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INTERIM COMPUTER PROGRAM FOR ESTIMATING AIRCRAFT ENGINE WEIGHT AND DIMENSIONS ON A COMPONENT BASIS

by Leo Franciscus
Lewis Research Center
Cleveland, Ohio 44135
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Abstract

A rapid approximate computer program is described which estimates aircraft engine weights and dimensions on a component by component basis. Weights and dimensions can be estimated for any engine whose components can be represented in the program. Components now included in the program are primarily representative of supersonic engines. The program, however, is designed in modular fashion so that component representations can be readily added or refined to broaden its scope or improve its accuracy.

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CONTENTS

SUMMARY	Page 1
INTRODUCTION	Page 2
METHOD OF ANALYSIS	Page 5
COMPUTER PROGRAM	Page 9
SAMPLE CALCULATIONS	Page 17
CONCLUDING REMARKS	Page 20
APPENDICES	
A - Symbols	Page 22
B - Program Subroutines	Page 24
C - Program Listing	Page 25
REFERENCES	Page 47

E-8730

INTERIM COMPUTER PROGRAM FOR ESTIMATING AIRCRAFT ENGINE WEIGHT AND DIMENSIONS ON A COMPONENT BASIS

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SUMMARY

A rapid, approximate, general-purpose aircraft engine weight and dimension computer program is described. It is designed to complement modern cycle performance programs in that any engine configuration may be specified by input. A representative flowpath is generated internally using thermodynamic properties supplied by a cycle program. Mechanical and technological features of the engine are defined by further input. Thus directed, the program estimates engine weights and major dimensions on a component by component basis for any engine whose components can be represented within the program.

The component weight data base now included in this report reflects selected high technology supersonic cruise aircraft research study engines together with NASA in-house results and some older military supersonic engines in an averaged or representative sense. The component

correlations included at present are highly simplified and involve a minimum number of parameters. Nevertheless, based on a limited number of trials using uncalibrated input, the program results agree reasonably well with contractor data. If better agreement or other component types are required, the program input provides means for calibrating the weight relations for specific engine types and technologies. In general, each component is represented by an individual subroutine using empirical correlations derived from the data base. Refined component definitions or additional components can, therefore, be easily incorporated.

This is regarded as an interim code; it is expected that a more sophisticated version (which will probably contain proprietary information) will be developed within one to two years.

INTRODUCTION

Aircraft propulsion system studies are being conducted by NASA and the industry for a variety of applications; e.g., supersonic cruise aircraft research (SCAR) study engines, engines for low fuel consumption and military engines. As shown by the examples in figure 1 these studies encompass a wide variety of engine concepts ranging from advanced conventional turbojets and turbofans to a number of complicated variable cycle engine (VCE) concepts.

The components for these engines are in some cases novel and in many others involve weight/cycle performance tradeoffs that may differ significantly from older practice.

In order to evaluate these engine concepts and their associated component tradeoffs, performance and weight estimates are equally necessary. The best available estimates in terms of accuracy and realism are of course provided by contractual studies, in view of the engine companies' expertise and experience. However, this approach would be costly and time consuming, especially for brief in-house concept tradeoff studies and broad ranging in-house parametric studies which normally should precede major contractual efforts. It has also been found unreasonably time consuming to devise a new, separate program for each new cycle concept.

At present, there are few, if any, general purpose engine weight codes available. Reference 1 describes a correlation technique for estimating the entire engine weight for turbojets or turbofans based on a few gross parameters such as bypass ratio and overall pressure ratio. It is limited, however, to conventional engine types and lacks the sensitivity required for perturbation or tradeoff studies at the component level. In reference 2, Sagerser, et al provide a weight estimating procedure on a component basis which was coded at LeRC for a limited

number of cycles only. There is, therefore, a need for a highly flexible, rapid, general purpose engine weight code for NASA in-house studies. Although certain simplifications must be accepted for the sake of speed and flexibility, it would allow engine configuration and weight to be approximated when the performance of a new cycle is calculated. Such capability would be a particularly valuable adjunct to modern cycle performance programs such as the NAVY/NASA Engine Program (NNEP, reference 3), which can accept any engine definition on a component by component basis.

The present report describes a companion program to NNEP for preliminary estimates of engine weight and dimensions. Like NNEP it will accept an arbitrary engine definition on a component by component basis, specified by input. Flowpath data and thermodynamic characteristics of the components are first calculated by NNEP or an equivalent performance program. This information together with data to define the type, number and inter-connection of components, key mechanical features and technology details is then input into the program to determine weight and dimension estimates.

The program is written in FORTRAN IV for the UNIVAC 1110 series computer. Included in this report are a presentation and discussion of the current weight and dimension relations, a description of the computer program itself, input and output characteristics, instructions for use and several sample applications.

It should be noted that in its present form the program contains comparatively simple correlations derived from a limited and specialized data base. It is not represented as being necessarily suitable for different or more general applications without calibrating or revising the correlations or using more sophisticated weight models which reflect a wider data base. A more sophisticated version is being planned which will supercede the present program in one to two years. However, this later version will probably contain proprietary features and will, therefore, be available to government agencies only. This interim version is, therefore, being reported both for the sake of its immediate utility and its possible use as a building-base by non-government users.

METHOD OF ANALYSIS

Thermodynamic data, flow properties and representative annulus ratio are used to calculate flow areas and component diameters. Empirical expressions are used to determine weights and lengths. The empirical expressions for estimating the weights and lengths for fans, compressors, combustors, turbines and ducts are similar to those provided by Sagerser, et al in reference 2. Correlating data for these expressions was taken from selected SCAR study engines (references 4 and 5), selected NASA in-house results and some representative military supersonic engines--

all averaged together with appropriate weighting factors and adjustments. For components and weight items not included in reference 2, new but comparably simple correlations were adjusted to the same data base. With component weights estimated in this manner, the total engine weight is obtained by summation. The components and weight items now included in the program are listed in Table 1.

Component Diameters

Flow areas are calculated from known or calculated thermodynamic and flow properties.

$$A = \frac{\dot{W}\left[1 + 0.5(\gamma - 1) M^2\right]^{\frac{\gamma+1}{2(\gamma-1)}}}{PM} \sqrt{\frac{RT}{\gamma g}} \tag{1}$$

Front hub and tip diameters are calculated by inputing a specified hub to tip diameter ratio or hub diameter.

a. Hub to tip diameter ratio specified:

$$D_T = \sqrt{\frac{4A}{\pi(1 - D_H^2/D_T^2)}} \tag{2}$$

b. Hub diameter specified

$$D_T = \sqrt{4A/\pi + D_H^2} \tag{3}$$

Rear hub and tip diameters are calculated by specifying the rear to front hub diameter ratio or the hub diameter.

a. Rear/front hub diameter ratio specified:

$$D_{H_2} = D_{H_1} \; D_{H_2}/D_{H_1}$$

use equation (3)

b. Hub diameter specified:
use equation (3)

For dual flow components such as inverting valves (figure 2) the inner flow tip diameters are calculated first and then used as the hub diameters in equation (3) for calculating the component tip diameters.

Component Length and Weight

The length and weight relations for the components in the program thus far are given in Table II. Correlation curves for fans, compressors, main burners and turbines are shown in figures 3 through 6 with curves from reference 2 for comparison. Correlating weight relations for duct burners is shown in figure 7. Though admittedly based on scanty data, the weight equation given in Table II was derived from the curves in figure 7. In the length relation the L/H term provides for the burner pilot length and values of 1.5 to 2 are appropriate for supersonic engines. The second part of the equation provides for the length required for efficient burning. Values for the effective volume, VBEFF, are on the order of $1.6 m^3$ ($60 ft.^3$).

Diverter valve schemes (figure 2) are studied in many variable cycle engine concepts. The purpose of the valve is to divert some of the bypass airflow either around or through the core engine at a variety of flight conditions for improved off-design engine performance. Since this is a new component, only a few data points are available for weight and length estimates.

Due to the cooler gases, the front valves are much lighter than rear valves as indicated by the weight factors, K. No significant variation was observed in the valve length parameters. As seen in Table II, length to average annulus height ratios are in the range of 4 to 5.

In many engines, the structural casing between components is a significant weight item. In some turbofans, for example, the aerodynamic design of the duct between the fan and compressor separates the fan and compressor by a significant distance and the duct inner wall becomes a structural member. The weight equation for intermediate casings in Table II was derived from the curve shown in figure 8.

Nozzle weight data from the data base engines (ejector or plug type nozzles) did not encompass a sufficient range of sizes or parameters for correlating purposes. Also in many cases reversers and suppressors

were included in the nozzle weight so that it was difficult to isolate nozzle weight from the overall exhaust system weight. At the present time, therefore, the duct weight relation is used for nozzles. This requires calibrating the duct weight factor for a baseline nozzle of known weight and dimensions. Results using this procedure compared reasonably well with contractors' data for engine sizing calculations. In Table II a typical nozzle weight factor is shown. The length/diameter ratios of 1.5 to 2.0 are representative of the nozzles considered.

Weight data for controls, accessories and the lubrication system showed little variation among the data-base engines considered. For large engines on the order of 400Kg/sec (900 lbm/sec) to 500Kg/sec (1100 lbm/sec) this item may range from 363Kg(800 lbm) to 450Kg (1000 lbm).

COMPUTER PROGRAM

The computer program will calculate the weight and dimensions of engines having any combination of the components shown in Table I. The program is arranged to provide a separate subroutine for each type of component. This allows the addition of new components into the program with a minimum of changes. Appendix B describes the subroutines now in the program. Appendix C gives

the program Fortran listing and figure 9 shows the flow diagram. Figure 10 illustrates the operation of the program. The engine components making up the cycle and the interconnections of the components are selected. A cycle program provides the thermodynamic properties of the components. The weight program then computes the dimensions (hub and tip diameters and lengths) of the components. These dimensions are then used by the component weight relations. Each component is identified in the main program and the calculation is then directed to the appropriate subroutine. After the calculations for all of the components have been completed, the total engine weight is computed by summation.

PROGRAM INPUT

The program input consists of four parts:

1. General
2. Engine layout
3. Component definition
4. Component thermodynamic properties

A description of the input is provided in Table III. Figure 11 shows a sample input for a rear valve variable cycle engine from the SCAR studies.

General Input

All of the input is in NAMELIST format except for

the title which is in A format. The program will calculate any number of cases with each case beginning with the title card. The numbers shown in the schematic in figure 11 are component sequence numbers and show the sequence of inputing the component descriptions and the sequence in which the component weights and dimensions will be calculated. The input item, NCOMP, in Table III must be the same as the last component sequence number (NCOMP = 11 in this example). The sizing factor, SIZE, enables scaling the engine airflow from the input value to other sizes. The program changes the component airflows specified in the thermodynamic properties using the scaling factor and computes component weights and dimensions for the revised airflows. For example, if the input airflows are for a 408Kg/sec (900 lbm/sec) engine and it is desired to compute the weight of a 272 Kg/sec (600 lbm/sec) engine, SIZE would be input as 0.67.

Engine Layout Array

The engine layout array identifies and links the components. Each line of the array represents a component (see figure 11). Each line contains a maximum of thirty possible input items described in Table III. The first item is the component sequence number mentioned in the General input description. The second item is

the component identification number. Component types are assigned identification numbers in the program. These are defined in Table IV.

For instance, the first component in the schematic of figure 11 is the fan and the first line of the engine layout array, COMPON (1,1), is for the fan. The first item of this line is the component sequence number, 1, and the second item is the identification number, 3. The second component in the schematic is the compressor and the second line of the array, COMPON (1,2), is for the compressor. The first item of this line is, 2, the component sequence number and the second item is 4, identifying the component as a compressor. Items 3 through 9 of each line are the hub diameter specifications defined in Table III. As mentioned before, tip diameters are calculated from flow areas by using the following options:

1. Specify the front hub/tip diameter ratio
2. Specify the rear/front hub diameter ratio
3. Connect the front or rear hubs to the hubs or tips of other components

The first two options are used for the fan in figure 11; item 3 of the first line of the array is 0 and items 8 and 9 give the front hub/tip diameter ratio and the rear/front hub diameter ratio as 0.4 and 1.7

respectively. An example of the use of the third option is shown by the rear inverting valve, component 10 (COMPON (1,10), in the layout array). Item 3=3 indicating the front and rear hub diameters are specified by the dimensions of other components; the front hub diameter equals the first low pressure turbine (component 6, item 4=6) rear hub diameter and item 5=9 which is the rear hub diameter identification number from Table V. The valve rear hub diameter equals the second low pressure turbine (component 7, item 6-7) front hub diameter (item 7=7).

Item 10 (Table III) indicates that the component length is defined by the lengths of other components. The number of other components is specified by this item and the other components are identified by their sequence numbers in items 20 through 30. Item 10 can be used when a component length is not known or defined. At the present time it is used for ducts and intermediate casings only. Item 11 can be used to specify the component length and is also used for ducts and intermediate casings only at the present time. Lengths for the other components now included in the program are calculated by the expressions given in Table II.

Items 12 through 19 may be used to specify the thermodynamic properties of one component with respect to others. An example of the use of this option is shown by the main burner of the example in figure 11. Referring to the fourth line in the layout array for the burner, COMPON (1, 4), item 12=2 indicating that the burner entrance thermodynamic properties are specified by the compressor exit conditions. If items 12 through 19 are not used, the thermodynamic properties are input in the thermodynamic array.

Items 20 through 30 are used in conjunction with item 10. For example, for the duct, component 11, (COMPON (1, 11) in the layout array) item 10=1 indicating that the duct length is specified by the length of one component which is the second low pressure turbine, component 7, and item 20=7.

Component Definition Arrays

Each type of component is provided with a definition array described in Table III and illustrated in figure 11. Each line of each array is reserved for a component of that particular type. Except for the duct array each array is sized for a maximum of five components. The duct array includes ducts, duct burners and intermediate casings and is sized for a total of ten of any combination of these components. The components are input in each

definition array in the same order as they appear in the engine layout array. For example, for an engine with three turbines as in figure 11, the three turbines, components 5, 6 and 7, in the layout array are defined in the turbine array as turbines 1, 2 and 3 (TURBD (1, 1), TURBD (1, 2) and TURBD (1, 3).

Component Thermodynamic Array

The component thermodynamic properties are input in the component thermodynamic array (Table III) in the same order as the components appear in the engine layout array as illustrated in figure 11. If it is desired to specify these properties by those of other components (item 12 through 19 of the engine layout array) zeroes are input for each thermodynamic property. For example, the entering thermodynamic properties for components 4, 5, 6 and 7 in figure 11 are specified by those of other components (see item 12 for these components in the engine layout array). In the thermodynamic array zeroes are input for the entering properties for these components. For the inverting valve, component 10, in figure 11 the entering conditions for the inner and outer streams are specified by the first low pressure turbine and the duct burner exit properties respectively. In the engine layout array, therefore, for COMPON (1, 10), item 12=6 indicating the inner stream entrance properties are those of the component 6 exit properties. Item 13=0 as described in

Table III. Item 14=9 indicating the outer stream entrance properties are those of the component 9 exit properties. In the thermodynamic array the entrance properties for the inner stream (PTIN, TTIN, etc) and outer stream (PTINO, TTINO, etc) are zero for component 10. It is seen that the exiting inner and outer stream properties (PTEX, TTEX, etc and PTEXO, TTEXO, etc.) are input in the thermodynamics array.

Instead of inputing exit Mach numbers in the thermodynamics array for fans and compressors, an alternate method of defining the exit Mach numbers is provided by specifying the exit to entrance velocity ratios in the fan and compressor component definition arrays, FAND and COMPD. These are input in item 9 in the fan array and item 6 in the compressor array (Table III). In this case the exit Mach number in the thermodynamic array is ignored and calculated by the program. This alternate method is used for the fan and compressor in figure 11. The velocity ratios, 0.85, for the fan and compressor are typical values.

Similarly, the turbine exit Mach number, total temperature and total pressure may be calculated by the program instead of inputing them by setting item 15 of the turbine component definition array equal to 1. When this is used the values in the thermodynamic array for these properties are ignored by the program. This method is used in the

sample input in figure 11; item 15 for the three turbines is equal to 1 in the turbine array, TURBD.

Figure 12 shows the computer output for the sample input of figure 11. The identification is printed first. The components are listed in the same order as they appear in the engine layout array. The number of each component type is also indentified (TURBINE 1, TURBINE 2, TURBINE 3 etc.). The diameters, length and weight of each component are listed and the total engine weight is shown last.

SAMPLE CALCULATIONS

To illustrate the use of the program and compare results with engine company estimates, the weight and dimensions were calculated for cycles comparable to the Pratt & Whitney 112B rear valve variable cycle and the VSCE 502B duct burning turbofan. Also, the effects of engine size and cycle parameters such as overall pressure ratio and bypass ratio on engine weight were calculated and compared with Pratt & Whitney estimates.

Calculations for The Rear Valve Variable Cycle (P&W 112B) and The Duct Burning Turbofan (P&W VSCE 502B)

Cycle calculations to simulate the thermodynamic properties of the 112B and 502B were performed with the cycle computer programs of references 3 and 6. Figures 13 and 14 show the engines calculated by the weight program compared to those scaled from

drawings and dimensions given in reference 5. It is assumed that the drawings provided in reference 5 are reasonable approximations of the actual engine layouts. The calculated lengths are somewhat shorter than Pratt & Whitney's layouts especially for the 112B. This is due in part to the fact that the Table II correlations are for "annulus-inverter" type valves whereas the 112B actually uses a somewhat different type. However, the flow areas and diameters for both engines compare well with the drawings from reference 5. A comparison of the base engine weights in figures 13 and 14 show that the calculated values are within 5% of the estimates given in reference 5.

Table VI shows calculated weight breakdowns for the two engines on a component basis. Comparisons with the engine company estimates cannot be made due to proprietary considerations.

Effect of Engine Size on Base Engine Weight

Many engine studies involve tradeoffs between engine size, weight and performance to determine the best engine size. In some cases a reference engine size and weight are known from contractor data. In this event the weight program can be calibrated to duplicate the reference size and weight. Weights for other sizes can then be calculated by specifying the desired size as described in Table III.

If a reference size and weight are not known, a reference size is chosen. Weight calculation for the P&W 502B type engine described in the previous section can be used to illustrate engine sizing calculations with the program. Weight estimates were calculated for a reference size of 409 Kg/sec (900 lb/sec). For a 272 Kg/sec (600 lb/sec) engine (SIZE = 0.666 in Table III), the component flows (duct, core, fuel) are ratioed by 0.666 and weights and dimensions are calculated component by component. Weight estimates for other 502B engine sizes were calculated and the results shown in figure 15 compare within 3% of the Pratt & Whitney estimates from reference 5.

