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TITLE WATER DROPLET IMPINGEMENT PREDICTION FOR ENGINE
INLETS BY TRAJECTORY ANALYSIS IN A POTENTIAL
FLOW FIELD - FINAL REPORT

CONTRACT NO. NOW 65-0273-f Item 1 MODEL R&D

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1.0

OBJECT

This report is written to fulfill the requirements of Bureau of Naval Weapons contract NOW 65-0273-f Item 4. This contract was issued for development of a digital computer program to predict the anti-icing requirements for engine inlets by predicting water droplet impingement. The determination of the design requirements is made by establishing the potential flow field around the subject surface and then calculating the trajectory of the water droplet as it approaches and impinges on the surface.

During the execution of this contract, any new discoveries or inventions (subject inventions) were to be reported to the Government.

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2.0 SUMMARY

2.1 Development Summary

With the signing of the development contract on March 9, 1965, the Contractor started work on the two basic digital computer programs to provide an accurate method of water droplet impingement. The potential flow computer program was updated and refined by the addition of variable distance incrementation, improved plotting and table preparation routines and more output.

The water droplet trajectory computer program was adapted to the improved potential flow program and expanded to include methods to calculate trajectories that included smaller droplets, droplet reversal, gravity and buoyancy effects and random input. Provisions for summing the results from a given droplet size distribution and for determining the tangent droplet trajectories were also included. Both computer programs were verified by comparison with theoretical and NACA analytical and test results.

In compliance with contract Section V (PATENT RIGHTS), the Contractor hereby certifies that there are no Subject Inventions relative to the fulfillment of this contract.

2.2 Descriptive Summary

The Boeing Company under contract to the Bureau of Naval Weapons has developed a digital computer program to predict the anti-icing requirements of engine inlets by calculating water droplet trajectories toward the particular inlet through a potential flow field. The incompressible potential flow field is determined by a separate computer program using known boundary conditions. The potential flow field results are combined with the droplet and flow physical data for input to a droplet trajectory computer program. This water droplet trajectory program is based on balancing the drag, buoyancy and weight forces on the water droplet with the rate of change of the water droplet momentum.

The water droplet computer program is extremely versatile because the actual design shape is used in the study and therefore the results do not need to be extrapolated.

Verification of the computer programs was accomplished by comparisons with theoretical and NACA test and analytical data.

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3.0 CONCLUSIONS

Based on historical and current development experience as shown by the references and this report, it is concluded that:

1. This method of determining water impingement on cylindrical and plane objects is accurate, efficient and rapid.
2. The water droplet trajectory computer program can be used to predict the trajectories of large and small water droplets starting at arbitrary conditions.
3. The potential flow computer program is a useful tool to describe complex flow fields to assist in surface and duct pressure distribution studies.
4. The developed computer program does not contain any new inventions or discoveries that could be classed as a Subject Invention (contract section V).

4.0

RECOMMENDATIONS

Based on the results and conclusion described in this document, it is recommended that:

1. This method of water impingement prediction be adopted as a standard for anti-icing requirements determination.
2. Development of the water droplet trajectory program be continued to expand its utility, simplify its usage and increase its accuracy especially for heavier, larger particles.
3. The potential flow computer program be expanded to include compressibility effects.

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DESCRIPTION

A preliminary water droplet trajectory calculation computer program was refined, expanded and verified during the completion of Item 1 of the subject contract. Specific effort was devoted to accomplishing the following.

- (a) The potential flow field computer program was updated and refined for increased utility and versatility. Variable distance incrementation in both the horizontal and vertical (or radial) directions was provided to more adequately define a potential flow field by using fine increments in areas of special interest. The potential flow program output was also increased to include velocity, velocity ratio and pressure coefficients at coordinate points on selected streamlines.
- (b) The water droplet trajectory computer program's capabilities were expanded to permit the calculation of smaller droplet trajectories and droplet direction reversal. These changes were accomplished by making the water droplet horizontal distance increments independent of those selected for the potential flow grid and by using an additional set of equations for vertical travel. For droplet direction change calculations, the droplet primary direction of travel is changed whenever the perpendicular distance traveled is greater than an element in that direction. The droplet direction is reversed whenever the droplet inertia is insufficient to carry it across an increment and the perpendicular velocity component is small.
- (c) The water droplet trajectory computer program was modified to provide for variation in the water droplet's initial state with respect to the free stream flow (random input) and for the effects of gravity and buoyancy on the droplet trajectories. The random input feature permits starting the droplet trajectory from any point in the potential flow field with any velocity components. The inclusion of gravity and buoyancy effects destroys the symmetry of the cylindrical flow field trajectories and requires calculations with negative ordinate values. The capability of calculating below the centerline has been included.
- (d) The water droplet trajectory computer program was verified by comparison of the program's impingement predictions with NACA analytical and test results. Analytical comparisons were made against the NACA cylinder, sphere and airfoil data and comparisons with the test data were made for the sphere, airfoil and supersonic engine inlet.

METHOD

This analytical method of water droplet impingement prediction utilizes a digital computer and a finite difference solution of the trajectory equations of particles in an incompressible potential flow field. The potential flow field is determined from known boundary stream function values by using the relaxation technique for solving the stream function equations derived from continuity and irrotationality.

The results of the potential flow computer program are used with additional water droplet and flow physical data as input to the water droplet trajectory computer program. The water droplet trajectory program calculations result in an accurate determination of water impingement intensity on a desired surface.

Flow charts and listing of the computer programs are presented in appendices 1 through 4.

6.1.1 Potential Flow Field Analysis

Since the computer program solves the stream function equations to obtain the potential flow field from boundary stream function values, these boundary values must be determined analytically. The generalized flow field for an engine inlet is shown on page 12. Using this figure with the y-values as radial lengths, we can develop the boundary values as follows.

For two dimensional (plane) incompressible steady fluid flow, the velocity component in any direction is found by differentiating the stream function at right angles to that direction. Assuming the positive flow direction as upward (increasing y-values) and to the right (increasing x-values) the velocity components are

$$V_x = \frac{\partial \psi}{\partial y} \quad (1)$$

$$V_y = - \frac{\partial \psi}{\partial x} \quad (2)$$

In the case of axially-symmetric flow, such as that of an engine inlet the velocity components are

$$V_x = V_{\text{axial}} = \frac{\partial \psi}{y \partial y} \quad (3)$$

$$V_y = V_{\text{radial}} = - \frac{\partial \psi}{y \partial x} \quad (4)$$

The airflow toward the engine inlet is assumed to be from left to right with a value of U_{∞} at the left boundary. At this boundary the flow velocity is uniform and horizontal. Therefore,

$$v_{y1} = v_y \text{ left} = 0 \quad (5)$$

$$v_{x1} = v_x \text{ left} = \frac{\partial \psi}{\partial y} = U_1 = U_{\infty} = k U'_{\infty} \quad (6)$$

$$\text{then } \int d\psi = \int k U'_{\infty} y dy \quad (7)$$

$$\text{and } \psi = k U'_{\infty} y^2/2 + C \quad (8)$$

$$\text{or } \psi_1 = k U'_{\infty} y_1^2/2 + C \quad (9)$$

To evaluate the constants (k and c) the following boundary conditions are used.

$$(a) \quad \psi_1 = 0 \text{ at } y_1 = 0$$

$$(b) \quad \psi_1 = 1 \text{ at } y_1 = R_{\infty} \quad (\text{stream tube radius})$$

Using (a) c is evaluated as zero.

Using (b) k is evaluated as $2 / (U'_{\infty} R_{\infty}^2)$ and equation (9) can be rewritten as

$$\psi_1 = y_1^2 / R_{\infty}^2 \quad (10)$$

At the radial extremity of the control volume ($y = y_{\max}$)

$$\psi_1 = \psi_{\max} = (y_{\max}^2 / R_{\infty}^2)$$

Since $y_{\max}$ is a constant and assumed to be the ordinate of a horizontal stream line, $\psi_{\max}$ is a constant for all values of x.

The arbitrary selection of the stream function value of one (1.0) for the value at the stream tube radius on the left boundary establishes this value everywhere on the stream tube boundary including the cowl surface. Similarly, selection of the zero stream function value on the centerline establishes this value on the centerline and on the centerbody surface.

At the right boundary, uniform horizontal flow is assumed to exist within the inlet and also outside the cowl. These flows can (and generally do) have different velocities. With these assumptions the following basic equation can be developed and evaluated.

$$\psi = k U y^2/2 + c. \quad (11)$$

Inside the engine inlet

$$\psi = 0 \text{ at } y_r = y_{ocb} \text{ so } c_2 = -k_2 U y_{ocb}^2/2.$$

$$\psi = 1.0 \text{ at } y_r = y_{ic} \text{ so } k_2 = 2/(U(y_{ic}^2 - y_{ocb}^2)).$$

Then

$$\psi_{ri} = (y_r^2 - y_{ocb}^2) / (y_{ic}^2 - y_{ocb}^2) \quad (12)$$

This equation for the stream function is valid between the engine inlet centerbody and cowl at the right side of the control volume.

Outside the engine inlet equation (11) is evaluated with these conditions.

$$\psi = 1.0 \text{ at } y_r = y_{oc}$$

$$\psi = \psi_{\max} = \frac{y_m^2}{R_\infty^2} \text{ at } y_r = y_{\max}$$

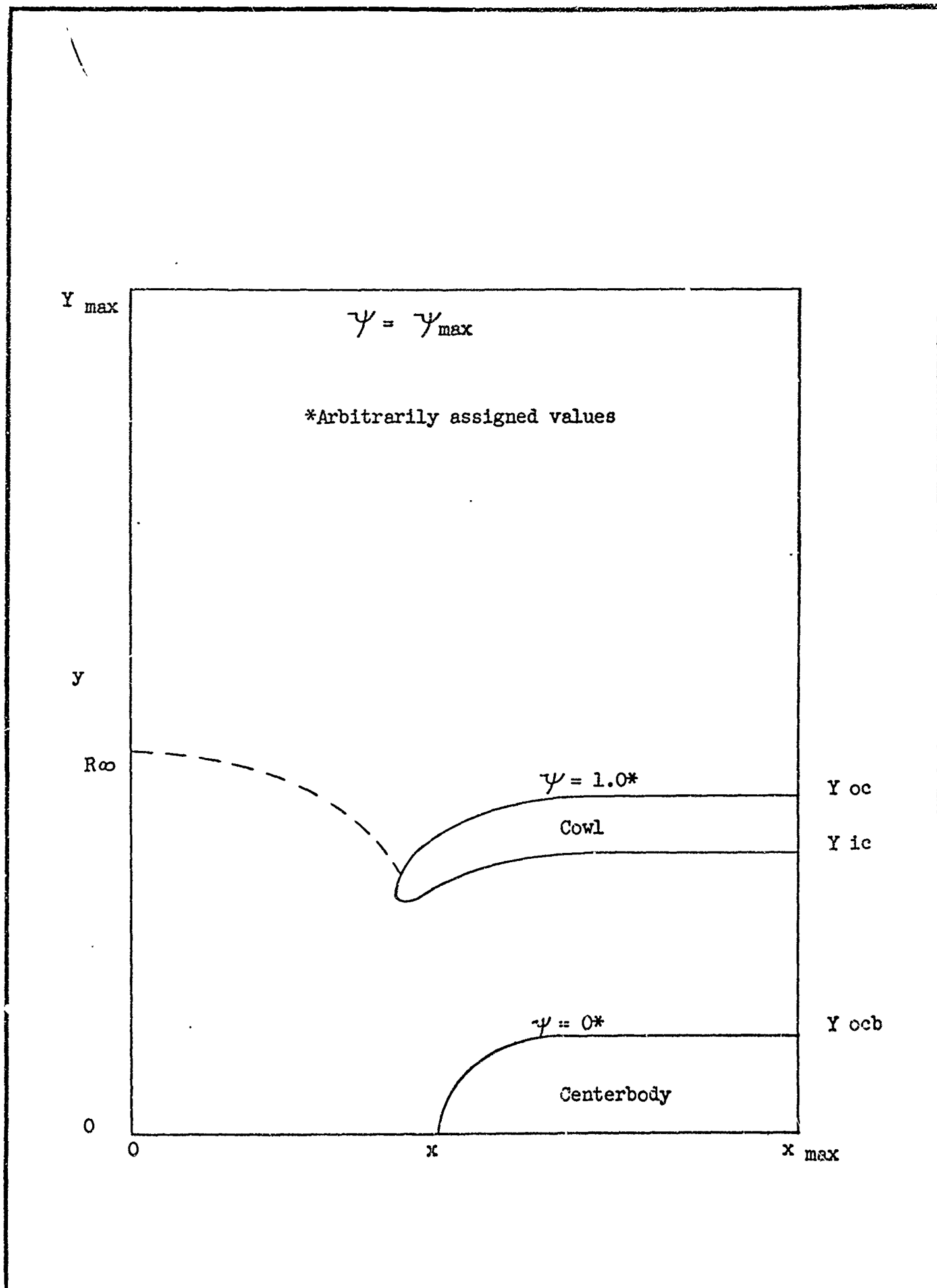
$$\text{Then } c_3 = 1 - k_3 U y_{oc}^2 / 2$$

