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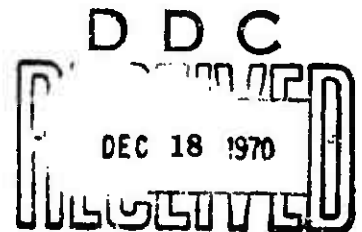
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GENERALIZED ANALYTICAL COMPUTER PROGRAM
FOR TURBOMACHINE-DRIVEN CRYOGENIC
SYSTEMS IN HELIUM

by
F. Edward McDonald
Principal Investigator

June 1970



U. S. ARMY
MOBILITY EQUIPMENT
RESEARCH & DEVELOPMENT CENTER

Prepared under Contract No. DA-44-009-AMC-787(T)
by the University of Colorado, Boulder, Colorado.

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FORT BELVOIR, VIRGINIA

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ABSTRACT

In accordance with specified contractual requirements, the present program will analyze any presently foreseeable turbomachine-driven cryogenic system in general, employing helium as the working fluid.....and will readout size, weight and performance capability of each major component.

Likewise, with the planned broad input spectrum, the effect of numerical changes in various selected variables or input parameters may be studied, either individually or in combination with others as desired.

The cryogenic load, also an elective input variable, may be either wholly within the vapor phase or within the gas phase or partly within both phases as required. These input data are selected from the attached T-S diagram.

It will be noted, however, that the present analytical procedure specifically considers the porous-plate type heat exchanger, as recently developed, wherein very high numerical values of "thermodynamic effectiveness" ϵ can be achieved.

Upon activating either one of two input codes, the computer will evaluate heat exchanger performance based on use of either Al-1100-F or Al-3003-F as the plate material.

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I. INTRODUCTION

The primary purpose of the present work is that of generating an analytical procedure for both study and design of turbomachine-driven cryogenic systems in general, utilizing helium as the working fluid.

In consideration of the comparatively large number of inter-related variables necessary to broad analytical study of these systems, and in order to find either the individual or collective effect of these various parameters on overall system size, weight and performance..... a rather broad input spectrum was indicated.

With this approach, the computer readout not only indicates the comparative effect of changes in the various design parameters, but will guide the designer in optimizing a system design for a particular application.

The present program is so arranged that data specifying the selected cryogenic load is accepted as inputs.....That is to say, upon referring to the T-S diagram Fig. 1, one selects a set of temperatures and pressures that simultaneously defines the desired cryogenic load. Thus with this election, the selected cryogenic load may be either entirely within the vapor phase, or within the gas phase, or partly within both areas.

It will be noted, however, that only those systems employing a JT-valve (Joule-Thompson expansion valve) are considered within the present program, therefore selected numerical values for T_{14} (referring now to both Figs. 1 and 2) must be well below the inversion temperature for helium.....i.e., well below 40°K or 72°R.....Thus for comparatively large cryogenic loads primarily within the vapor phase, one would select T_{14} at or below 10°R.

In general therefore, referring again to Fig. 1, the computer accepts input data for a specified cryogenic load, and with further input data defining various selected design parameters.....the machine then defines the number and design of the heat exchangers and turbines necessary to reach 540°R within the external low-pressure compressor line.....i.e., outside of the vacuum or cryogenic flask.

It will also be noted that, depending upon the selected numerical values of such inputs as pressure ratio, turbine efficiency η_t , effectiveness ϵ , and etc., some systems may require three turbines while others will require only two.

With the exception of station designations and actual numerical values.....the equations and calculation procedure for HX-3, 5 and 7 is exactly similar to that of HX-1.

Likewise, with the same exceptions, the equations and calculation procedure for HX-4 and 6 is exactly similar to that of HX-2.

II. THE HELIUM T-S DIAGRAM

In order to select numerical load data required for inputs to the main computer program, a portion of the helium T-S diagram is shown in Fig. 1. This map covers the temperature range of 6 to 16°R, and pressures of 10 to 300 psia.....within which area very nearly all presently specified low temperature cryogenic loads will occur.

As an example in the use of Fig. 1, let it be agreed that our desired load is to be wholly within the vapor phase, at say 6.894°R and 10 psia, and that our load exit is to be on the saturated vapor line at this same temperature and pressure. One then selects a JT-valve inlet temperature and pressure comprising T14 and P14. The associated constant H line is then followed down to the point of intersection with the 10 psia line, which establishes T15, P15 and H15 entering the load.....Note, here, that H15 equals H14. Then with known values of ΔH_{fg} along the various constant pressure lines (see Table 1), H16 is readily determined. The load ΔH_L is then equal to

$$\Delta H_L = H16 - H15 = \text{BTU/lb} \quad (1)$$

and with assigned mass flow W, the cryogenic load in watts is

$$\text{Watts} = L_w = 1054.54 \ W \ \Delta H_L \quad (2)$$

The tabulated values of H along both the saturated liquid and saturated vapor lines, and tabulated values of the heat of vaporization ΔH_{fg} ; have been reproduced from ref.(1).

Then as required by the program, all load input data comprising T14, P14, T15, P15, T16, P16 and W, are then known.

III. THE SPECIFIC HEAT EQUATION

In helium, between temperatures of about 40 and 540°R; and for pressures between 10 and 300 psia, the specific heat is essentially a straight line function ranging from approximately 1.38 or so at 40°R, down to about 1.250 BTU/lb°R at 540°R.

In that temperature region between about 6 and 40°R, however, and for pressures between 10 and 300 psia.....the specific heat exhibits very wide excursions and tends to plot as a rapidly varying carpet, with some disagreement among various authorities.

In view of the considerable complications involved in programming derived specific heat equations for this region, and since the operating conditions of heat exchanger HX-1 will invariably lie within this questionable area, as may part of HX-2.....a special matrix type computer subroutine has been devised, with which c_p can be determined. These c_p values will closely match the tabulated H values of ref. (1).....i.e. where

$$dH = c_p dT \quad (3)$$

IV THE POROUS PLATE TYPE HEAT EXCHANGER

The porous plate type heat exchanger considered here is, as its name implies, constructed of a comparatively large number of thin perforated plates (usually of aluminum), with thin plastic separators inserted between each plate.....see ref. (5).

These plastic separators, here assumed as Teflon, are bonded to the aluminum plates and, due to their comparatively low thermal conductivity, also serve to reduce the endwise heat leakage. Should the plastic or other low-thermal-conductivity separators not be employed, the endwise heat loss, by conduction through the aluminum plates, could reach such values that a high thermal effectiveness ϵ could not be attained.

The present state-of-the-art is such that practical numerical values of thermal effectiveness ϵ can approach 99%. At this point, however, any further increase in ϵ is achieved only with considerably increased heat exchanger surface area and physical size.....Thus the economics of a particular application enters at this point.

It therefore is suggested that numerical values of ϵ , whether inputs or computed, be limited to about .985 or .987 throughout comparative studies. Thereafter, should the computer readout values for $\epsilon \geq .987$, one merely alters the associated inputs and continues.

Referring now to Fig. 3.....here a typical heat exchanger plate is shown in order to define some of the associated nomenclature. It is

to be noted, however, that the present program will accept input data for any of several different mechanical configurations, which variations will be discussed later.

As shown in Fig. 3, flow through the plates occurs through a large number of closely spaced, small diameter holes.

The generalized mathematical relations between hole diameter dh , porosity σ , hole spacing s , and heat transfer surface area A_x per plate per unit of plate face area....have been derived as follows.....

Upon inspection of the magnified or blown up area of Fig. 3-B, one can write

$$\sigma = \frac{\left(\frac{2 \pi dh^2}{4} \right)}{a \cdot b} \quad (4)$$

$$= \frac{\left(\frac{\pi dh^2}{2} \right)}{a \cdot b} \quad (5)$$

Now from the figure,

$$a = 2 (s \sin \alpha) \quad (6)$$

and

$$b = 2 (s \cos \alpha) \quad (7)$$

As employed within the present program, α is assumed and held constant at 30 degrees.

$$\therefore a \cdot b = s^2 \sin 30^\circ \cdot \cos 30^\circ \quad (8)$$

$$= 1.732060 s^2 \quad (9)$$

$$\therefore \sigma = \frac{\left(\frac{\pi dh^2}{2} \right)}{1.73206 s^2} \quad (10)$$

$$= \frac{.906894 dh^2}{s^2} \quad (11)$$

Thus

$$s = \sqrt{.906894 \frac{dh^2}{\sigma}} \quad (12)$$

Here it is suggested, for mechanical and other reasons, that porosity σ be restricted to the range of

$$.40 \leq \sigma \leq .60 \quad (13)$$

Then the number of holes n_1 per inch² of plate face area on the hot or driving side, becomes

$$n_1 = \frac{4 \sigma}{\pi dh^2} \quad (14)$$

and the theoretical heat transfer surface area per inch² of plate face area is then

$$Ax_1 = (n_1 \pi dh tp) + 2 (1-\sigma) \quad (15)$$

Thereafter, the total hole area required for a given flow rate at given velocity, Reynold's Number, etc.....is readily found by solving the continuity equation wherein

$$\frac{W}{A} = \rho V = \frac{V}{\bar{N}} \quad (16)$$

and total hole-flow area in inches²

$$ah_1 = \frac{144 W \bar{N}}{V} \quad (17)$$

Therefore total required face area (on one side of the plate and for the hot or driving side only) in inches²

$$Af_1 = \frac{ah_1}{\sigma} \quad (18)$$

Particular attention is directed to the fact that area requirements are first generated or found on the hot or "driving side" of the heat exchangers.

In addition to the major advantage of very large heat transfer surface area per unit of total volume.....2600 ft²/f.³ or more being readily

attainable.....the comparatively thin plates employed (.004 to .010 inches thick) involve such hole length/diameter ratios that, at Reynold's Numbers of 2000 and less.....a laminar boundary layer will not be established.

Under these conditions, i.e., boundary layer thickness approaching zero, it is known that relative Nusselt Numbers (and heat transfer film coefficients) can easily reach numerical values approximately ten times that found in say a long tube after the boundary layer has been established.

For instance, in accordance with ref. (4)

$$NN_u = 3.66 + \left[\frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe \cdot Npr} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe \cdot Npr} \right]^{.8}} \right)} \right] \quad (19)$$

at constant wall temperature. Reference (3) also reports similar findings within this area.

In recent exploratory runs with the present program, utilizing a plate thickness tp of .0063 inches and hole diameter dh of .0080 inches.....Nusselt

Numbers approaching 30 have been achieved at reasonable Reynold's Numbers N_{Re} and Prandtl Numbers N_{Pr} .

Now since the film coefficient

$$h = \frac{N_{Nu} \cdot K}{d_h} \quad (20)$$

or

$$h = \frac{12 \ N_{Nu} \cdot k}{d_h} \quad (21)$$

(where K is the thermal conductivity of the gas) then the capabilities of the plate type heat exchanger are readily visualized.

Simultaneously referring now to the input section for say HX-1, and to Fig. 3-A.....While the computer evaluates almost all of the physical plate dimensions, working with certain "key" ratios and border dimensions as inputs, some discussion of the related concept is in order.

In general, any desired numerical value can be employed for the various input dimensions and ratios, however, some degree of relative compatibility must also be observed in selection of the various inputs.

For instance, in specifying the C factor and in order to maintain approximately equal heat flow-path-lengths in both the hot-to-cold directions.....it is obvious that a hot strip must always lie between two cold strips. It will also be noted that an external or outside cold flow strip must be one half the height of an internal cold flow strip.....

i.e., Y_2' as compared with Y_3' , and that both Y_2' and Y_3' will be greater than the associated hot strip height Y_1' Thus the selected C factor should always be an odd number, such as 3, 5, 7, or 9 etc.

$$C = N_h + N_c \quad (22)$$

Then with specified inputs C, N_h , N_c , F_s , R_a , B_x , B_y and B' , the computer determines all other plate dimensions, including the various heat flow-path lengths.

Upon specifying the shape factor F_s , the computer determines all X and Y dimensions required to handle the specified flow at the specified temperature, Pressure and Reynold's Number conditions.

Then with A_{fi} known from prior machine calculation, the computer selects

$$X = \text{assume} \quad (23)$$

$$X' = X - (2 B_x) \quad (24)$$

$$Y' = \frac{X}{F_s} - (2 B_y) \quad (25)$$

$$Y_1' = \frac{Y' - [(C-1) B'] - N_h}{2 (C-1)} \quad (26)$$

$$A_{fi} \text{ calculated} = N_h (X' Y_1') \quad (27)$$

The machine then iterates on X until A_{fi} calculated equals A_{fi} required.

Thereafter,

$$Y_2' = Y_1' \frac{Ra}{2} \quad (28)$$

$$Y_3' = Y_1' \cdot Ra \quad (29)$$

$$\lambda_1 = \frac{Y_1'}{24} \quad (30)$$

$$\lambda_2 = \frac{B'}{12} \quad (31)$$

$$\lambda_3 = \frac{Y_3'}{12 \cdot Ra} \quad (32)$$

The computer then evaluates required flow areas and various pressure drops.

V. ANALYTICAL TECHNIQUE FOR THE COUNTER-FLOW HEAT EXCHANGER

Within the present program the idea of the ϵ -Ntu or effectiveness-number of heat transfer units approach is employed in counter-flow heat exchanger analysis, wherein thermal effectiveness is defined as

$$\epsilon = \frac{Q}{Q_{\max}} \quad (33)$$

$$= \frac{C_h (Th1 - Th2)}{C_{\min} (Th1 - Tc1)} \quad (34)$$

$$= \frac{C_c (Tc2 - Tc1)}{C_{\min} (Th1 - Tc1)} \quad (35)$$

where

$$C_h = (W \bar{c}_p) \text{ hot side} \quad (36)$$

$$C_c = (W \bar{c}_p) \text{ cold side} \quad (37)$$

and $C_{\min}$ is the smaller numerical value of the two.

In each case $\bar{c}_p$ is either the hot or cold side specific heat integrated over the particular temperature range of interest.

Ntu, usually referred to as the number of heat transfer units, essentially expresses the "thermodynamic size" of the heat exchanger, and is defined by

$$Ntu = \frac{A \cdot U_{\text{avg}}}{C_{\min}} \quad (38)$$

$$= \frac{1}{C_{min}} \int_0^A U \, dA \quad (39)$$

Referring now to Fig. 4 and deriving further working equations from those of ref. (3).....It will be noted that on the temperature-temperature plane, and with given endpoint temperatures but with no flow present, the thermal equilibrium condition of a counter-flow heat exchanger may be represented by a straight line having the slope dY/dX equal to 1.0. It will also be noted that with no flow present, the endpoint temperature gradients ∇_1 and ∇_2 are equal to zero.

Upon establishing a finite flow, however, a steady state operating line may be defined, which operating line will have a slope dY/dX exactly equal to C_{max}/C_{min} .

With this idea in mind, and considering the ϵ -Ntu approach, many useful relations can be derived, which relations permit very rapid and direct analysis as compared with the older log mean $-\Delta T$ approach.

Here attention is directed to the fact, however, that the relative disposition or location of the endpoint temperature gradients ∇_1 and ∇_2 must be carefully observed at all times.

Under these conditions it can be readily shown that

$$\frac{\nabla_2}{\nabla_1} = e^{-Ntu [1-(C_{min}/C_{max})]} \quad (40)$$

and that

$$\frac{\nabla_2}{\nabla_1} = \frac{1 - \epsilon}{1 - \epsilon (C_{min}/C_{max})} \quad (41)$$

Likewise, referring simultaneously to Fig. 5,

$$\Delta X = \frac{\nabla_1 - \nabla_2}{\left(\frac{dY}{dX}\right) - 1} \quad (42)$$

$$= \frac{\Delta Y}{\left(\frac{dY}{dX}\right)} \quad (43)$$

and

$$\Delta Y = \frac{\left[\frac{dY}{dX} \cdot (\nabla_1 - \nabla_2)\right]}{\left(\frac{dY}{dX}\right) - 1} \quad (44)$$

$$= \frac{dY}{dX} \cdot \Delta X \quad (45)$$

Therefore, in Fig. 4,

$$Y_2 = Y_1 + \Delta Y \quad (46)$$

and

$$X_2 = X_1 + \Delta X \quad (47)$$

then

$$\nabla_1 = Y_2 - X_2 \quad (48)$$

and

$$\nabla_2 = Y_1 - X_1 \quad (49)$$

Further, returning to equations (33) through (35),

$$\epsilon = \frac{Q}{Q_{\max}} \quad (50)$$

$$= \frac{C_h \cdot \Delta Y}{C_{\min} (T_{h1} - T_{c1})} \quad (51)$$

$$= \frac{C_c \cdot \Delta X}{C_{\min} (T_{h1} - T_{c1})} \quad (52)$$

Upon combining equations (40) and (41), one can arrive at the basic relation

$$\epsilon = \frac{1 - e^{-Ntu [1 - (C_{\min}/C_{\max})]}}{1 - \left\{ \left(\frac{C_{\min}}{C_{\max}} \right) e^{-Ntu [1 - (C_{\min}/C_{\max})]} \right\}} \quad (53)$$

where $Ch \neq Cc$.

In those rare cases where $Ch \equiv Cc$, that is to say, where

$$\frac{Ch}{Cc} = 1.0 \quad (54)$$

or vice-versa, then

$$\epsilon = \frac{Ntu}{1 + Ntu} \quad (55)$$

and

$$Ntu = \frac{\epsilon}{1 - \epsilon} \quad (56)$$

The foregoing, and various additional expressions derived therefrom, are employed throughout the main analytical program.

Attention is also directed to the distinction between thermal effectiveness ϵ_i and ϵ , as employed here.

Since a very considerable amount of iteration on temperature is avoided by analytically finding actual or desired temperature based on a thermal effectiveness ϵ_i and finding required surface area based on calculation with a higher thermal effectiveness ϵ (reflecting the effect of heat loss)..... ϵ_i and ϵ are not to be considered as "ideal" and "actual" as usually employed.

Here,

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (57)$$

where λ reflects the effect of loss by endwise heat leakage.

This approach is believed to be valid since it can be shown that

$$\frac{Q_{\text{loss}}}{Q} \cong \frac{\Delta \epsilon}{\epsilon} = \lambda \quad (58)$$

where

$$\lambda = \frac{[(K/\lambda_e) A_k]_{\text{loss path}}}{Q_{\text{min}}} \quad (59)$$

Therefore, with the inverse problem, equation (57) in effect demands a greater heat transfer surface area, to reach given temperatures, in the presence of heat loss.

VI. HEAT LEAKAGE PATHS NOT CONSIDERED

In addition to the effect of heat loss by endwise conduction, as discussed within Section IV, there remains four possible heat leakage paths which can not be rationally considered within the present generalized analytical program.....since an actual mechanical design or configuration would first be necessary, along with planned grouping or arrangement of the various components.

These additional heat leakage paths are,

1. Radiation between the various system components and the enclosing vacuum-flask walls.
2. Heat conduction through all bracing and support members.
3. Heat conduction through all thermocouple wire leads.
4. And heat conduction through the turbogenerator lead wires (assuming the turbogenerator load to be external of the cryogenic section).

Regarding radiation effects.....Once an actual design and grouping of components has been established, the effect of radiated heat loss from the various components can be readily evaluated with known areas, emissivity and temperature difference by

$$Q_r = .173 \epsilon' A \left[\left(\frac{T_1}{100} \right)^4 - \left(\frac{T_2}{100} \right)^4 \right] \quad (60)$$

whers ϵ' is the equivalent emissivity.

Regarding heat loss through bracing and support members.....One
possible solution, for minimum heat leakage, is that of employing a strong, low-thermal-conductivity material such as Teflon in these areas, however, an actual established design is required before radiation and conduction losses can be evaluated.

Regarding heat loss through wires.....Here, again, wire length, size and material must necessarily be known before heat loss can be determined. However, it can be noted, at this point, that one or two "cold sinks" may be provided at judicious points along all "bundles" of wire leads, by tapping off coolant from the main string of heat exchangers. The required amount of refrigeration could not be large.

The item 1 and 2 heat loss can and should be charged to affected heat exchangers after a particular system design is established, along with planned physical grouping. This can be accomplished by small modifications within the main program.

In the case of radiation effects, and considering the equations of HX-1 as an example..... Q_r can be computed and added to the numerator of such equations as (102), (105) and (108).....which results in a larger λ and, thereby, HX design for greater cooling capacity.

In the case of heat lost by conduction through various bracing and support members, another Q loss can be determined by a group of equations similar to (95) through (101)....This additional Q loss would also be added into the numerator of equations (102), (105) and (108), again using HX-1 as an example.

VII. PROGRAM OPERATIONAL PROCEDURE

Referring now to Fig. 2.....The computer is instructed to "stack" or employ any number of turbogenerators up to a maximum of three, and any number of heat exchangers up to a maximum of seven..... as required to reach the selected temperature of 540°R in the external low pressure compressor line, shown here as station 23.

In general, however, two turbogenerators and five heat exchangers will usually be sufficient to reach any desired cryogenic load temperature, in helium, from 540°R . On the other hand, since it may be desirable to study very low pressure ratio-low efficiency systems for some particular application, the analytical capability to handle three turbines and seven heat exchangers has been incorporated within the program.

In good rational system design, this ambient condition should be reached either at station 21 for two-turbine designs, or at station 23 for three-turbine systems.....This means that a final heat exchanger should always be employed above the final turbine, since considerable "cooling capability" is always present within the turbine exit flow stream.

Therefore, in those cases where the desired final exit temperature (540°R as employed here) is either exceeded, or not reached, with a given set of inputs.....one merely alters various inputs until the desired exit conditions are achieved. It may be noted that in those cases where it

is desirable to retain certain input values, a change in overall system pressure ratio will usually serve the purpose.

In actual practice it has been found that little is to be gained in driving or forcing actual heat exchanger effectiveness ϵ to values greater than say .985 to .987 since, at this point, heat exchanger size and weight tends to increase rapidly.

In "driving" or loading heat exchangers up to their economic limit, however, it should be observed that in those cases where the "corner" temperatures are controlled by turbine thermodynamics, i.e. turbine inlet and exit temperatures, nothing other than added weight will be gained by adding plates in an effort to increase ϵ That is to say, where the turbine establishes such corner temperatures that reflect a heat exchanger effectiveness of say only .820, nothing is to be gained by designing that particular heat exchanger for an ϵ of say .980..... This situation can be encountered at HX-2, HX-4 and HX-6.

As a fine point in further refinement of heat exchanger design, attention is directed to the "fin effectiveness" η_f , which values are read out as a result of equations (126) (for HX-1,3,5,7) and (125) (for HX-2,4,6).....Experience to date has shown that best optimization will usually occur when numerical values of η_f are restricted to

$$.40 \leq \eta_f \leq .60 \quad (61)$$

In those cases where η_f tends to fall beyond these limits, one can usually force η_f into this desired range by altering the numerical

value of the "shape factor" F_s , which factor is listed as an input for all HX components. The net effect of the foregoing is that of optimizing (to a limited extent) the various heat flow-path lengths which, in effect, tends to utilize plate material more economically.

It will also be observed that turbine efficiency per se will have little effect on overall system performance at very low temperature levels. However, at higher temperature levels, i.e. for turbine 2 (and turbine 3 where employed), higher turbine efficiency will permit greater work extraction and will result in the more effective overall system. This effect can be demonstrated as follows.....

Since

$$\eta_t = \frac{1 - \frac{T_2}{T_1}}{1 - (P_2/P_1)^{(\bar{\tau}-1)/\bar{\tau}}} \quad (62)$$

$$1 - \frac{T_2}{T_1} = \eta_t \left[1 - (P_2/P_1)^{(\bar{\tau}-1)/\bar{\tau}} \right] \quad (63)$$

$$\frac{T_2}{T_1} = 1 - \eta_t \left[1 - (P_2/P_1)^{(\bar{\tau}-1)/\bar{\tau}} \right] \quad (64)$$

Now if T_1 is say only 4 or 5 degrees, T_2 can not possibly be much lower, numerically.....regardless of turbine efficiency and pressure ratio.

On the other hand, however, at higher temperature levels such as 100, 200, 300 degrees, it is obvious that the highest possible turbine efficiency and/or pressure ratio will effectively extract a much larger amount of heat (work).....therefore use of the highest attainable turbine efficiency is recommended, regardless of pressure ratio.

Within all analytical work, referring again to Fig. 2, particular attention is directed to the fact that T16 through T23 can never be equal to or greater (respectively) than T14 through T7.....as a violation of the Second Law would be involved.

In general, within the temperature-iterative procedures, the program is so arranged that the machine will not select a numerical value in violation of the Second Law.

VIII. INPUT PREPARATION

Referring now to Appendix I.....Section I of the input data is concerned with the selected cryogenic load, of which some numerical values are employed in calculation while others are entered and readout for identification and record purposes only.

For the JT-valve inlet, one selects desired numerical values for T14, P14, H14 and S14, either from the attached T-S Diagram Fig. 1, or from the Tables of ref. (1).

For the JT-valve exit conditions (load inlet), the associated constant H line (Fig. 1) is followed down to the desired load inlet pressure and T15, P15, H15 and S15 values are recorded. (Note here that H15 will equal H14.)

For the load exit, one then selects desired values for T16, P16, H16 and S16. Then with these values the load ΔH_L is determined by

$$\Delta H_L = H16 - H15 = \text{BTU/lb} \quad (65)$$

and actual watts

$$LW = 1054.54 \ W_1 \cdot \Delta H_L \quad (66)$$

.

Input data for Section II.....Section II is concerned with the inputs for the first heat exchanger HX-1. In general, a major portion

of the input data is related to plate and hole sizing, as discussed within Section IV of the text, and is self explanatory. It should be noted, however, particularly in relation to Reynold's Number NRe_1 , that the computer is instructed to handle laminar flow only, therefore numerical values initially selected for NRe_1 should be restricted to 2,000 or less. In those cases where limiting environmental conditions are encountered, the computer will readout a message requesting a smaller NRe_1 .

Values for the plate porosity σ , as discussed elsewhere within the text, should be limited to the range of .40 to .60.

While the number of heat transfer units Nt_{ui} can theoretically reach any numerical value, the computer is also instructed to readout a message calling for less Nt_{ui} when limiting environmental conditions have been encountered. While any value that the machine will accept can be employed, numerical values in the order of 10 or so are suggested for initial runs. Thereafter, in order to drive the heat exchanger to its economical limit, or in optimizing a heat exchanger, one can increase these values until this or some other limit is encountered.

The remaining dimensional and/or shape factors or ratios C , N_c , N_h , F_s and R_a are discussed in the text, within Section IV. For instance, C is the sum of all the flow strips, i.e.,

$$C = N_c + N_h \quad (67)$$

N_c and N_h are the selected number of cold and hot flow strips or face areas (see Fig. 3), and will always be in the following relation

$$N_h = N_c - 1 \quad (68)$$

and

$$N_c = N_h + 1 \quad (69)$$

The factor R_a reflects the ratio by which Y_3' is greater than Y_1' . For instance Fig. 3-A, as drawn, reflects an R_a factor of 4.0.

The shape factor F_a is numerically selected at some value greater than 1.0, in those cases where it is desirable to have a rectangular rather than square cross-section heat exchanger.....without specifying either X or Y.....In those cases where a square cross-section is desired, the numerical value of 1.0 is inserted.....With a specified value for F_s , the computer will determine the required X-Y values in consideration of the local environment of temperature, pressure and flow.

The flow factor R_f is not directly employed for calculation purposes within the program, but is entered as a record of the mass flow ratio within the heat exchanger. Therefore

$$R_f = \frac{W \text{ cold side}}{W \text{ hot side}} \quad (70)$$

It will be noted that for HX-1, 3, 5 and 7, R_f will always equal 1.0 since the cold side flow must equal that of the hot side. Within HX-2, 4 and 6, however, the cold side flow will always be greater than the hot side by an amount equal to the associated turbine flow.....Hence R_f reflects the choice of turbine flow relative to the hot side flow. Thus

$$Rf = \frac{Wt + Wh}{Wh} \quad (71)$$

$$= \frac{Wc}{Wh} \quad (72)$$

The numerical value for (1P-31) "CODE," will in all cases be selected as either 1 or 2. Upon inserting the value of 1, the computer will assume the plate material Al-1100-F, and will determine HX-1 size based on this material. Upon inserting the CODE value 2, the computer will evaluate the heat exchanger (HX-1) based on use of Al-3003-F material.

.

Input data for Section III.....Section III is concerned with the input data for heat exchanger HX-2 and turbine 1.

While the input values for HX-2 and turbine 1 may be numerically different from those of HX-1, they are similar in character, with certain deletions and additional data.

Since the presence of turbine 1 now controls two of the HX-2 end-point or "corner" temperatures, Ntui becomes a calculated result and, therefore, can not be used as an input.

Also, since it is desirable to see the effect of various turbine efficiency levels on overall system performance, turbine efficiency η_t is added as an input.....In running the program it is suggested that numerical values be restricted to the range of .30 to .90 or so.

Since a turbine "bridges" HX-2, it will be noted (see Fig. 2) that the cold side flow will be greater than that of the hot side, therefore three flows are now specified..... W_1 for the hot side, W_t for turbine, and W_2 for the cold side.

No restriction is placed on numerical values for these flows other than the following.....Upon inspection of Fig. 2, it will be noted that W_1 must obviously equal the flow through HX-1..... W_t can be any desired value, limited primarily by acceptable Reynold's Number, pressure drop, size of the equipment, and similar limits imposed by all upatream heat exchangers..... W_2 must obviously equal W_1 plus W_t .

In regards to the heat exchanger material CODE, either 1 or 2 is inserted here in accordance with the desired material.

.

Input data for all other sections.....Here, it will be seen that all input data for HX-3, HX-5, and HX-7 is exactly similar, in character, to that of HX-1.....and all input data for HX-4 and HX-6 (including the respective turbines 2 and 3) is exactly similar, in character, to that of HX-2 and turbine 1.

IX. CONCLUSIONS AND RECOMMENDATIONS

From various exploratory runs in checking out the complete program, it is felt that the porous-plate type heat exchanger is probably one of the few configurations capable of reaching very low temperatures, with reasonable component size and weight.

It has been noted, however that while the stack of plates with plastic separators are bonded into a solid assembly as it were, these heat exchangers are mechanically very weak in the endwise direction and would tend to separate as appreciable internal pressure is applied..... Therefore, with the present state-of-the-art, these units must be tightly clamped or held in bolted fixtures such that endwise "blowout" pressure can be resisted.

Their radial resistance to internal pressure is apparently much higher as seen by inspection of Fig. 3, and they have been known to withstand differential pressures of some 2 or 3 atmospheres. It is conceivable, however, that the plastic separators would or could blowout at pressure differentials exceeding say 4 or 5 atmospheres.

Since it may be desirable to design future cryogenic systems with pressure ratios in the order of 8 or 10/1 or more, it is recommended that tests be made with a heat exchanger first wrapped with a plastic layer, e.g. Teflon, then tightly wrapped with a single layer of small diameter, high strength wire.....in addition to endwise bolting or clamping.

X. NOMENCLATURE

<u>Symbol</u>	<u>Entity</u>	<u>Units</u>
A	Area in general	ins ² or ft ²
Af1	Plate face area, hot side	ins ²
Ak2	Face area of heat loss path	ft ²
Ax1	Heat transfer surface area per in ² face area, hot side	ins ²
Axp	Total heat transfer surface area per plate, hot side	ins ²
Ax tot.hs	Total heat transfer surface area, hot side	ft ²
Av	Total hot side heat transfer surface area per unit total volume	ft ² /ft ³
ah1	Total hole flow area, hot side	ins ²
ah2	Total hole flow area, cold side	ins ²
Bx	External border dimension	ins
By	External border dimension	ins
B'	Internal border dimension	ins
C	Configuration factor	= Nh + Nc
Cc2	Heat flow potential, cold side	= W cpcm
Ch1	Heat flow potential, hot side	= W cphm
cp	Specific heat at constant pressure	BTU/lb °R
$\overline{cp}$	Mean specific heat	BTU/lb °R
cpcm	Mean specific heat, cold side	BTU/lb °R
cphm	Mean specific heat, hot side	BTU/lb °R
dh	Hole diameter	ins
e	Base of natural logarithm	2.7182818 etc.

<u>Symbol:</u>	<u>Entity:</u>	<u>Units:</u>
F_s	Shape factor	X/Y
H	Total heat	BTU/lb
H_f	Total heat in fluid or liquid state	BTU/lb
H_g	Total heat in gas state	BTU/lb
ΔH	Total heat change	BTU/lb
ΔH_{fg}	Latent heat of vaporization	BTU/lb
ΔH_L	Total heat load	BTU/lb
ΔH_t	Total turbine work	BTU/lb
h	Film coefficient	BTU-ft/hr-ft ² °R
K	Thermal conductivity	BTU-ft/hr-ft ² °R
$\overline{K_l}$	Thermal conductivity, loss path	BTU-ft/hr-ft ² °R
K_m	Mean thermal conductivity	BTU-ft/hr-ft ² °R
K_p	Plate thermal conductivity	BTU-ft/hr-ft ² °R
L	A length	in or ft
LG	Logic gate in computer program	-
L_w	Total cryogenic load	Watts
l_1	A heat flow path length	ft
l_2	A heat flow path length	ft
l_3	A heat flow path length	ft
l_c	A heat flow path length, loss	ft
N_c	Number of cold flow strips, see Fig. 3	-
N_h	Number of hot flow strips, see Fig. 3	-

<u>Symbol:</u>	<u>Quantity:</u>	<u>Units:</u>
NNu	Nusselt Number	$h \cdot rh / K$
NPr	Prandtl Number	$cp \cdot \mu / K$
NRe	Reynold's Number	$dh \cdot V / \mu$
Ntu	Number of heat transfer units, see text	$AL / Cmin$
ni	Number of holes per in ² face area, hot side	-
np	Number of plates in heat exchanger	-
ns	Number of spacers in heat exchanger	$np + 1$
P	Pressure	psia
ΔP	Pressure difference, actual	psia
$\Delta P'$	Pressure difference, loss	psia
Pcm	Mean Pressure, cold side	psia
Phm	Mean Pressure, hot side	psia
Q	A quantity of heat	BTU
Ql	A quantity of heat, loss	BTU
Qmax	Maximum available quantity of heat	BTU
Rs	Face area ratio per plate	cold side/hot side
Rf	Flow ratio	cold/hot
S	Entropy	BTU/lb °R
s	Hole spacing, center to center	ins
T	Temperature	°R
Tcm	Mean temperature, cold side	°R
Thm	Mean temperature, hot side	°R
Tti	Mean temperature, cold end	°R

Symbol:	Entity:	Units:
T_2	Mean temperature, hot end	$^{\circ}\text{R}$
T_x	Average temperature, hot to cold side	$^{\circ}\text{R}$
t_p	Plate thickness	ins
t_s	Spacer thickness	ins
U	Overall heat transfer coefficient	$\text{BTU-ft/hr-ft}^2\text{ }^{\circ}\text{R}$
V	Velocity	ft/sec
$\bar{v}$	Specific volume	ft^3/lb
W	Flow in general	lbs/sec
W_1	Flow at various points in system, see Fig. 2	lbs/sec
W_2	Flow at various points in system, see Fig. 2	lbs/sec
W_3	Flow at various points in system, see Fig. 2	lbs/sec
W_4	Flow at various points in system, see Fig. 2	lbs/sec
W_{t1}	Turbine 1 flow	lbs/sec
W_{t2}	Turbine 2 flow	lbs/sec
W_{t3}	Turbine 3 flow	lbs/sec
x	External dimension, see Fig. 3	ins
x'	Internal dimension, see Fig. 3	ins
Δx	Temperature difference, cold side	$^{\circ}\text{R}$
y	External dimension, see Fig. 3	ins
y'	Internal dimension, see Fig. 3	ins
y_1'	Internal dimension, see Fig. 3	ins
y_2'	Internal dimension, see Fig. 3	ins
y_3'	Internal dimension, see Fig. 3	ins
Δy	Temperature difference, hot side	$^{\circ}\text{R}$

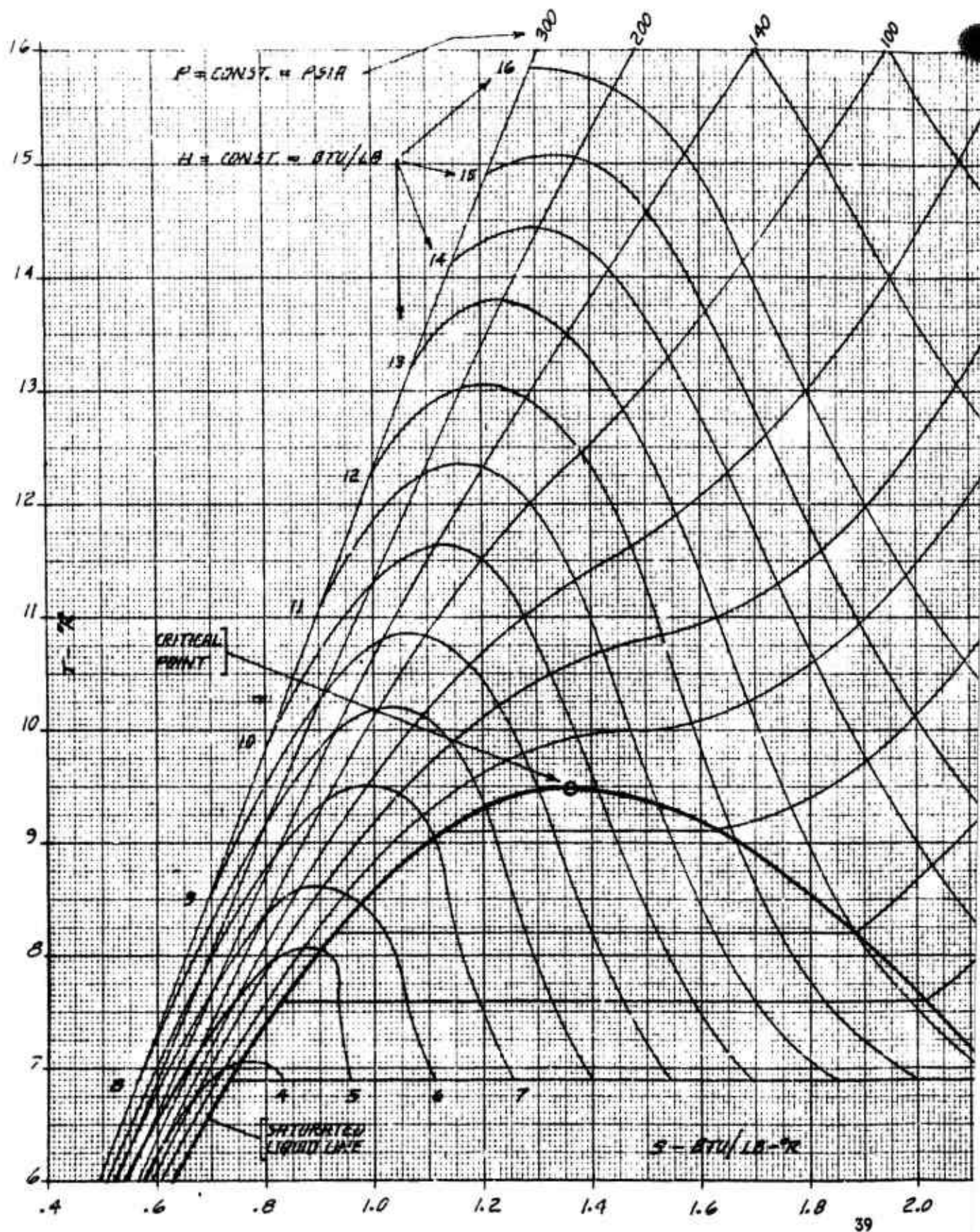
<u>Symbol:</u>	<u>Entity:</u>	<u>Units:</u>
∇_1	Temperature gradient, hot end, see Figs. 4 & 5	$^{\circ}\text{R}$
∇_2	Temperature gradient, cold end, see Figs. 4 & 5	$^{\circ}\text{R}$
Z	Maximum temperature difference	$^{\circ}\text{R}$
∞	Infinity	-
<u>Greek:</u>		
α	An angle	degrees
γ	Specific heat ratio	cp/cv
$\bar{\gamma}$	Mean specific heat ratio	cp/cv
ϵ	Actual heat exchanger effectiveness, with loss	$Q/Q_{\max}$
ϵ_i	Ideal exchanger effectiveness, no loss	$Q/Q_{\max}$
η_f	Fin effectiveness, see equation (124) in HX-1	-
η_t	Turbine efficiency	$\% \times 10^{-2}$
λ	A heat loss function	-
μ	Viscosity	lbs/ft sec
π	Circumference to diameter ratio of the circle	3.14159
σ	Porosity	hole area/in ² face area
<u>Subscripts:</u>		
1	Location identification, see various Figures	-
2	Location identification, see various Figures	-
3 etc	Location identification, see various Figures	-
avg	Average	-
c	Cold	-
h	Hot	-

XI. REFERENCES

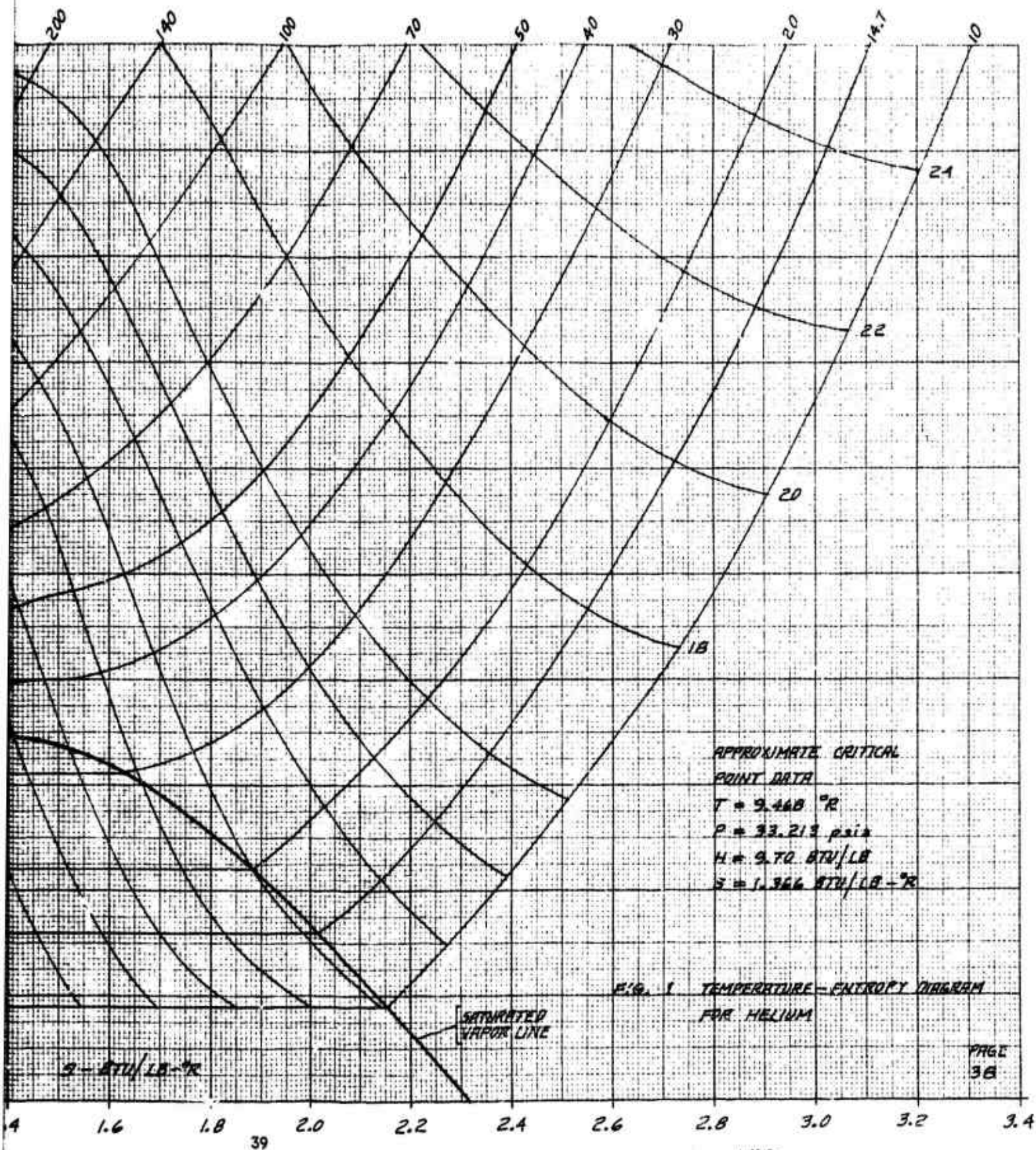
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XII. FIGURES AND TABLES

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A



39

39

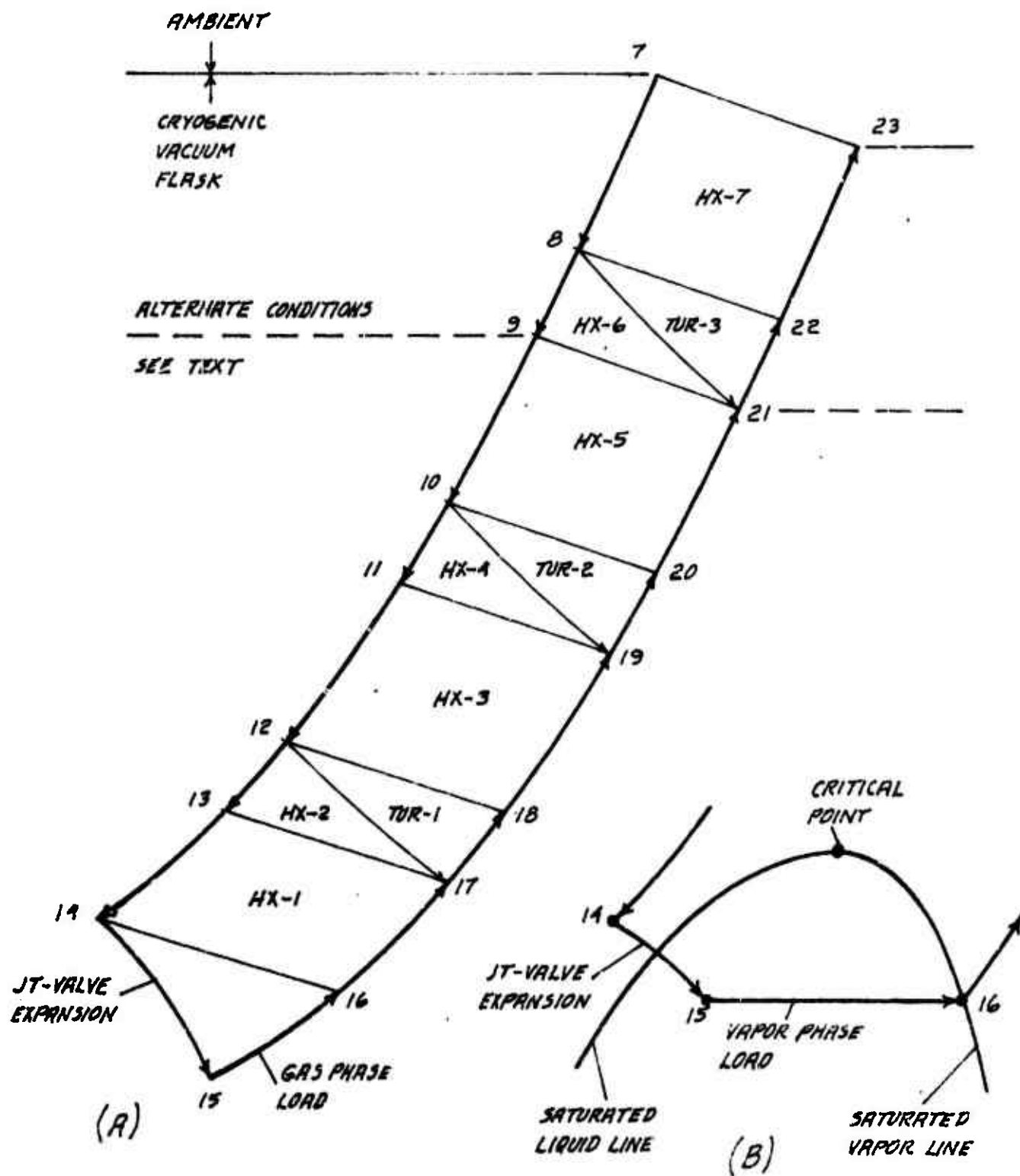
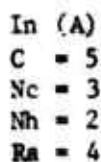
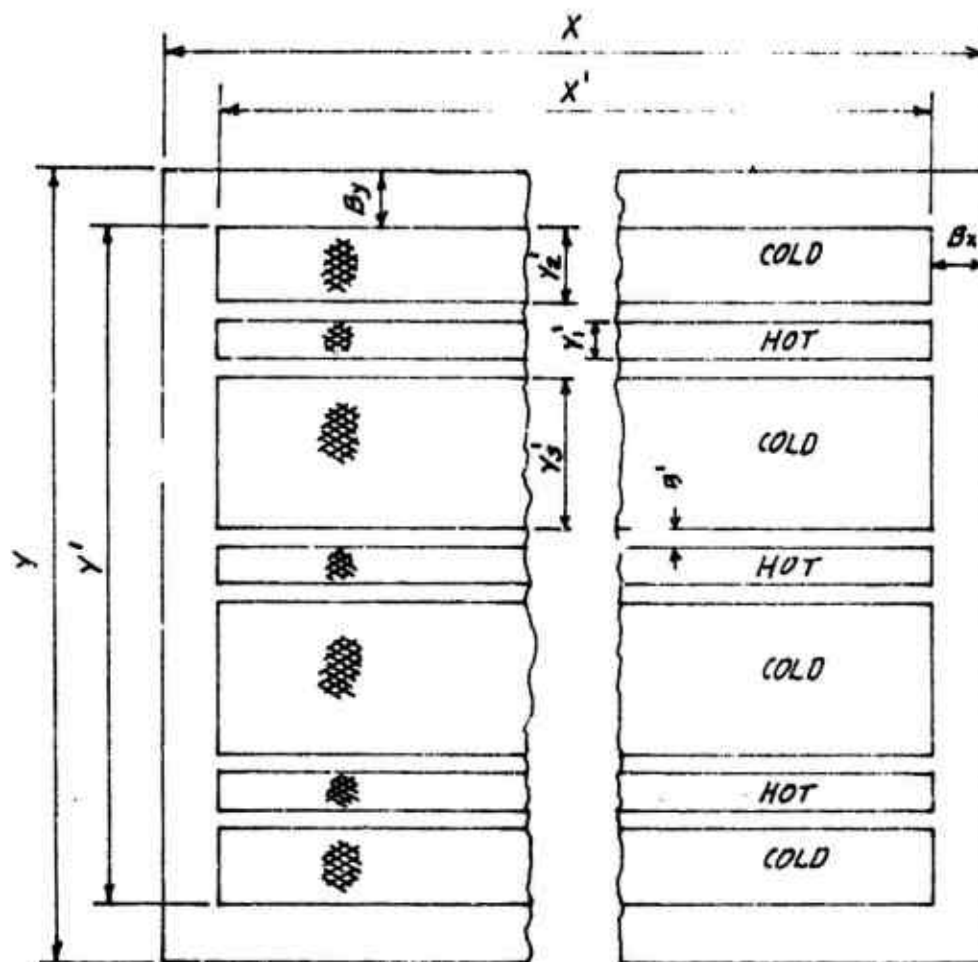


FIG. 2 CRYOGENIC SYSTEM ON THE T-S PLANE
EXTERNAL COMPRESSORS NOT SHOWN



Fs can be	>	1.0
Ra can be	>	1.0
Rf can be	>	1.0

42



In (C)
 $C = 7$
 $N_c = 4$
 $N_h = 3$
 $R_a = 4$

(C)

F_s can be > 1.0
 R_a can be > 1.0
 R_f can be > 1.0

FIG. 3 CONTINUED

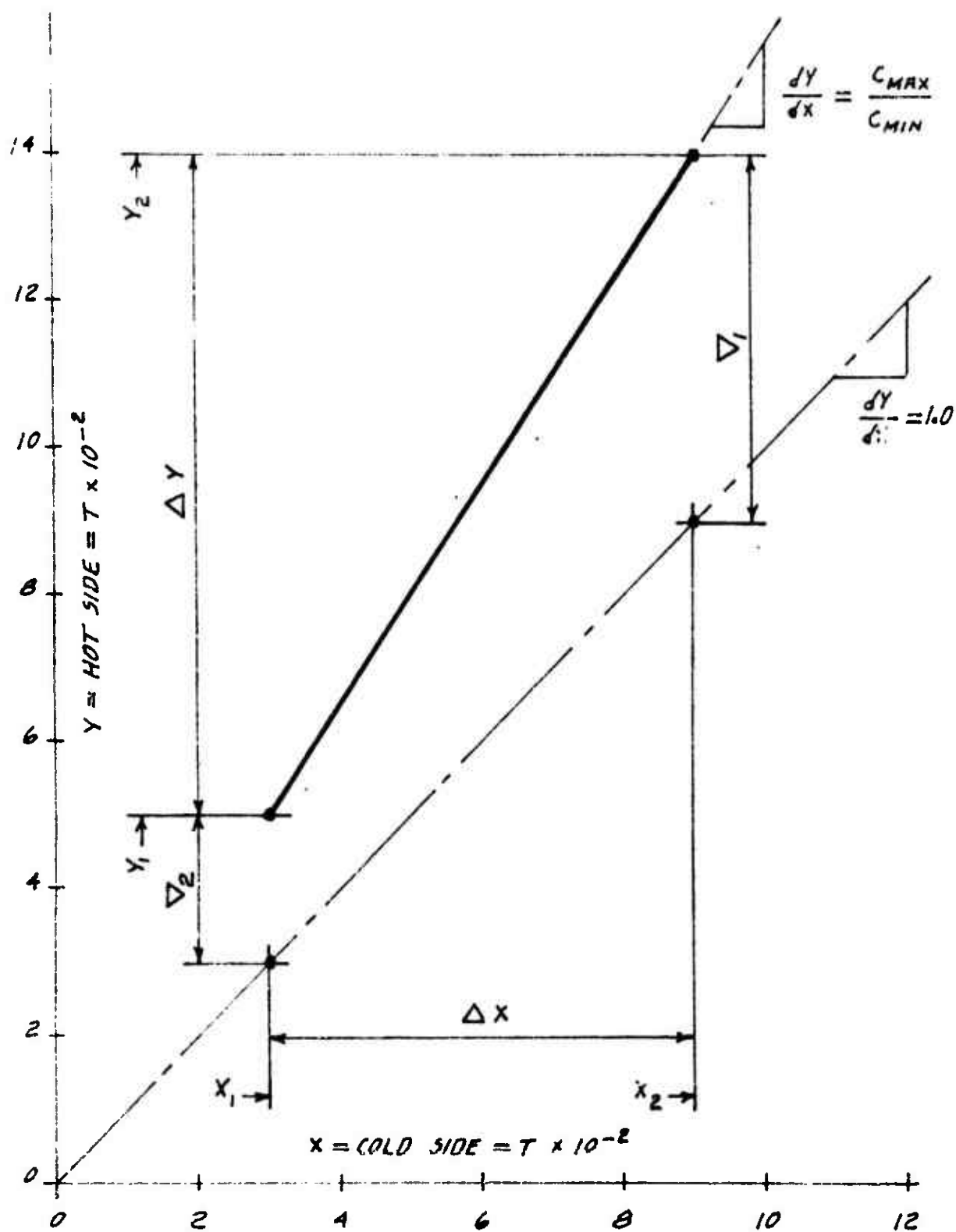


FIG. 4 COUNTER-FLOW HEAT EXCHANGER ON THE TEMPERATURE-TEMPERATURE PLANE

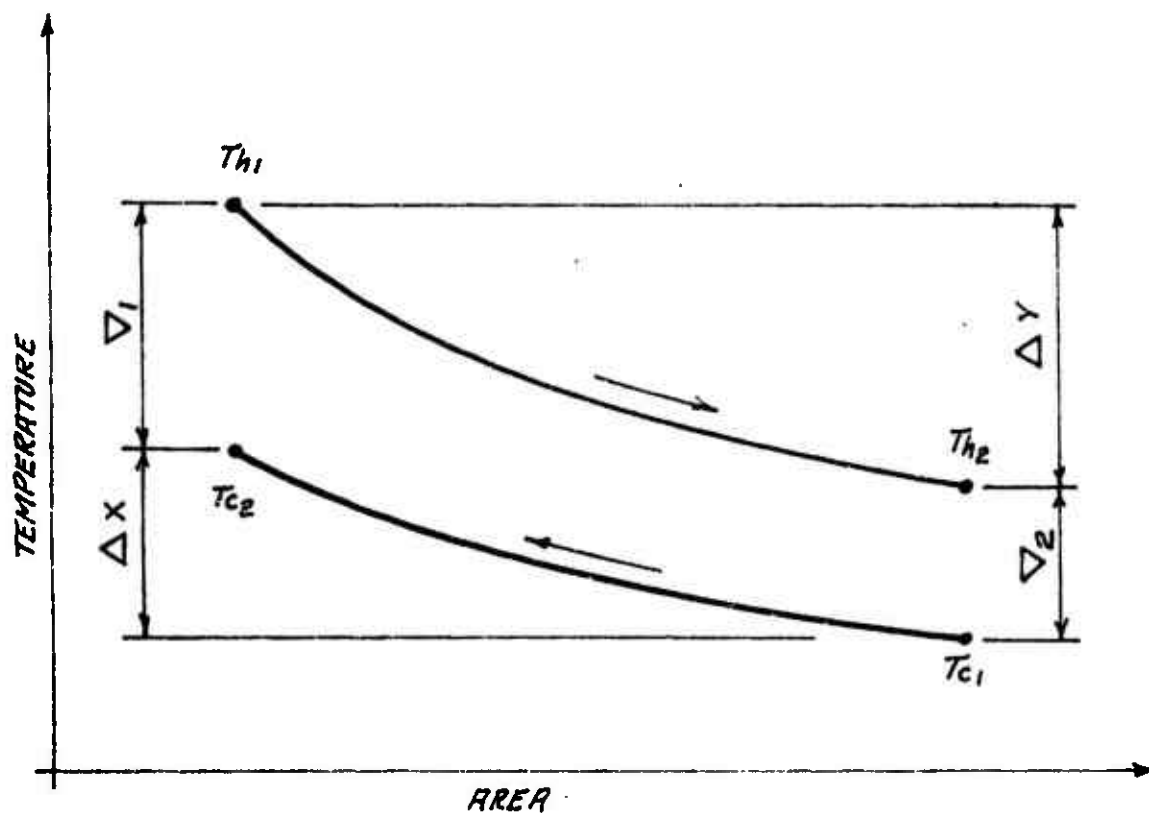


FIG. 5 COUNTER-FLOW HEAT EXCHANGER ON THE TEMPERATURE-AREA PLANE

TABLE 1 HEATS OF VAPORIZATION:

T°R:	P psia:	H _l :	S _l :	H _g :	S _g :	Δ H _{fg} :
6.0	5.58	2.70	.630	12.81	2.315	10.11
6.2	6.44	2.81	.653	12.91	2.271	10.10
6.4	7.35	3.02	.675	12.99	2.231	9.97
6.6	8.35	3.20	.700	13.06	2.195	9.86
6.8	9.44	3.38	.725	13.13	2.160	9.75
7.0	10.64	3.58	.750	13.17	2.125	9.59
7.2	11.93	3.79	.778	13.21	2.095	9.42
7.4	13.31	4.01	.805	13.23	2.050	9.22
7.6	14.80	4.28	.831	13.23	2.010	8.95
7.8	16.43	4.56	.861	13.21	1.970	8.65
8.0	18.13	4.84	.890	13.15	1.928	8.31
8.2	19.90	5.16	.902	13.05	1.886	7.89
8.4	21.85	5.50	.957	12.90	1.841	7.40
8.6	23.91	5.88	.996	12.72	1.794	6.84
8.8	26.28	6.34	1.042	12.45	1.738	6.11
9.0	28.53	6.88	1.098	12.05	1.672	5.17

NOTES.....All temperature = °R

All pressure = psia

All H = BTU/lb

All S = BTU/lb - °R

From ref. (1)

Use with Fig. 1 in preparing load inputs.