Effects of Overall Pressure Ratio and Bypass Ratio on Bare Engine Weight

In parametric cycle studies it is necessary to determine the effects of cycle parameters (bypass ratio, turbine inlet temperature, overall pressure ratio, etc.) on engine weight. Figures 16 and 17 show examples of engine weight studies for overall pressure ratio and bypass ratio. In figure 16 the overall pressure ratio is varied by varying the compressor pressure ratio for a constant fan pressure ratio. The variation of the number of compressor stages with pressure ratio is shown in the figure. It is seen that there is little variation in

base engine weight with pressure ratio. Although the compressor weight increases with compressor pressure ratio, the higher pressure leads to reduced turbine size and weight. It should be noted, however, that these results are applicable to the range of pressure ratios considered here. Larger excursions in pressure ratio may very well require additional turbine stages resulting in higher weights. Figure 17 shows base engine weight versus bypass ratio for duct burning turbofans. The calculated weights are seen to be within the band of estimates by Pratt & Whitney from reference 5.

CONCLUDING REMARKS

The computer program described in this report can be applied to a wide variety of engine cycle concepts provided that appropriate component subroutines are available. It is intended mainly for such purposes as preliminary analysis of novel engine concepts, preliminary cycle selection studies and component tradeoff and sensitivity studies. Its application to more detailed design or evaluation would be questionable.

It should be noted that the program is an interim version and no attempt has been made to provide a comprehensive data base or correlations which are elaborate enough to encompass a wide variety of applications. However, the program has been designed so that different

data bases, other types of components and/or more refined component definitions may be readily incorporated. It may, therefore, be considered as a building-base which can be adapted by the user to suit a variety of needs.

In general, results from the program show reasonably good agreement with contractor results for engines relevant to its present data base. As a general rule, it is felt that the best use of the present program is for perturbation or cycle selection studies within a given concept. For good relative results the program should be initially calibrated to agree in detail with a well known baseline engine which is representative of the particular concept and technology level of interest. The use of the program for comparing fundamentally different engine concepts is more prone to error since the accuracy of the weight trends generated by the program are dependent upon the accuracy of the data base. Hence, a good data base substantially enhances the reliability of the program. Therefore, the user should carefully review his needs and choice of data base when using the program.

APPENDIX A

SYMBOLS

A	area, m^2; ft^2
AR	aspect ratio
C	chord length, m; ft
D	diameter, m; ft
g	gravitational constant, m/sec^2; ft/sec^2
H	height, m; ft
K	weight correlation factor
L	length, m; ft
M	Mach number
N	number of stages
P	stagnation pressure, N/m^2; lb/ft^2
R	specific gas constant, joules/(kg)(K); ft-lb/(lbm)(^oR)
S^p	axial spacing, m; ft
T	stagnation temperature, K; ^oR
U	tip speed, m/sec; ft/sec
W	weight, kg; lb
$\dot{W}$	gas weight flow rate, kg/sec; lbm/sec
σ	solidity
γ	specific heat ratio

Subscripts:

a	air
b	burner
c	compressor
H	hub or inner
M	mean
R	rotor

REF reference

S stator

T tip or outer

X axial

1 front

2 rear

Superscripts:

— average

APPENDIX B

PROGRAM SUBROUTINES

FAN	compute diameters, length and weight for conventional or split fans
COMP	computes diameters, length and weight for compressors
COMB	computes diameters, length and weight for main burners
TURB	computes diameters, length and weight for turbines. Uses symmetrical velocity vector diagrams to compute turbine efficiency. Matches turbine speed and work with the driven component. Calculates thermodynamic and flow conditions (P, T, M, etc) at rotor entrance and exit.
VALV	computes diameters, length and weight for valves or ducts with dual streams
DUCT	computes diameters and weight for ducts, duct burners and intermediate casing
TRANS	obtains thermodynamic and flow properties for a component from the propteries of other specified components. For example, the entrance and exit conditions of a duct connecting the fan to a duct burner can be obtained with this subroutine by specifying that the upstream and downstream components of the duct are the fan and ductburner.
POLY	calculates enthalpy (real gas) as a function of temperature and fuel-air ratio
VISC	calculates viscosity of a gas as a function of temperature

