MATL COST/LB AT REF WT - INSTRUMENTS                 ,
CEHYDM= 80.     ,DEF=55H  MATL COST/LB AT REF WT - HYDRULICS/PNEUMATICS        ,
CLECM  = 67.    ,DEF=55H  MATL COST/LB AT REF WT - ELECTRICAL                  ,
CEACM  = 42.    ,DEF=55H  MATL COST/LB AT REF WT - AIR-CONDITIONING            ,
CEAIM  = 42.    ,DEF=55H  MATL COST/LB AT REF WT - ANTI-ICING                  ,
CEAUXM= 47.     ,DEF=55H  MATL COST/LB AT REF WT - AUXILLARY GEAR              ,
CEAPUM= 84.     ,DEF=55H  MATL COST/LB AT REF WT - AUXILLARY POWER UNIT        ,
CFURNM= 19.     ,DEF=55H  MATL COST/LB AT REF WT - FURNISHINGS                 ,
$END
```

DIRECT OPERATING COST PROGRAM

TEKVAL TEST CASE - .90 MACH 195 PASS 3000 NM

TOTAL COST PER A/C = $ 15295462

AVERAGE AIRFRAME MANUFACTURING COST

	LABOR	MAT,L	TOTAL
FUSELAGE	405939	472530	878469
WING	306577	360527	667104
HORIZONTAL TAIL	68874	49000	117874
VERTICAL TAIL	53300	40000	93300
NACELLES	119306	44322	163628
LANDING GEAR	45500	245209	290709
STRUCTURE TOTAL	999496	1211587	2211084
SOUND PROOFING	4900	7000	11900
STARTING	980	10640	11620
ENGINE CONTROLS	1365	14040	15405
WATER INJECTION	6006	19500	25506
FUEL SYSTEM	36	172	208
PROPULSION RELATED TOTAL	13287	51352	64639
SURFACE CONTROLS	177766	78039	255805
INSTRUMENTS	0	522000	522000
YDRAULICS/PNEUMATICS	21327	145035	166362
ELECTRICAL	73772	213971	287743
AIR CONDITIONING	17075	146470	163545
ANTI-ICING	2688	21995	24682
AUXILIARY GEAR	0	3995	3995
AUXILIARY POWER UNIT	0	76272	76272
FURNISHINGS	113528	440211	553739
SYSTEMS AND EQUIP TOTAL	406156	1647988	2054143
AIRFRAME HARDWARE TOTAL	1418939	2910927	4329866
ASSEMBLY AND INTEGRATION			562883
SUSTAINING TOOLING			721664
SUSTAINING ENGINEERING			3799796
PROFIT AND WARRANTY EXPENSE			432987
RECURRING AIRFRAME COST			12349779
CRUISE ENGINES(EACH)			815227
AVIONICS			500800

DIRECT OPERATING COSTS - ATA EQUATIONS ($ / AIRCRAFT-NM)

AIR DELAY(MIN) 6.0 GND DELAY(MIN) 0.0

FUEL RATE, AIR DELAY (1000 LB/MIN) 1.0000 GND DELAY (1000 LB/MIN) 1.0000

DISTANCE (NM)	BLOCK TIME	BLOCK SPEED	FLIGHT TIME	FLIGHT SPEED	TOTAL DOC	CREW	FUEL +OIL	INSURANCE	MAINTENANCE
100.0	.346	289.0	.346	289	9.9958	.5957	2.2644	.5751	4.3598
200.0	.540	370.7	.540	371	5.8800	.4644	1.2691	.3533	2.4412
300.0	.733	409.3	.733	409	4.5081	.4206	.9374	.2794	1.8017
500.0	1.120	446.5	1.120	446	3.4106	.3856	.6720	.2202	1.2900
700.0	1.507	464.6	1.507	465	2.9402	.3706	.5582	.1949	1.0708
1000.0	2.087	479.1	2.087	479	2.5874	.3593	.4729	.1759	.9063
1500.0	3.055	491.1	3.055	491	2.3131	.3505	.4066	.1611	.7784
2000.0	4.022	497.3	4.022	497	2.1759	.3462	.3734	.1537	.7145
2500.0	4.989	501.1	4.989	501	2.0935	.3435	.3535	.1493	.6761
3000.0	5.957	503.6	5.957	504	2.0387	.3418	.3402	.1463	.6505

MAINTENANCE COST BREAKDOWN ($ / AIRCRAFT-NM)

DISTANCE (NM)	AIRFRAME LABOR	AIRFRAME MATERIAL	ENGINE LABOR	ENGINE MATERIAL	MAINT BURDEN	DEPRECIATION	UTILIZ
100.0	.5064	.9388	.4651	.7007	1.7487	2.2008	1840.6
200.0	.2772	.5077	.2671	.4095	.9797	1.3520	2335.5
300.0	.2008	.3640	.2011	.3124	.7234	1.0691	2675.1
500.0	.1397	.2490	.1483	.2348	.5183	.8428	3111.0
700.0	.1135	.1997	.1256	.2015	.4304	.7458	3378.8
1000.0	.0938	.1628	.1087	.1765	.3645	.6730	3630.3
1500.0	.0786	.1340	.0955	.1571	.3132	.6164	3867.0
2000.0	.0709	.1197	.0889	.1474	.2876	.5881	4002.4
2500.0	.0663	.1111	.0849	.1416	.2722	.5712	4090.1
3000.0	.0633	.1053	.0823	.1377	.2620	.5598	4151.5

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P$ROIIN
 AF    =.33      ,DEF=55H  SYSTEM GROWTH FACTOR BY CITY PAIR                          ,
 DELR  =.05      ,DEF=55H  STEPPING FACTOR IN ROI ITERATION-DEC. FRACTION             ,
 EPSA  =.001     ,DEF=55H  ERROR FRACTION IN ROI ITERATION-DEC. FRACTION              ,
 FAREI =7.       ,DEF=55H  FIXED CHARGE PER PASS - $                                  ,
 FARES =.0644    ,DEF=55H  CHARGE PER PASS N MI - $                                   ,
 FLM   =.55      ,DEF=55H  MAX. PERMITTED CITY PAIR LOAD FACTOR-DEC FRACTION          ,
 IRTE  = 1,       DEF=55H  FLAG - 1 = READ ROUTE DATA, 0 = DO NOT READ                ,
 ISUB  =1,        DEF=55H  1 = PRINT DATA BY CITIES , 2 = PRINT SUMMARY ONLY          ,
 MINF  =4,        DEF=55H  MINIMUM FLIGHTS / DAY                                      ,
 T     =10.      ,DEF=55H  DAILY OPERATING PERIOD - HOURS                             ,
 TAX   =.48      ,DEF=55H  INCOME TAX RATE - DEC. FRACTION                            ,
C Z(1) = SERVICE COST AND LANDING FEE/1000 LB - DOLLARS
C Z(2) = PASS. SERVICE COST/MILE              - DOLLARS
C Z(3) = RESERV, SALES , PASS HANDLING/PASS   - DOLLARS
C Z(4) = STEWARDESS COST/BLOCK HOUR           - DOLLARS
C Z(5) = MEAL COST/PASS HOUR                  - DOLLARS
C Z(6) = GENERAL AND ADMINISTRATIVE IOC FACTOR- PERCENT
 Z     = 1.37, .0047, .09, 15.03, .45 , 1.091                                         ,
 $END
```