$$k_3 = (2/U) (y_{\max}^2 / R_\infty^2 - 1) / (y_{\max}^2 - y_{oc}^2)$$

$$\psi_{ro} = 1 + (y_r^2 - y_{oc}^2) (y_{\max}^2 / R_\infty^2 - 1) / (y_{\max}^2 - y_{oc}^2) \quad (13)$$

This equation is used to evaluate the stream function values on the right control volume boundary in the constant velocity region outside the engine inlet.

For a particular engine inlet configuration and engine power setting (airflow requirement), the input left and right boundary stream function values for the potential flow program are determined from equations (10), (12) and (13). The lower, upper and model surface stream function boundary values are arbitrarily assigned at zero, maximum and one, respectively.



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6.1.2 Potential Flow Computer Program

Incompressible, inviscous and irrotational fluid flow problems in plane and axially-symmetric flow fields can be solved with the assistance of the IBM 7094/ FORTRAN digital computer program described herein.

Input data for the program includes a geometric description of the flow field boundaries and stream function values for the boundaries. Program results include a complete description of the potential flow field by enumerating stream function values at mesh intersections and streamline coordinates, as well as fluid velocities and pressure coefficients for selected streamlines.

The stream function, ψ , for incompressible, steady, fluid flow is defined as the volume of fluid passing between a base streamline and the point in question. For a plane flow field the field depth is considered to be one unit and for an axially symmetric flow field, the depth varies with the radius.

The velocity component in any direction is the differential of the stream function at right angles to that direction. The usual convention of positive flow upward and to the right results in the following derivatives for velocity components.

<u>Field</u>	<u>Plane</u>	<u>Axially Symmetric</u>
Horizontal velocity, V_x	$\partial \psi / \partial y$	$(1/y) (\partial \psi / \partial y)$
Vertical velocity, V_y	$-\partial \psi / \partial x$	$(-1/y) (\partial \psi / \partial x)$

Limiting the flow to be irrotational introduces the following equation:

$$\partial V_y / \partial x - \partial V_x / \partial y = 0$$

$$\text{or} \quad \partial^2 \psi / \partial x^2 + \partial^2 \psi / \partial y^2 = 0 \quad (14)$$

for plane flow. For axially symmetric flow this limitation yields

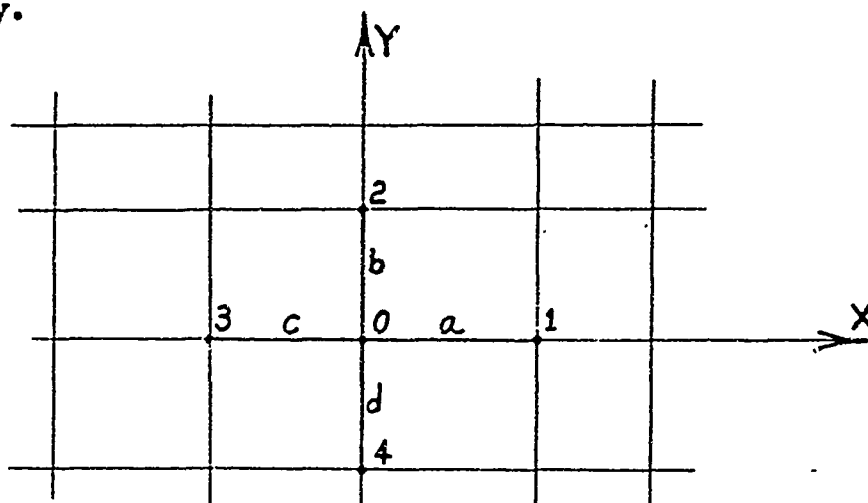
$$\begin{aligned} \partial / \partial x (-1/y \partial \psi / \partial x) - \partial / \partial y (1/y \partial \psi / \partial y) &= 0 \\ \partial^2 \psi / \partial x^2 + \partial^2 \psi / \partial y^2 - 1/y \partial \psi / \partial y &= 0 \end{aligned} \quad (15)$$

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Equations (14) and (15) define the stream function for incompressible, steady, inviscous and irrotational fluid flow in plane and axially symmetric flow fields. Numerical evaluation of these equations by the relaxation technique is the primary function of the potential flow computer program.

The potential flow computer program is divided into three distinct sections: potential flow field solution; derivative calculation and contour mapping. The potential flow field solution is accomplished by a finite difference approximation of equations (14) and (15). This solution is based on the use of a rectangular grid with the origin of coordinates temporarily at the point being considered. For a typical mesh point, ψ_0 is the stream function to be calculated and a , b , c and d are the distances to adjacent mesh points with stream function values of ψ_1 , ψ_2 , ψ_3 and ψ_4 , respectively.



An example of a mesh point coordinate system showing variable mesh spacing and coordinate orientation is illustrated by this sketch. The average first partial derivatives of ψ with respect to x from the origin to points 1 and 3 are:

$$\partial \psi / \partial x)_{0,1} = \Delta \psi / \Delta x)_{0,1} = (\psi_1 - \psi_0) / a \quad (16)$$

$$\partial \psi / \partial x)_{3,0} = \Delta \psi / \Delta x)_{3,0} = (\psi_0 - \psi_3) / c \quad (17)$$

The average second partial derivative of ψ with respect to x to be used between the distance $a/2$ to the right of the origin to $c/2$ to the left of the origin is

$$\begin{aligned}\partial^2 \psi / \partial x^2)_0 &= (\partial \psi / \partial x)_{0,1} - \partial \psi / \partial x)_{3,0} / (a+c) / 2 \\ &= 2(\psi_1 - \psi_0) / (a(a+c)) - 2(\psi_0 - \psi_3) / (c(a+c)) \quad (18)\end{aligned}$$

By similar analysis in the vertical direction

$$\partial^2 \psi / \partial y^2)_0 = 2(\psi_2 - \psi_0) / (b(b+d)) - 2(\psi_0 - \psi_4) / (d(b+d)) \quad (19)$$

The first partial derivative of ψ with respect to y at the origin is approximated by a linear interpolation of the average first partial derivatives in the adjacent intervals above and below the origin.

$$\begin{aligned}\partial \psi / \partial y)_0 &= (d(\partial \psi / \partial y)_{0,2} + b(\partial \psi / \partial y)_{4,0}) / (b+d) \\ &= d(\psi_2 - \psi_0) / (b(b+d)) + b(\psi_0 - \psi_4) / (d(b+d)) \quad (20)\end{aligned}$$

Substitution of equations (18), (19) and (20) into equations (14) and (15) results in the following finite difference approximations for plane and axially symmetric flow, respectively.

$$\psi_0 = \frac{\frac{2\psi_1}{a(a+c)} + \frac{2\psi_2}{b(b+d)} + \frac{2\psi_3}{c(a+c)} + \frac{2\psi_4}{d(b+d)}}{\frac{2}{a(a+c)} + \frac{2}{b(b+d)} + \frac{2}{c(a+c)} + \frac{2}{d(b+d)}} \quad (21)$$

$$\psi_0 = \frac{\frac{2\psi_1}{a(a+c)} + \frac{(2-d/y)\psi_2}{b(b+d)} + \frac{2\psi_3}{c(a+c)} + \frac{(2+b/y)\psi_4}{d(b+d)}}{\frac{2}{a(a+c)} + \frac{(2-d/y)}{b(b+d)} + \frac{2}{c(a+c)} + \frac{(2+b/y)}{d(b+d)}} \quad (22)$$

In the computer program equation (22) is reduced to equation (21) for plane flow by making d/y and b/y equal zero.

The computer program constructs a finite difference solution at each mesh point and sweeps through them in a definite order. Repetitive calculations (sweeps) result in the stream function values converging to values consistent

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with the specified boundary values. To improve convergence over-relaxation is used. That is, the calculated change in the stream function value at each point is multiplied by a relaxation factor which is greater than one. This result is added to the previous value and the sum is used for the new stream function value.

Sweeping is done in alternate directions, first by columns from lower left to upper right, and then, also by columns, from upper right to lower left. (This improves the rate of convergence somewhat for cases with normal derivative enforcement on the boundaries). A series of 40 sweeps (20 pairs of alternate direction sweeps) is carried out to establish the pattern of convergence; then the point with maximum error is located and followed through ten more sweeps. The change in the indicated error over this last sequence of eleven sweeps is used to define the ratio for a geometric series. The ratio is used to extrapolate the migration of the field over the sequence of eleven sweeps to an indicated limit, subject to a hedge factor and a maximum limit on the indicated extrapolation. This procedure has been found to accelerate the convergence of well behaved configurations by about 30% and the convergence of poorly behaved configurations by a factor of three.

The second part of the computer program operates on the potential flow field obtained above and calculates the partial derivatives of Ψ with respect to x and y at all mesh points. These derivatives are obtained by linear interpolation using the Ψ values at the desired point and at the adjacent points on each side at the same ordinate or abscissa value. Derivatives at points on boundaries are extrapolated linearly from the two points closest to the boundary at the same ordinate or abscissa value.

The absolute velocity at each mesh point is calculated as the square root of the sum of the squares of the x and y partial derivatives of Ψ at the point. For axially symmetric flow fields this calculation includes division by the y value (radius) to obtain the true velocity.

Contour mapping of selected stream lines or constant partial derivatives is accomplished in the third program section. The ordinate values of stream lines (stream function isolines) or contours of constant partial derivative values are determined at the input abscissa values from the potential flow field and/or either of the derivative fields by linear interpolation. The flow velocity at the stream line coordinates is also determined by interpolation.

The pressure coefficient is calculated at each point on the contour lines. The pressure coefficient is calculated as $1 - (\text{local velocity}/\text{free stream velocity})^2$.

6.1.3 Potential Flow Computer Program Usage

Input for the potential flow computer program is prepared on six field, 72 column floating decimal data cards as illustrated on the following Potential Flow Program Input Format. The individual input quantities are described as follows.