APPENDIX C

PROGRAM LISTING

```
*FOR,IS  MAIN,ENGWT.MAIN
      DIMENSION PTIN(25), PTEX(25), TTIN(25), WAIN(25), WAEX(25), AMIN(2
     15), AMINO(25), AMEX(25), GAMIN(25), GAMEX(25), GAMINO(25), GAMEXO(
     225), CPIN(25), CPINO(25), PTINO(25), PTEXO(25), TTINO(25), TTEXO(2
     35), WAINO(25), WAEXO(25), RIN(25), REX(25), RINO(25), REXO(25), CP
     4EX(25), CPEXO(25), COMPON(30,30), FAND(15,5), COMPD(10,5), DUCTD(1
     55,20), TURBD(20,5), BURND(10,5), ANS(25,25), TTEX(25), AMEXO(25),
     6DCOMPN(25), VALVD(5,5), A(13)
      NAMELIST / IN/PTIN,PTEX,TTIN,TTEX,WAIN,WAEX,AMIN,AMINO,AMEX,AMEXO,
     1GAMIN,GAMEX,GAMINO,GAMEXO,CPIN,CPINO,PTINO,PTEXO,TTINO,TTEXO,WAINO
     2,WAEXO,RIN,REX,RINO,REXO,CPEX,CPEXO,FAND,COMPD,DUCTD,TURBD,BURND,C
     3OMPON,NCOMP,VALVD,SIZE,ACC,ISI
      COMMON /THEE/ PTIN,PTEX,TTIN,TTEX,WAIN,WAEX,AMIN,AMINO,AMEX,AMEXO,
     1GAMIN,GAMEX,GAMINO,GAMEXO,CPIN,CPINO,PTINO,PTEXO,TTINO,TTEXO,WAINO
     2,WAEXO,RIN,REX,RINO,REXO,CPEX,CPEXO,PT1,PT2,TT1,TT2,WA1,WA2,AM1,AM
     32,CP1,CP2,R1,R2,GAM1,GAM2,PT1O,PT2O,TT1O,TT2O,WA1O,WA2O,AM1O,AM2O,
     4CP1O,CP2O,R1O,R2O,GAM1O,GAM2O,DCOMPN,INUM,IS,JS,KS
      NAMELIST / OUT1/PT1,PT2,TT1,TT2,WA1,WA2,AM1,AM2
      NAMELIST / OUT2/PT1O,PT2O,TT1O,TT2O,WA1O,WA2O,AM1O,AM2O
C
5     READ (5,340,END=335) A
      WRITE (6,350) A
      READ (5,IN)
      IAMB=0
      I=0
      IF=0
      IC=0
      IB=0
      IDUCT=0
      IAUXIN=0
      IVALV=0
      ITURB=0
      IDUCBN=0
10    I=I+1
      IF (I.GT.NCOMP) GO TO 5
      INUM=COMPON(1,I)
      ITYPE=COMPON(2,I)
      IVAR=0
      IHUB=COMPON(3,I)
      ILNGTH=COMPON(10,I)
      IUP=COMPON(4,I)
      IHUB1=COMPON(5,I)
      IDN=COMPON(6,I)
      IHUB2=COMPON(7,I)
      IF (IHUB.EQ.0) GO TO 30
      IF (IHUB.LT.3) GO TO 20
      DH1=ANS(IUP,IHUB1)
      DH2=ANS(IDN,IHUB2)
      GO TO 30
20    IF (IHUB.EQ.1) DH1=ANS(IUP,IHUB1)
      IF (IHUB.EQ.2) DH2=ANS(IDN,IHUB2)
30    IF (ILNGTH.EQ.0) GO TO 50
      AL=0.0
      JX=19+ILNGTH
```

```
      DO 40 J=20,JX
      JA=COMPON(J,I)
40    AL=ANS(JA,10)+AL
50    IF (COMPON(12,I).EQ.0.0) GO TO 60
      AS=COMPON(12,I)
      BS=COMPON(13,I)
      JS=IFIX(AS)
      KS=IFIX(BS)
      IS=1
      CALL TRANS
60    IF (COMPON(14,I).EQ.0.0) GO TO 70
      AS=COMPON(14,I)
      BS=COMPON(15,I)
      JS=IFIX(AS)
      KS=IFIX(BS)
      IS=2
      CALL TRANS
70    IF (COMPON(16,I).EQ.0.0) GO TO 80
      AS=COMPON(16,I)
      BS=COMPON(17,I)
      JS=IFIX(AS)
      KS=IFIX(BS)
      IS=3
      CALL TRANS
80    IF (COMPON(18,I).EQ.0.0) GO TO 90
      AS=COMPON(18,I)
      BS=COMPON(19,I)
      JS=IFIX(AS)
      KS=IFIX(BS)
      IS=4
      CALL TRANS
90    PT1=PTIN(INUM)
      PT2=PTEX(INUM)
      TT1=TTIN(INUM)
      TT2=TTEX(INUM)
      WA1=WAIN(INUM)*SIZE
      WA2=WAEX(INUM)*SIZE
      AM1=AMIN(INUM)
      AM10=AMINO(INUM)
      AM2=AMEX(INUM)
      AM20=AMEXO(INUM)
      PT10=PTINO(INUM)
      PT20=PTEXO(INUM)
      TT10=TTINO(INUM)
      TT20=TTEXO(INUM)
      WA10=WAINO(INUM)*SIZE
      WA20=WAEXO(INUM)*SIZE
      R1=RIN(INUM)
      R2=REX(INUM)
      R10=RINO(INUM)
      R20=REXO(INUM)
      GAM1=GAMIN(INUM)
      GAM2=GAMEX(INUM)
      GAM10=GAMINO(INUM)
```

```
      GAM2O=GAMEXO(INUM)
      CP1=CPIN(INUM)
      CP1O=CPINO(INUM)
      CP2=CPEX(INUM)
      CP2O=CPEXO(INUM)
      GO TO (100,130,110,120,140,150,160,170,180),ITYPE
C     AMBIENT
100   CONTINUE
      GO TO 190
C     COMPONENT  FAN
110   IF=IF+1
      NS=FAND(2,IF)
      ARR=FAND(3,IF)
      ARS=FAND(4,IF)
      SR=FAND(5,IF)
      SS=FAND(6,IF)
      SIG=FAND(7,IF)
      UT=FAND(8,IF)
      DHODT=COMPON(8,I)
      DHODH=COMPON(9,I)
      VR=FAND(9,IF)
      VRO=FAND(10,IF)
      IVAR=FAND(11,IF)
      AKW=FAND(12,IF)
      AX=FAND(13,IF)
      CALL FAN (PT1,PT2,TT1,TT2,WA1,WA2,AM1,AM1O,PT1O,PT2O,TT1O,TT2O,AX,
     1WA1O,WA2O,R1,R1O,GAM1,GAM1O,CP1,CP1O,DHODH,DHODT,VR,VRO,IVAR,NS,AR
     2R,ARS,SR,SS,SIG,UT,IHUB,DT1,DH1,DT2,DH2,AM2,DT1O,DH1O,DT2O,DH2O,AM
     32O,AL,WT,AKW,ISI)
      AMEX(INUM)=AM2
      AMEXO(INUM)=AM2O
      ALO=0.0
      GO TO 190
C     COMPONENT  COMPRESSOR
120   IC=IC+1
      ANC=COMPD(2,IC)
      ARR=COMPD(3,IC)
      ARS=COMPD(4,IC)
      UT=COMPD(5,IC)
      DHODT=COMPON(8,I)
      DHODH=COMPON(9,I)
      VR=COMPD(6,IC)
      PR=COMPD(7,IC)
      AKW=COMPD(8,IC)
      AX=COMPD(9,IC)
      CALL COMP (PT1,PT2,TT1,TT2,WA1,WA2,AM1,P1,GAM1,CP1,ARR,ARS,UT,DHOD
     1T,DHODH,VR,PR,AKW,ANC,IHUB,AX,DT1,DH1,DT2,DH2,AM2,AL,WT,ISI)
      ALO=0.0
      DT1O=DT1
      DT2O=DT2
      DH1O=DH1
      DH2O=DH2
      AMEX(INUM)=AM2
      GO TO 190
```

```
C        AUX  INLET
130     CONTINUE
        GO TO 190
C       VALVE  COMPONENT
140     IVALV=IVALV+1
        DH6DT6=COMPON(8,I)
        DH7DH6=COMPON(9,I)
        AKW=VALVD(2,IVALV)
        AX=VALVD(3,IVALV)
        CALL VALV (PT1,PT2,TT1,TT2,WA1,WA2,AM1,AM10,PT10,PT20,TT10,TT20,WA
       110,WA20,R1,R10,GAM1,GAM10,CP1,CP10,AKW,IHUB,DH6DT6,DH7DH6,AX,DT1,D
       2H1,DT2,DH2,AM2,DT10,DH10,DT20,DH20,AM20,AL,WT,ISI)
        GO TO 190
C       COMBUSTOR
150     IB=IB+1
        DH3DT3=COMPON(8,I)
        DH2DH1=COMPON(9,I)
        ALBOH=BURND(2,IB)
        VR=BURND(3,IB)
        VREF=BURND(4,IB)
        AKW=BURND(5,IB)
        AX=BURND(6,IB)
        CALL COMB (PT1,PT2,TT1,TT2,WA1,WA2,VREF,VR,AM1,GAM1,GAM2,R1,R2,IHU
       1B,DH2DH1,ALBOH,AKW,DH3DT3,AX,DT1,DT2,DH1,DH2,AM2,AL,WT,ISI)
        ALD=0.0
        DT10=DT1
        DT20=DT2
        DH10=DH1
        DH20=DH2
        AMFX(INUM)=AM2
        GO TO 190
C        TURBINE
160     ITURB=ITURB+1
        EN=TURBD(2,ITURB)
        DHDTT=COMPON(8,I)
        DH5DH4=COMPON(9,I)
        DMTD1=TURBD(3,ITURB)
        IDRVN=TURBD(4,ITURB)
        DH54=TURBD(5,ITURB)
        UST=TURBD(6,ITURB)
        IHIDLD=TURBD(7,ITURB)
        F4=TURBD(8,ITURB)
        AKV=TURBD(9,ITURB)
        ALPHD=TURBD(10,ITURB)
        AKC=TURBD(11,ITURB)
        DFACT=TURBD(12,ITURB)
        AKW=TURBD(13,ITURB)
        AX=TURBD(14,ITURB)
        VR=TURBD(15,ITURB)
        D1=DH1
        DT1F=ANS(IDRVN,2)
        DT2F=ANS(IDRVN,4)
        D10=ANS(IUP,3)
        CALL TURB (AM1,PT1,TT1,F4,GAM1,CP1,R1,AM2,PT2,TT2,DH54,WA1,ALPHD,U
```

```
     1ST,FN,AKC,AKV,DFACT,IHIOLD,DMTD1,D1D,D1,DT1F,DT2F,IHUB,DHDTT,DH5DH
     24,AKW,AX,DT1,DT2,DH1,DH2,AL,WT,VR,ISI)
      DT1D=DT1
      DT2D=DT2
      DH1D=DH1
      DH2D=DH2
      AMIN(INUM)=AM1
      AMEX(INUM)=AM2
      GO TO 190
C     DUCT
170   IDUCT=IDUCT+1
      INTR=DUCTD(2,IDUCT)
      WOAD=DUCTD(3,IDUCT)
      IACOUS=DUCTD(4,IDUCT)
      WOAAW=DUCTD(5,IDUCT)
      WOAASP=DUCTD(6,IDUCT)
      ALSPL=DUCTD(7,IDUCT)
      NSPL=DUCTD(8,IDUCT)
      AX=DUCTD(9,IDUCT)
      NW=DUCTD(10,IDUCT)
      VBEFF=DUCTD(11,IDUCT)
      ALOH=DUCTD(12,IDUCT)
      DH1DT1=COMPON(8,I)
      DH2DH1=COMPON(9,I)
      IF (ILNGTH.EQ.0) AL=COMPON(11,I)
      CALL DUCT (PT1,PT2,TT1,TT2,WA1,WA2,AM1,AM2,GAM1,GAM2,R1,R2,IHUB,DH
     12DH1,WOAD,IACOUS,WOAAW,WOAASP,ALSPL,NSPL,INTR,DH1DT1,NW,AX,VBEFF,A
     2LOH,DT1,DT2,DH1,DH2,AL,WT,ISI)
      DT1D=DT1
      DT2D=DT2
      DH1D=DH1
      DH2D=DH2
      ALD=0.0
      IF (INTR.EQ.2) ITYPE=9
      GO TO 190
C     DUCT  BURNER
180   CONTINUE
190   ANS(INUM,2)=DT1D
      ANS(INUM,3)=DT1
      ANS(INUM,4)=DT2D
      ANS(INUM,5)=DT2
      ANS(INUM,6)=DH1D
      ANS(INUM,7)=DH1
      ANS(INUM,8)=DH2D
      ANS(INUM,9)=DH2
      ANS(INUM,10)=AL
      ANS(INUM,11)=WT
      ANS(INUM,12)=ALD
      GO TO (200,210,220,240,250,260,270,280,290),ITYPE
200   WRITE (6,360)
      GO TO 300
210   WRITE (6,370)
      GO TO 300
220   IF (IVAR.EQ.1) GO TO 230
```

```
      WRITE (6,380) IF
      GO TO 300
230   WRITE (6,390) IF
      GO TO 300
240   WRITE (6,400) IC
      GO TO 300
250   WRITE (6,410)
      GO TO 300
260   WRITE (6,420) IB
      GO TO 300
270   WRITE (6,430) ITURB
      GO TO 300
280   WRITE (6,440) IDUCT
      GO TO 300
290   WRITE (6,450)
300   WRITE (6,460) PT1,TT1,WA1,AM1
      WRITE (6,470) PT2,TT2,WA2,AM2
      IF (ITYPE.NE.5) GO TO 310
      WRITE (6,480) PT10,TT10,WA10,AM10
      WRITE (6,490) PT20,TT20,WA20,AM20
310   WRITE (6,500) DH1,DT1,DH2,DT2,AL
      IF (ITYPE.NE.5) GO TO 320
      WRITE (6,510) DH10,DT10,DH20,DT20
320   WRITE (6,520) WT
      IF (I.LT.NCOMP) GO TO 10
      WTOT=0.0
      DO 330 IW=1,NCOMP
330   WTOT=WTOT+ANS(IW,11)
C     CONTROLS, ACCESSORIES, BEARINGS, LUBE,ENGINE  SIZES  800 TO 1100
      WACC=ACC
      WTOT=WTOT+WACC
      WRITE (6,530) WTOT
      IF (I.GT.0) GO TO 10
335   STOP
C
340   FORMAT (13A6)
350   FORMAT (1HK,13A6)
360   FORMAT (1HK,50X,12HENGINE  FACE)
370   FORMAT (1HK,50X,10HAUX  INLET)
380   FORMAT (1HJ,29X,3HFAN,2X,I2)
390   FORMAT (1HJ,29X,10HSPLIT  FAN,2X,I2)
400   FORMAT (1HJ,29X,10HCOMPRESSOR,2X,I2)
410   FORMAT (1HJ,29X,5HVALVE)
420   FORMAT (1HJ,29X,9HCOMBUSTOR,2X,I2)
430   FORMAT (1HJ,29X,7HTURBINE,2X,I2)
440   FORMAT (1HJ,29X,4HDUCT,2X,I2)
450   FORMAT (1HJ,29X,12HDUCT  BURNER)
460   FORMAT (1HK,3X,5HPT1 =F5.2,4X,5HTT1 =F7.2,4X,5HWA1 =F7.2,4X,4HM1 =
     1F4.2)
470   FORMAT (1HK,3X,5HPT2 =F5.2,4X,5HTT2 =F7.2,4X,5HWA2 =F7.2,4X,4HM2 =
     1F4.2)
480   FORMAT (1HK,3X,5HPT10=F5.2,4X,5HTT10=F7.2,4X,5HWA10=F7.2,4X,4HM10=
     1F4.2)
490   FORMAT (1HK,3X,5HPT20=F5.2,4X,5HTT20=F7.2,4X,5HWA20=F7.2,4X,4HM20=
```

```
      1F4.2)
500    FORMAT (1HK,3X,5HDH1 =F5.2,4X,5HDT1 =F7.2,4X,5HDH2 =F7.2,4X,5HDT2
      1=F4.2,4X,7HLENGTH=F5.2)
510    FORMAT (1HK,3X,5HDH10=F5.2,4X,5HDT10=F7.2,4X,5HDH20=F7.2,4X,5HDT20
      1=F4.2)
520    FORMAT (1HK,3X,19HCOMPONENT   WEIGHT =F7.2)
530    FORMAT (1HK,3X,21HBARE   ENGINE   WEIGHT=F8.2)
       END


"FOR,IS     FANN,ENGWT.FANN
       SUBROUTINE FAN (P1,P2,T1,T2,W1,W2,AMA1,AMA10,P10,P20,T10,T20,AX,W1
      10,W20,R,RO,GAM,GAMO,CP,CPO,DHOH,DHOT,VR,VRO,IV,NS,ARR,ARS,SR,SS,SI
      2G,UT,IHUB,DT1,DH1,DT2,DH2,AMA2,DT10,DH10,DT20,DH20,AM20,ALF,WFAN,A
      3KW,ISI)
       G=32.2
       PFACT=2116.0
       IF (ISI.EQ.0) GO TO 10
       G=1.0
       PFACT=1.0
10     IT=0
       W=W1
       GA=GAM
       AMA=AMA1
       AMB=AMA2
       TA=T1
       RF=R
       PA=P1
       VOV=VR
       PB=P2
       TB=T2
       DHH=DHOH
       DHT=0.5
       IF (IHUB.EQ.0.OR.IHUB.EQ.2) DHT=1.0/DHOT
20     F1A=1.0+(GA-1.0)*AMA**2/2.0
       F2A=F1A**((GA+1.0)/(2.0*(GA-1.0)))
       F3A=SQRT(RF*TA/(G*GA))
       AA=W*F2A*F3A/(PFACT*PA*AMA)
       IF (VOV.EQ.0.0) GO TO 30
       VA=AMA*SQRT(G*GA*RF*TA/F1A)
       VB=VA*VOV
       AMBSQ=VB**2/(G*GA*RF*TB-(GA-1.0)/2.0*VB**2)
       AMB=SQRT(AMBSQ)
30     AMBSQ=AMB**2
       F1B=1.0+(GA-1.0)*AMBSQ/2.0
       F2B=F1B**((GA+1.0)/(2.0*(GA-1.0)))
       F3B=SQRT(RF*TB/(G*GA))
       AB=W*F2B*F3B/(PFACT*PB*AMB)
       DHA=SQRT(AA/(.785*(DHT*DHT-1.0)))
       IF (IHUB.EQ.1.OR.IHUB.EQ.3.AND.IT.EQ.0) DHA=DH1
       DTA=SQRT(DHA*DHA+AA/.785)
       DHB=DHA*DHH
       IF (IHUB.EQ.2.OR.IHUB.EQ.3.AND.IT.EQ.0) DHB=DH2
       DTB=SQRT(AB/.785+DHB**2)
```

```
      IF (IT.EQ.1) GO TO 40
      DT1=DTA
      DH1=DHA
      DT2=DTB
      DH2=DHB
      AMA2=AMB
      DT10=DT1
      DH10=DH1
      DT20=DT2
      DH20=DH2
      AM20=AMA2
      DOUT1=DT1
      DIN1=DH1
      DOUT2=DT2
      DIN2=DH2
40    IF (IV.EQ.0) GO TO 60
      IF (IT.EQ.1) GO TO 50
      W=W10
      GA=GAMO
      AMA=AMA10
      AMB=AM20
      TA=T10
      RE=RO
      PA=P10
      VOV=VRO
      TB=T20
      PB=P20
      DHT=DTA/DHA
      DHH=DTB/DTA
      IT=1
      GO TO 20
50    DT10=DTA
      DT20=DTB
      DH10=DHA
      DH20=DHB
      DOUT1=DT10
      DOUT2=DT20
C     FAN   LENGTH
60    DELDT=DOUT2-DOUT1
      DELDH=DIN2-DIN1
      AI=1.0
      ANS=NS
      ALF=0.0
      AKS=1.0
      DT=DOUT1
      DH=DIN1
      DO 70 I=1,NS
      DTNEXT=DOUT1+DELDT*AI/ANS
      DHNEXT=DIN1+DELDH*AI/ANS
      DTAV=(DT+DTNEXT)/2.0
      DHAV=(DH+DHNEXT)/2.0
      DTAVR=(DT+DTAV)/2.0
      DHAVR=(DH+DHAV)/2.0
      CXR=.5*(DTAVR-DHAVR)/ARR
```

```
      DTAVS=(DTNEXT+DTAV)/2.0
      DHAVS=(DHNEXT+DHAV)/2.0
      CXS=.5*(DTAVS-DHAVS)/ARS
      ALF=CXR*(1.0+AKS*SR)+CXS+ALF
      AKS=0.0
      AI=AI+1.0
      DT=DTNEXT
70    DH=DHNEXT
C     FAN    WEIGHT
      SIGR=(SIG/1.25)**0.3
      UR=(UT/1150.0)**0.3
      DPOW=(0.5*(DOUT1+DOUT2))**AX
      WFAN=AKW*ANS*SIGR*UR*DPOW/(ARR**0.5)
      RETURN
      END


"FOR,IS     COMPI,ENGWT.COMPI
      SUBROUTINE COMP (P1,P2,T1,T2,W1,W2,AMA,R,GA,CP,APR,ARS,UT,DHODT,DH
     1ODH,VR,PR,AKW,ANCM,IHUB,AX,DT1,DH1,DT2,DH2,AM2,ALC,WCOMP,ISI)
      G=32.2
      PFACT=2116.0
      IF (ISI.EQ.0) GO TO 10
      G=1.0
      PFACT=1.0
10    GAG=G*GA
      GAT=GA+1.0
      GAU=GA-1.0
      F1A=1.0+GAU*AMA**2.0/2.0
      F2A=F1A**(GAT/(2.0*GAU))
      F3A=SQRT(R*T1/GAG)
      A1=W1*F2A*F3A/(PFACT*P1*AMA)
      IF (VR.EQ.0.0) GO TO 20
      V1=AMA*SQRT(GAG*R*T1/F1A)
      V2=V1*VR
      AMSQ=V2**2/(GAG*R*T2-.5*GAU*V2**2)
      AM2=SQRT(AMSQ)
20    AMSQ=AM2**2
      F1B=1.0+GAU*AMSQ/2.0
      F2B=F1B**(GAT/(2.0*GAU))
      F3B=SQRT(R*T2/GAG)
      A2=A1*P1*AMA*F3B*F2A/(P2*AM2*F3A*F2B)
      IF (IHUB.EQ.1.OR.IHUB.EQ.3) GO TO 30
      DHT=1.0/DHODT
      DH1=SQRT(A1/(.785*(DHT**2-1.0)))
30    DT1=SQRT(DH1**2+A1/.785)
      IF (IHUB.EQ.2.OR.IHUB.EQ.3) GO TO 40
      DH2=DH1*DHODH
40    DT2=SQRT(A2/.785+DH2**2)
C      COMPRESSOR  LENGTH
      DM1=(DT1+DH1)/2.0
      DM2=(DT2+DH2)/2.0
      PRPS=1.0+(UT/1530.0-.000654*PR**1.8-.324)*(.8*DM2/DM1+.2)
      ANC=ALOG(PR)/ALOG(PRPS)
```

```
      IF (ANCM.GT.0.0) ANC=ANCM
      ALCDM=.2+ANC*(.234-.218*DHDDT)
      ALCR=.2+.081*ANC
      ALC=ALCDM*DM1
C      COMPRESSOR  WEIGHT
      DMAV=(DM1+DM2)/2.0
      WCOMP=AKW*DMAV**AX*ANC**1.2*(UT/1100.0)**.3*(1.0+ALCDM/ALCR)
      RETURN
      END


"FOR,IS     COMBB,ENGWT.COMBB
      SUBROUTINE COMB (P1,P2,T1,T2,W1,W2,VREF,VR,AM1,GA1,GA2,R1,R2,IHUB,
     1DH2DH1,ALBDH,AKW,DH3DT3,AX,DT1,DT2,DH1,DH2,AM2,AL,WB,ISI)
      G=32.2
      PFACT=2116.0
      IF (ISI.EQ.0) GO TO 10
      G=1.0
      PFACT=1.0
10    ICOM=0
      GA=GA1
      V=AM1*SQRT(GA1*G*R1*T1/(1.0+0.5*(GA1-1.0)*AM1**2))
      P=P1
      T=T1
      W=W1
      R=R1
20    GAG=G*GA
      GAT=GA+1.0
      GAU=GA-1.0
      AMSQ=V**2/(GAG*R*T-.5*GAU*V**2)
      AM=SQRT(AMSQ)
      F1=1.0+GAU*AM**2/2.0
      F2=F1**(GAT/(2.0*GAU))
      F3=SQRT(R*T/GAG)
      A=W*F2*F3/(PFACT*P*AM)
      IF (ICOM.EQ.1) GO TO 30
      ICOM=1
      A1=A
      GA=GA2
      V=V*VR
      P=P2
      T=T2
      W=W2
      R=R2
      GO TO 20
30    A2=A
      AM2=AM
C      DIAMETERS
      IF (IHUB.EQ.1.OR.IHUB.EQ.3) GO TO 40
      DHT=1.0/DH3DT3
      DH1=SQRT(A1/(.785*(DHT**2-1.0)))
40    DT1=SQRT(A1/.785+DH1**2)
      IF (IHUB.EQ.2.OR.IHUB.EQ.3) GO TO 50
      DH2=DH1*DH2DH1
```

```
50      DT2=SQRT(A2/.785+DH2**2)
C        LENGTH
        DM1=(DT1+DH1)/2.0
        DM2=(DT2+DH2)/2.0
        DMAV=(DM1+DM2)/2.0
        AL=ALBOH*W1*T1*P1/(3.14*VREF*P1*DMAV*2115.0)
C        WEIGHT
        WB=AKW*DMAV**AX*(ALBOH/3.2)**.5
        RETURN
        END


"FOR,IS     TURBI,ENGWT.TURBI
        SUBROUTINE TURB (VMX4,P4PSO,T4,F4,GAMMA4,CP4,R4,VMX5,P5PSO,T5,DH54
       1,WC,ALPHD,UST,EN,AKC,AKV,DEACT,IHIOLO,DMTD1,D1O,D1,DT1F,DT2F,IHUB,
       2DHDTT,DH5DH4,AKW,AX,D4T,D5T,D4H,D5H,AL,WTURB,VR,ISI)