APPENDIX I

INPUT DATA

Note.....Readout all inputs for record purposes.

I. LOAD DATA:

At JT-valve inlet:

<u>Input No:</u>	<u>Entity:</u>	<u>Numerical Value:</u>	<u>Units:</u>
(IP-1)	T14 Temperature		°R
(IP-2)	P14 Pressure		psia
(IP-3)	H14 Enthalpy		BTU/lb
(IP-4)	S14 Entropy		BTU/lb°R

At JT-valve exit:

(IP-5)	T15 Temperature		°R
(IP-6)	P15 Pressure		psia
(IP-7)	H15 Enthalpy		BTU/lb
(IP-8)	S15 Entropy		BTU/lb°R

At load exit:

(IP-9)	T16 Temperature		°R
(IP-10)	P16 Pressure		psia
(IP-11)	H16 Enthalpy		BTU/lb
(IP-12)	S16 Entropy		BTU/lb°R
(IP-13)	Δ HL Load		BTU/lb
(IP-14)	Lw Load		Watts

II. HX-1 DATA:

<u>Input No:</u>	<u>Entity:</u>	<u>Numerical Value:</u>	<u>Units:</u>
(IP-15)	dh Hole diameter		inches
(IP-16)	tp Plate thickness		inches
(IP-17)	ts Spacer thickness		inches
(IP-18)	σ Porosity		hole area/face area
(IP-19)	NRe Reynold's Number, hot side		dhV/μ
(IP-20)	Ntui Number of heat transfer units, hot side		
(IP-21)	C Configuration factor		
(IP-22)	Nh Number of hot flow strips		
(IP-23)	Nc Number of cold flow strips		
(IP-24)	Fs Shape factor		
(IP-25)	Ra Face area ratio		see text
(IP-26)	Rf Flow ratio		
(IP-27)	Bx External border dimension		inches
(IP-28)	By External border dimension		inches
(IP-29)	B' Internal border dimension		inches
(IP-30)	W Flow		lbs/sec
(IP-31)	CODE Plate material		see note

III. HX-2 AND TURBINE 1 DATA:

(IP-32)	dh Hole diameter	inches
(IP-33)	tp Plate thickness	inches

<u>Input No:</u>	<u>Entity:</u>	<u>Numerical Value:</u>	<u>Units:</u>
(IP-34)	ta Spacer thickness		inches
(IP-35)	σ Porosity		hole area/face area
(IP-36)	NRe Reynold's Number, hot side		dhV/μ
(IP-37)	C Configuration factor		
(IP-38)	Nh Number of hot flow strips		
(IP-39)	Nc Number of cold flow strips		
(IP-40)	Fa Shape factor		
(IP-41)	Ra Face area ratio		
(IP-42)	Rf Flow ratio		
(IP-43)	Bx External border dimension		
(IP-44)	By External border dimension		
(IP-45)	B' Internal border dimension		
(IP-46)	W1 Hot side flow		
(IP-47)	Wt1 Turbine flow		lbs/sec
(IP-48)	W2 Cold side flow		lbs/sec
(IP-49)	η_t Turbine efficiency		% x 10 ⁻²
(IP-50)	CODE Plate material		see note

IV. HX-3 DATA:

(IP-51)	dh Hole diameter	inches
(IP-52)	tp Plate thickness	inches
(IP-53)	ts Spacer thickness	inches

Input No:	Entity:	Numerical Value:	Units:
(IP-54)	σ Porosity		hole area/face area
(IP-55)	NRe: Reynold's Number, hot side		$dhV/\bar{\mu} \mu$
(IP-56)	Ncu: Number of heat transfer units, hot side		
(IP-57)	C Configuration factor		
(IP-58)	Nh Number of hot flow strips		
(IP-59)	Nc Number of cold flow strips		
(IP-60)	Fs Shape factor		
(IP-61)	Ra Face area ratio		see text
(IP-62)	Rf Flow ratio		
(IP-63)	Bx External border dimensions		
(IP-64)	By External border dimension		
(IP-65)	B' Internal border dimension		
(IP-66)	W2 Flow		lbs/sec
(IP-67)	CODE Plate material		see note

V. HX-4 AND TURBINE 2 DATA:

(IP-68)	dh	Hole diameter	inches
(IP-69)	tp	Plate thickness	inches
(IP-70)	ts	Spacer thickness	inches
(IP-71)	σ	Porosity	hole area/face area
(IP-72)	NRe:	Reynold's Number, hot side	$dhV/\bar{\mu} \mu$

<u>Input No:</u>	<u>Entity:</u>	<u>Numerical Value:</u>	<u>Units:</u>
(IP-73)	C Configuration factor		
(IP-74)	Nh Number of hot flow strips		
(IP-75)	Nc Number of cold flow strips		
(IP-76)	Fs Shape factor		
(IP-77)	Ra Face area ratio		
(IP-78)	Rf Flow ratio		
(IP-79)	Bx External border dimension		inches
(IP-80)	By External border dimension		inches
(IP-81)	B' Internal border dimension		inches
(IP-82)	W2 Hot side flow		lbs/sec
(IP-83)	Wt2 Turbine flow		lbs/sec
(IP-84)	W3 Cold side flow		lbs/sec
(IP-85)	η_t Turbine efficiency		% x 10 ⁻²
(IP-86)	'CODE Plate material		see note

VI. HX-5 DATA:

(IP-87)	dh	Hole diameter	inches
(IP-88)	tp	Plate thickness	inches
(IP-89)	ts	Spacer thickness	inches
(IP-90)	ϕ	Porosity	hole area/face area
(IP-91)	NRe	Reynold's Number, hot side	$dhV/\overline{\nu} \mu$

<u>Input No:</u>	<u>Entity:</u>	<u>Numerical Value:</u>	<u>Units:</u>
(IP-92)	Ntut Number of heat transfer units, hot side		 see text
(IP-93)	C Configuration factor		
(IP-94)	Nh Number of hot flow strips		
(IP-95)	Nc Number of cold flow strips		
(IP-96)	Fs Shape factor		
(IP-97)	Ra Face area ratio		
(IP-98)	Rf Flow ratio		
(IP-99)	Bx External border dimension		inches
(IP-100)	By External border dimension		inches
(IP-101)	B' Internal border dimension		inches
(IP-102)	W3 Flow		lbs/sec
(IP-103)	CODE Plate material		see note

VII. HX-6 AND TURBINE 3 DATA:

(IP-104)	dh	Hole diameter	inches
(IP-105)	tp	Plate thickness	inches
(IP-106)	ts	Spacer thickness	inches
(IP-107)	σ	Porosity	hole area/face area
(IP-108)	NRe	Reynold's Number, hot side	dhV/μ
(IP-109)	C	Configuration factor	see text
(IP-110)	Nh	Number of hot flow strips	see text

<u>Input No:</u>	<u>Entity:</u>	<u>Numerical Value:</u>	<u>Units:</u>
(IP-111)	Nc Number of cold flow strips		↑
(IP-112)	Fs Shape factor		
(IP-113)	Ra Face area ratio		see text
(IP-114)	Rf Flow ratio		↓
(IP-115)	Bx External border dimension		inches
(IP-116)	By External border dimension		inches
(IP-117)	B' Internal border dimension		inches
(IP-118)	W3 Hot side flow		lbs/sec
(IP-119)	Wt3 Turbine flow		lbs/sec
(IP-120)	W4 Cold side flow		lbs/sec
(IP-121)	η_t Turbine efficiency		% x 10 ⁻²
(IP-122)	CODE Plate material		see note

VIII. HX-7 DATA:

(IP-123)	dh Hole diameter		inches
(IP-124)	tp Plate thickness		inches
(IP-125)	ts Spacer thickness		inches
(IP-126)	σ Porosity		hole area/face area
(IP-127)	NRe Reynold's Number, hot side		$dhV/\bar{\nu} \mu$
(IP-128)	Ntui Number of heat transfer units, hot side		↑
(IP-129)	C Configuration factor		see text
(IP-130)	Nh Number of hot flow strips		↓

<u>Input No:</u>	<u>Entity:</u>	<u>Numerical Value:</u>	<u>Units:</u>
(IP-131)	Nc	Number of cold flow strips	 see text
(IP-132)	Fs	Shape factor	
(IP-133)	Rs	Face area ratio	
(IP-134)	Rf	Flow ratio	
(IP-135)	Bx	External border dimension	inches
(IP-136)	By	External border dimension	inches
(IP-137)	B'	Internal border dimension	inches
(IP-138)	W4	Flow	lbs/sec
(IP-139)	CODE	Plate material	see note

Note.....For (IP-31-50-67-86-103-122 and 139),
 Insert "1" for AL-1100-F, or
 Insert "2" for AL-3003-F

APPENDIX II

HX-1 PROGRAM.....CALL HX(J) $j = 1.0$

Inputs:

Call numerical values from APPENDIX I, Sections I and II.

Initial numerical assumptions:

Equa. No.	Initial value:
(4)	150.0
(5)	T14+10
(6)	1.02 P14
(13)	2.0
(35)	T16+10
(36)	.98 P16

Notes:

Readout last result of all equations marked with a star "*".
Do not stop machine at TEST 9.

HOT SIDE:

$$S = \sqrt{.906894 \frac{dh^2}{\sigma}} \quad (1)^*$$

$$n = \frac{4 \sigma}{\pi dh^2} \quad (2)^*$$

$$Ax1 = \left(n \pi dh \right) + " (1-\sigma) \quad (3)^*$$

$$np = \text{assume} \quad (4)^*$$

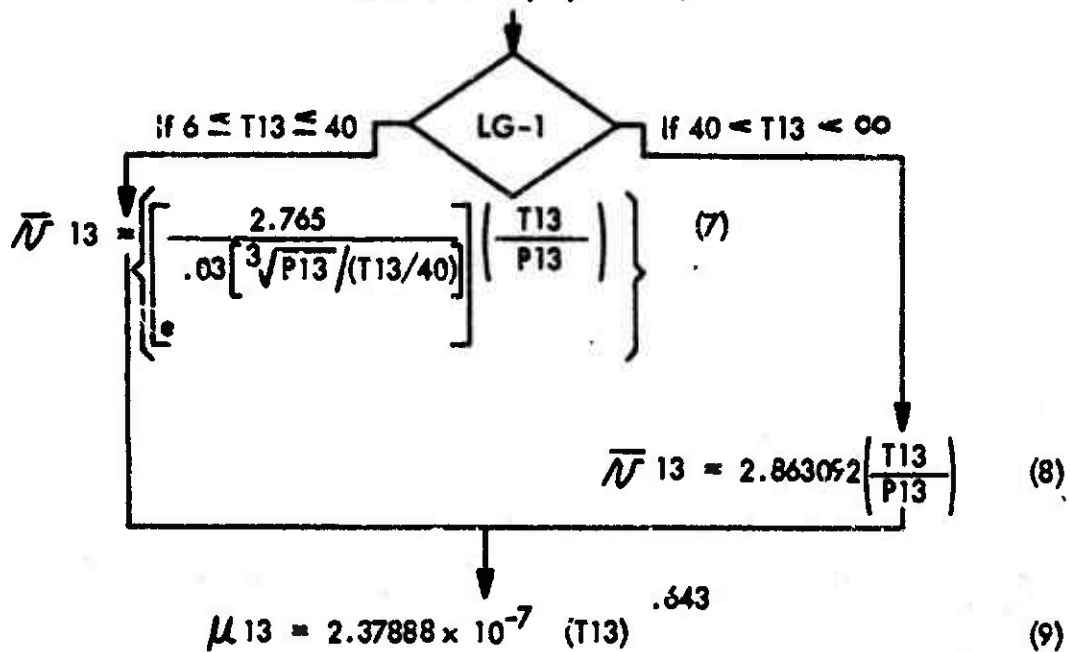
(Will be altered only by TEST 8)

T13 = assume
(Will be altered only by TEST 6)

(5)*

P13 = assume
(Will be altered only by TEST 2)

(6)*



$$V13 = \frac{12 \text{ NRei } \bar{N}_{13} \mu_{13}}{d_h} \quad (10)*$$

$$d_{h1} = \frac{144 \text{ Wi } \bar{N}_{13}}{V13} \quad (11)*$$

$$Af1 = \frac{d_{h1}}{\sigma} \quad (12)*$$

X = assume
(Will be altered only by TEST 1)

(13)*

$$X' = X - (2 Bx) \quad (14)*$$

$$Y' = \frac{X}{F_s} - (2 B_y) \quad (15)^*$$

$$Y'_1 = \frac{Y' - \left[\frac{(C-1) B'}{2} \right] - N_h}{2 (C-1)} \quad (16)^*$$

$$Af_1 \text{ calculated} = N_h (X' Y'_1) \quad (17)$$

TEST 1

(17) must = (12) $\pm$.001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " " "

$$Y'_2 = Y'_1 \frac{Ra}{2} \quad (18)^*$$

$$Y'_3 = Y'_1 \cdot Ra \quad (19)^*$$

$$\zeta_1 = \frac{Y'_1}{24} \quad (20)$$

$$\zeta_2 = \frac{B'}{12} \quad (21)$$

$$\zeta_3 = \frac{Y'_3}{12 \cdot Ra} \quad (22)$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} V_{13}^2}{\bar{\mu}^{13}} \sqrt{\frac{|t_p/dh|}{NRe_1}} \quad (23)$$

$$\Delta P_1 = n_p \cdot \Delta P'_1 \quad (24)^*$$

$$P_{13} \text{ calculated} = P_{14} + \Delta P_1 \quad (25)$$

TEST 2

(25) must = (6) $\pm$.001

If (25) $>$ (6), increase (6) and iterate from (6).

" " $<$ " , reduce " " " " " " .

$$\mu m_1 = \frac{8.55497 \times 10^{-4}}{(T_{13} - T_{14})} \left\{ \frac{[(T_{13})^{1.643} - (T_{14})^{1.643}]}{1.643} \right\} \quad (26)$$

$$K_{m1} = \frac{57.79 \times 10^{-3}}{[.00355 (T_{13} - T_{14})]} \left\{ \frac{[(.00355 T_{13})^{1.642} - (.00355 T_{14})^{1.642}]}{1.642} \right\} \quad (27)$$

$$Thm = \frac{\left(\frac{K_{m1}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (28)$$

$$Phm = \frac{(P_{13} + P_{14})}{2} \quad (29)$$

Call cp subroutine and, with
Thm and Phm.....get (30)

$$cphm = \leftarrow$$

$$Ch_1 = cphm \cdot W_1 \quad (31)^*$$

$$NP_{r1} = \frac{cphm \cdot \mu m_1}{K_{m1}} \quad (32)^*$$

$$NNu1 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe1 \cdot NPr1} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{Nre1 \cdot Npr1} \right] \cdot .8} \right)} \right\} \quad (33)^*$$

$$h_{1-2} = \frac{NNu1 \cdot Km1}{dh} \quad (34)^*$$

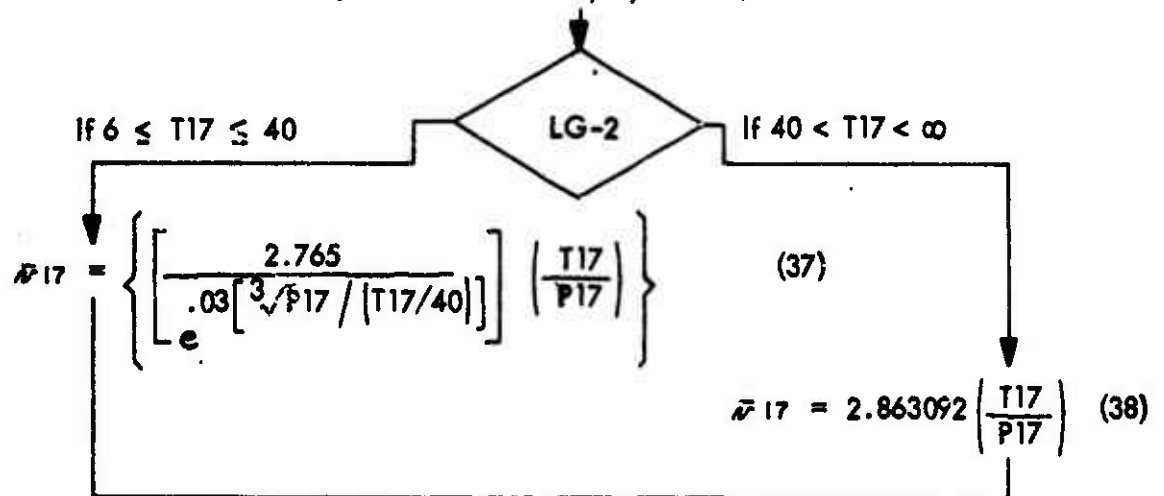
COLD SIDE:

$$T17 = \text{assume} \quad (35)^*$$

(Will be altered only by TEST 5)

$$P17 = \text{assume} \quad (36)^*$$

(Will be altered only by TEST 3)



$$ah2 = ah1 \cdot Ra \quad (39)^*$$

$$V17 = \frac{144 W1}{ah2} \cdot \bar{N}17 \quad (40)^*$$

$$\mu_{17} = 2.37888 \times 10^{-7} (T17)^{.643} \quad (41)$$

$$NRe_2 = \frac{V17 \cdot dh}{12 \bar{\mu}_{17} \cdot \mu_{17}} \quad (42)^*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} V17^2}{\bar{\mu}_{17}} \sqrt{\frac{(tp/dh)}{NRe_2}} \quad (43)$$

$$\Delta P_2 = n_p \cdot \Delta P'_2 \quad (44)^*$$

$$P17 \text{ calculated} = P16 - \Delta P_2 \quad (45)$$

TEST 3

(45) must = (36) $\pm$.001

If (45) > (36), increase (36) and iterate from (36).

" " < " , reduce " " " " " " ,

TEST 4

"REDUCE NRe1, or

If (45) < 10, stop & readout message..... INCREASE Ra "

" " $\geq$ " , continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T17 - T16)} \left\{ \frac{[(T17)^{1.643} - (T16)^{1.643}]}{1.643} \right\} \quad (46)$$

$$Km_2 = \frac{57.79 \times 10^{-3}}{[.00355 (T17 - (T16))]} \left\{ \frac{[(.00355 T17)^{1.642} - (.00355 T16)^{1.642}]}{1.642} \right\} \quad (47)$$

$$T_{cm} = \frac{\left(\frac{K_{m2}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (48)$$

$$P_{cm} = \frac{(P16 + P17)}{2} \quad (49)$$

Call cp subroutine and, with
Tcm and Pcm get

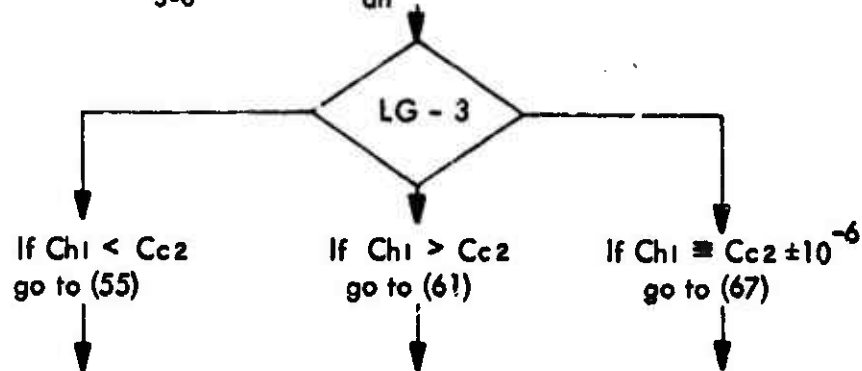
$$cpcm = \leftarrow \quad (50)$$

$$Cc2 = cpcm \cdot W1 \quad (51)^*$$

$$NPr2 = \frac{cpcm \cdot \mu \cdot m2}{K_{m2}} \quad (52)^*$$

$$NNu2 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left(\frac{tp/dh}{NRe2 \cdot NPr2} \right)} \right)}{1 + \left(\frac{.016}{\left(\frac{tp/dh}{NRe2 \cdot NPr2} \right)^{.8}} \right)} \right\} \quad (53)^*$$

$$h = \frac{12 \text{ } N N u_2 \cdot K m_2}{5-6 \text{ } d h} \quad (54)^*$$



If $Ch_1 < C_{c2}$

$$\nabla_1 = (T_{14} - T_{16}) \cdot N t u_1 \left[1 - (Ch_1 / C_{c2}) \right] \quad (55)$$

$$\Delta X = \frac{\nabla_1 - (T_{14} - T_{16})}{\left(\frac{C_{c2}}{Ch_1} \right) - 1} \quad (56)$$

$$\Delta Y = \left(\frac{C_{c2}}{Ch_1} \right) \cdot \Delta X \quad (57)$$

$$T_{17} \text{ calculated} = T_{16} + \Delta X \quad (58)$$

TEST 5-A

(58) must = (35) ± .001

If (58) > (35), Increase (35) and iterate from (35).

" " < " , reduce " " " " " "

$$T13 \text{ calculated} = T14 + \Delta Y \quad (59)$$

TEST 6-A

(59) must = (5) $\pm .001$

If (59) > (5), increase (5) and iterate from (5).

" " < " , reduce " " " " " "

$$\epsilon_i = \frac{1 - e^{-N_{tui} [1 - (C_{h1}/C_{c2})]}}{1 - \left\{ \left(\frac{C_{h1}}{C_{c2}} \right) e^{-N_{tui} [1 - (C_{h1}/C_{c2})]} \right\}} \quad (60)^*$$

Then go to (71)

If $C_{h1} > C_{c2}$

$$\nabla_1 = (T14 - T16) e^{N_{tui} [1 - (C_{c2}/C_{h1})]} \quad (61)$$

$$\Delta X = \frac{\nabla_1 - (T14 - T16)}{\left(\frac{C_{h1}}{C_{c2}} \right) - 1} \quad (62)$$

$$\Delta Y = \left(\frac{C_{h1}}{C_{c2}} \right) \cdot \Delta X \quad (63)$$

$$T17 \text{ calculated} = T16 + \Delta X \quad (64)$$

TEST 5-B

(64) must = (35) $\pm .001$

If (64) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " " "

$$T13 \text{ calculated} = T14 + \Delta Y \quad (65)$$

TEST 6-B

(65) must = (5) ± 0.001

If (65) > (5), increase (5) and iterate from (5).

" " < " , reduce " " " " " " .

$$\epsilon_i = \frac{1 - e^{-Nt_{ui} \left[1 - (C_{c2}/C_{hi}) \right]}}{1 - \left\{ \left(\frac{C_{c2}}{C_{hi}} \right) e^{-Nt_{ui} \left[1 - (C_{c2}/C_{hi}) \right]} \right\}} \quad (66)^*$$

Then go to (71)

$$\boxed{\text{If } C_{hi} \equiv C_{c2} \pm 10^{-6}}$$

$$Z = \frac{(T14 - T16)}{1 - \left(\frac{Nt_{ui}}{1 + Nt_{ui}} \right)} \quad (67)$$

$$T17 \text{ calculated} = (T16 + Z) - (T14 - T16) \quad (68)$$

TEST 5-C

(68) must = (35) ± 0.001

If (68) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " " " .

$$T13 \text{ calculated} = T16 + Z \quad (69)$$

TEST 6-C

(69) must = (5) ± 0.001

If (69) > (5), increase (5) and iterate from (5).

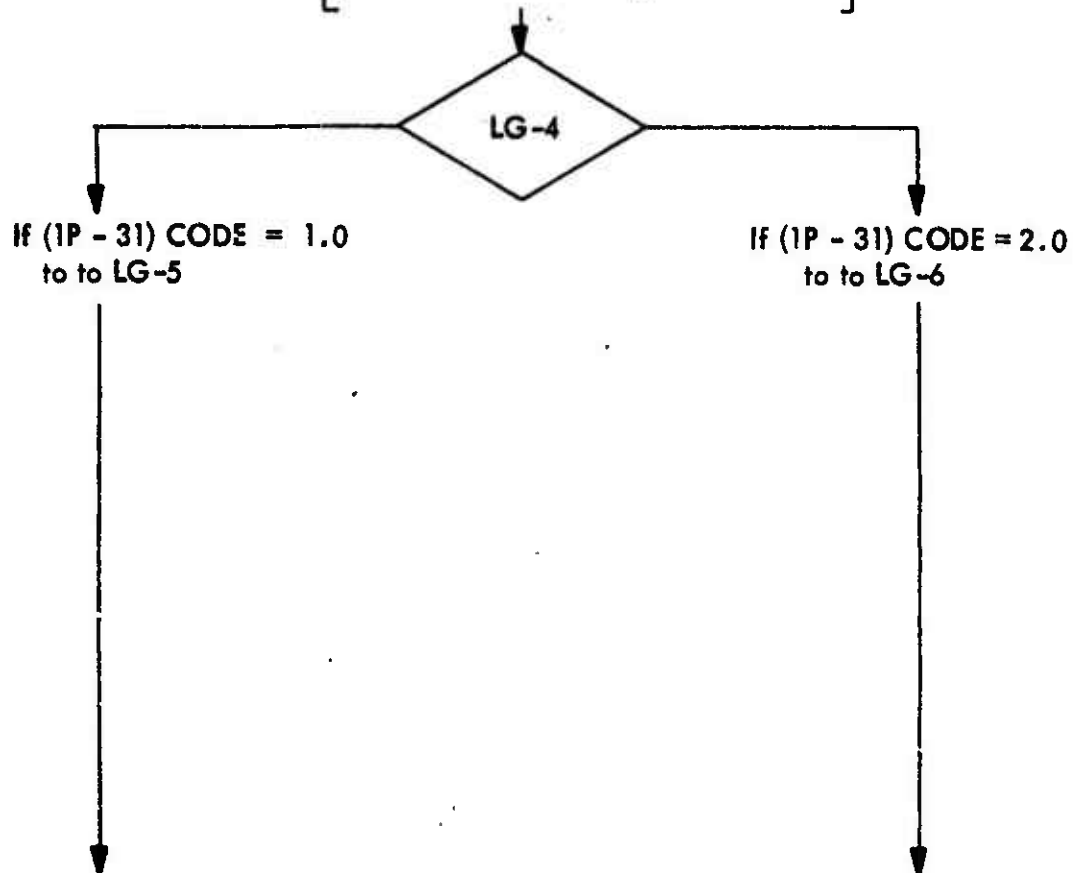
" " < " , reduce " " " " " " .

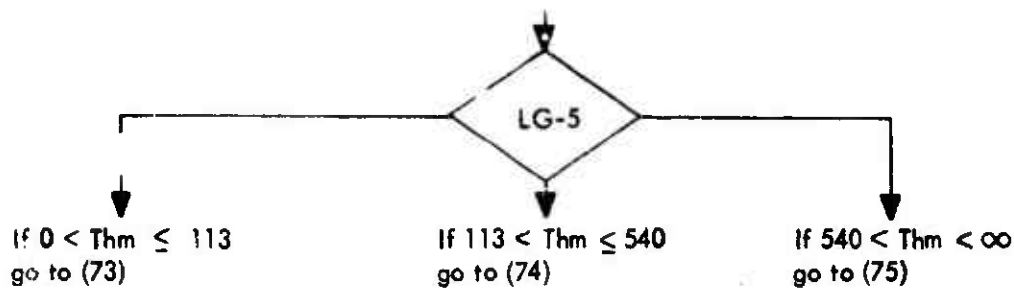
$$\epsilon_i = \frac{N_{tui}}{1 + N_{tui}} \quad (70)^*$$

Then go to (71)

$$T'_1 = T_{hm} - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3} \right) (T_{hm} - T_{cm}) \right] \quad (71)$$

$$T'_2 = T_{hm} - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3} \right) (T_{hm} - T_{cm}) \right] \quad (72)$$





$$K_p = \frac{1}{[.1 (Thm - T'i)]} \left\{ \frac{49}{2} \left[(.1 Thm)^2 - (.1 T'i)^2 \right] - \frac{1}{3.47} \left[(.1 Thm)^{3.47} - (.1 T'i)^{3.47} \right] \right\} \quad (73)$$

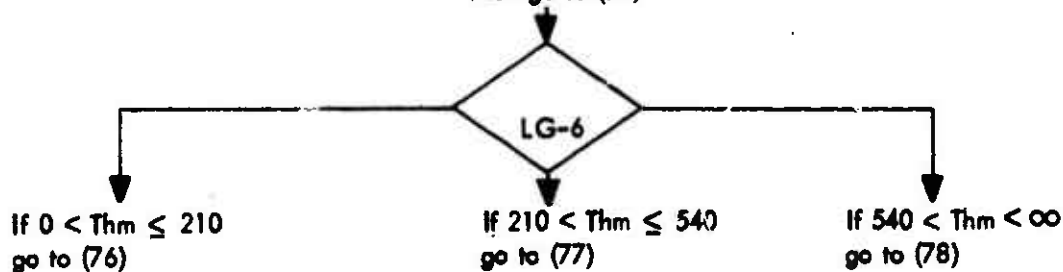
Then go to (79)

$$K_p = \frac{1}{[.1 (Thm - T'i)]} \left\{ \left[-\frac{[(.1 Thm)^{2.708} - (.1 T'i)^{2.708}]}{2.708} \right] + \left[9.551 \left[(.1 Thm)^2 - (.1 T'i)^2 \right] \right] \right\} \quad (74)$$

Then go to (79)

$$K_p = 111.74 = \text{constant} \quad (75)$$

Then go to (79)



$$K_p = \frac{1}{(Thm - T'i)} \left\{ \left[\frac{2.765}{2} \left[(Thm)^2 - (T'i)^2 \right] \right] - \left[\frac{[(Thm)^{2.16} - (T'i)^{2.16}]}{2.16} \right] \right\} \quad (76)$$

Then go to (79)

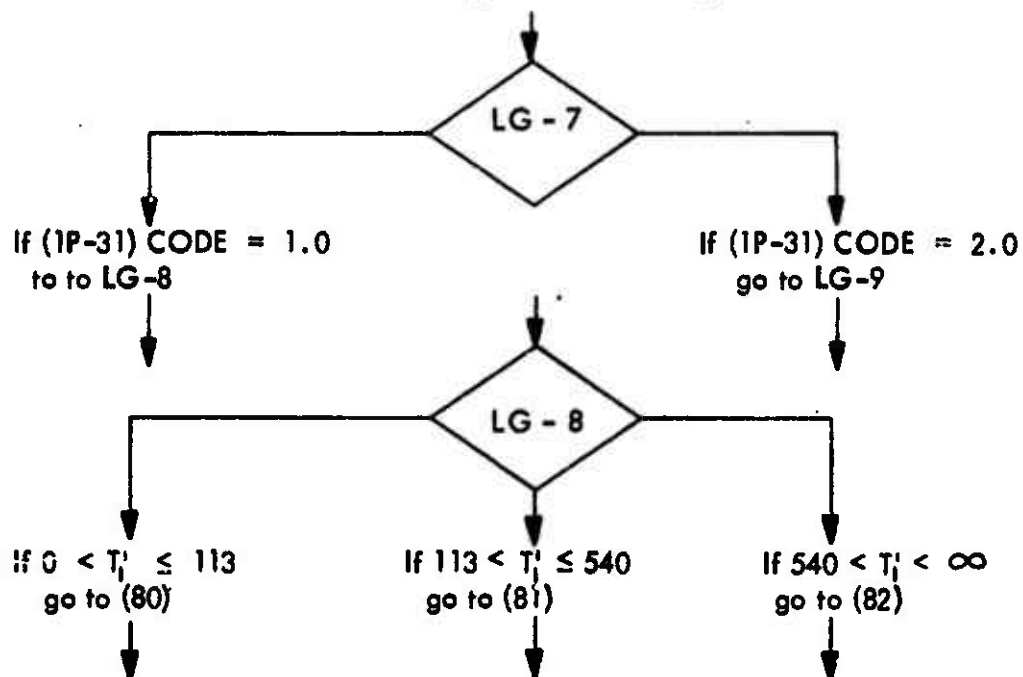
$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T_{hm} + T'_1) / 2] - 210}{330} \right) \right\} \quad (77)$$

Then go to (79)

$$K_p = 92.25 = \text{constant} \quad (78)$$

Then go to (79)

$$K_{2-3} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (79)^*$$



$$K_p = \frac{1}{[.1 (T'_1 - T'_2)]} \left\{ \frac{49}{2} [(.1 T'_1)^2 - (.1 T'_2)^2] - \frac{1}{3.47} [(.1 T'_1)^{3.47} - (.1 T'_2)^{3.47}] \right\}$$

Then go to (86)

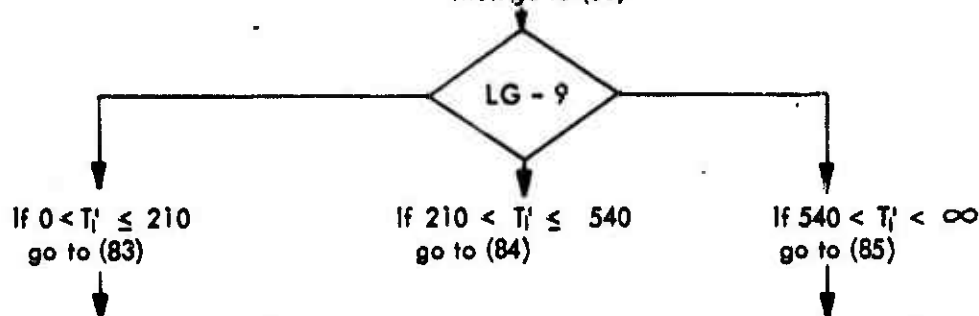
(80)

$$K_p = \frac{1}{[.1(T_1' - T_2')]} \left\{ \left[-\frac{(.1 T_1')^{2.708} - (.1 T_2')^{2.708}}{2.708} \right] + \left[9.551 [(.1 T_1')^2 - (.1 T_2')^2] \right] \right\} \quad (81)$$

Then go to (86)

$$K_p = 111.74 = \text{constant} \quad (82)$$

Then go to (86)



$$K_p = \frac{1}{(T_1' - T_2')} \left\{ \frac{2.765}{2} [(T_1')^2 - (T_2')^2] - \left[\frac{(T_1')^{2.16} - (T_2')^{2.16}}{2.16} \right] \right\} \quad (83)$$

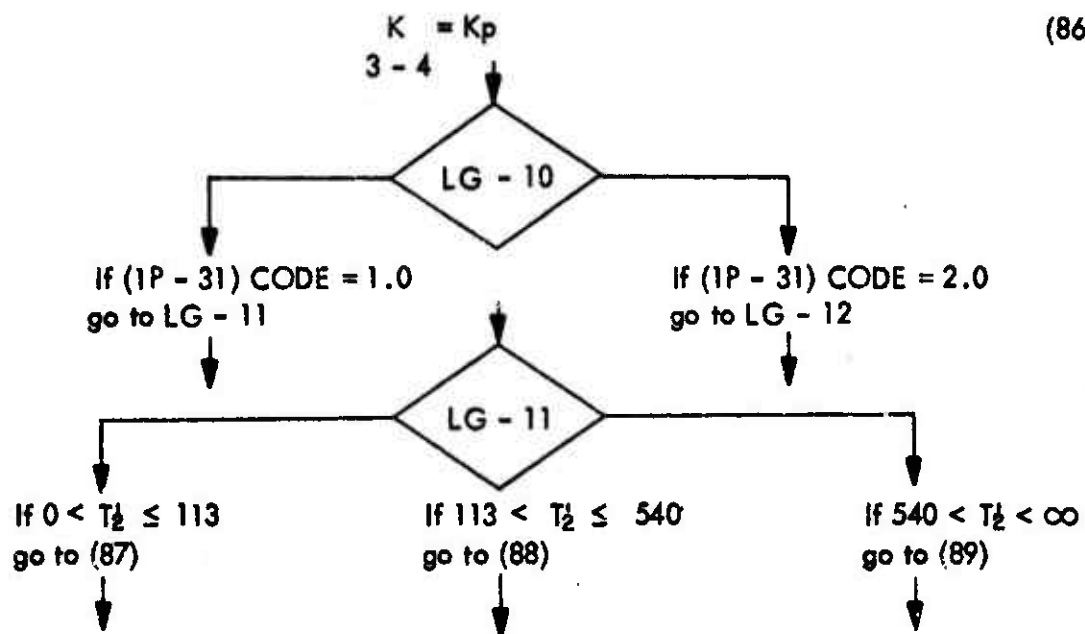
Then go to (86)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T_1') + T_2'] / 2 - 210}{330} \right) \right\} \quad (84)$$

Then go to (86)

$$K_p = 92.25 = \text{constant} \quad (85)$$

Then go to (86)



$$K_p = \frac{1}{[.1 (T'_{1/2} - T_{cm})]} \left\{ \frac{49}{2} \left[(.1 T'_{1/2})^2 - (.1 T_{cm})^2 \right] - \frac{1}{3.47} \left[(.1 T'_{1/2})^{3.47} - (.1 T_{cm})^{3.47} \right] \right\} \quad (87)$$

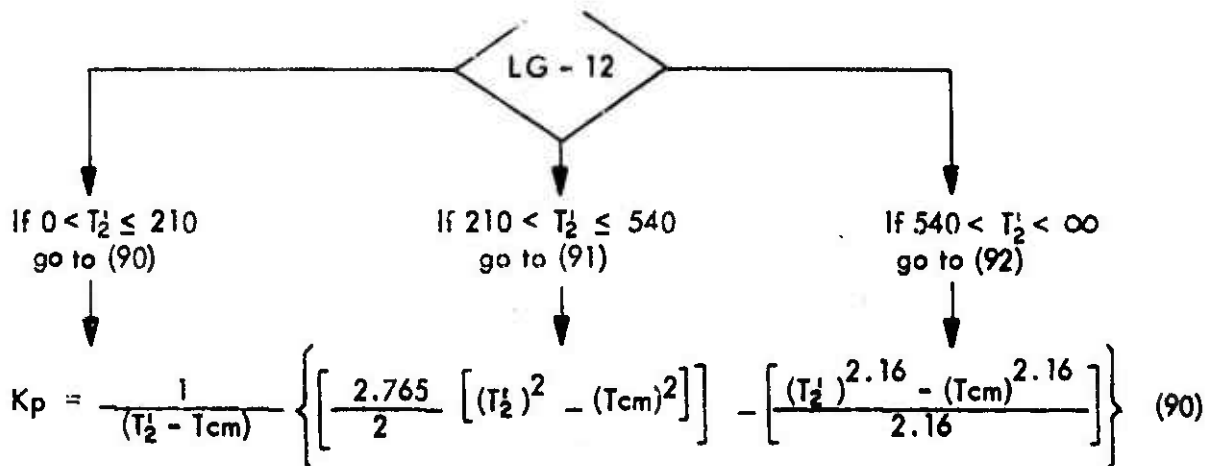
Then go to (93)

$$K_p = \frac{1}{[.1 (T'_{1/2} - T_{cm})]} \left\{ \left[- \frac{2.708}{2.708} \frac{(.1 T'_{1/2})^{2.708} - (.1 T_{cm})^{2.708}}{2.708} \right] + \left[9.551 \left[(.1 T'_{1/2})^2 - (.1 T_{cm})^2 \right] \right] \right\} \quad (88)$$

Then go to (93)

$$K_p = 111.74 = \text{constant} \quad (89)$$

Then go to (93)



Then go to (93)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T_2') + T_{cm}] / 2 - 210}{330} \right) \right\} \quad (91)$$

Then go to (93)

$$K_p = 92.25 = \text{constant} \quad (92)$$

Then go to (93)

$$K_{4-5} = K_p \cdot 0.93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (93)^*$$

$$U = \frac{1}{\frac{1}{h_{1-2}} + \frac{\lambda_1}{K_{2-3}} + \frac{\lambda_2}{K_{3-4}} + \frac{\lambda_3}{K_{4-5}} + \frac{1}{h_{5-6}}} \quad (94)^*$$

$$n_s = n_p + 1 \quad (95)^*$$

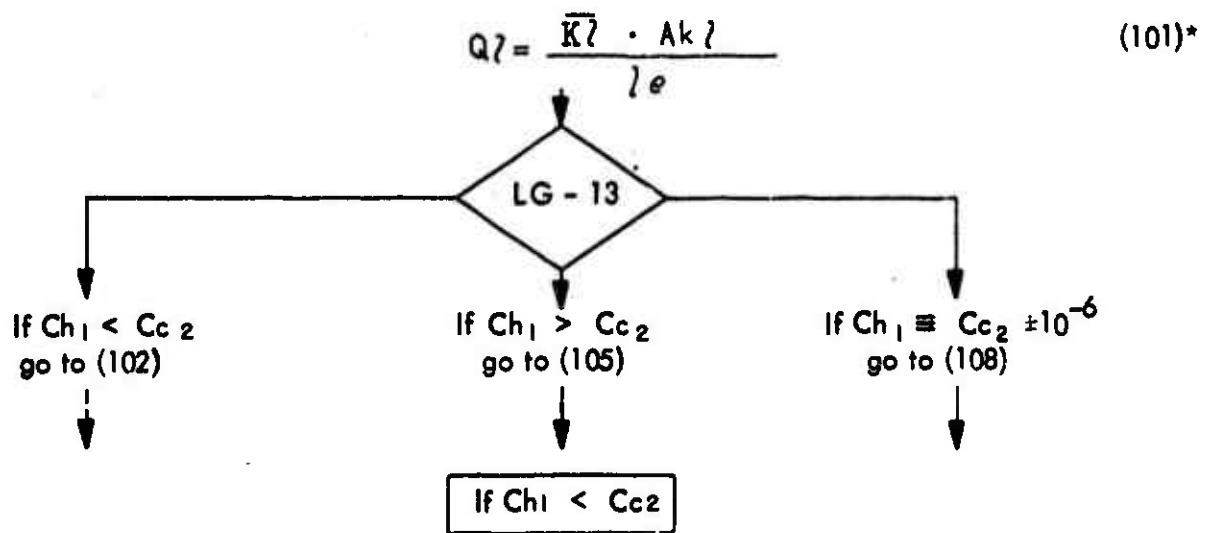
$$\lambda_e = \frac{n_s \cdot t_s}{12} \quad (96)$$

$$T \lambda_1 = \frac{(T14 + T16)}{2} \quad (97)$$

$$T \lambda_2 = \frac{(T13 + T17)}{2} \quad (98)$$

$$Ak \lambda = \frac{\left[(X^2 / F_s) - (X' Y') \right] + \left[(C-1) X' B' \right]}{144} \quad (99)$$

$$\overline{K \lambda} = \frac{7.27 \times 10^{-3}}{(T \lambda_2 - T \lambda_1)} \left[\frac{(T \lambda_2)^{1.585} - (T \lambda_1)^{1.585}}{1.585} \right] \quad (100)$$



$$\lambda = \frac{Q \lambda}{3600 \text{ Ch}_1} \quad (102)*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (103)^*$$

TEST 7-A

If (103) ≥ 1.0 , stop & readout message "REDUCE Ntui"
 " " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(\frac{Ch_1}{Cc_2} \right)}{1 - \epsilon} \right]}{1 - \left(\frac{Ch_1}{Cc_2} \right)} \quad (104)^*$$

Then go to LG-14

If $Ch_1 > Cc_2$

$$\lambda = \frac{Q_i}{3600 Cc_2} \quad (105)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (106)^*$$

TEST 7-B

If (106) ≥ 1.0 , stop & readout message "REDUCE Ntui"
 " " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(\frac{Cc_2}{Ch_1} \right)}{1 - \epsilon} \right]}{1 - \left(\frac{Cc_2}{Ch_1} \right)} \quad (107)^*$$

Then go to LG-14

$$\boxed{\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}}$$

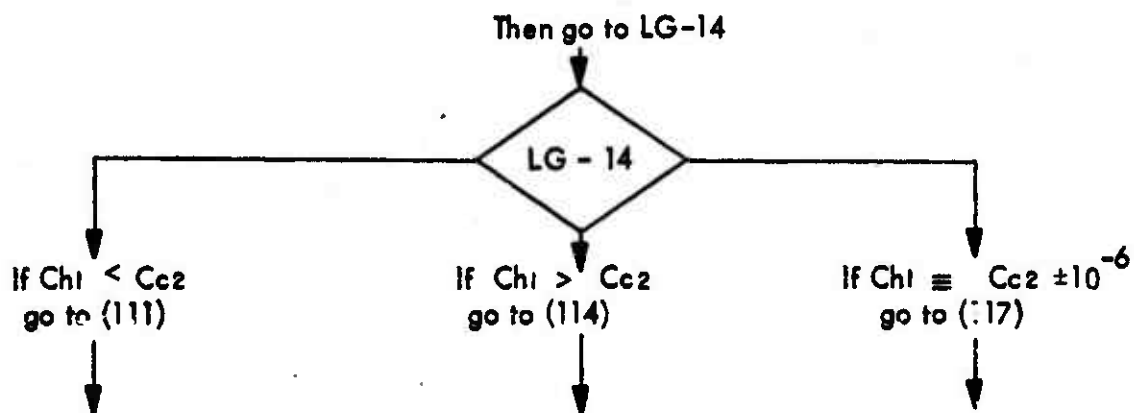
$$\lambda = \frac{Q}{3600 Ch_1} \quad (108)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (109)^*$$

TEST 7-C

If (109) ≥ 1.0 , stop & readout message "REDUCE Ntu"
 " " < " , continue.

$$Ntu = \frac{\epsilon}{1 - \epsilon} \quad (110)^*$$



$$\boxed{\text{If } Ch_1 < Cc_2}$$

$$Ax_{\text{tot. hot side}} = \frac{3600 Ntu Ch_1}{U} \quad (111)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (112)^*$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{A_{xp}} \quad (113)$$

Note If a fraction results, go to next higher whole number.

TEST 8-A

$$(113) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (113) > (4), increase (4) and iterate from (4).
 " " < " , reduce " " " " " "

Then go to (120)

If $Ch_1 > C_{c2}$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu } C_{c2}}{U} \quad (114)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (115)^*$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{A_{xp}} \quad (116)$$

Note If a fraction results, go to next higher whole number.

TEST 8-B

$$(116) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (116) > (4), increase (4) and iterate from (4).
 " " < " , reduce " " " " " "

Then go to (120)

$$\boxed{\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}}$$

$$Ax_{\text{tot. hat side}} = \frac{3600 Ntu \ Ch_1}{U} \quad (117)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (118)^*$$

$$np_{\text{calculated}} = \frac{144 \ Ax_{\text{tot. hat side}}}{A_{xp}} \quad (119)$$

Note..... If a fraction results, go to next higher whole number.

TEST 8-C

$$(119)_{\text{must}} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (119) > (4), increase (4) and iterate from (4).
 " " < " , reduce " " " " " "

Then go to (120)

$$\text{width } X = \frac{\text{equation (13)}}{\text{after closure}} = \text{inches} \quad (120)^*$$

$$\text{height } Y = \frac{X}{F_s} = \text{inches} \quad (121)^*$$

$$\text{core length } L = [(np \cdot tp) + (ns \cdot ts)] = \text{inches} \quad (122)^*$$

$$\begin{aligned} \text{core weight} &= .098 \text{ np tp } \left\{ \left[(XY) - (X' Y') \right] + \left[X' B' (C-1) \right] + \left[Afl (Ro + 1) (1 - \sigma') \right] \right\} + \\ &.78 \text{ ns ts } \left\{ \left[(XY) - (X' Y') \right] + \left[X' B' (C - 1) \right] \right\} = \text{lbs} \end{aligned} \quad (123)^*$$

$$\text{header weight} = .196 \left[(XY) - Afl (Ro + 1) + \frac{XY}{8} \right] = \text{lbs} \quad (124)^*$$

$$\text{total weight} = (123) + (124) = \text{lbs} \quad (125)^*$$

$$\eta_f = \frac{1}{1 + \left[\frac{h_{1-2} \left(\frac{A_{xp}}{N_h \cdot Y'_1} \right) (Y'_1)^2}{3 \text{ np } 2-3 \left\{ X' \text{ tp } .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \quad (126)^*$$

TEST 9

if (126) < .40, readout message "INCREASE (1P-24)."

" " > .60, readout message "REDUCE " ."

Do not stop machine on TEST 9.

$$A_v = \frac{A_x \text{ tot. hot side}}{\left(\frac{X \cdot Y \cdot L}{1728} \right)} = \text{ft}^2 / \text{ft}^3 \quad (127)^*$$

FINAL TEST

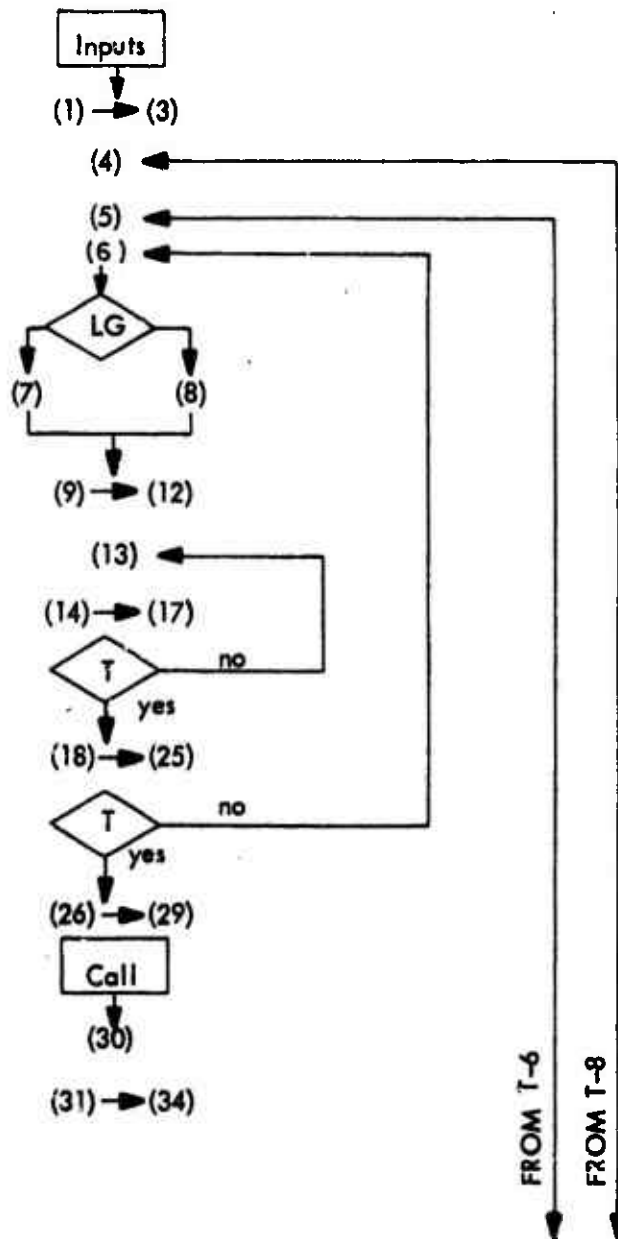
If (35) $\geq$ 540, stop machine.

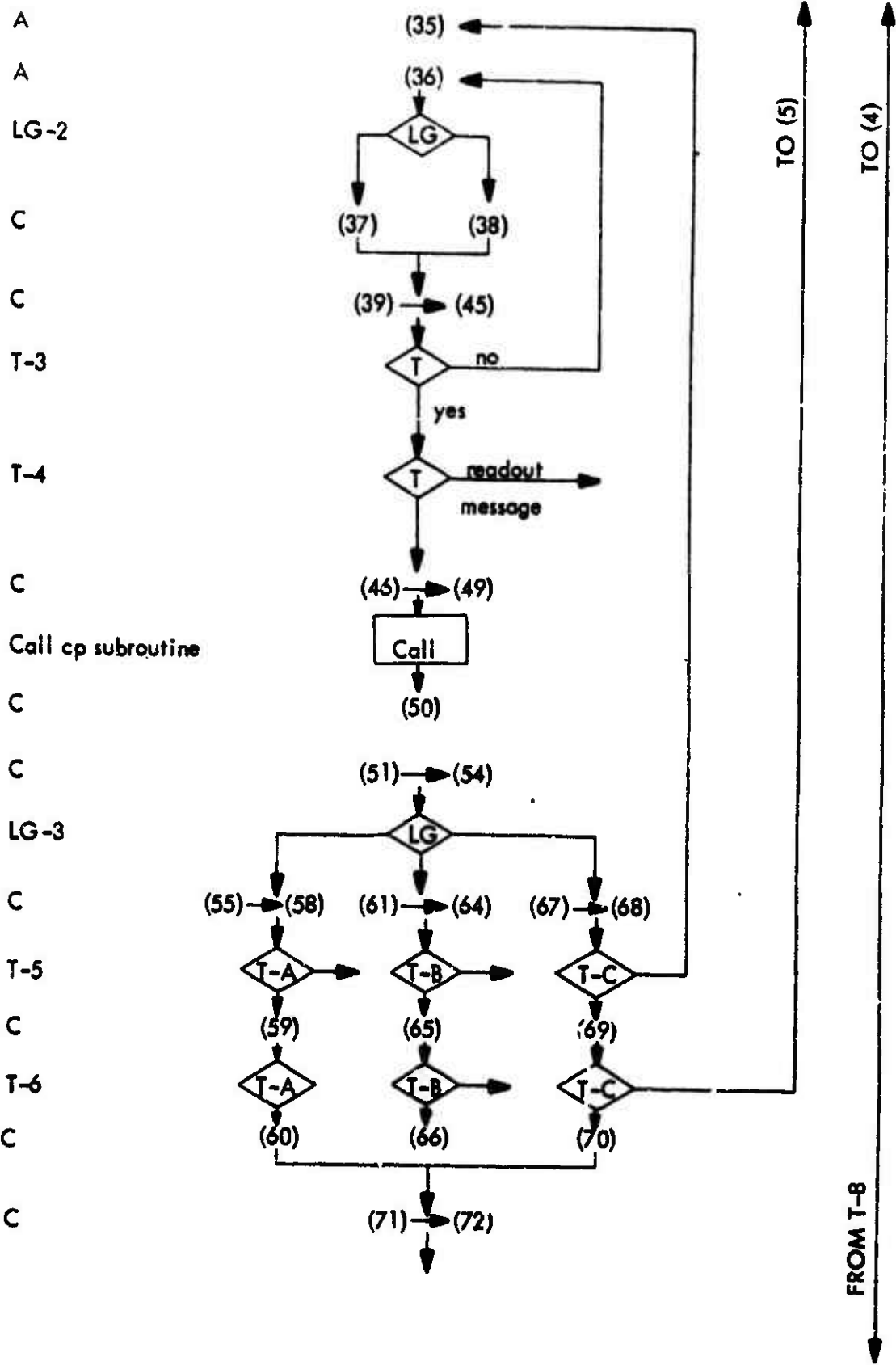
" " < " , coll HX (J) J = 2.0 and continue.