TITLE	Identification of the problem - used as a heading in the printout.
AXYM	Flow field type key - zero for a plane flow field and one for the axially symmetric flow field.
CVGS	Relaxation convergence tolerance - when the maximum difference between two successive sweep's PSI value is less than this number, the flow field iteration will stop. This value should be greater than 3×10^{-8} due to machine limitations.
NSWPS	Number of sweeps - maximum number of sweeps permitted. The iteration will stop after this number of sweeps.
PUNCH	Potential flow field table punch key - table will be punched if this value is one.
NDERIV	Normal derivative key - one to force the normal derivatives at boundaries to zero. Normally input as zero and Y0 and Y1 are ignored.
Y0	Y-value of the lower boundary on which the normal derivatives are forced to zero.
Y1	Y-value of the upper boundary on which the normal derivatives are forced to zero.
*XSCL	Scale factor in the X direction for plot of stream lines equal to the number of inches which correspond to a unit change in X.
*YSCL	Scale factor in the Y direction.
*XL1	Lower limit in the X direction of area to be plotted.
*XL2	Upper limit in the X direction of area to be plotted.
*YL1	Lower limit in the Y direction of area to be plotted.
*YL2	Upper limit in the Y direction of the area to be plotted.

* XSCLA, YSCLA, XL1A, XL2A, YL1A and YL2A are the corresponding parameters for a second plot. If only one plot is desired the sixth card should be blank.

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$Y_1, Y_2, Y_3, \dots Y_m$	First, second, third ... m'th selected ordinate mesh line values.
$X_a, X_b, X_c, \dots X_{n/2}$	First, second, third ... n/2'th abscissa boundary values at a given ordinate value.
$\psi_a, \psi_b, \psi_c, \dots \psi_{n/2}$	Stream function boundary values at $X_a, X_b, X_c, \dots X_{n/2}$ or at $Y_a, Y_b, Y_c, \dots Y_{n/2}$.
n	The number of boundary coordinates and stream function values along that particular mesh line.
$X_1, X_2, X_3, \dots X_m$	First, second, third ... m'th selected abscissa mesh line values.
$Y_a, Y_b, Y_c, \dots Y_{n/2}$	First, second, third ... n/2'th ordinate boundary value at a given abscissa value.
NSL	Number of stream lines of a type (see CSCH).
CSCH	Determines whether stream lines connect points of equal stream function value (CSCH = 2), derivative of PSI with respect to X (CSCH = 3) or derivative of PSI with respect to Y (CSCH = 4).
NNLNS	Number of types of SLINES. NSL, CSCH, and the SLINES must be input>NNLNS times.
SLINES	Values of PSI (or derivatives of PSI with respect to X or Y) through which lines will be drawn.

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Programmer Potential Flow Program Input Format

FIELD 1		FIELD 2		FIELD 3		FIELD 4		FIELD 5		FIELD 6		ID
Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	
TITLE												
TITLE		(continued)										
AXYM		CVGS		NSWPS		PUNCH						
NDERIV		YO		Y1								
XSCL		YSCL		XL1		XL2		YL1		YL2		
XSCLA		YSCLA		XL1A		XL2A		YL1A		YL2A		
Y1		n		Xa		γ_a		Xb		γ_b		
Xc		γ_c		Xd		γ_d						
Xe		γ_e		Xf		γ_f						
...		...		...		...						
Xn/2-1		$\gamma_{n/2-1}$		Xn/2		$\gamma_{n/2}$						
Y2		n		Xa		γ_a		Xb		γ_b		
Xc		γ_c		Xd		γ_d						
...		...		...		...						
Xn/2-1		$\gamma_{n/2-1}$		Xn/2		$\gamma_{n/2}$						
Y3		ln		Xa		γ_a		Xb		γ_b		
Xc		γ_c		Xd		γ_d						

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Programmer Potential Flow Program Input Format

FIELD 1		FIELD 2		FIELD 3		FIELD 4		FIELD 5		FIELD 6		ID
Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	
...		...		...		...						
$X_{n/2-1}$		$\gamma_{n/2-1}$		$X_{n/2}$		$\gamma_{n/2}$						
...		...		...		...		...		...		
Y_m		γ_n		X_a		γ_a		X_b		γ_b		
X_c		γ_c		X_d		γ_d						
...		...		...		...						
$X_{n/2-1}$		$\gamma_{n/2-1}$		$X_{n/2}$		$\gamma_{n/2}$						
Blank Card												
X_1		γ_1		Y_a		γ_a		X_b		γ_b		
Y_c		γ_c		Y_d		γ_d						
...		...		...		...						
$Y_{n/2-1}$		$\gamma_{n/2-1}$		$Y_{n/2}$		$\gamma_{n/2}$						
X_2		γ_2		Y_a		γ_a		X_b		γ_b		
Y_c		γ_c		Y_d		γ_d						
...		...		...		...						
$Y_{n/2-1}$		$\gamma_{n/2-1}$		$Y_{n/2}$		$\gamma_{n/2}$						
...		...		...		...						

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Programmer	Potential Flow Program Input Format

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Comments:

Output from the potential flow computer program is self explanatory and is printed in the following order.

Input Input is printed out to provide a permanent record.

Sweep history Record of convergence is printed out with residue at point of largest deviation.

Potential flow field solution - The stream function values, derivatives and flow velocity are printed out at each mesh point.

Contour lines Stream line or constant partial derivative coordinate values, velocities and pressure coefficients at these points are printed.

On request, the program will also provide a plotter tape for a Gerber plotter of the contour lines. The potential flow field is punched on data cards in table form for use in the water droplet trajectory computer program.

6.2.1 Water Droplet Trajectory Analysis

The equations of motion for a water droplet in air are obtained by a summation of forces on the drop. Ignoring the gravitational force, the drag force on the water drop must be equal and opposite to the rate of change of the water drop momentum. The drag force in the x-direction is

$$D_x = C_D (\rho_a \mathcal{N}_{rel}^2 / 2) (\pi a^2) (\mathcal{V}_x - \mathcal{V}_{xw}) / \mathcal{N}_{rel} \quad (23)$$

where $\mathcal{N}_{rel} = \mathcal{V} - \mathcal{V}_w$.

The rate of change of drop momentum in the x-direction is

$$F_x = \text{mass} \times \text{acceleration} = (4 \pi a^3 \rho_w / 3) d\mathcal{V}_{xw} / dt. \quad (24)$$

The drop Reynolds number is

$$R = (2 a \rho_a \mathcal{N}_{rel}) / \mu \quad (25)$$

$$\text{then } D_x = C_D R \pi a \mu (\mathcal{V}_x - \mathcal{V}_{xw}) / 4 \quad (26)$$

$$\text{and } F_x = D_x \quad (27)$$

$$(4 \pi a^3 \rho_w / 3) d\mathcal{V}_{xw} / dt = (C_D R / 4) \pi a \mu (\mathcal{V}_x - \mathcal{V}_{xw}) \quad (28)$$

$$\text{or } (2 a^2 \rho_w U / 9 \mu) d\dot{\mathcal{V}}_{xw} / dt = (U C_D R / 24) (\dot{\mathcal{V}}_x - \dot{\mathcal{V}}_{xw}) \quad (29)$$

where $\dot{N}_{xw} = U \dot{N}_{xw}$, $\dot{N}_x = U \dot{N}_x$

$$d\dot{N}_{xw} = U d\dot{N}_{xw}$$

$$d\dot{N}_{xw}/dt = (UC_D R/24K) (\dot{N}_x - \dot{N}_{xw}) \quad (30)$$

$$\text{where } K = 2 a^2 \rho_w U / 9 \mu \quad (31)$$

$$\text{and since } dt = dx / \dot{N}_{xw} U \quad (32)$$

$$\dot{N}_{xw} d\dot{N}_{xw} = (C_D R/24K) (\dot{N}_x - \dot{N}_{xw}) dx. \quad (33)$$

Similarly in the y-direction

$$d\dot{N}_{yw}/dt = UC_D R/24K (\dot{N}_y - \dot{N}_{yw}) \quad (34)$$

Equation (33) can be integrated using mean values of velocity over an interval.

$$\int_{(\dot{N}_{xw})_n}^{(\dot{N}_{xw})_{n+1}} \dot{N}_{xw} d\dot{N}_{xw} = (C_D R/24K)_{\text{mean}} (\dot{N}_x - \dot{N}_{xw})_{\text{mean}} \int_{X_n}^{X_{n+1}} dx \quad (35)$$

$$\begin{aligned} & \left[(\dot{N}_{xw})_{n+1}^2 - (\dot{N}_{xw})_n^2 \right] / 2 \\ & = (C_D R/24K)_{\text{mean}} (\dot{N}_x - \dot{N}_{xw})_{\text{mean}} (X_{n+1} - X_n) \quad (36) \end{aligned}$$

Equation (34) can be integrated in a similar manner.

$$\int_{(\dot{N}_{yw})_n}^{(\dot{N}_{yw})_{n+1}} d\dot{N}_{yw} = (UC_D R/24K)_{\text{mean}} (\dot{N}_y - \dot{N}_{yw})_{\text{mean}} \int_{t_n}^{t_{n+1}} dt \quad (37)$$

$$(\dot{V}_{yw})_{n+1} - (\dot{V}_{yw})_n = (UC_D R / 24K)_{\text{mean}} (\dot{V}_y - \dot{V}_{yw})_{\text{mean}} (t_{n+1} - t_n) \quad (38)$$

From equation (32) is obtained

$$t_{n+1} - t_n = 2(X_{n+1} - X_n) / [U(\dot{V}_{xwn+1} + \dot{V}_{xwn})] \quad (39)$$

and similarly

$$Y_{n+1} = Y_n + U \left[(\dot{V}_{yw})_{n+1} + (\dot{V}_{yw})_n \right] (t_{n+1} - t_n) / 2. \quad (40)$$

By similar analysis using mean values of velocity over an interval in the y-direction the following equations are derived.

$$\left[(\dot{V}_{yw})_{n+1}^2 - (\dot{V}_{yw})_n^2 \right] / 2 = (C_{DR} / 24K)_{\text{mean}} (\dot{V}_y - \dot{V}_{yw})_{\text{mean}} (Y_{n+1} - Y_n) \quad (41)$$

$$(\dot{V}_{xw})_{n+1} - (\dot{V}_{xw})_n = (UC_D R / 24K)_{\text{mean}} (\dot{V}_x - \dot{V}_{xw})_{\text{mean}} (t_{n+1} - t_n) \quad (42)$$

$$t_{n+1} - t_n = 2(Y_{n+1} - Y_n) / U(\dot{V}_{yw})_{n+1} + (\dot{V}_{yw})_n \quad (43)$$

$$X_{n+1} = X_n + U \left[(\dot{V}_{xw})_{n+1} + (\dot{V}_{xw})_n \right] (t_{n+1} - t_n) / 2 \quad (44)$$

Equations (36), (38), (39) and (40) are the basic equations of the water droplet trajectory computer program for droplet travel that is predominately in the horizontal direction. For droplet travel in the vertical direction equations (41) through (44) are used. The use of equations for travel either horizontally or vertically permits the calculation of droplet trajectories in areas where a fixed interval is not traversed in the selected direction.

The inclusion of gravitational and buoyancy effects on the water droplet trajectories results in the following modifications to the trajectory equations. Equation (38) contains the additional term $-(g/\rho_w U) (\rho_w - \rho_a) (t_{n+1} - t_n)$ on the right side. Equation (41) must include the term $-(g/\rho_w U^2) (\rho_w - \rho_a) (Y_{n+1} - Y_n)$ on the right side.