        NAMELIST / OUT3/ALPHD,UST,DH54,EN,AKC,DMTD1,D1O,D1,WC,T4,AKV,OMEGA
       1,AKV1,SDV,F4,DEACT,P4PSO,DH5DH4,IHIOLO,DT1F,DT2F
        NAMELIST / OUT4/U,UCAL
        NAMELIST / OUT5/STATI,P4,T4,TS4,VM4,VMX4,V4,VX,AE4
        NAMELIST / OUT6/P5PSO,T5,TS5,VM5,VMX5,V5,A5
C       AKV=0.0     NO  EXIT  VANE
C       AKV=0 -1.9 IMPULSE  EXIT  STRAIGHTING  VANE
C       AKV=2.0     DIFFUSING  EXIT  STRAIGHTING  VANE
C
C       FIRST=1  FOR  HIGH  TURB, 0  FOR  LOW  TURB
C
C       UST=AVERAGE  TIP  SPEED  OF  DRIVEN  COMPONENT
        IF (IST.EQ.0) GO TO 10
        P4PSO=P4PSO/101325.0
        T4=1.8*T4
        CP4=CP4/4182.8
        R4=.186*R4
        P5PSO=P5PSO/101325.0
        T5=1.8*T5
        DH54=DH54/2324.0
        WC=WC/.454
        F=.3048
        UST=UST/F
        D1O=D1O/F
        D1=D1/F
        DT1F=DT1F/F
        DT2F=DT2F/F
        D4H=D4H/F
        D5H=D5H/F
10      PIE=3.14
        ZZ=.0108
        RA=53.35
        PSIP=1.73
        AJ=778.0
        G=32.2
        IU=1
        FIRST=1.0
        IF (IHIOLO.EQ.0) FIRST=0.0
```

```
      RPM=120.0*UST/(PIE*(DT1E+DT2E))
      U=UST
      ALPHA=ALPHD/57.29578
      IF (VR.GT.0.0) GO TO 20
      P5P4=P5PS0/P4PS0
      VM4=VMX4
      VM5=VMX5
      GO TO 90
20    AMBAR=U*U/G/AJ/DH54
      AMBDA=AMBAR*EN
C     CALCULATE VELOCITY DIAGRAM
      AMBP=(AMBDA+1.)/2.
      AMBM=(AMBDA-1.)/2.
      DVU=U/AMBDA
      VX=DVU*AMBP/TAN(ALPHA)
      VU1=DVU*AMBP
      VU2=DVU*AMBM
      V4=SQRT(VX*VX+VU1*VU1)
      V5=SQRT(VX*VX+VU2*VU2)
      BETA1=ATAN2(-VU2,VX)*57.29578
      VXU=VX/U
C     FIND FIRST STAGE EFFICIENCY
      ERD=2.
      IF (AMBDA.GT.1.) AMBDA=1.0
      CAYC=AKC
      DMT=DMTD1*D1
      RE=WC/DMT/VISC(T4)*2.
      EXPO=0.1
      CA=CAYC*(1.5E+6)**(EXPO-.2)/PE**EXPO*TAN(ALPHA)
      EST=1.0
C     ASSUME VX0=VX1 AND VU0=0
      AMBP=(AMBDA+1.)/2.
      AMBPSQ=AMBP*AMBP
      AMBM=(AMBDA-1.)/2.
      AMBMSQ=AMBM*AMBM
      COTSP=2./TAN(ALPHA)/TAN(ALPHA)+1.
      CX=AMBPSQ*COTSP
      D=AMBPSQ*COTSP+AMBMSQ
      AA=CA*(EST*CX+ERD*D)
      ETAA=AMBDA/(AMBDA+AA/2.)
      B=CA*AKV*(2.-AMBDA)*V5*V5/DVU/DVU
      IF (AKV.GT.1.9) B=0.
      IF (EN.GT.1.) GO TO 30
      ETABAR=AMBDA/(AMBDA+.5*(AA+B))
      GO TO 40
C     CALCULATE INTERMEDIATE AND LAST STAGE EFFICIENCIES
30    EST=2.-AMBDA
      CX=AMBPSQ*COTSP+AMBMSQ
      A=CA*(EST*CX+ERD*D)
      ETATI=AMBDA/(AMBDA+A/2.)
      ETAL=AMBDA/(AMBDA+.5*(A+B))
      DA=1.+FIRST
      ETABAR=EN/(FIRST/ETAA+(EN-DA)/ETATI+1./ETAL)
40    ETATI=ETABAR
```

```
      H4G=POLY(T4,1)+F4*POLY(T4,4)
      H5G=H4G-DH54
      T5=T4-DH54/.24
      DO 50 I=1,20
      DT=(H5G-POLY(T5,1)-F4*POLY(T5,4))/(POLY(T5,3)+F4*POLY(T5,6))
      T5=T5+DT
      IF (ABS(DT)-.1) 60,50,50
50    CONTINUE
60    PHI4=POLY(T4,2)+F4*POLY(T4,5)
      R4=RA+F4*PSIR
      DH54I=DH54/ETATI
      H5GI=H4G-DH54I
      T5I=T5
      DO 70 I=1,20
      DT=(H5GI-POLY(T5I,1)-F4*POLY(T5I,4))/(POLY(T5I,3)+F4*POLY(T5I,6))
      T5I=T5I+DT
      IF (ABS(DT)-.1) 80,70,70
70    CONTINUE
80    DPHI54=POLY(T5I,2)+F4*POLY(T5I,5)-PHI4
      P5P4=EXP(AJ*DPHI54/R4)
      CP4=POLY(T4,-1)+F4*POLY(T4,6)
      GAMMA4=1./(1.-R4/AJ/CP4)
      TS4=T4-V4*V4/(2.*G*AJ*CP4)
      VM4=V4/SQRT(GAMMA4*G*R4*TS4)
      VMX4=VX/SQRT(GAMMA4*G*R4*TS4)
90    GF4=.5*(GAMMA4+1.0)/(GAMMA4-1.0)
      WON=(1.0+(GAMMA4-1.0)*0.5*VM4*VM4)**GF4
      TWO=SQRT(GAMMA4*G/R4)
      P4=P4PSO*2116.
      AF4=WC*SQRT(T4)*WON/(P4*TWO*VMX4)
      IF (IHUB.EQ.1.OR.IHUB.EQ.3) GO TO 100
      DHT=1.0/DHOTT
      D4H=SQRT(AF4/(.785*(DHT**2-1.0)))
      GO TO 110
100   D4H=D4H*DMTD1
110   D4T=SQRT(AF4/.785+D4H**2)
      HTP4=D4H/D4T
      P5PSO=P4PSO*P5P4
      CP5=POLY(T5,3)+F4*POLY(T5,6)
      GAMMA5=1.0/(1.0-R4/AJ/CP5)
      GF2=0.5*(GAMMA5+1.0)/(GAMMA5-1.0)
      GF3=(GAMMA5-1.)/GAMMA5
      GF5=(GAMMA5-1.)/2.
      IF (VR.EQ.0.0) GO TO 120
      TS5=T5-V5*V5/(2.*G*AJ*CP5)
      VMX5=VX/SQRT(GAMMA5*G*R4*TS5)
      VM4=V5/SQRT(GAMMA4*G*R4*TS4)
      VM5=V5/SQRT(GAMMA5*G*R4*TS5)
120   F2=(1.0+(GAMMA5-1.0)*.5*VM5*VM5)**GF2
      F3=SQRT(R4*T5/(G*GAMMA5))
      A5=WC*F2*F3/(2116.0*P5PSO*VMX5)
      IF (IHUB.EQ.2.OR.IHUB.EQ.3) GO TO 130
      D5H=D4H*DH5DH4
130   D5T=SQRT(A5/.785+D5H*D5H)
```

```
      DTAV=(D4T+D5T)/2.0
      DHAV=(D4H+D5H)/2.0
      IF (VR.EQ.0.0) GO TO 170
      UCAL=RPM*PIE*DTAV/60.0
      IF (ABS(UCAL/U-1.0).LT.0.01) GO TO 150
      IU=IU+1
      IF (IU.GT.20) GO TO 140
      U=UCAL
      GO TO 20
140   WRITE (6,190)
      WRITE (6,OUT4)
150   HTR5=D5H/D5T
      HTRAV=(HTR4+HTR5)/2.0
C     IHIOLO    0  FOR  LOW  PRESS  TURBINE,  1  FOR  HIGH  PRESS  TURB
      IF (IHIOLO.EQ.0) GO TO 160
      A=10.44
      B=-10.0
      C=6.45
      D=-5.97
      GO TO 170
160   A=13.36
      B=-11.78
      C=10.95
      D=-10.9
C     ROTOR  AVERAGE  ASPECT  RATIO  AND  CHORD
170   ARRAV=A+B*HTRAV
      CXRAV=(DTAV-DHAV)/(2.0*ARRAV)
C     STATOR  AVERAGE  ASPECT  RATIO  AND  CHORD
      ARSAV=C+D*HTRAV
      CXSAV=(DTAV-DHAV)/(2.0*ARSAV)
      STAV=.4*CXRAV
C      LENGTH
      AL=EN*(CXRAV+CXSAV)+(2.0*EN-1.0)*STAV
      DMAV=.5*(DTAV+DHAV)
      UM=UCAL*DMAV/DTAV
      WTURB=AKW*DMAV**AY*EN*UM**.6
      ALO=ABS(D4H+D4T-D1-D1O)/1.4
      IF (IST.EQ.0) GO TO 180
      P4PSO=P4PSO*101325.0
      T4=T4/1.8
      CP4=CP4*4182.8
      R4=R4/.186
      P5PSO=P5PSO*101325.0
      T5=T5/1.8
      DH54=2324.0*DH54
      WC=.454*WC
      UST=F*UST
      D1O=F*D1O
      D1=F*D1
      DT1F=F*DT1F
      DT2F=F*DT2F
      D4H=F*D4H
      D5H=F*D5H
      D4T=F*D4T
```

```
      D5T=F*D5T
      AL=F*AL
      WTURB=.454*WTURB
180   CONTINUE
      RETURN
C
190   FORMAT (1HK,5X,19HSPEED  NOT  MATCHED)
      END


"FOR,IS     VALVI,ENGWT.VALVI
      SUBROUTINE VALV (P1,P2,T1,T2,W1,W2,AMA1,AMA10,P10,P20,T10,T20,W10,
     1W20,R,RO,GAM,GAMO,CP,CPO,AKW,IHUB,DH6DT6,DH7DH6,AX,DT1,DH1,DT2,DH2
     2,AMA2,DT10,DH10,DT20,DH20,AM20,ALV,WVALV,IST)
      G=32.2
      PFACT=2116.0
      IF (IST.EQ.0) GO TO 10
      G=1.0
      PFACT=1.0
10    IT=0
      W=W1
      GA=GAM
      AMA=AMA1
      TA=T1
      WB=W2
      RF=R
      PA=P1
      PB=P2
      TB=T2
      IV=1
      DHT=0.5
      DHA=DH1
      DHB=DH2
      IF (IHUB.EQ.0.OR.IHUB.EQ.2) DHT=1.0/DH6DT6
      AMB=AMA2
20    F1A=1.0+(GA-1.0)*AMA**2/2.0
      F2A=F1A**((GA+1.0)/(2.0*(GA-1.0)))
      F3A=SQRT(RF*TA/(G*GA))
      AA=W*F2A*F3A/(PFACT*PA*AMA)
      AMBSQ=AMB*AMB
      F1B=1.0+(GA-1.0)*AMBSQ/2.0
      F2B=F1B**((GA+1.0)/(2.0*(GA-1.0)))
      F3B=SQRT(RF*TB/(G*GA))
      AB=WB*F2B*F3B/(PFACT*PB*AMB)
      IF (IHUB.EQ.0.OR.IHUB.EQ.2.AND.IT.EQ.0) DHA=SQRT(AA/(.785*(DHT**2-
     11.0)))
      DTA=SQRT(AA/.785+DHA**2)
      IF (IHUB.EQ.0.OR.IHUB.EQ.1.AND.IT.EQ.0) DHB=DHA*DH7DH6
      DTB=SQRT(AB/.785+DHB**2)
      IF (IT.EQ.1) GO TO 30
      DT1=DTA
      DH1=DHA
      DT2=DTB
      DH2=DHB
```

```
      AMA2=AMB
      DT10=DT1
      DH10=DH1
      DT20=DT2
      DH20=DH2
      AM20=AMA2
30    IF (IV.EQ.0) GO TO 50
      IF (IT.EQ.1) GO TO 40
      W=W10
      WB=W20
      GA=GAM0
      AMA=AMA10
      AMB=AM20
      TA=T10
      RF=R0
      PA=P10
      TB=T20
      PB=P20
      DHA=DT1
      DHB=DT2
      IT=1
      GO TO 20
40    DT10=DTA
      DT20=DTB
      DH10=DHA
      DH20=DHB
50    IVL=0
      DTOA=DT10
      DHOA=DH10
      DTB=DT2
      DHB=DH2
      DTAV=(DT10+DT20)/2.0
      DHAV=(DH1+DH2)/2.0
      DAV=((DTAV+DHAV)/2.0)**AX
      ALV=4.5*(DT10-DH1+DT20-DH2)/8.0
      WVALV=AKW*ALV*DAV
      RETURN
      END


"FOR,IS     DUCTI,ENGWT.DUCTI
      SUBROUTINE DUCT (P1,P2,T1,T2,W1,W2,AM1,AM2,GA1,GA2,R1,R2,THUB,DH20
     1H1,WOAD,IACOUS,WOAAW,WOAASP,ALSPL,NSPL,INTR,DH1DT1,NW,AX,VREFF,ALO
     2H,DT1,DT2,DH1,DH2,AL,WD,ISI)
      ICOM=0
      GA=GA1
      P=P1
      T=T1
      W=W1
      R=R1
      AM=AM1
      G=32.2
      PFACT=2116.0
      IF (ISI.EQ.0) GO TO 10
```

```
      G=1.0
      PFACT=1.0
10    GAG=G*GA
      GAT=GA+1.0
      GAU=GA-1.0
      F1=1.0+GAU*AM**2/2.0
      F2=F1**(GAT/(2.0*GAU))
      F3=SQRT(R*T/GAG)
      A=W*F2*F3/(PFACT*P*AM)
      IF (ICOM.EQ.1) GO TO 20
      ICOM=1
      A1=A
      GA=GA2
      P=P2
      T=T2
      W=W2
      R=R2
      AM=AM2
      GO TO 10
20    A2=A
C      DIAMETERS
      IF (IHUB.EQ.1.OR.IHUB.EQ.3) GO TO 30
      DHT=1.0/DH1DT1
      DH1=SQRT(A1/(.785*(DHT**2-1.0)))
30    DT1=SQRT(A1/.785+DH1**2)
      IF (IHUB.EQ.2.OR.IHUB.EQ.3) GO TO 40
      DH2=DH1*DH2DH1
40    DT2=SQRT(A2/.785+DH2**2)
      IF (INTR.LT.2) GO TO 50
C     DUCT  BURNER  WEIGHT
      WD=WOAD*((DT1+DT2+DH1+DH2)/4.0)**AX
      AAV=.3925*(DT1**2+DT2**2-DH1**2-DH2**2)
      AL=0.5*ALOH*(DT1-DT2)+VBEEE/AAV
      GO TO 90
50    IF (INTR.EQ.0) GO TO 60
C     INTERMEDIATE  CASING
      WD=WOAD*AL*((DH1+DH2)/2.0+0.72)
      GO TO 90
C     DUCT  CASING  WEIGHT
60    IF (NW.EQ.0) DTAV=(DH1+DH2+DT1+DT2)/2.0
      IF (NW.EQ.1) DTAV=(DH1+DH2)/2.0
      IF (NW.EQ.2) DTAV=(DT1+DT2)/2.0
      DTAV=DTAV**AX
      WD=DTAV*AL*WOAD
C
C      DUCT  WALL  ACOUSTIC  LINING
      IF (IACOUS.EQ.0) GO TO 70
      DHAV=(DH1+DH2)/2.0
      WWAC=3.14*AL*WOAAW*(DTAV+DHAV)
      WD=WD+WWAC
C
C     SPLITTER  RINGS
70    IF (NSPL.EQ.0) GO TO 90
      ANSP=NSPL
```

```
      DELD1=(DT1-DH1)/(ANSP+1.0)
      DELD2=(DT2-DH2)/(ANSP+1.0)
      DTA=DT1
      DTB=DT2
      DTAV=0.0
      DO 80 I=1,NSPL
      DTA=DTA-DELD1
      DTB=DTB-DELD2
80    DTAV=(DTA+DTB)/2.0+DTAV
      WSPL=3.14*AL*ALSPL*WDAASP*DTAV
      WD=WD+WSPL
90    CONTINUE
      RETURN
      END


"FOR,IS       TRXNS,ENGWT.TRXNS
      SUBROUTINE TRANS
      DIMENSION PTIN(25), PTEX(25), TTIN(25), WAIN(25), WAEX(25), AMIN(2
     15), AMIND(25), AMEX(25), GAMIN(25), GAMEX(25), GAMIND(25), GAMEXD(
     225), CPIN(25), CPIND(25), PTIND(25), PTEXD(25), TTIND(25), TTEXD(2
     35), WAIND(25), WAEXD(25), RIN(25), REX(25), RIND(25), REXD(25), CP
     4EX(25), CPEXD(25), TTEX(25), AMEXD(25), DCOMPN(25), PROP(15)
      COMMON /THER/ PTIN,PTEX,TTIN,TTEX,WAIN,WAEX,AMIN,AMIND,AMEX,AMEXD,
     1GAMIN,GAMEX,GAMIND,GAMEXD,CPIN,CPIND,PTIND,PTEXD,TTIND,TTEXD,WAIND
     2,WAEXD,RIN,REX,RIND,REXD,CPEX,CPEXD,PT1,PT2,TT1,TT2,WA1,WA2,AM1,AM
     32,CP1,CP2,R1,R2,GAM1,GAM2,PT1D,PT2D,TT1D,TT2D,WA1D,WA2D,AM1D,AM2D,
     4CP1D,CP2D,R1D,R2D,GAM1D,GAM2D,DCOMPN,INUM,IS,JS,KS
      GO TO (10,30,50,70),IS
10    IF (KS.GT.0) GO TO 20
      PTIN(INUM)=PTEX(JS)
      TTIN(INUM)=TTEX(JS)
      WAIN(INUM)=WAEX(JS)
      AMIN(INUM)=AMEX(JS)
      RIN(INUM)=REX(JS)
      GAMIN(INUM)=GAMEX(JS)
      CPIN(INUM)=CPEX(JS)
      GO TO 90
20    PTIN(INUM)=PTEXD(JS)
      TTIN(INUM)=TTEXD(JS)
      WAIN(INUM)=WAEXD(JS)
      AMIN(INUM)=AMEXD(JS)
      RIN(INUM)=REXD(JS)
      GAMIN(INUM)=GAMEXD(JS)
      CPIN(INUM)=CPEXD(JS)
      GO TO 90
30    IF (KS.GT.0) GO TO 40
      PTIND(INUM)=PTEX(JS)
      TTIND(INUM)=TTEX(JS)
      WAIND(INUM)=WAEX(JS)
      AMIND(INUM)=AMEX(JS)
      RIND(INUM)=REX(JS)
      GAMIND(INUM)=GAMEX(JS)
      CPIND(INUM)=CPEX(JS)
```

```
      GO TO 90
40    PTINO(INUM)=PTEXO(JS)
      TTINO(INUM)=TTEXO(JS)
      WAINO(INUM)=WAEXO(JS)
      AMINO(INUM)=AMEXO(JS)
      RINO(INUM)=REXO(JS)
      GAMINO(INUM)=GAMEXO(JS)
      CPINO(INUM)=CPEXO(JS)
      GO TO 90
50    IF (KS.GT.0) GO TO 60
      PTEX(INUM)=PTIN(JS)
      TTEX(INUM)=TTIN(JS)
      WAEX(INUM)=WAIN(JS)
      AMEX(INUM)=AMIN(JS)
      REX(INUM)=RIN(JS)
      GAMEX(INUM)=GAMIN(JS)
      CPEX(INUM)=CPIN(JS)
      GO TO 90
60    PTEX(INUM)=PTINO(JS)
      TTEX(INUM)=TTINO(JS)
      WAEX(INUM)=WAINO(JS)
      AMEX(INUM)=AMINO(JS)
      REX(INUM)=RINO(JS)
      GAMEX(INUM)=GAMINO(JS)
      CPEX(INUM)=CPINO(JS)
      GO TO 90
70    IF (KS.GT.0) GO TO 80
      PTEXO(INUM)=PTIN(JS)
      TTEXO(INUM)=TTIN(JS)
      WAEXO(INUM)=WAIN(JS)
      AMEXO(INUM)=AMIN(JS)
      REXO(INUM)=RIN(JS)
      GAMEXO(INUM)=GAMIN(JS)
      CPEXO(INUM)=CPIN(JS)
      GO TO 90
80    PTEXO(INUM)=PTINO(JS)
      TTEXO(INUM)=TTINO(JS)
      WAEXO(INUM)=WAINO(JS)
      AMEXO(INUM)=AMINO(JS)
      REXO(INUM)=RINO(JS)
      GAMEXO(INUM)=GAMINO(JS)
      CPEXO(INUM)=CPINO(JS)
90    RETURN
      END


"FOR,IS     POLYA,ENGWT.POLYA
      FUNCTION POLY (X,M)
C     REVISED 12/03/68
      DIMENSION ICC(8), IORD(8), C(300)
      DATA (ICC(I),I=1,8)/133,146,161,174,187,200,209,226/
      DATA (IORD(I),I=1,8)/4,5,4,4,4,2,6,6/
      DATA (C(I),I=133,242)/100.,107.2616,2.4975E-1,-2.2658E-5,1.96075E-
     18,-3.675E-12,2000.,116.484,.209610,2.554713E-5,-3.338588E-9,1.8843
```

```
      2E-13,6000.,100.,1.14506,1.49413E-3,-1.79831E-6,1.39476E-9,-5.8514E
      3-13,1.0156E-16,1400.,1.42938,4.437122E-4,-1.48918E-7,3.4627E-11,-4
      4.513E-15,2.47E-19,6000.,100.,.25232,-5.44152E-5,7.0682E-8,-2.0171E
      5-11,-5.1E-16,1400.,.1861,8.0148E-5,-2.3278E-8,3.41635E-12,-1.989E-
      616,6000.,100.,957.028,-1.397247E-2,2.728088E-4,-7.874997E-8,1.1311
      784E-11,2000.,989.0299,2.421058E-2,1.719852E-4,-2.13151E-8,1.027056
      8E-12,6000.,100.,-.224336,4.84768E-4,-7.194546E-8,-4.315008E-12,3.1
      934744E-15,2000.,-4.089761,5.504657E-3,-2.446699E-6,4.899351E-10,-3
      $.617383E-14,6000.,100.,3.986078E-2,3.562965E-4,-6.512821E-8,2000.,
      $.2063979,1.764343E-4,-1.683137E-8,6000.,100.,-62.685516,-6.9221196
      $E-1,1.9220060E-2,-1.1345611E-5,-9.8360870E-8,2.2458196E-10,-1.4509
      $678E-13,614.,1946.1462,-8.5195086,2.6225174E-2,-2.6543759E-5,1.147
      $9667E-8,-6.4275539E-13,-6.082041E-16,2000.,1.4,415.37102,58.865753
      $,-312.50006,16.528755,-29.769562,5.6792908,53.206712,1.93384,553.8
      $4976,123.43567,-174.32129,22.184326,-104.70823,-43.322374,82.93804
      $9,2.3/
       J=IABS(M)
       K=ICC(J)
       L=IORD(J)+2
10     IF (X-C(K)) 20,30,30
20     K=K-L
       GO TO 10
30     K=K+L
       IF (X-C(K)) 40,40,30
40     IF (M) 70,50,50
50     L=L-1
       POLY=C(K-1)
       DO 60 N=2,L
       KN=K-N
60     POLY=POLY*X+C(KN)
       GO TO 90
70     L=L-2
       POLY=FLOAT(L)*C(K-1)
       DO 80 N=2,L
       KN=K-N
       LN=L-N+1
80     POLY=POLY*X+FLOAT(LN)*C(KN)
90     RETURN
       END


"FOR,IS     VISCOS,ENGWT.VISCOS
       FUNCTION VISC (T)
C      REVISED 12/03/68
       DIMENSION A(50), V(50)
       DATA (V(J),J=1,50)/73.8,136.0,185.2,227.2,264.7,299.2,331.3,361.4,
      1389.8,417.1,443.5,469.5,495.1,519.7,543.6,567.0,589.8,612.1,633.9,
      2655.3,676.3,697.0,717.3,737.3,757.0,776.5,795.6,814.5,833.2,851.6,
      3869.8,887.8,905.6,923.2,940.6,957.9,974.9,991.8,1008.6,1025.2,1041
      4.6,1058.0,1074.1,1090.2,1106.1,1121.9,1137.5,1153.1,1168.5,1183.8/
       TKELVN=T*5./9.
       A(1)=100.
       DO 10 N=2,50
       A(N)=A(N-1)+100.
```

```
10    CONTINUE
      IF (TKELVN.LE.A(1)) GO TO 40
      IF (TKELVN.GE.A(50)) GO TO 50
      K=2
20    IF (TKELVN.LT.A(K)) GO TO 30
      K=K+1
      GO TO 20
30    TOP=A(K)-TKELVN
      DELTT=TOP/100.
      DV=V(K)-V(K-1)
      DIFF=DELTT*DV
      VISM=V(K)-DIFF
      VISC=VISM/14882000.
      GO TO 60
40    VISC=V(1)/14882000.
      WRITE (6,70)
      GO TO 60
50    VISC=V(50)/14882000.
      WRITE (6,80)
60    RETURN
C
70    FORMAT (32H TKELVN IS LESS THAN 100 DEGREES)
80    FORMAT (36H TKELVN IS GREATER THAN 5000 DEGREES)
      END
```