RETURN ON INVESTMENT PROGRAM

TEKVAL TEST CASE - .90 MACH 195 PASS 3000 NM

CONSTANTS INDEPENDENT OF AIRCRAFT TYPE

IDEALIZED ANNUAL UTILIZATION, HOURS	4500
TURNAROUND TIME / TRIP, HOURS	.500
DAILY OPERATIONS TIME, HOURS	10.00
MAX. PASSENGER LOAD FACTOR	.55
FEDERAL TAX, PERCENT	48.00
MINIMUM FLIGHTS / DAY / CITY-PAIR	4

CONSTANTS DEPENDING ON AIRCRAFT TYPE

PASSENGER CAPACITY	195
INVESTMENT BASE PER AIRPLANE, $M	17.509
DESIGN TOGW, LB	242845

U. S. DOMESTIC CITY PAIRS - 150 - 2500 NM 1985 TRAFFIC

IOC FACTOR, $ / 1000 LB TOGW	1.370
IOC FACTOR, $ / REVENUE PSGR N MI	.0047
IOC FACTOR, $ / PASSENGER	.090
IOC FACTOR, $ / STEWARDESS HR	15.03
IOC FACTOR, $ / TRIP - FOOD	.45
IOC FACTOR, $ / SUBTOTAL IOC $	1.091