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6.2.2 Water Droplet Trajectory Computer Program

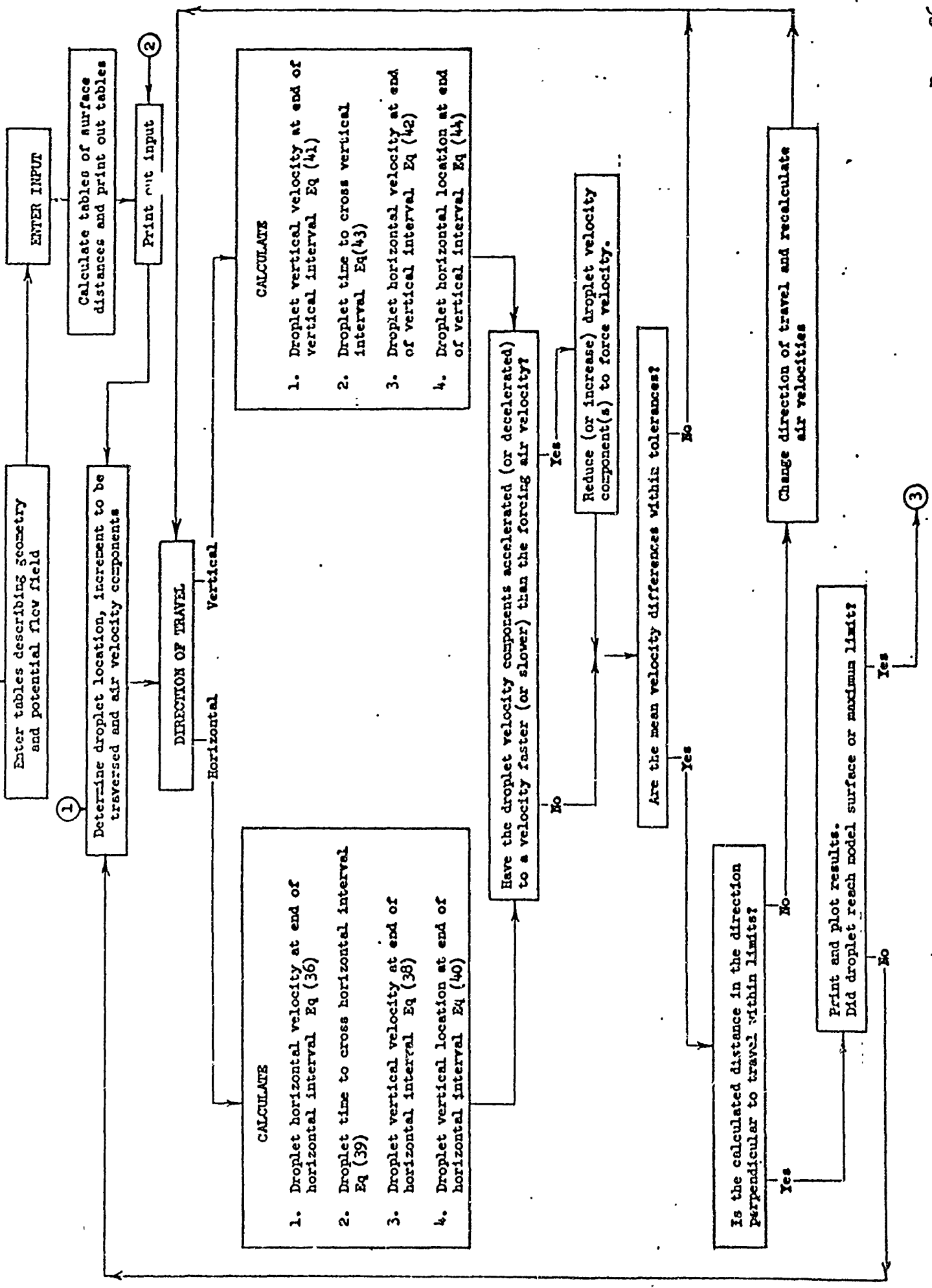
The water droplet trajectory computer program traces the trajectories of individual drops across finite incremental distances through the incompressible potential flow field until they impinge on a surface or pass out of the area of interest. This program includes air velocity components and trajectory routines with appropriate tests as shown on the following abbreviated flow chart and on the detail flow chart and listing of the appendix.

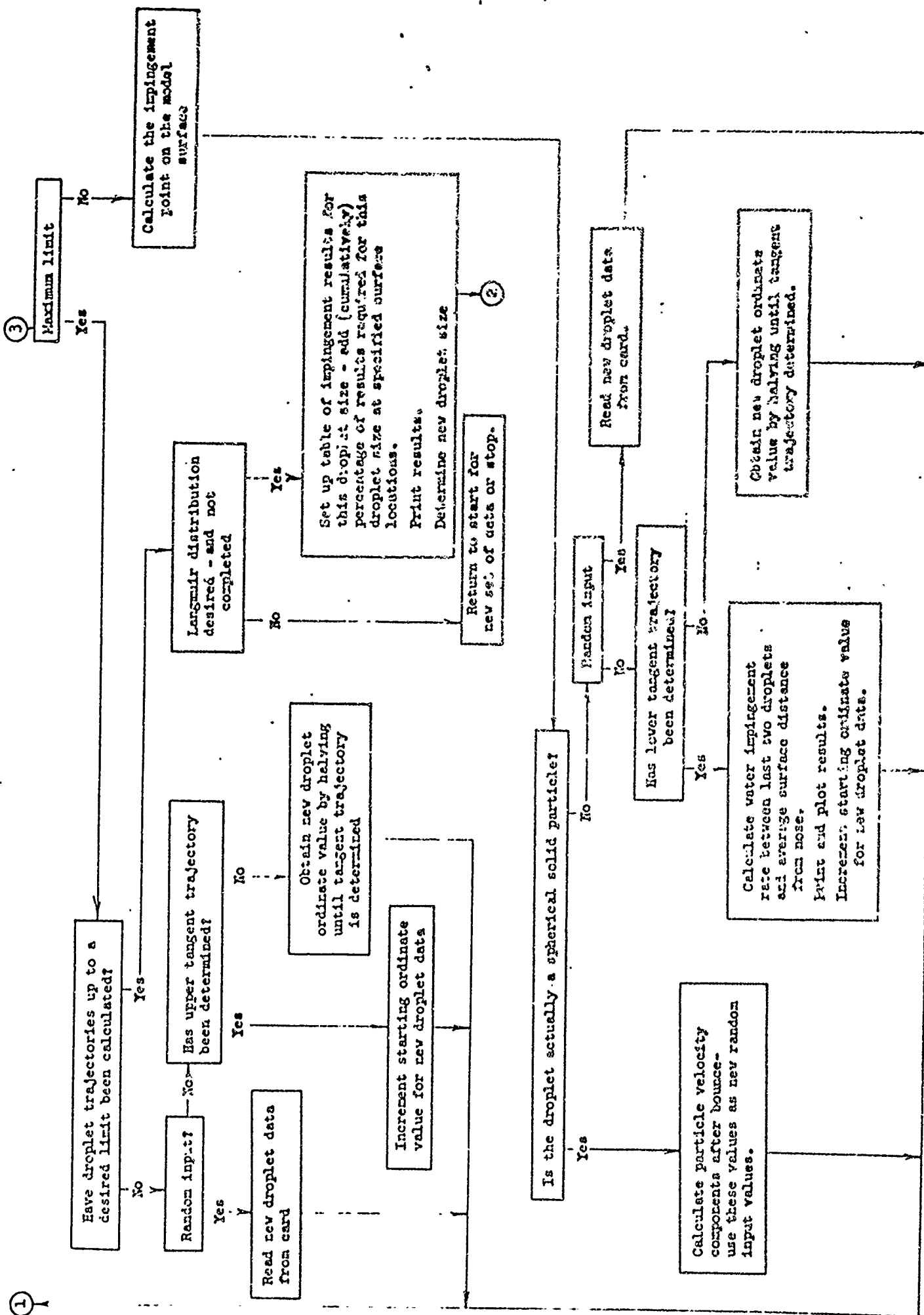
A droplet size distribution impingement intensity summation routine was added to the water droplet trajectory program as an option. This routine was added to provide a more accurate comparison of the program results with experimental data in artificial and natural icing conditions. The Langmuir "D" droplet size distribution of reference 1 was selected and incorporated in the program. Other droplet distributions could be added with small program changes. The Langmuir "D" distribution is as follows.

<u>Liquid water in size group,</u> <u>percent</u>	<u>Average group drop radius/volume</u> <u>mean drop radius</u>
5	0.31
10	0.52
20	0.71
30	1.00
20	1.37
10	1.74
5	2.22

WATER DROPLET TRAJECTORY COMPUTER PROGRAM

START





6.2.3 Water Droplet Trajectory Computer Program Usage

Input for the water droplet trajectory computer program consists of geometric and potential flow descriptive tables and data cards. The tables are read first in numerical order from one through nine. Table arrangement is shown on the following Table Input Format. Symbols used in the Table Input Format are described as follows.

YNO	Number of ordinate values in the table plus one. (NOTE: YNO is 2. for a single function table.)
XNO	Number of abscissa values in the table plus one.
Table No.	Index number of table.
$Y_1, Y_2 \dots Y_n$	First, second ... n'th ordinate values
$X_1, X_2 \dots X_n$	First, second ... n'th abscissa values
$F(X_i, Y_j)$	Dependent variable value at (X_i, Y_j) where i has values 1, 2, ... m and j has values 1, 2, ... n.

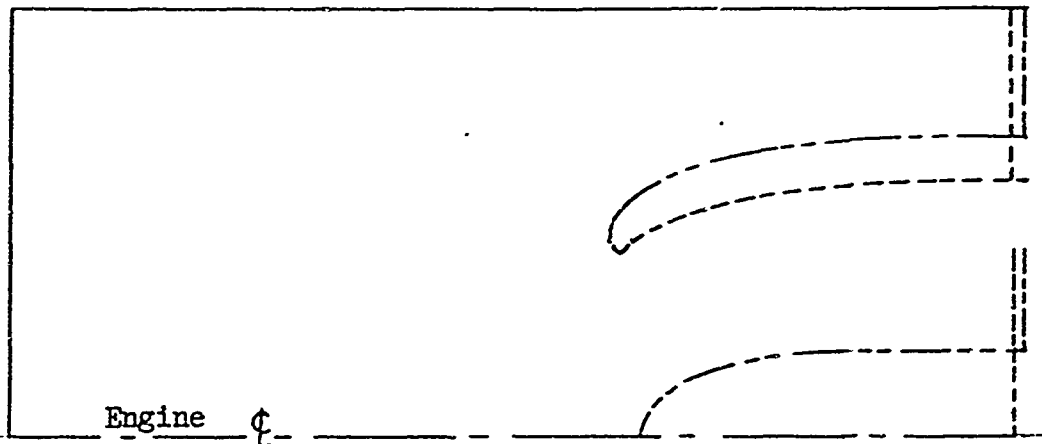
The physical orientation of the individual tables is shown on the Water Droplet Trajectory Computer Program Table Key. A written description of these tables is as follows.