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5. Howlett, R. A.; Sabatella, J.; Johnson, J.; and Aronstamm, G.: Advanced Supersonic Propulsion Study, Phase 2. (PWA-5312, Pratt& Whitney Aircraft; NAS3-16948) NASA CR-134904, 1975.
6. Fishbach, Laurence H.; and Koenig, Robert W.: GENENG II - A Program for Calculating Design and Off-Design Performance of Two- and Three-Spool Turbofans with as Many as Three Nozzles. NASA TN D-6553, 1972.

TABLE I. - TYPES OF COMPONENTS INCLUDED IN THE PROGRAM

Fan

Split fan(figure 2)

Compressor

Main burner

Duct burner

Turbine

Inverting valve(figure 2)

Duct

Intermediate casing

Nozzle

Controls,Accessories,Lubrication

TABLE II.- COMPONENT LENGTH AND WEIGHT RELATIONS

Component	Equations	Suggested values for weight factor, K
Fan	$W=K(D_{TM})^{2.4}N(\sigma/\sigma_{REF})^{0.3}(U_T/U_{TREF})^{0.3}/\sqrt{\overline{AR}_X}$ $L=\sum_{i=1}^{i=N} C_{RX}(1 + SP/C_{RX}) + C_{SX}$	173 (22)
Compressor	$W=K(D_M)^{2.4}(N)^{1.2}(U_T/U_{TREF})^{0.3}\left[1+\frac{(L_C/D_{M1})}{(L_C/D_{M1})_{REF}}\right]$ $L=7.24(D_H/D_T) + (1.81-2.17D_H/D_T)N - 5.6$	52 (7)
Main burner	$W=K(D_M)^{2.0}\left[(L_B/H)/3.2\right]^{0.5}$ $L=\frac{R}{(\pi V_{REFF})}\left[\frac{(L_B/H)\mathring{W}T_1}{P_1D_M}\right]$	360 (74)
Turbine	$W=K(D_M)^{2.5}N(\bar{U})^{0.6}$ $L=N(\overline{C_{SX}} + \overline{C_{RX}}) + (2N-1)SP$	7.7 (0.42)
Duct	$W=KD_ML$	10.75 (2.2) (each wall)
Duct burner	$W=K(\overline{D_M})^{2.2}$ $L=(L/H)\left(\frac{D_{T_1}-D_{H_1}}{2}\right)+\frac{2VB_{EFF}}{\pi(D_{T_1}^2 - D_{H_1}^2)}$	195 (31)

TABLE II.- CONTINUED

Component	Equations	Suggested values for weight factor, K
Valve	$W=KD_M L$ $L=(L/H)\overline{H}_M$, $L/H \approx 4-5$	front 300-400(62-82) rear 600-700(123-143)
Intermediate casing	$W=K(\overline{D}_H + C)L$ $K(\overline{D}_H + C)L$	400 , C=0.22 (82 , C=0.72)
Nozzle	$W=KD_M L$ $L=D_M(L/D_M)$, $L/D_M \approx 1.5-2.0$	170 (35)
Controls, Accessories, Lubrication	W=360-450Kg (800-1000 lbm)	

TABLE III.- PROGRAM INPUT

1. General Input

Fortran Name	Description
13A6 -	title or comment
NCOMP-	total number of components
SIZE -	sizing factor; airflow/input airflow
ACC -	weight of controls,accessories,lubrication
ISI -	0-U.S. customary units;1-SI units

2. Engine Layout Array

Item

1 - component sequence number
2 - component identification number
3 - hub diameter specification
  0- hub diameter not determined from other components
  1- front hub diameter specified by a dimension of another component
  2- rear hub diameter specified by a dimension of another component
  3- front and rear hub diameters specified by dimensions of other components
4 - sequence number of component determining the front hub diameter (item 3=1 or 3)
5 - identifies the dimension of the component of item 4 (see Table V for dimension identification numbers)
6 - sequence number of component determining the rear hub diameter (item 3=2 or 3)
7 - identifies the dimension of the component of item 6
8 - front hub/tip diameter ratio (item 3=0 or 2)
9 - rear hub/front hub diameter ratio (item 3=0 or 1)
10 - the number of components determining the length of this component (0 if length is calculated or specified)
11 - length (item 10=0)

The following items (12-19) are used when it is desired to define the entrance or exit thermodynamic properties by specifying upstream or downstream components.

12 - sequence number of upstream component connected to the innerstream of this component
13 - defines which stream of item 12 if the upstream component has 2 streams
  0- inner stream
  1- outer stream
14 - sequence number of the upstream component connected to the outer stream of this component

TABLE III.- CONTINUED

Item		Description
15	-	defines which stream of item 14 if the upstream component has 2 streams 0- inner stream 1- outer stream
16	-	sequence number of the downstream component connected to the inner stream of this component
17	-	defines which stream of item 16 if the downstream component has 2 streams 0- inner stream 1- outer stream
18	-	sequence number of the downstream component connected to the outer stream of this component
19	-	defines which stream of item 18 if the downstream component has 2 streams 0- inner stream 1- outer stream
20-30	-	sequence numbers of the components determining the length of this component (item 10>0)

3. <u>Component Definition Arrays</u>

Fan Array- Fortran name and dimension- FAND (15,5)

Item		Description
1	-	fan number
2	-	number of stages
3	-	rotor blade axial aspect ratio
4	-	stator blade axial aspect ratio
5	-	distance between rotor and stator blades (axial chords)
6	-	distance between stator and rotor blades (axial chords)
7	-	blade solidity, kg/m^2 (lb_m/ft^2)
8	-	average tip speed, m/sec (ft/sec)
9	-	exit/entrance velocity ratio (inner stream for split fans)
10	-	exit/entrance velocity ratio of outer stream for split fans
11	-	indicates conventional or split fans 0- conventional 1- split
12	-	weight factor, K (table II)
13	-	exponent of diameter in weight equation (table II)

TABLE III.- CONTINUED

Compressor Array- Fortran name and dimension- COMPD (10,5)

Item		Description
1	-	compressor number
2	-	number of stages
3	-	rotor blade axial aspect ratio
4	-	stator blade axial aspect ratio
5	-	average tip speed,m/sec (ft/sec)
6	-	exit/entrance velocity ratio
7	-	pressure ratio
8	-	weight factor,K (table II)
9	-	exponent of diameter in weight equation (Table II)

Main Burner Array- Fortran name and dimendion-BURND (10,5)

Item		Description
1	-	burner number
2	-	length/height ratio
3	-	exit/entrance velocity ratio
4	-	reference velocity,m/sec (ft/sec)
5	-	weight factor,K (Table II)
6	-	exponent of diameter in weight equation (Table II)

Turbine Array- Fortran name and dimension- (TURBD (15,5)

Item		Description
1	-	turbine number
2	-	number of stages
3	-	front hub diameter/diameter of the component specified in item 4 of the Engine Layout Array
4	-	sequence number of the driven component
5	-	work of the driven component,J/kg (Btu/lbm)
6	-	average tip speed of the driven component,m/sec (ft/sec)
7	-	indicates high or low pressure turbine 0- low 1- high
8	-	fuel/air ratio
9	-	type of exit guide vanes 0- no exit guide vanes 0<item 9>2- impulse exit straightening vanes 2 -diffusing exit straightening vanes
10	-	stator exit angle,degrees
11	-	loss factor
12	-	exit diffusing vanes D factor
13	-	weight factor,K (Table II)
14	-	exponent of diameter in weight equation (Table II)
15	-	turbine matching calculations 1- yes 0- no

TABLE III.- CONTINUED

Duct Array- Fortran name and dimension- (DUCTD (15,20)

Item		Description
1	-	duct number
2	-	type of component 0- duct 1- intermediate casing 2- duct burner
3	-	weight factor,K (Table II)
4	-	acoustic lining 0- no 1- yes
5	-	acoustic lining weight per unit area,kg/m^2 (lb$_m$/ft^2)
6	-	splitter ring weight per unit area,kg/m^2 (lb$_m$/ft^2)
7	-	ratio of splitter ring length to duct length
8	-	number of splitter rings
9	-	exponent of diameter in weight equation (Table II)
10	-	number of walls included in weight calculation 0- inner and outer walls 1- inner wall only 2- outer wall only
11	-	duct burner effective volume,m^3 (ft^3)
12	-	duct burner pilot length/height ratio

Valve Array- Fortran name and dimension- VALVD (5,5)

Item		Description
1	-	valve number
2	-	weight factor,K (Table II)
3	-	exponent of diameter in weight equation (Table II)

4. Component Thermodynamic Array

Fortran name & dimension		Description
PTIN(25)-	entrance	total pressure,N/m^2 (lb/ft^2)
TTIN(25)-	"	total temperature,K (^{o}R)
WAIN(25)-	"	gas flow rate,kg/sec (lb$_m$/sec)
AMIN(25)-	"	Mach number
GAMIN(25)-	"	ratio of specific heats
CPIN(25)-	"	specific heat,J/kg K (Btu/lb$_m$^{o}R)
RIN (25)-	"	specific gas constant,J/kg K (ft-lb/lb$_m$^{o}R)
PTEX(25)-	exit	total pressure,N/m^2 (lb/ft^2)
TTEX(25)-	"	total temperature,K (^{o}R)
WAEX(25)-	"	gas flow rate,kg/sec (lb$_m$/sec)
AMEX(25)-	"	Mach number

TABLE III.- CONTINUED

Component Thermodynamic Array(continued)

Fortran name & dimension		Description
GAMEX(25)-	exit	ratio of specific heats
CPEX(25) -	"	specific heat, J/kg K (Btu/lb_m °R)
REX (25)-	"	specific gas constant, J/kg K (ft-lb/lb_m °R)

The following are for the outer stream of dual flow components

PTINO (25)-	entrance	total pressure, N/m^2 (lb/ft^2)
TTINO (25)-	"	total temperature, K (°R)
WAINO (25)-	"	gas flow rate, kg/sec (lb_m/sec)
AMINO (25)-	"	Mach number
GAMINO(25)-	"	ratio of specific heats
CPINO (25)-	"	specific heat, J/kg K (Btu/lb_m °R)
RINO (25)-	"	specific gas constant, J/kg K (ft-lb/lb_m °R)
PTEXO (25)-	exit	total pressure, N/m^2 (lb/ft^2)
TTEXO (25)-	"	total temperature, K (°R)
WAEXO (25)-	"	gas flow rate, kg/sec (lb_m/sec)
AMEXO (25)-	"	Mach number
GAMEXO(25)-	"	ratio of specific heats
CPEXO (25)-	"	specific heat, J/kg K (Btu/lb_m °R)
REXO (25)-	"	specific gas constant, J/kg K (ft-lb/lb_m °R)

TABLE IV.- COMPONENT IDENTIFICATION NUMBERS

Component	Number
Fan	3
Compressor	4
Valve	5
Main Burner	6
Turbine	7
Duct, Duct Burner, Intermediate Casing	8

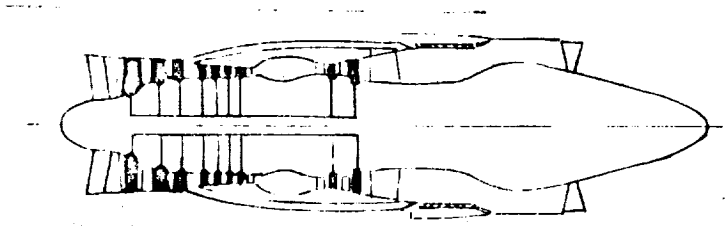
TABLE V.- COMPONENT DIMENSION IDENTIFICATION NUMBERS

Dimension	Number
Front outer tip diameter (dual flow components)	2
Front tip diameter	3
Rear outer tip diameter (dual flow components)	4
Rear tip diameter	5
Front outer hub diameter (dual flow components)	6
Front hub diameter	7
Rear outer hub diameter (dual flow components)	8
Rear hub diameter	9

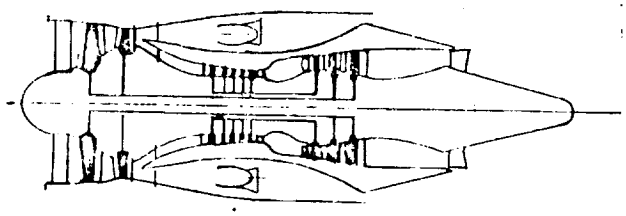
TABLE VI.- BARE ENGINE WEIGHT BREAKDOWN CALCULATED WITH WEIGHT PROGRAM

Component	Pratt & Whitney 112B variable cycle Weight		Pratt & Whitney 502B Duct burning turbofan Weight	
	kg	lb_m	kg	lb_m
Fan	1889	4162	996	2193
Intermediate casing	385	849	342	754
Compressor	260	573	699	1539
Combustor	127	279	329	724
HP turbine	98	216	200	440
LP $turbine_1$	397	374	786	1731
LP $turbine_2$	648	1427		
Diffuser/Burner	418	921	907	1998
Valve	820	1806		
Controls, Accessories, Lubrication	386	850	386	850
Total bare engine	5428	11953	4645	10229

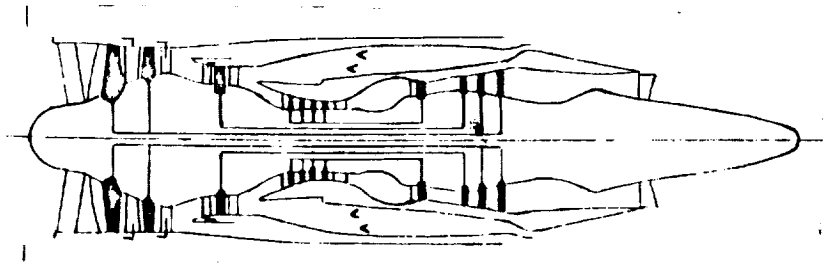
Engine size- 409kg/sec (900lb_m/sec)



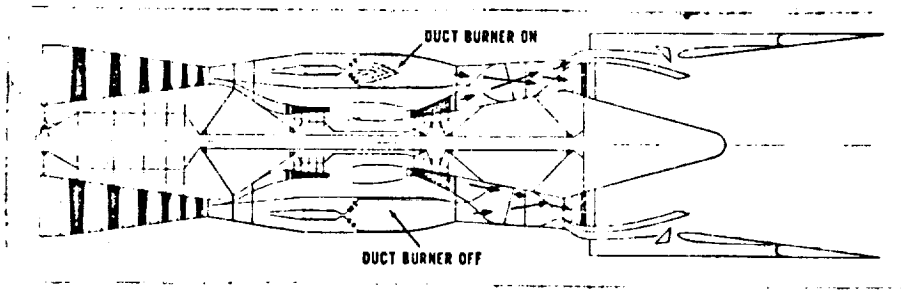
TURBOJET



DUCT BURNING TURBOFAN



THREE ROTOR MODULATING AIRFLOW



REAR VALVE VARIABLE CYCLE

FIGURE 1. - SCAR STUDY ENGINES

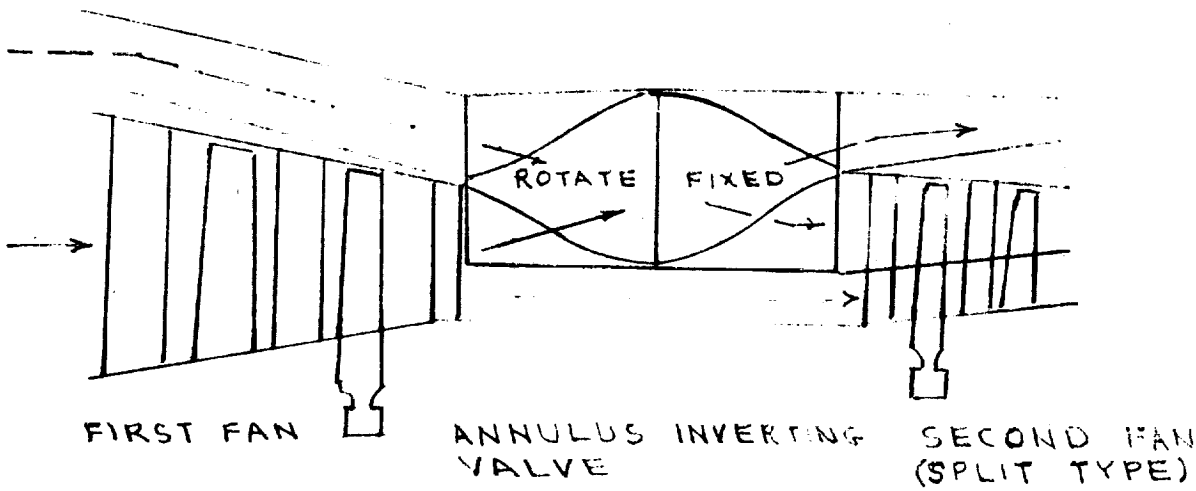


FIGURE 2 .- ANNULUS INVERTING VALVE (AIV)