FLOW DIAGRAM FOR HX-1

A = assume
C = compute
LG = logic gate
T = test

C
A
A
A
LG-1
C
C
A
C
T-1
C
T-2
C
Call cp subroutine
C
C





LG-4

LG-5, 6

C

C

LG-7

LG-8, 9

C

C

LG-10

LG-11, 12

C

C

LG-13

C

T-7

C

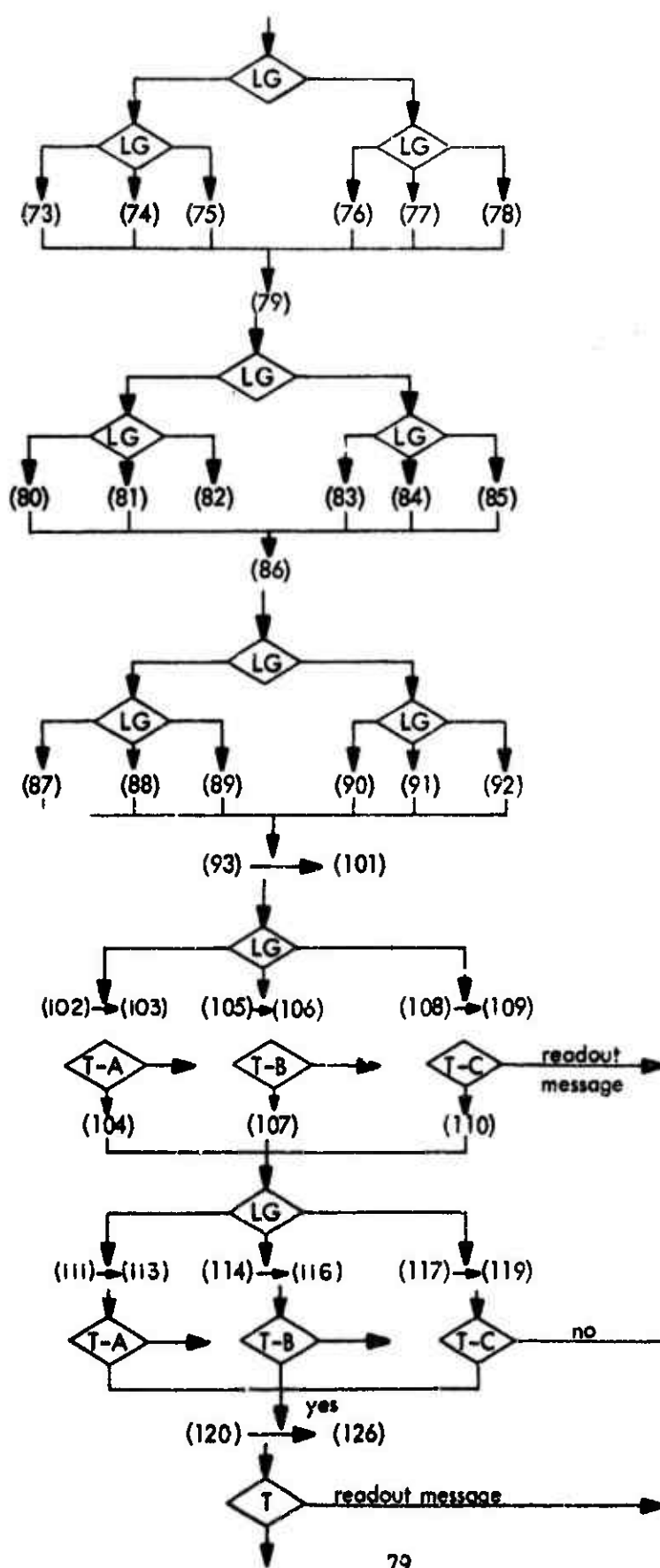
LG-14

C

T-8

C

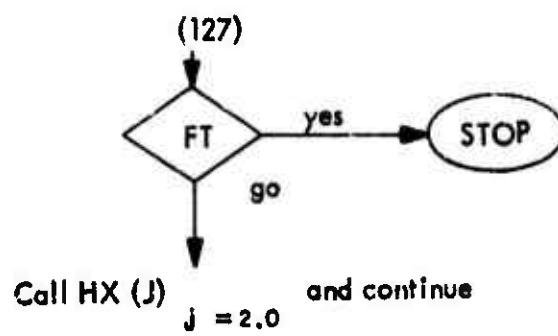
T-9



TO (4)

C

Final Test



APPENDIX III

HX-2 AND TURBINE 1 PROGRAM CALL HX (J) ; = 2.0'

Inputs:

Call numerical values from APPENDIX I, Section III.
Also call last result for T13, P13, T17 and P17 from
output of HX-1.

Initial numerical assumptions:

<u>Eqa. No:</u>	<u>Initial value:</u>
(4)	30.0
(5)	T13 + 5
(6)	1.02 P13
(13)	2.0
(41)	T17 + 5
(42)	.98 P17

Notes:

Readout last result of all equations marked with a star "*"
Do not stop machine for TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \frac{dh^2}{\sigma}} \quad (1)^*$$

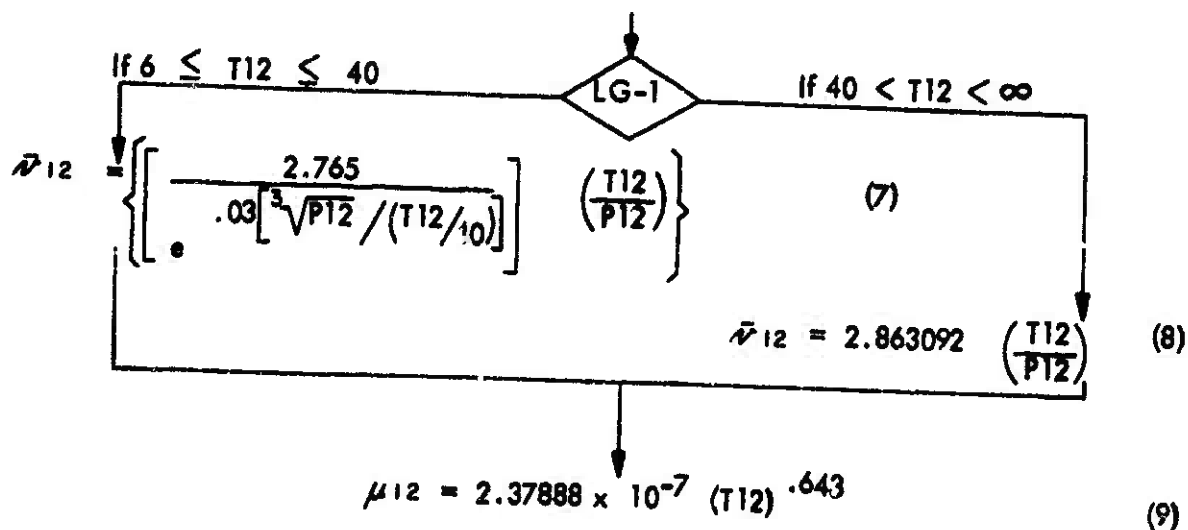
$$n = \frac{4\sigma}{\pi dh^2} \quad (2)^*$$

$$Ax_1 = (n \pi dh tp) + 2(1-\sigma) \quad (3)^*$$

$$\begin{aligned} np &= \text{assume} \\ (\text{Will be altered only by TEST 8}) \end{aligned} \quad (4)^*$$

$$\begin{aligned} T12 &= \text{assume} \\ (\text{Will be altered only by TEST 3}) \end{aligned} \quad (5)^*$$

$$\begin{aligned} P12 &= \text{assume} \\ (\text{Will be altered only by TEST 2}) \end{aligned} \quad (6)^*$$



$$V_{12} = \frac{12 N_{re1} \bar{\mu}_{12} \mu_{12}}{dh} \quad (10)^*$$

$$ah_1 = \frac{144 W_1 \bar{\mu}_{12}}{V_{12}} \quad (11)^*$$

$$Af_1 = \frac{ah_1}{\sigma} \quad (12)^*$$

$$X = \text{assume} \quad (13)^*$$

(Will be altered only by TEST 1)

$$X' = X - (2 Bx) \quad (14)^*$$

$$Y' = \frac{X}{F_s} - (2 By) \quad (15)^*$$

$$Y_i' = \frac{Y' - [(C-1)B'] - Nh}{2(C-1)} \quad (16)^*$$

$$Af_1 \text{ calculated} = Nh (X' Y_i') \quad (17)$$

TEST !

(17) must = (12) $\pm$.001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " " "

$$Y_2 = Y_1 \frac{Ra}{2} \quad (18)^*$$

$$Y_3 = Y_1 \cdot Ra \quad (19)^*$$

$$\lambda_1 = \frac{Y_1}{24} \quad (20)$$

$$\lambda_2 = \frac{B_1}{12} \quad (21)$$

$$\lambda_3 = \frac{Y_3}{12 \cdot Ra} \quad (22)$$

$$\Delta P_1 = \frac{370 \times 10^{-6}}{\bar{\lambda}_{12}} V_{12}^2 \sqrt{\frac{(tp/dh)}{NRe_1}} \quad (23)$$

$$\Delta P_1 = n_p \cdot \Delta P_1 \quad (24)^*$$

$$P_{12} \text{ calculated} = P_{13} + \Delta P_1 \quad (25)$$

TEST 2

(25) must = (6) $\pm$.001

If (25) > (6), increase (6) and iterate from (6).

" " < " , reduce " " " " " " .

Call cp subroutine and, with
T12 and P12 get

$$cp_{12} =$$

(26)

Call cp subroutine and, with
T17 and P17 get

$$cp17 \quad (27)$$

$$\bar{cp} = \frac{(cp12 + cp17)}{2} \quad (28)$$

$$\bar{\tau} = \frac{1}{1 - \left(\frac{.496447487}{\bar{cp}} \right)} \quad (29)$$

$$\frac{T17}{T12} = 1 - \eta_t \left[1 - \left(\frac{P17}{P12} \right)^{(\bar{\tau}-1)/\bar{\tau}} \right] \quad (30)$$

$$T12 \text{ calculated} = \frac{T17}{(T17/T12)} \quad (31)$$

TEST 3

(31) must = (5) $\pm$.001

If (31) > (5), Increase (5) and iterate from (5).

" " < " , reduce " " " " " "

$$\mu_{m1} = \frac{8.55497 \times 10^{-4}}{(T12 - T13)} \left\{ \frac{(T12)^{1.643} - (T13)^{1.643}}{1.643} \right\} \quad (32)$$

$$K_{m1} = \frac{57.79 \times 10^{-3}}{[.00355 (T_{12} - T_{13})]} \left\{ \frac{[(.00355 T_{12})^{1.642} - (.00355 T_{13})^{1.642}]}{1.642} \right\} \quad (33)$$

$$Th_m = \frac{\left(\frac{K_{m1}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (34)$$

$$Ph_m = \frac{(P_{12} + P_{13})}{2} \quad (35)$$

Call cp subroutine and, with
Thm and Phm.....get

$$c_{phm} = \quad (36)$$

$$Ch_1 = c_{phm} \cdot W_1 \quad (37)^*$$

$$N_{Pr1} = \frac{c_{phm} \cdot \mu_{m1}}{K_{m1}} \quad (38)^*$$

$$NNu_1 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{N_{Re1} \cdot N_{Pr1}} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{N_{Re1} \cdot N_{Pr1}} \right] \cdot .8} \right)} \right\} \quad (39)^*$$

$$h_{1-2} = \frac{12 \text{ NNu1} \cdot \text{Kml}}{dh} \quad (40)^*$$

COLD SIDE:

$$T18 = \text{assume} \quad (41)^*$$

(Will be altered only by TEST 6)

$$P18 = \text{assume} \quad (42)^*$$

(Will be altered only by TEST 4)

If $6 \leq T18 \leq 40$ If $40 < T18 < \infty$

LG-2

(43)

$$k18 = \left\{ \frac{2.765}{e^{.03 \left[\sqrt[3]{P18} / (T18/40) \right]}} \right\} \left(\frac{T18}{P18} \right)$$

(44)

$$k18 = 2.863092 \left(\frac{T18}{P18} \right)$$

(45)

$$\mu18 = 2.37888 \times 10^{-7} (T18)^{.643}$$

$$ah2 = ah1 \cdot Ro \quad (46)^*$$

$$V18 = \frac{144 \text{ W2} \cdot k18}{ah2} \quad (47)^*$$

$$\text{NRe2} = \frac{V18 \cdot dh}{12 k18 \cdot \mu18} \quad (48)^*$$

$$\Delta P_2' = \frac{370 \times 10^{-6} V_{18}^2}{\sqrt{18}} \sqrt{\frac{(1p/dh)}{NRe_2}} \quad (49)$$

$$\Delta P_2 = n_p \cdot \Delta P_2' \quad (50)^*$$

$$P_{18} \text{ calculated} = P_{17} - \Delta P_2 \quad (51)$$

TEST 4

(51) must = 1 ± 0.001

If (51) > (42), increase (42) and iterate from (42).

" " < " , reduce " " " " " " .

TEST 5

If (51) < 10, stop & readout message "INCREASE Ra"

" " ≥ " , continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T_{18} - T_{17})} \left\{ \frac{[(T_{18})^{1.643} - (T_{17})^{1.643}]}{1.643} \right\} \quad (52)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{[.00355 (T_{18} - T_{17})]} \left\{ \frac{[(.00355 T_{18})^{1.642} - (.00355 T_{17})^{1.642}]}{1.642} \right\} \quad (53)$$

$$T_{cm} = \frac{\left(\frac{K_{m2}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (54)$$

$$P_{cm} = \frac{(P_{17} + P_{18})}{2} \quad (55)$$

Call cp subroutine ond, with
Tcm and Pcm.....get

$$cpcm = \text{[arrow from box above]}$$

(56)

$$Cc2 = cpcm \cdot W2$$

(57)*

$$NPr2 = \frac{cpcm \cdot \mu m2}{Km2}$$

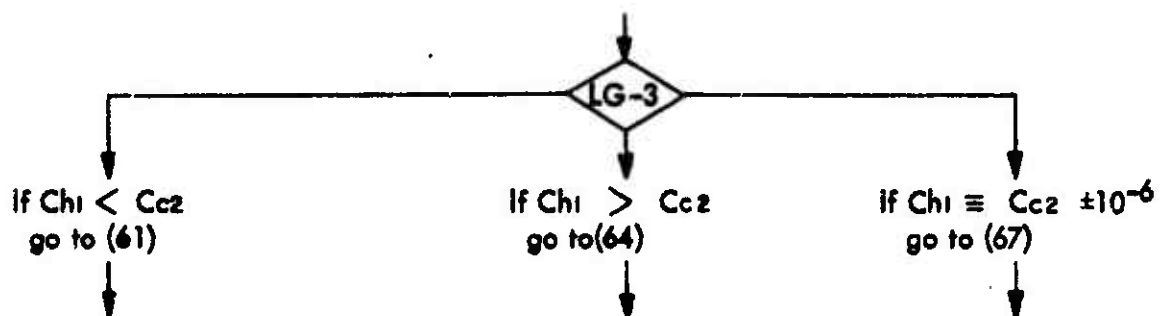
(58)*

$$NNu2 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left(\frac{tp/dh}{NRe2 \cdot NPr2} \right)} \right)}{1 + \left(\frac{.016}{\left(\frac{tp/dh}{NRe2 \cdot NPr2} \right)^{.8}} \right)} \right\}$$

(59)*

$$\frac{h}{5-6} = \frac{12 \cdot NNu2 \cdot Km2}{dh}$$

(60)*



If $Ch_1 < Cc_2$

$$T_{18} \text{ calculated} = T_{17} + \left[\frac{(T_{12} - T_{13})}{(C_{c2}/Ch_1)} \right] \quad (61)$$

TEST 6-A

(61) must = (41) $\pm .001$

If (61) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " " "

$$N_{tui} = \frac{\log_e \left[\frac{(T_{12} - T_{18})}{(T_{13} - T_{17})} \right]}{1 - \left(\frac{Ch_1}{Cc_2} \right)} \quad (62)^*$$

$$\epsilon_i = \frac{1 - e^{-N_{tui} \left[1 - \left(\frac{Ch_1}{Cc_2} \right) \right]}}{1 - \left\{ \left(\frac{Ch_1}{Cc_2} \right) e^{-N_{tui} \left[1 - \left(\frac{Ch_1}{Cc_2} \right) \right]} \right\}} \quad (63)^*$$

Then go to (70)

If $Ch_1 > Cc_2$

$$T_{18} \text{ calculated} = T_{17} + \left[\frac{(T_{12} - T_{13})}{(Ch_1/Cc_2)} \right] \quad (64)$$

TEST 6-B

(64) must = (41) $\pm .001$

If (64) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " " "

$$N_{tui} = \frac{\log_e \left[\frac{(T_{12} - T_{18})}{(T_{13} - T_{17})} \right]}{1 - \left(\frac{Cc_2}{Ch_1} \right)} \quad (65)^*$$

$$\epsilon_i = \frac{1 - e^{-Nt_{ui} \left[1 - \left(C_{c2}/Ch_1 \right) \right]}}{1 - \left\{ \left(\frac{C_{c2}}{Ch_1} \right) e^{-Nt_{ui} \left[1 - \left(C_{c2}/Ch_1 \right) \right]} \right\}} \quad (66)^*$$

Then go to (70)

If $Ch_1 \equiv C_{c2} \pm 10^{-6}$

$$T_{18} \text{ calculated} = T_{12} - (T_{13} - T_{17}) \quad (67)$$

TEST 6-C

(67) must = (41) $\pm$.001

If (67) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " " "

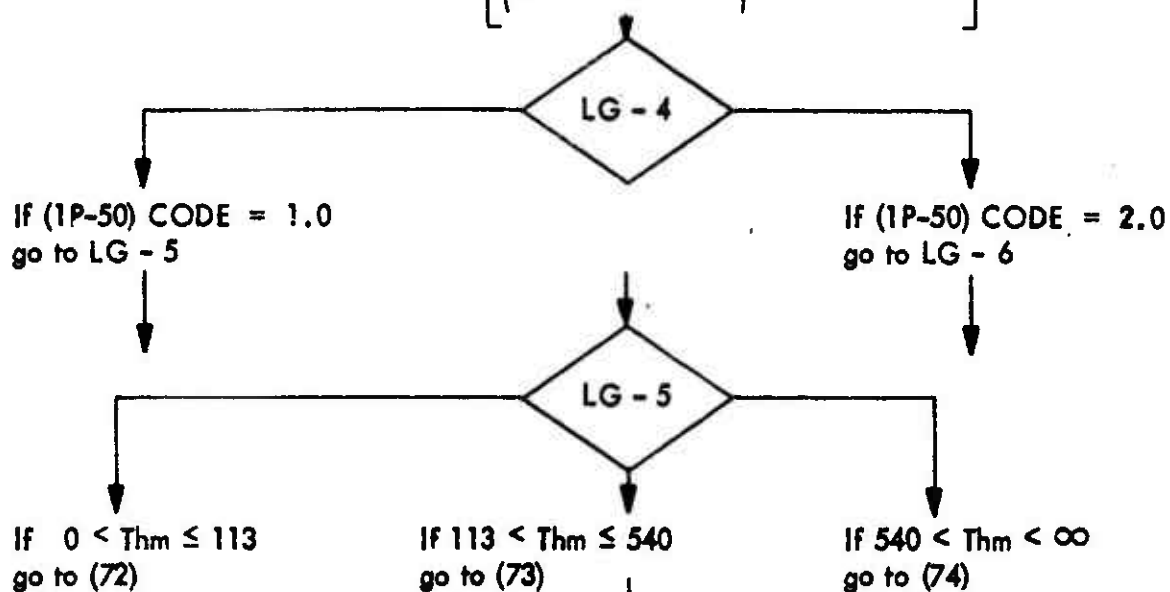
$$Nt_{ui} = \frac{\left[\frac{(T_{12} - T_{13})}{(T_{12} - T_{17})} \right]}{1 - \left[\frac{(T_{12} - T_{13})}{(T_{12} - T_{17})} \right]} \quad (68)^*$$

$$\epsilon_i = \frac{Nt_{ui}}{1 + Nt_{ui}} \quad (69)^*$$

Then go to (70)

$$T'1 = T_{hm} - \left[\left(\frac{Y'1}{Y'1 + Y'2 + Y'3} \right) (T_{hm} - T_{cm}) \right] \quad (70)$$

$$T'2 = T_{hm} - \left[\left(\frac{Y'1 + Y'2}{Y'1 + Y'2 + Y'3} \right) (T_{hm} - T_{cm}) \right] \quad (71)$$



$$K_p = \frac{1}{[.1 (T_{hm} - T'1)]} \left\{ \frac{49}{2} [(.1 T_{hm})^2 - (.1 T'1)^2] - \frac{1}{3.47} [(.1 T_{hm})^{3.47} - (.1 T'1)^{3.47}] \right\} \quad (72)$$

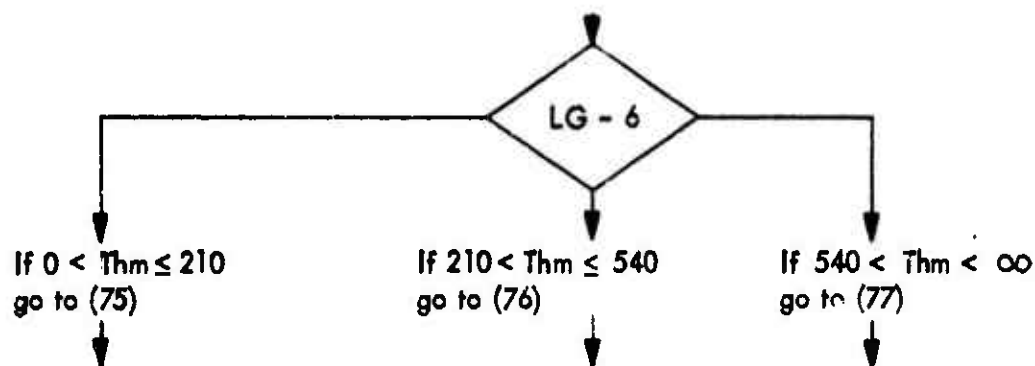
Then go to (78)

$$K_p = \frac{1}{[.1 (T_{hm} - T'1)]} \left\{ - \left[\frac{(.1 T_{hm})^{2.708} - (.1 T'1)^{2.708}}{2.708} \right] + \left[9.551 [(.1 T_{hm})^2 - (.1 T'1)^2] \right] \right\} \quad (73)$$

Then go to (78)

$$K_p = 111.74 = \text{constant} \quad (74)$$

Then go to (78)



$$K_p = \frac{1}{(Thm - T'_{i1})} \left\{ \frac{2.765}{2} [(Thm)^2 - (T'_{i1})^2] - \left[\frac{(Thm)^{2.16} - (T'_{i1})^{2.16}}{2.16} \right] \right\} \quad (75)$$

Then go to (78)

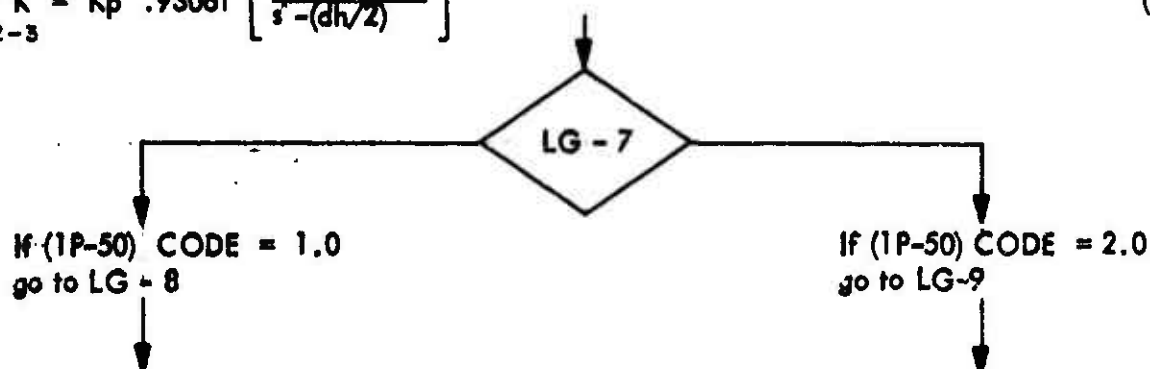
$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(Thm + T'_{i1}) / 2] - 210}{330} \right) \right\} \quad (76)$$

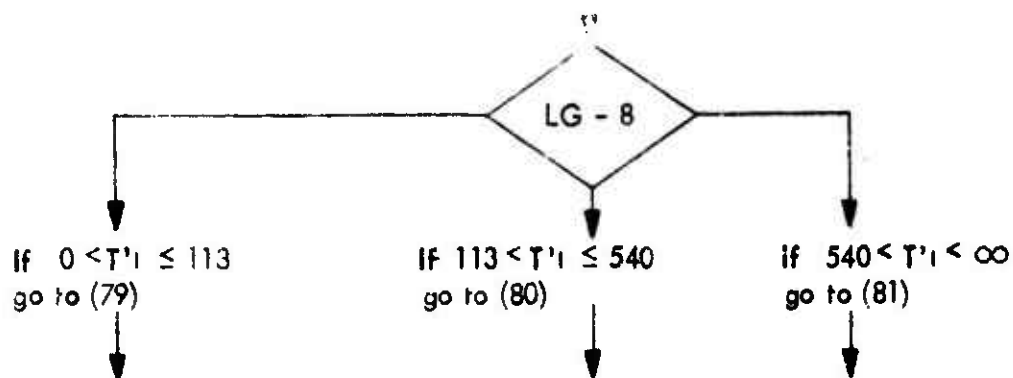
Then go to (78)

$$K_p = 92.25 = \text{constant} \quad (77)$$

Then go to (78)

$$K_{2-3} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (78)^*$$





$$K_p = \frac{1}{[.1(T'1 - T'2)]} \left\{ \frac{49}{2} [(.1 T'1)^2 - (.1 T'2)^2] - \frac{1}{3.47} [(.1 T'1)^{3.47} - (.1 T'2)^{3.47}] \right\} \quad (79)$$

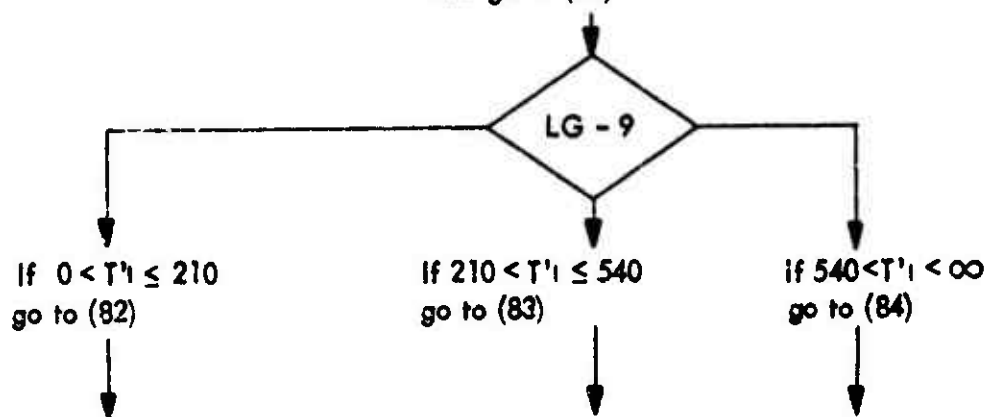
Then go to (85)

$$K_p = \frac{1}{[.1(T'1 - T'2)]} \left\{ - \left[\frac{(.1 T'1)^{2.708} - (.1 T'2)^{2.708}}{2.708} \right] + 9.551 [(.1 T'1)^2 - (.1 T'2)^2] \right\} \quad (80)$$

Then go to (85)

$$K_p = 111.74 = \text{constant} \quad (81)$$

Then go to (85)



$$K_p = \frac{1}{(T'_1 - T'_2)} \left\{ \frac{2.765}{2} [(T'_1)^2 - (T'_2)^2] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16} \right] \right\} \quad (82)$$

Then go to (85)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T'_1 + T'_2) / 2] - 210}{330} \right) \right\} \quad (83)$$

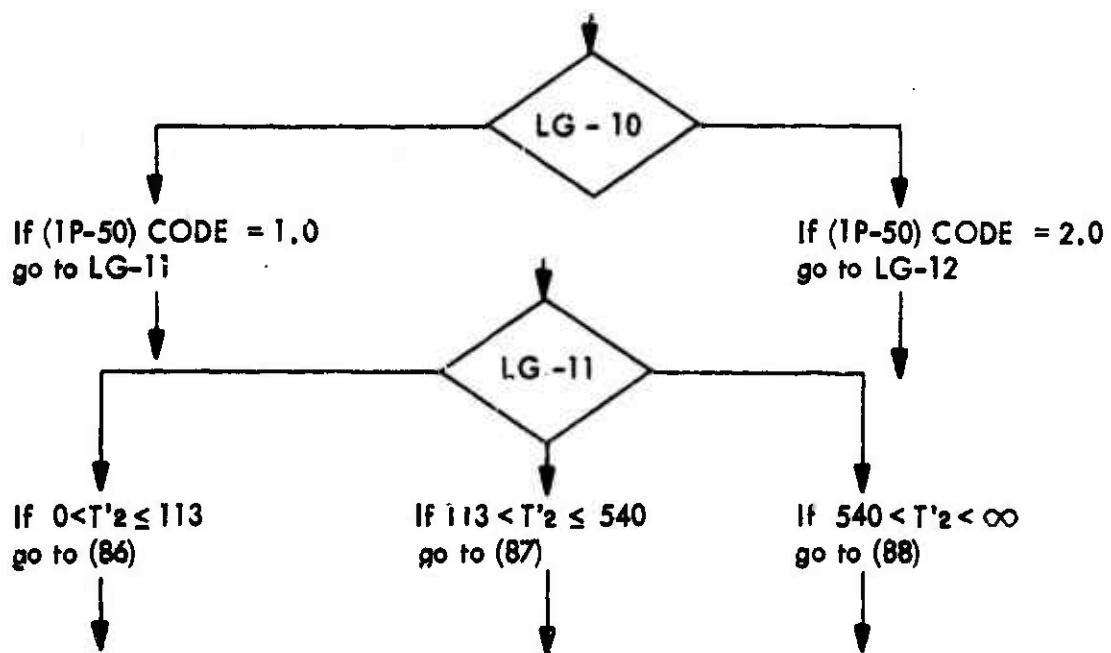
Then go to (85)

$$K_p = 92.25 = \text{constant} \quad (84)$$

Then go to (85)

$$K = K_p \quad (85)$$

3-9



$$K_p = \frac{1}{[.1 (T'_2 - T_{cm})]} \left\{ \frac{49}{2} [(.1 T'_2)^2 - (.1 T_{cm})^2] - \frac{1}{3.47} [(.1 T'_2)^{3.47} - (.1 T_{cm})^{3.47}] \right\} \quad (86)$$

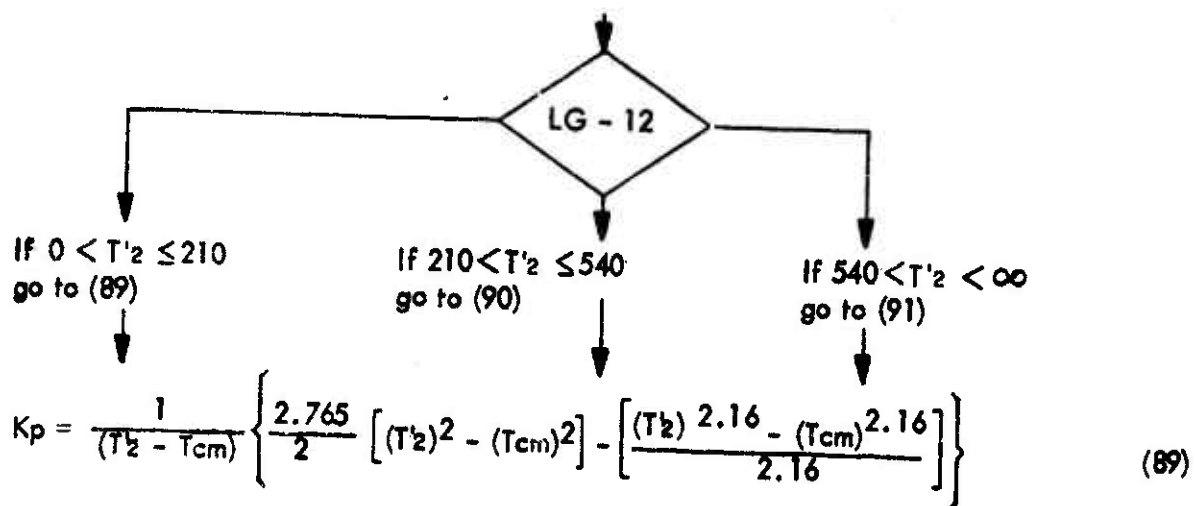
Then go to (92)

$$K_p = \frac{1}{[.1 (T'_2 - T_{cm})]} \left\{ - \left[\frac{(.1 T'_2)^{2.708} - (.1 T_{cm})^{2.708}}{2.708} \right] + 9.551 [(.1 T'_2)^2 - (.1 T_{cm})^2] \right\} \quad (87)$$

Then go to (92)

$$K_p = 111.74 = \text{constant} \quad (88)$$

Then go to (92)



Then go to (92)

$$K_p = 86.0 + \left\{ 6.25 \left[\frac{(T'_2 + T_{cm})/2 - 210}{330} \right] \right\} \quad (90)$$

Then go to (92)

$$K_p = 92.25 = \text{constant} \quad (91)$$

Then go to (92)

$$K_{4-5} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (92)^*$$

$$U = \frac{1}{\frac{1}{h_{1-2}} + \frac{\lambda_1}{K_{2-3}} + \frac{\lambda_2}{K_{3-4}} + \frac{\lambda_3}{K_{4-5}} + \frac{1}{h_{5-6}}} \quad (93)^*$$

$$n_s = n_p + 1 \quad (94)^*$$

$$\lambda_e = \frac{n_s \cdot t_s}{12} \quad (95)$$

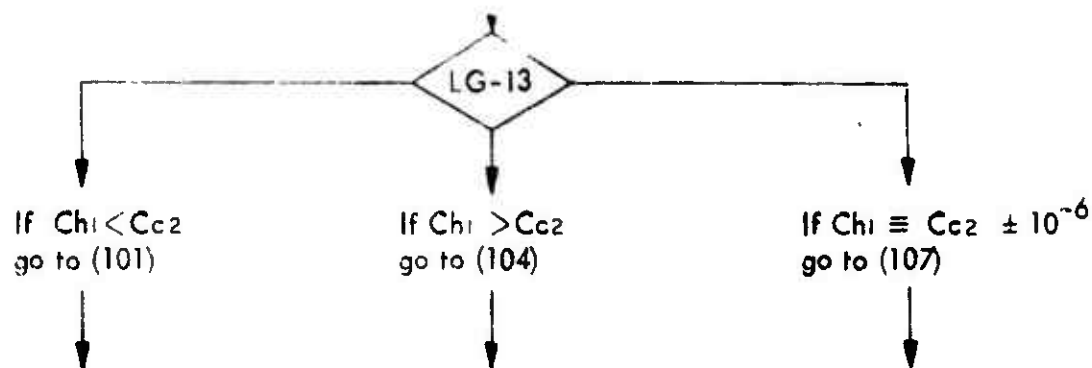
$$T_{21} = \frac{(T_{13} + T_{17})}{2} \quad (96)$$

$$T_{22} = \frac{(T_{12} + T_{18})}{2} \quad (97)$$

$$AK_2 = \frac{[(X^2/F_s) - (X'Y')] + [(C-1)X'B']}{144} \quad (98)$$

$$\bar{K}_2 = \frac{7.27 \times 10^{-3}}{(T_{22} - T_{21})} \left[\frac{\frac{1.585}{(T_{22})} - \frac{1.585}{(T_{21})}}{1.585} \right] \quad (99)$$

$$Q_2 = \frac{\bar{K}_2 \cdot Ak_2}{\lambda_e} \quad (100)^*$$



If $Ch_1 < C_{c2}$

$$\lambda = \frac{q_l}{3600 \text{ } Ch_1} \quad (101)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (102)^*$$

TEST 7 - A

If (102) ≥ 1.0 , stop & readout message "REDUCE BORDER DIMENSIONS OR INCREASE t_b "

If (102) < 1.0 , continue.

$$N_{tu} = \frac{\log_e \left[\frac{1 - \epsilon (Ch_1/C_{c2})}{1 - \epsilon} \right]}{1 - (Ch_1/C_{c2})} \quad (103)^*$$

Then go to LG - 14

If $Ch_1 > C_{c2}$

$$\lambda = \frac{q_l}{3600 \text{ } C_{c2}} \quad (104)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (105)^*$$

TEST 7-B

If (105) ≥ 1.0 , stop & readout message "REDUCE BORDER DIMENSIONS OR INCREASE t_s "

If (105) < 1.0 , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon (C_{c2}/Ch_1)}{1 - \epsilon} \right]}{1 - (C_{c2}/Ch_1)} \quad (106)^*$$

Then go to LG - 14

If $Ch_1 \equiv C_{c2} \pm 10^{-6}$

$$\lambda = \frac{Ql}{3600 Ch_1} \quad (107)^*$$

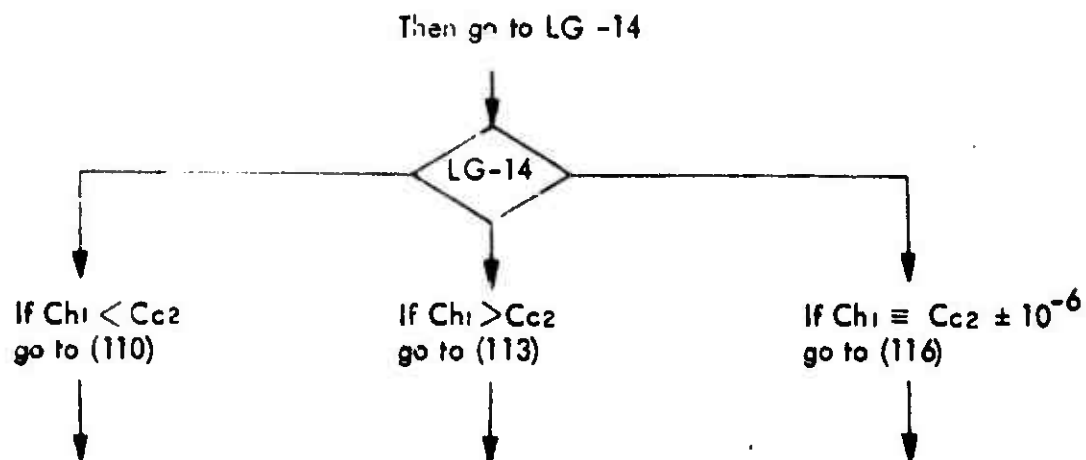
$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (108)^*$$

TEST 7-C

If (108) ≥ 1.0 , stop & readout message "REDUCE BORDER DIMENSIONS OR INCREASE t_s "

If (108) < 1.0 , continue.

$$Ntu = \frac{\epsilon}{1 - \epsilon} \quad (109)^*$$



If Ch1 < Cc2

$$Ax \text{ tot. hot side} = \frac{3600 Ntu Ch_1}{U} \quad (110)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (111)^*$$

$$n\beta \text{ calculated} = \frac{144 Ax \text{ tot. hot side}}{A_{xp}} \quad (112)$$

Note If a fraction results, go to next higher whole number.

TEST 8-A

$$(112) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (112) > (4), increase (4) and iterate from (4).

If (112) < (4), reduce (4) and iterate from (4).

Then go to (119)

If $Ch_1 > Cc_2$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu } Cc_2}{U} \quad (113)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (114)^*$$

$$np \text{ calculated} = \frac{144 \text{ } Ax \text{ tot. hot side}}{A_{xp}} \quad (115)$$

Note If a fraction results, go to next higher whole number.

TEST 8-B

$$(115) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If $(115) > (4)$, increase (4) and iterate from (4) .

If $(115) < (4)$, reduce (4) and iterate from (4) .

Then go to (119)

If $Ch_1 \approx Cc_2 \pm 10^{-6}$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu } Ch_1}{U} \quad (116)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (117)^*$$

$$np \text{ calculated} = \frac{144 A_x \text{ tot. hot side}}{A_{xp}} \quad (118)$$

Note If a fraction results, go to next higher whole number.

TEST 8-C

$$(118) \text{ must} = (4) \begin{matrix} + 1 \\ - 0 \end{matrix}$$

If $(118) > (4)$, increase (4) and iterate from (4) .

If $(118) < (4)$, reduce (4) and iterate from (4) .

Then go to (119)

$$\text{width } X = \text{equation (13)} = \text{inches} \quad (119)^*$$

after closure

$$\text{height } Y = \frac{X}{F_s} = \text{inches} \quad (120)^*$$

$$\text{core length } L = [(np \cdot tp) + (ns \cdot ts)] = \text{inches} \quad (121)^*$$

$$\begin{aligned} \text{core weight} = .098 np tp \left\{ [(XY) - (X'Y')] + [X'B' (C-1)] + [Afi (Ra+1) (1-\sigma)] \right\} + \\ .078 ns ts \left\{ [(XY) - (X'Y')] + [X'B' (C-1)] \right\} = \text{lbs} \end{aligned} \quad (122)^*$$

$$\text{header weight} = .196 \left[(XY) - Afi (Ra+1) + \frac{XY}{8} \right] = \text{lbs} \quad (123)^*$$

$$\text{total weight} = (122) + (123) = \text{lbs} \quad (124)^*$$

$$\eta_f = \frac{1}{1 + \left[\frac{h}{1-2} \frac{(A_{xp}/N_h \cdot Y_i')}{(Y_i')^2} \right] \left\{ 3 \eta_p K_{2-3} \left[X' \eta_p .93061 \left[\frac{s-dh}{s-(dh/2)} \right] \right] \right\}} \quad (125)^*$$

TEST 9

If (125) < .40, read out message "INCREASE (1P-40)."

If (125) > .60, readout message "REDUCE (1P-40)."

Do not stop machine on TEST 9

$$A_v = \frac{A_{x \text{ tot. hot side}}}{\left(\frac{X \cdot Y \cdot L}{1728} \right)} \quad (126)^*$$

$$\Delta H_{t1} = \bar{c}_p T_{12} \eta_t \left[1 - (P_{17}/P_{12})^{(\bar{\tau} - 1)/\bar{\tau}} \right] = \text{BTU/lb} \quad (127)^*$$

$$\text{Turbine output} = 1054.54 W_{t1} \cdot \Delta H_{t1} = \text{Watts} \quad (128)^*$$

FINAL TEST

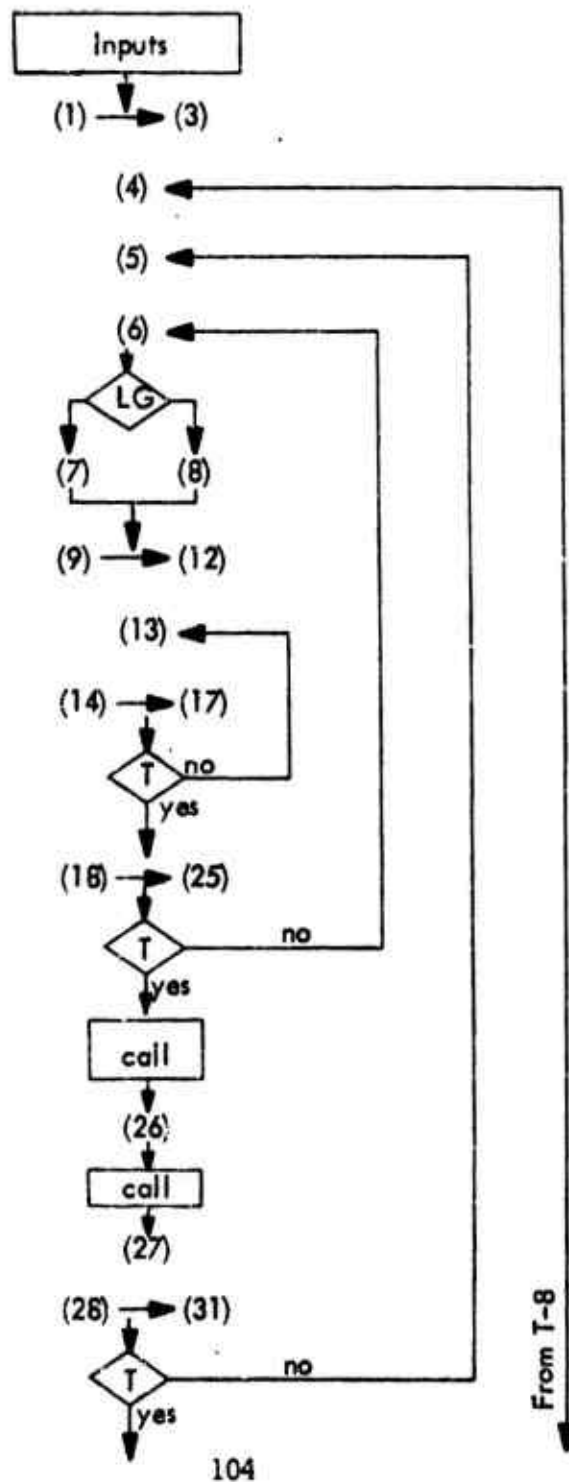
If (41) $\geq$ 540, stop machine.

If (41) < 540, call HX(J)_{j=3} and continue.

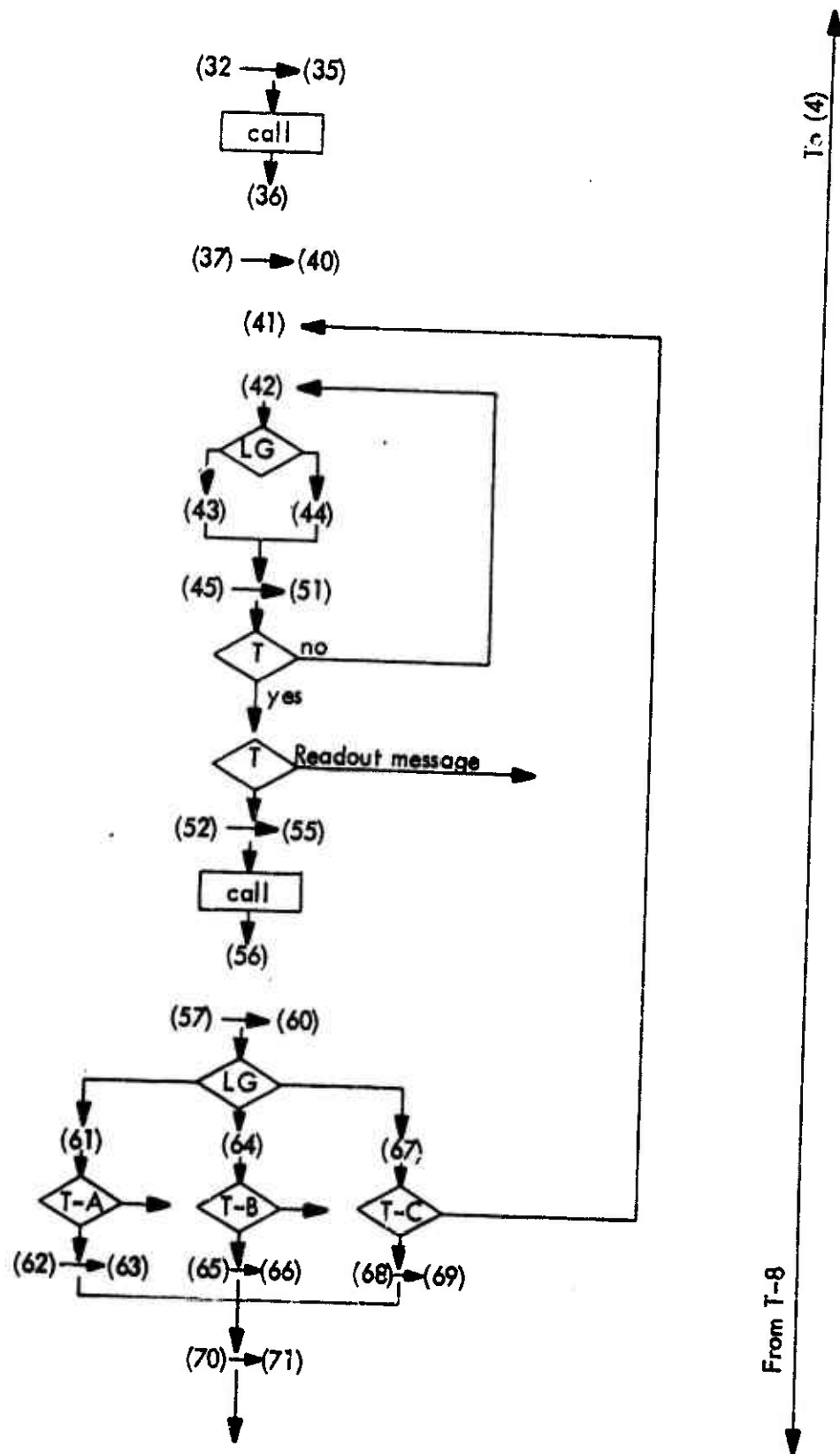
FLOW DIAGRAM FOR HX-2 AND TUBINE 1

A = assume
C = compute
LG = logic gate
T = test

C
A
A
A
LG-1
C
C
A
C
T-1
C
T-2
call cp subroutine
C
call cp subroutine
C
C
T-3



C
 Call cp subroutine
 C
 C
 A
 A
 LG-2
 C
 C
 T-4
 T-5
 C
 Call cp subroutine
 C
 C
 LG-3
 C
 T-6
 C
 C



LG-4

LG- 5, 6

C

C

LG-7

LG-8,9

C

C

LG-10

LG-11,12

C

C

LG-13

C

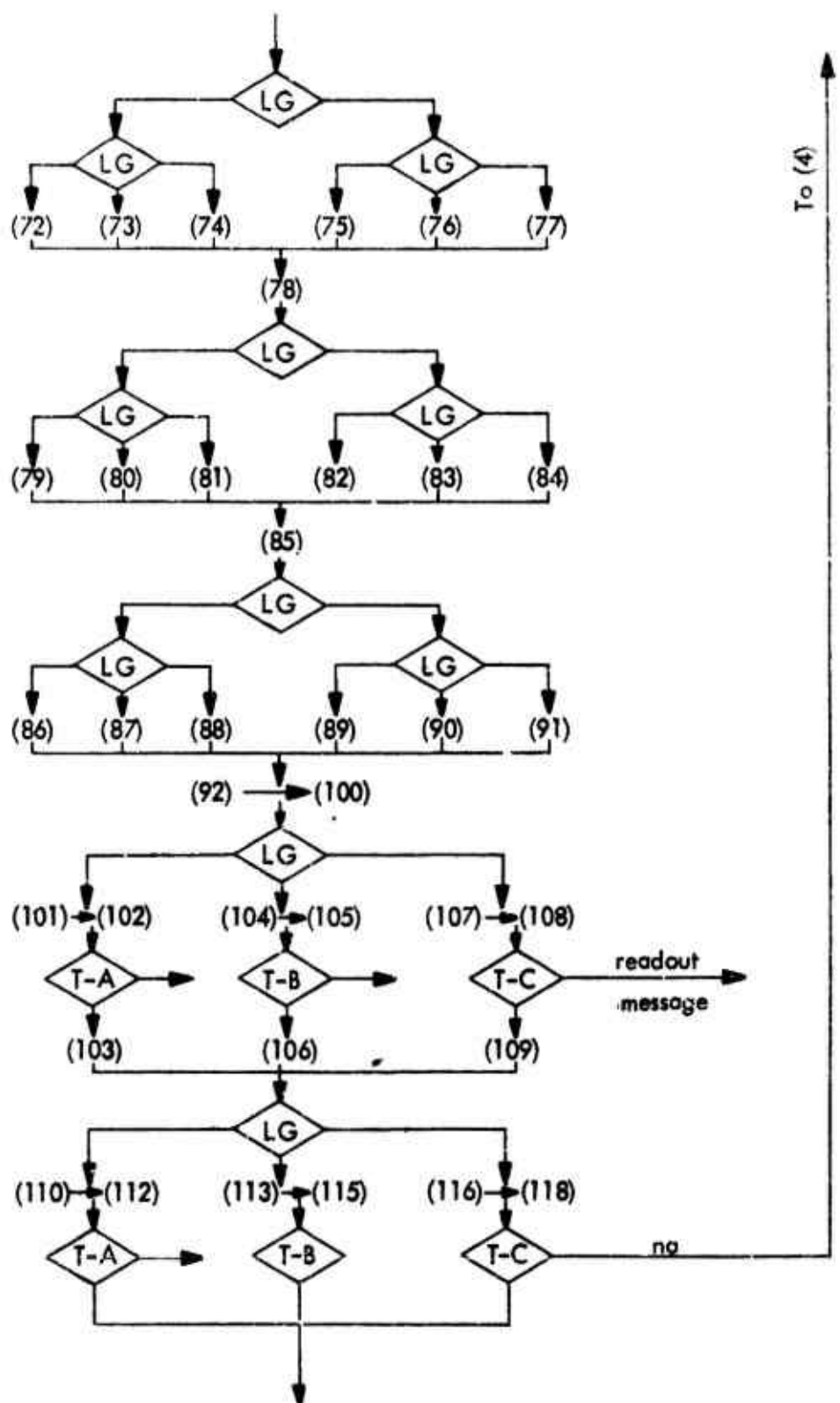
T-7

C

LG-14

C

T-8

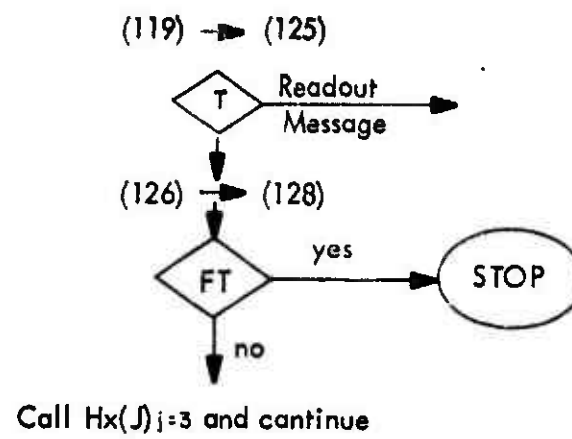


C

T-9

C

Final test



APPENDIX IV

HX-3 PROGRA CALL HX(J) j=3.0:

Inputs:

Call numerical values from APPENDIX I, Section IV.
Also call last resut far T12, P12, T18 and P18 from
autput af HX-2.

Initial numerical assumptions:

<u>Equa.</u> <u>Na:</u>	<u>Initial</u> <u>Value:</u>
(4)	200.0
(5)	T12 + 75.0
(6)	1.02 P12
(13)	2.0
(35)	T18 + 75
(36)	.98 P18

Notes:

Readout last result of all equations marked with a star "*".
Do not stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{-906894 \frac{dh^2}{\sigma}} \quad (1)^*$$

$$n = \frac{4 \sigma}{\pi dh^2} \quad (2)^*$$

$$Ax1 = (n \pi dh tp) + 2 (1 - \sigma) \quad (3)^*$$

$$np = assume \quad (4)^*$$

(Will be altered only by TEST 8)

$$T11 = \text{assume} \quad (5)^*$$

(Will be altered only by TEST 6)

$$P11 = \text{assume} \quad (6)^*$$

(Will be altered only by TEST 2)

$$\bar{v}_{11} = \left\{ \left[\frac{2.765}{.03 \left[\sqrt[3]{P11} / (T11/40) \right]} \right] \left(\frac{T11}{P11} \right) \right\} \quad (7)$$

$$\bar{v}_{11} = 2.863092 \left(\frac{T11}{P11} \right) \quad (8)$$

$$\mu_{11} = 2.37888 \times 10^{-7} (T11)^{.643} \quad (9)$$

$$V11 = \frac{144 \text{ NRei } \bar{v}_{11} \mu_{11}}{dh} \quad (10)^*$$

$$ah1 = \frac{144 \text{ W2 } \bar{v}_{11}}{V11} \quad (11)^*$$

$$Afi = \frac{ah1}{\sigma} \quad (12)^*$$

$$X = \text{assume} \quad (13)^*$$

(Will be altered only by TEST 1)

$$X' = X - (2 Bx) \quad (14)^*$$

$$Y' = \frac{X}{Fs} - (2 By) \quad (15)^*$$

$$Y'_1 = \frac{Y' - \frac{[(C-1) B']}{2} - Nh}{2(C-1)} \quad (16)^*$$

$$Af: \text{calculated} = Nh (X' Y'_1) \quad (17)$$

TEST 1

$$(17) \text{ must} = (12) \pm .001$$

If $(17) > (12)$, reduce (13) and iterate from (13).