RANGE, NM	3000
DEPRECIATION PERIOD, YEARS	15
PASSENGERS / STEWARDESS RATIO	R

CONSTANTS DEPENDING ON DISTANCE

DISTANCE, N MI	100	200	300	500	700	1000	1500	2000	2500	3000
BLOCK TIME, HR	.3460	.5395	.7330	1.1199	1.5068	2.0872	3.0546	4.0219	4.9892	5.9565
DOC / ACFT-N MI	9.9958	5.8800	4.5081	3.4106	2.9402	2.5874	2.3131	2.1759	2.0935	2.0387
TRIP FARE, $	13.44	19.88	26.32	39.20	52.08	71.40	103.60	135.80	168.00	200.20

TEKVAL TEST CASE - .90 MACH 195 PASS 3000 NM

U. S. DOMESTIC CITY PAIRS - 150 - 2500 NM 1985 TRAFFIC

CITY PAIR		DISTANCE	PASS/DAY	HOURLY PEAK	DOC	IOC	INCOME	LOAD FACT	PROFIT	ROI	FARE	FLT/DAY	ACFT
NEW YORK	BALTIMORE	156	189	19	4799	2317	3218	.2420	-2027	-.1875	17.05	4	.31
NEW YORK	BOSTON	165	1945	194	22950	12087	34274	.5248	-397	-.0103	17.63	19	1.50
K C	ST LOUIS	200	240	24	4704	2469	4776	.3080	-1246	-.1155	19.88	4	.34
N Y	BUFFALO	251	701	70	9102	4924	16236	.5135	1150	.0605	23.16	7	.65
NEW YORK	NORFOLK	254	259	26	5221	2625	6051	.3321	-934	-.0824	23.36	4	.37
CHICAGO	MINNEAPOL	300	392	39	5410	2957	10314	.5024	1013	.0829	26.32	4	.40
L A	S F	307	420	42	5489	3026	11237	.5382	1416	.1103	26.77	4	.40
N Y	CLEVELAND	356	1063	106	14955	7998	31800	.5449	4601	.1295	29.93	10	1.09
N Y	CINCINNATI	504	376	38	6857	3564	14844	.4823	2300	.1329	39.46	4	.53
NEW YORK	CHICAGO	626	1862	186	35091	18297	88108	.5305	18054	.1896	47.31	18	2.72
N Y	ATLANTA	656	513	51	9983	5193	25287	.5266	5258	.1923	49.25	5	.78
WASHINGTON	MIAMI	799	290	29	9025	4118	16976	.3723	1993	.0907	58.46	4	.71
NEW YORK	N ORLEANS	1023	225	23	10536	4366	16429	.2890	794	.0341	72.88	4	.85
NEW YORK	HOUSTON	1235	261	26	12145	5090	22617	.3351	2799	.0919	86.53	4	.99
CHICAGO	SAN DIEGO	1502	132	13	13894	4751	13692	.1692	-2575	-.0739	103.73	4	1.15
L A	WASH	1987	235	24	17322	6708	31746	.3016	4013	.0894	134.96	4	1.46
S F	WASH	2111	249	25	18219	7158	35663	.3198	5349	.1098	142.95	4	1.54
NEW YORK	L A	2129	1076	108	50459	24099	155050	.5016	41856	.2633	144.11	11	4.26
L A	BOSTON	2258	363	36	19269	8843	55327	.4654	14152	.2375	152.42	4	1.63
S F	BOSTON	2347	215	22	19891	7319	34027	.2758	3545	.0702	158.15	4	1.68

SYSTEM DATA

GROWTH FACTOR	.330
PASSENGERS PER DAY	11008
PASSENGER-N MILES/1000	8550.0
DOC ($/1000)	295.3
IOC ($/1000)	137.9
TOC ($/1000)	433.2
INCOME ($/1000)	627.7
LOAD FACTOR	.4480
PROFIT ($/1000)	101.1
RETURN ON INVESTMENT	.1322
NUMBER OF AIRCRAFT	23.4