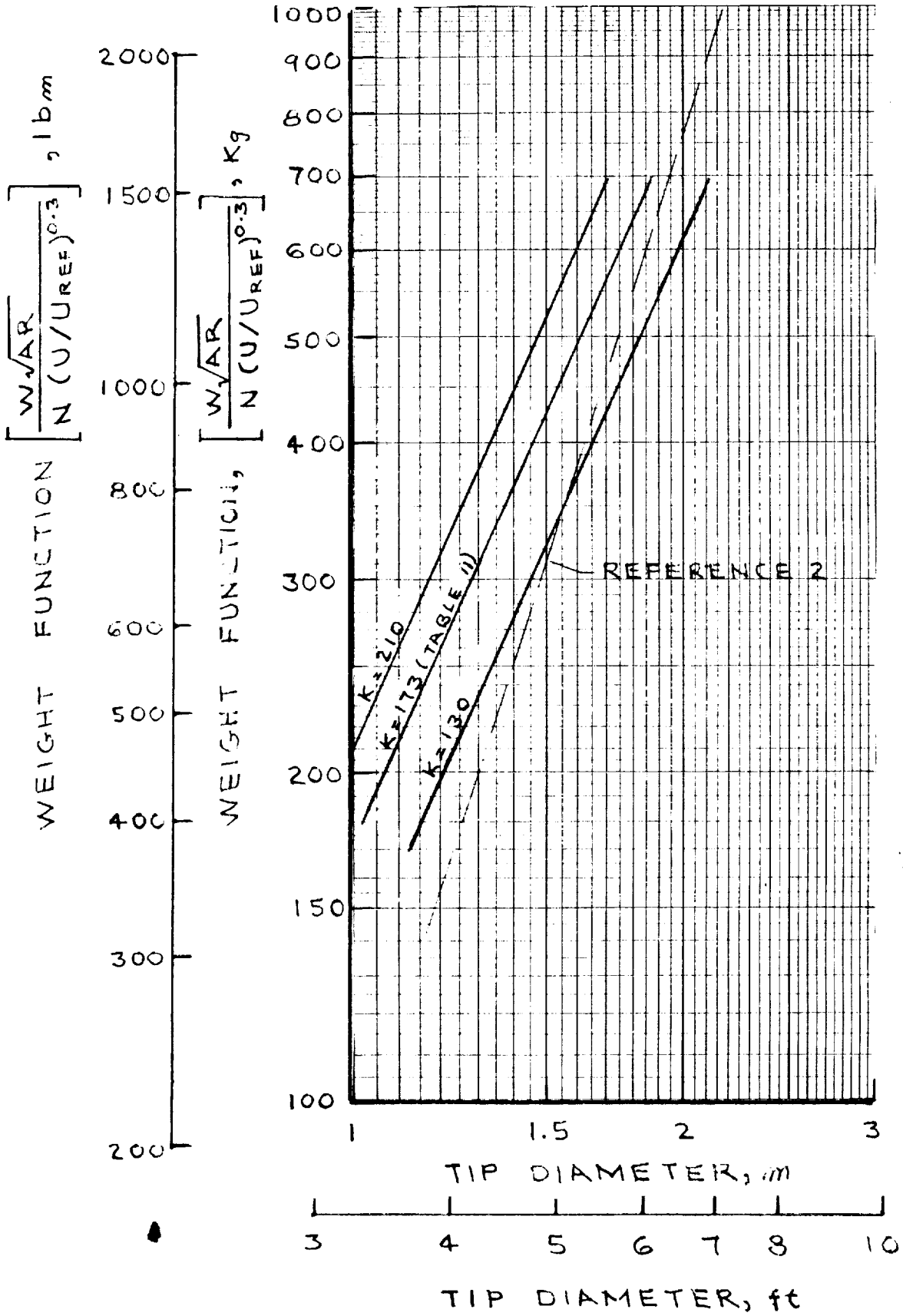


FIGURE 3.-FAN WEIGHT CORRELATION

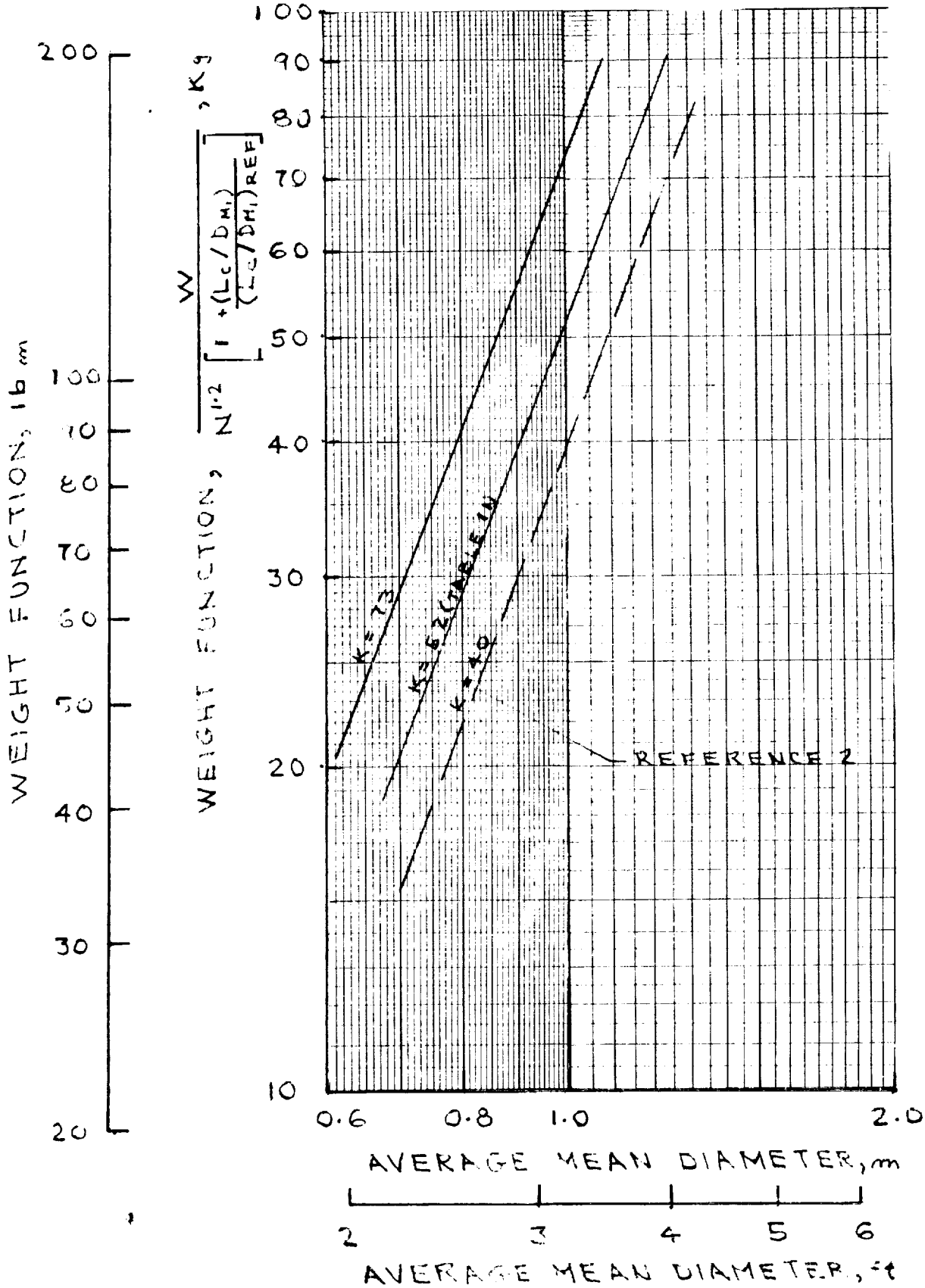


FIGURE 4.-COMPRESSOR WEIGHT CORRELATION

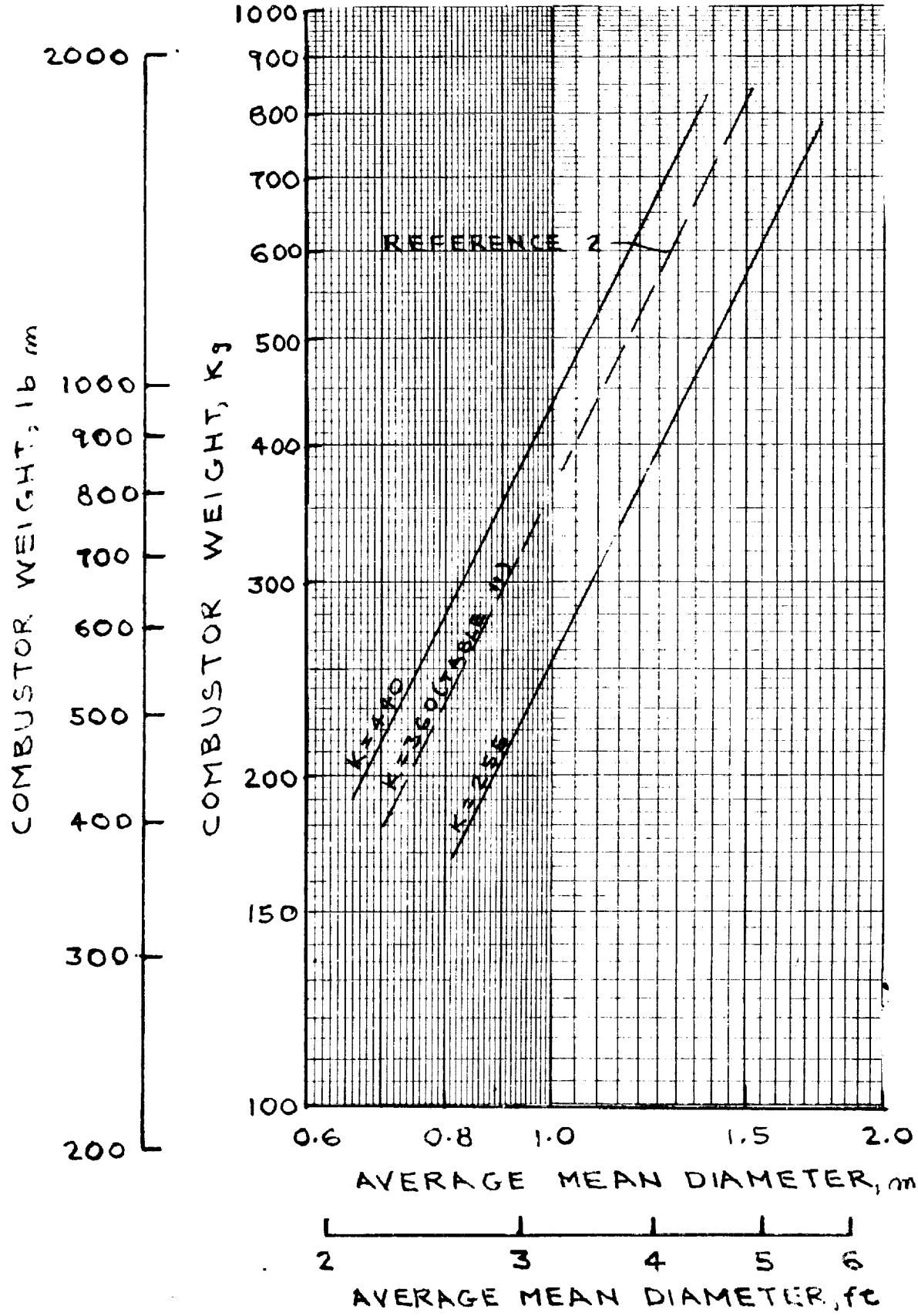


FIGURE 5.-COMBUSTOR WEIGHT CORRELATION

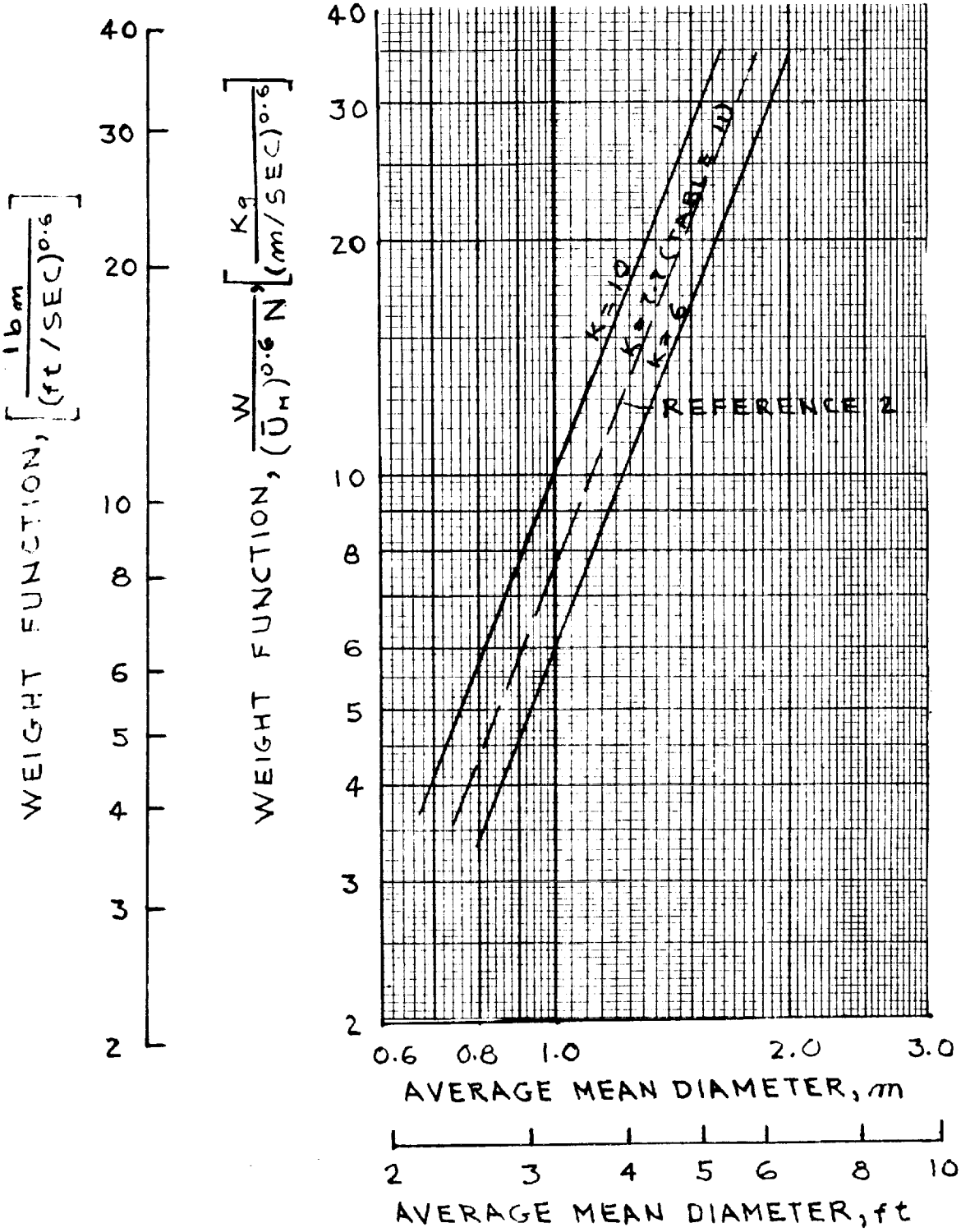


FIGURE 6-TURBINE WEIGHT CORRELATION

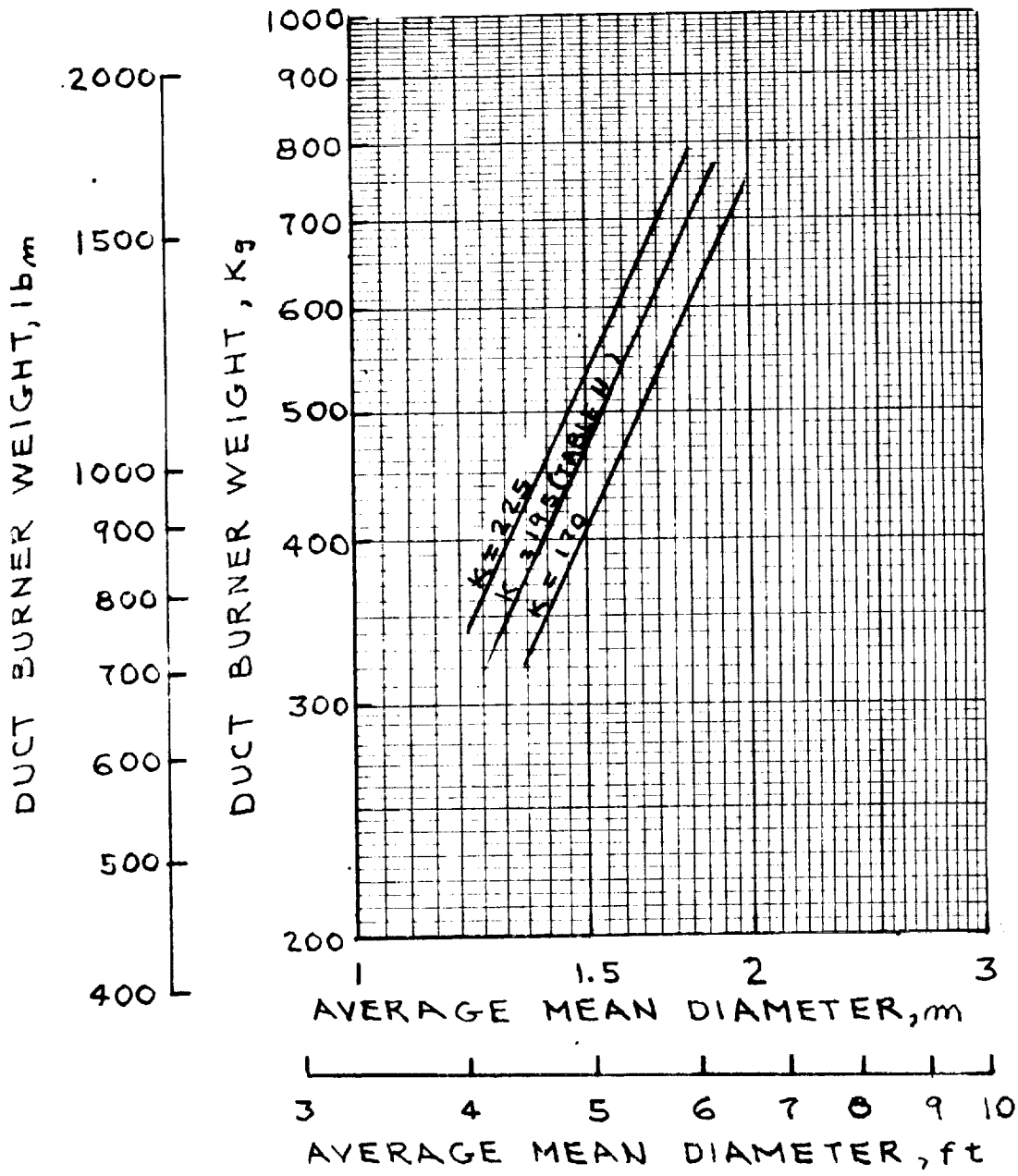


FIGURE 7.-DUCT BURNER WEIGHT CORRELATION

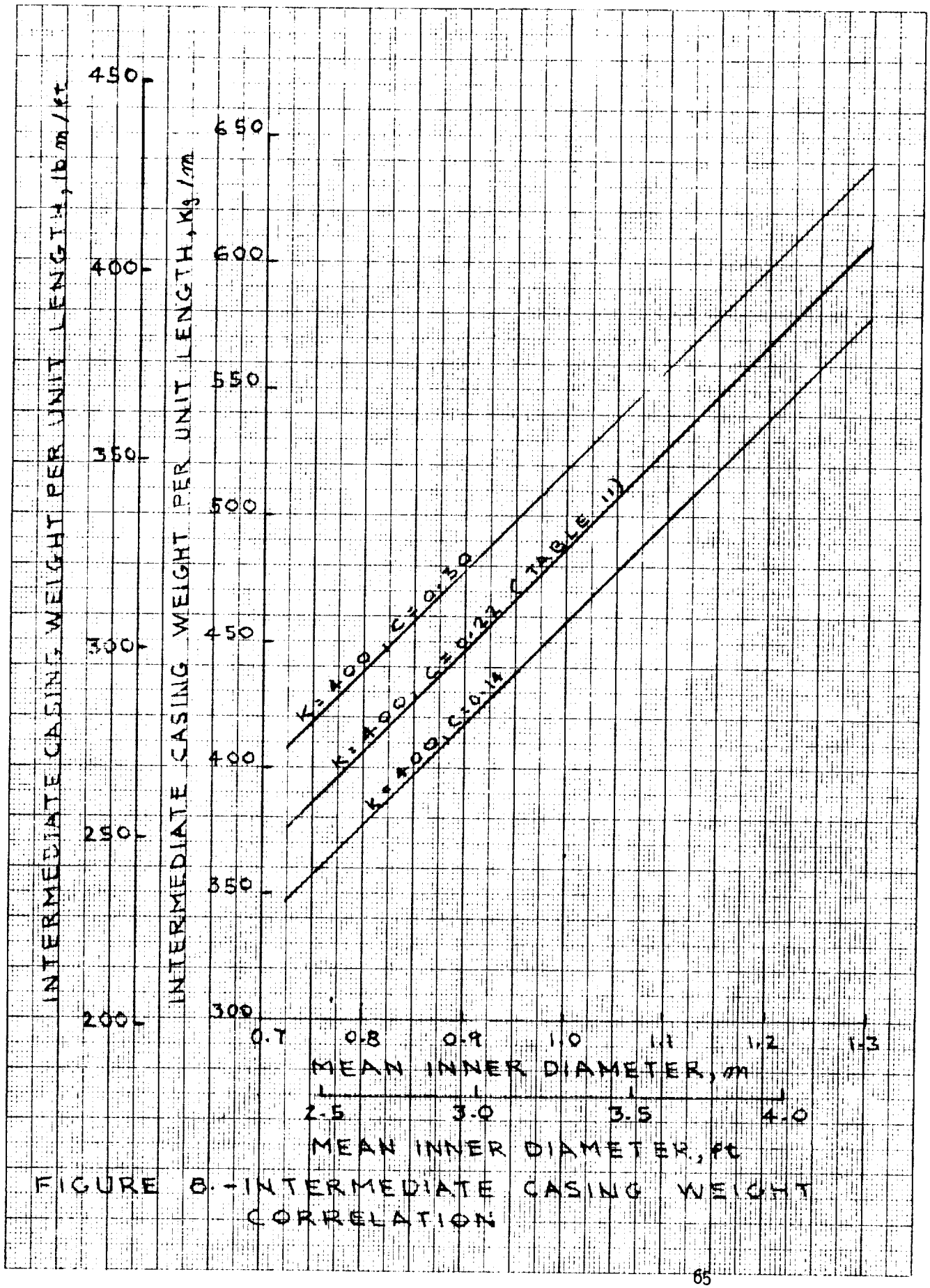


FIGURE 8.-INTERMEDIATE CASING WEIGHT CORRELATION

SQUARE 10 X 10 TO THE CENTIMETER AS 8014-01

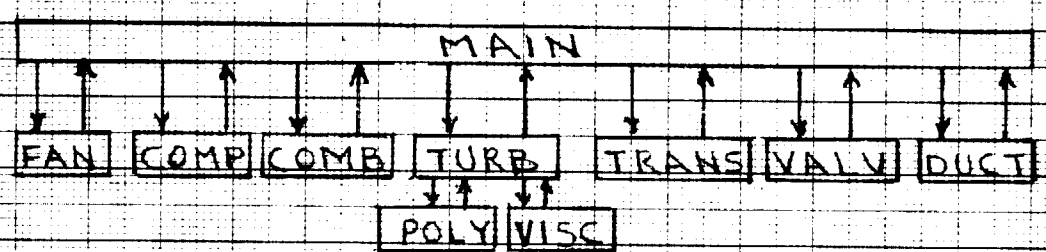


FIGURE 9.- FLOW CHART FOR COMPUTER PROGRAM

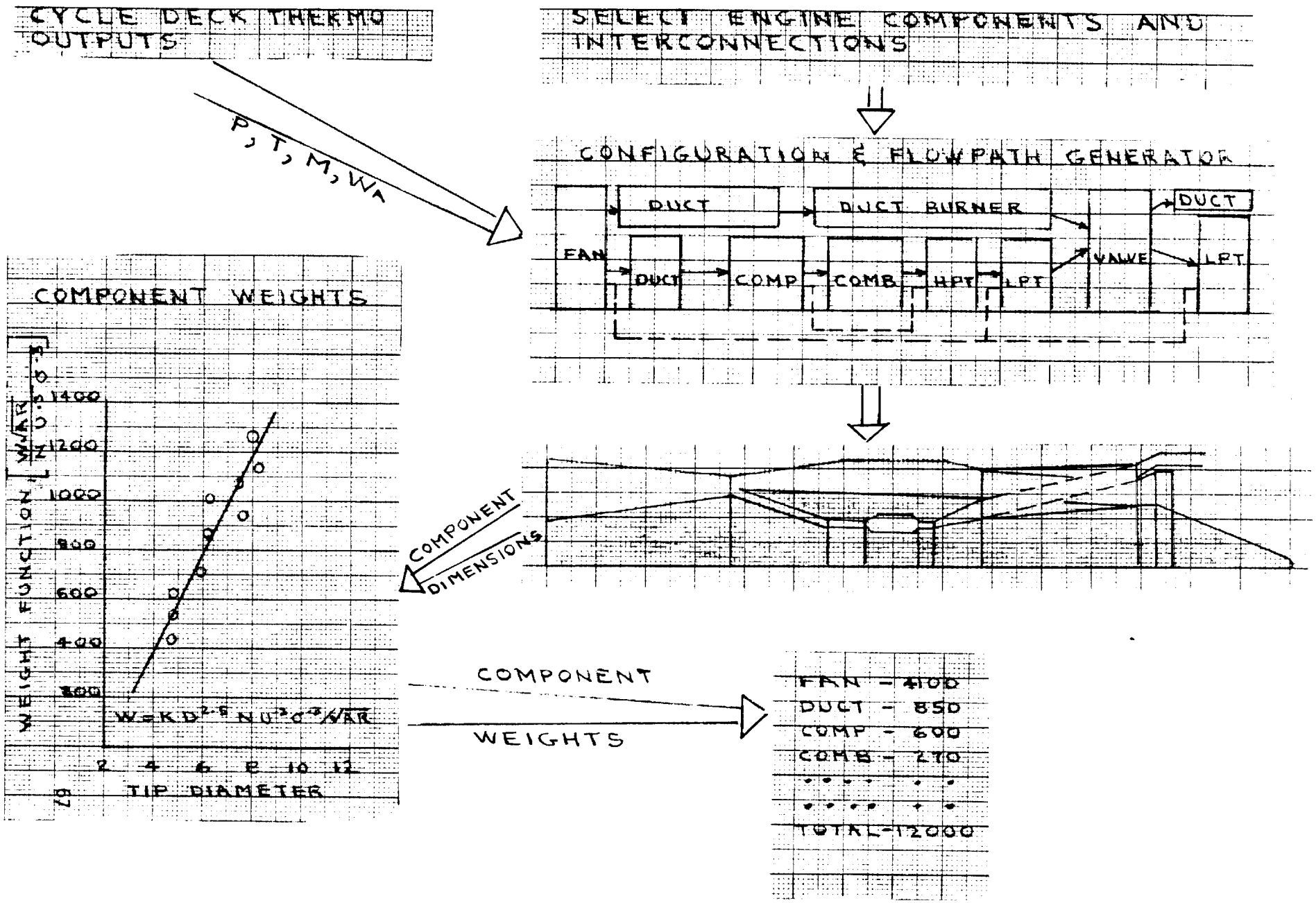
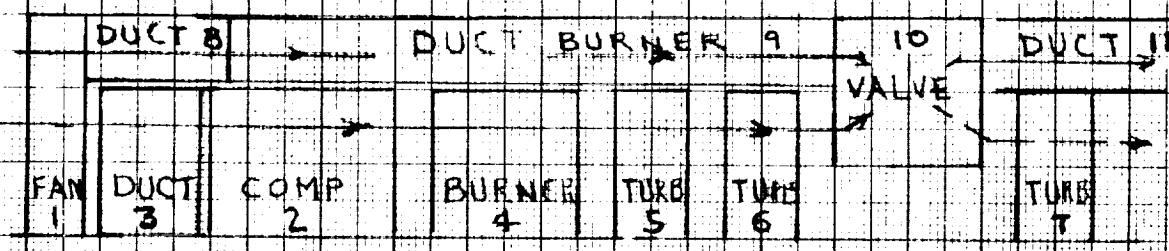


FIGURE 10.- ILLUSTRATION OF PROGRAM OPERATION

SCHEMATIC OF DUCT BURNING TURBOFAN WITH REAR VALVE



GENERAL INPUT:

TURBOFAN WITH REAR VALVE-CUSTOMARY U.S. UNITS
NCOMP=11, SIZE=1, ACC=.000, ISI=0

ENGINE LAYOUT ARRAY

```
COMPON(1,1) = 1,3,0,0,0,0,0,.4,1.7,
COMPON(1,2) = 2,4,0,0,0,0,0,.8,1.1,
COMPON(1,3) = 3,8,3,1,9,2,7,0,0,0,2.5,0,0,0,0,2,0,
COMPON(1,4) = 4,6,1,2,9,0,0,0,1,0,0,2,0,
COMPON(1,5) = 5,7,1,4,9,0,0,0,1,0,0,4,0,
COMPON(1,6) = 6,7,1,5,9,0,0,0,1.2,0,0,5,0,
COMPON(1,7) = 7,7,0,0,0,0,0,.6,.8,0,0,10,0,
COMPON(1,8) = 8,8,1,3,3,0,0,0,.8,0,2.5,
COMPON(1,9) = 9,8,3,8,9,6,5,0,0,0,0,8,0,
COMPON(1,10) = 10,5,3,6,9,7,3,0,0,0,0,6,0,9,0,
COMPON(1,11) = 11,8,3,10,6,7,5,0,0,1,0,10,1,0,0,0,0,0,0,7,
```

FIGURE 11.- SAMPLE INPUT FOR WEIGHT CODE

SQUARE 10 X 10 TO THE CENTIMETER AS-8014-01

COMPONENT DEFINITION ARRAYS

```
FAND(1,1) = 1, 6, 3, 3, 1, 0, 1.25, 1590, .85, 0, 0, 20, 2.4,
COMPD(1,1) = 1, 5, 3, 3, 1250, .85, 4.3, 7, 2.4,
BURND(1,1) = 1, 2, 2, 80, 70, 2,
TURBD(1,1) = 1, 1, 1, 2, 116, 1250, 1, .02, 0, .65, .4, .5, .35, 2.5, 1,
TURBD(1,2) = 2, 4, 1, 1, 148, 1590, 0, .022, 0, .65, .4, .5, .24, 2.5 1,
TURBD(1,3) = 3, 1, 1, 1, 80, 1590, 0, .022, 0, .65, .4, .5, .60, 2.5 1,
DUCTD(1,1) = 1, 1, 82, 0, 0, 0, 0, 0, 1, 1,
DUCTD(1,2) = 2, 0, 2.2, 0, 0, 0, 0, 0, 1, 0,
DUCTD(1,3) = 3, 2, 39, 0, 0, 0, 0, 0, 2.2, 0, 40, 1.6,
DUCTD(1,4) = 4, 0, 2.2, 0, 0, 0, 0, 0, 1, 0,
VALVD(1,1) = 1, 143, 1, 0, 0,
```

FIGURE 11.- CONTINUED

SQUARE 10 X 10 TO THE CENTIMETER AS-8014-BT

COMPONENT THERMODYNAMIC ARRAY

COMPONENT →	1	2	3	4	5	6	7	8	9	10	11
PTIN =	.932,	5.32,	5.32,	0,	0,	0,	0,	5.32,	0,	0,	0,
TTIN =	537,	940,	940,	0,	0,	0,	0,	940,	0,	0,	0,
WAIN =	823,	210,	210,	0,	0,	0,	0,	613,	0,	0,	0,
AMIN =	.4,	.4,	.32,	0,	0,	0,	0,	.32,	0,	0,	0,
GAMIN =	1.4,	1.4,	1.4,	0,	0,	0,	0,	1.4,	0,	0,	0,
CPIN =	.24,	.24,	.24,	0,	0,	0,	0,	.24,	0,	0,	0,
RIN =	53.3,	53.3,	53.3,	0,	0,	0,	0,	53.3,	0,	0,	0,
PTEX =	5.32,	19.6,	0,	18.6,	9.2,	3.06,	2.09,	5.2,	5.0,	4.7,	3.06,
TTEX =	940,	1425,	0,	2900,	2480,	1940,	1715,	940,	2064,	2060,	1940,
WAEX =	823,	210,	0,	215,	215,	215,	623,	613,	623,	623,	215,
AMEX =	0,	0,	0,	.35,	.38,	.34,	0,	.20,	.35,	.35,	.34,
GAMEX =	1.4,	1.4,	0,	1.33,	1.33,	1.33,	1.33,	1.4,	1.33,	1.33,	1.33,
CPEX =	.24,	.24,	0,	.276,	.276,	.276,	.276,	.24,	.276,	.276,	.276,
REX =	53.3,	53.3,	0,	58,	58,	58,	58,	53.3,	58,	58,	58,

FIGURE 11. - CONTINUED

SQUARE 10 X 10 TO THE CENTIMETER AS-0014-01

COMPONENT THERMODYNAMIC ARRAY (CONT.)

COMPONENT →	1 - 9	10	11
PTEXO =	9*0,	2.9,	0
TTEXO =	9*0,	1940,	0
WAEXO =	9*0,	215,	0
AMEXO =	9*0,	.34,	0