Table Input Format (Two dimensional)

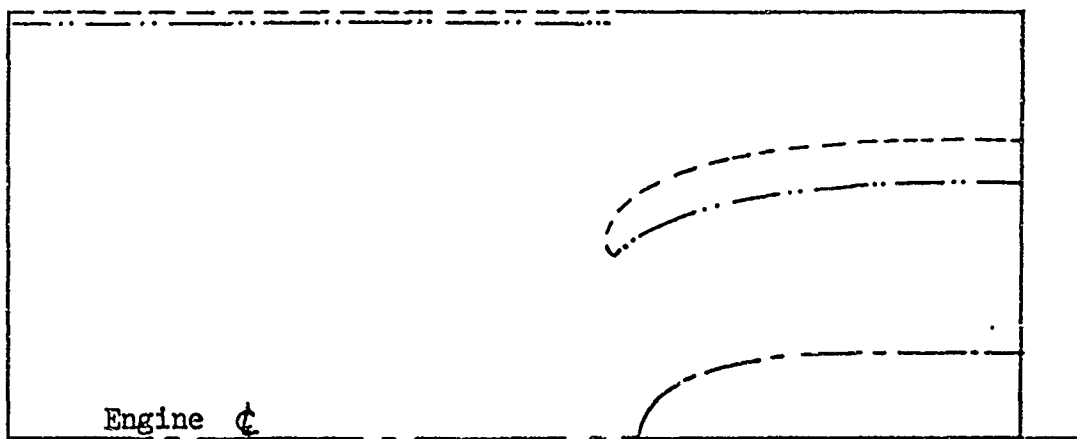
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[illegible]

Water Droplet Trajectory Computer Program Table Key



----- XB2 Table 4
 ----- XB3 Table 5



----- YB1 Table 8*
 ----- YB2 Table 6**
 ----- YB3 Table 7**

* Table 9 is generated from Table 8 from the centerbody highlight aft.

** Tables 1 and 2 are generated from Tables 6 and 7, respectively,
 from the cowl highlight aft.

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Table NumberVariable Description

- | | |
|---|--|
| 1 | Lower cowl surface distance from highlight versus horizontal distance to right of highlight. A dummy table is input and the actual values are generated internally from Table 6 values. (SUP vs. X-XHL) |
| 2 | Upper cowl surface distance from highlight versus horizontal distance to right of highlight. A dummy table is input and the actual values are generated internally from Table 7 values. (SUP vs. X-XHL). |
| 3 | Stream function values versus X and Y. This is the only double function table used and it is generated by the potential flow program. The X and Y values used are the mesh points (ψ vs. X, Y) |
| 4 | First boundary value of X after left hand boundary at given Y value (XB2 vs. Y). |
| 5 | Second boundary value of X after left hand boundary at given Y value. (XB3 vs. Y) |
| 6 | First boundary value of Y above lower boundary at given X value. (YB2 vs. X). |
| 7 | Second boundary value of Y above lower boundary at given X value (YB3 vs. X) |
| 8 | Lowest boundary value of Y at given X value. This is normally an extension of the engine centerline and the centerbody surface (YB1 vs. X) |
| 9 | Centerbody surface distance from highlight versus horizontal distance to right of highlight. A dummy table is input and the actual values are generated from table 8 values. (SUP vs. X-XHL). |

After the tables are read into the computer, the input data is called. These data are arranged on six field 72-column floating decimal cards as shown on the following Water Droplet Trajectory Computer Program Input Format. The individual input quantities are described as follows.

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Identification	Problem title - used as a heading on printout and title on machine plot.
Tape No.	Index number of plotting tape unit (usually 6)
X scale 1	X-scale factor for first curve
Y scale 1	Y-scale factor for first curve
X set 1	Minimum X-value of first curve-inches
Y set 1	Minimum Y-value of first curve-inches
X max 2	Maximum X-value of second curve-inches
Y max 2	Maximum Y-value of second curve - inches
X scale 2	X-scale factor for second curve
Y scale 2	Y-scale factor for second curve
X set 2	Minimum X-value of second curve-inches
Y set 2	Minimum Y-value of second curve-inches
LWC	Liquid water content of air-lb/cu. inch
a	Droplet radius - ft.
U_{∞}	Actual remote free stream velocity - ft/sec.
U'_{∞}	Potential flow remote free stream velocity - relative
ρ_a	Air density - lb/cu. ft.
μ_a	Air viscosity - lb/ft. sec.
Xmax	Maximum value of X-inches
Ymax	Maximum value of Y -inches
Ydrop	Initial Y-value for first water droplet-inches
ΔY_{drop}	Vertical increment between water droplets at initial X-value - inches
XL	Initial X -value for water droplets - inches
X_{HL1}	Centerbody highlight X-value- inches

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YSL	Minimum model Y-value-inches
YSM	Maximum model Y-value for droplet calculations-inches
VXWIN	Initial droplet velocity in the X-direction-ft/sec.
VYWIN	Initial droplet velocity in the Y-direction-ft/sec.
DIRECT	Direction of droplet travel key - negative is for vertical travel and positive indicates horizontal travel.
RANDOM	Random input key - negative is for normal input (increment Y drop) and positive indicates random input.
X _{HL}	Cowl highlight X-value-inches
Y _{HL}	Cowl highlight Y-value-inches
ALAMDA	Flow field type key - zero indicates plane flow and one indicates axially symmetric flow.
RESIL	Solid particle-surface resilience factor-ratio of the particle normal velocity after impingement to the normal velocity before impingement (absolute values)
ρ_w	Particle density - lb/cu. ft.
Langmr	Water droplet distribution summation key -mean droplet size of Langmuir D distribution if desired, otherwise input zero.
GRAVITY	Gravity and buoyancy effects key - zero if effects neglected and one to include effects in the calculations.
$\Delta X1$	Coarse increment of X for calculations-inches
$\Delta X2$	Fine increment of X for calculations-inches
XREF1	X-value at change from coarse to fine X-increment-inches
XREF2	X-value at change from fine to coarse X-increment-inches

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YTRAP1	Lower limit of particle trap - inches.
YTRAP2	Upper limit of particle trap - inches.
XTRAP1	Left limit of particle trap - inches.
XTRAP2	Right limit of particle trap - inches.
TABLE	Tables 1, 2 and 9 generation key - calculate if 1.0 and omit if zero.

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FLOATING DECIMAL DATA FOR 7094

Programmer Water Droplet Trajectory Computer Program Input Format

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FIELD 1		FIELD 2		FIELD 3		FIELD 4		FIELD 5		FIELD 6		ID
Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	Co-efficient	Exp.	
Identification												
Tape No.		0		Xscale 1		Yscale 1		Xset 1		Yset 1		
Xmax 2		Ymax 2		Xscale 2		Yscale 2		Xset 2		Yset 2		
LWC		a		U ∞		U' ∞		ρ_a		μ_a		
Xmax		Ymax		Ydrop		$\Delta Ydrop$		XL		XHL1		
YSL		YSM		VXWIN		VYWIN		DIRECT		RANDOM		
XHL		YHL		ALAMDA		RESIL		ρ_w		LANGMR		
GRAVITY		X1		X2		XREF1		XREF2				
YTRAP1		YTRAP2		XTRAP1		XTRAP2		TABLE				
YDROP		XL		VXW		VYW		} Random input cards as many as required followed by a blank card to trigger a new data set.				
YDROP		XL		VXW		VYW						
YDROP		XL		VXW		VYW						
YDROP		XL		VXW		VYW						
YDROP		XL		VXW		VYW						
Comments:												

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Output of the water droplet trajectory computer program consists of tabular print out and a plotting magnetic tape. The tabular print out includes a listing of the tables and input data, droplet starting conditions, a step-by-step trajectory record and impingement data. If a droplet size distribution summation is requested, the results are printed at the end of each droplet size calculation and at the completion of the total distribution. The tabular print out includes the following items.

XNN1	X-value at completion of calculation across an interval. This value is the XNN (starting) value of the next interval - inches.
YNN1	Y-value at completion of calculation across an interval. This value is the YM (starting) value of the next interval - inches.
DTW	Time interval required for droplet to cross interval from XNN to XNN1. Units of feet at remote free stream velocity.
CK	Drag coefficient parameter, $C_D R_{rel}/24$
REN	Relative Reynolds Number of water droplet to air, R_{rel} .
VDX	Normalized average horizontal air velocity between XNN and XNN1.
VDXWNN1	Normalized horizontal water droplet velocity at XNN1.
VDYWNN1	Normalized vertical water droplet velocity at XNN1.
VDY	Normalized average vertical air velocity between XNN and XNN1.
XKT	Iteration of mean velocity counter used to control non-converging solutions.
DIRECT	Direction of droplet travel key.
WATRAT	Rate of water impingement between last two drops, lb./min-sq. in.
AVS	Average surface distance from highlight for impingement of last two droplets - inches.
XP	X-value at droplet impingement - inches.

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YP

Y-value at droplet impingement - inches.

7.0

WATER

Water contained in area between starting points
of last two droplets lb/sec.- in.of depth.

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Comparison of the computer program results with theoretical and NACA analytical and test data for program verification is shown on Figures 1 through 8. Figures 1, 2 and 3 verify the accuracy of the potential flow computer program for both plane and axially-symmetric flow fields.

Stream lines calculated by the updated potential flow computer program around a cylinder at right angles to a uniform stream (plane flow) are shown on Figure 1. Theoretical stream line points are shown for comparison. This Figure indicates complete agreement between theory and the program results in the area that would affect water droplet impingement with a slight variation further from the cylinder.

Figure 2 presents the potential flow stream lines for a sphere in a uniform stream. These data for the axially-symmetric flow field compare favorably with the theoretical stream line points and are adequate for accurate water droplet trajectory calculations.

The surface velocity calculated by the potential flow program is compared to test results (reference 22), on Figure 3 for the front section of an NACA 651-212, 72 inch chord airfoil. These data show good agreement in the area of water droplet impingement. Disagreement on the aft section is due to intentionally abbreviated program input and could be improved if required.

Figures 4 through 8 verify the accuracy of the water droplet trajectory program for both plane and axially-symmetric flow fields.

The bounding (tangent) water droplet trajectories calculated by the contracted computer program and from Figure 2 of NACA report No. 1215 (reference 2), are superimposed on the cylinder-in-a-uniform-stream potential flow field on Figure 4. These data do not agree but the differences can probably be attributed to calculation differences. The NACA data do not consider the effects of gravity on the droplets and the differential equations of motion were linearized at distances greater than five radii ahead of the cylinder. The contracted digital computer solution considers gravitational effects and is computed from 20 radii ahead of the object. The difference in the bounding trajectory ordinate values at the origin results in the computer program calculating ten percent less impinged water than the NACA data indicate.

The water impingement efficiency comparison on the NACA 651-212 airfoil is shown on Figure 5. These data indicate very good agreement in curve shape and near agreement in magnitude between the NACA TN 3839 (reference 17), test values and the computer program results. A slight difference in droplet size distribution from the assumed Langmuir "D" distribution could account for the difference in the curve values.

The computed water impingement results for the 18 inch diameter sphere are shown with NACA test and calculated data on Figure 6. The computer program results for the 14.7 micron volume mean droplet diameter drops compare with the NACA test results as well as the NACA calculated data does, but they are on opposite sides. NACA TN 4092 (reference 12) noted that the accuracy of determining the test droplet size was $\pm 6\%$ and that this variation would account for the apparent test and calculation results discrepancy. Refining the calculation increment (shorter time interval) to provide the most accurate finite difference solution of the differential equations of motion resulted in a lower water impingement efficiency. It is believed that the earlier NACA calculations were not refined as well as the contracted computer program and therefore were not as accurate.

The computed water impingement intensity on a supersonic engine inlet is compared to the NACA test results (reference 9) on Figures 7 and 8. The centerbody impingement intensity shown on Figure 7 indicates excellent agreement between the test and calculated data. These results show that the computer program provides an accurate determination of the water impingement intensity on an axially-symmetric model when the proper inputs are supplied.

Figure 8 illustrates the more difficult comparison of test and calculated impingement on the supersonic inlet cowl. These data show very good agreement in both magnitude and location. The computed results would definitely provide an adequate design solution.

Machine plotting results are illustrated by Figure 9 for the potential flow program and on Figures 10 and 11 for the water droplet trajectory program.