If $(17) < (12)$, increase (13) and iterate from (13).

$$Y'_2 = Y'_1 \frac{Ra}{2} \quad (18)^*$$

$$Y'_3 = Y'_1 \cdot Ra \quad (19)^*$$

$$\lambda_1 = \frac{Y'_1}{24} \quad (20)$$

$$\lambda_2 = \frac{B'}{12} \quad (21)$$

$$\lambda_3 = \frac{Y'_3}{12 \cdot Ra} \quad (22)$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} V_{11}^2}{\bar{\mu}_{11}} \sqrt{\frac{(\eta_p/dh)}{NRe_1}} \quad (23)$$

$$\Delta P_1 = n_p \cdot \Delta P'_1 \quad (24)^*$$

$$P_{11} \text{ calculated} = P_{12} + \Delta P_1 \quad (25)$$

TEST 2

(25) must = (6) $\pm$.001

If (25) > (6), increase (6) and iterate from (6).

If (25) < (6), reduce (6) and iterate from (6).

$$\mu_{m1} = \frac{8.55497 \times 10^{-4}}{(T11 - T12)} \left\{ \frac{(T11)^{1.643} - (T12)^{1.643}}{1.643} \right\} \quad (26)$$

$$K_{m1} = \frac{57.79 \times 10^{-3}}{[.00355 (T11 - T12)]} \left\{ \frac{(.00355 T11)^{1.642} - (.00355 T12)^{1.642}}{1.642} \right\} \quad (27)$$

$$Thm = \frac{\left(\frac{K_{m1}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (28)$$

$$Phm = \frac{(P11 + P12)}{2} \quad (29)$$

Call cp subrautine and, with
Thm and Phm get

$$cphm = \quad (30)$$

$$Ch1 = cphm \cdot W2 \quad (31)^*$$

$$NPr1 = \frac{cphm \cdot \mu_{m1}}{K_{m1}} \quad (32)^*$$

$$N_{Nui} = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(h_p/dh)}{N_{Re1} \cdot N_{Pr1}} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(h_p/dh)}{N_{Re1} \cdot N_{Pr1}} \right]^{.8}} \right)} \right\} \quad (33)^*$$

$$h_{1-2} = \frac{12 N_{Nui} \cdot K_{mi}}{dh} \quad (34)^*$$

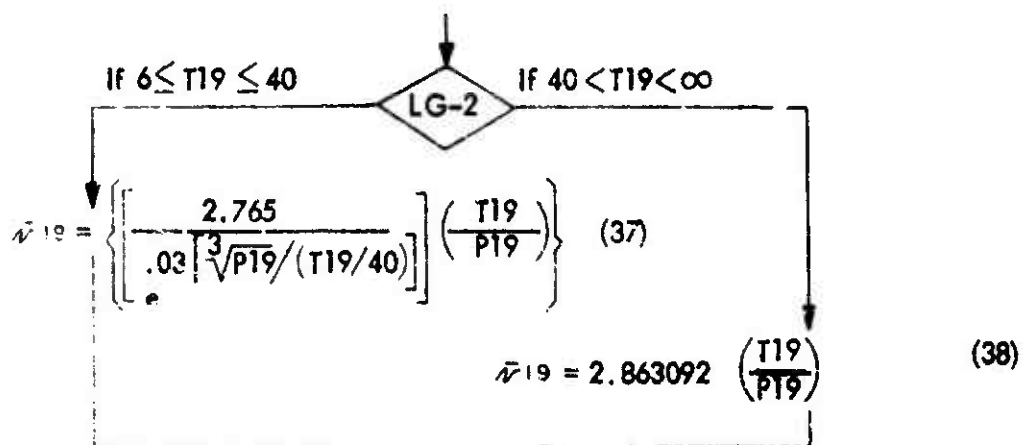
COLD SIDE:

$$T19 = \text{assume} \quad (35)^*$$

(Will be altered only by TEST 5)

$$P19 = \text{assume} \quad (36)^*$$

(Will be altered only by TEST 3)



$$oh_2 = ah_1 \cdot Ra \quad (39)^*$$

$$V_{19} = \frac{144 W_2 \bar{V}_{19}}{a h_2} \quad (40)^*$$

$$\mu_{19} = 2.37888 \times 10^{-7} (T_{19})^{.643} \quad (41)$$

$$NRe_2 = \frac{V_{19} \cdot dh}{12 \bar{V}_{19} \cdot \mu_{19}} \quad (42)^*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} V_{19}^2}{\bar{V}_{19}} \sqrt{\frac{(fp/dh)}{NRe_2}} \quad (43)$$

$$\Delta P_2 = n_p \cdot \Delta P'_2 \quad (44)^*$$

$$P_{19 \text{ calculated}} = P_{18} - \Delta P_2 \quad (45)$$

TEST 3

(45) must = (36) $\pm$.001

If (45) > (36), increase (36) and iterate from (36)

If (45) < (36), reduce (36) and iterate from (36).

TEST 4

If (45) < 10, stop & readout message "REDUCE NRe1 OR INCREASE Ra"

If (45) $\geq$ 10, continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T19 - T18)} \left\{ \frac{(T19)^{1.643} - (T18)^{1.643}}{1.643} \right\} \quad (46)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{[.00355 (T19 - T18)]} \left\{ \frac{(.00355 T19)^{1.642} - (.00355 T18)^{1.642}}{1.642} \right\} \quad (47)$$

$$T_{cm} = \frac{\left(\frac{K_{m2}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (48)$$

$$P_{cm} = \frac{(P18 + P19)}{2} \quad (49)$$

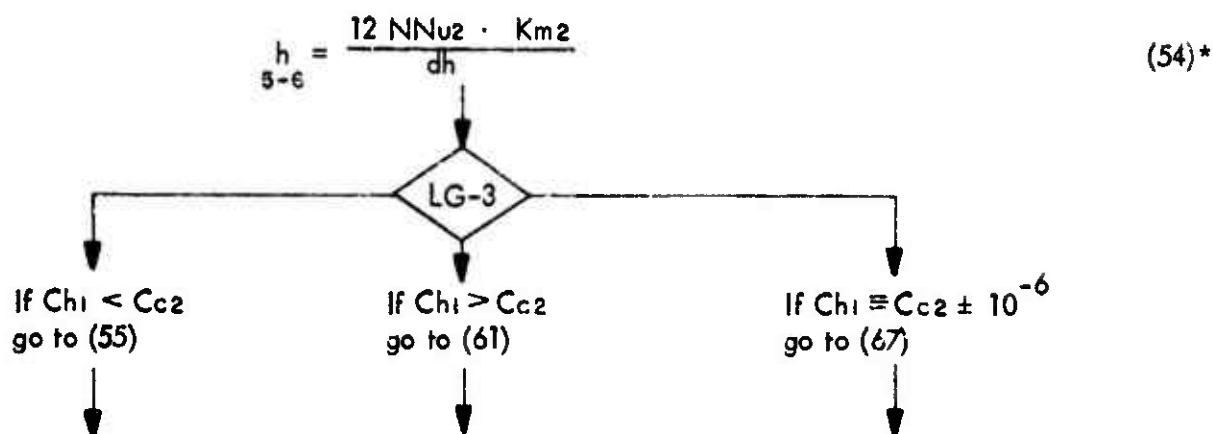
Call cp subroutine and, with
Tcm and Pcm get

$$c_{pcm} = \quad (50)$$

$$C_{c2} = c_{pcm} \cdot W2 \quad (51)^*$$

$$NPr_2 = \frac{c_{pcm} \cdot \mu_{m2}}{K_{m2}} \quad (52)^*$$

$$NNu_2 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left(\frac{tp/dh}{NR_{e2} \cdot NPr_2} \right)} \right)}{1 + \left(\frac{.016}{\left(\frac{tp/dh}{NR_{e2} \cdot NPr_2} \right)^{.8}} \right)} \right\} \quad (53)^*$$



If $Ch_1 < C_{c2}$

$$\nabla_1 = (T_{12} - T_{18}) e^{N_{tuf} \left[1 - (Ch_1 / C_{c2}) \right]} \quad (55)$$

$$\Delta X = \frac{\nabla_1 - (T_{12} - T_{18})}{\left(\frac{C_{c2}}{Ch_1} \right) - 1} \quad (56)$$

$$\Delta Y = \left(\frac{C_{c2}}{Ch_1} \right) \cdot \Delta X \quad (57)$$

$$T_{19} \text{ calculated} = T_{18} + \Delta X \quad (58)$$

TEST 5-A

$$(58) \text{ must} = (35) \pm .001$$

If $(58) > (35)$, increase (35) and iterate from (35) .

If $(58) < (35)$, reduce (35) and iterate from (35) .

$$T_{11} \text{ calculated} = T_{12} + \Delta Y \quad (59)$$

TEST 6-A

(59) must = (5) $\pm$.001

If (59) > (5), increase (5) and iterate from (5).

If (59) < (5), reduce (5) and iterate from (5).

$$\epsilon_i = \frac{1 - e^{-N_{tui} [1 - (Ch_1 / C_{c2})]}}{1 - \left\{ \left(\frac{Ch_1}{C_{c2}} \right) e^{-N_{tui} [1 - (Ch_1 / C_{c2})]} \right\}} \quad (60)^*$$

Then go to (71)

If $Ch_1 > C_{c2}$

$$\nabla_1 = (T_{12} - T_{18}) e^{N_{tui} [1 - (C_{c2} / Ch_1)]} \quad (61)$$

$$\Delta X = \frac{\nabla_1 - (T_{12} - T_{18})}{\left(\frac{Ch_1}{C_{c2}} \right) - 1} \quad (62)$$

$$\Delta Y = \left(\frac{Ch_1}{C_{c2}} \right) \cdot \Delta X \quad (63)$$

$$T_{19} \text{ calculated} = T_{18} + \Delta X \quad (64)$$

TEST 5-B

(64) must = (35) $\pm$.001

If (64) > (35), increase (35) and iterate from (35).

If (64) < (35), reduce (35) and iterate from (35).

$$T11 \text{ calculated} = T12 + \Delta Y \quad (65)$$

TEST 6-B

$$(65) \text{ must} = (5) \pm .001$$

If $(65) > (5)$, increase (5) and iterate from (5) .

If $(65) < (5)$, reduce (5) and iterate from (5) .

$$\epsilon_i = \frac{1 - e^{-N_{tui} [1 - (C_{c2}/Ch_1)]}}{1 - \left\{ \left(\frac{C_{c2}}{Ch_1} \right)^e e^{-N_{tui} [1 - (C_{c2}/Ch_1)]} \right\}} \quad (66)^*$$

Then go to (71)

$$\boxed{\text{If } Ch_1 \equiv C_{c2} \pm 10^{-6}}$$

$$Z = \frac{(T12 - T18)}{1 - \left(\frac{N_{tui}}{1 + N_{tui}} \right)} \quad (67)$$

$$T19 \text{ calculated} = (T18 + Z) - (T12 - T18) \quad (68)$$

TEST 5-C

$$(68) \text{ must} = (35) \pm .001$$

If $(68) > (35)$, increase (35) and iterate from (35) .

If $(68) < (35)$, reduce (35) and iterate from (35) .

$$T11 \text{ calculated} = T18 + Z \quad (69)$$

TEST 6-C

(69) must = (5) ± .001

IF (69) > (5), increase (5) and iterate from (5).

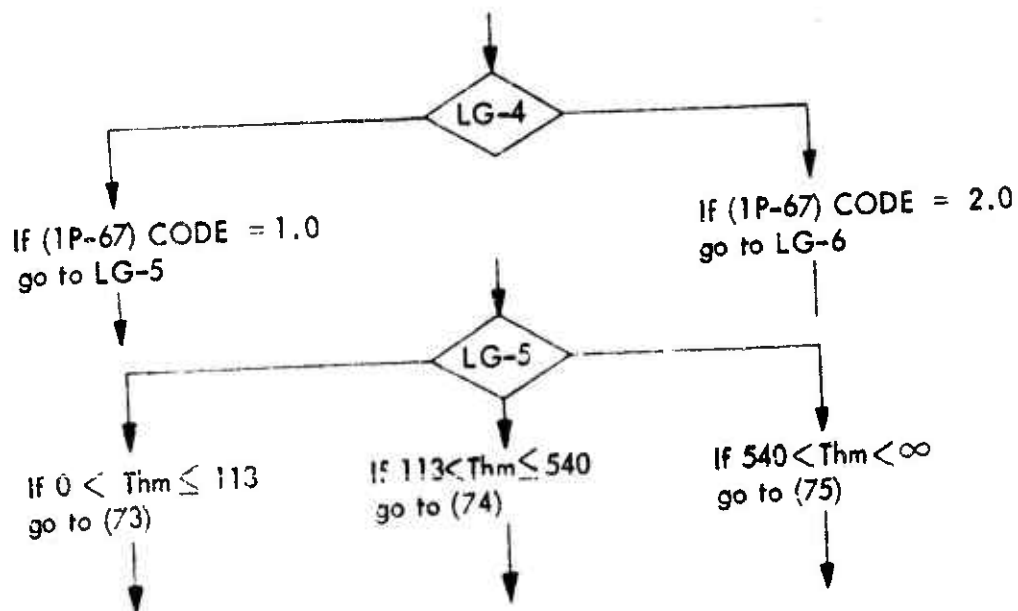
IF (69) < (5), reduce (5) and iterate from (5).

$$e_i = \frac{N t_{ui}}{T + N t_{ui}} \quad (70)^*$$

Then to to (71)

$$T'_1 = T_{hm} - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3} \right) (T_{hm} - T_{cm}) \right] \quad (71)$$

$$T'_2 = T_{hm} - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3} \right) (T_{hm} - T_{cm}) \right] \quad (72)$$



$$K_p = \frac{1}{[.1 (T_{hm} - T_l)]} \left\{ \frac{49}{2} [(T_{hm})^2 - (T_l)^2] - \frac{1}{3.47} [(T_{hm})^{3.47} - (T_l)^{3.47}] \right\} \quad (73)$$

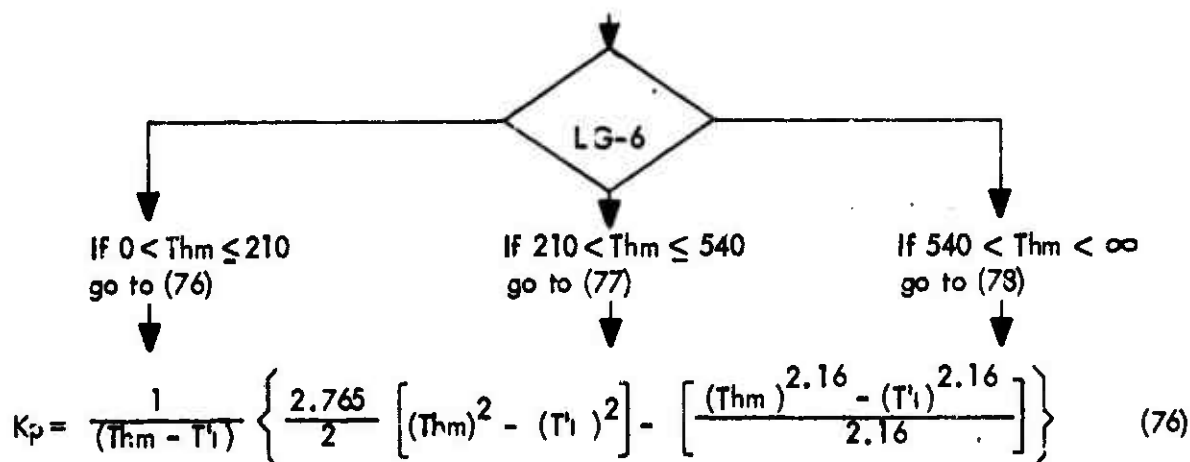
Then go to (79)

$$K_p = \frac{1}{[.1 (T_{hm} - T_l)]} \left\{ - \left[\frac{(T_{hm})^{2.708} - (T_l)^{2.708}}{2.708} \right] + 9.551 [(T_{hm})^2 - (T_l)^2] \right\} \quad (74)$$

Then go to (79)

$$K_p = 111.74 = \text{constant} \quad (75)$$

Then go to (79)



Then go to (79)

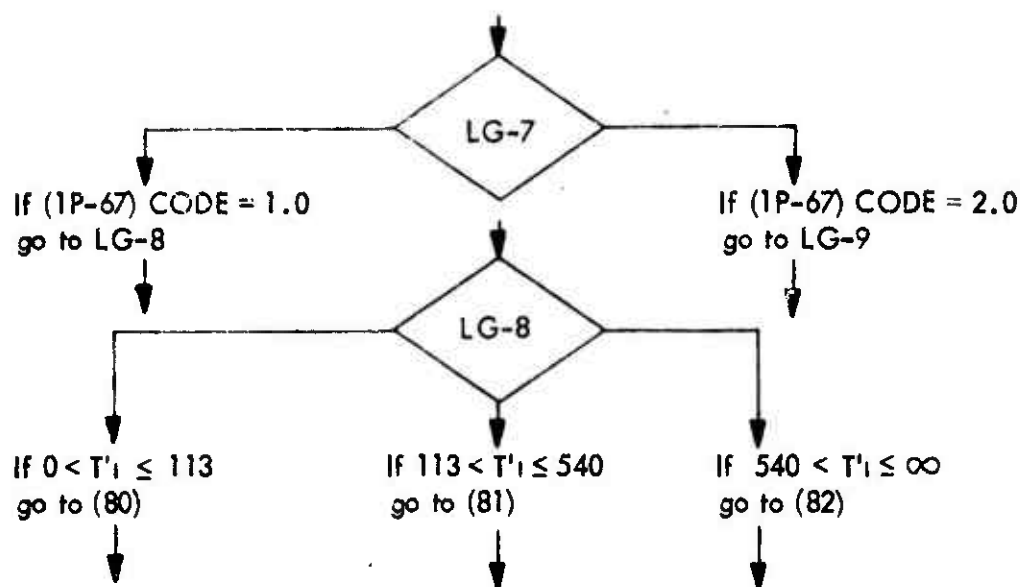
$$K_p = 85.0 + \left\{ 6.25 \left(\frac{[(T_{hm} + T_l) / 2] - 210}{330} \right) \right\} \quad (77)$$

Then go to (79)

$$K_p = 92.25 = \text{constant} \quad (78)$$

Then go to (79)

$$K_{2-3} = K_p \cdot .93061 \left[\frac{s-dh}{s-(dh/2)} \right] \quad (79)^*$$



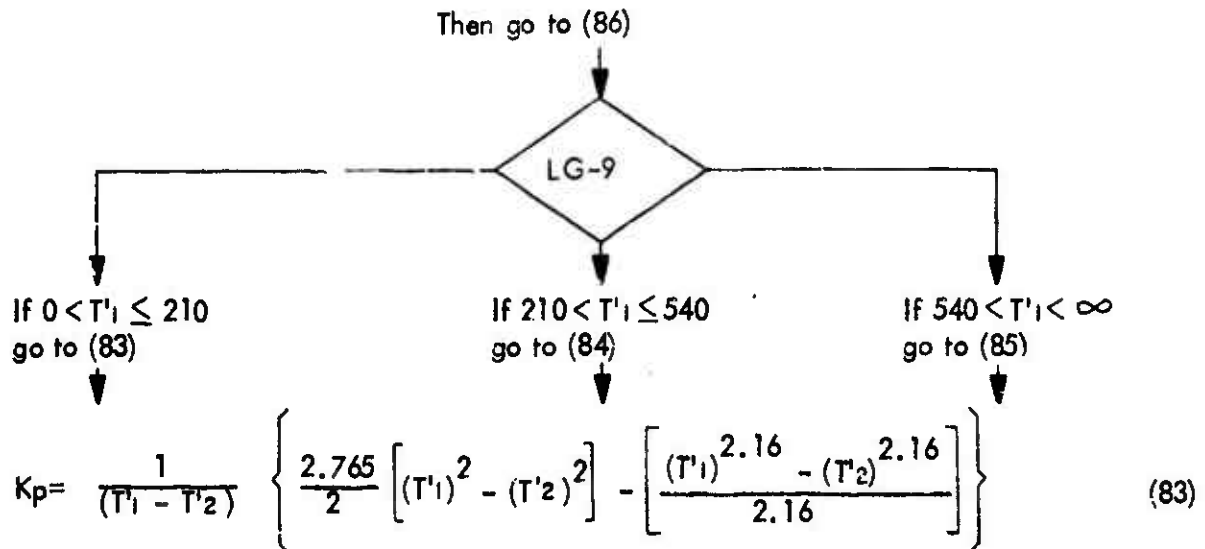
$$K_p = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ \frac{49}{2} [(.1 T'_1)^2 - (.1 T'_2)^2] - \frac{1}{3.47} [(.1 T'_1)^{3.47} - (.1 T'_2)^{3.47}] \right\} \quad (80)$$

Then go to (86)

$$K_p = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ - \left[\frac{(.1 T'_1)^{2.708} - (.1 T'_2)^{2.708}}{2.708} \right] + 9.551 [(.1 T'_1)^2 - (.1 T'_2)^2] \right\} \quad (81)$$

Then go to (86)

$$K_p = 111.74 = \text{constant} \quad (82)$$



Then go to (86)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T'_1 + T'_2) / 2] - 210}{330} \right) \right\} \quad (84)$$

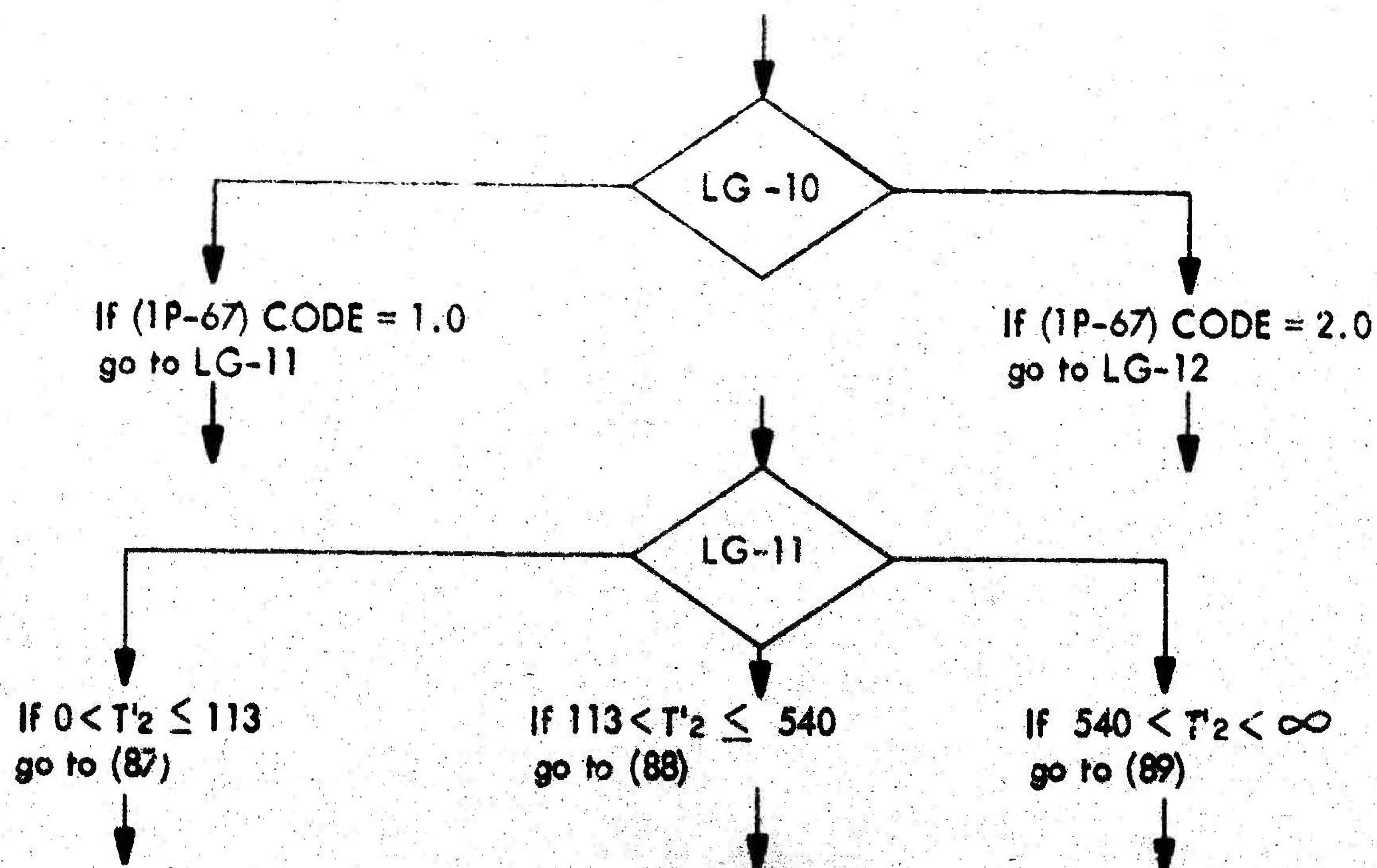
Then go to (86)

$$K_p = 92.25 = \text{constant} \quad (85)$$

Then go to (86)

$$K_{3-4} = K_p$$

(86)*



$$K_p = \frac{1}{[.1 (T'_2 - T_{cm})]} \left\{ \frac{49}{2} \left[(.1 T'_2)^2 - (.1 T_{cm})^2 \right] - \frac{1}{3.47} \left[(.1 T'_2)^{3.47} - (.1 T_{cm})^{3.47} \right] \right\} \quad (87)$$

Then go to (93)

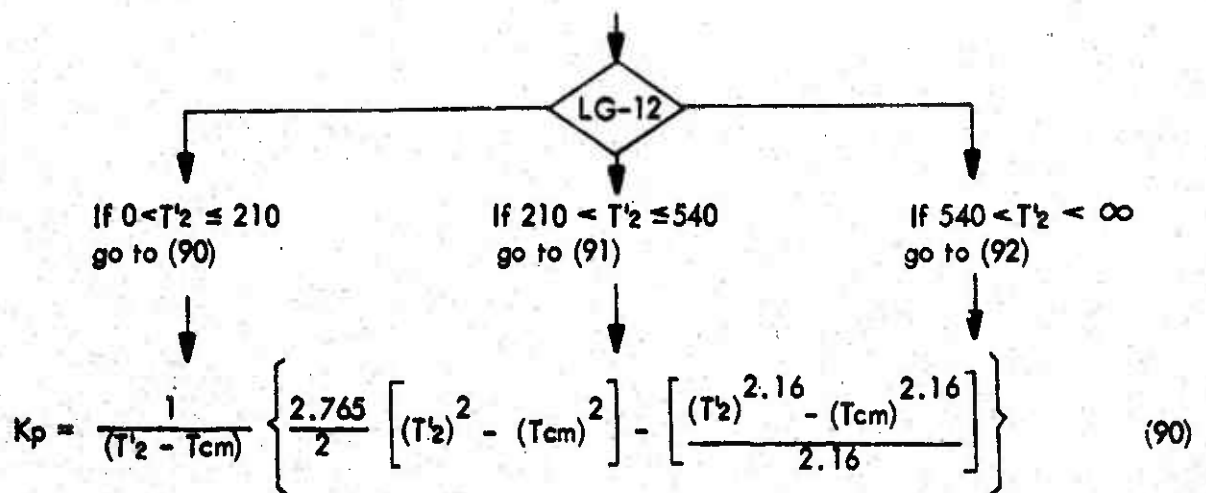
$$K_p = \frac{1}{[.1 (T'_2 - T_{cm})]} \left\{ - \left[\frac{(.1 T'_2)^{2.708} - (.1 T_{cm})^{2.708}}{2.708} \right] + 9.551 \left[(.1 T'_2)^2 - (.1 T_{cm})^2 \right] \right\} \quad (88)$$

Then go to (93)

$$K_p = 111.74 = \text{constant}$$

(89)

Then go to (93)



Then go to (93)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T_2 + T_{cm})/2] - 210}{330} \right) \right\} \quad (91)$$

Then go to (93)

$$K_p = 92.25 = \text{constant}$$

(92)

Then go to (93)

$$k_{4-5} = K_p \cdot 93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (93)^*$$

$$U = \frac{1}{\left(\frac{1}{h_{1-2}} + \frac{1}{K_{2-3}} + \frac{1}{K_{3-4}} + \frac{1}{K_{4-5}} + \frac{1}{h_{5-6}} \right)} \quad (94)^*$$

$$n_s = n_p + 1 \quad (95)^*$$

$$\lambda_e = \frac{n_s \cdot t_s}{12} \quad (96)$$

$$T_{11} = \frac{(T_{12} + T_{18})}{2} \quad (97)$$

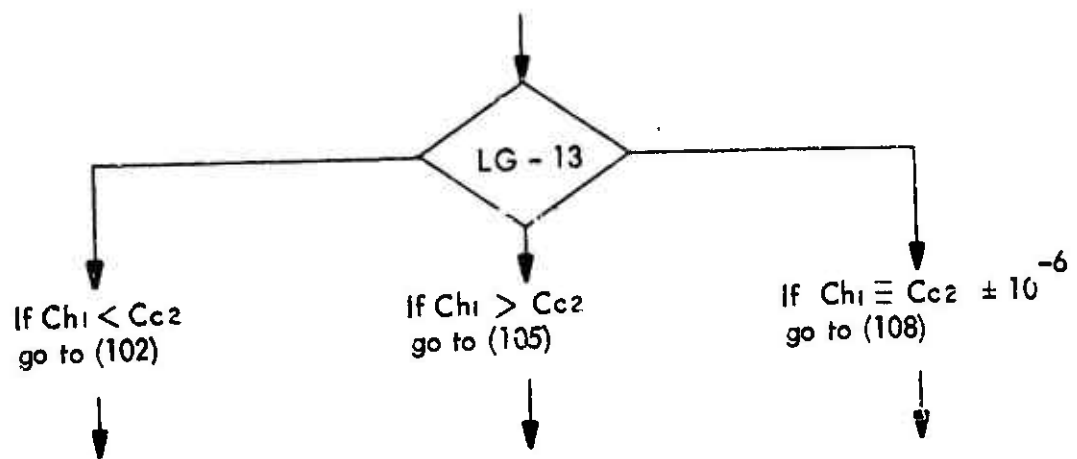
$$T_{12} = \frac{(T_{11} + T_{19})}{2} \quad (98)$$

$$Ak\lambda = \frac{\left[\left(\frac{X^2}{F_s} \right) - (X'Y') \right] + \left[(C-1) X'B' \right]}{144} \quad (99)$$

$$\bar{K}_1 = \frac{7.27 \times 10^{-3}}{(T_{12} - T_{11})} \left[\frac{(T_{12})^{1.585} - (T_{11})^{1.585}}{1.585} \right] \quad (100)$$

$$Q_l = \frac{\bar{K}l \cdot A_k l}{l_e}$$

(101)*



[If $Ch1 > Cc2$]

$$\lambda = \frac{Q1}{3600 Cc2} \quad (102)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (103)^*$$

TEST 7 - A

If (103) $\geq$ 1.0, stop & readout message "REDUCE Ntui"
 " " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon (Ch1/Cc2)}{1 - \epsilon} \right]}{1 - (Ch1/Cc2)} \quad (104)^*$$

Then go to LG - 14

[If $Ch1 > Cc2$]

$$\lambda = \frac{Q1}{3600 Cc2} \quad (105)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (106)^*$$

TEST 7 - B

If (106) $\geq$ 1.0, stop & readout message "REDUCE Ntui"
 " " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon (Cc2/Ch1)}{1 - \epsilon} \right]}{1 - (Cc2/Ch1)} \quad (107)^*$$

Then go to LG - 14

$$\boxed{\text{If } Ch1 \equiv Cc2 \pm 10^{-6}}$$

$$\lambda = \frac{QZ}{3600 Ch1} \quad (108)^*$$

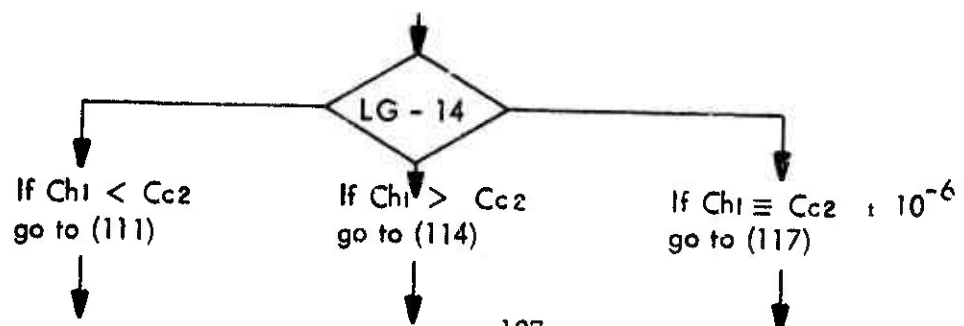
$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (109)^*$$

TEST 7 - C

If (109) $\geq$ 1.0, stop & readout message "REDUCE Ntui"
 " " < " , continue.

$$N!J = \frac{\epsilon}{1 - \epsilon} \quad (110)^*$$

Then go to LG - 14



If $Ch1 < C \cdot 2$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu} \cdot Ch1}{U} \quad (111)*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (112)*$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{A_{xp}} \quad (113)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8-A

(113) must = (4) $\pm \frac{1}{0}$

If (113) > (4), increases (4) and iterate from (4).

" " < " reduce " " " "

Then go to (120)

If $Ch1 > Cc2$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu} \cdot Cc2}{U} \quad (114)*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (115)*$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{A_{xp}} \quad (116)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8 - B

+ 1
 (116) must = (4) - 0
 If (116) > (4), increase (4) and iterate from (4).
 " " < ", reduce " " " "

Then go to (120)

$$\boxed{\text{If } Chl \equiv Cc2 \pm 10^{-6}}$$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu} \cdot Chl}{U} \quad (117)$$

$$Axp = Ax1 \cdot Af1 \quad (118)$$

$$np \text{ calculated} = \frac{114 \text{ Ax tot. hot side}}{Axp} \quad (119)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8 - C

+ 1
 (119) must = (4) - 0
 If (119) > (4), increase (4) and iterate from (4).
 " " < ", reduce " " " "

Then go to (120)

$$\text{width } X = \frac{\text{equation (13)}}{\text{afie. closure}} = \text{inches} \quad (120)^*$$

$$\text{height } = \frac{Y}{F_s} = \text{inches} \quad (121)^*$$

$$\text{core length } L = [(np \cdot tp) + (ns \cdot ts)] = \text{inches} \quad (122)^*$$

$$\begin{aligned} \text{core weight} = & .098 np tp \left\{ [(XY) - (X' Y')] + [X' B' (C - 1)] + [Af_1 (Ra + 1)(1 - \sigma)] \right\} + \\ & .078 ns ts \left\{ [(XY) - (X' Y')] + [X' B' (c - 1)] \right\} = \text{lbs} \end{aligned} \quad (123)^*$$

$$\text{header weight} = .196 \left[(XY) - Af_1 (Ra + 1) + \frac{XY}{8} \right] = \text{lbs} \quad (124)^*$$

$$\text{total weight} = (123) + (124) = \text{lbs} \quad (125)^*$$

$$\eta_f = \frac{1}{1 + \left[\frac{h^{1-2} \left(\frac{A_{xp}}{N_h \cdot Y'_{11}} \right) (Y'_{11})^2}{3 np \frac{K}{2-3} \left\{ X' tp .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \quad (126)^*$$

TEST 9

If (126) < .40, readout message "INCREASE (IP-60)."

" " > .60, " " "REDUCE (IP-60)."

Do not stop machine on TEST 9.

$$A_v = \frac{A_x \text{ tot. hat side}}{\left(\frac{X \cdot Y \cdot L}{1728} \right)} = \text{ft}^2/\text{ft}^3 \quad (127)^*$$

FINAL TEST

If $(35) \geq 540$, stop machine.

" " < " , call HX (J) and continue.
j=4

The FLOW DIAGRAM for HX-3 is exactly similar
to that of HX-1.

*

*

APPENDIX V

HX-4 AND TURBINE 2 PROGRAM CALL HX(J) $j = 4.0$:

Inputs:

Call numerical values from APPENDIX I, Section V.
Also call last result for T11, P11, T19 and P19 from
output of HX-3.

Initial numerical assumptions:

<u>Equa. No.</u>	<u>Initial Value:</u>
(4)	30.0
(5)	T11 + 10
(6)	1.02 P11
(13)	2.0
(41)	T19 + 10
(42)	.98 P19

Notes:

Readout last result of all equations marked with a star "*".
Do not stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \frac{dh^2}{\sigma}} \quad (1)^*$$

$$n = \frac{4 \sigma}{\pi dh^2} \quad (2)^*$$

$$Ax_1 = (n \pi dh t_p) + 2(1 - \sigma) \quad (3)^*$$

$$np = \text{assume} \quad (4)^*$$

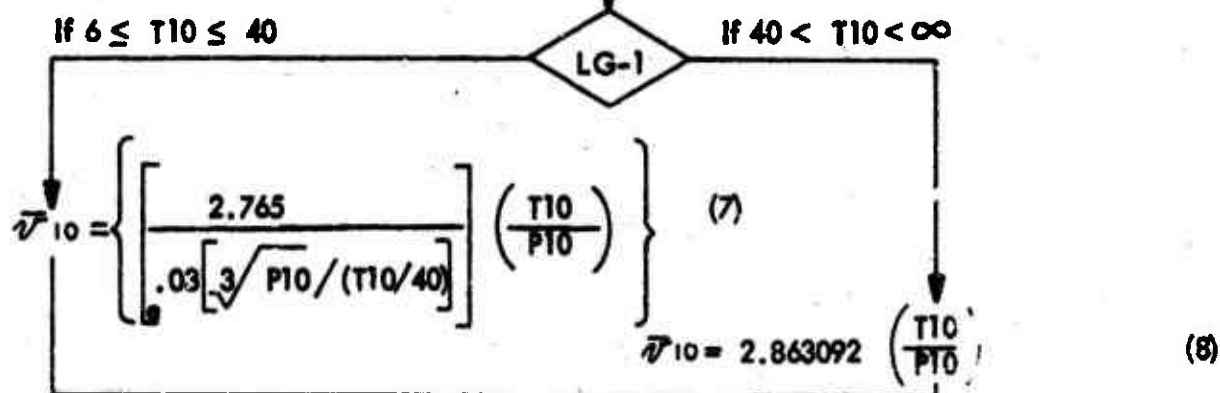
(Will be altered only by TEST 8)

$$T_{10} = \text{assume} \quad (5)^*$$

(Will be altered only by TEST 3)

$$P_{10} = \text{assume} \quad (6)^*$$

(Will be altered only by TEST 2)



$$\mu_{10} = 2.37888 \times 10^{-7} (T_{10})^{.643} \quad (9)$$

$$V_{10} = \frac{12 NRe! \bar{\nu}_{10} \mu_{10}}{dh} \quad (10)^*$$

$$ahI = \frac{144 W_2 \bar{\nu}_{10}}{V_{10}} \quad (11)^*$$

$$AfI = \frac{ahI}{\sigma} \quad (12)^*$$

$$X = \text{assume} \quad (13)^*$$

(Will be altered only by TEST 1)

$$X' = X - (2 Bx) \quad (14)^*$$

$$Y' = \frac{X}{F_s} - (2 By) \quad (15)^*$$

$$Y_1 = \frac{Y' - [(C-1) B'] - Nh}{2 (C-1)} \quad (16)^*$$

$$AfI \text{ calculated} = Nh (X' Y_1) \quad (17)$$

TEST 1

(17) must = (12) $\pm$.001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " " " .

$$Y_2 = Y_1 \frac{Ra}{2} \quad (18)^*$$

$$Y_3 = Y_1 \cdot Ra \quad (19)^*$$

$$\lambda_1 = \frac{Y'_1}{24} \quad (20)$$

$$\lambda_2 = \frac{B'}{12} \quad (21)$$

$$\lambda_3 = \frac{Y'_3}{12 \cdot Ra} \quad (22)$$

$$\Delta P_1 = \frac{370 \times 10^{-6} V_{10}^2}{\mu_{10}} \sqrt{\frac{(tp/dh)}{NRe_1}} \quad (23)$$

$$\Delta P_1 = n_p \cdot \Delta P_1 \quad (24)^*$$

$$P_{10} \text{ calculated} = P_{11} + \Delta P_1 \quad (25)$$

TEST 2

(25) must = (6) $\pm$.001

If (25) > (6) increase (6) and iterate from (6).

" " < " , reduce " " " " " " .

Call cp subroutine and, with
T10 and P10 get

$$cp_{10} = \quad (26)$$

Call cp subroutine and, with
T19 and P19 get

$$cp_{19} = \quad (27)$$

$$\overline{cp} = \frac{(cp_{10} + cp_{19})}{2} \quad (28)$$

$$\overline{\tau} = \frac{1}{1 - \left(\frac{.496447487}{\overline{cp}} \right)} \quad (29)$$

$$\frac{T_{19}}{T_{10}} = 1 - \tau \left[1 - \left(\frac{P_{19}}{P_{10}} \right)^{(\overline{\tau} - 1)/\overline{\tau}} \right] \quad (30)$$

$$T_{10} \text{ calculated} = \frac{T_{19}}{(T_{19}/T_{10})} \quad (31)$$

TEST 3

(31) must = (5) $\pm$.001

If (31) > (5), increases (5) and iterate from (5).

" " < " reduce " " " " " "

$$\mu_{ml} = \frac{8.55497 \times 10^{-4}}{(T_{10} - T_{11})} \left\{ \frac{(T_{10})^{1.643} - (T_{11})^{1.643}}{1.643} \right\} \quad (32)$$

$$K_{ml} = \frac{57.79 \times 10^{-3}}{[.00355 (T_{10} - T_{11})]} \left\{ \frac{(.00355 T_{10})^{1.642} - (.00355 T_{11})^{1.642}}{1.642} \right\} \quad (33)$$

$$Thm = \frac{\left(\frac{K_{mi}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (34)$$

$$Phm = \frac{(P_{10} + P_{11})}{2} \quad (35)$$

Call cp subroutine and, with
Thm and Phm get

$$cphm = \leftarrow \quad (36)$$

$$Ch1 = cphm \cdot W2 \quad (37)^*$$

$$NPr1 = \frac{cphm \cdot \mu_{mi}}{K_{mi}} \quad (38)^*$$

$$NNu1 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe1 \cdot NPr1} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe1 \cdot NPr1} \right]^{.8}} \right)} \right\} \quad (39)^*$$

$$h_{1-2} = \frac{12 \cdot NNu1 \cdot K_{mi}}{dh} \quad (40)^*$$

COLD SIDE:

T_{20} assume

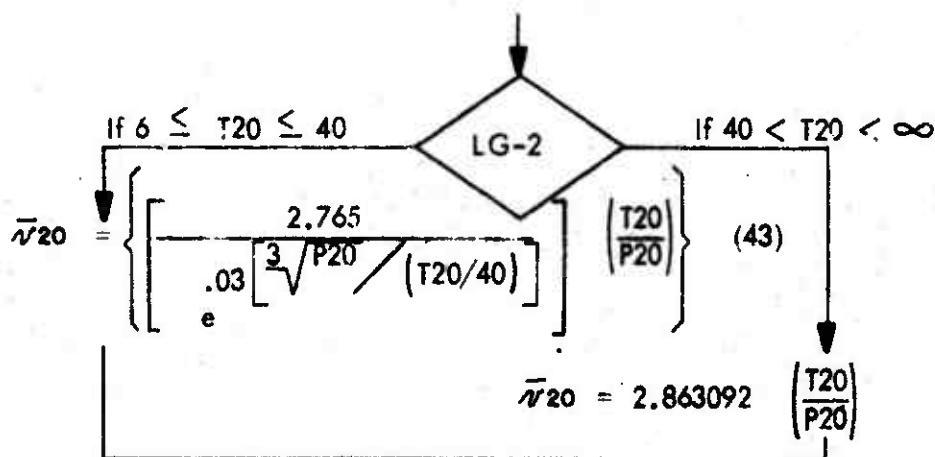
(41)*

(Will be altered only by TEST 6)

P_{20} = assume

(42)*

(Will be altered only by TEST 4)



$$\Delta P'2 = \frac{370 \times 10^{-6} V_{20}^2}{\bar{N}_{20}} \sqrt{\frac{(t_p/dh)}{NRe_2}} \quad (49)$$

$$\Delta P_2 = n_p \cdot \Delta P'2 \quad (50)^*$$

$$P_{20 \text{ calculated}} = P_{19} - \Delta P_2 \quad (51)$$

TEST 4

(51) must = (42) $\pm$.001

If (51) > (42), increase (42) and iterate from (42).

" " < " , reduce " " " " " " .

TEST 5

If (51) < 10, stop and readout message "INCREASE Ra"

" " $\geq$ " , continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T_{20} - T_{19})} \cdot \left\{ \frac{(T_{20})^{1.643} - (T_{19})^{1.643}}{1.643} \right\} \quad (52)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{[.00355 (T_{20} - T_{19})]} \cdot \left\{ \frac{(.00355 T_{20})^{1.642} - (.00355 T_{19})^{1.642}}{1.642} \right\} \quad (53)$$

$$T_{cm} = \frac{\left(\frac{K_{m1}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (54)$$

$$P_{cm} = \frac{(P_{19} + P_{20})}{2} \quad (55)$$

Call cp subroutine and, with
Tcm and Pcm get

(56)

cpcm =

$$Cc2 = cpcm \cdot W3$$

(57)*

$$NPr2 = \frac{cpcm \cdot \mu m^2}{Km2}$$

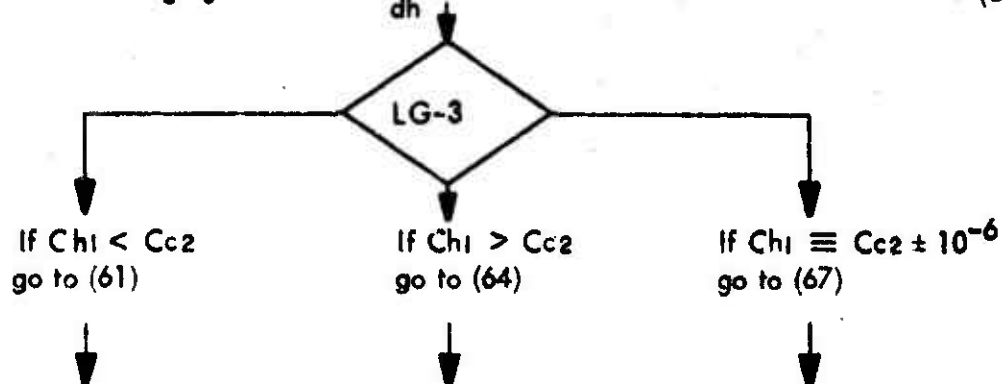
(58)*

$$NNu2 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)^{.8}} \right\}$$

(59)*

$$\frac{h}{5-6} = \frac{12 NNu2 \cdot Km2}{dh}$$

(60)*



If $Ch_1 < Cc_2$

$$T20 \text{ calculated} = T19 + \left[\frac{(T10 - T11)}{(C_{c2} / Ch1)} \right] \quad (61)$$

TEST 6 - A

(61) must = (41) $\pm$.001

If $(61) > (41)$, increase (41) and iterate from (41) .

" " < ", reduce " " " " " ".

$$N_{tui} = \frac{\log_e \left[\frac{(T_{10} - T_{20})}{(T_{11} - T_{19})} \right]}{1 - \left(\frac{C_{H1}}{C_{C2}} \right)} \quad (62)^*$$

$$\epsilon / = \frac{1 - N t u_i \left[1 - \left(\frac{C_{H1}}{C_{C2}} \right) \right]}{1 - \left\{ \left(\frac{C_{H1}}{C_{C2}} \right) - N t u_i \left[1 - \left(\frac{C_{H1}}{C_{C2}} \right) \right] \right\}} \quad (63)^*$$

Then go to (70)

If $Ch_1 > Cc_2$

$$T_{20} \text{ calculated} = T_{19} + \left[\frac{(T_{10} - T_{11})}{\left(\frac{Ch_1}{Cc_2}\right)} \right] \quad (64)$$

TEST 6 - B

(64) must = (41) $\pm$.001

If (64) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " " " .

$$N_{tui} = \frac{\log_e \left[\frac{(T_{10} - T_{20})}{(T_{11} - T_{19})} \right]}{1 - \left(\frac{Cc_2}{Ch_1}\right)} \quad (65)^*$$

$$\epsilon_i = \frac{1 - e^{-N_{tui} \left[1 - \left(\frac{Cc_2}{Ch_1}\right) \right]}}{1 - \left\{ \left(\frac{Cc_2}{Ch_1}\right) e^{-N_{tui} \left[1 - \left(\frac{Cc_2}{Ch_1}\right) \right]} \right\}} \quad (66)^*$$

Then go to (70)

$$\text{If } Ch1 \equiv Cc2 \pm 10^{-6}$$

$$T20 \text{ calculated} = T10 - (T11 - T19) \quad (67)$$

TEST 6 - C

$$(67) \text{ must} = (41) \pm .001$$

If (67) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " " "

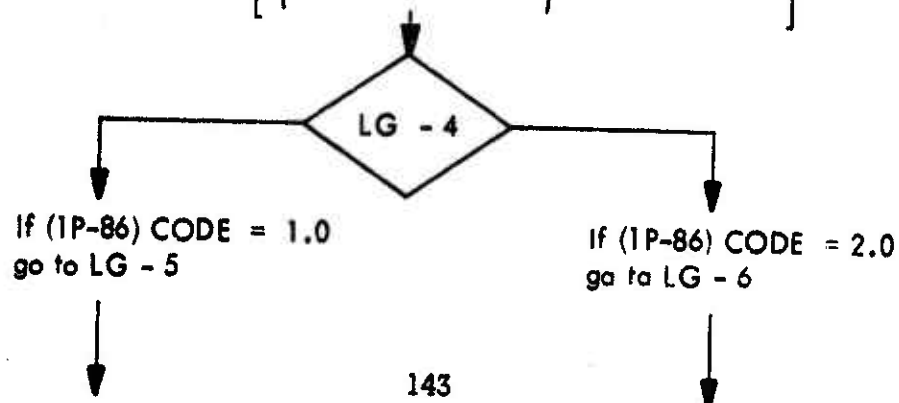
$$N_{tui} = \frac{\left[\frac{(T10 - T11)}{(T10 - T19)} \right]}{1 - \left[\frac{(T10 - T11)}{(T10 - T19)} \right]} \quad (68)^*$$

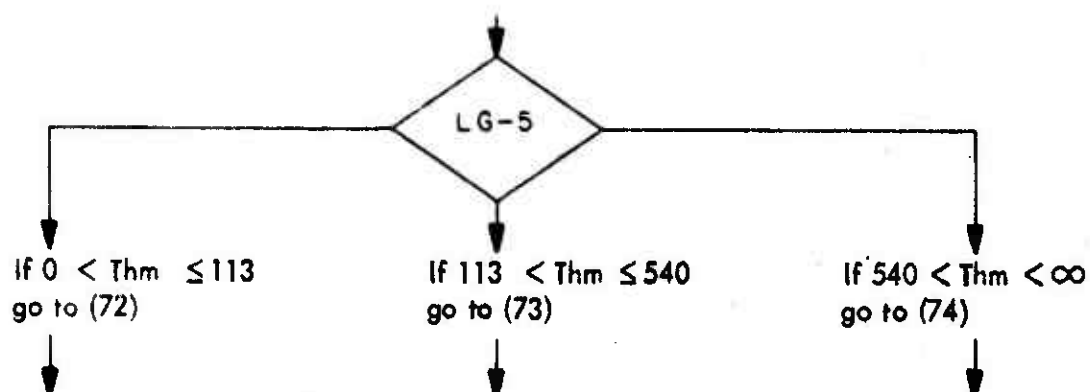
$$\epsilon_i = \frac{N_{tui}}{1 + N_{tui}} \quad (69)^*$$

Then go to (70)

$$T'1 = T_{hm} - \left[\left(\frac{Y_1}{Y_1 + Y_2 + Y_3} \right) (T_{hm} - T_{cm}) \right] \quad (70)$$

$$T'2 = T_{hm} - \left[\left(\frac{Y_1 + Y_2}{Y_1 + Y_2 + Y_3} \right) (T_{hm} - T_{cm}) \right] \quad (71)$$





$$K_p = \frac{1}{[.1 (Thm - T'l)]} \left\{ \frac{49}{2} \left[(.1 Thm)^2 - (.1 T'l)^2 \right] - \frac{1}{3.47} \left[(.1 Thm)^{3.47} - (.1 T'l)^{3.47} \right] \right\} \quad (72)$$

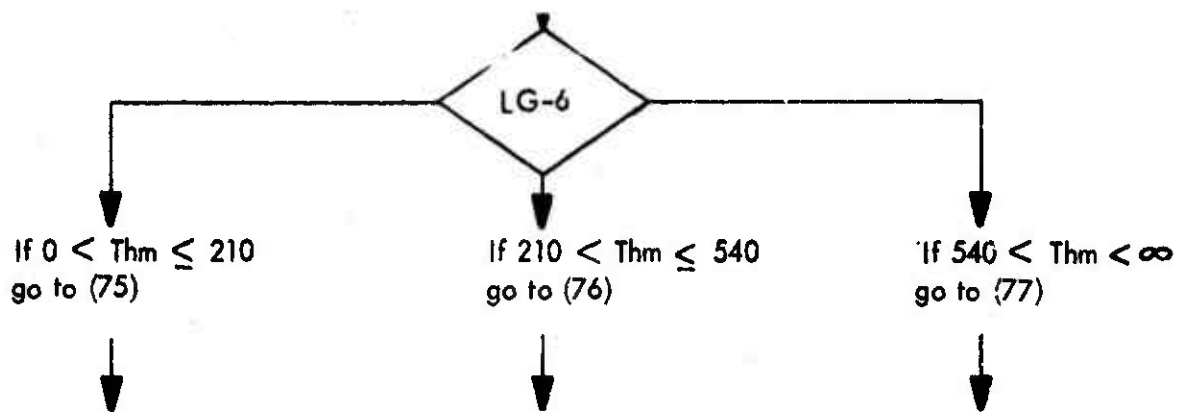
Then go to (78)

$$K_p = \frac{1}{[.1 (Thm - T'l)]} \left\{ - \left[\frac{2.708}{(.1 Thm) - (.1 T'l)} \right] + 9.551 \left[(.1 Thm)^2 - (.1 T'l)^2 \right] \right\} \quad (73)$$

Then go to (78)

$$K_p = 111.74 = \text{constant} \quad (74)$$

Then go to (78)



$$K_p = \frac{1}{(Thm - T'_{l1})} \left\{ \frac{2.765}{2} [(Thm)^2 - (T'_{l1})^2] - \left[\frac{(Thm)^{2.16} - (T'_{l1})^{2.16}}{2.16} \right] \right\} \quad (75)$$

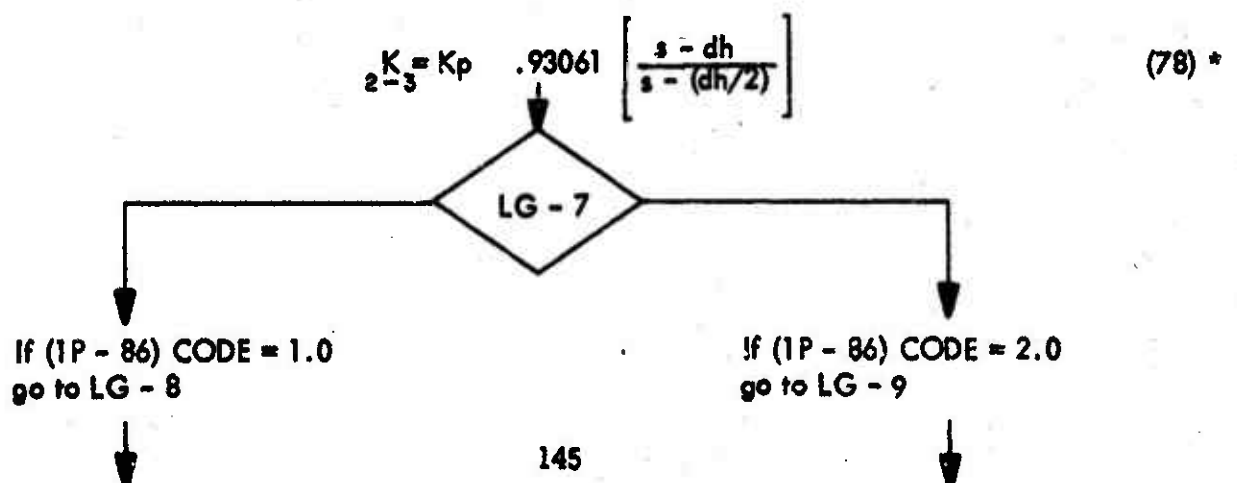
Then go to (78)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(Thm + T'_{l1})/2] - 210}{330} \right) \right\} \quad (76)$$