GAMEXO =	9*0,	1.33,	0
CPEXO =	9*0,	.276,	0
REXO =	9*0,	58,	0

FIGURE 11 - CONTINUED

```
TURBOFAN WITH BEAR VALVE - CUSTOMARY U.S. UNITS
                              FAN    1
PT1 =   .93     TT1 = 537.00     WA1 = 823.00     M1 = .60
PT2 = 5.32      TT2 = 940.00     WA2 = 823.00     M2 = .38
DH1 = 2.29      DT1 =   5.72     DH2 =   3.82     DT2 =4.85     LENGTH= 5.02
COMPONENT  WEIGHT =4156.22
                              COMPRESSOR    1
PT1 = 5.32      TT1 = 940.00     WA1 = 210.00     M1 = .40
PT2 =19.60      TT2 =1425.00     WA2 = 210.00     M2 = .27
DH1 = 1.97      DT1 =   2.46     DH2 =   2.16     DT2 =2.41     LENGTH= 1.10
COMPONENT  WEIGHT = 640.33
                              DUCT    1
PT1 = 5.32      TT1 = 940.00     WA1 = 210.00     M1 = .32
PT2 = 5.32      TT2 = 940.00     WA2 = 210.00     M2 = .40
DH1 = 3.32      DT1 =   4.15     DH2 =   1.97     DT2 =2.46     LENGTH= 2.50
COMPONENT  WEIGHT = 741.33
                              COMBUSTOR    1
PT1 =19.60      TT1 =1425.00     WA1 = 210.00     M1 = .27
PT2 =18.60      TT2 =2900.00     WA2 = 215.00     M2 = .38
DH1 = 2.16      DT1 =   2.39     DH2 =   2.16     DT2 =2.44     LENGTH= 1.34
COMPONENT  WEIGHT = 289.55
                              TURBINE    1
PT1 =18.60      TT1 =2900.00     WA1 = 215.00     M1 = .34
PT2 = 9.33      TT2 =2514.35     WA2 = 215.00     M2 = .35
DH1 = 2.16      DT1 =   2.54     DH2 =   2.16     DT2 =2.67     LENGTH=  .29
COMPONENT  WEIGHT = 219.30
                              TURBINE    2
PT1 = 9.20      TT1 =2430.00     WA1 = 215.00     M1 = .19
PT2 = 3.11      TT2 =1973.62     WA2 = 215.00     M2 = .21
DH1 = 2.16      DT1 =   3.04     DH2 =   2.60     DT2 =4.09     LENGTH= 1.40
COMPONENT  WEIGHT = 862.93
                              TURBINE    3
PT1 = 4.70      TT1 =2060.00     WA1 = 623.00     M1 = .32
PT2 = 2.41      TT2 =1779.59     WA2 = 623.00     M2 = .33
DH1 = 3.13      DT1 =   5.22     DH2 =   2.50     DT2 =5.46     LENGTH=  .49
COMPONENT  WEIGHT =1437.80
                              DUCT    2
PT1 = 5.32      TT1 = 940.00     WA1 = 613.00     M1 = .32
PT2 = 5.20      TT2 = 940.00     WA2 = 613.00     M2 = .20
DH1 = 4.15      DT1 =   4.99     DH2 =   3.45     DT2 =4.90     LENGTH= 2.50
COMPONENT  WEIGHT =  48.10
                              DUCT  BURNER
PT1 = 5.20      TT1 = 940.00     WA1 = 613.00     M1 = .20
PT2 = 5.00      TT2 =2060.00     WA2 = 623.00     M2 = .35
DH1 = 3.45      DT1 =   4.90     DH2 =   4.09     DT2 =5.37     LENGTH= 3.82
COMPONENT  WEIGHT =1041.47
                              VALVE
PT1 = 3.06      TT1 =1940.00     WA1 = 215.00     M1 = .21
PT2 = 4.70      TT2 =2060.00     WA2 = 623.00     M2 = .35
PT10= 5.00      TT10=2060.00     WA10= 623.00     M10= .35
PT20= 2.90      TT20=1940.00     WA20= 215.00     M20= .35
DH1 = 2.60      DT1 =   4.14     DH2 =   3.13     DT2 =4.77     LENGTH= 2.89
DH10= 4.14      DT10=   5.41     DH20=   4.77     DT20=5.45
COMPONENT  WEIGHT =1713.55
                              DUCT    4
PT1 = 2.90      TT1 =1940.00     WA1 = 215.00     M1 = .34
PT2 = 3.06      TT2 =1940.00     WA2 = 215.00     M2 = .34
DH1 = 4.14      DT1 =   4.93     DH2 =   5.46     DT2 =6.05     LENGTH=  .49
COMPONENT  WEIGHT =  11.12
BARE  ENGINE  WEIGHT=11961.39
```