8.0 SYMBOLS AND REFERENCES

8.1 Symbols

<u>Symbol</u>	<u>Description</u>
a	water droplet radius
c	constant of integration
C_D	Drag Coefficient
D	Drag, lb.
F	Force, lb.
g	Gravitational acceleration, 32.174 ft/sec.-sec.
k	Proportionality constant between air velocity and stream function that is eliminated by arbitrary stream function values.
K	inertia parameter, $2 \rho_a^2 U_\infty^2 / 9 \mu_a$, ft.
r	radius, in.
R	Reynolds Number
t	time, sec.
U	free stream velocity, ft/sec.
U'_∞	potential flow free stream velocity
v	local velocity, ft/sec.
$\bar{v}$	normalized local velocity, v/U
x	horizontal distance, inch
y	vertical distance, inch
μ	viscosity lb/ft.-sec.
ρ	density - lb/cu. ft.
ψ	stream function, relative

Subscripts

a	air
i	inside
ic	inside cowl
l	left
N	value at current coordinate location
N + i	value at next coordinate location
o	outside
oc	outside cowl
ocb	outside centerbody
r	right
rel	relative
w	water or water droplet
x	in horizontal direction
y	in vertical (or radial) direction
∞	remote

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References

1. Langmuir, Irving & Blodgett, Katherine B.; A Mathematical Investigation of Water Droplet Trajectories - Technical Report No. 5418, Air Material Command, AAF, Feb. 19, 1946. (Contract No. W-33-038-ac-9151 with General Electric Co.) .
2. Brun, R. J.; Lewis, W.; Perkins, P. J. & Serafini, J. S.; Impingement of Cloud Droplets on a Cylinder and Procedure for Measuring Liquid-Water Content and Droplet Sizes in Supercooled Clouds by Rotating Multicylinder Method. NACA Report 1215, 1955.
3. Bureau of Naval Weapons Contract Number NOW 65-0273-f dated March 9, 1965.
4. Pope, Alan; Basic Wing and Airfoil Theory. McGraw-Hill Book Company, Inc. 1951.
5. Emmons, Howard W.; Fundamentals of Gas Dynamics. Princeton University Press, 1958.
6. Bergrun, Normal P ; A Method for Numerically Calculating the Area and Distribution of Water Impingement on the Leading Edge of an Airfoil in a Cloud. NACA TN 1397, August 1947.
7. Tribus, Myron; Modern Icing Technology, University of Michigan Project M992-E ARDC, USAF Contract AF 18(600)-51, E.O. No. 462 Br-1, January 1952.
8. Prince, David C.; Kushevics, Guntis & Edwards, Russell N.; Computer Evaluation of Ion Engines. Summary Report prepared by General Electric Company, Evendale, Ohio for NASA. Contract NASA 8-623, March 6, 1963.
9. Gelder, Thomas F.; Droplet Impingement and Ingestion by Supersonic Nose Inlet in Subsonic Tunnel Conditions. NACA TN 4268, May 1958
10. Brun, Rinaldo J.; Cloud-Droplet Ingestion in Engine Inlets with Inlet Velocity Ratios of 1.0 and 0.7. NACA Report 1317, 1957.
11. Torgeson, W. L. & Abramson A. E.; A Study of Heat Requirements for Anti-Icing Radome Shapes with Dry and Wet Surfaces. WADC Technical Report 53-284, September 1953.
12. Lewis, James P. & Ruggeri, Robert S. Experimental Droplet Impingement on Four Bodies of Revolution. NACA TN 4092, December 1957.
13. Brun, Rinaldo J. & Dorsch, Robert G.; Impingement of Water Droplets on an Ellipsoid with Fineness Ratio 10 in Axisymmetric Flow. NACA TN 3147, May 1954

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14. Dorsch, Robert G.; Brun, Rinaldo J. & Gregg, John L.; Impingement of Water Droplets on an Ellipsoid with Fineness Ratio 5 in Axisymmetric Flow. NACA TN 3099, March 1954.
15. Lewis, William & Brun, Rinaldo J.; Impingement of Water Droplets on a Rectangular Half Body in a Two-Dimensional Incompressible Flow Field. NACA TN 3658, February 1956.
16. von Glahn, Uwe H.; Use of Truncated Flapped Airfoils for Impingement and Icing Tests of Full-Scale Leading Edge Section. NACA RM E56E11, July 1956.
17. Gelder, Thomas F.; Smyers, William H. Jr. & von Glahn, Uwe; Experimental Droplet Impingement on Several Two-Dimensional Airfoils with Thickness Ratios of 6 to 16 Percent. NACA TN 3839, December 1956.
18. Brun, Rinaldo J.; Gallagher, Helen M. & Vogt, Dorothea; Impingement of Water Droplets on NACA 65A004, Airfoil and Effect of Change in Airfoil Thickness from 12 to 4 percent at 4° Angle of Attack. NACA TN 3047, November 1953.
19. Brun, Rinaldo J.; Gallagher, Helen M. & Vogt, Dorothea E.; Impingement of Water Droplets on NACA 65A004, Airfoil at 8° Angle of Attack. NACA TN 3155, July 1954.
20. Brun, Rinaldo J. & Vogt, Dorothea E.; Impingement of Water Droplets on NACA 65A004 Airfoil at 0° Angle of Attack. NACA TN 3586, November 1955.
21. Gray, Vernon H.; Correlations Among Ice Measurements, Impingement Rates, Icing Conditions and Drag Coefficients for Unswept NACA-65A 004 Airfoil. NACA TN 4151, February 1958.
22. Brun, Rinaldo J.; Gallagher, Helen M. & Vogt, Dorothea E.; Impingement of Water Droplets on NACA 65₁ - 208 and 65₁ - 212 Airfoils at 4° Angle of Attack. NACA TN 2952, May 1953.
23. Brun, Rinaldo J.; Serafini, John S. & Moshos, George J.; Impingement of Water Droplets on an NACA 65₁ - 212 Airfoil at an Angle of Attack at 4°. NACA RME52B12, September 1952.

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9.0 PLATES

- Figure 1 Potential Flow Field for Cylinder
- Figure 2 Potential Flow Field for Sphere
- Figure 3 NACA 65₁-212 Airfoil Surface Velocity, 4° Angle of Attack
- Figure 4 Water Droplet Trajectory Comparison on Cylinder
- Figure 5 NACA 65₁-212 Airfoil Water Impingement, 4° Angle of Attack
- Figure 6 NACA TN 4092 Sphere Water Impingement
- Figure 7 Supersonic Nose Inlet Centerbody Water Impingement Comparison
- Figure 8 Supersonic Nose Inlet Cowl Water Impingement Comparison
- Figure 9 Potential Flow Field for 18 inch Diameter Sphere
- Figure 10 Water Droplet Trajectories - 5.77 Micron Drop
- Figure 11 Water Droplet Trajectories - 18.6 Micron Drop

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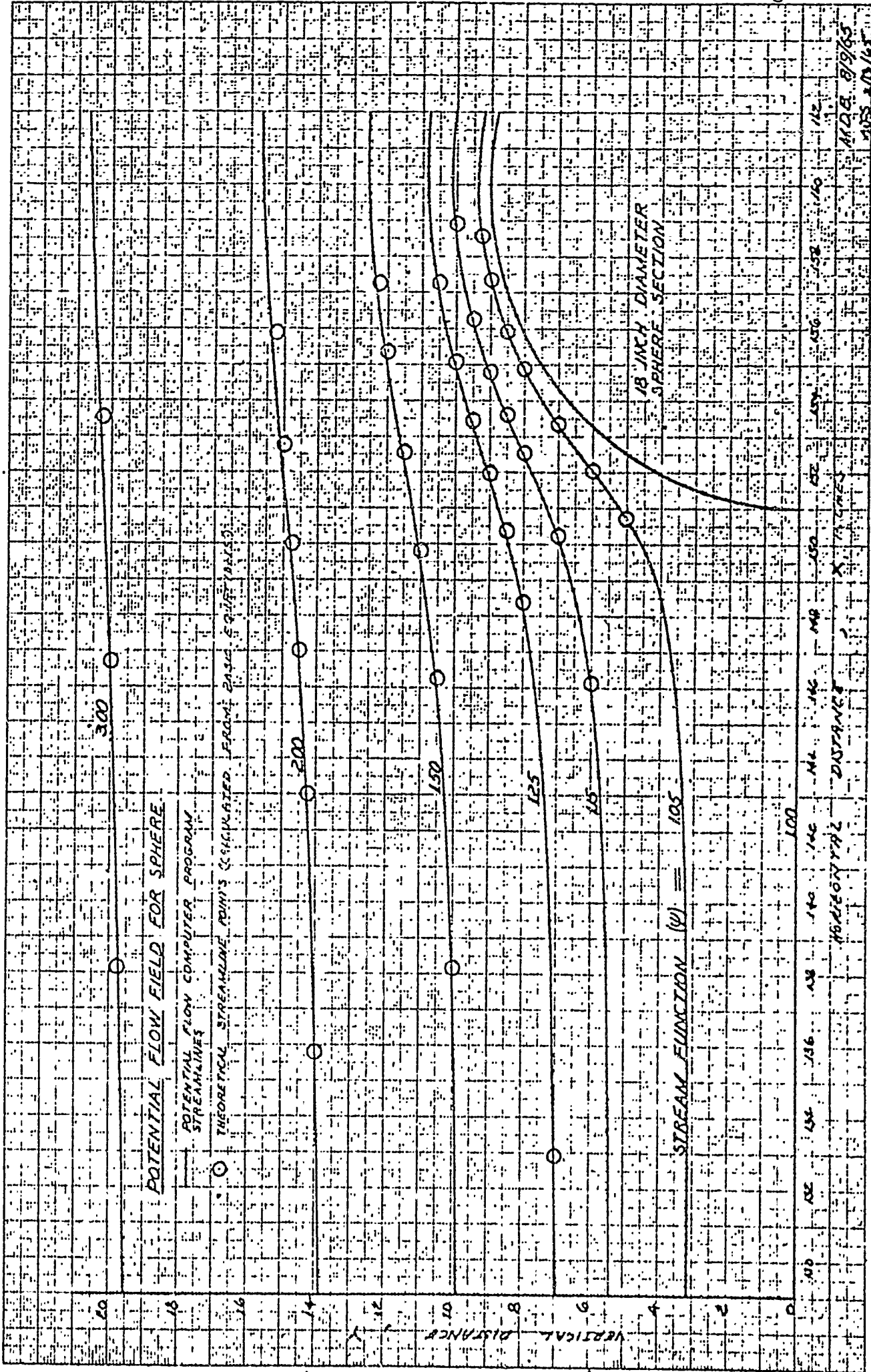
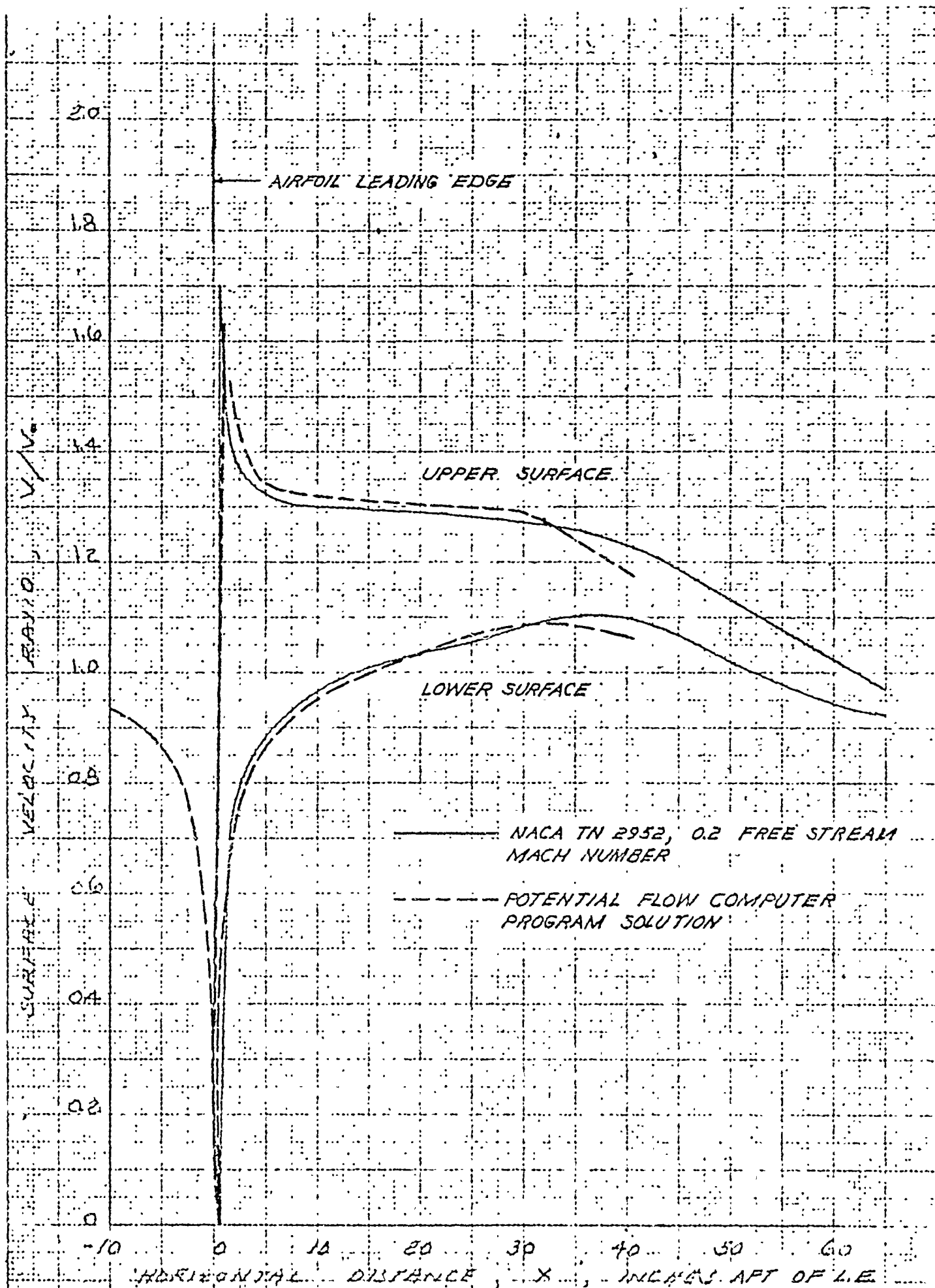