Then go to (78)

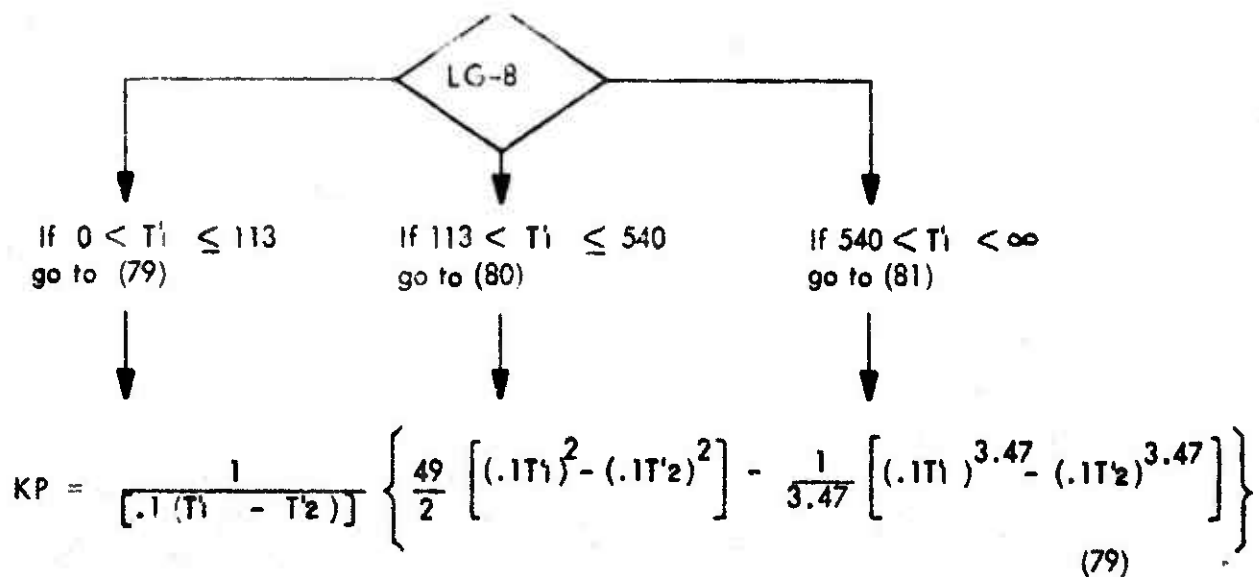
$$K_p = 92.25 = \text{constant} \quad (77)$$

Then go to (78)



$${}_2K_{-3} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right]$$

(78) *

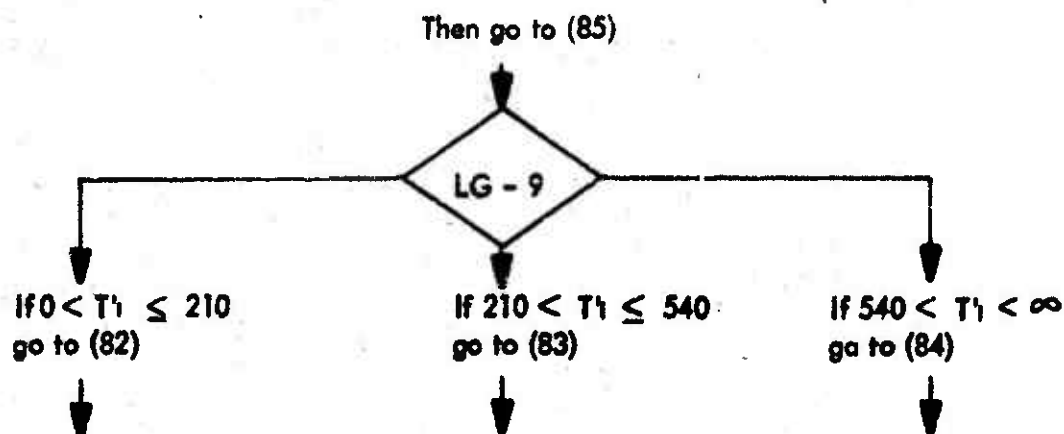


Then go to (85)

$$K_p = \frac{1}{[.1(T_1 - T_2)]} \left\{ - \left[\frac{(.1T_1)^{2.708} - (.1T_2)^{2.708}}{2.708} \right] + 9.551 \left[(.1T_1)^2 - (.1T_2)^2 \right] \right\} \quad (80)$$

Then go to (85)

$$K_p = 111.74 = \text{constant} \quad (31)$$



$$K_p = \frac{1}{(T'_1 - T'_2)} \left\{ \frac{2.765}{2} \left[(T'_1)^2 - (T'_2)^2 \right] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16} \right] \right\} \quad (82)$$

Then go to (85)

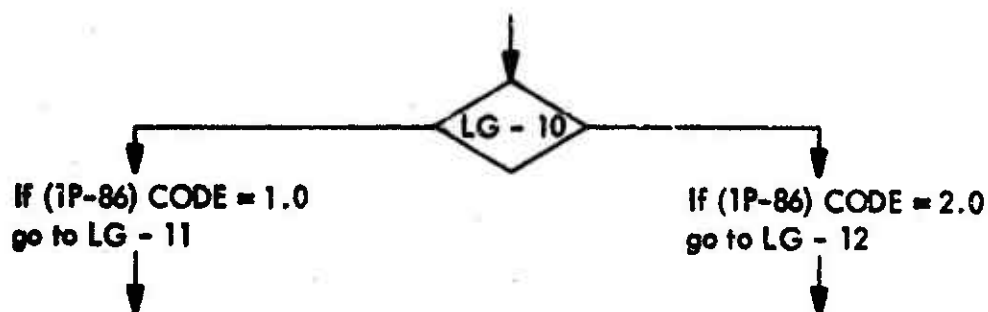
$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T'_1 + T'_2)/2] - 210}{330} \right) \right\} \quad (83)$$

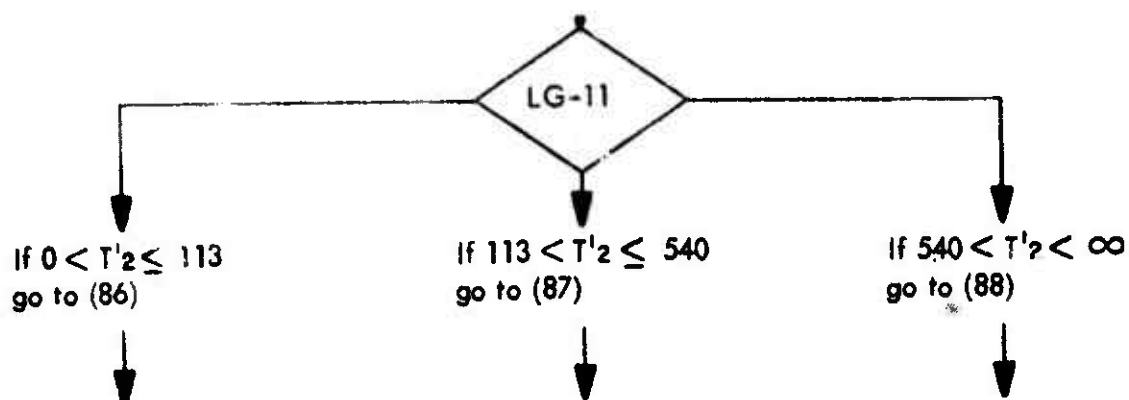
Then go to (85)

$$K_p = 92.25 = \text{constant} \quad (84)$$

Then go to (85)

$$K_{3-4} = K_p \quad (85)^*$$





$$K_p = \frac{1}{[.1(T'_2 - T_{cm})]} \left\{ \frac{49}{2} \left[(.1T'_2)^2 - (.1T_{cm})^2 \right] - \frac{1}{3.47} \left[(.1T'_2)^{3.47} - (.1T_{cm})^{3.47} \right] \right\} \quad (86)$$

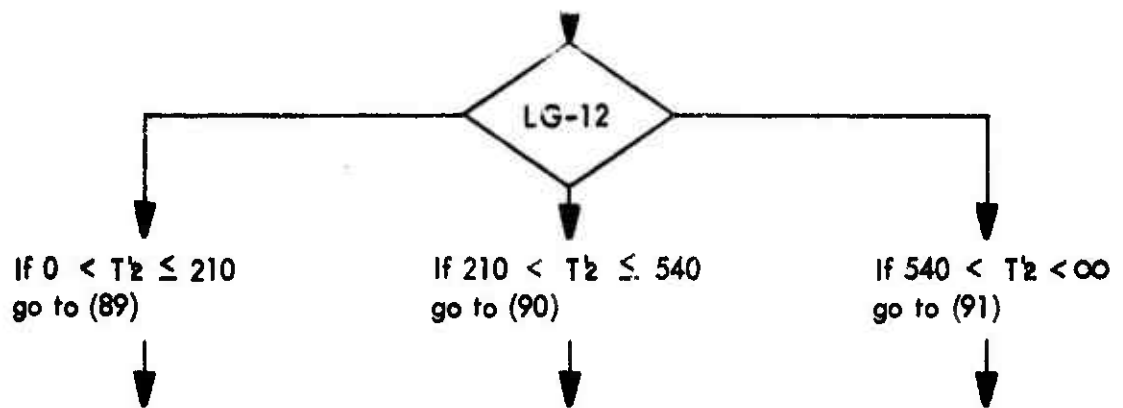
Then go to (92)

$$K_p = \frac{1}{[.1(T'_2 - T_{cm})]} \left\{ - \left[\frac{(.1T'_2)^{2.708} - (.1T_{cm})^{2.708}}{2.708} \right] + 9.551 \left[(.1T'_2)^2 - (.1T_{cm})^2 \right] \right\} \quad (87)$$

Then go to (92)

$$K_p = 111.74 = \text{constant} \quad (88)$$

Then go to (92)



$$K_p = \frac{1}{(T_2 - T_{cm})} \left\{ \frac{2.765}{2} \left[(T_2)^2 - (T_{cm})^2 \right] - \left[\frac{(T_2)^{2.16} - (T_{cm})^{2.16}}{2.16} \right] \right\} \quad (89)$$

Then go to (92)

$$K_p = 86.0 + \left\{ 6.25 \left(\left[\frac{(T_2 + T_{cm})/2}{330} \right] - 210 \right) \right\} \quad (90)$$

Then go to (92)

$$K_p = 92.25 = \text{constant} \quad (91)$$

Then go to (92)

$$K_{4-5} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (92)^*$$

$$U = \frac{1}{\frac{1}{h_{1-2}} + \frac{\lambda_1}{K_{2-3}} + \frac{\lambda_2}{K_{3-4}} + \frac{\lambda_3}{K_{4-5}} + \frac{1}{h_{5-6}}} \quad (93)^*$$

$$n_s = n_p + 1 \quad (94)^*$$

$$l_e = \frac{n_s \cdot t_s}{12} \quad (95)$$

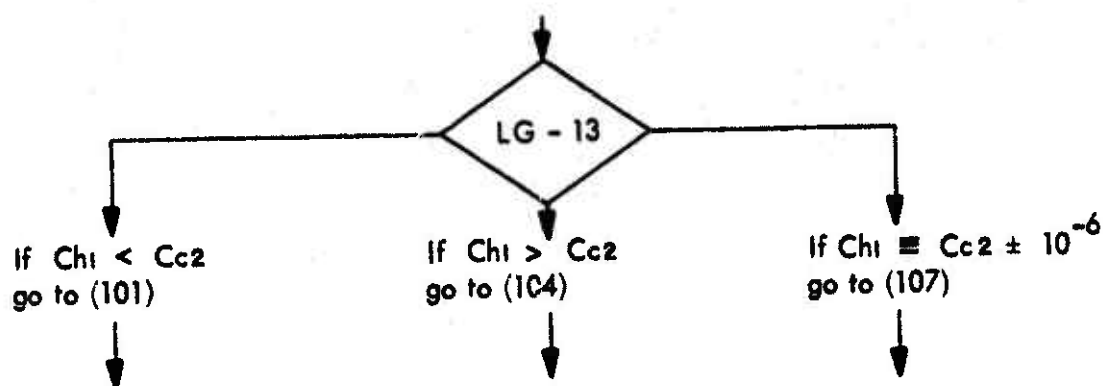
$$Tl_1 = \frac{(T11 + T19)}{2} \quad (96)$$

$$Tl_2 = \frac{(T10 + T20)}{2} \quad (97)$$

$$Ak_l = \frac{[(X^2/F_s) - (X' \cdot Y')] + [(C - 1) X' \cdot B']}{144} \quad (98)$$

$$\overline{Kl} = \frac{7.27 \times 10^{-3}}{(Tl_2 - Tl_1)} \left[\frac{(Tl_2)^{1.585} - (Tl_1)^{1.585}}{1.585} \right] \quad (99)$$

$$Ql = \frac{\overline{Kl} \cdot Ak_l}{l_e} \quad (100)^*$$



If $Ch1 < Cc2$

$$\lambda = \frac{Q2}{3600 \text{ } Ch1} \quad (101)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \quad (102)^*$$

TEST 7 - A

If $(102) \geq 1.0$, stop and readout message "REDUCE BORDER DIMS. OR INCREASE t_5 "

" " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(Ch1 / Cc2 \right)}{1 - \epsilon} \right]}{1 - \left(Ch1 / Cc2 \right)} \quad (103)^*$$

Then go to LG - 14

If $Ch1 > Cc2$

$$\lambda = \frac{Q2}{3600 \text{ } Cc2} \quad (104)^*$$

$$\epsilon = \epsilon i \left(\frac{1}{1 - \lambda} \right) \quad (105)^*$$

TEST 7 - B

If (105) ≥ 1.0 , stop and readout message "REDUCE BORDER DIMS. OR INCREASE t_s "

" " < " , continue

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(C_{c2}/Ch1 \right)}{1 - \epsilon} \right]}{1 - \left(C_{c2}/Ch1 \right)} \quad (106)^*$$

Then go to LG - 14

If $Ch1 \equiv C_{c2} \pm 10^{-6}$

$$\lambda = \frac{Q?}{3600 Ch1} \quad (107)^*$$

$$\epsilon = \epsilon_l \left(\frac{1}{1 - \lambda} \right) \quad (108)^*$$

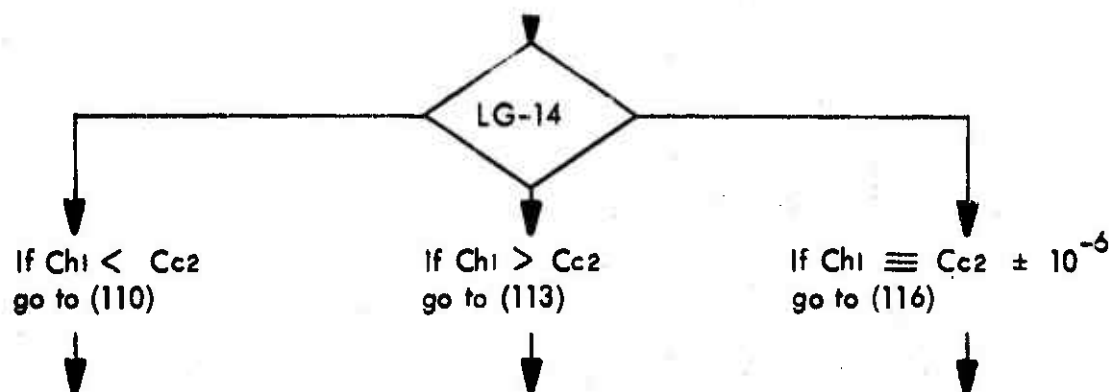
TEST 7 - C

If (108) ≥ 1.0 , stop and readout message "REDUCE BORDER DIMS. OR INCREASE t_s "

" " < " , continue

$$Ntu = \frac{\epsilon}{1 - \epsilon} \quad (109)^*$$

Then go to LG - 14



If Ch1 < Cc2

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu} \cdot Ch1}{U} \quad (110)^*$$

$$Axp = Axl \cdot Afl \quad (111)^*$$

$$np \text{ calculoted} = \frac{144 \text{ Ax tot. hot side}}{Axp} \quad (112)$$

Note If a froction results, go to next higher whole number

TEST 8 - A

$$(112) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (112) > (4), increase (4) and iterote from (4).

" " < " , reduce " " " " " "

Then go to (119)

If Ch1 > Cc2

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu} \cdot Cc2}{U} \quad (113)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (114)^*$$

$$np \text{ calculated} = \frac{144 A_{x \text{ tot. hot side}}}{A_{xp}} \quad (115)$$

Note If a fraction results, go to next higher whole number.

TEST 8 - B

$$(115) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (115) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " " .

Then go to (119)

$$\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}$$

$$A_{x \text{ tot. hot side}} = \frac{3600 N_{tu} Ch_1}{U} \quad (116)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (117)^*$$

$$np \text{ calculated} = \frac{144 A_{x \text{ tot. hot side}}}{A_{xp}} \quad (118)$$

Note If a fraction results, go to next higher whole number.

TEST 8 - C

$$(118) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (118) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " " .

Then go to (119)

$$\text{width } X = \text{equation (13)} = \text{inches after closure} \quad (119)^*$$

$$\text{height } Y = \frac{X}{F_s} = \text{inches} \quad (120)^*$$

$$\text{core length } L = [(np \cdot tp) + (ns \cdot ts)] = \text{inches} \quad (121)^*$$

$$\begin{aligned} \text{core weight} = & .098 np tp \left\{ [(XY) - (X'Y')] + [X'B' (C-1)] + [Afl (Ra + 1) (1 - \sigma)] \right\} + \\ & .078 ns ts \left\{ [(XY) - (X'Y')] + [X'B' (C-1)] \right\} = \text{lbs} \end{aligned} \quad (122)^*$$

$$\text{header weight} = .196 \left[(XY) - Afl (Ra + 1) + \frac{XY}{8} \right] = \text{lbs} \quad (123)^*$$

$$\text{total weight} = (122) + (123) = \text{lbs} \quad (124)^*$$

$$\eta f = \frac{1}{1 + \left[\frac{h_{-2} \left(\frac{A_{xp}}{N_h \cdot Y_1} \right) (Y_1)^2}{3 np_2 K_3 \left\{ X' t_f \quad 3061 \left[\frac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \quad (125)^*$$

TEST 9

If (125) < .40, readout message "INCREASE (IP-76) ."

If " > " " " "REDUCE " ."

Do not stop machine on TEST 9.

$$A_v = \frac{A_{x \text{ tot. hot side}}}{\left(\frac{X \cdot Y \cdot L}{1728} \right)} = \text{ft}^2 / \text{ft}^3 \quad (126)^*$$

$$\Delta H_{t2} = \epsilon_p T_{10} \eta_t \left[1 - \left(\frac{P_{19}}{P_{10}} \right) (\bar{p} - 1) / \bar{p} \right] = \text{BTU/lb} \quad (127)^*$$

$$\text{Turbine output} = 1054.54 \text{ Wt}_2 \cdot \Delta H_{t2} = \text{Watts} \quad (128)^*$$

FINAL TEST

If (41) ≥ 540 , stop machine

" " < " , coll HX (J)_{1=5.0} and continue.

The FLOW DIAGRAM for HX - 4 is exactly similar to that of HX - 2.

APPENDIX VI

HX - 5 PROGRAM CALL HX(J)_{J=5,0} :

Inputs:

Call numerical values from APPENDIX I, Section VI.

Also call last result for T10, P10, T20 and P20 from output of HX-4

Initial numerical assumptions:

<u>Equa.</u> <u>No</u>	<u>Initial</u> <u>Value</u>
(4)	250.0
(5)	T10 + 100
(6)	1.02 P10
(13)	2.0
(35)	T20 + 100
(36)	.98 P20

Notes:

Readout last result of all equations marked with a star " * "

Do not stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{.706894 \frac{dh^2}{\sigma}} \quad (1)^*$$

$$n = \frac{4\sigma}{\Pi dh^2} \quad (2)^*$$

$$Ax1 = (n \Pi dh tp) + 2 (1 - \sigma) \quad (3)^*$$

$$np = \text{assume} \quad (4)^*$$

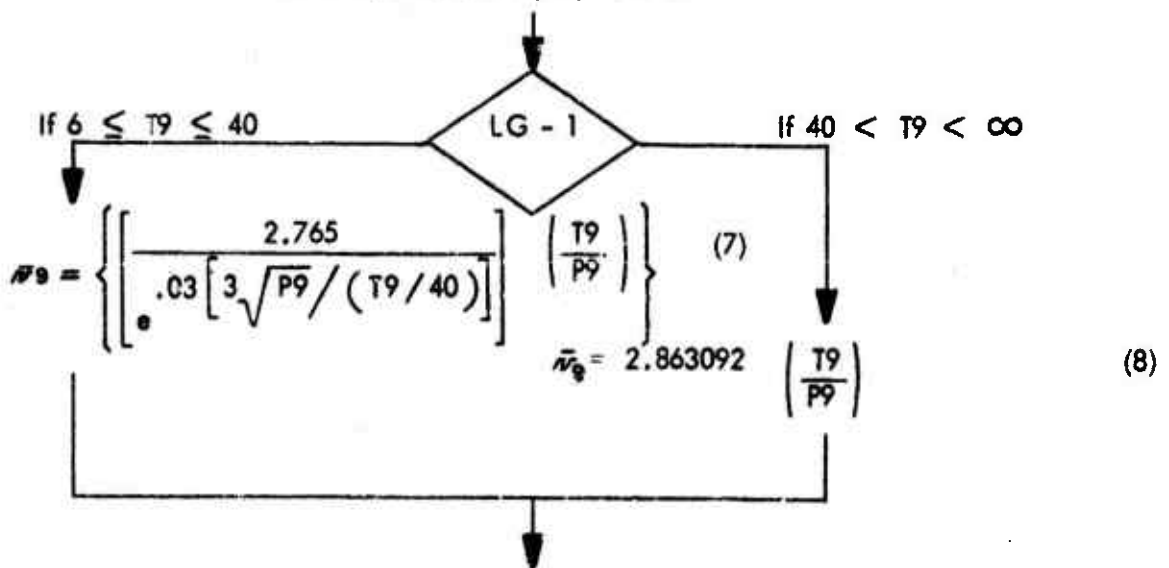
(Will be altered only by TEST 8)

$$T9 = \text{assume} \quad (5)^*$$

(Will be altered only by TEST 6)

$$P9 = \text{assume} \quad (6)^*$$

(Will be altered only by TEST 2)



$$\mu_9 = 2.37888 \times 10^{-7} (T_9)^{.643} \quad (9)$$

$$V_9 = \frac{12 \text{ NRe}_1 \bar{\nu}_9 \mu_9}{dh} \quad (10)^*$$

$$ah_1 = \frac{144 W_3 \bar{\nu}_9}{V_9} \quad (11)^*$$

$$Af_1 = \frac{ahi}{\sigma} \quad (12)^*$$

$$X = \text{assume} \quad (13)^*$$

(Will be altered only by Test 1)

$$X' = X - (2 Bx) \quad (14)^*$$

$$Y' = \frac{X}{F_s} - (2 By) \quad (15)^*$$

$$Y'_1 = \frac{Y' - \left[\frac{(C-1) B'}{2} \right] - Nh}{(C-1)} \quad (16)^*$$

$$Af_1 \text{ calculated} = Nh (X'Y'_1) \quad (17)$$

TEST 1

(17) must = (12) $\pm$.001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " " .

$$Y'_2 = Y'_1 \cdot \frac{Ra}{2} \quad (18)^*$$

$$Y'_3 = Y'_1 \cdot Ra \quad (19)^*$$

$$\lambda_1 = \frac{Y'_1}{24} \quad (20)$$

$$\lambda_2 = \frac{B'}{12} \quad (21)$$

$$\lambda_3 = \frac{Y'_3}{12 \cdot Ra} \quad (22)$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} V_g^2}{\bar{\nu}^9} \sqrt{\frac{(tp/dh)}{Nre_1}} \quad (23)$$

$$\Delta P_1 = n_p \cdot \Delta P'_1 \quad (24)^*$$

$$P_9 \text{ calculated} = P_{10} + \Delta P_1 \quad (25)$$

TEST 2

(25) must = (6) $\pm$.001

If (25) > (6), increase (6) and iterate from (6).

" " < " , reduce " " " " " " .

$$\mu_{m1} = \frac{8.55497 \times 10^{-4}}{(T9 - T10)} \left\{ \frac{(T9)^{1.643} - (T10)^{1.643}}{1.643} \right\} \quad (26)$$

$$K_{m1} = \frac{57.79 \times 10^{-3}}{[.00355 (T9 - T10)]} \left\{ \frac{(.00355 T9)^{1.642} - (.00355 T10)^{1.642}}{1.642} \right\} \quad (27)$$

$$Thm = \frac{\left(\frac{K_{m1}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (28)$$

$$Phm = \frac{(P9 + P10)}{2} \quad (29)$$

Call cp subroutine and, with
Thm and Phm get

$$cphm = \leftarrow \quad (30)$$

$$Ch1 = cphm \cdot W3 \quad (31)^*$$

$$NPr1 = \frac{cphm \cdot \mu_{m1}}{K_{m1}} \quad (32)^*$$

$$NNu1 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe1 \cdot NPr1} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe1 \cdot NPr1} \right]^{.8}} \right)} \right\} \quad (33)^*$$

$$h_{1-2} = \frac{12 \cdot NNu1 \cdot K m1}{dh} \quad (34)^*$$

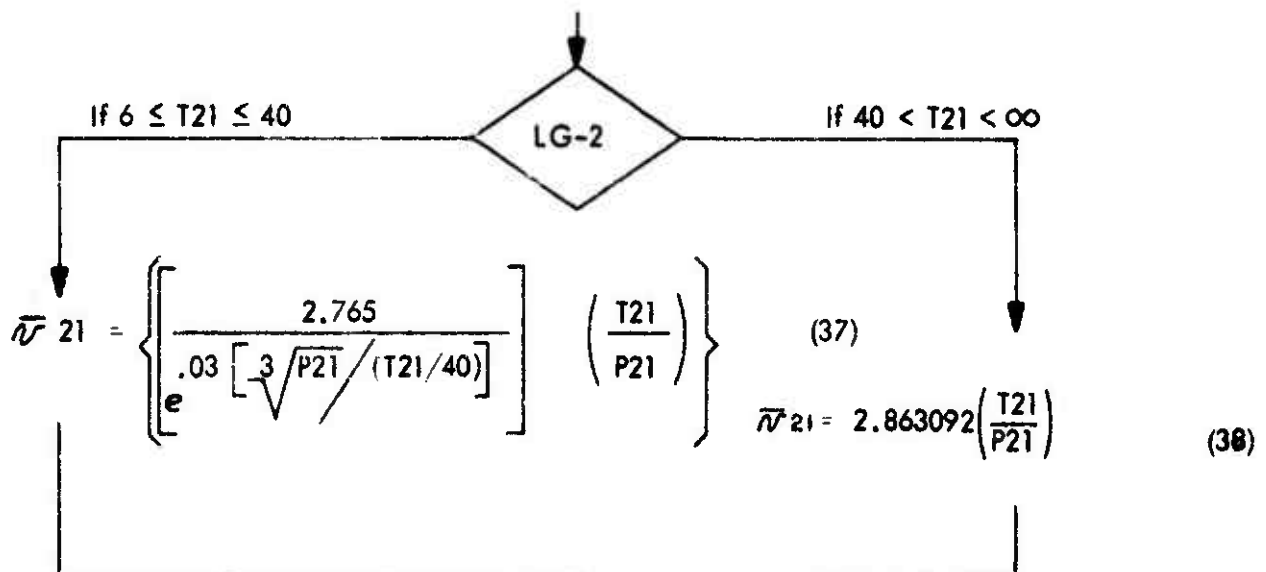
COLD SIDE:

T21 = assume

(Will be altered only by TEST 5) (35)*

P21 = assume

(Will be altered only by TEST 3) (36)*



$$ah_2 = oh_1 \cdot Ra \quad (39)^*$$

$$V_{21} = \frac{144 W_3 \bar{N}_{21}}{ah_2} \quad (40)^*$$

$$\mu_{21} = 2.37888 \times 10^{-7} (T_{21})^{.643} \quad (41)$$

$$NRe_2 = \frac{V_{21} dh}{12 \bar{N}_{21} \cdot \mu_{21}} \quad (42)^*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} V_{21}^2}{\bar{N}_{21}} \sqrt{\frac{(tp/dh)}{NRe_2}} \quad (43)$$

$$\Delta P_2 = n_p \cdot \Delta P'_2 \quad (44)^*$$

$$P_{21} \text{ calculated} = P_{20} - \Delta P_2 \quad (45)$$

TEST 3

(45) must = (36) $\pm$.001

If (45) > (36), increase (36) and iterate from (36).

" " < " , reduce " " " " " " .

TEST 4

If (45) < 10, stop and readout message "REDUCE NRe1 OR
INCREASE Ra"

" " $\geq$ " , continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T_{21} - T_{20})} \left\{ \frac{(T_{21})^{1.643} - (T_{20})^{1.643}}{1.643} \right\} \quad (46)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{[.00355 (T_{21} - T_{20})]} \left\{ \frac{(.00355 T_{21})^{1.642} - (.00355 T_{20})^{1.642}}{1.642} \right\} \quad (47)$$

$$T_{cm} = \frac{\left(\frac{K_{m2}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (48)$$

$$P_{cm} = \frac{(P_{20} + P_{21})}{2} \quad (49)$$

Call cp subroutine and, with
Tcm and Pcm.....get

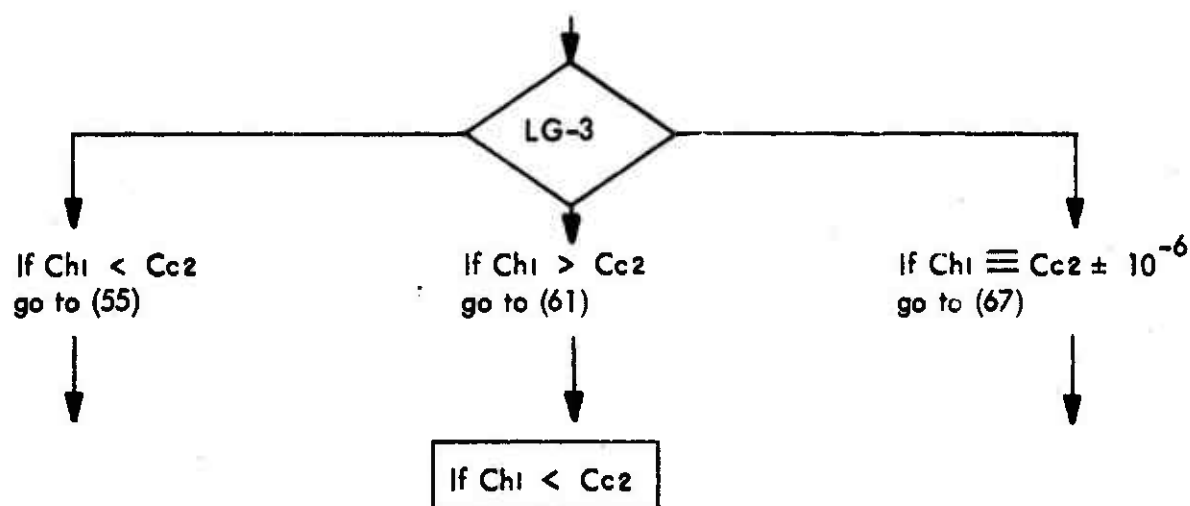
$$c_{pcm} = \leftarrow \quad (50)$$

$$C_{c2} = c_{pcm} \cdot W_3 \quad (51)^*$$

$$NPr_2 = \frac{c_{pcm} \cdot \mu_{m2}}{K_{m2}} \quad (52)^*$$

$$NNu_2 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe_2 \cdot NPr_2} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe_2 \cdot NPr_2} \right]} \right) \cdot .8} \right\} \quad (53)^*$$

$$h_{5-6} = \frac{12 \cdot NNu_2 \cdot Km_2}{dh} \quad (54)^*$$



$$\nabla_1 = (T_{10} - T_{20}) \cdot e^{Ntu_1} \left[1 - \left(\frac{Chi}{Cc_2} \right) \right] \quad (55)$$

$$\Delta X = \frac{\nabla_1 - (T_{10} - T_{20})}{\left(\frac{Cc_2}{Chi} \right) - 1} \quad (56)$$

$$\Delta Y = \left(\frac{Cc_2}{Chi} \right) \cdot \Delta X \quad (57)$$

$$T21 \text{ calculated} = T20 + \Delta X \quad (58)$$

TEST 5 - A

(58) must $\leq$ (35) $\pm$.001

If (58) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " " " .

$$T9 \text{ calculated} = T10 + \Delta Y \quad (59)$$

TEST 6 - A

(59) must $\leq$ (5) $\pm$.001

If (59) > (5), increase (5) and iterate from (5)

" " < " , reduce " " " " " " .

$$\epsilon_i = \frac{1 - e^{-N_{tui}} \left[1 - \left(\frac{Ch_i}{Cc_2} \right) \right]}{1 - \left\{ \left(\frac{Ch_i}{Cc_2} \right) e^{-N_{tui}} \left[1 - \left(\frac{Ch_i}{Cc_2} \right) \right] \right\}} \quad (60)^*$$

Then go to (71)

If $Ch_i > Cc_2$

$$\nabla 1 = (T10 - T20) e^{-N_{tui}} \left[1 - \left(\frac{Cc_2}{Ch_i} \right) \right] \quad (61)$$

$$\Delta X = \frac{\nabla 1 - (T10 - T20)}{\left(\frac{Ch_i}{Cc_2} \right) - 1} \quad (62)$$

$$\Delta Y = \left(\frac{Ch_i}{Cc_2} \right) \cdot \Delta X \quad (63)$$

$$T21 \text{ calculated} = T20 + \Delta X \quad (64)$$

TEST 5 - B

$$(64) \text{ must} = (35) \pm .001$$

If (64) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " "

$$T9 \text{ calculated} = T10 + \Delta Y \quad (65)$$

TEST 6 - B

$$(65) \text{ must} = (5) \pm .001$$

If (65) > (5), increase (5) and iterate from (5).

" " < " , reduce " " " " "

$$\epsilon_i = \frac{1 - e^{-Nt_{ui} \left[1 - (C_{c2}/Ch_1) \right]}}{1 - \left\{ \left(\frac{C_{c2}}{Ch_1} \right) e^{-Nt_{ui} \left[1 - (C_{c2}/Ch_1) \right]} \right\}} \quad (66)^*$$

Then go to (71)

$$\boxed{\text{If } Ch_1 \equiv C_{c2} \pm 10^{-6}}$$

$$Z = \frac{(T10 - T20)}{1 - \left(\frac{Nt_{ui}}{1 + Nt_{ui}} \right)} \quad (67)$$

$$T21 \text{ calculated} = (T20 + Z) - (T10 - T20) \quad (68)$$

TEST 5 - C

$$(68) \text{ must} = (35) \pm .001$$

If (68) > (35), increase (35) and iterate from (35)

" " < " , reduce " " " " " "

$$T9 \text{ calculated} = T20 + Z \quad (69)$$

TEST 6 - C

$$(69) \text{ must} = (5) \pm .001$$

If (69) > (5) , increase (5) and iterate from (5)

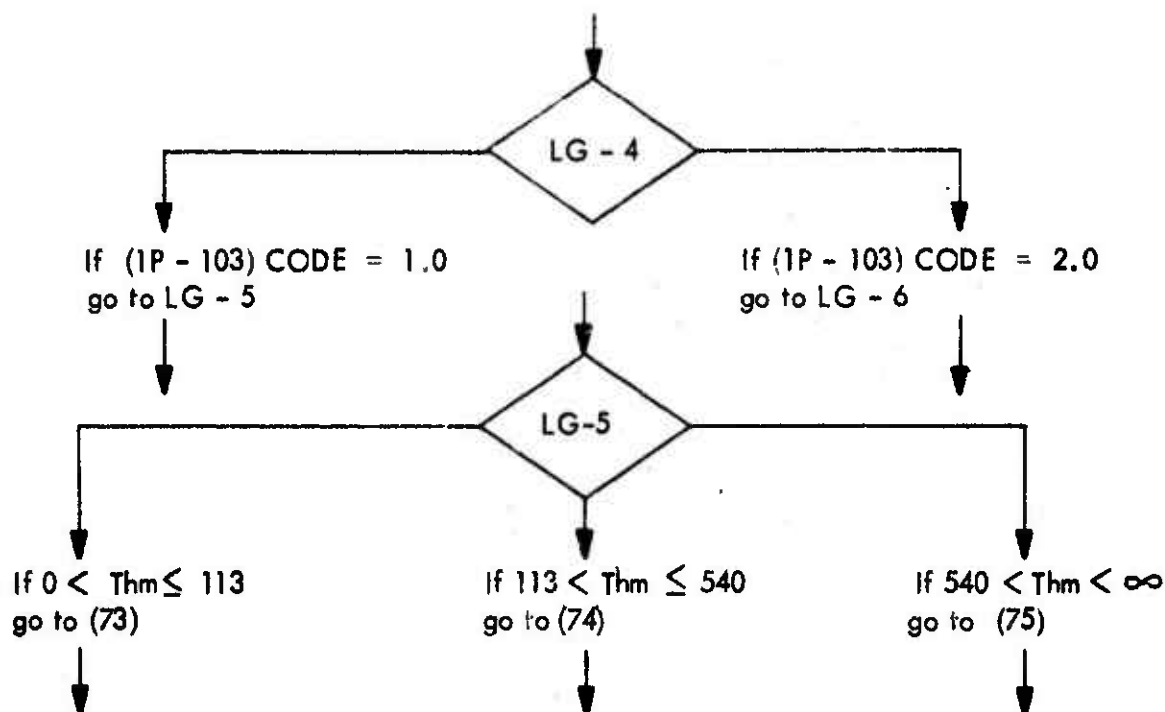
" " < " , reduce " " " " " "

$$\epsilon_i = \frac{N_{tui}}{1 + N_{tui}} \quad (70)^*$$

Then go to (71)

$$T1 = T_{hm} - \left[\left(\frac{Y1}{Y1 + Y2 + Y3} \right) (T_{hm} - T_{cm}) \right] \quad (71)$$

$$T2 = T_{hm} - \left[\left(\frac{Y1 + Y2}{Y1 + Y2 + Y3} \right) (T_{hm} - T_{cm}) \right] \quad (72)$$



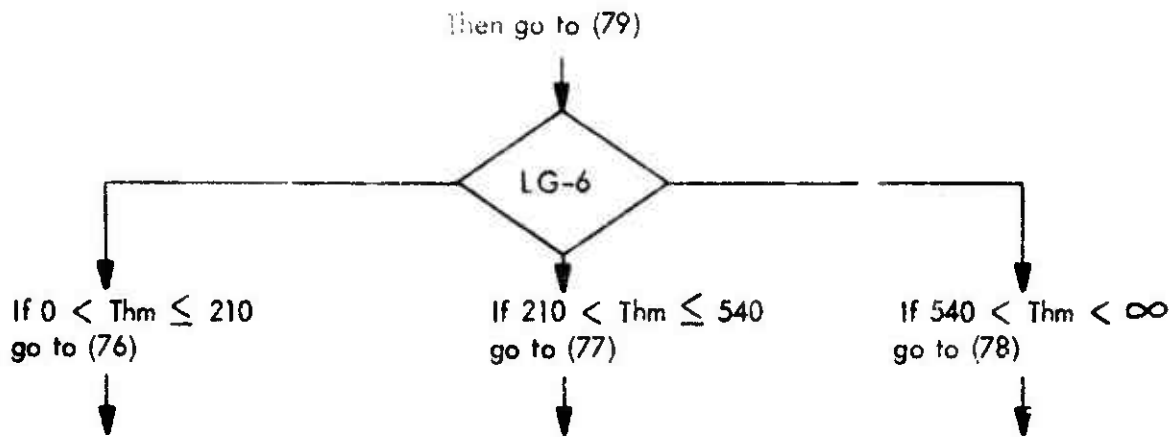
$$K_p = \frac{1}{[.1 (Th_m - T'_1)]} \left\{ \frac{49}{2} [(.1 Th_m)^2 - (.1 T'_1)^2] - \frac{1}{3.47} [(.1 Th_m)^{3.47} - (.1 T'_1)^{3.47}] \right\} \quad (73)$$

Then go to (79)

$$K_p = \frac{1}{[.1 (Th_m - T'_1)]} \left\{ - \left[\frac{(.1 Th_m)^{2.708} - (.1 T'_1)^{2.708}}{2.708} \right] + 9.551 [(.1 Th_m)^2 - (.1 T'_1)^2] \right\} \quad (74)$$

Then go to (79)

$$K_p = 111.74 = \text{constant} \quad (75)$$



$$K_p = \frac{1}{(Thm - T_i)} \left\{ \frac{2.765}{2} [(Thm)^2 - (T_i)^2] - \left[\frac{(Thm)^{2.16} - (T_i)^{2.16}}{2.16} \right] \right\} \quad (76)$$

Then go to (79)

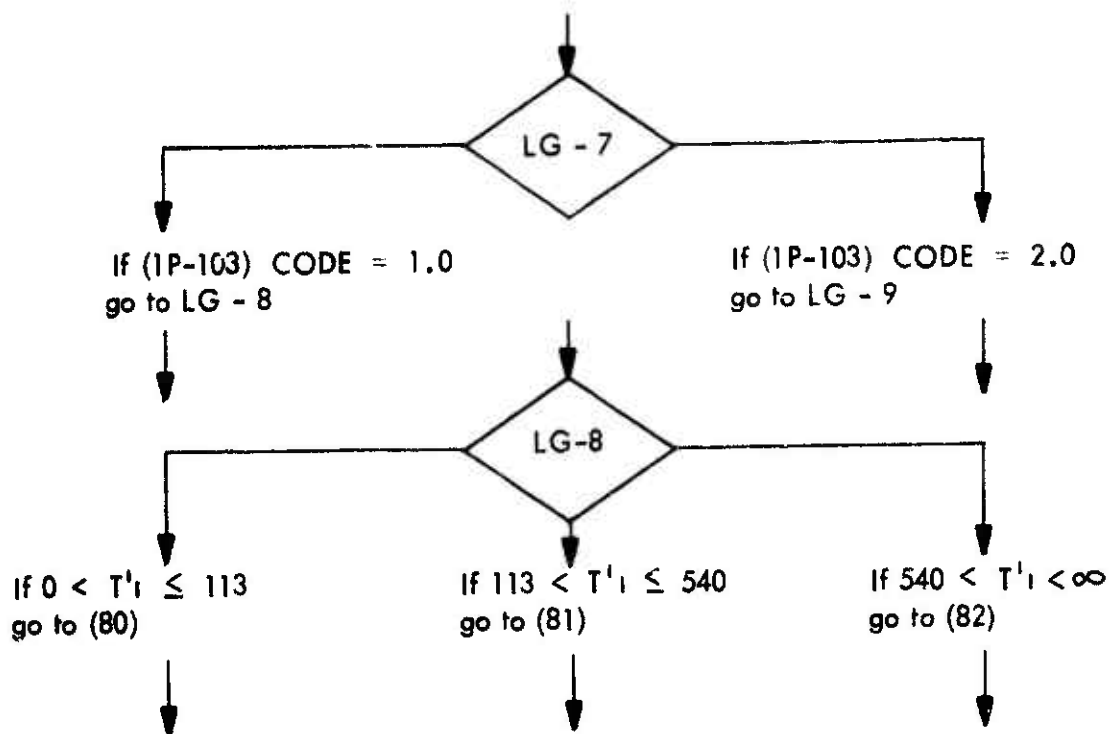
$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(Thm + T_i) / 2] - 210}{330} \right) \right\} \quad (77)$$

Then go to (79)

$$K_P = 92.25 = \text{constant} \quad (78)$$

Then go to (79)

$$K_{2-3} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (79)^*$$



$$K_p = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ \frac{49}{2} \left[(.1T'_1)^2 - (.1T'_2)^2 \right] - \frac{1}{3.47} \left[(.1T'_1)^{3.47} - (.1T'_2)^{3.47} \right] \right\} \quad (80)$$

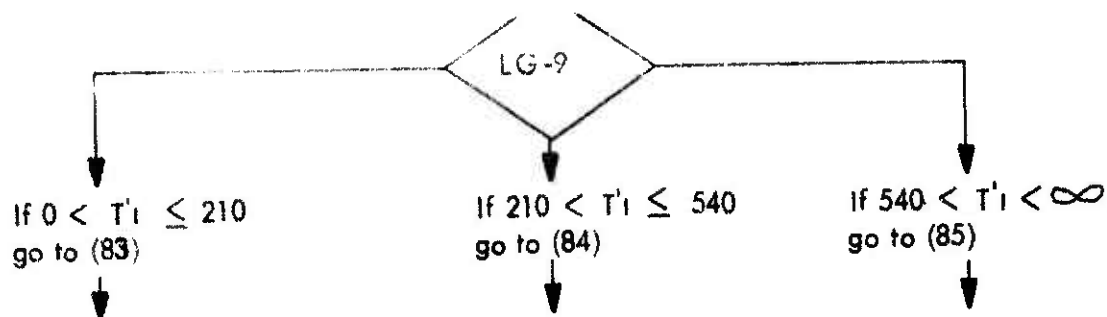
Then go to (86)

$$K_p = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ - \left[\frac{(.1T'_1)^{2.708} - (.1T'_2)^{2.708}}{2.708} \right] + 9.551 \left[(.1T'_1)^2 - (.1T'_2)^2 \right] \right\} \quad (81)$$

Then go to (86)

$$K_p = 111.74 = \text{constant} \quad (82)$$

Then go to (86)



$$K_p = \frac{1}{(T'_1 - T'_2)} \left\{ \frac{2.765}{2} \left[(T'_1)^2 - (T'_2)^2 \right] - \left[\frac{(T'_1)^{2.16} - (T'_2)^{2.16}}{2.16} \right] \right\} \quad (83)$$

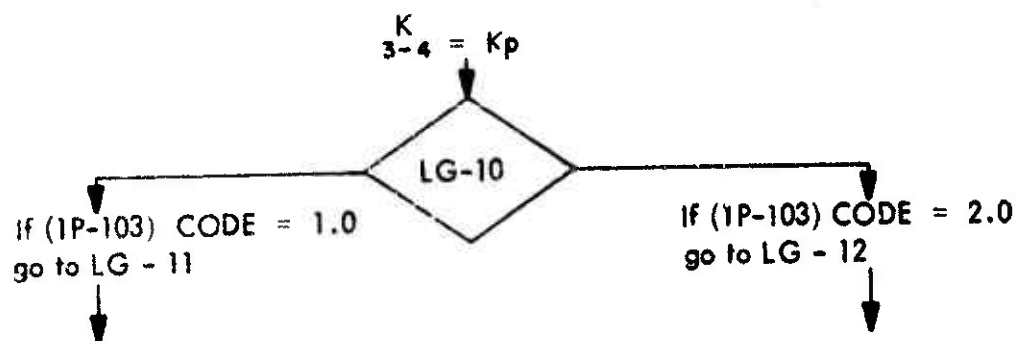
Then go to (86)

$$K_p = 86.0 + \left\{ 0.25 \left(\frac{[(T'_1 + T'_2) / 2] - 210}{330} \right) \right\} \quad (84)$$

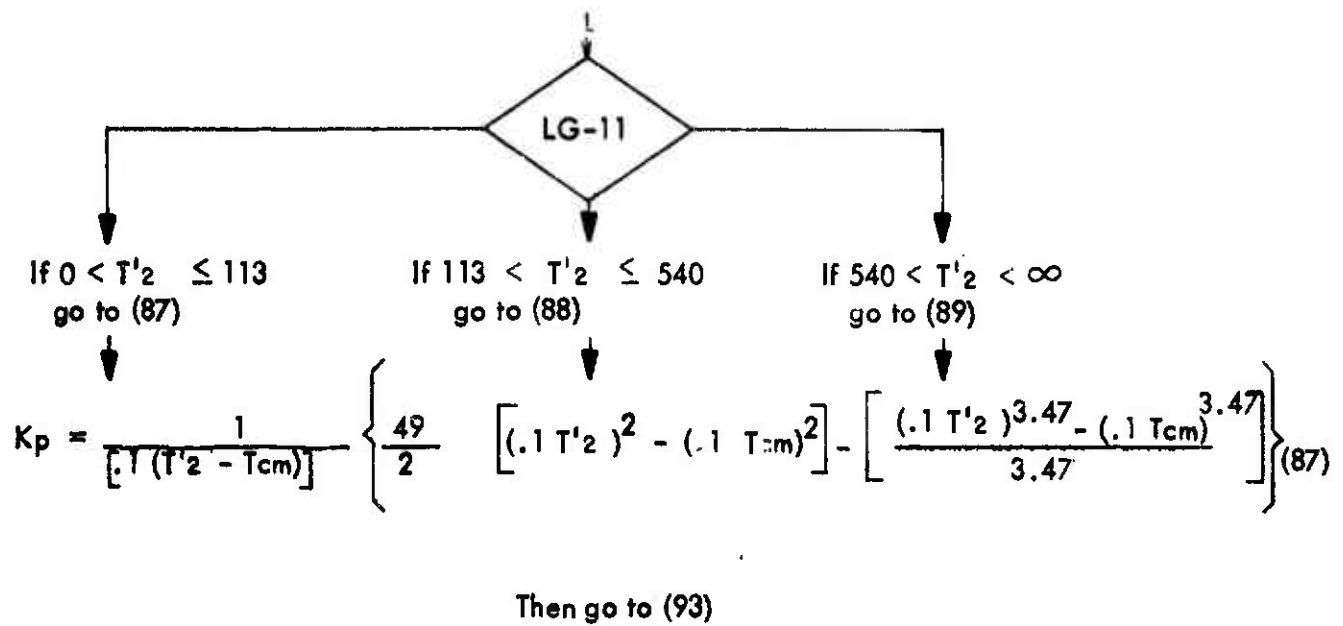
Then go to (86)

$$K_p = 92.25 = \text{constant} \quad (85)$$

Then go to (86)



(86)*

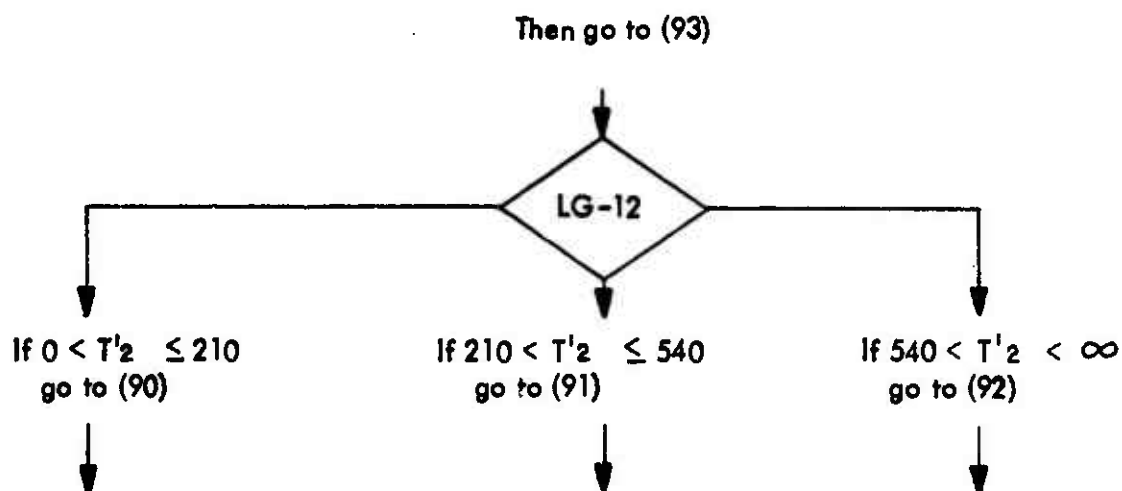


$$K_p = \frac{1}{[.1 (T'_2 - T_{cm})]} \left\{ - \left[\frac{(.1 T'_2)^{2.708} - (.1 T_{cm})^{2.708}}{2.708} \right] + 9.551 \left[(.1 T'_2)^2 - (.1 T_{cm})^2 \right] \right\} \quad (88)$$

Then go to (93)

$$K_p = 111.74 = \text{constant}$$

(89)



$$K_p = \frac{1}{(T_2 - T_{cm})} \left\{ \frac{2.765}{2} [(T_2)^2 - (T_{cm})^2] - \left[\frac{(T_2)^{2.16} - (T_{cm})^{2.16}}{2.16} \right] \right\} \quad (90)$$

Then go to (93)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T_2 + T_{cm})/2] - 210}{330} \right) \right\} \quad (91)$$

Then go to (93)

$$K_p = 92.25 = \text{constant} \quad (92)$$

Then go to (93)

$$K_{4-5} = K_p \cdot 0.93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (93)^*$$

$$U = \frac{1}{\frac{1}{h_{1-2}} + \frac{1}{k_{2-3}} + \frac{1}{k_{3-4}} + \frac{1}{k_{4-5}} + \frac{1}{h_{5-6}}} \quad (94)^*$$

$$n_s = n_p + 1 \quad (95)^*$$

$$\lambda_e = \frac{n_s \cdot t_s}{12} \quad (96)$$

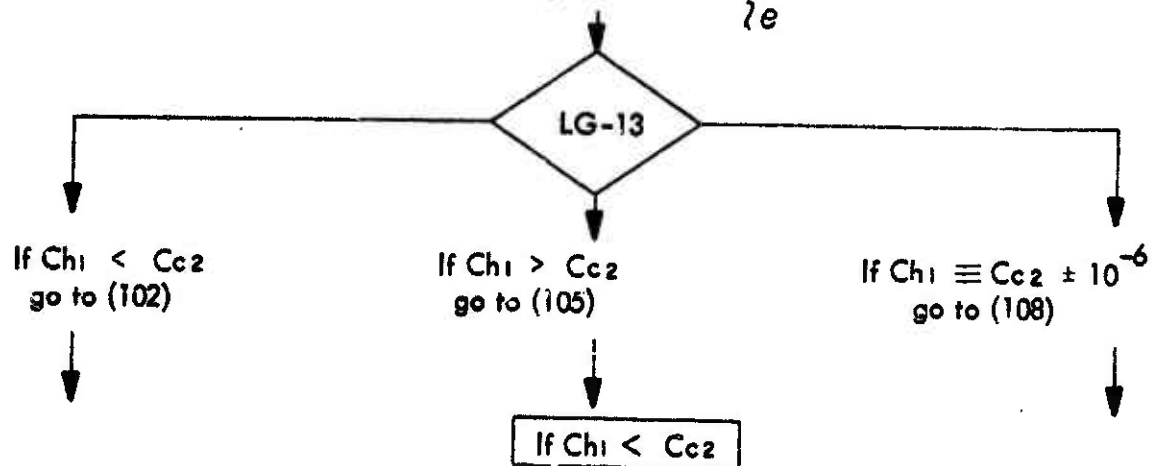
$$T_{\lambda 1} = \frac{(T_{10} + T_{20})}{2} \quad (97)$$

$$T_{\lambda 2} = \frac{(T_9 + T_{21})}{2} \quad (98)$$

$$AK_{\lambda} = \frac{[(X^2/F_s) - (X'Y)] + [(C-1) X'B']}{144} \quad (99)$$

$$\overline{K}_{\lambda} = \frac{7.27 \times 10^{-3}}{(T_{\lambda 2} - T_{\lambda 1})} \left[\frac{(T_{\lambda 2})^{1.585} - (T_{\lambda 1})^{1.585}}{1.585} \right] \quad (100)$$

$$Q_{\lambda} = \frac{\overline{K}_{\lambda} \cdot AK_{\lambda}}{\lambda_e} \quad (101)^*$$



$$\lambda = \frac{Q?}{3600 \text{ } Ch_1} \quad (102)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (103)^*$$

TEST 7 - A

If (103) $\geq$ 1.0, stop and readout message "REDUCE Ntui"

" " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon (Ch_1 / Cc_2)}{1 - \epsilon} \right]}{1 - (Ch_1 / Cc_2)} \quad (104)^*$$

Then go to LG - 14

If $Ch_1 > Cc_2$

$$\lambda = \frac{Q?}{3600 \text{ } Cc_2} \quad (105)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (106)^*$$

TEST 7 - B

If (106) $\geq$ 1.0, stop and readout message "REDUCE Ntui"

" " < " , continue

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon (Cc2/Ch1)}{1 - \epsilon} \right]}{1 - (Cc2/Ch1)} \quad (107)^*$$

Then go to LG - 14

$$\boxed{\text{If } Ch1 \equiv Cc2 \pm 10^{-6}}$$

$$\lambda = \frac{Q2}{3600 Ch1} \quad (108)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (109)^*$$

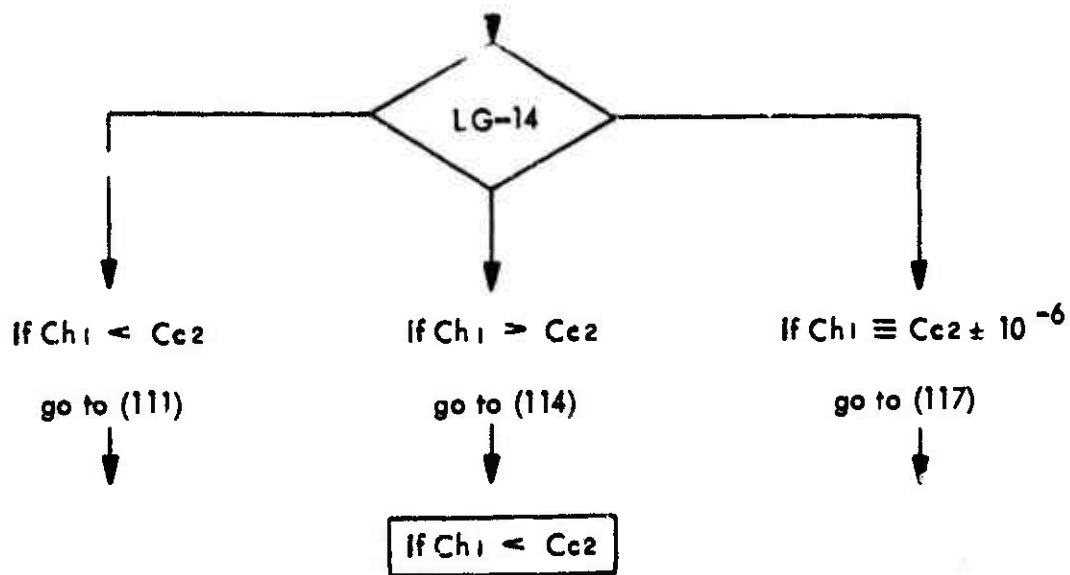
TEST 7 - C

If (109) ≥ 1.0 , stop and readout message "REDUCE Ntui"

" " < " , continue

$$Ntu = \frac{\epsilon}{1 - \epsilon} \quad (110)^*$$

Then go to LG - 14



$$Ax_{tot. \text{ hot side}} = \frac{3600 Ntu. Ch_1}{U} \quad (111)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (112)^*$$

$$\eta_{np \text{ calculated}} = \frac{144 Ax_{tot. \text{ hot side}}}{A_{xp}} \quad (113)$$

Note If a fraction results, go to next
higher whole number.