Figure 12.- Sample output from weight program

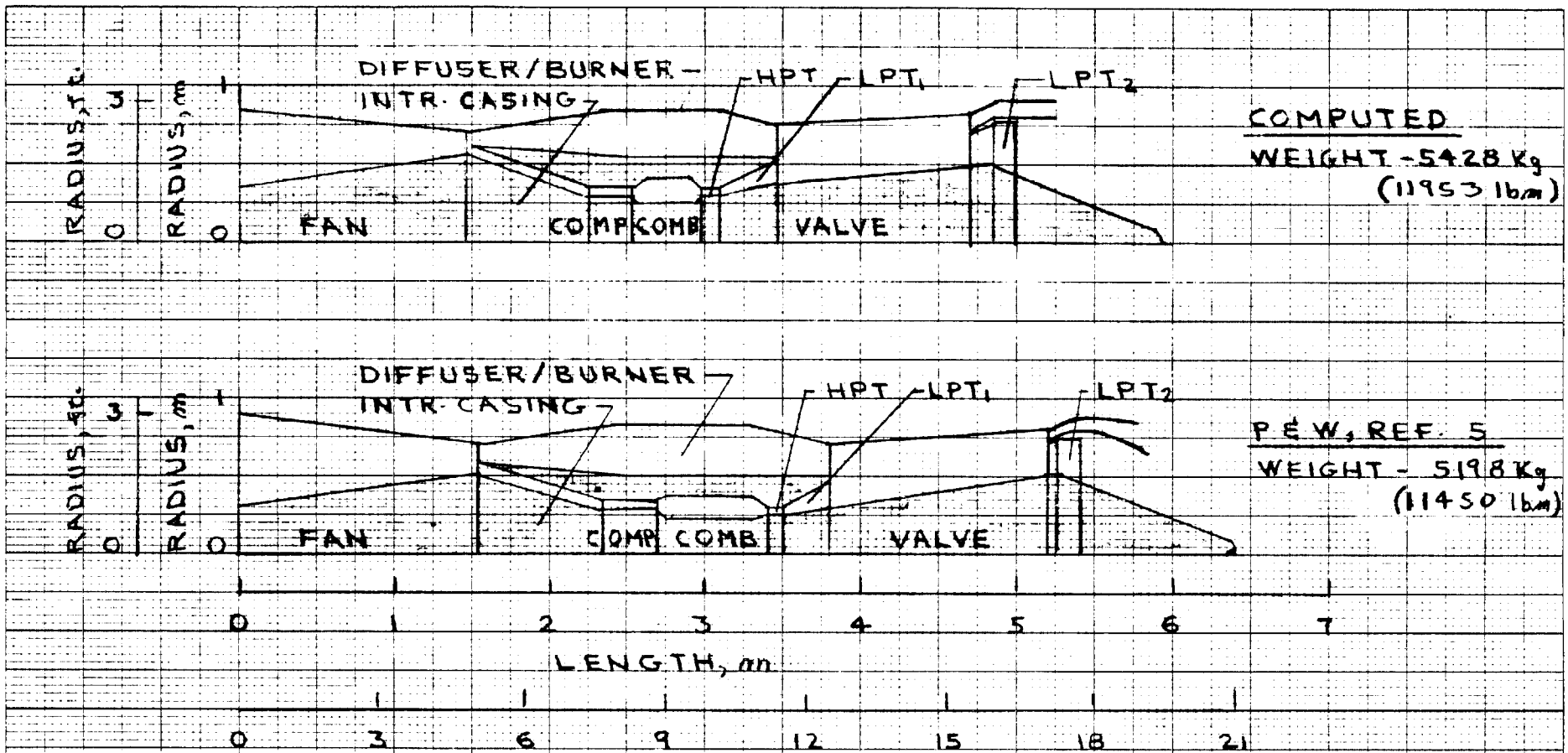


FIGURE 13 — COMPARISON OF ENGINE DIMENSIONS COMPUTED BY THE WEIGHT PROGRAM WITH THE PRATT & WHITNEY LAYOUT FOR THE 112B VARIABLE CYCLE ENGINE. ENGINE SIZE - 409 Kg/SEC (900 lbm/SEC)

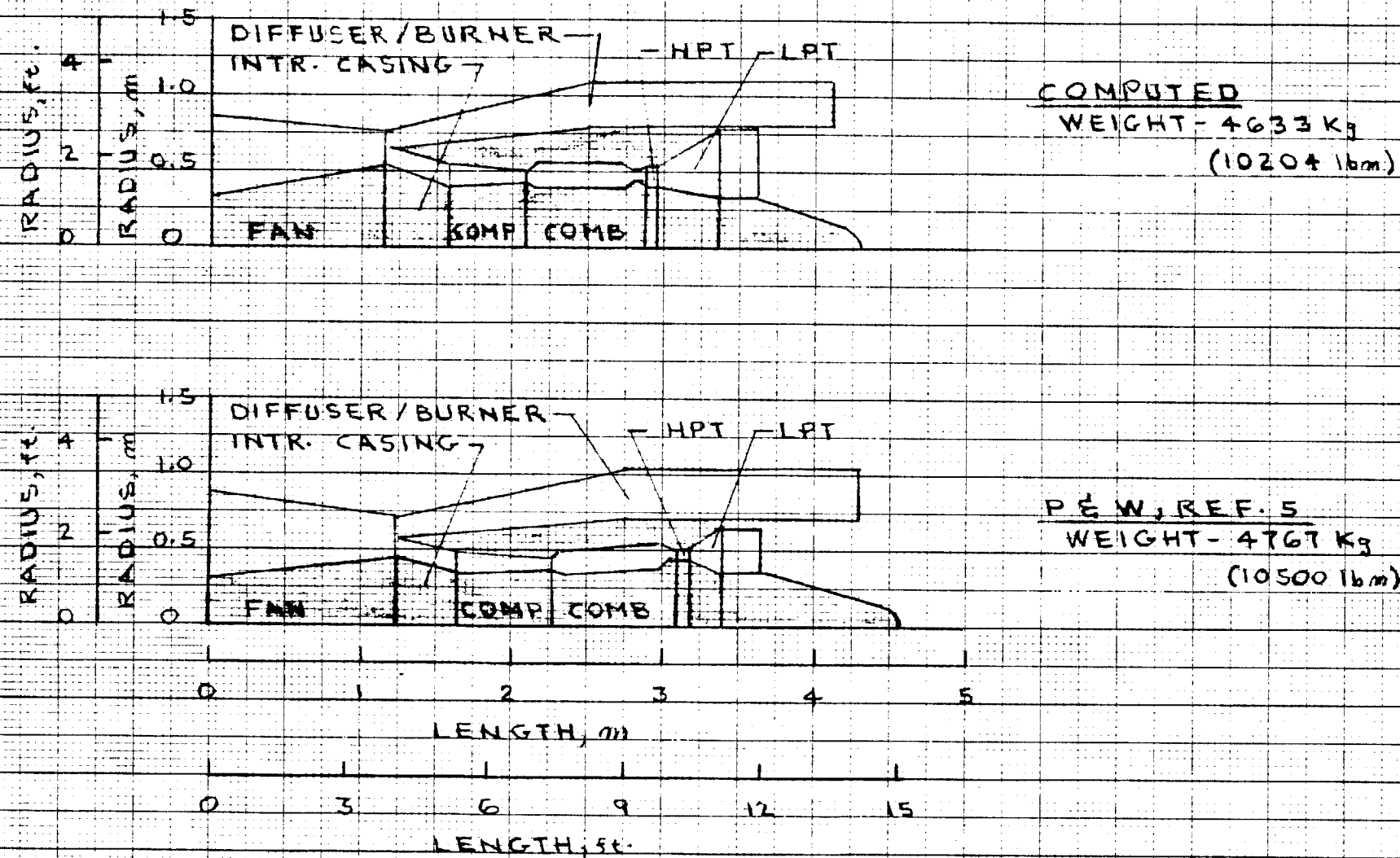


FIGURE 14 - COMPARISON OF ENGINE DIMENSIONS COMPUTED BY THE WEIGHT PROGRAM WITH THE PRATT & WHITNEY LAYOUT FOR THE 502B DUCT BURNING TURBOFAN ENGINE. ENGINE - 409 Kg/SEC (900 lbm/SEC)

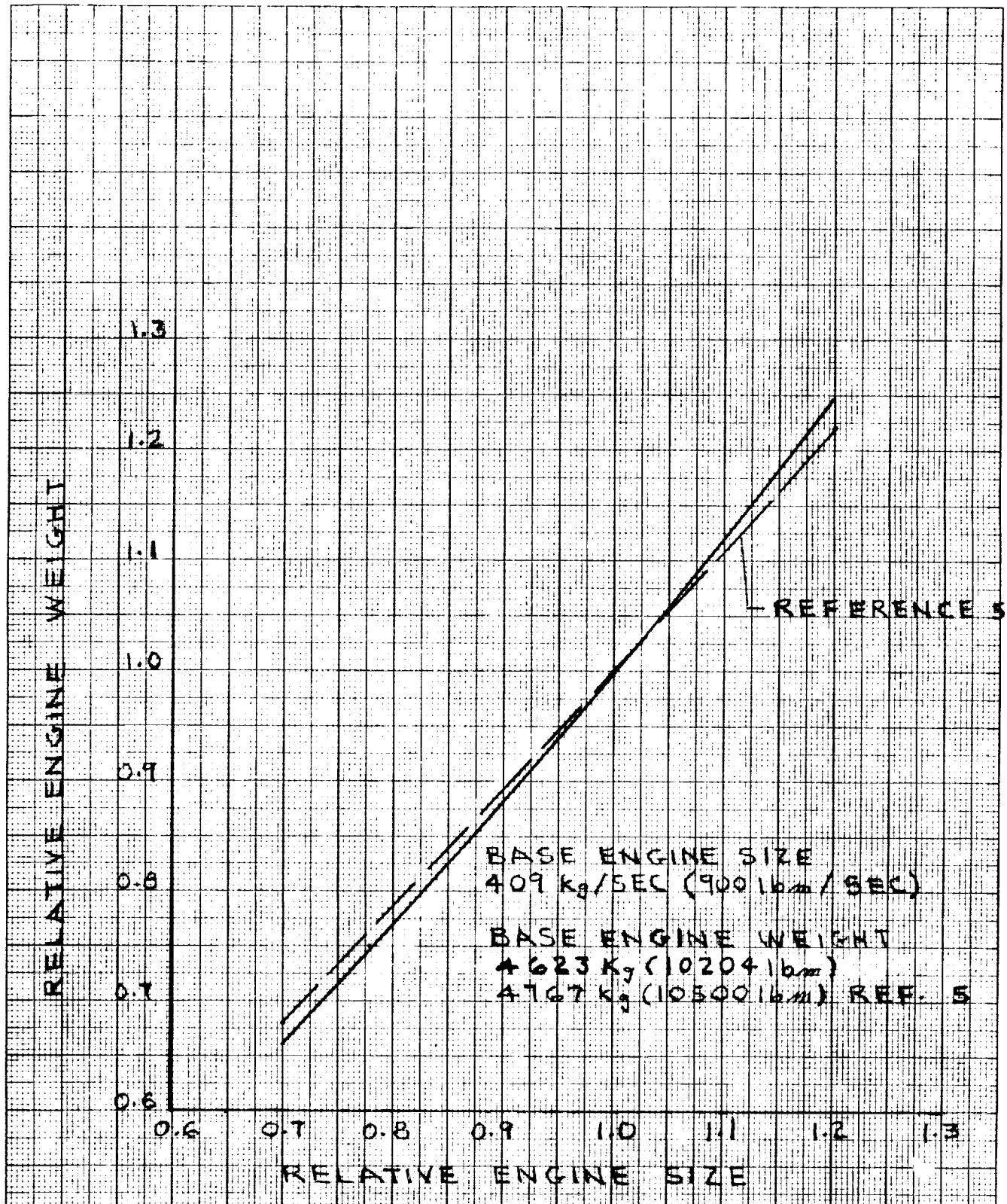


FIGURE 15 - BARE ENGINE WEIGHT OF THE PRATT & WHITNEY VSCE 502B DUCT BURNING TURBOFAN

SQUARE 16 X 10 TO THE HALF INCH AS 1113 01

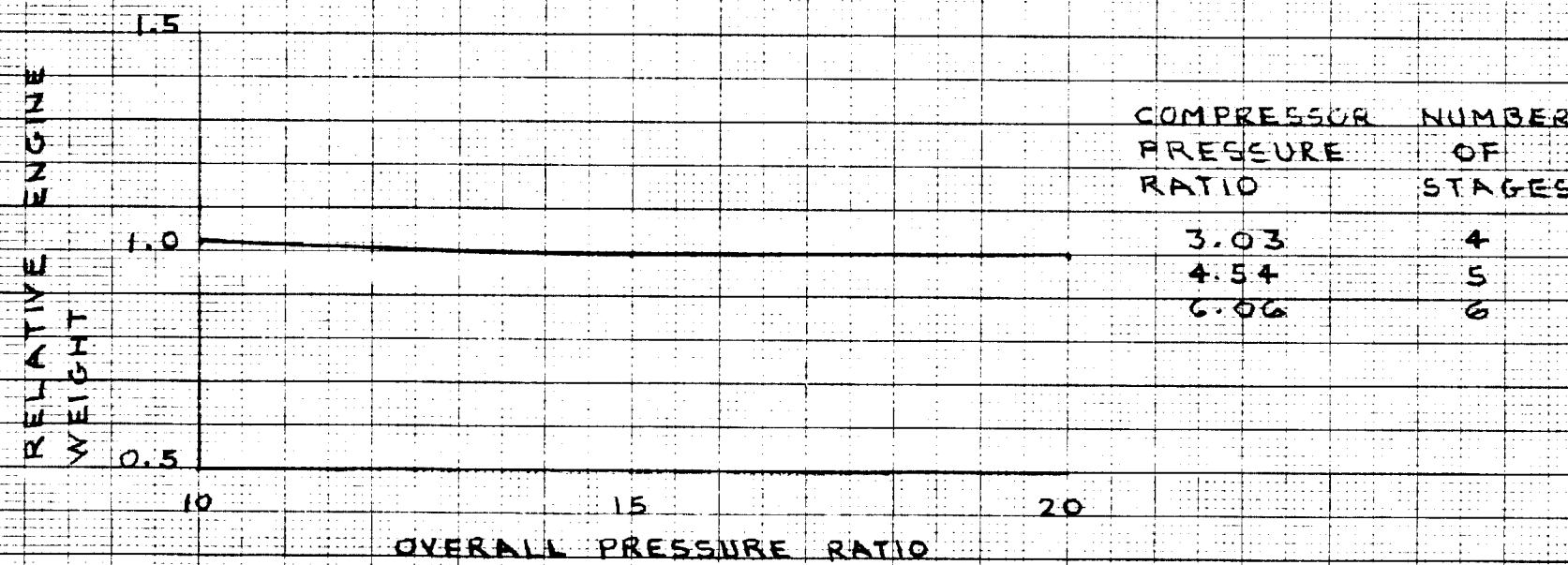


FIGURE 16.- EFFECT OF OVERALL PRESSURE RATIO ON BARE ENGINE WEIGHT. BYPASS RATIO, 1.3; FAN PRESSURE RATIO, 3.3;

SQUARE 10 X 10 TO THE HALF INCH AS-1113 07

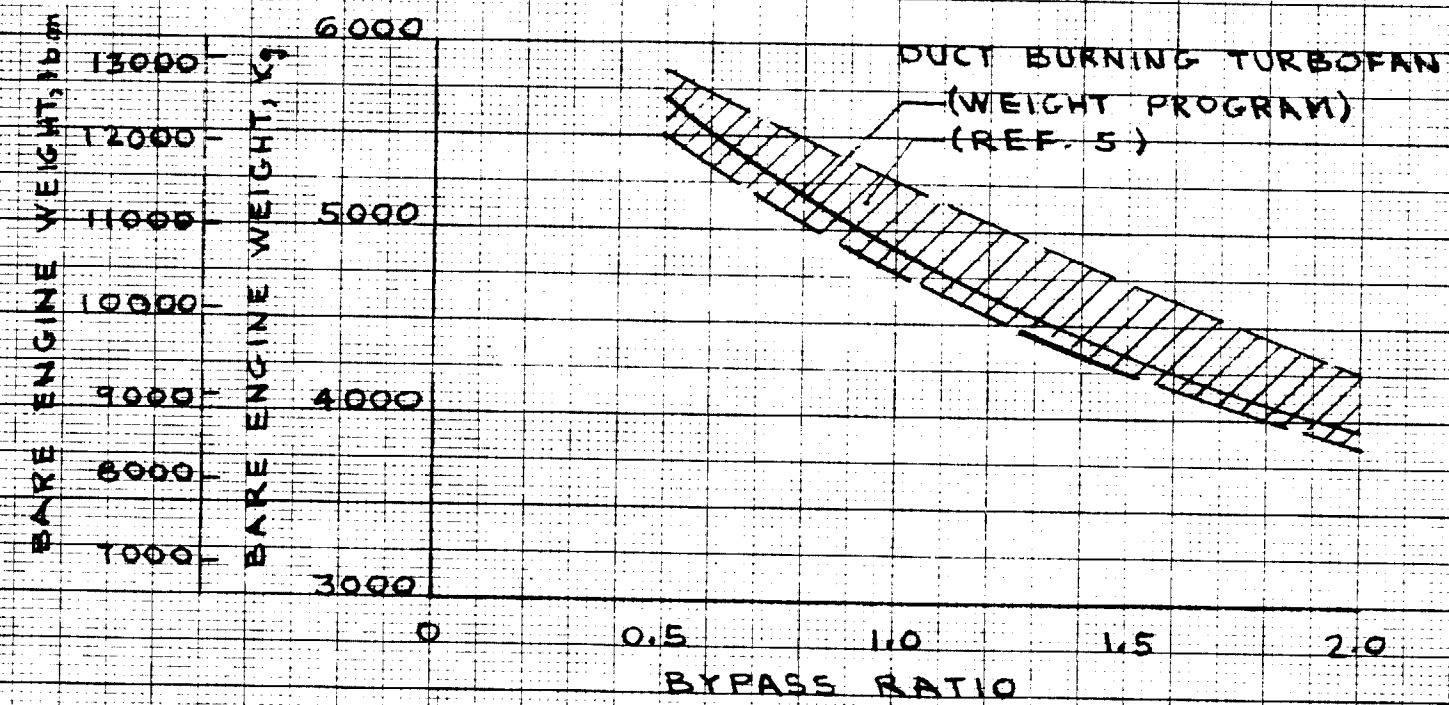


FIGURE 17. - EFFECT OF BYPASS RATIO ON BARE ENGINE WEIGHT.
ENGINE SIZE - 409 Kg/SEC (900 lbm/SEC)