FIGURE 2



CALC	M.D.B.	8/9/65	REVISED	DATE	NACA 65, -212 AIRFOIL SURFACE VELOCITY, 4° ANGLE OF ATTACK
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APPD					
APPD					

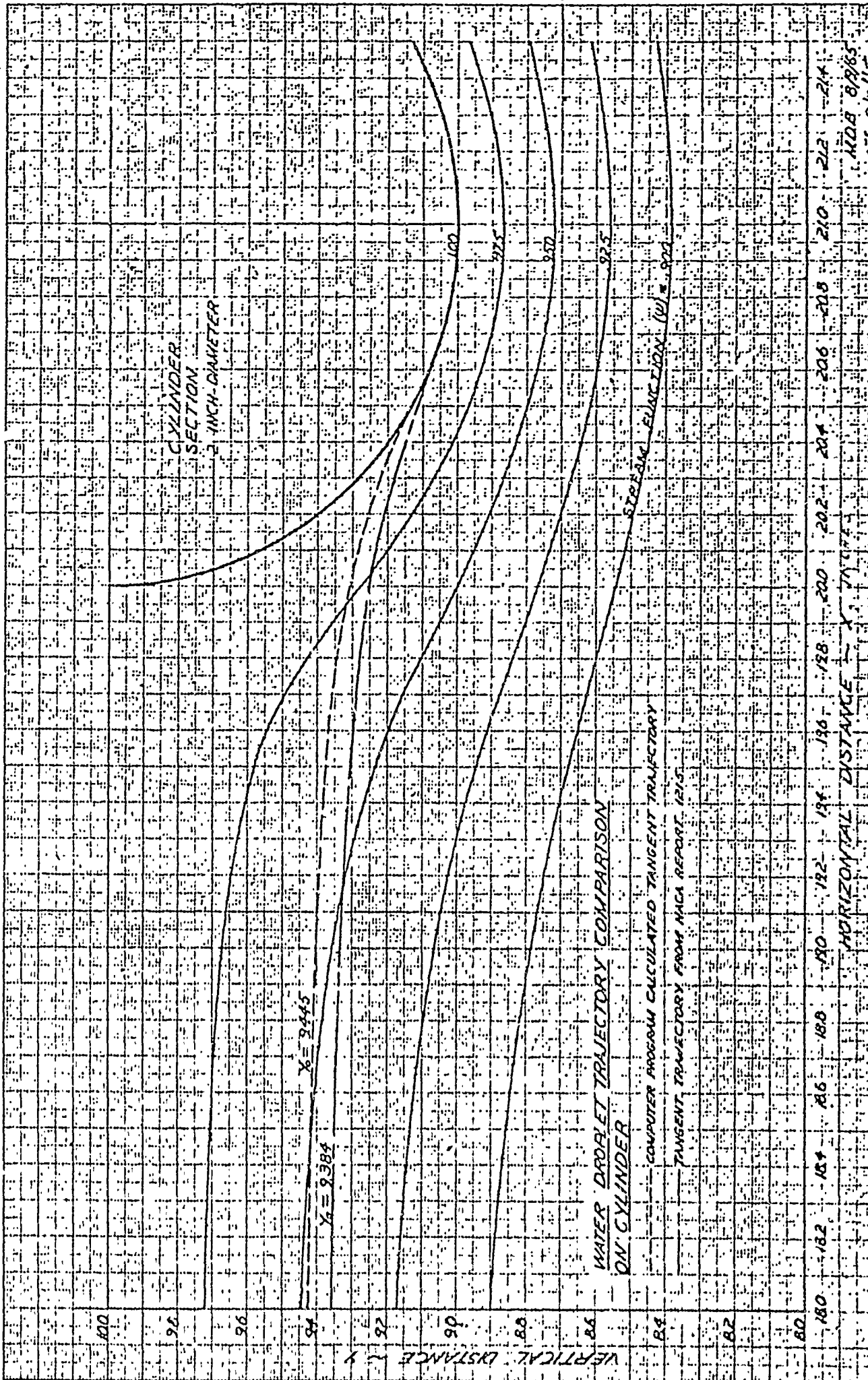
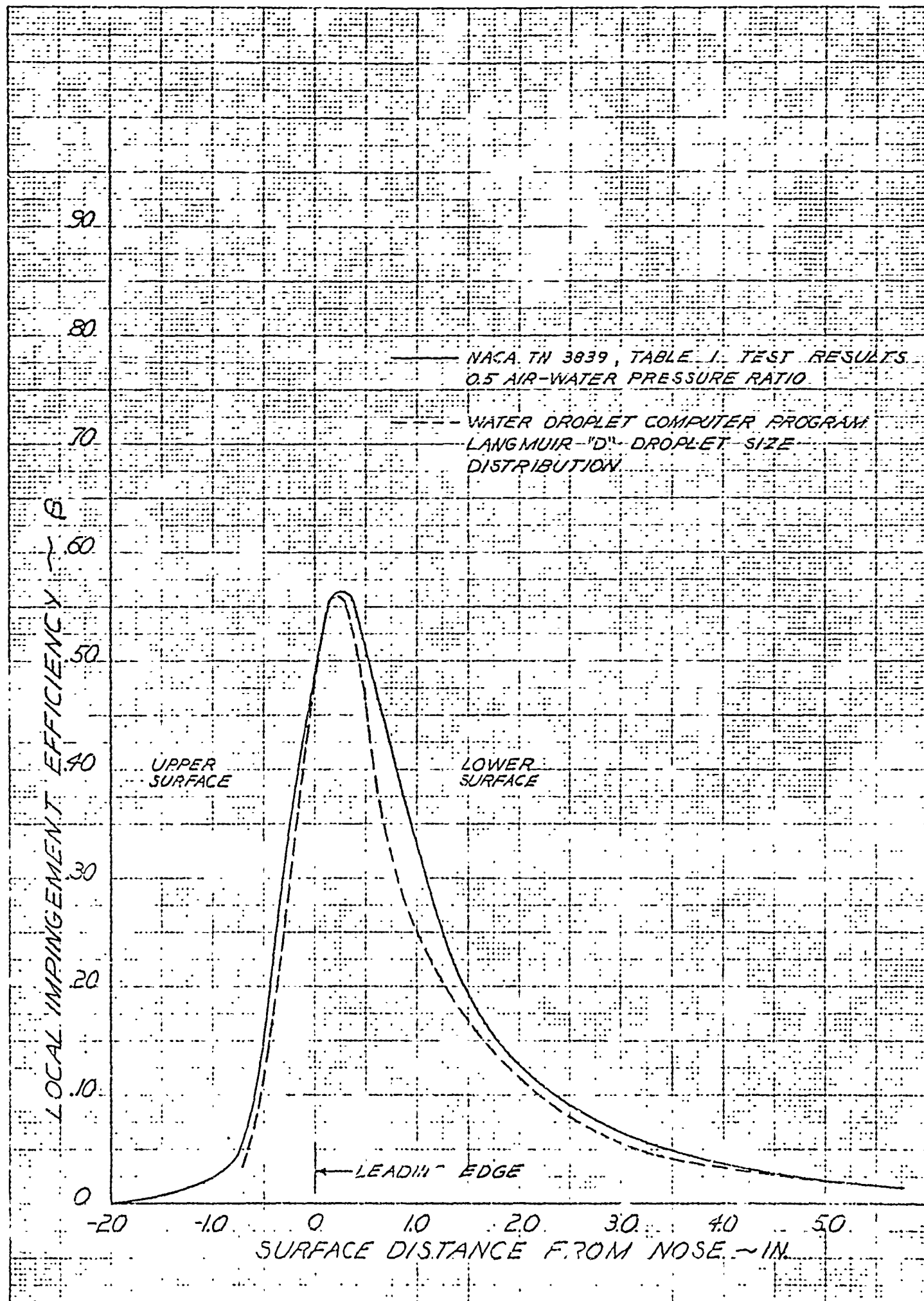


FIGURE 4



CALC	MDB	3/2/	REVISED	DATE	NACA 65, -212 AIRFOIL WATER IMPINGEMENT, 4° ANGLE OF ATTACK
CHECK	WES	8/13/65			
APPD					
APPD					