TEST 8-A

$$(113)_{\text{must}} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (113) $>$ (4), increase (4) and iterate from (4).

" " $<$ " , reduce " " " " " .

Then go to (120)

If $Ch1 > Cc2$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu} \cdot Cc2}{U} \quad (114)^*$$

$$Axp = Ax1 \cdot Af1 \quad (115)^*$$

$$np \text{ calculated} = \frac{114 \text{ Ax tot. hot side}}{Axp} \quad (116)$$

Note.....If a fraction results, go to next higher whole number.

Test 8 - B

(116) must = (4) $\begin{smallmatrix} +1 \\ -0 \end{smallmatrix}$

If (116) > (4), increase (4) and inerate from (4).

" < " , reduce " " " " " "

Then go to (120)

If $Ch1 \equiv Cc2 \pm 10^{-6}$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu} \cdot Ch1}{U} \quad (117)^*$$

$$Axp = Ax1 \cdot Af1 \quad (118)^*$$

$$\text{np calculated} = \frac{144 \text{ Ax tot. hot side}}{\text{Axp}} \quad (119)$$

Note.....If a fraction results, go to next higher whole number.

Test 8 - C

(119) must = (4) $\frac{+1}{-0}$

If (119) > (4), increases (4) and iterate from (4).
 " " < " , reduce " " " " "

Then go to (120)

$$\text{width X} = \text{equation (13)} = \text{inches after closure} \quad (120)*$$

$$\text{height Y} = -\frac{X}{F_s} = \text{inches} \quad (121)*$$

$$\text{core length L} = \left[(\text{np} \cdot \text{tp}) + (\text{ns} \cdot \text{ts}) \right] = \text{inches} \quad (122)*$$

$$\begin{aligned} \text{core weight} &= .098 \text{ np tp} \left\{ \left[(\text{XY}) - (\text{X}'\text{Y}') \right] + \left[\text{X B}' (\text{C}-1) \right] + \left[\text{Af} (\text{Ra}+1)(1-\sigma) \right] \right\} + \\ &\quad .078 \text{ ns} \cdot \text{ts} \left[(\text{XY}) - (\text{X}'\text{Y}') \right] + \left[\text{X}' \text{B}' (\text{C}-1) \right] = \text{lbs} \quad (123)* \end{aligned}$$

$$\text{header weight} = .196 \left[(\text{XY}) - \text{Af} (\text{Ra}+1) + \frac{\text{XY}}{8} \right] = \text{lbs} \quad (124)*$$

$$\text{total weight} = (123) + (124) \quad \text{lbs} \quad (125)*$$

(126)*

```
If (I26)<.40, readout message..... "INCREASE (IP - 96).
" " >.60, " " " ..... "REDUCE (IP - 96).
```

Do not stop machine on TEST 9.

(127)*

```

If (35) ≥ 540, stop machine
" " < " , call HX (J) and continue.

```

The FLOW DIAGRAM for HX-5 is exactly similar to that of HX - 1.

APPENDIX VII

HX - 6 AND TURBINE 3PROGRAM -----CALL HX (J) =6.0

Inputs:

Call out numerical values from APPENDIX I, section VII.
Also call last result for T9, P9, T21 and P21 from output
of HX - 5.

Initial numerical assumptions:

<u>Equa. No:</u>	<u>Initial Value:</u>
(4)	30.0
(5)	T9 + 10
(6)	1.02 P9
(13)	2.0
(41)	T21 + 10
(42)	.98 P21

Notes:

Readout last result of all equations marked with a star "*."
Do not stop machine at TEST 9.

$$s = \sqrt{.906894 \frac{dh^2}{\sigma}} \quad (1)*$$

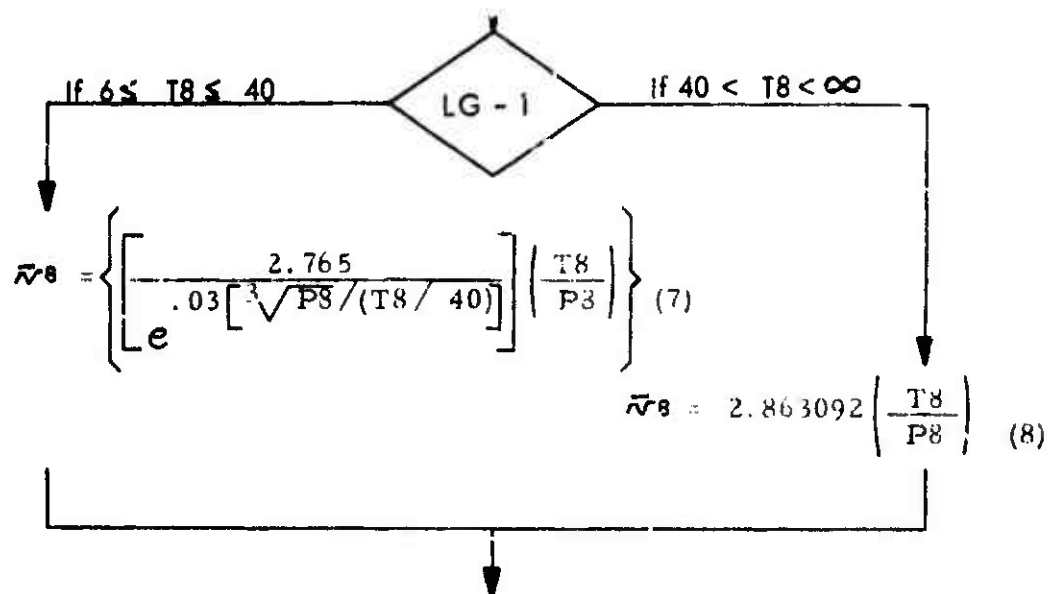
$$n = \frac{4\sigma}{\pi dh^2} \quad (2)*$$

$$Ax1 = (n \pi dh tp) + 2(1-\sigma) \quad (3)*$$

$$\begin{aligned} np &= \text{assume} \\ (\text{Will be altered only by TEST 8}) \end{aligned} \quad (4)*$$

$$\begin{aligned} T8 &= \text{assume} \\ (\text{Will be altered only by TEST 3}) \end{aligned} \quad (5)*$$

$$\begin{aligned} P8 &= \text{assume} \\ (\text{Will be altered only by TEST 2}) \end{aligned} \quad (6)$$



$$\mu_8 = 2.37888 \times 10^{-7} (T_8)^{.643} \quad (9)$$

$$V_8 = \frac{12 \text{ NReI } \bar{N}_8 \mu_8}{dh} \quad (10)*$$

$$ahl = \frac{144 W_3 \bar{N}_8}{V_8} \quad (11)*$$

$$Afl = \frac{ahl}{\sigma} \quad (12)*$$

$$X = \text{assume} \quad (13)*$$

(Will be altered only by TEST 1)

$$X' = X - (2 Bx) \quad (14)*$$

$$Y' = \frac{X}{F_s} - (2 By) \quad (15)*$$

$$Y'_1 = \frac{Y' - \frac{[(C-1) B']}{2} - Nh}{2(C-1)} \quad (16)*$$

$$Aft \text{ calculated} = Nh (X'Y'_1) \quad (17)$$

TEST 1

(17) must = (12) $\pm$.001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " " "

$$Y'_2 = Y'_1 \cdot \frac{Ra}{2} \quad (18)*$$

$$Y'_3 = Y'_1 \cdot Ra \quad (19)*$$

$$\lambda_1 = \frac{Y'_1}{24} \quad (20)$$

$$\lambda_2 = \frac{B'}{12} \quad (21)$$

$$\lambda_3 = \frac{Y'_3}{12 \cdot Ra} \quad (22)$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} V_8^2}{\bar{\mu}^8} \sqrt{\frac{(tp/dh)}{NRe1}} \quad (23)$$

$$\Delta P_1 = n_p \cdot \Delta P'_1 \quad (24)*$$

$$P_8 \text{ calculated} = P_9 + \Delta P_1 \quad (25)$$

TEST 2

(25) must = (6) $\pm$.001

If (25) > (6), increase (6) and iterate from (6).

" " < " , reduce " " " " .

Call cp subroutine and, with
T8 and P8.....get

cp 8 = $\leftarrow$

(26)

Call cp subroutine and, with
T21 and P21 ... get

cp 21 = $\leftarrow$

(27)

$$\overline{cp} = \frac{(cp\ 8 + cp\ 21)}{2}$$

(28)

$$\bar{\tau} = \frac{1}{1 - \left| \frac{.496447487}{\overline{cp}} \right|}$$

(29)

$$\frac{T21}{T8} = 1 - \eta_t \left[1 - \left| \frac{P21}{P8} \right| (\bar{\tau} - 1) / \bar{\tau} \right]$$

(30)

$$T8\ \text{calculated} = \frac{T21}{(T21/T8)}$$

(31)

TEST 3

(31) must = (5) $\pm$.001

If (31) > (5), increase (5) and iterate from (5).

" " < " , reduce " " " " " " " "

$$\mu_{ml} = \frac{8.55497 \times 10^{-4}}{(T8 - T9)} \left\{ \frac{(T8)^{1.643} - (T9)^{1.643}}{1.643} \right\} \quad (32)$$

$$K_{ml} = \frac{57.79 \times 10^{-3}}{[.00355 (T8 - T9)]} \left\{ \frac{(.00355 T8)^{1.642} - (.00355 T9)^{1.642}}{1.642} \right\} \quad (33)$$

$$Thm = \frac{\left(\frac{K_{ml}}{57.79 \times 10^{-3}} \right)^{1/1.642}}{.00355} \quad (34)$$

$$Phm = \frac{(P8 + P9)}{2} \quad (35)$$

Call cp subroutine and, with
Thm and Phm.....get

$$cphm = \leftarrow \quad (36)$$

$$chl = cphm \cdot W_3 \quad (37)*$$

$$NPr1 = \frac{cphm \cdot \mu_{ml}}{K_{ml}} \quad (38)*$$

$$NNu1 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe1 \cdot NPr1} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe1 \cdot NPr1} \right]} \right)^{.8}} \right\} \quad (39)*$$

$$h_{l-2} = \frac{12 \cdot NNu1 \cdot Km1}{dh} \quad (40)*$$

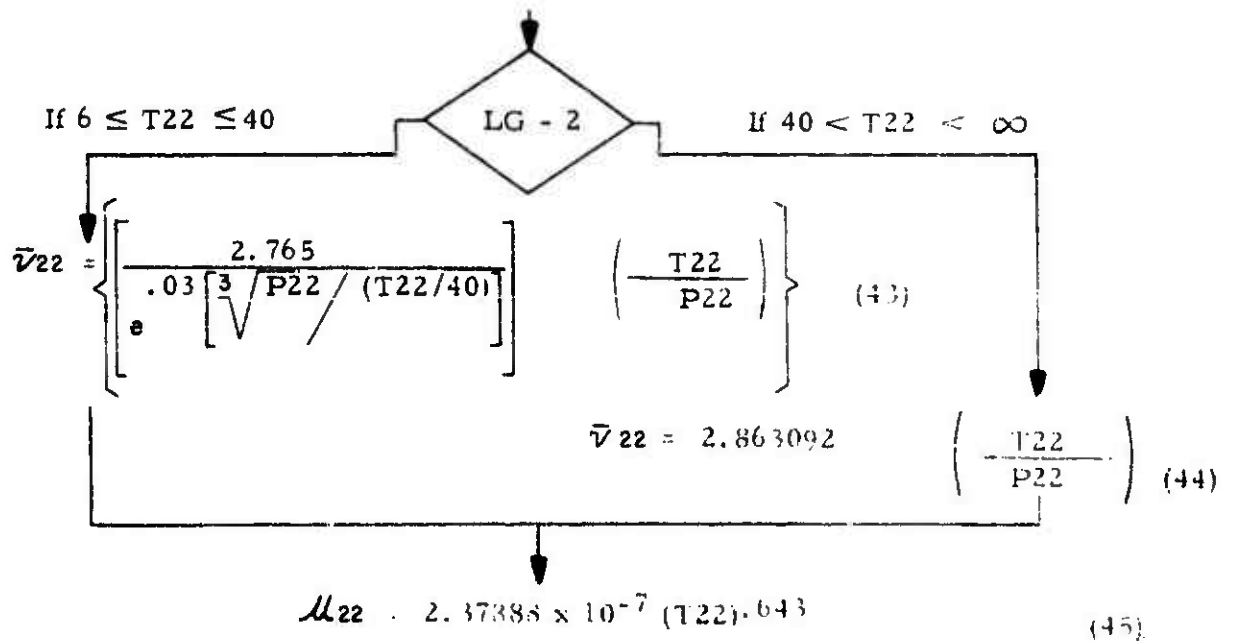
COLD SIDE:

$$T22 = \text{assume} \quad (41)*$$

(Will be altered only by TEST 6)

$$P22 = \text{assume} \quad (42)*$$

(Will be altered only by TEST 4)



$$ah_2 = ah_1 \cdot Ra \quad (46)*$$

$$V_{22} = \frac{144 W_4 \bar{V}_{22}}{ah_2} \quad (47)*$$

$$NRe_2 = \frac{V_{22} \cdot dh}{12 \bar{V}_{22} \cdot \mu_{22}} \quad (48)*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} V_{22}^2}{\bar{V}_{22}} \sqrt{\frac{(tp/dh)}{NRe_2}} \quad (49)$$

$$\Delta P_2 = n_p \cdot \Delta P'_2 \quad (50)*$$

$$P_{22} \text{ calculated} = P_{21} - \Delta P_2 \quad (51)$$

TEST 4

(51) must = (42) $\pm$.001

If (51) > (42), increase (42) and iterate from (42).

" " < " , reduce " " " " .

TEST 5

If (51) < 10, stop & readout message..... "INCREASE Ra"

" " $\geq$, continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T_{22} - T_{21})} \left\{ \frac{\frac{1.643}{(T_{22})} - \frac{1.643}{(T_{21})}}{1.643} \right\} \quad (52)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{[.00355 (T_{22} - T_{21})]} \left\{ \frac{(.00355 T_{22})^{1.642} - (.00355 T_{21})^{1.642}}{1.642} \right\} \quad (53)$$

$$T_{cm} = \frac{\left(\frac{K_{m2}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (54)$$

$$P_{cm} = \frac{(P_{21} + P_{22})}{2} \quad (55)$$

Call cp subroutine, and, with
Tcm and Pcm get

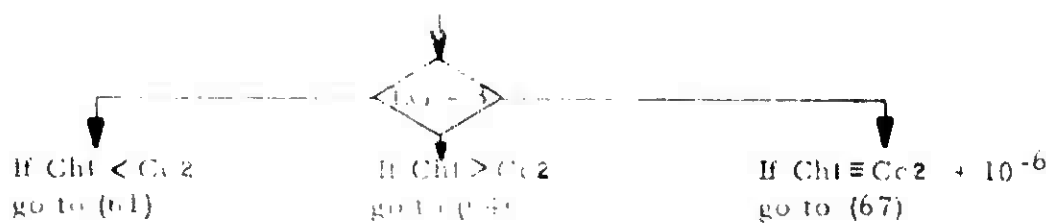
$$c_{pcm} = \leftarrow \quad (56)$$

$$C_{c2} = c_{pcm} \cdot W_4 \quad (57)^*$$

$$N_{Pr2} = \frac{c_{pcm} \cdot \mu_{m2}}{K_{m2}} \quad (58)^*$$

$$NNu_2 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{N_{Re2} \cdot N_{Pr2}} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{N_{Re2} \cdot N_{Pr2}} \right]^{.8}} \right)} \right\} \quad (59)^*$$

$$\frac{h}{5-6} = \frac{12 NNu_2 \cdot K_{m2}}{dh} \quad (60)^*$$



If Ch1 < Cc2

$$T22 \text{ calculated} = T21 + \left[\frac{(T8 - T9)}{\left(\frac{Cc2}{Ch1} \right)} \right] \quad (61)$$

TEST 6-A

(61) must = (41) $\pm$.001

If (61) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " " " .

$$Nt_{ui} = \frac{\log_e \left[\frac{(T8 - T22)}{(T9 - T21)} \right]}{1 - \left(\frac{Ch1}{Cc2} \right)} \quad (62)^*$$

$$\epsilon_i = \frac{1 - e^{-Nt_{ui} \left[1 - \left(\frac{Ch1}{Cc2} \right) \right]}}{1 - \left\{ \frac{\left(\frac{Ch1}{Cc2} \right)}{e^{-Nt_{ui} \left[1 - \left(\frac{Ch1}{Cc2} \right) \right]}} \right\}} \quad (63)^*$$

Then go to (70)

If Ch1 > Cc2

$$T22 \text{ calculated} = T21 + \left[\frac{(T8 - T9)}{\left(\frac{Ch1}{Cc2} \right)} \right] \quad (64)$$

TEST 6 - B

(64) must = (41) $\pm$.001

If (64) > (41), increase (41) and iterate from (41)

" " < " , reduce " " " " " "

$$Ntui = \frac{\log_e \left[\frac{(T8 - T22)}{(T9 - T21)} \right]}{1 - \left(\frac{Cc2}{Ch1} \right)} \quad (65)*$$

$$\epsilon_i = \frac{1 - e^{-Ntui \left[1 - \left(\frac{Cc2}{Ch1} \right) \right]}}{1 - \left\{ \left(\frac{Cc2}{Ch1} \right)^e - Ntui \left[1 - \left(\frac{Cc2}{Ch1} \right) \right] \right\}} \quad (66)*$$

Then go to (70)

If $Ch1 \equiv Cc2 \pm 10^{-6}$

$$T22 \text{ calculated} = T8 - (T9 - T21) \quad (67)$$

TEST 6-C

(67) must = (41) $\pm$.001

If (67) > (41), increase (41) and iterate from (41).

" " < " , reduce " " " " " "

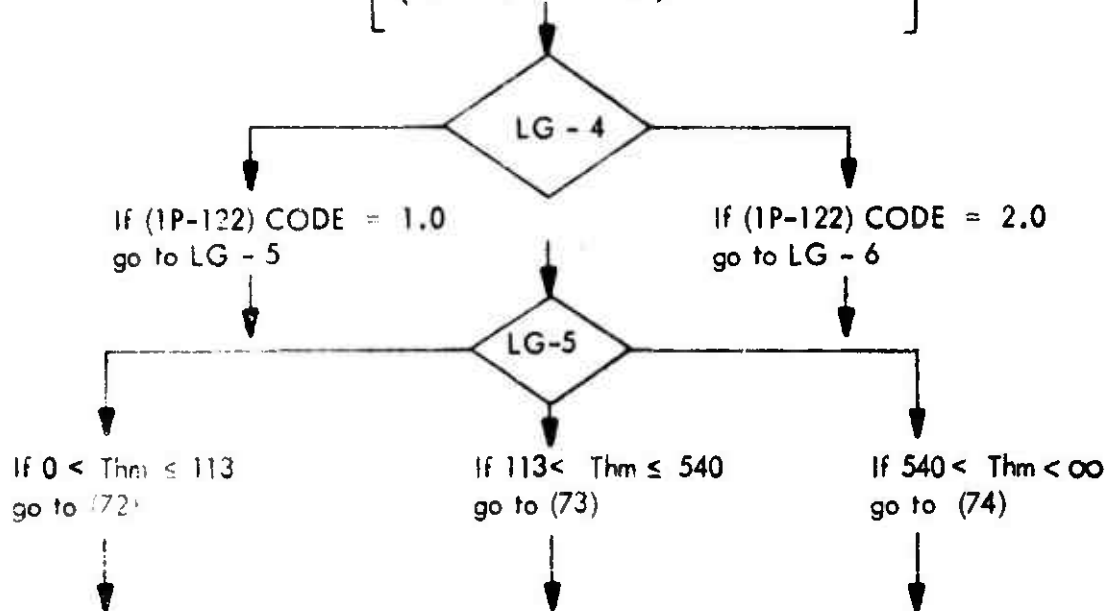
$$N_{tui} = \frac{\left[\frac{(T_8 - T_9)}{(T_8 - T_{21})} \right]}{1 - \left[\frac{(T_8 - T_9)}{(T_8 - T_{21})} \right]} \quad (68)^*$$

$$\epsilon_i = \frac{N_{tui}}{1 + N_{tui}} \quad (69)^*$$

Then go to (70)

$$T'_1 = T_{hm} - \left[\left(\frac{Y'_{11}}{Y'_{11} + Y'_{12} + Y'_{13}} \right) (T_{hm} - T_{cm}) \right] \quad (70)$$

$$T'_{12} = T_{hm} - \left[\left(\frac{Y'_{11} + Y'_{12}}{Y'_{11} + Y'_{12} + Y'_{13}} \right) (T_{hm} - T_{cm}) \right] \quad (71)$$



$$K_p = \frac{1}{[.1(T_{hm} - T'_1)]} \left\{ \frac{49}{2} \left[(.1T_{hm})^2 - (.1T'_1)^2 \right] - \frac{1}{3.47} \left[(.1T_{hm})^{3.47} - (.1T'_1)^{3.47} \right] \right\} \quad (72)$$

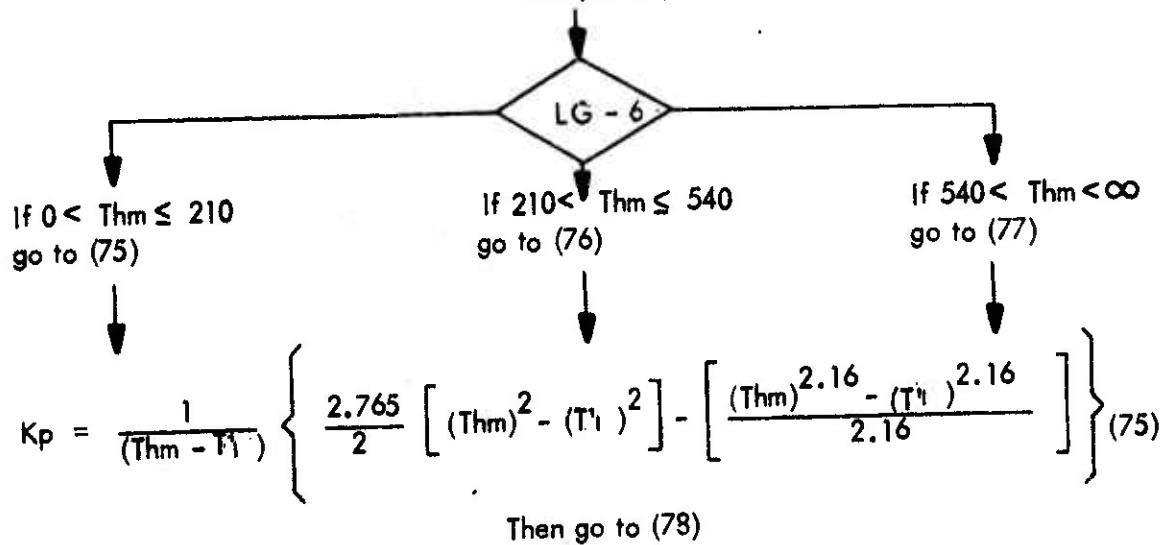
Then go to (78)

$$K_p = \left[\frac{1}{.1(T_{hm} - T'_{l1})} \right] \left\{ - \left[\frac{(.1T_{hm})^{2.708} - (.1T'_{l1})^{2.708}}{2.708} \right] + 9.551 \left[(.1T_{hm})^2 - (.1T'_{l1})^2 \right] \right\} \quad (73)$$

Then go to (78)

$$K_p = 111.74 = \text{constant} \quad (74)$$

Then go to (78)



$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(Thm + T'_{l1}) / 2] - 210}{330} \right) \right\} \quad (76)$$

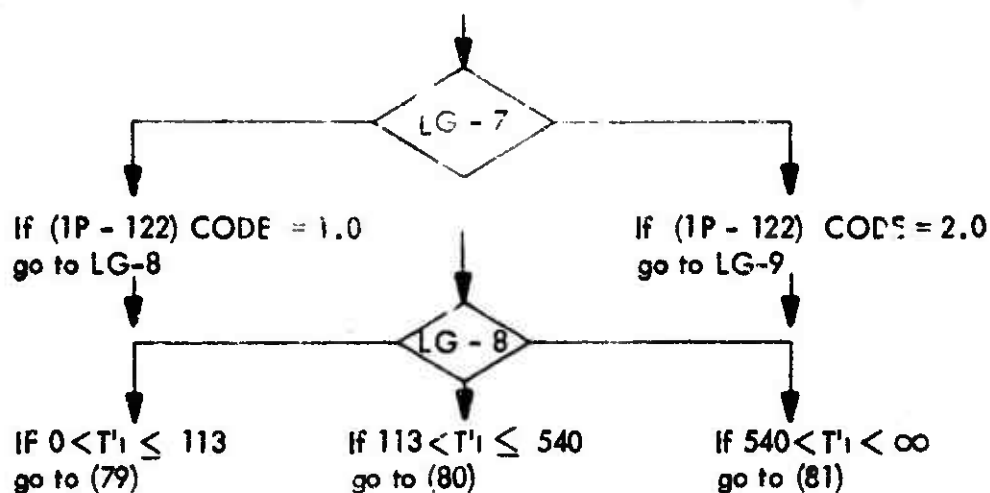
Then go to (78)

$$K_p = 92.25 = \text{constant} \quad (77)$$

Then go to (78)

$$K_{2-3} = K_p \cdot .93061 \left[\frac{s}{s - (dh/2)} \right]$$

(78)



$$K_p = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ \frac{49}{2} [(.1 T'_1)^2 - (.1 T'_2)^2] - \frac{1}{3.47} [(.1 T'_1)^{3.47} - (.1 T'_2)^{3.47}] \right\}$$

(79)

Then go to (85)

$$K_p = \frac{1}{[.1(T'_1 - T'_2)]} \left\{ \left[\frac{(.1 T'_1)^{2.708} - (.1 T'_2)^{2.708}}{2.708} \right] + 9.551 [(.1 T'_1)^2 - (.1 T'_2)^2] \right\}$$

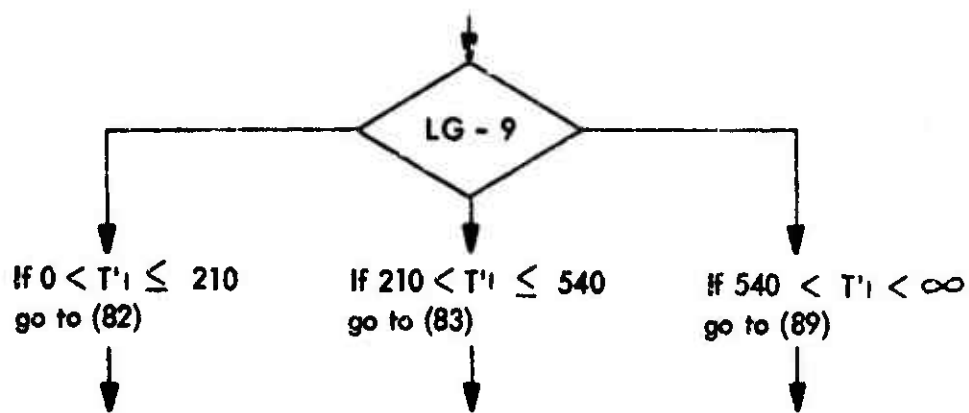
(80)

Then go to (85)

$$K_p = 111.74 = \text{constant}$$

(81)

Then go to (85)



$$K_p = \frac{1}{(T'1 - T'2)} \left\{ \frac{2.765}{2} \left[(T'1)^2 - (T'2)^2 \right] - \left[\frac{(T'1)^{2.16} - (T'2)^{2.16}}{2.16} \right] \right\} \quad (82)$$

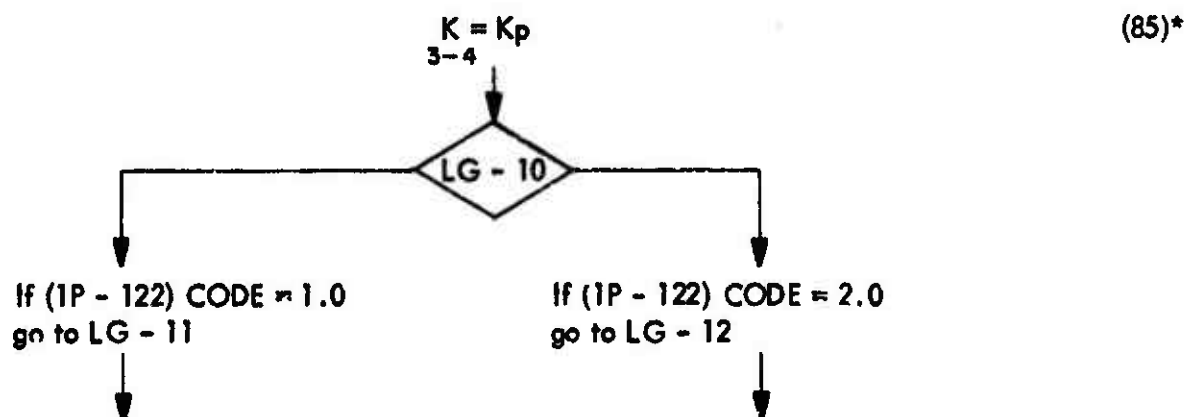
Then go to (85)

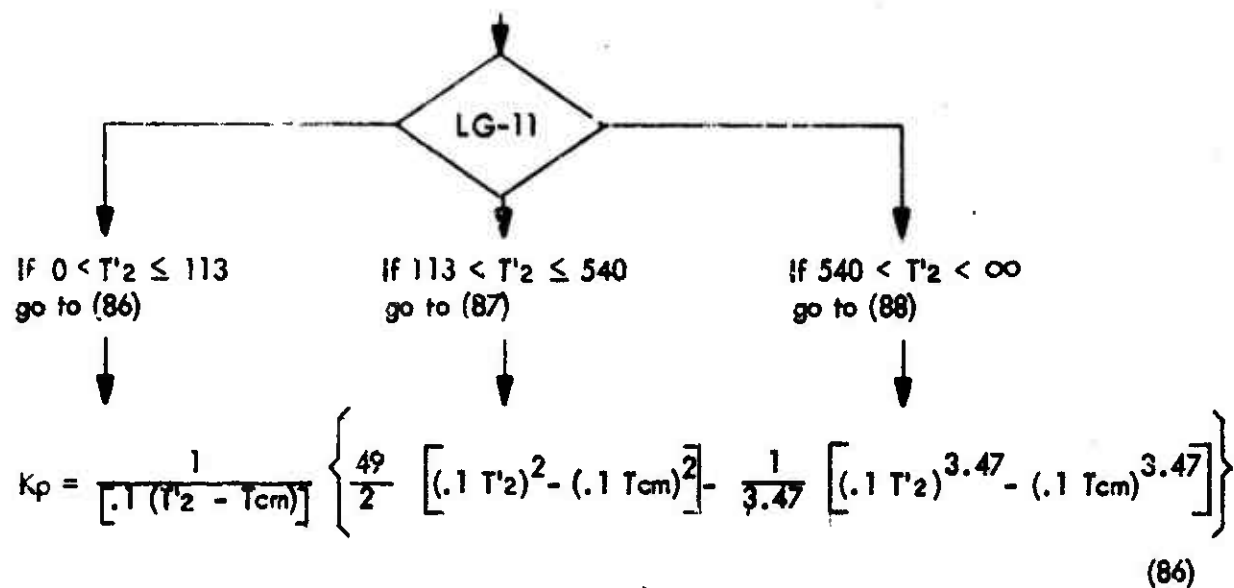
$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T'1 + T'2)/2] - 210}{330} \right) \right\} \quad (83)$$

Then go to (85)

$$K_p = 92.25 = \text{constant} \quad (84)$$

Then go to (85)





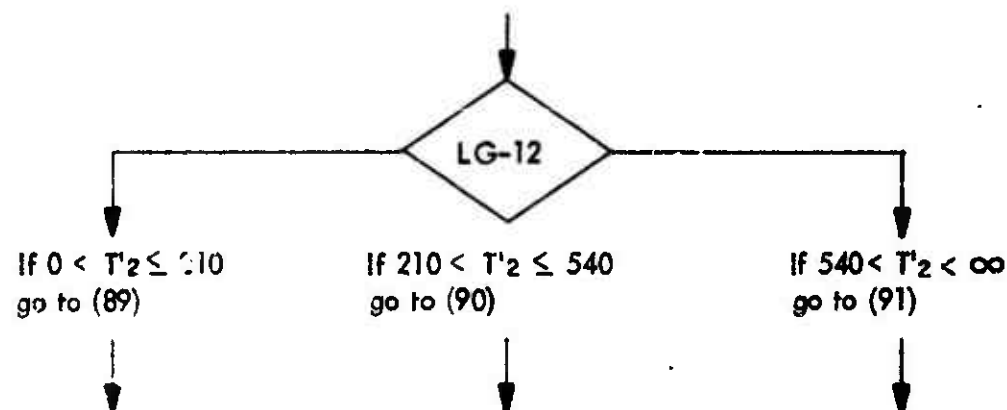
Then go to (92)

$$K_p = \frac{1}{[.1(T'_2 - T_{cm})]} \left\{ - \left[\frac{(.1 T'_2)^{2.708} - (.1 T_{cm})^{2.708}}{2.708} \right] + 9.551 [(.1 T'_2)^2 - (.1 T_{cm})^2] \right\} \quad (87)$$

Then go to (92)

$$K_p = 111.74 = \text{constant} \quad (88)$$

Then go to (92)



$$K_p = \frac{1}{(T_2' - T_{cm})} \left\{ \frac{2.16}{2} \left[(T_2')^2 - (T_{cm})^2 \right] - \left[\frac{(T_2')^{2.16} - (T_{cm})^{2.16}}{2.16} \right] \right\} \quad (89)$$

Then go to (92)

$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T_2' + T_{cm})/2] - 210}{330} \right) \right\} \quad (90)$$

Then go to (92)

$$K_p = 92.25 = \text{constant} \quad (91)$$

Then go to (92)

$$K_{4-5} = K_p \cdot 0.93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (92)^*$$

$$U = \frac{1}{\left(\frac{1}{h_{1-2}} + \frac{1}{K_{2-3}} + \frac{1}{K_{3-4}} + \frac{1}{K_{4-5}} + \frac{1}{h_{5-6}} \right)} \quad (93)^*$$

$$n_s = n_p + 1 \quad (94)^*$$

$$l_e = \frac{n_s \cdot t_s}{12} \quad (95)$$

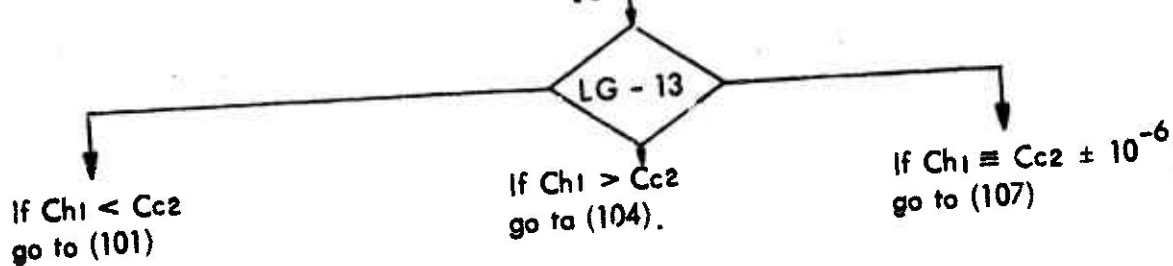
$$T_{21} = \frac{(T_9 + T_{21})}{2} \quad (96)$$

$$T_{22} = \frac{(T_8 + T_{22})}{2} \quad (97)$$

$$Ak_2 = \frac{\left[\left(\frac{X^2}{F_s} \right) - (X \cdot Y) \right] + [(C-1) X \cdot B]}{144} \quad (98)$$

$$\bar{K}_2 = \frac{7.27 \times 10^{-3}}{(T_{22} - T_{21})} \left[\frac{(T_{22})^{1.585} - (T_{21})^{1.585}}{1.585} \right] \quad (99)$$

$$Q_2 = \frac{\bar{K}_2 \cdot Ak_2}{le} \quad (100)^*$$



If Ch1 < Cc2

$$\lambda = \frac{Q_2}{3600 \text{ Ch}_1} \quad (101)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (102)^*$$

TEST 7 - A

If (102) $\geq$ 1.0, stop and readout message "REDUCE BORDER DIMS.
OR INCREASE t_s "

" " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(\frac{Ch1}{Cc2} \right)}{1 - \epsilon} \right]}{1 - \left(\frac{Ch1}{Cc2} \right)} \quad (103)^*$$

Then go to LG - 14

If $Ch1 > Cc2$

$$\lambda = - \frac{Q1}{3600 Cc2} \quad (104)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (105)^*$$

TEST 7-B

"REDUCE BORDER DIMS.

If $(105) \geq 1.0$, stop & readout message..... OR INCREASE ts "

" " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon \left(\frac{Cc2}{Ch1} \right)}{1 - \epsilon} \right]}{1 - \left(\frac{Cc2}{Ch1} \right)} \quad (106)^*$$

Then go to LG - 14

If $Ch1 \neq Cc2 \pm 10^{-6}$

$$\lambda = \frac{Q1}{3600 Ch1} \quad (107)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (108)*$$

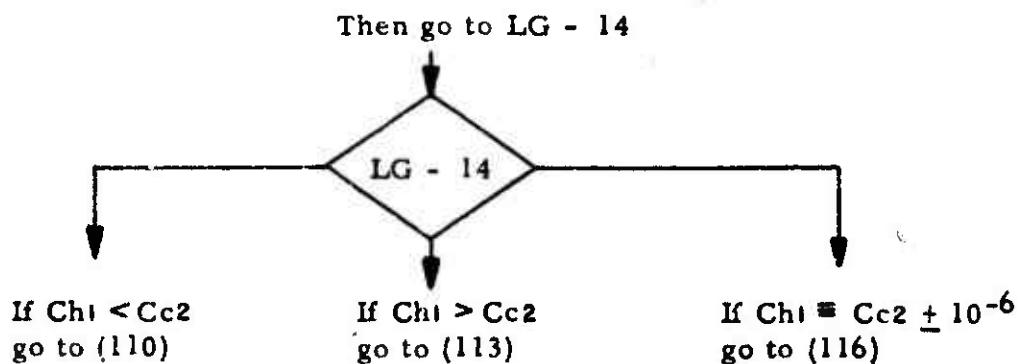
TEST 7-C

"REDUCE BORDER DIMS.

If (108) ≥ 1.0 , stop & readout message.....OR INCREASE t_s "

" " < " , continue.

$$Ntu = \frac{\epsilon}{1 - \epsilon} \quad (109)*$$



If Ch1 < Cc2

$$Ax \text{ tot. hot side} = \frac{3600 Ntu Ch1}{U} \quad (110)*$$

$$Axp = Ax1 \cdot Af1 \quad (111)*$$

$$np \text{ calculated} = \frac{14^4 Ax \text{ tot. hot side}}{Axp} \quad (112)$$

Note..... If a fraction results, go to next higher whole number.

TEST 8-A

$$(112) \text{ must} = (4) \pm \begin{matrix} +1 \\ -0 \end{matrix}$$

If (112) $\geq$ (4), increase (4) and iterate from (4).

" " $<$ ", reduce " " " " " "

Then go to (119)

If $Ch1 > Cc2$

$$Ax \text{ tot. hot side} = \frac{3600 \text{ Ntu } Cc2}{U} \quad (113)*$$

$$Axp = Ax1 \cdot Af1 \quad (114)*$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{Axp} \quad (115)$$

Note.....If a fraction results, go to next higher whole number.

TEST 8 - B

$$(115) \text{ must} = (4) \pm \begin{matrix} +1 \\ -0 \end{matrix}$$

If (115) $\geq$ (4), increase (4) and iterate from (4).

" " $<$ ", reduce " " " " " "

Then go to (119)

If $Ch1 \equiv Cc2 \pm 10^{-6}$

$$A_{x \text{ tot. hot side}} = \frac{3600 \text{ Ntu } Ch_i}{U} \quad (116)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (117)^*$$

$$np \text{ calculated} = \frac{144 \text{ } A_{x \text{ tot. hot side}}}{A_{xp}} \quad (118)$$

Note If a fraction results, go to next higher whole number.

TEST 8 - C

$$(118) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (118) > (4), increase (4) and iterate from (4).

" " < ", reduce " " " " "

Then go to (119)

$$\text{width } X = \text{equation (13)} = \text{inches after closure.} \quad (119)^*$$

$$\text{height } Y = \frac{X}{F_s} = \text{inches} \quad (120)^*$$

$$\text{core length } L = \left[(np \cdot tp) + (ns \cdot ts) \right] = \text{inches} \quad (121)^*$$

$$\begin{aligned} \text{core weight} = & .098 \text{ } np \text{ } tp \left\{ \left[(XY) - (X'Y') \right] + \left[X'B'(C-1) \right] + \left[Af1(Ra+1)(1-\sigma) \right] \right\} + \\ & .078 \text{ } ns \text{ } ts \left\{ \left[(XY) - (X'Y') \right] + \left[X'B'(C-1) \right] \right\} = \text{lbs} \end{aligned} \quad (122)^*$$

$$\text{header weight} = .196 \left[(XY) - Afl (Ra+1) + \frac{XY}{8} \right] - \text{lbs} \quad (123)*$$

$$\text{total weight} = (122) + (123) \quad \text{lbs} \quad (124)*$$

$$\eta_f = \frac{1}{1 + \left[\frac{h_{1-2} \left(\frac{A_{xp}}{N_h \cdot Y'_{11}} \right) (Y'_{11})^2}{3 \text{ np } K_{2-3} \left\{ X' \text{ tp } .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \quad (125)*$$

TEST 9

If (125) < .40, readout message....."INCREASE (1P - 112)"
 " " > .60 , " " "REDUCE (1P - 112)"

Do not stop machine on TEST 9.

$$A_v = \frac{A_{x \text{ tot. hot side}}}{\left(\frac{X \cdot Y \cdot L}{1728} \right)} = \text{ft}^2/\text{ft}^3 \quad (126)*$$

$$\Delta H_{13} = \bar{c}_p T_8 \eta_t \left[1 - \left(\frac{P_{21}}{P_8} \right)^{(\bar{\gamma} - 1)/\bar{\gamma}} \right] = \text{BTU/lb} \quad (127)*$$

$$\text{Turbine output} = 1054.54 \text{ Wt3 } \Delta H_{13} = \text{Watts} \quad (128)*$$

FINAL TEST

IF (41) $\geq$ 540, stop machine

IF (41) < 540, call hix (J) and continue.

J=7.0

The FLOW DIAGRAM for HX - 6 is exactly similar to that of HX-2.

APPENDIX VIII

HX-7 PROGRAM CALL HX (J) $j = 7.0$:

Inputs:

Call numerical values from APPENDIX I, Section VIII.

Also call last result for T8, P8, T22 and P22 from output of HX-6.

Initial numerical assumptions:

<u>Equa. No.</u>	<u>Initial value:</u>
(4)	300.0
(5)	T8 + 150
(6)	1.02 P8
(13)	2.0
(35)	T22 + 150
(36)	.98 P22

Notes:

Readout last result of all equations marked with a star "*".
Do not stop machine at TEST 9.

HOT SIDE:

$$s = \sqrt{.906894 \frac{dh^2}{8}} \quad (1)^*$$

$$n = \frac{4\sigma}{\pi dh^2} \quad (2)^*$$

$$Ax1 = (N \pi dh tp) + 2 (1 - \sigma) \quad (3)^*$$

$$np = \text{assume} \quad (4)^*$$

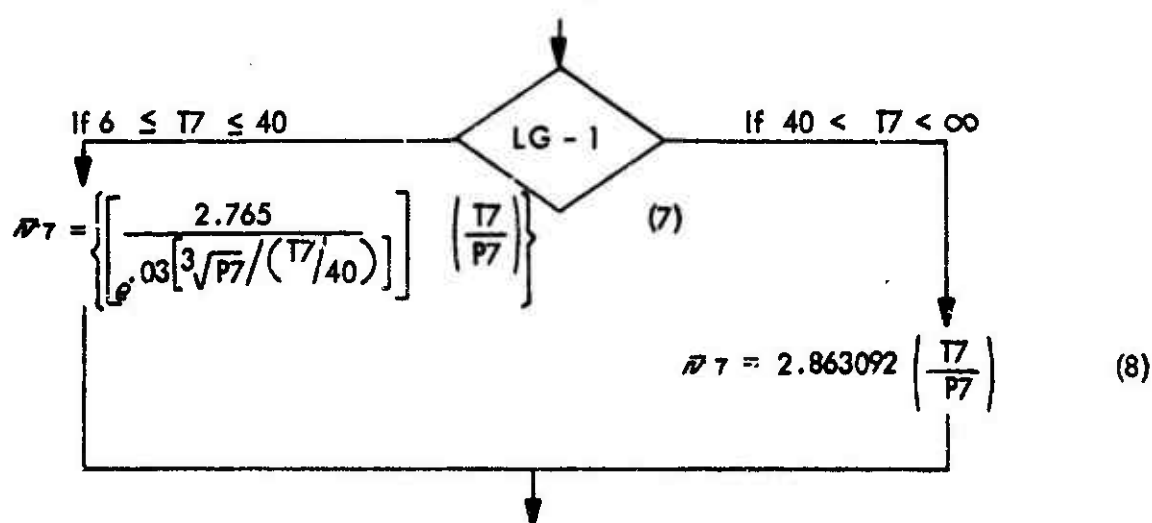
(Will be altered only by TEST 8)

$$T7 = \text{assume} \quad (5)^*$$

(Will be altered only by TEST 6)

$$P7 = \text{assume} \quad (6)^*$$

(Will be altered only by TEST 2)



$$\mu_7 = 2.37888 \times 10^{-7} (T7)^{.643} \quad (7)$$

$$V_7 = \frac{12 \text{ NRe1 } \bar{N}^7 \mu_7}{dh} \quad (10)^*$$

$$ah_1 = \frac{144 W_4 \bar{N}^7}{V_7} \quad (11)^*$$

$$Af_1 = \frac{ah_1}{\sigma} \quad (12)^*$$

$$\begin{aligned} X &= \text{assume} \\ (\text{Will be altered only by TEST 1}) \end{aligned} \quad (13)^*$$

$$X' = X - (2 Bx) \quad (14)^*$$

$$Y' = \frac{X}{F_s} - (2 By) \quad (15)^*$$

$$Y'_1 = \frac{Y' - [(C-1) B']}{2 (C-1)} - Nh \quad (16)^*$$

$$Afi \text{ calculated} = Nh (X' Y'_i) \quad (17)$$

TEST 1

(17) must = (12) $\pm$.001

If (17) > (12), reduce (13) and iterate from (13).

" " < " , increase " " " " " " .

$$Y'_2 = Y'_1 \frac{Ra}{2} \quad (18)^*$$

$$Y'_3 = Y'_1 \cdot Ra \quad (19)^*$$

$$\lambda_1 = \frac{Y'_1}{24} \quad (20)$$

$$\lambda_2 = \frac{B'}{12} \quad (21)$$

$$\lambda_3 = \frac{Y'_3}{12 \cdot Ra} \quad (22)$$

$$\Delta P'_1 = \frac{370 \times 10^{-6} V_T^2}{\bar{\nu}^7} \sqrt{\frac{(tp/dh)}{NR_{e1}}} \quad (23)$$

$$\Delta P_1 = n_p \cdot \Delta P'_1 \quad (24)^*$$

$$P7 \text{ calculated} = P8 + \Delta P_1 \quad (25)$$

TEST 2

(25) must = (6) $\pm$.001

If (25) > (6), increase (6) and iterate from (6).

" " < " , reduce " " " " " "

$$\mu_{m1} = \frac{8.55497 \times 10^{-4}}{(T7 - T8)} \left[\frac{(T7)^{1.643} - (T8)^{1.643}}{1.643} \right] \quad (26)$$

$$K_{m1} = \frac{57.79 \times 10^{-3}}{[.00355 (T7 - T8)]} \left[\frac{(.00355 T7)^{1.642} - (.00355 T8)^{1.642}}{1.642} \right] \quad (27)$$

$$Thm = \frac{\left(\frac{K_{m1}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (28)$$

$$Phm = \frac{(P7 + P8)}{2} \quad (29)$$

Call cp subroutine and, with
Thm and Phm get

$$cphm = \leftarrow \quad (30)$$

$$Ch1 = cphm \cdot W4 \quad (31)^*$$

$$N_{Pr1} = \frac{c_{phm} \cdot \mu_{m1}}{K_{m1}} \quad (32)^*$$

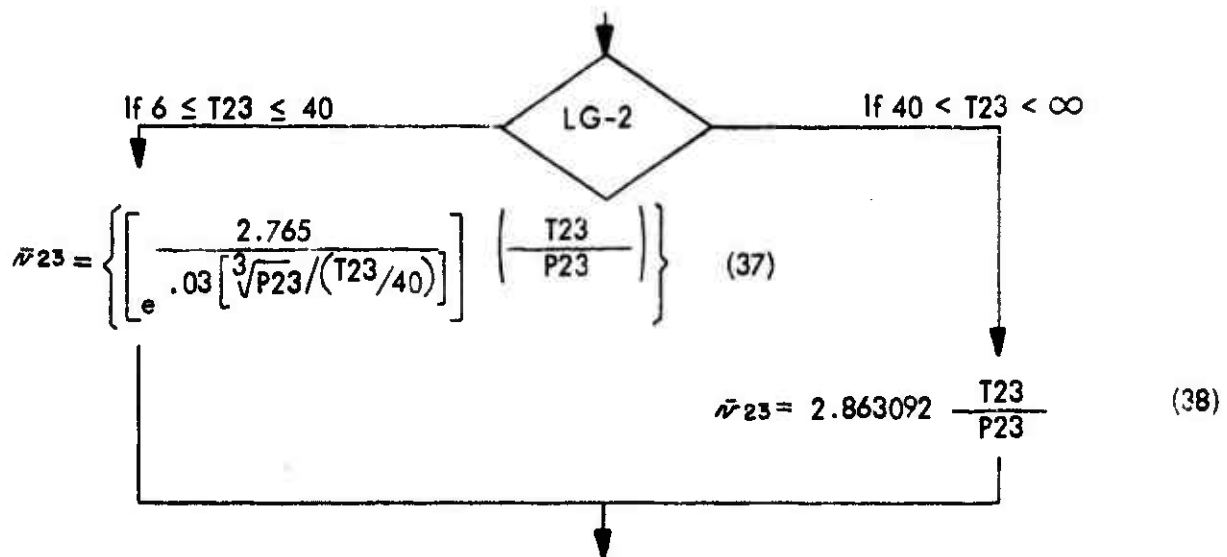
$$NNu1 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{N_{Re1} \cdot N_{Pr1}} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{N_{Re1} \cdot N_{Pr1}} \right]^{.8}} \right)} \right\} \quad (33)^*$$

$$h_{1-2} = \frac{12 \cdot NNu1 \cdot K_{m1}}{dh} \quad (34)^*$$

COLD SIDE:

$$\begin{aligned} T_{23} &= \text{assume} \\ &(\text{Will be altered only by TEST 5}) \end{aligned} \quad (35)^*$$

$$\begin{aligned} P_{23} &= \text{assume} \\ &(\text{Will be altered only by TEST 3}) \end{aligned} \quad (36)^*$$



$$ah_2 = ah_1 \cdot Ra \quad (39)^*$$

$$V_{23} = \frac{144 W_4 \bar{N}_{23}}{ah_2} \quad (40)^*$$

$$\mu_{23} = 2.37888 \times 10^{-7} (T_{23})^{.643} \quad (41)$$

$$NRe_2 = \frac{V_{23} \cdot dh}{12 \bar{\nu}_{23} \cdot \mu_{23}} \quad (42)^*$$

$$\Delta P'_2 = \frac{370 \times 10^{-6} V_{23}^2}{\bar{N}_{23}} \sqrt{\frac{(tp/dh)}{NRe_2}} \quad (43)$$

$$\Delta P_2 = n_p \cdot \Delta P'_2 \quad (44)^*$$

$$P23 \text{ calculated} = P22 - \Delta P_2 \quad (45)$$

TEST 3

(45) must = (36) $\pm$.001

If (45) > (36), increase (36) and iterate from (36).

" " < " , reduce " " " " " "

TEST 4

"DECREASE NRei or

If (45) < 10, stop & readout message INCREASE Ra "

" " $\geq$ 10, continue.

$$\mu_{m2} = \frac{8.55497 \times 10^{-4}}{(T23 - T22)} \left[\frac{(T23)^{1.643} - (T22)^{1.643}}{1.643} \right] \quad (46)$$

$$K_{m2} = \frac{57.79 \times 10^{-3}}{[.00355 (T23 - T22)]} \left[\frac{(.00355 T23)^{1.642} - (.00355 T22)^{1.642}}{1.642} \right] \quad (47)$$

$$T_{cm} = \frac{\left(\frac{K_{m2}}{57.79 \times 10^{-3}} \right)^{1/.642}}{.00355} \quad (48)$$

$$P_{cm} = \frac{(P22 + P23)}{2} \quad (49)$$

Call cp subrautine and, with
Tcm and Pcm get

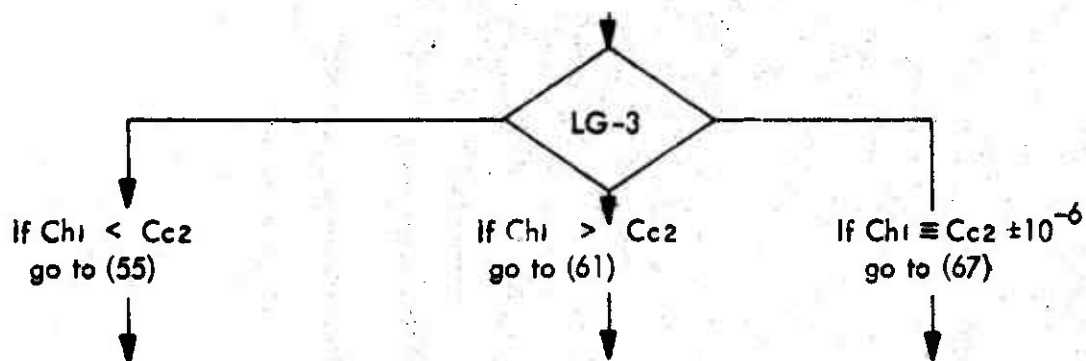
$$cpcm = \leftarrow \quad (50)$$

$$Cc2 = cpcm \cdot W4 \quad (51)^*$$

$$NPr2 = \frac{cpcm \cdot \mu m2}{Km2} \quad (52)^*$$

$$NNu2 = 3.66 + \left\{ \frac{\left(\frac{.104}{\left[\frac{(tp/dh)}{NRe2 \cdot NPr2} \right]} \right)}{1 + \left(\frac{.016}{\left[\frac{(tp/dh)}{NRe2 \cdot NPr2} \right]^{.8}} \right)} \right\} \quad (53)^*$$

$$h_{5-6} = \frac{12 NNu2 \cdot Km2}{dh} \quad (54)^*$$



If Chi < Cc2

$$\nabla 1 = (T8 - T22) e^{Ntui \left[1 - \left| \frac{Chi}{Cc2} \right| \right]} \quad (55)$$

$$\Delta X = \frac{\nabla 1 - (T8 - T22)}{\left(\frac{Cc2}{Ch1}\right) - 1} \quad (56)$$

$$\Delta Y = \left(\frac{Cc2}{Ch1}\right) \cdot \Delta X \quad (57)$$

$$T23 \text{ calculated} = T22 + \Delta X \quad (58)$$

TEST 5-A

(58) must = (35) $\pm$.001

If (58) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " " " .

$$T7 \text{ calculated} = T8 + \Delta Y \quad (59)$$

TEST 6-A

(59) must = (5) $\pm$.001

If (59) > (5), increase (5) and iterate from (5).

" " < " , reduce " " " " " " .

$$\epsilon_i = \frac{1 - e^{-Nt_{ui} [1 - (Ch1/Cc2)]}}{1 - \left\{ \left(\frac{Ch1}{Cc2}\right) e^{-Nt_{ui} [1 - (Ch1/Cc2)]} \right\}} \quad (60)^*$$

Then go to (71)

If $Ch1 > Cc2$

$$\nabla 1 = (T8 - T22) e^{Nt_{ui} \left[1 - \left(\frac{Cc2}{Ch1} \right) \right]} \quad (61)$$

$$\Delta X = \frac{\nabla 1 - (T8 - T22)}{\left(\frac{Ch1}{Cc2} \right) - 1} \quad (62)$$

$$\Delta Y = \left(\frac{Ch1}{Cc2} \right) \cdot \Delta X \quad (63)$$

$$T23 \text{ calculated} = T22 + \Delta X \quad (64)$$

TEST 5-B

(64) must = (35) $\pm .001$

If (64) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " " " .

$$T7 \text{ calculated} = T8 + \Delta Y \quad (65)$$

TEST 6-B

(65) must = (5) $\pm .001$

If (65) > (5), increase (5) and iterate from (5).

" " < " , reduce " " " " " " .

$$\epsilon_i = \frac{1 - e^{-Nt_{ui} \left[1 - \left(\frac{Cc2}{Ch1} \right) \right]}}{1 - \left\{ \left(\frac{Cc2}{Ch1} \right) e^{-Nt_{ui} \left[1 - \left(\frac{Cc2}{Ch1} \right) \right]} \right\}} \quad (66)^*$$

Then go to (71)

$$\boxed{\text{If } Ch1 \equiv Cc2 \pm 10}$$

$$Z = \frac{(T8 - T22)}{1 - \left(\frac{Ntui}{1 + Ntui} \right)} \quad (67)$$

$$T23 \text{ calculated} = (T22 + Z) - (T8 - T22) \quad (68)$$

TEST 5 - C

$$(68) \text{ must} = (35) \pm .001$$

If (68) > (35), increase (35) and iterate from (35).

" " < " , reduce " " " " " " .

$$T7 \text{ calculated} = T22 + Z \quad (69)$$

TEST 6 - C

$$(69) \text{ must} = (5) \pm .001$$

If (69) > (5) , increase (5) and iterate from (5).

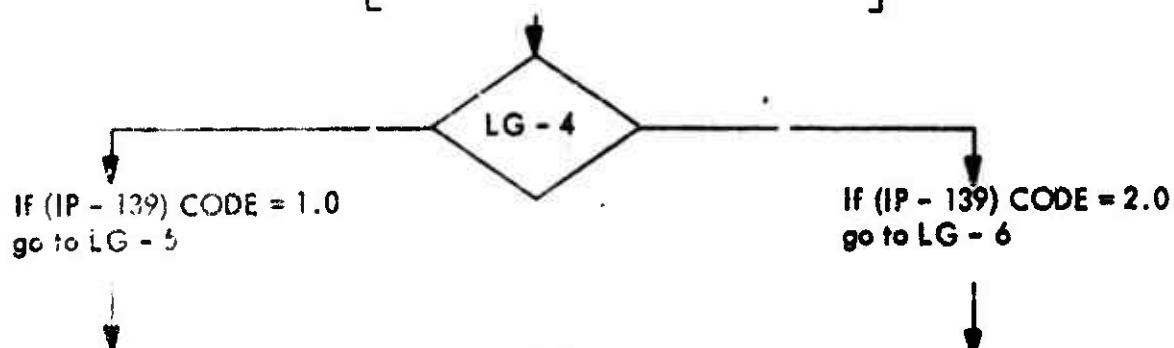
" " < " , reduce " " " " " " .

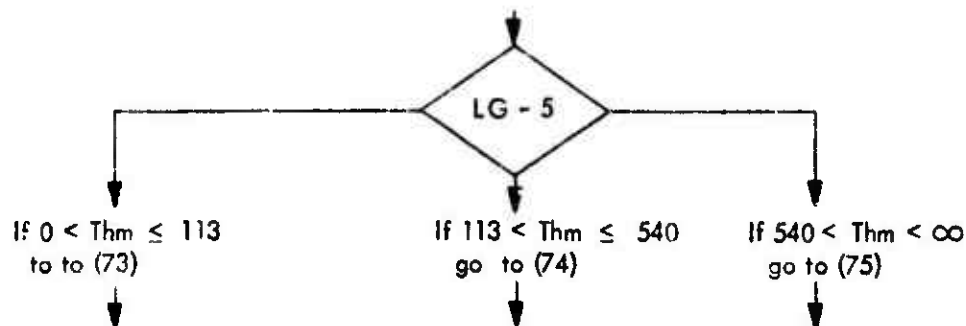
$$\epsilon_i = \frac{Ntui}{1 + Ntui} \quad (70)^*$$

Then go to (71)

$$T'_1 = Thm - \left[\left(\frac{Y'_1}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \quad (71)$$

$$T'_2 = Thm - \left[\left(\frac{Y'_1 + Y'_2}{Y'_1 + Y'_2 + Y'_3} \right) (Thm - Tcm) \right] \quad (72)$$





$$K_p = \frac{1}{[.1 (Thm - T_l)]} \left\{ \frac{49}{2} [(Thm)^2 - (T_l)^2] - \frac{1}{3.47} [(Thm)^{3.47} - (T_l)^{3.47}] \right\} \quad (73)$$

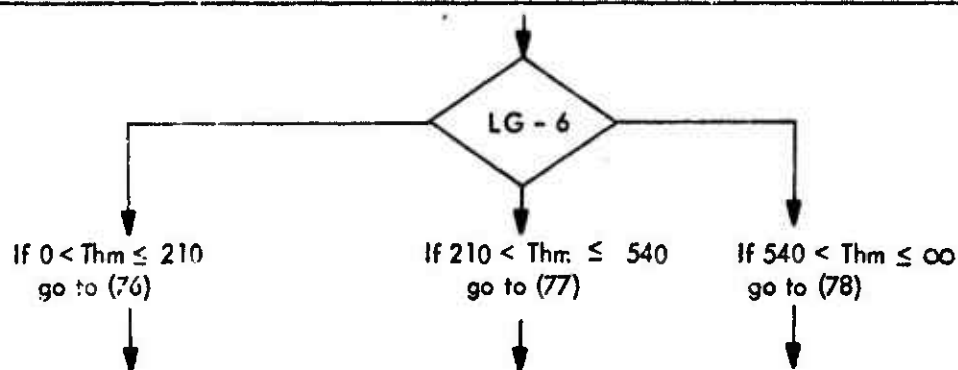
Then go to (79)

$$K_p = \frac{1}{[.1 (Thm - T_l)]} \left\{ - \left[\frac{(.1 Thm)^{2.708} - (.1 T_l)^{2.708}}{2.708} \right] + 9.551 [(Thm)^2 - (T_l)^2] \right\} \quad (74)$$

Then go to (79)

$$K_p = 111.75 = \text{constant} \quad (75)$$

Then go to (79)

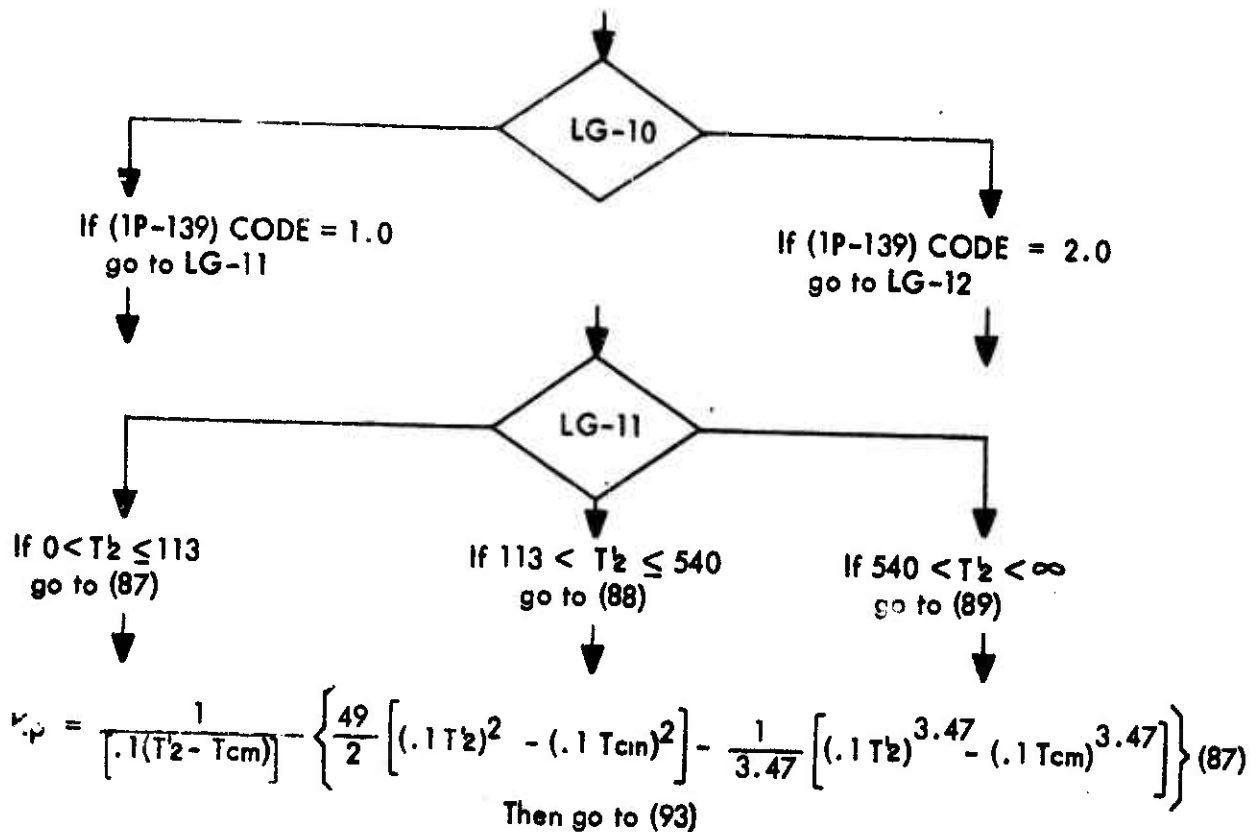


$$K_p = \frac{1}{(Thm - T_l)} \left\{ \frac{2.765}{2} [(Thm)^2 - (T_l)^2] - \left[\frac{(Thm)^{2.16} - (T_l)^{2.16}}{2.16} \right] \right\} \quad (76)$$

Then go to (79)

$$K_{3-4} = K_p$$

(86)*



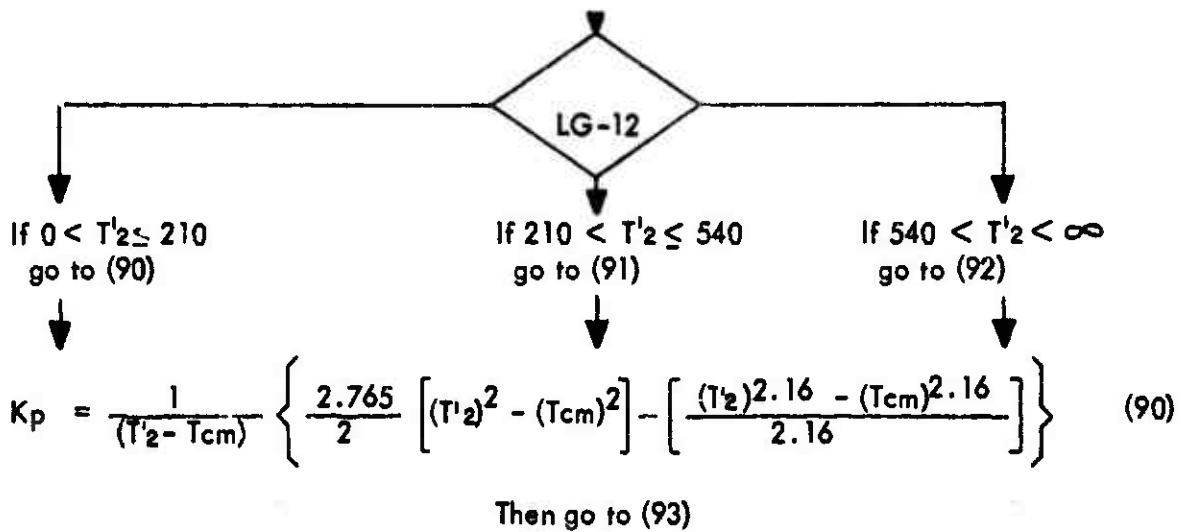
$$K_p = \frac{1}{[.1(T_2 - T_{cm})]} \left\{ - \left[\frac{(.1T_2)^{2.708} - (.1T_{cm})^{2.708}}{2.708} \right] + 9.551 \left[(.1T_2)^2 - (.1T_{cm})^2 \right] \right\} \quad (88)$$

Then go to (93)

$$K_p = 111.74 = \text{constant}$$

(89)

Then go to (93)



$$K_p = 86.0 + \left\{ 6.25 \left(\frac{[(T'_2 + T_{cm})/2] - 210}{330} \right) \right\} \quad (91)$$

Then go to (93)

$$K_p = 92.25 = \text{constant} \quad (92)$$

Then go to (93)

$$K_{4-5} = K_p \cdot .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \quad (93)^*$$

$$U = \frac{1}{\left(\frac{1}{h_{1-2}} + \frac{\lambda_1}{K_{2-3}} + \frac{\lambda_2}{K_{3-4}} + \frac{\lambda_3}{K_{4-5}} + \frac{1}{h_{5-6}} \right)} \quad (94)^*$$

$$n_s = n_p + 1 \quad (95)^*$$

$$\lambda_e = \frac{n_s \cdot t_s}{12} \quad (96)$$

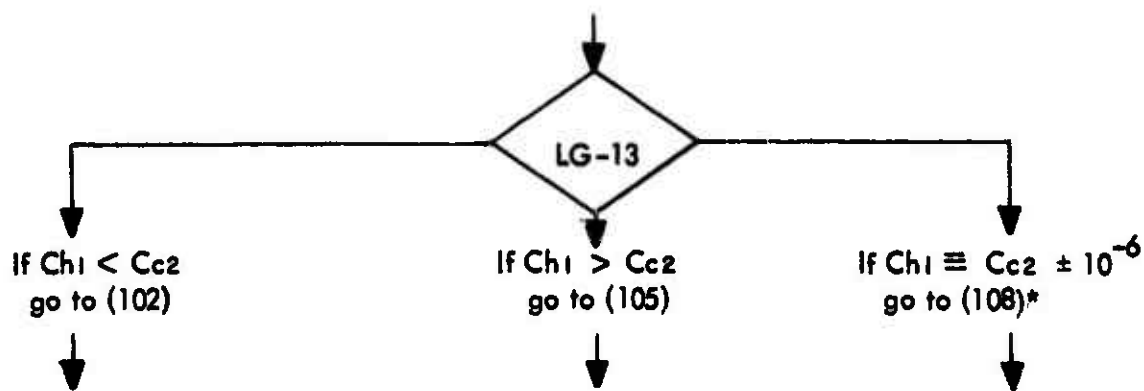
$$T_{\lambda 1} = \frac{(T8 + T22)}{2} \quad (97)$$

$$T_{\lambda 2} = \frac{(T7 + T23)}{2} \quad (98)$$

$$A_{K\lambda} = \frac{[(X2/F_s) - (X' Y') + [(C-1) X' B']}{144} \quad (99)$$

$$\overline{K\lambda} = \frac{7.27 \times 10^{-3}}{(T_{\lambda 2} - T_{\lambda 1})} \left[\frac{(T_{\lambda 2})^{1.585} - (T_{\lambda 1})^{1.585}}{1.585} \right] \quad (100)$$

$$Q\lambda = \frac{\overline{K\lambda} \cdot A_{K\lambda}}{\lambda_e} \quad (101)^*$$



If $Ch1 < Cc2$

$$\lambda = \frac{Q \cdot l}{3600 \cdot Ch1} \quad (102)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (103)^*$$

TEST 7-A

If (103) $\geq$ 1.0, stop & readout message "REDUCE Ntui"
 " " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon (Ch1/Cc2)}{1 - \epsilon} \right]}{1 - (Ch1/Cc2)} \quad (104)^*$$

Then go to LG-14.

If $Ch1 > Cc2$

$$\lambda = \frac{Q \cdot l}{3600 \cdot Cc2} \quad (105)^*$$

$$\epsilon = \epsilon_i \left(\frac{1}{1 - \lambda} \right) \quad (106)^*$$

TEST 7-B

If (106) $\geq$ 1.0, stop & readout message "REDUCE Ntui "
 " " < " , continue.

$$Ntu = \frac{\log_e \left[\frac{1 - \epsilon (C_{c2}/Ch_1)}{1 - \epsilon} \right]}{1 - (C_{c2}/Ch_1)} \quad (107)^*$$

Then go to LG-14

$$\boxed{\text{If } Ch_1 \equiv C_{c2} \pm 10^{-6}}$$

$$\lambda = \frac{Q_1}{3600 Ch_1} \quad (108)^*$$

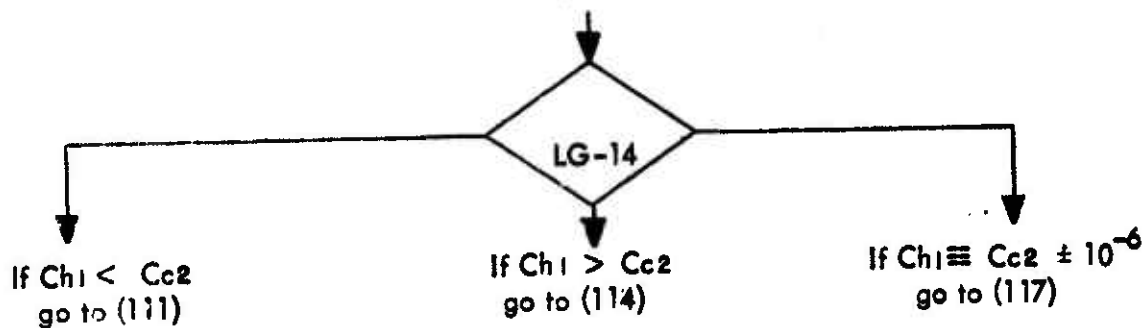
$$\epsilon = \epsilon_1 \left(\frac{1}{1 - \lambda} \right) \quad (109)^*$$

TEST 7-C

If (109) ≥ 1.0 , stop & readout message "REDUCE Ntui"
 " " < " , continue.

$$Ntu = \frac{\epsilon}{1 - \epsilon} \quad (110)^*$$

Then go to LG-14



If $Ch_1 < Cc_2$

$$A_{x \text{ tot. hot side}} = \frac{3600 \text{ Ntu Ch}_1}{U} \quad (111)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (112)^*$$

$$np_{\text{calculated}} = \frac{144 A_{x \text{ tot. hot side}}}{A_{xp}} \quad (113)$$

Note . . . If a fraction results, go to next higher whole number.

TEST 8-A

TEST 8-A
(113) must = (4) $\begin{matrix} +1 \\ -0 \end{matrix}$

If (113) $\geq$ (4), increase (4) and iterate from (4).
 " " $<$ " , reduce " " " " " " .

Then go to (120)

If $Ch_1 > Cc_2$

$$A_{x \text{ tot. hot side}} = \frac{3600 \text{ Ntu } C_{c2}}{U} \quad (114)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (115)^*$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{A_{xp}} \quad (116)$$

Note..... If a fraction results, go to next higher whole number.

TEST 8-B

$$(116) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (116) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " " " .

Then go to (120)

$$\text{If } Ch_1 \equiv Cc_2 \pm 10^{-6}$$

$$Ax \text{ tot. hot side} = \frac{3600 N_{tu} Ch_1}{U} \quad (117)^*$$

$$A_{xp} = A_{x1} \cdot A_{f1} \quad (118)^*$$

$$np \text{ calculated} = \frac{144 \text{ Ax tot. hot side}}{A_{xp}} \quad (119)$$

Note..... If a fraction results, go to next higher whole number.

TEST 8-C

$$(119) \text{ must} = (4) \begin{matrix} +1 \\ -0 \end{matrix}$$

If (119) > (4), increase (4) and iterate from (4).

" " < " , reduce " " " " " " .

Then go to (120)

$$\text{width } X = \text{equation (13)} = \text{inches} \quad (120)^*$$

after closure

$$\text{height } Y = \frac{X}{F_s} = \text{inches} \quad (121)^*$$

$$\text{core length } L = [(np \cdot tp) + (ns \cdot ts)] = \text{inches} \quad (122)^*$$

$$\begin{aligned} \text{core weight} &= .098 \, np \, tp \left\{ [(XY) - (X'Y')] + [X'B'(C-1)] + [Af_1(Ra+1)(1-\sigma)] \right\} + \\ &\quad .078 \, ns \, ts \left\{ [(XY) - (X'Y')] + [X'B'(C-1)] \right\} = \text{lbs} \end{aligned} \quad (123)^*$$

$$\text{header weight} = .196 \left[(XY) - Af_1(Ra+1) + \frac{XY}{8} \right] = \text{lbs} \quad (124)^*$$

$$\text{total weight} = (123) + (124) = \text{lbs} \quad (125)^*$$

$$\eta f = \frac{1}{1 + \left[\frac{l_{-2} (A_{xp}/N_h \cdot Y_1') (Y_1')^2}{3 \, np \, {}_2K_3 \left\{ X' \, tp \, .93061 \left[\frac{s - dh}{s - (dh/2)} \right] \right\}} \right]} \quad (126)^*$$

TEST 9

If (126) < .40, readout message "INCREASE (IP - 132)"
 " " > .60, " " "REDUCE" " "

Do not stop machine on TEST 9

$$Av = \frac{Ax \text{ tot. hot side}}{\left(\frac{X \cdot Y \cdot L}{1728} \right)} = ft^2 / ft^3 \quad (127)^*$$

FINAL TEST

Final test does not apply STOP after (127).

The FLOW DIAGRAM for HX-7 is exactly similar to that of HX-1.

APPENDIX IX

BASIC FORTRAN MACHINE LISTING:

The following comprises the Fortran machine listing for the complete program.

```

C      MAIN PROGRAM
C      FOR USE WITH ANALYTICAL PROGRAM FOR CRYOGENIC TURBOMACHINE
C      SYSTEMS
C      VERSION 17 JULY 1970
      DIMENSION S(8),AN(8),AX1(8),AH1(8),AF1(8)
      DIMENSION XPR(8),YPR(8),ANP(8),DPI(8),ANPRI(8)
      DIMENSION ANPR(8),ANNUI(8),H12(8),ANRE2(8)
      DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
      DIMENSION AK23(8),AK34(8),AK45(8),U(8)
      DIMENSION AXTHS(8),AXP(8),EI(8),ANS(8)
      DIMENSION QL(8),AE(8),IX(8),HY(8),ALL(8)
      DIMENSION CM(8),HW(8),TW(8),ANF(8),AV(8)
      DIMENSION CH1(8),CC2(8),S2(8),AN2(8),AH2(8)
      DIMENSION K1(8),K21(8),K3(8),K4(8)
      DIMENSION ANTU(8),DHT(8),AKWT(8),ANTUI(8),AKP(5),TLX(5)
      DIMENSION XPRI(8),YPRI(8),YPR2(8),YPR3(8)
      DIMENSION ALAM(5),TX(8)
      COMMON S,AN,AX1,AH1,AF1,XPR,YPR,ANP,DPI,ANPRI,ANPR
      COMMON ANNUI,H12,ANRE2,DP2,ANPR2,ANNU2,H56,AK23,AK34
      COMMON AK45,U,AXTHS,AXP,EI,ANS,QL,AE,IX,HY,ALL,CM,HW,TW
      COMMON ANF,AV,CH1,CC2,S2,AN2,AH2,K1,K21,K3,K4
      COMMON T14,P14,VBI4,H14,S14,WI
      COMMON T15,P15,VBI5,H15,S15
      COMMON T16,P16,VBI6,H16,S16
      COMMON DH,TP,SIG,ANRE1,C,FS,RF,ANTU,TS
      COMMON ANTI,DH2,SIG1,SIG2,M2,WTI
      COMMON DHT,AKWT,ANTUI,MAT,TLX
      COMMON BX,BY,ANH,ANC
      COMMON XPRI,YPRI,YPR2,YPR3
      COMMON ALAM,TX,BPR,RA
1      FORMAT(1X,18HPROGRAM INPUT DATA)
2      FORMAT(1X,11H1 LOAD DATA)
3      FORMAT(1X,22H      AT JT VALVE INLET:)
4      FORMAT(1X,5H T14=F15.8,2X,5HDEG.R)
5      FORMAT(1X,5H P14=F15.8,2X,4HPSIA)
6      FORMAT(1X,6H VBI4=F15.8,1X,9HCU.FT./LB)
7      FORMAT(1X,5H H14=F15.8,2X,6HBTU/LB)
8      FORMAT(1X,5H S14=F15.8,2X,12HBTU/LB-DEG.R)
9      FORMAT(1X,4H WI=F15.8)
10     FORMAT(1X,70(1H*))
11     FORMAT(1X,21H      AT JT VALVE EXIT:)
12     FORMAT(1X,5H T15=F15.8,2X,5HDEG.R)
13     FORMAT(1X,5H P15=F15.8,2X,4HPSIA)
14     FORMAT(1X,6H VBI5=F15.8,1X,9HCU.FT./LB)
15     FORMAT(1X,5H H15=F15.8,2X,6HBTU/LB)
16     FORMAT(1X,5H S15=F15.8,2X,12HBTU/LB-DEG.R)
17     FORMAT(1X,17H      AT LOAD EXIT:)
18     FORMAT(1X,5H T16=F15.8,2X,5HDEG.R)
19     FORMAT(1X,5H P16=F15.8,2X,4HPSIA)
20     FORMAT(1X,6H VBI6=F15.8,1X,9HCU.FT./LB)

```

```

21  FORMAT(1X,5H H16=F15.8,2X,6HBTU/LB)
22  FORMAT(1X,5H S16=F15.8,2X,12HBTU/LB-DEG.R)
23  FORMAT(1X,9H HX1 DATA)
24  FORMAT(1X,5H T17=F15.8,2X,5HDEG.R)
25  FORMAT(1X,5H DH=F15.8,2X,6HINCHES)
26  FORMAT(1X,4H TP=F15.8)
27  FORMAT(1X,4H TS=F15.8)
28  FORMAT(1X,7H SIGMA=F15.8)
29  FORMAT(1X,6H NRE1=F15.8)
30  FORMAT(1X,3H C=F15.8)
31  FORMAT(1X,4H FS=F15.8)
32  FORMAT(1X,4H RF=F15.8)
34  FORMAT(1X,16H OUTPUT FROM HX1)
55  FORMAT(1X,25HOUTPUT FROM HX2&TURBINE 1)
56  FORMAT(1X,5H P12=F15.8,5H V12=F15.8,5H T12=F15.8)
57  FORMAT(1X,5H P13=F15.8,5H V13=F15.8,5H T13=F15.8)
58  FORMAT(1X,5H P17=F15.8,5H V17=F15.8,5H T17=F15.8)
59  FORMAT(1X,5H P18=F15.8,5H V18=F15.8,5H T18=F15.8)
60  FORMAT(1X,5H V14=F15.8)
61  FORMAT(1X,5H NT1=F15.8)
62  FORMAT(1X,5H DH2=F15.8,2X,6HINCHES)
63  FORMAT(1X,8H SIGMA1=F15.8)
64  FORMAT(1X,8H SIGMA2=F15.8)
65  FORMAT(1X,3H WT,11,1H=F15.8)
66  FORMAT(1X,2H W,11,1H=F15.8)
67  FORMAT(1X,9H HX2 DATA)
68  FORMAT(1X,5H V13=F15.8)
69  FORMAT(12I2)
70  FORMAT(1X,9H HX3 DATA)
71  FORMAT(1X,16H OUTPUT FROM HX3)
72  FORMAT(1X,5H NTU=F15.8)
C   LOAD DATA:AT JT VALVE INLET
    OPEN(3,INPUT,/APDAT/)
100  FORMAT(5(1X,F15.8))
101  FORMAT(2I5)
102  FORMAT(1X,15HT14,P14,T16,P16)
103  FORMAT(1X,9HT17,ANRE1)
104  FORMAT(1X,12HG0=1,N0G0=-1)
105  FORMAT(1X,10HANT1,ANRE1)
106  FORMAT(1X,11HANRE1,ANTUI)
    I1=0
    I2=1
    I3=3
    TLX(1)=113.
    TLX(2)=210.
    TLX(3)=0.
    TLX(4)=0.
    TLX(5)=0.
    READ(13,100)T14,P14,H14,S14
    READ(11,101) KR,MAT

```

```

C          AT JT VALVE EXIT
  READ(13,100)T15,P15,H15,S15
C          AT LOAD EXIT
  READ(13,100)T16,P16,H16,S16
  READ(13,100)DHL,ALW
  WRITE(12,1)
  WRITE(12,2)
  WRITE(12,3)
  WRITE(12,4)T14
  WRITE(12,5)P14
  WRITE(12,6)VB14
  WRITE(12,7)H14
  WRITE(12,8)S14
  WRITE(12,9)W1
  WRITE(12,10)
  WRITE(12,11)
  WRITE(12,12)T15
  WRITE(12,13)P15
  WRITE(12,14)VB15
  WRITE(12,15)H15
  WRITE(12,16)S15
  WRITE(12,10)
  WRITE(12,17)
  WRITE(12,18)T16
  WRITE(12,19)P16
  WRITE(12,20)VB16
  WRITE(12,21)H16
  WRITE(12,22)S16
  WRITE(12,10)
C          HX1 DATA
  READ(13,69)J
  READ(13,100)DH,TP,TS,SIG,ANREI
  READ(13,100)ANTUI(J),C,ANH,ANC,FS
  READ(13,100)RA,RF,BX,BY,BPR
  READ(13,100)W1
  WRITE(12,23)
  WRITE(12,25)DH
  WRITE(12,26)TP
  WRITE(12,27)TS
  WRITE(12,28)SIG
  WRITE(12,29)ANREI
  WRITE(12,30)C
  WRITE(12,31)FS
  WRITE(12,32)RF
  WRITE(12,24)T17
  WRITE(12,10)
  READ(13,100)XI,ANPI
  SE14=1.60
  SF16=2.9225
10007  CONTINUE

```

C*****INITIAL CONDITIONS*****

T131=T14+10.

P131=1.02*P14

T171=T16+10.

P171=0.98*P16

CALL HXI(1,P13,V13,T13,P14,V14,T14,P16,V16,T16,P17,V17,T17,

1 XI,ANPI,P131,T131,P171,T171,CPCM,CPHM)

SE13=1.66+((CPHM*ALOG(T13/T14))-(1.98718*ALOG(P13/P14)))

SE17=2.9225+((CPCM*ALOG(T17/T16))-(1.98718*ALOG(P16/P17)))

WRITE(12,10)

WRITE(12,34)

IF(KR)900,1900,901

901 GO TO 903

900 CALL OUTPUT(1)

903 CONTINUE

WRITE(12,57)P13,V13,T13

WRITE(12,58)P17,V17,T17

WRITE(12,60)V14

WRITE(12,10)

1900 CONTINUE

WRITE(12,104)

READ(11,101) NG0

IF(NG0)10007,10007,10008

10008 CONTINUE

C HX2 &TURBINE DATA

READ(13,69)J

READ(13,100)DH,TP,TS,SIG,ANRE1

READ(13,100)C,ANH,ANC,FS

READ(13,100)RA,RF,BX,BY,BPR

READ(13,100)WT1,W2,ANT1

WRITE(12,73)J

WRITE(12,61)ANT1

WRITE(12,25)DH

WRITE(12,62)DH2

WRITE(12,26)TP

WRITE(12,27)TS

WRITE(12,63)SIG1

WRITE(12,64)SIG2

WRITE(12,29)ANRE1

WRITE(12,30)C

WRITE(12,31)FS

WRITE(12,32)RF

WRITE(12,66)J,W2

JXA=J-1

WRITE(12,65)JXA,WT1

WRITE(12,10)

READ(13,100)XI,ANPI

10005 CONTINUE

C*****INITIAL CONDITIONS*****

T121=T13+5.

```

P12I=1.02*P13
T18I=T17+5.
P18I=0.98*P17
CALL HX2(2,P12,V12,T12,P13,V13,T13,P17,V17,T17,P18,V18,T18,
1 XI,ANPI,P12I,T12I,P18I,T18I,CPCM,CPHM)
SE12=SE13 +((CPHM*ALOG(T12/T13))-(1.98718*ALOG(P12/P13)))
SE18=SE17 +((CPCM*ALOG(T18/T17))-(1.98718*ALOG(P17/P18)))
WRITE(12,10)
WRITE(12,74)J
IF(KR)904,1904,905
905 GO TO 906
904 CALL GUTPUT(2)
906 CONTINUE
WRITE(12,56)P12,V12,T12
WRITE(12,59)P18,V18,T18
WRITE(12,68)V13
WRITE(12,10)
1904 CONTINUE
WRITE(12,104)
READ(11,101) NG0
IF(NG0)10005,10005,10006
10006 CONTINUE
C HX3 OATA
READ(13,69)J
READ(13,100)OH,TP,TS,SIG,ANREI
READ(13,100)ANTUI(J),C,ANH,ANC,FS
READ(13,100)RA,RF,BX,BY,BPR
READ(13,100)W2
WRITE(12,73)J
WRITE(12,25)DH
WRITE(12,26)TP
WRITE(12,27)TS
WRITE(12,28)SIG
WRITE(12,29)ANREI
WRITE(12,30)C
WRITE(12,31)FS
WRITE(12,32)RF
WRITE(12,72)ANTUI(J)
WRITE(12,10)
READ(13,100)XI,ANPI
C*****INITIAL CONDITIONS*****
T11I=T12+75.
P11I=1.02*P12
T19I=T11+75.
P19I=0.98*P18
10003 CONTINUE
CALL HX1(3,P11,V11,T11,P12,V12,T12,P18,V18,T18,P19,V19,T19,
1 XI,ANPI,P11I,T11I,P19I,T19I,CPCM,CPHM)
SE11=SE12 +((CPHM*ALOG(T11/T12))-(1.98718*ALOG(P11/P12)))
SE19=SE18 +((CPCM*ALOG(T19/T18))-(1.98718*ALOG(P18/P19)))

```

```

WRITE(12,10)
73  FORMAT(1X,3HMX-,12,5H DATA)
74  FORMAT(1X,15HOUTPUT FROM HX-,12)
WRITE(12,74)J
IF(KR)907,1907,908
908  GO TO 909
907  CALL OUTPUT(3)
909  CONTINUE
WRITE(12,75)P11,V11,T11
WRITE(12,76)P19,V19,T19
WRITE(12,77)V12
75  FORMAT(1X,5H P11=F15.8,5H V11=F15.8,5H T11=F15.8)
76  FORMAT(1X,5H P19=F15.8,5H V19=F15.8,5H T19=F15.8)
77  FORMAT(1X,5H V12=F15.8)
1907 CONTINUE
WRITE(12,104)
READ(11,101) NG0
IF(NG0)10003,10003,10004
10004 CONTINUE
WRITE(12,10)
IF(T19-540.)504,999,999
504  CONTINUE
C    HX4 DATA
READ(13,69)J
READ(13,100)DH,TP,TS,SIG,ANRE1
READ(13,100)C,ANH,ANC,FS
READ(13,100)RA,RF,BX,BY,BPR
READ(13,100)W2,WT2,W3,ANT1
WRITE(12,73)J
WRITE(12,61)ANT1
WRITE(12,25)DH
WRITE(12,62)DH2
WRITE(12,26)TP
WRITE(12,27)TS
WRITE(12,63)SIG1
WRITE(12,64)SIG2
WRITE(12,29)ANRE1
WRITE(12,30)C
WRITE(12,31)FS
WRITE(12,32)RF
WRITE(12,66)J,W2
JXA=J-1
WRITE(12,65)JXA,WT1
WRITE(12,10)
READ(13,100)XI,ANP1
10504 CONTINUE
*****INITIAL CONDITIONS*****
T101=T11+10.
P101=1.02*P11
T201=T19+10.

```

```

P201=3.050P19
CALL HX2(4,P10,V10,T10,P11,V11,T11,P19,V19,T19,P20,V20,T20,
1 XI, ANPI,P101,T101,P201,T201,CPCM,CPHM)
SE10=SE11 +(((CPHM*ALOG(T10/T11))-(1.98718*ALOG(P10/P11)))
SE20=SE19 +(((CPCM*ALOG(T20/T19))-(1.98718*ALOG(P19/P20)))
WRITE(12,10)
WRITE(12,74)J
IF(KR)910,1910,911
911 GO TO 912
910 CALL OUTPUT(4)
912 CONTINUE
456 FORMAT(1X,5H P10=F15.8,5H V10=F15.8,5H T10=F15.8)
459 FORMAT(1X,5H P20=F15.8,5H V20=F15.8,5H T20=F15.8)
468 FORMAT(1X,5H V11=F15.8)
WRITE(12,456)P10,V10,T10
WRITE(12,459)P20,V20,T20
WRITE(12,468)V11
1910 CONTINUE
WRITE(12,104)
READ(11,101) NEG
IF(NG0)10504,10504,10002
10002 CONTINUE
WRITE(12,10)
IF(T20-540.)505,999,999
505 CONTINUE
C HX5 DATA
READ(13,69)J
READ(13,100)DH,TP,TS,SIG,ANRE1
READ(13,100)ANTUI(J),C,ANH,ANC,FS
READ(13,100)RA,RF,BX,BY,BPR
READ(13,100)W3
WRITE(12,73)J
WRITE(12,25)DH
WRITE(12,26)TP
WRITE(12,27)TS
WRITE(12,28)SIG
WRITE(12,29)ANRE1
WRITE(12,30)C
WRITE(12,31)FS
WRITE(12,32)RF
WRITE(12,72)ANTUI(J)
WRITE(12,10)
READ(13,100)XI,ANPI
T91=T10+100.
P91=1.02*P10
T211=T20+100.
P211=0.98*P20
10505 CONTINUE
CALL HX1(5,P9,V9,T9,P10,V10,T10,P20,V20,T20,P21,V21,T21,
1 XI, ANPI,P91,T91,P211,T211,CPCM,CPHM)

```

```

SE9=SE10 +((CPHM*ALOG(T9/T10))-(1.98718*ALOG(P9/P10)))
SE21=SE20 +((CPCM*ALOG(T21/T20))-(1.98718*ALOG(P20/P21)))
WRITE(12,10)
WRITE(12,74)J
IF KR>913,1913,914
914 GO TO 915
913 CALL OUTPUT(5)
915 CONTINUE
WRITE(12,575)P9,V9,T9
WRITE(12,576)P21,V21,T21
WRITE(12,577)V10
575 FORMAT(1X,5H P9 =F15.8,5H V9 =F15.8,5H T9 =F15.8)
576 FORMAT(1X,5H P21=F15.8,5H V21=F15.8,5H T21=F15.8)
577 FORMAT(1X,5H V10=F15.8)
1913 CONTINUE
WRITE(12,104)
READ(11,101) NG0
IF(NG0)10505,10505,10001
10001 CONTINUE
WRITE(12,10)
IF(T21-540.)506,999,999
506 CONTINUE
C HX6 DATA
READ(13,69)J
READ(13,100)DH,TP,TS,SIG,ANRE1
READ(13,100)C,ANH,ANC,FS
READ(13,100)RA,RF,BX,BY,BPR
READ(13,100)W3,WT3,W4,ANT1
WRITE(12,73)J
WRITE(12,61)ANT1
WRITE(12,25)DH
WRITE(12,62)DH2
WRITE(12,26)TP
WRITE(12,27)TS
WRITE(12,63)SIG1
WRITE(12,64)SIG2
WRITE(12,29)ANRE1
WRITE(12,30)C
WRITE(12,31)FS
WRITE(12,32)RF
WRITE(12,66)J,W2
JXA=J-1
WRITE(12,65)JXA,WT1
WRITE(12,10)
READ(13,100)XI,ANP1
C*****9INITIAL CONDITIONS*****
T81=T9+10.
P81=1.02*P9
T221=T21+10.
P221=0.98*P21

```

```

CALL HX2(6,P8 ,V8 ,T8 ,P9 ,V9 ,T9 ,P21,V21,T21,P22,V22,T22,
1 X1, ANP1,P31,T31 ,P221,T221,CPCM,CPHM)
SE8=SE9 +(((CPHM*ALOG(T8/T9))-(1.98718*ALOG(P8/P9)))
SE22=SE21 +(((CPCM*ALOG(T22/T21))-(1.98718*ALOG(P21/P22)))
WRITE(12,10)
WRITE(12,74)J
IF(KR)916,1916,917
917 GO TO 918
916 CALL OUTPUT(6)
918 CONTINUE
WRITE(12,656)P8,V8,T8
WRITE(12,659)P22,V22,T22
WRITE(12,668)V9
656 FORMAT(1X,5H P8 =F15.8,5H V8 =F15.8,5H T8 =F15.8)
659 FORMAT(1X,5H P22=F15.8,5H V22=F15.8,5H T22=F15.8)
668 FORMAT(1X,5H V9 =F15.8)
1916 CONTINUE
WRITE(12,10)
IF(T22-540.1FVFFVLRM7 CONTINUE
C HX7 DATA
READ(13,69)J
READ(13,100)DH,TP,TS,SIG,ANREI
READ(13,100)ANTUI(J),C,ANH,ANC,FS
READ(13,100)RA,RF,BX,BY,BPR
READ(13,100)W4
WRITE(12,73)J
WRITE(12,25)DH
WRITE(12,P6)TP
WRITE(12,27)TS
WRITE(12,28)SIG
WRITE(12,29)ANREI
WRITE(12,30)C
WRITE(12,31)FS
WRITE(12,32)RF
WRITE(12,72)ANTUI(J)
WRITE(12,10)
READ(13,100)X1,ANP1
C*:::::9INITIAL CONDITIONS*****
T71 =T8+150.
P71=1.02*P8
T231=T22+150.
P231=0.98*P22
IF(KR)2005,2006,2005
2006 GO TO 1999
2005 CONTINUE
CALL HX1(7,P7 ,V7 ,T7 ,P8 ,V8,T8 ,P22,V22,T22,P23,V23,T23,
1 X1, ANP1,P71,T71 ,P231,T231,CPCM,CPHM)
SE7=SE8 +(((CPHM*ALOG(T7/T8))-(1.98718*ALOG(P7/P8)))
SE23=SE22 +(((CPCM*ALOG(T23/T22))-(1.98718*ALOG(P22/P23)))

```

```

        WRITE(12,10)
        WRITE(12,74)J
        IF(KR)919,1919,920
920      GO TO 921
919      CALL OUTPUT(7)
921      CONTINUE
        WRITE(12,775)P7,V7,T7
        WRITE(12,776)P23,V23,T23
        WRITE(12,777)V8
775      FORMAT(1X,5H P7 =F15.8,5H V7 =F15.8,5H T7 =F15.8)
776      FORMAT(1X,5H P23=F15.8,5H V23=F15.8,5H T23=F15.8)
777      FORMAT(1X,5H V8 =F15.8)
1919     CONTINUE
        WRITE(12,10)
        IF(KR)999,1999,1001
1999     SEM=AMAX1(SE7,SE8,SE9,SE10,SE11,SE12,SE13,SE14,SE15,SE16,
1      SE17,SE18,SE19,SE20,SE21,SE22,SE23)
        TM=AMAX1(T7,T8,T9,T10,T11,T12,T13,T14,T15,T16,T17,T18,T19,
1      T20,T21,T22,T23)
        DX=SEM/10.
        DY=540./10.
1001     READ(11,101) J
        CALL OUTPUT(J)
        GO TO 1001
999      STOP
        END
        END

```

```

EOF READ($MAINS)100
+

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```

SUBROUTINE HX1(J,PA0,VA0,TA0,PA1,VA1,TA1,PE1,VB1,TB1,PC0,VC0,
1 TC0,XI,ANPI,PA01,TA01,PC01,TC01,CPCM,CPHM)
C TURBINE DESIGN PROGRAM-HELIUM
C CRYOGENIC TURBOMACHINE SYSTEMS WITH JT VALVE---GAS AND
C /OR VAPOR PHASE LOAD
C VERSION 15JULY 1970
  DIMENSION S(8),AN(8),AX1(8),AH1(8),AF1(8)
  DIMENSION XPR(8),YPR(8),ANP(8),DP1(8),ANPRI(8)
  DIMENSION ANPR(8),ANNUI(8),HI2(8),ANRE2(8)
  DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
  DIMENSION AK23(8),AK34(8),AK45(8),U(8)
  DIMENSION AXTHS(8),AXP(8),EI(8),ANS(8)
  DIMENSION QL(8),AE(8),WX(8),HY(8),ALL(8)
  DIMENSION CW(8),HW(8),TW(8),ANF(8),AV(8)
  DIMENSION CHI(8),CC2(8),S2(8),AN2(8),AH2(8)
  DIMENSION K1(8),K21(8),K3(8),K4(8)
  DIMENSION ANTU(8),DHT(8),AKWT(8),ANTUI(8),AKP(5),TLX(5)
  DIMENSION XPRI(8),YPRI(8),YPR2(8),YPR3(8)
  DIMENSION ALAM(8),TX(8)
  COMMON S,AN,AX1,AH1,AF1,XPR,YPR,ANP,DP1,ANPRI,ANPR
  COMMON ANNUI,HI2,ANRE2,DP2,ANPR2,ANNU2,H56,AK23,AK34
  COMMON AK45,U,AXTHS,AXP,EI,ANS,QL,AE,WX,HY,ALL,CW,HW,TW
  COMMON ANF,AV,CHI,CC2,S2,AN2,AH2,K1,K21,K3,K4
  COMMON T14,P14,VB14,HI4,S14,K1
  COMMON T15,P15,VB15,HI5,S15
  COMMON T16,P16,VB16,HI6,S16
  COMMON DH,1P,SIG,ANRE1,C,FS,RF,ANTU,TS
  COMMON ANTI,DH2,SIG1,SIG2,W2,WTI
  COMMON DHT,AKWT,ANTUI,MAT,TLX
  COMMON BX,BY,ANH,ANC
  COMMON XPRI,YPRI,YPR2,YPR3
  COMMON ALAM,TX,BPR,RA
1  FORMAT(1X,10HERROR STOP,2X,F15.8)
2  FORMAT(1X,4(F15.8,2X))
3  FORMAT(1X,27HREDUCE ANRE1 OR INCREASE RA)
4  FORMAT(1X,12HREDUCE ANTUI)
5  FORMAT(1X,11HINCREASE FS)
6  FORMAT(1X,9HREDUCE FS)
7  FORMAT(1X,15HXI IS TOO LARGE)
  I2=1
C INITIAL VALUES
  KT1=0
  ANP(J)=ANPI
  TA0=TA01
  PC0=PC01
C*****INITIAL X VALUE IS CALCULATED NEXT***
  X=FS*(((C-1.)*BPR)+ANH+(2.*BY))
  XI=X
  PA0=PA01
  TC0=TC01

```

```

K1(J)=0
K2=0
K3(J)=0
K4(J)=0
K5=0
  K21(J)=0
  NN3=0
N1=0
N2=0
  N3=0
PI=3.14159
E=2.718282
C HOT SIDE
C EQ.1*
  S(J)= SQRT(0.906894*((DH**2)/SIG))
  AN(J)=(4.*SIG)/(PI*(DH**2))
  AX1(J)=(AN(J)*PI*DH*TP)+(2.*(1.-SIG))
C EQ.4
200 ANP(J)=ANP(J)
300 TA0=TA0
42 PA0=PA0
  K1(J)=0
C LG1
  IF(TA0-40.)50,50,60
C EQ.7
50 VBA0=(2.765/E**((0.03*((PA0**0.333333)/(TA0/40.))))*(TA0/PA0)
  GO TO 61
C EQ.8
60 VBA0=2.863092*(TA0/PA0)
61 CONTINUE
C EQ.9
  UA0=(2.37888E-07)*(TA0**0.643)
  VA0=(12.*ANRE1*VBA0*UA0)/QH
  AH1(J)=(144.*W1*VBA0)/VA0
  AF1(J)=AH1(J)/SIG
C EQ.13, ASSUME X
100 X=X
  XPR(J)=X-(2.*BX)
  YPR(J)=((X/FS)-(2.*BY))
C EQ.16
  YPR1(J)=(YPR(J)-((C-1.)*BPR)-ANH)/(2.*(C-1.))
  AF1C=ANH*(XPR(J)*YPR1(J))
  K1(J)=K1(J)+1
C TEST1
  IF(AF1C-(AF1(J)+0.001))101,101,10101
101 IF(AF1C-(AF1(J)-0.001))10100,150,150
10101 IF(K1(J)-1)2000,10111,10102
10111 X=X/1.5
  K1(J)=0
  GO TO 100

```

```

10100 IF(KT1-4)10105,10104,10104
10105 IF(K1(J)-1)2000,10115,10116
10115 T1XA=X
      T1YA=AF1C
      T1ZA=AF1(J)
10116 X=1.5+X
      GO TO 100
10102 IF(KT1-4)10106,10104,10104
10106 T1XB=X
      T1YB=AF1C
      T1ZB=AF1(J)
      KT1=3
10104 CALL ITERA(T1XA,T1XB,T1YA,T1YB,T1ZA,T1ZB,T1DYA1,T1DYA2,
1 T1DYB3,T1DYB4,T1DY1,X,AF1C,AF1(J),KT1)
      KT1=KT1+1
      GO TO 100
C      EQ.18
150 YPR2(J)=YPR1(J)*(RA/2.)
      YPR3(J)=YPR1(J)*RA
      AL1=YPR1(J)/24.
      KT1=0
      K1(J)=0
      AL2=BPR/12.
      AL3=YPR3(J)/(12.*RA)
C      HOT SIDE PRESSURE DROP
      DP1A=(VA0**2)/VBA0
      DP1P=370.0E-06*DP1A*SQR((TP/DH)/ANRE1)
C      EQ.24
      DP1(J)=ANP(J)*DP1P
      PA0C=PA1+DP1(J)
      NN3=NN3+1
C      TEST2
474 IF(PA0C-(PA0-1.0E-03))476,477,477
477 IF(PA0C-(PA0+1.0E-03))478,478,476
476 IF(NN3-9)4761,4762,4763
4762 PA0A=PA0
      PA0CA=PA0C
      PA0ZA=PA0
      GO TO 4761
4763 IF(NN3-6)4765,4765,4766
4765 PA0B=PA0
      PA0CB=PA0C
      PA0ZB=PA0
      K31=NN3-3
      CALL ITERA(PA0A,PA0B,PA0CA,PA0CB,PA0ZA,PA0ZB,T3DYA1,T3DYA2,
1 T3DYB3,T3DYB4,T3DY1,PA0,PA0C,PA0,K31)
      GO TO 42
4761 PA0 =PA0C
      GO TO 42
C      EQ.26

```

```

478  CONTINUE
      UMI=(8.55497E-04/(TA0-TAI))*(((TA0**1.643)-(TAI**1.643))/1.643)
      AKM1=(57.79E-03/(0.00355*(TA0-TAI))*(((0.00355*TA0)**1.642)
5    -(0.00355*TAI)**1.642))/1.642)
      THM=((AKM1/57.79E-03)**(1./1.642))/0.00355
      PHM=(PA0+PAI)/2.
      NN3=0
      CALL CPSUB(THM,PHM,CP)
350  CPHM=CP
C    EQ.29
      CH1(J)=W1*CPHM
      ANPR1(J)=(CPHM*UMI)/AKM1
      ANNU1(J)=3.66+(((0.104)/((TP/DH)/(ANRE1*ANPR1(J))))/(1.+((0.016)
1    /(((TP/DH)/(ANRE1*ANPR1(J))**0.8))))))
      H12(J)=(12.*ANNU1(J)*AKM1)/DH
C    COLD SIDE
4000  TC0=TC0
400  PC0=PC0
C    LG2
      IF(TC0-40.)441,441,442
441  VBC0=(2.765/(E**((0.03*((PC0**0.333333)/(TC0/40.))))))*(TC0/PC0)
      GO TO 443
442  VBC0=2.863092*(TC0/PC0)
443  AH2(J)=RA*AH1(J)
      VC0=(144.*W1*VBC0)/AH2(J)
C    EQ.41
      UC0=(2.37888E-07)*(TC0**0.643)
      ANRE2(J)=(VC0*DH)/(12.*VBC0*UC0)
      DPM=(VC0**2)/VBC0
      DP2P=370.0E-06*DPM*SQR1((TP/DH)/ANRE2(J))
      DP2(J)=ANP(J)*DP2P
C    EQ.45
      PC0C=PBI-DP2(J)
      K2=K2+1
C    TEST3
4862  IF(PC0C-(PC0+0.001 ))4863,4863,4861
4863  IF(PC0C-(PC0-0.001))4861,483,483
4861  IF(K2-5)4881,481,4882
481  PC0A=PC0
      T2YA=PC0C
      T2ZA=PC0
      GO TO 4881
4882  IF(K2-6)487,487,4883
487  PC0B=PC0
      T2YB=PC0C
      T2ZB=PC0
4883  KM=K2-3
      CALL ITERA(PC0A,PC0B,T2YA,T2YB,T2ZA,T2ZB,T2DYA1,T2DYA2,
1    T2DYB3,T2DYB4,T2DYI,PC0,PC0C,PC0,KM)
      IF(PC0 )2000,400,400

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```

4881 PC0=PC0C
      GO TO 400
C      EQ. 46
483  CONTINUE
C      TEST4
      IF(PC0C-10.) 4830, 4831, 4831
4830  WRITE(12,3)
      GO TO 9999
4831  CONTINUE
      UM2=(8.55497E-04/(TC0-TBI))*(((TC0**1.643)-(TBI**1.643))/1.643)
      AKM2=(57.79E-03/(0.00355*(TC0-TBI)))*
S      (((0.00355*TC0)**1.642)-((0.00352*TBI)**1.642))/1.642)
      TCM=((AKM2/57.79E-03)**(1./0.642))/0.00355
      PCM=(P01+PC0)/2.
      K21(J)=K21(J)+K2
      K2=0
      CALL CPSUB(TCM,PCM,CP)
550   CPCM=CP
C      EQ. 49
      CC2(J)=W1*CPCM
      ANPR2(J)=(CPCM*UM2)/AKM2
      ANNU2(J)=3.66+(((0.104)/((TP/DH)/(ANRE2(J)*ANPR2(J))))
1      /(1.+((0.016)/(((TP/DH)/(ANRE2(J)*ANPR2(J))*0.8))))))
C      EQ. 70
      H56(J)=(12.*ANNU2(J)*AKM2)/DH
      IF(K3(J)-5000) 5570, 5570, 9999
5570  CONTINUE
C      LG3
      K3(J)=K3(J)+1
      IF(CH1(J)-(CC2(J)-1.0E-06)) 556, 557, 557
557   IF(CH1(J)-(CC2(J)+1.0E-06)) 560, 560, 558
C      EQ. 50
556   DEL1=(TA1-TBI)*(E**((ANTUI(J)*(1.-(CH1(J)/CC2(J))))))
      DELX=(DEL1-(TA1-TBI))/((CH1(J)/CC2(J))-1.)
      DELY=(CC2(J)/CH1(J))*DELX
      TC0C=TBI+DELX
      GO TO 5750
C      EQ. 62
560   Z=(TA1-TBI)/(1.-(ANTUI(J)/(1.+ANTUI(J))))
      TC0C=(TBI+Z)-(TA1-TBI)
      GO TO 5750
C      EQ. 56
558   DEL1=(TA1-TBI)*(E**((ANTUI(J)*(1.-(CC2(J)/CH1(J))))))
      DELX=(DEL1-(TA1-TBI))/((CH1(J)/CC2(J))-1.)
      DELY=(CH1(J)/CC2(J))*DELX
      TC0C=TBI+DELX
5750  N3=N3+1
C      TEST5
575   IF(TC0C-(TC0-1.0E-03)) 576, 577, 577
577   IF(TC0C-(TC0+1.0E-03)) 578, 578, 576

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```

576   IF(N3-5) 5761, 5762, 5763
5762   TC0A=TC0
      TC0CA=TC0C
      TC0ZA=TC0
      GO TO 5761
5763   IF(N3-6) 5765, 5765, 5766
5765   TC0B=TC0
      TC0CB=TC0C
      TC0ZB=TC0
5766   K31=N3-3
      CALL ITERA(TC0A, TC0B, TC0CA, TC0CB, TC0ZA, TC0ZB, T3DYA1, T3DYA2,
1      T3DYB3, T3DYB4, T3DYI, TC0, TC0C, TC0, K31)
      GO TO 4000
5761   TC0 = TC0C
      GO TO 4000
578   IF(CH1(J)-(CC2(J)-1.0E-06)) 5781, 5782, 5782
5782   IF(CH1(J)-(CC2(J)+1.0E-06)) 5783, 5783, 5784
5783   TA0C=TBI+Z
      GO TO 5785
5781   TA0C=TAI+DELY
      GO TO 5785
5784   TA0C=TAI+DELY
5785   N4=N4+1
      N3=0
C      TEST6
      IF(TA0C-(TA0-1.0E-03)) 57600, 57700, 57700
57700   IF(TA0C-(TA0+1.0E-03)) 57800, 57800, 57600
57600   IF(N4-5) 57610, 57620, 57630
57620   TA0A=TA0
      TA0CA=TA0C
      TA0ZA=TA0
      GO TO 57610
57630   IF(N4-6) 57650, 57650, 57660
57650   TA0B=TA0
      TA0CB=TA0C
      TA0ZB=TA0
57660   K41=N4-3
      CALL ITERA(TA0A, TA0B, TA0CA, TA0CB, TA0ZA, TA0ZB, T4DYA1, T4DYA2,
1      T4DYB3, T4DYB3, T4DYI, TA0, TA0C, TA0, K41)
      GO TO 300
57610   TA0 = TA0C
      GO TO 300
57800   IF(CH1(J)-(CC2(J)-1.0E-06)) 5791, 5790, 5790
5790   IF(CH1(J)-(CC2(J)+1.0E-06)) 5792, 5792, 5793
5791   EIA=CH1(J)/CC2(J)
      EI(J)=(1.-(E**(-ANTUI(J)*(1.-EIA))))
1      /(1.-(EIA*(E**(-ANTUI(J)*(1.-EIA))))
      GO TO 5795
5792   EI(J)=ANTUI(J)/(1.+ANTUI(J))
      GO TO 5795

```

```

5793 EIA= CC2(J)/CH1(J)
      EI(J)=(1.-(E**(-ANTUI(J)*(1.-EIA))))
      1 /((1.-(EIA*(E**(-ANTUI(J)*(1.-EIA))))))
C      EQ.66
5795 CONTINUE
      N1=0
      N2=0
      N3=0
      N4=0
C      LG4
      TPRI=THM-(((YPRI(J)/(YPRI(J)+YPR2(J)+YPR3(J)))*(THM-TCM))
      TPR2=THM-(((YPRI(J)+YPR2(J))/(YPRI(J)+YPR2(J)+YPR3(J)))*
      S (THM-TCM))
      IF(THM ) 601, 602, 602
602 IF(THM-TLX(MAT)) 666, 666, 604
604 IF(THM-540.) 667, 667, 6671
601 GO TO 2011
605 GO TO 2012
C      EQ.71
666 AKP(1)=(1./((.1*(THM-TPRI)))*(((49./2.)*(((.1*THM)**2))-
      S (((.1*TPRI)**2))-((1./3.47)*(((.1*THM)**3.47)-((.1*TPRI)**3.47
      S ))))
C      EQ.74
      AKP(2)=(1./((THM-TPRI))*(((2.765/2.)*((THM**2)-(TPRI**2)))-
      S (((THM**2.16)-(TPRI**2.16))/2.16))
      GO TO 668
C      EQ.73
6671 AKP(1)=111.74
C      EQ.76
      AKP(2)=92.25
      GO TO 668
C      EQ.72
667 AKP(1)=(1./((.1*(THM-TPRI)))*((-(((.1*THM)**2.708)-((.1*TPRI)
      S **2.708))/2.708)+(.955)*(((.1*THM)**2)-((.1*TPRI)**2)))
C      EQ.75
      AKP(2)=86.+(6.25*(((THM+TPRI)/2)-210.)/330.)
C      EQ.77
668 AK23(J)=AKP(MAT)*0.93061*((S(J)-DH)/(S(J)-(DH/2.)))
C      LG8
      IF(TPRI ) 660, 661, 661
661 IF(TPRI -TLX(MAT)) 670, 670, 662
662 IF(TPRI -540.) 671, 671, 6711
660 GO TO 2013
663 GO TO 2014
C      EQ.79
670 AKP(1)=(1./((.1*(TPRI-TPR2)))*(((49./2.)*(((.1*TPRI)**2))-
      S (((.1*TPR2)**2))-((1./3.47)*(((.1*TPRI)**3.47)-((.1*TPR2)**3.47
      S ))))
C      EQ82
      AKP(2)=(1./((TPRI-TPR2))*(((2.765/2.)*((TPRI**2)-(TPR2**2)))-

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```

S (((TPR1**2.16)-(TPR2**2.16))/2.16))
  G0 T0 672
C   EQ.81
6711 AKP(1)=111.74
C   EQ.84
    AKP(2)=92.25
    G0 T0 672
C   EQ.80
671  AKP(1)=(1./((.1*(TPR1-TPR2)))*((-(((.1*TPR1)**2.708)-((.1*TPR2)
S   **2.708))/2.708)+(0.9551*(((.1*TPR1)**2)-((.1*TPR2)**2))))
C   EQ.83
    AKP(2)=86.+(6.25*(((TPR1+TPR2)/2)-210.)/330.)
C   EQ.85
672  AK34(J)=AKP(MAT)
C   LG10
    IF(TPR2 ) 673, 674, 674
674  IF(TPR2-TLX(MAT)) 675, 675, 676
676  IF(TPR2-540.) 677, 677, 6771
673  G0 T0 2015
678  G0 T0 2016
C   EQ.86
675  AKP(1)=(1./((.1*(TPR2-TCM )))*(((49./2.)*(((.1*TPR2)**2))-
S   ((.1*TCM )**2))-((1./3.47)*(((.1*TPR2)**3.47)-((.1*TCM )**3.47
S   ))))
C   EQ.89
    AKP(2)=(1./((TPR2-TCM )))*(((2.765/2.)*((TPR2**2)-(TCM **2)))-
S   (((TPR2**2.16)-(TCM **2.16))/2.16))
    G0 T0 679
C   EQ.88
6771 AKP(1)=111.74
C   EQ.91
    AKP(2)=92.25
    G0 T0 679
C   EQ.87
677  AKP(1)=(1./((.1*(TPR2-TCM )))*((-(((.1*TPR2)**2.708)-((.1*TCM )
S   **2.708))/2.708)+(0.9551*(((.1*TPR2)**2)-((.1*TCM )**2))))
C   EQ.90
    AKP(2)=86.+(6.25*(((TPR2+TCM )/2)-210.)/330.)
    AKP(2)=86.+(6.25*(((TCM-210.)/330.))
C   EQ.92
679  AK45(J)=AKP(MAT)*0.93061*(((S(J)-DH)/(S(J)-(DH/2.)))
C   EQ.93
    U(J)=1./(((1./H12(J)))+(AL1/AK23(J)))+(AL2/AK34(J)))+(AL3/AK45(J))
    +((1./H56(J)))
C   EQ.94
708  ANS(J)=ANP(J)+1.
    N2=0
    ALE=(ANS(J)*TS)/12.
    TL1=(TA1+TB1)/2.
    TL2=(TA0+TC0)/2.

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```

Y=X/FS
AKL=((X*Y)-(XPR(J)*YPR(J)))+(C-1.)*XPR(J)*BPR)/144.
BA=1./(TL2-TL1)
AKBL=(7.27E-03)*BA*((TL2/1.585)**1.585)-((TL1/1.585)**1.585)
C      EQ.100
      QL(J)=(AKBL*AKL)/ALE
C      LG1
      IF(CH1(J)-(CC2(J)-1.0E-06))901,902,902
902    IF(CH1(J)-(CC2(J)+1.0E-06))903,903,904
C      EQ.101
901    ALAM(J)=QL(J)/(3600.*CH1(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C      TEST7A
      IF(AE(J)-1.)9040,9041,9041
9041   WRITE(12,4)
      GO TO 9999
9040   CONTINUE
      ANTU(J)=(ALOG((1.-(AE(J)*(CH1(J)/CC2(J))))/(1.-AE(J)))/
1      (1.-(CH1(J)/CC2(J))))
      GO TO 7020
C      EQ.107
903    ALAM(J)=QL(J)/(3600.*CH1(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C      TEST7C
      IF(AE(J)-1.)9042,9043,9043
9043   WRITE(12,4)
      GO TO 9999
9042   CONTINUE
      ANTU(J)=AE(J)/(1.-AE(J))
      GO TO 7020
904    ALAM(J)=QL(J)/(3600.*CC2(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C      TEST7B
      IF(AE(J)-1.)9045,9044,9044
9044   WRITE(12,4)
      GO TO 9999
9045   CONTINUE
      ANTU(J)=(ALOG((1.-(AE(J)*(CC2(J)/CH1(J))))/(1.-AE(J)))/
1      (1.-(CC2(J)/CH1(J))))
C      LG14
7020   K4(J)=K4(J)+1
      IF(CH1(J)-(CC2(J)-1.0E-06))701,702,702
702    IF(CH1(J)-(CC2(J)+1.0E-06))703,703,704
C      EQ.110
701    AXTHS(J)=(3600.*ANTU(J)*CH1(J))/U(J)
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINT(ANPC)
      IF((ANPC-ANPC1)-0.5)7011,7012,7012
7012   ANPC=ANPC1+.5

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      GO TO 7013
7011 ANPC=ANPC1+1.
7013 CONTINUE
      GO TO 705
C      EQ.116
703  AXTHS(J)=(3600.*ANTU(J)*CH1(J))/U(J)
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINTE(ANPC)
      IF((ANPC-ANPC1)-0.5) 7031, 7032, 7032
7032 ANPC=ANPC1+1.
      GO TO 7033
7031 ANPC=ANPC1+1.
7033 CONTINUE
      GO TO 705
C      EQ.113
704  AXTHS(J)=(3600.*ANTU(J)*CC2(J))/U(J)
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)
      ANPC1=AINTE(ANPC)
      IF((ANPC-ANPC1)-0.5) 7041, 7042, 7042
7042 ANPC=ANPC1+1.
      GO TO 7043
7041 ANPC=ANPC1+1.
7043 CONTINUE
C      TEST5
705  K5=K5+1
      IF(ANPC-ANP(J)) 706, 707, 707
707  IF(ANPC-(ANP(J)+1.)) 1000, 1000, 706
706  ANP(J)=ANPC
      GO TO 200
C      SIZE & WEIGHT
C      EQ.119
1000 WX(J)=X
      HY(J)=X/FS
      ALL(J)=((ANP(J)*TP)+(ANS(J)*TS))
      XYZ=(X*Y)-(XPR(J)*YPR(J))
      XYB=XPR(J)*BPR*(C-1.)
      XYA=AF1(J)*(RA+1.)*(1.-SIG)
      XYT1=XYZ+XYB+XYA
      XYT2=XYZ+XYB
      CW(J)=(0.098*ANP(J)*TP*XYT1)+(0.078*ANS(J)*TS*XYT2)
      HW(J)=0.196*((X*Y)-(AF1(J)*(RA+1.))+(X*Y/8.))
      TW(J)=CW(J)+HW(J)
      ANF1=YPR1(J)**2
      ANF2=AXP(J)/(ANH*YPR1(J))
      ANF3=H12(J)*ANF2*ANF1
      ANF4=(S(J)-DH)/(S(J)-(DH/2.))
      ANF5=XPR(J)*TP*0.93061*ANF4
      ANF6=3.*ANP(J)*AK23(J)*ANF5

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      ANF7=ANF3/ANF6
C      EQ.125
      ANF(J)=1./(1.+ANF7)
      IF(ANF(J)-.4)1970,1971,1971
1971  IF(ANF(J)-.6)1972,1972,1973
1970  WRITE(12,5)
      GO TO 1972
1973  WRITE(12,6)
1972  CONTINUE
      AV(J)=AXTHS(J)/((WX(J)*HY(J)*ALL(J))/1728.)
      GO TO 9999
2000  WRITE(12,1)THM
2001  WRITE(12,1)PHM
2002  WRITE(12,1)PHM
2003  WRITE(12,1)THM
2007  WRITE(12,1)TCM
2008  WRITE(12,1)TCM
2009  WRITE(12,1)PCM
2010  WRITE(12,1)PCM
2011  WRITE(12,1)THM
2012  WRITE(12,1)THM
2013  WRITE(12,1)TX(J)
2014  WRITE(12,1)TX(J)
2015  WRITE(12,1)TCM
2016  WRITE(12,1)TCM
9999  CONTINUE
      RETURN
      STOP
      END
      END

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SUBROUTINE HX2(J,P0,VA0,TA0,PAI,VAI,TAI,PBI,VBI,TBI,TS,
1 VB0,TB0,XI,ANP1,PA01,TA01,PB01,TB01,CPCM,CPHM)
C TURBINE DESIGN PROGRAM-HELIUM
C CRYOGENIC TURBOMACHINE SYSTEMS WITH JT VALVE----GAS AND
C /OR VAPOR PHASE LOAD
C VERSION 16JULY 1970
  DIMENSION S(8),AN(8),AX1(8),AH1(8),AF1(8)
  DIMENSION XPR(8),YPR(8),ANP(8),DP1(8),ANPR1(8)
  DIMENSION ANPR(8),ANNU1(8),H12(8),ANRE2(8)
  DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
  DIMENSION AK23(8),AK34(8),AK45(8),U(8)
  DIMENSION AXTHS(8),AXP(8),EI(8),ANS(8)
  DIMENSION OL(8),AE(8),WX(8),HY(8),ALL(8)
  DIMENSION CW(8),HW(8),TW(8),ANF(8),AV(8)
  DIMENSION CH1(8),CC2(8),S2(8),AN2(8),AH2(8)
  DIMENSION K1(8),K21(8),K3(8),K4(8)
  DIMENSION ANTU(8),DHT(8),AKWT(8),ANTUI(8),AKP(5),TLX(5)
  DIMENSION XPR1(8),YPR1(8),YPR2(8),YPR3(8)
  DIMENSION ALAM(8),TX(8)
  COMMON S,AN,AX1,AH1,AF1,XPR,YPR,ANP,DP1,ANPR1,ANPR
  COMMON ANNU1,H12,ANRE2,DP2,ANPR2,ANNU2,H56,AK23,AK34
  COMMON AK45,U,AXTHS,AXP,EI,ANS,OL,AE,WX,HY,ALL,CW,HW,TW
  COMMON ANF,AV,CH1,CC2,S2,AN2,AH2,K1,K21,K3,K4
  COMMON T14,P14,VB14,H14,S14,W1
  COMMON T15,P15,VB15,H15,S15
  COMMON T16,P16,VB16,H16,S16
  COMMON DH,TP,SIG,ANRE1,C,FS,RF,ANTU,TS
  COMMON ANT1,DH2,SIG1,SIG2,W2,WT1
  COMMON DHT,AKWT,ANTUI,MAT,TLX
  COMMON BX,BY,ANH,ANC
  COMMON XPR1,YPR1,YPR2,YPR3
  COMMON ALAM,TX,BPR,RA
1  FORMAT(1X,10HERROR STOP,2X,F15.8)
2  FORMAT(1X,4(F15.8,2X))
3  FORMAT(1X,11HINCREASE RA)
4  FORMAT(1X,39HREDUCE BORDER DIMENSIONS OR INCREASE TS)
5  FORMAT(1X,11HINCREASE FS)
6  FORMAT(1X,9HREDUCE FS)
7  FORMAT(1X,15HXI IS TOO LARGE)
  I2=1
C  INITIAL VALUES
  KT1=0
C*****INITIAL VALUE OF X IS CALCULATED NEXT***
  X=FS*(((C-1.)*BPR)+ANH+(2*BY))
  XI=X
  PB0=PB01
  TB0=TB01
  TA0=TA01
  ANP(J)=ANP1
  K1(J)=0

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```

K2=0
K3(J)=0
K4(J)=0
K5=0
  K21(J)=0
  K31=0
N1=0
N2=0
  N3=0
  N4=0
  NN3=0
PI=3.14159
E=2.718282
C  HOT SIDE
C  EQ.1*
  S(J)= SQRT(0.906694*((DH**2)/SIG))
  AN(J)=(4.*SIG)/(PI*(DH**2))
  AX1(J)=(AN(J)*PI*DH*TP)+(2.*(1.-SIG))
  EQ.4
200  ANP(J)=ANP(J)
3000  TAB=TAB
42  PA0=PA0
  K1(J)=0
C  LG1
  IF(TAB-40.)50,50,60
C  EQ.7
50  VBA0=(2.765/E**((0.03*((PA0**0.333333)/(TAB/40.))))*(TAB/PA0)
  GO TO 61
C  EQ.8
60  VBA0=2.863092*(TAB/PA0)
61  CONTINUE
C  EQ.9
  UA0=(2.37888E-07)*(TAB**0.643)
  VA0=(12.*ANRE1*VBA0*UA0)/DH
  AH1(J)=(134.*W1*VBA0)/VA0
  AF1(J)=AH1(J)/SIG
C  EQ.13, ASSUME X
100  X=X
  XPR(J)=X-(2.*BX)
  YPR(J)=(X/FS)-(2.*BY)
C  EQ.16
  YPRI(J)=(YPR(J)-((C-1.)*BPR)-ANH)/(2.*(C-1.))
  AF1C=ANH*(XPR(J)*YPRI(J))
  K1(J)=K1(J)+1
C  TEST1
  IF(AF1C-(AF1(J)+0.001))101,101,10101
101  IF(AF1C-(AF1(J)-0.001))10100,150,150
10101 IF(K1(J)-1)2000,10111,10102
10111 X=X/1.5
  K1(J)=0

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      GO TO 100
10100 IF(KT1-4)10105,10104,10104
10105 IF(K1(J)-1)2000,10115,10116
10115 T1XA=X
      T1YA=AF1C
      T1ZA=AF1(J)
10116 X=1.5*X
      GO TO 100
10102 IF(KT1-4)10106,10104,10104
10106 T1XB=X
      T1YB=AF1C
      T1ZB=AF1(J)
      KT1=3
10104 CALL ITERA(T1XA,T1XB,T1YA,T1YB,T1ZA,T1ZB,T1DYA1,T1DYA2,
1 T1DYB3,T1DYB4,T1DY1,X,AF1C,AF1(J),KT1)
      KT1=KT1+1
      GO TO 100
C      EQ.18
150 YPR2(J)=YPR1(J)*(RA/2.)
      YPR3(J)=YPR1(J)*RA
      AL1=YPR1(J)/24.
      KT1=0
      K1(J)=1
      AL2=BPR/12.
      AL3=YPR3(J)/(12.*RA)
C      HOT SIDE PRESSURE DROP
      DP1A=(VA0**2)/VBA0
      DP1P=370.0E-06*DP1A*SQRT((TP/DH)/ANRE1)
      DP1(J)=ANP(J)*DP1P
C      EQ.25
      PA0C=PA1+DP1(J)
C      GET CH1
C      TEST2
474 IF(PA0C-(PA0-1.0E-03))476,477,477
477 IF(PA0C-(PA0+1.0E-03))478,478,476
476 IF(NN3-5)4761,4762,4763
4762 PA0A=PA0
      PA0CA=PA0C
      PA0ZA=PA0
      GO TO 4761
4763 IF(NN3-6)4765,4765,4766
4765 PA0B=PA0
      PA0CB=PA0C
      PA0ZB=PA0
4766 K31=NN3-3
      CALL ITERA(PA0A,PA0B,PA0CA,PA0CB,PA0ZA,PA0ZB,T3DYA1,T3DYA2,
1 T3DYB3,T3DYB4,T3DY1,PA0,PA0C,PA0,K31)
      GO TO 42
4761 PA0 =PA0C
      GO TO 42

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```

478 CALL CPSUB(TA0,PA0,CP)
C EQ.36
3500 CP12=CP
CALL CPSUB(I01,P01,CP)
7500 CP17=CP
NN3=0
CPB=(CP12+CP17)/2.
GAMB=1./(1.-(.49(447487/CPB)))
C EQ.30
T17T12=1.-ANT1+(1.-(P01/PA0))*((GAMB-1.)/GAMB)
TA0C=T01/(T17T12)
C TEST3
K2=K2+1
2862 IF(TA0C-(TA0+0.001))2863,2863,2861
2863 IF(TA0C-(TA0-0.001))2861,2863,2861
2861 IF(K2-2)2861,2861,2862
281 TAGA=TA0
T2YA=TA0C
T2ZA=TA0
GO TO 2881
2882 IF(K2-6)287,287,2883
287 TA0B=TA0
T2YB=TA0C
T2ZB=TA0
2883 KM=K2-3
CALL ITERA(TAGA,TA0B,T2YA,T2YB,T2ZA,T2ZB,T20YA1,T20YA2,
1 T20YB3,T20YB4,T2DY1,TA0,TA0C,TAG,KM)
IF(TA0)2000,3000,3000
2881 TAG=TA0C
GO TO 3000
C EQ.32
283 CONTINUE
UM1=(8.55497E-04/(TA0-TA1))*(((TA0**1.643)-(TA1**1.643))/1.643)
AKM1=((57.79E-03)/(.00355*(TA0-TA1)))*(((.00355*TA0)**1.642)
1 -((.00355*TA1)**1.642))/1.642)
THM=(AKM1/57.79E-03)**1./1.642)/.00355
PHM=(PA0+PA1)/2.
K2=0
CALL CPSUB(THM,PHM,CP)
350 CPHM=CP
C EQ.35
CH1(J)=W1*CPHM
ANPR1(J)=(CPHM*UM1)/AKM1
ANNU1(J)=3.66+(((0.104)/((TP/DH)/(ANRE1*ANPR1(J))))/(1.+((0.016)
1 /(((TP/DH)/(ANRE1*ANPR1(J)))*0.8))))
HI2(J)=(12.*ANNU1(J)*AKM1)/DH
C COLD SIOE
C EQ.41
4000 TB0=TB0
C EQ.42

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400  PB0=PB0
C    LG2
      IF(TB0-40.) 441, 441, 442
441  VBB0=(2.765/(E*(0.03*((PB0**0.333333)/(TB0/40.))))*(TE0/PB0)
      GO TO 443
442  VBB0=2.863092*(TB0/PB0)
443  UB0=(2.88E-07)*(TB0**0.643)
      AH2(J)=AH1(J)*RA
      VB0=(144.*W2*VBB0)/AH2(J)
      ANRE2(J)=(VB0*DH)/(12.*VBB0*UB0)
      DPM=(VB0**2)/VBB0
      DP2P=370.0E-06*DPM*SQRT((TP/DH)/ANRE2(J))
      DP2(J)=ANP(J)*DP2P
      PB0C=PBI-DP2(J)
      K32=K32+1
C    TEST4
4862  IF(PB0C-(PB0-0.001)) 4863, 4863, 4861
4863  IF(PB0C-(PB0-0.001)) 4861, 4863, 4861
4861  IF(K32-2) 4881, 4881, 4882
481   PB0A=PB0
      PB0YA=PB0C
      PB0ZA=PB0
      GO TO 4881
4882  IF(K32-6) 487, 487, 4883
487   PB0B=PB0
      PB0YB=PB0C
      PB0ZB=PB0
4883  KM1=K32-3
      CALL ITERA(PB0A, PB0B, PB0YA, PB0YB, PB0ZA, PB0ZB, PB0DYA1, PB0DYA2,
1      PB0DYB3, PB0DYB4, PB0DYI, PB0, PB0C, PB0, KM1)
      IF(PB0) 2000, 400, 400
4881  PB0=PB0C
      GO TO 400
C    EQ. 52
C    TEST5
483   IF(PB0C-10.) 4831, 4832, 4832
4831  WRITE(12,3)
      GO TO 9999
4832  CONTINUE
      UM2=((8.55497E-04)/(TB0-TB1))*(((TB0**1.643)-(TB1**1.643))/1.643)
      AKM2=((57.79E-03)/(.00355*(TB0-TB1))*(((.00355*TB0)**1.642)-
1      ((.00355*TB1)**1.642))/1.642)
      TCM=((AKM2/57.79E-03)**1./1.642)/.00355
      PCM=(PBI+PB0)/2.
      K31=K31+K32
      K32=0
      CALL CP5UB(TCM, PCM, CP)
550  CP5CM=CP
C    EQ. 54
      CC2(J)=W2*CP5CM

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5570 IF(K=0.0-5000)5570,5570,9999
      CONTINUE
      ANPR2(J)=(CPCCH*LM2)/AKM2
      ANNU2(J)=3.66+(((0.104)/(TP/DH)/(ANRE2(J)*ANPR2(J)))
1      /(1.+(0.016)/(((TP/DH)/(ANRE2(J)*ANPR2(J))*0.8))))
      H.3(J)=(12.*ANNU2(J)*AKM2)/DH
C      L63
      K4(J)=K4(J)+1
      IF(CH1(J)-(CC2(J)-1.0E-06))556,557,557
557 IF(CH1(J)-(CC2(J)+1.0E-06))560,560,558
C      EQ.56
556 TB0C=1.1+((TA0-TAI)/(CC2(J)/CH1(J)))
      GO TO 5750
C      EQ.62
560 TB0C=TA0-(TAI-TBI)
      GO TO 5750
C      EQ.59
556 TB0C=TBI+((TA0-TAI)/(CH1(J)/CC2(J)))
5750 N4=N4+1
C      TEST6
575 IF(TB0C-(TB0-1.0E-03))576,577,577
577 IF(TB0C-(TB0+1.0E-03))578,578,576
576 IF(N4-5)5761,5762,5763
5762 TB0A=TB0
      TB0CA=TB0C
      TB0ZA=TB0

      GO TO 5761
5763 IF(N4-6)5765,5765,5766
5765 TB0B=TB0
      TB0CB=TB0C
      TB0ZB=TB0
5766 K41=N4-3
      CALL ITERA(TB0A,TB0B,TB0CA,TB0CB,TB0ZA,TB0ZB,T3DYA1,T3DYA2,
1      T3DYB3,T3DYB4,T3DY1,TB0,TB0C,TB0,K41)
      GO TO 4000
5761 TB0=TB0C
      GO TO 4000
578 IF(CH1(J)-(CC2(J)-1.0E-06))5781,5782,5782
5782 IF(CH1(J)-(CC2(J)+1.0E-06))5783,5783,5784
C      EQ.63
5783 ANTUI(J)=((TA0-TAI)/(TA0-TBI))/(1.-((TA0-TAI)/(TA0-TBI)))
      EI(J)=ANTUI(J)/(1.+ANTUI(J))
      GO TO 5785
C      EQ.57
5781 ANTUI(J)=ALOG((TA0-TB0)/(TA1-TBI))/(1.-((CH1(J)/CC2(J)))
      EIA=CH1(J)/CC2(J)
      EI(J)=(1.-(E**(-ANTUI(J)*(1.-EIA))))
1      /(1.-(EIA*(E**(-ANTUI(J)*(1.-EIA)))))
      GO TO 5785

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C      EQ.60
5784  ANTU1(J)=ALOG((TA0-TB0)/(TA1-TB1))/(1.-(CC2(J)/CH1(J)))
      E1A=CC2(J)/CH1(J)
      E1(J)=(1.-(E**(-ANTU(J)*(1.-E1A))))
1     /(1.-(E1A*(E**(-ANTU(J)*(1.-E1A))))))
C      EQ.65
5785  CONTINUE
      N1=0
      N2=0
      N3=0
      N4=0
      T1PR=THM- ((YPR1(J)/(YPR1(J)+YPR2(J)+YPR3(J)))*(THM-TCM))
      T2PR=THM- (((YPR1(J)+YPR2(J))/(YPR1(J)+YPR2(J)+YPR3(J)))*
1 (THM-TCM))
C      GET PLATE THERMAL CONDUCTIVITIES
C      LG4
      IF(THM      )601,602,602
602    IF(THM-TLX(MAT))666,666,604
604    IF(THM-540.)667,667,6671
601    GO TO 2011
605    GO TO 2012
C      EQ.70
666    AKP(1)=(1./(1.*(THM-T1PR)))*(((49./2.)*(((.1*THM)**2)-
1 ((.1*T1PR)**2)))-((1./3.47)*(((.1*THM)**3.47)-((.1*T1PR)**3.47
2 ))))
C      EQ.73
      AKP(2)=(1./(THM-T1PR))*(((2.765/2.)*((THM**2)-(T1PR)**2
1 )))-(((THM**2.16)-(T1PR**2.16))/2.16))
      GO TO 668
C      EQ.72
6671   AKP(1)=111.74
C      EQ.75
      AKP(2)=92.25
      GO TO 668
C      EQ.71
667.   AKP(1)=(1./(1.*(THM-T1PR)))*(- (((.1*THM)**2.708)-
1 ((.1*T1PR)**2.708))/2.708)+(9.551*(((.1*THM)**2)-((.1*
2 T1PR)**2))))
C      EQ.74
      AKP(2)=86.+(6.25*(((THM+T1PR)/2.)-210.)/330.)
C      EQ.76
668    AK23(J)=AKP(MAT)*0.93061*((S(J)-DH)/(S(J)-(DH/2.)))
      TX(J)=(THM+TCM)/2.
C      LG7
      IF(TX(J)      )660,661,661
661    IF(TX(J)-TLX(MAT))670,670,662
662    IF(TX(J)-540.)671,671,6711
660    GO TO 2013
663    GO TO 2014
C      EQ.78

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670      AKP(1)=(1./(1.+(T1PR-T2PR)))*((49./2.)*(((.1*T1PR)**2)-
1      ((.1*T2PR)**2)))-((1./3.47)*(((.1*T1PR)**3.47)-((.1*T2PR)**2.47
2      )))
C      EQ.81
          AKP(2)=(1./(T1PR-T2PR))*((2.765/2.)*((T1PR**2)-((T2PR)**2
1      )))-(((T1PR**2.16)-(T2PR**2.16))/2.16))
          GO TO 672
C      EQ.80
6711     AKP(1)=111.74
C      EQ.53
          AKP(2)=92.25
          GO TO 672
C      EQ.79
671      AKP(1)=(1./(1.*(T1PR-T2PR)))*(- (((.1*T1PR)**2.708)-
1      ((.1*T2PR)**2.708))/2.708)+(9.551*(((.1*T1PR)**2)-((.1*
2      T2PR)**2)))
C      EQ.82
          AKP(2)=86.+(6.25*(((T1PR+T2PR)/2.)-210.)/330.)
C      EQ.84
672      AK34(J)=AKP(MAT)
C      LG10
          IF(TCM )673,674,674
674      IF(TCM-TLX(MAT))675,675,676
676      IF(TCM-540.)677,677,6771
673      GO TO 2015
678      GO TO 2016
C      EQ.85
675      AKP(1)=(1./(1.*(T2PR-TCM)))*(((49./2.)*(((.1*T2PR)**2)-
1      ((.1*TCM)**2)))-((1./3.47)*(((.1*T2PR)**3.47)-((.1*TCM)**3.47
2      )))
C      EQ.88
          AKP(2)=(1./(T2PR-TCM))*((2.765/2.)*((T2PR**2)-((TCM)**2
1      )))-(((T2PR**2.16)-(TCM**2.16))/2.16))
          GO TO 679
C      EQ.87
6771     AKP(1)=111.74
C      EQ.90
          AKP(2)=92.25
          GO TO 679
C      EQ.86
677      AKP(1)=(1./(1.*(T2PR-TCM)))*(- (((.1*T2PR)**2.708)-
1      ((.1*TCM)**2.708))/2.708)+(9.551*(((.1*T2PR)**2)-((.1*
2      TCM)**2)))
C      EQ.89
          AKP(2)=86.+(6.25*(((T2PR+TCM )/2.)-210.)/330.)
C      EQ.91
679      AK45(J)=AKP(MAT)*0.93061*((S(J)-DH )/(S(J)-(DH /2.)))
C      EQ.92
          U(J)=1./(((1./H12(J)))+(AL1/AK23(J)))+(AL2/AK34(J)))+(AL3/AK45(J))
1          +(1./H56(J)))

```

```

C      GET ENDWISE HEAT LEAKAGE
C      EQ.93
      ANS(J)=ANP(J)+1.
      N2=0
      ALE=(ANS(J)*TS)/12.
      TL1=(TA1+TB1)/2.
      TL2=(TA0+TB0)/2.
      AKL=((X*(X/FS))-(XPR(J)*YPR(J)))+(C-1.)*XPR(J)*BPR)/144.
      BA=1./(TL2-TL1)
      AKBL=(7.27E-03)*BA*(((TL2)**1.585)-((TL1)**1.585))/1.585)
C      EQ.99
      QL(J)=(AKBL*AKL)/ALE
C      LG13
      IF(CH1(J)-(CC2(J)-1.0E-06))901,902,902
902    IF(CH1(J)-(CC2(J)+1.0E-06))903,903,904
C      EQ.100
901    ALAM(J)=QL(J)/(3600.*CH1(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C      TEST 7A
      IF(AE(J)-1.)9001,9002,9002
9002    WRITE(12,4)
      GO TO 9999
9001    CONTINUE
      ANTU(J)=(ALOG((1.-(AE(J)*(CH1(J)/CC2(J))))/(1.-AE(J)))/
1      (1.-(CH1(J)/CC2(J))))
      GO TO 70200
C      EQ.106
903    ALAM(J)=QL(J)/(3600.*CH1(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C      TEST7C
      IF(AE(J)-1.0)9003,9002,9002
9003    CONTINUE
      ANTU(J)=AE(J)/(1.-AE(J))
      GO TO 70200
C      EQ.103
904    ALAM(J)=QL(J)/(3600.*CC2(J))
      AE(J)=EI(J)/(1.-ALAM(J))
C      TEST7B
      IF(AE(J)-1.)9004,9002,9002
9004    CONTINUE
      ANTU(J)=(ALOG((1.-(AE(J)*(CC2(J)/CH1(J))))/(1.-AE(J)))/
1      (1.-(CC2(J)/CH1(J))))
C      LG14
70200  K5(J)=K5(J)+1
      IF(CH1(J)-(CC2(J)-1.0E-06))701,702,702
702    IF(CH1(J)-(CC2(J)+1.0E-06))703,703,704
C      EQ.109
701    AXTHS(J)=(ANTU(J)*CH1(J))/U(J))*3600.
      AXP(J)=AX1(J)*AF1(J)
      ANPC=(144.*AXTHS(J))/AXP(J)

```

```

ANPC1=ANPC1+1
IF (ANPC-ANPC1)-0.5) 7011, 7012, 7012
7012 ANPC=ANPC1+1.
GO TO 7013
7011 ANPC=ANPC1+1.
7013 CONTINUE
GO TO 705
C EQ.115
703 AXTHS(J)=(ANTU(J)*CH1(J))/U(J))*3600.
AXP(J)=AX1(J)*AF1(J)
ANPC=(144.*AXTHS(J))/AXP(J)
ANPC1=AINT(ANPC)
IF((ANPC-ANPC1)-0.5) 7031, 7032, 7032
7032 ANPC=ANPC1+1.
GO TO 7033
7031 ANPC=ANPC1+1.
7033 CONTINUE
GO TO 705
C EQ.112
704 AXTHS(J)=(ANTU(J)*CC2(J))/U(J))*3600.
AXP(J)=AX1(J)*AF1(J)
ANPC=(144.*AXTHS(J))/AXP(J)
ANPC1=AINT(ANPC)
IF((ANPC-ANPC1)-0.5) 7041, 7042, 7042
7042 ANPC=ANPC1+1.
GO TO 7043
7041 ANPC=ANPC1+1.
7043 CONTINUE
C TEST8
705 IF(ANPC-ANP(J)) 706, 707, 707
707 IF(ANPC-(ANP(J)+1.)) 1000, 1000, 706
706 ANP(J)=ANPC
GO TO 200
C SIZE & WEIGHT
C EQ.113
1000 WX(J)=X
HY(J)=X/FS
ALL(J)=((ANP(J)*TP)+(ANS(J)*TS))
XYZ=(X*(X/FS))-(XPR(J)*YPR(J))
XYB=XPR(J)*BPR*(C-1.)
XYA=AF1(J)*(RA+1.)*(1.-SIG)
C(J)=10.098*ANP(J)*TP*(XYZ+XYB+XYA)+(0.073*ANS(J)*TS*(XYZ+XYB)
HE(J)=0.196*((X*HY(J))-((RA+1.)*AF1(J))+((X*HY(J))/8.))
TE(J)=CE(J)+HE(J)
ANF1=YPR1(J)**2
ANF2=AXP(J)/(ANH*YPR1(J))
ANF3=H12(J)*ANF2*ANF1
ANF4=(S(J)-DH)/(S(J)-(DH/2.))
ANF5=XPR(J)*TP*0.93061*ANF4
ANF6=3.*ANP(J)*AK23(J)*ANF5

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      ANF7=ANF3/ANF6
      ANF(J)= 1./(1.+ANF7)
C      TEST9
      IF(ANF(J)-.4) 7001, 7002, 7002
7002   IF(ANF(J)-.6) 7003, 7003, 7004
7001   WRITE(12,5)
      GO TO 7003
7004   WRITE(12,6)
7003   CONTINUE
      AV(J)=AXTHS(J)/((WX(J)*HY(J)*ALL(J))/1728.)
C      TURBINE 1 OUTPUT
      DHT(J)=CPB*TA0*ANT1*(1.-((PBI/PA0)**((GAMB-1.)/GAMB)))
      GO TO 9999
2000   WRITE(12,1)THM
2001   WRITE(12,1)PHM
2002   WRITE(12,1)PHM
2003   WRITE(12,1)THM
2007   WRITE(12,1)TCM
2008   WRITE(12,1)TCM
2009   WRITE(12,1)PCM
2010   WRITE(12,1)PCM
2011   WRITE(12,1)THM
2012   WRITE(12,1)THM
2013   WRITE(12,1)TX(J)
2014   WRITE(12,1)TX(J)
2015   WRITE(12,1)TCM
2016   WRITE(12,1)TCM
9999   CONTINUE
      RETURN
      STOP
      END
      END

```

```

SUBROUTINE ITERA(XA,XB,YA,YB,ZA,ZB,DYA1,DYA2,DYB3,DYB4,DYI,YI,ZI,
&ZI,N)
C
C PRO  RAM REQUIRES INPUTS(FROM MAIN) --XA,XB,YA,YB,ZA,ZB,YI,ZI
C AND  OUTPUTS(To MAIN)--XI
      IF(N-4)10,20,100
10    CALL ITER1(XA,XB,YA,YB,ZA,ZB,XI,DYA1,DYA2,DYB3,DYB4)
      N=N+1
      RETURN
20    CALL ITER2(XA,XB,YA,YB,ZA,ZB,XI,DYI,DYA1,DYA2,DYB3,DYB4,YI,ZI,N)
      N=N+1
      RETURN
100   CONTINUE
      CALL ITER3(XA,XB,YA,YB,ZA,ZB,XI,DYI,DYA1,DYA2,DYB3,DYB4,YI,ZI,N)
      N=N+1
      RETURN
      END
      END
      SUBROUTINE ITER1(XA,XB,YA,YB,ZA,ZB,XI,DYA1,DYA2,DYB3,DYB4)
      DYA1=ZA-YA
      DYA2=YA-ZA
      DYB3=ZB-YB
      DYB4=YB-ZB
C      WRITE(D,2)DYA1,DYA2,DYB3,DYB4
2      FORMAT(1X,4F15.7)
      IF(YA-ZA)99,99,100
99     XI=XA+((DYA1/(DYA1+DYB4))*(XB-XA))
C      WRITE(D,2)XI
      RETURN
100    XI=XA+((DYA2/(DYA2+DYB3))*(XB-XA))
C      WRITE(D,2)XI
      RETURN
      END
      END
      SUBROUTINE ITER2(XA,XB,YA,YB,ZA,ZB,XI,DYI,DYA1,DYA2,DYB3,DYB4,
&YI,ZI,N)
      XIA=XI
      IF(YA-ZA)99,99,100
99     DYI=ZI-YI
C      WRITE(D,1)DYI
1      FORMAT(1X,2F15.7)
      IF(DYI)200,200,300
100    DYI=YI-ZI
      IF(DYI)400,400,500
200    XI=XB-((DYB4/(DYB4+DYA1))*(XB-XA))
C      WRITE(D,1)XI
      RETURN
300    RETURN
400    XI=XB-((DYB3/(DYB3+DYA2))*(XB-XA))
      RETURN

```

```

500  RETURN
      ENO
      END
      SUBROUTINE ITER3(XA,XB,YA,YB,ZA,ZB,XI,DYI,OYA1,DYA2,DYB3,OYB4,
&YI,ZI,N)
      IF(YA-ZA)99,99,100
99    DYI=ZI-YI
      C  WRITE(0,1)DYI
      I  FORMAT(1X,2F15.7)
      IF(DYI)200,200,300
100   DYI=YI-ZI
      C  WRITE(0,1)OYI
      IF(DYI)400,400,500
200   XIA=XI
      DYI= ABS(DYI)
      XI=XIA-((DYI/(DYI+DYA1))*(XIA-XA))
      C  WRITE(0,1)XIA,XI
      C  WRITE(0,1)DYI,OYA1
      RETURN
300   XIA=XI
      DYI= ABS(DYI)
      XI=XIA+((DYI/(OYI+OYB4))*(XB-XIA))
      RETURN
400   XIA=XI
      DYI= ABS(DYI)
      XI=XI-((DYI/(DYI+DYA2))*(XIA-XA))
      RETURN
500   XIA=XI
      DYI= ABS(OYI)
      XI=XIA+((DYI/(DYI+DYB3))*(XB-XIA))
      RETURN
      END
      END

```

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EZ F READ(SMAINS)100
+

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SUBROUTINE OUTPUT(J)
C
VERSION 20 JULY 1970
DIMENSION S(8),AN(8),AX1(8),AH1(8),AF1(8)
DIMENSION XPR(8),YPR(8),ANP(8),DP1(8),ANPR1(8)
DIMENSION ANPR(8),ANNUI(8),H12(8),ANRE2(8)
DIMENSION DP2(8),ANPR2(8),ANNU2(8),H56(8)
DIMENSION AK23(8),AK34(8),AK45(8),U(8)
DIMENSION AXTHS(8),AXP(8),EI(8),ANS(8)
DIMENSION OL(8),AE(8),WX(8),HY(8),ALL(8)
DIMENSION CW(8),HW(8),TW(8),ANF(8),AV(8)
DIMENSION CH1(8),CC2(8),S2(8),AN2(8),AH2(8)
DIMENSION K1(8),K21(8),K3(8),K4(8)
DIMENSION ANTU(8),DHT(8),AKWT(8),ANTUI(8),AKP(8),TLX(8)
DIMENSION XPR1(8),YPR1(8),YPR2(8),YPR3(8)
DIMENSION ALAM(8),TX(8)
COMMON S,AN,AX1,AH1,AF1,XPR,YPR,ANP,DP1,ANPR1,ANPR
COMMON ANNUI,H12,ANRE2,DP2,ANPR2,ANNU2,H56,AK23,AK34
COMMON AK45,U,AXTHS,AXP,EI,ANS,OL,AE,WX,HY,ALL,CW,HW,TW
COMMON ANF,AV,CH1,CC2,S2,AN2,AH2,K1,K21,K3,K4
COMMON T14,P14,VB14,H14,S14,W1
COMMON T15,P15,VB15,H15,S15
COMMON T16,P16,VB16,H16,S16
COMMON DH,TP,S1G,ANRE1,C,FS,RF,ANTU,TS
COMMON ANT1,DH2,SIG1,SIG2,W2,WT1
COMMON DHT,AKWT,ANTUI,MAT,TLX
COMMON BX,BY,ANH,ANC
COMMON XPR1,YPR1,YPR2,YPR3
COMMON ALAM,TX
35  FORMAT(1X,8HWIDTH X=F15.8,2X,6HINCHES)
36  FORMAT(1X,9HHEIGHT Y=F15.8,2X,6HINCHES)
37  FORMAT(1X,9HLENGTH L=F15.8,2X,6HINCHES)
38  FORMAT(1X,12HCORE WEIGHT=F15.8,2X,3HLBS)
39  FORMAT(1X,14HHEADER WEIGHT=F15.8,2X,3HLBS)
40  FORMAT(1X,13HTOTAL WEIGHT=F15.8,2X,3HLBS)
41  FORMAT(1X,4H NF=F15.8)
42  FORMAT(1X,4H AV=F15.8)
43  FORMAT(1X,3H S=F15.8,3X,4H N=F15.8,3X,5H AF1=F15.8)
44  FORMAT(1X,5H XPR=F15.8,3X,5H YPR=F15.8,3X,5H ANP=F15.8)
45  FORMAT(1X,5H DP1=F15.8)
46  FORMAT(1X,5H CH1=F15.8,3X,6H NPR1=F15.8,6H NNU1=F15.8)
47  FORMAT(1X,5H H12=F15.8)
48  FORMAT(1X,6H NRE2=F15.8,3X,5H DP2=F15.8)
49  FORMAT(1X,5H CC2=F15.8,3X,6H NPR2=F15.8,3X,6H NNU2=F15.8)
50  FORMAT(1X,5H H56=F15.8,3X,5H K23=F15.8,3X,5H K34=F15.8)
51  FORMAT(1X,5H K45=F15.8,3X,3H U=F15.8,3X,7H AXTHS=F15.8)
52  FORMAT(1X,5H AXP=F15.8,3X,4H EI=F15.8,3X,4H NS=F15.8)
53  FORMAT(1X,4H OL=F15.8,3X,3H E=F15.8)
54  FORMAT(1X,7I10)
55  FORMAT(1X,5H NTU=F15.8,3X,6H NTUI=F15.8)
56  FORMAT(1X,5H AX1=F15.8,3X,5H AH1=F15.8,3X,5H AH2=F15.8)

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57   FORMAT(1X, 4H S2=F15.8, 3X, 5H AN2=F15.8)
58   FORMAT(1X, 5H DHT=F15.8, 3X, 5H KWT=F15.8)
59   FORMAT(1X, 6H ALAM=F15.8, 3X, 4H TX=F15.8)
60   FORMAT(1X, 6H YPR1=F15.8, 3X, 6H YPR2=F15.8)
61   FORMAT(1X, 6H YPR3=F15.8)
    WRITE(12, 35) WX(J)
    WRITE(12, 36) HY(J)
    WRITE(12, 37) ALL(J)
    WRITE(12, 38) CW(J)
    WRITE(12, 39) HW(J)
    WRITE(12, 40) TW(J)
    WRITE(12, 55) ANTU(J), ANTUI(J)
    WRITE(12, 41) ANF(J)
    WRITE(12, 42) AV(J)
    WRITE(12, 43) S(J), AN(J), AF1(J)
    WRITE(12, 44) XPR(J), YPR(J), ANP(J)
    WRITE(12, 45) DP1(J)
    WRITE(12, 46) CH1(J), ANPR1(J), ANNU1(J)
    WRITE(12, 47) H12(J)
    WRITE(12, 48) ANRE2(J), DP2(J)
    WRITE(12, 49) CC2(J), ANPR2(J), ANNU2(J)
    WRITE(12, 50) H56(J), AK23(J), AK34(J)
    WRITE(12, 51) AK45(J), U(J), AXTHS(J)
    WRITE(12, 52) AXP(J), EI(J), ANS(J)
    WRITE(12, 53) QL(J), AE(J)
    WRITE(12, 56) AX1(J), AH1(J), AH2(J)
    WRITE(12, 57) S2(J), AN2(J)
    WRITE(12, 58) DHT(J), AKWT(J)
    WRITE(12, 59) ALAM(J), TX(J)
    WRITE(12, 60) YPR1(J), YPR2(J)
    WRITE(12, 61) YPR3(J)
    WRITE(12, 54) K1(J), K21(J), K3(J), K4(J)
    RETURN
    END

```

```

      SUBROUTINE CP5UBC(Y,ZCP,
      DIMENSION IP(24),IT(14),CP(24,14)
      OPEN(5,INPUT,/'CPDAT/')
1      FORMAT(8I7)
      N=1
      NA=6
      I3=5
      I2=1
      DO 10 KIP=1,3
      READ(I3,1)(IP(MIP),MIP=N,NA)
      N=NA+1
      NA=NA+8
10     CONTINUE
2      FORMAT(7I7)
      N=1
      NA=7
      DO 11 KIP=1,2
      READ(I3,2)(IT(MIP),MIP=N,NA)
      N=NA+1
      NA=NA+7
11     CONTINUE
3      FORMAT(11F6.3)
      DO 12 KCP=1,23
12     READ(I3,3)(CP(KCP,KCT),KCT=3,13)
      CP(1,1)=1.906
      DO 13 KCP=6,23
13     READ(I3,3)CP(KCP,2)
      IXT=IFIX(1000.*XT)
      IYP=IFIX(1000.*YP)
      IF(XT-9.468)100,101,102
101    DO 103 K=1,23
      IF(IP(K)-IYP)200,201,201
200    IF(K-23)103,202,202
103    CONTINUE
201    KB=K
      KA=K-1
      IF(KA)210,211,212
211    ZCP=CP(1,3)
      GO TO 900
212    DPB=FLOAT(IP(KB)-IP(KA))
      DPP=FLOAT(IYP-IP(KA))
      DCP=CP(KB,3)-CP(KA,3)
      ZCP=(DCP*(DPP/DPB))*CP(KA,3)
      GO TO 900
102    DO 300 LT=3,13
      IF(IT(LT)-IXT)301,302,302
301    IF(LT-13)300,303,303
300    CONTINUE
302    LTB=LT
      LTA=LT-1

```

```

DTB=FLOAT(IT(LTB)-IT(LTA))
DTT=FLOAT(IXT-IT(LTA))
400 D0401 LP=1,23
    IF(IP(LP)-IYP) 402, 403, 403
402 IF(LP-23) 401, 404, 404
401 CONTINUE
403 LPB=LP
    LPA=LP-1
    IF(LPA) 410, 411, 412
411 DCPTB=CP(LPB,LTB)-CP(LPB,LTA)
    ZCP=(DCPTB*(DTT/DTB))+CP(LPB,LTA)
    GO TO 900
412 DPB=FLOAT(IP(LPB)-IP(LPA))
    DPP=FLOAT(IYP-IP(LPA))
    DCPTA=CP(LPA,LTB)-CP(LPA,LTA)
    DCPTB=CP(LPB,LTB)-CP(LPB,LTA)
    ZCPTA=(DCPTA*(DTT/DTB))+CP(LPA,LTA)
    ZCPTB=(DCPTB*(DTT/DTB))+CP(LPB,LTA)
    DCP=ZCPTB-ZCPTA
    ZCP=(DCP*(DPP/DPB))+ZCPTA
    GO TO 900
100 IF(YP-40.) 500, 501, 501
501 D0503 LP=6,23
    IF(IP(LP)-IYP) 504, 505, 505
504 IF(LP-23) 503, 506, 506
503 CONTINUE
505 LPB=LP
    LPA=LP-1
    IF(LP-6) 510, 511, 517
511 DTB=FLOAT(IT(3)-IT(2))
    DTT=FLOAT(IXT-IT(2))
    IF(DTT) 515, 516, 517
516 ZCP=CP(6,2)
    GO TO 900
517 DPB=FLOAT(IP(LPB)-IP(LPA))
    DPP=FLOAT(IYP-IP(LPA))
    DCPTA=CP(LPA,3)-CP(LPA,2)
    DCPTB=CP(LPB,3)-CP(LPA,2)
    DTB=FLOAT(IT(3)-IT(2))
    DTT=FLOAT(IXT-IT(2))
    ZCPTA=(DCPTA*(DTT/DTB))+CP(LPA,2)
    ZCPTB=(DCPTB*(DTT/DTB))+CP(LPB,2)
    DCP=ZCPTB-ZCPTA
    ZCP=(DCP*(DPP/DPB))+ZCPTA
    GO TO 900
500 YP1=((30./1.106)*XT)-177.
    IYP1=FIX(YP1)
    DCP1=0.618-1.906
    CP1=((YP1-10.)/30.)*DCP1)+1.906
    D0700 LP=1,6

```

```

IF(IP(LP)-IYP) 701, 702, 702
701 IF(LP-6) 703, 704, 704
700 CONTINUE
702 LPB=LP
LPA=LP-1
IF(LPA) 710, 711, 712
711 DTT=XT-6.894
DTB=9.468-6.894
DCP=1.781-1.906
ZCP=DCP*(DTT/DTB)+1.906
GO TO 900
712 XTB=(YP+177.)*(1.106/30.)
DTT=XT-XTB
DTB=9.468-XTB
DPP=FLOAT(IYP-IP(LPA))
DPB=FLOAT(IP(LPB)-IP(LPA))
YP1=YP
CP1=((YP1-10.)/30.)*DCP1)+1.906
DCP=CP(LPB,3)-CP(LPA,3)
ZCPA=DCP*(DPP/DPB)+CP(LPA,3)
DZCP=ZCPA-CP1
ZCP=DZCP*(DTT/DTB)+CP1
GO TO 900
C ERROR CODES
202 WRITE(12,1001)
GO TO 9999
210 WRITE(12,1101)
GO TO 9999
303 WRITE(12,1201)
GO TO 9999
404 WRITE(12,1301)
GO TO 9999
410 WRITE(12,14)
GO TO 9999
506 WRITE(12,15)
GO TO 9999
510 WRITE(12,16)
GO TO 9999
515 WRITE(12,17)
GO TO 9999
704 WRITE(12,18)
GO TO 9999
710 WRITE(12,19)
GO TO 9999
1001 FORMAT(1X,7HK GT 23)
1101 FORMAT(1X,6HK LT 1)
1201 FORMAT(1X,8HLT GT 13)
1301 FORMAT(1X,8HLP GT 23)
14 FORMAT(1X,7HLP LT 1)
15 FORMAT(1X,8HLP GT 23)

```

```
16  FORMAT(1X,7HLP LT 6)
17  FORMAT(1X,6HDT LT 0)
18  FORMAT(1X,7HLP GT 6)
19  FORMAT(1X,7HLP LT 1)
900  CONTINUE
      CLOSE(5)
      RETURN
9999  STOP
      END
```


CREATING FILE 3, SYMBOLIC IN 3: / 2011/

9.43	50.	7.00	1.047	
7.59	14.7	7.00	1.191	
7.59	14.7	13.2	2.017	
6.2	6.54			
1				
0.0080	0.0063	.0050	.5	2000.
10.	5.	3.	2.	1.
2.	1.	.250	.250	.125
.001				
2.	50.			
2				
.008	.0063	.005	.50	2000.
5.	3.	2.	2.	
2.	2.	.250	.250	.125
.001	.002	.90		
2.	30.			
3				
.008	.0063	.005	.5	2000.
10.	5.	3.	2.	2.
2.	1.	.250	.250	.125
.002				
2.	50.			
4				
.008	.0063	.0050	.50	2000.
5.	3.	2.	2.	
2.	1.5	.250	.250	.125
.002	.001	.003	.9	
2.	30.			
5				
.008	.0063	.005	.5	2000.
10.	5.	3.	2.	2.
2.	1.	.250	.250	.125
.003				
2.	150.			
6				
.008	.0063	.0 5	.5	2000.
5.	3.	2.	2.	
2.	1.333	.250	.250	.125
.003	.001	.004	.9	
2.	30.			
7				
.008	.0063	.005	.5	2000.
10.	5.	3.	2.	2.
2.	1.	.250	.25	.125
.004				
2.	200.			

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14. ABSTRACT The present work comprises a generalized computer program for the performance analysis and study of turbomachine-driven cryogenic systems in general, employing helium as the working fluid. With the facility of the broad input spectrum incorporated, the effect of numerical changes in all major variables or input parameters may be studied, either individually or in combination as desired. Systems may also be optimized for minimum size, weight, number of components, and power input requirements....by judicious selection of the various input parameters. The porous-plate type heat exchanger is specifically considered (see ref. 5). Upon activating either one of two input codes, the computer will evaluate heat exchanger characteristics based on use of either AL-1100-F or AL-3003-F as the plate material.			

DD FORM 1473

REPLACES DD FORM 1473, 1 JAN 56, WHICH IS OBSOLETE FOR ARMY USE.

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1A KEY WORDS	LINK A		LINK B		LINK C	
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Analytical program. Cryogenic systems. Turbomachine-driven helium cryogenic systems. Heat exchangers, porous plate type in helium cryogenic systems. Performance analysis of turbomachine-driven cryogenic systems, with helium working fluid and porous plate type heat exchangers.						