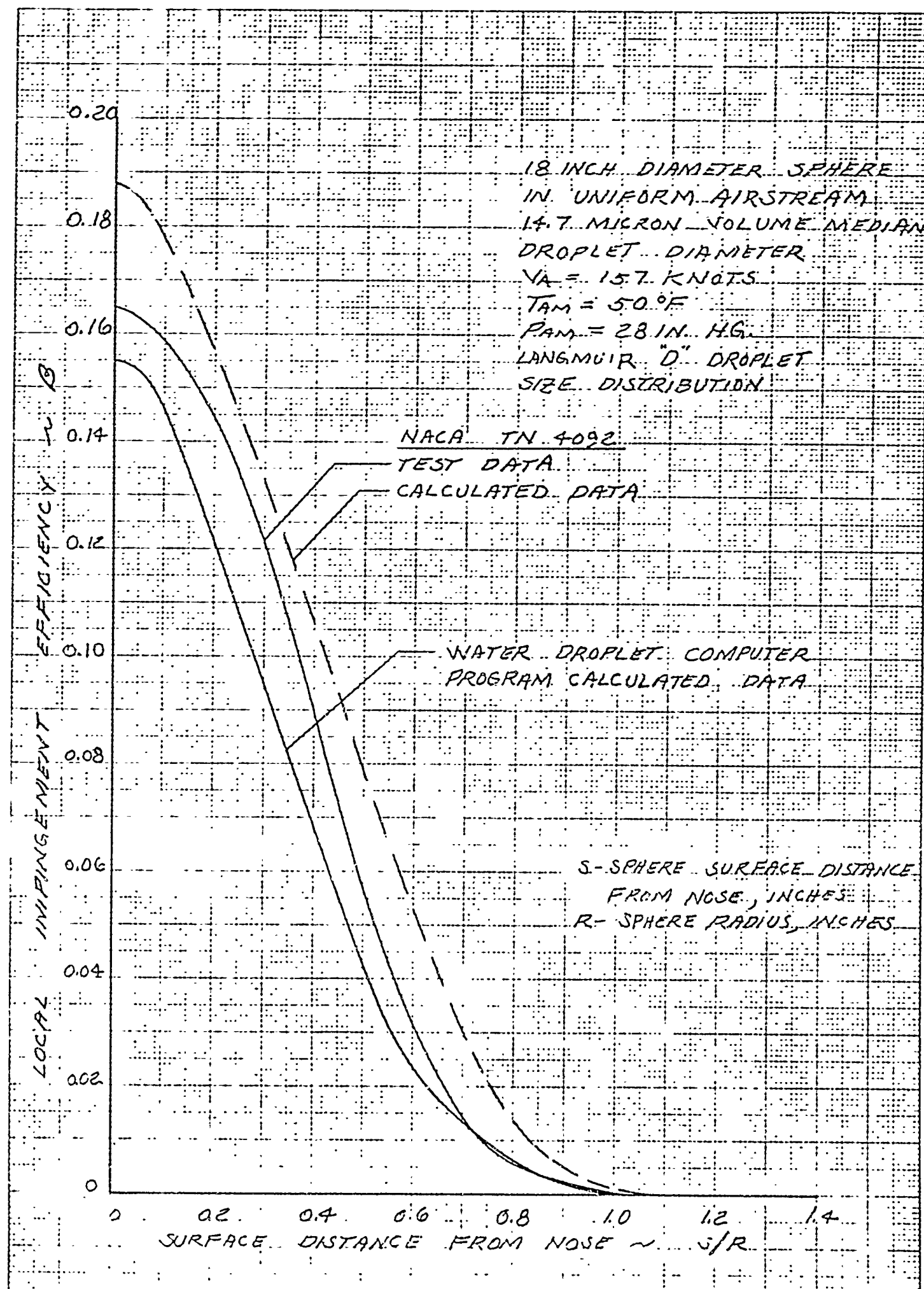
REV I TR:

DOERING

NO. FIGURE 5

SECT

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CALC	WFS	7/13/55	REVISED	DATE	NACA TN 4092	SPHERE
CHECK						
APPD						
APPD						

WATER IMPINGEMENT

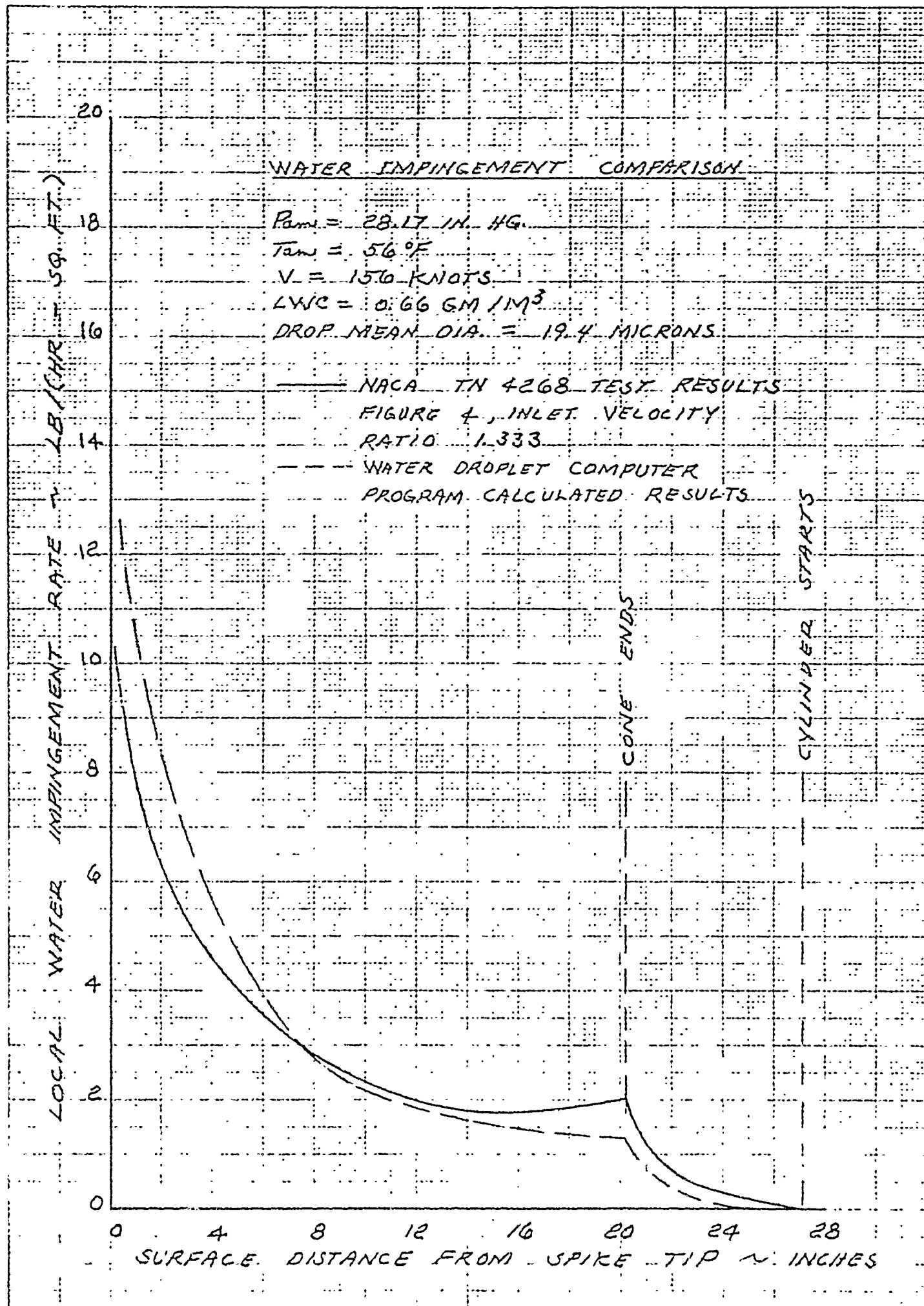
DOEING

NO. FIGURE 6

REV LTR

SECT

PAGE 50



CALC	WFS	11-2-5	REVISED	DATE
CHECK				
APPD				
APPD				

SUPERSONIC NOSE INLET
CENTERBODY

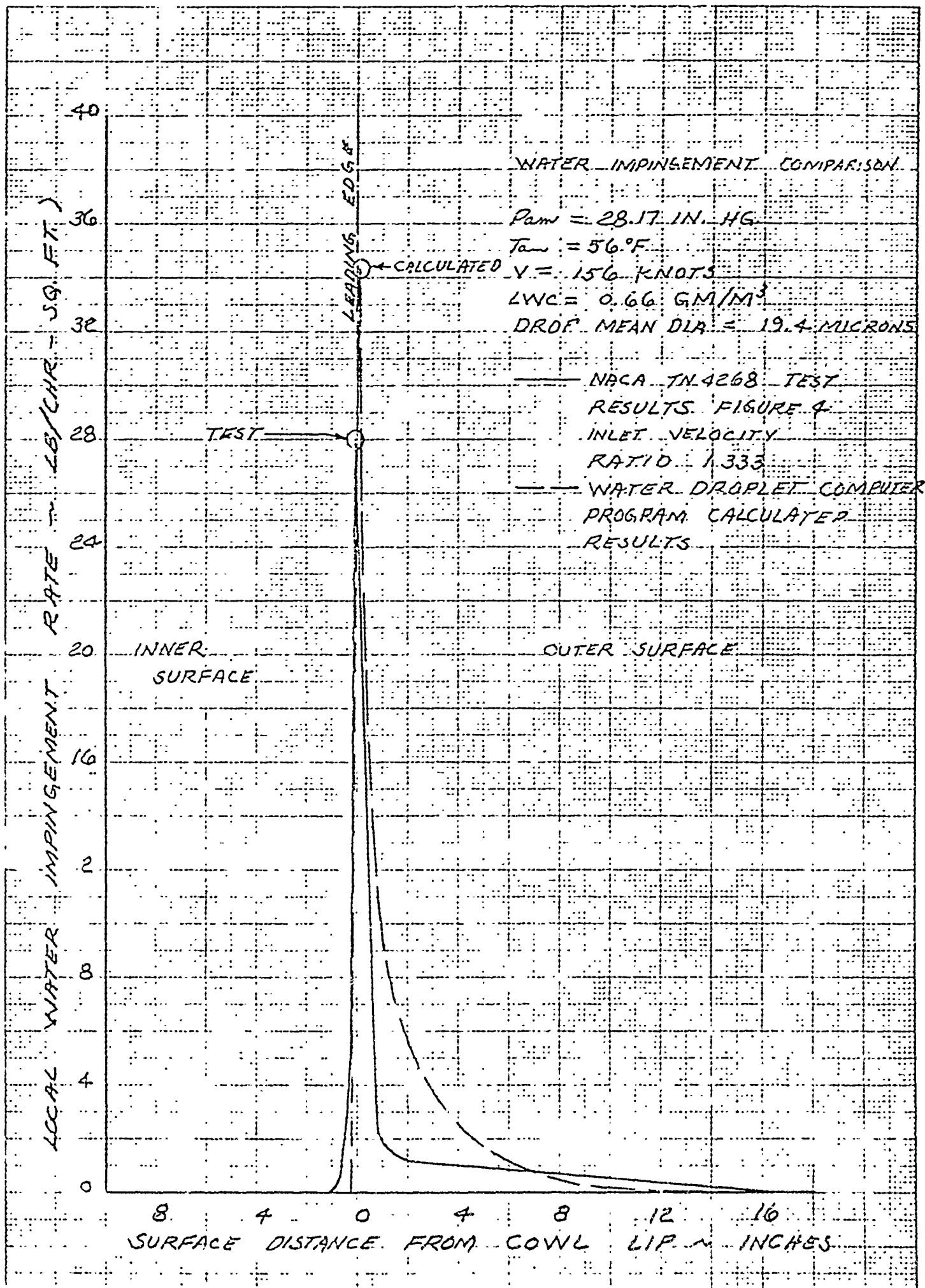
BOEING

NO. FIGURE 7

REV LTR:

SECT

DATE



CALC	JTF-S	6-12-65	REVISED	DATE
CHECK				
APPD				
APPD				

SUPERSONIC NOSE INLET
COWL

DRAFT

NO. FIGURE 8

REV LTR:

SECT

PAGE 4

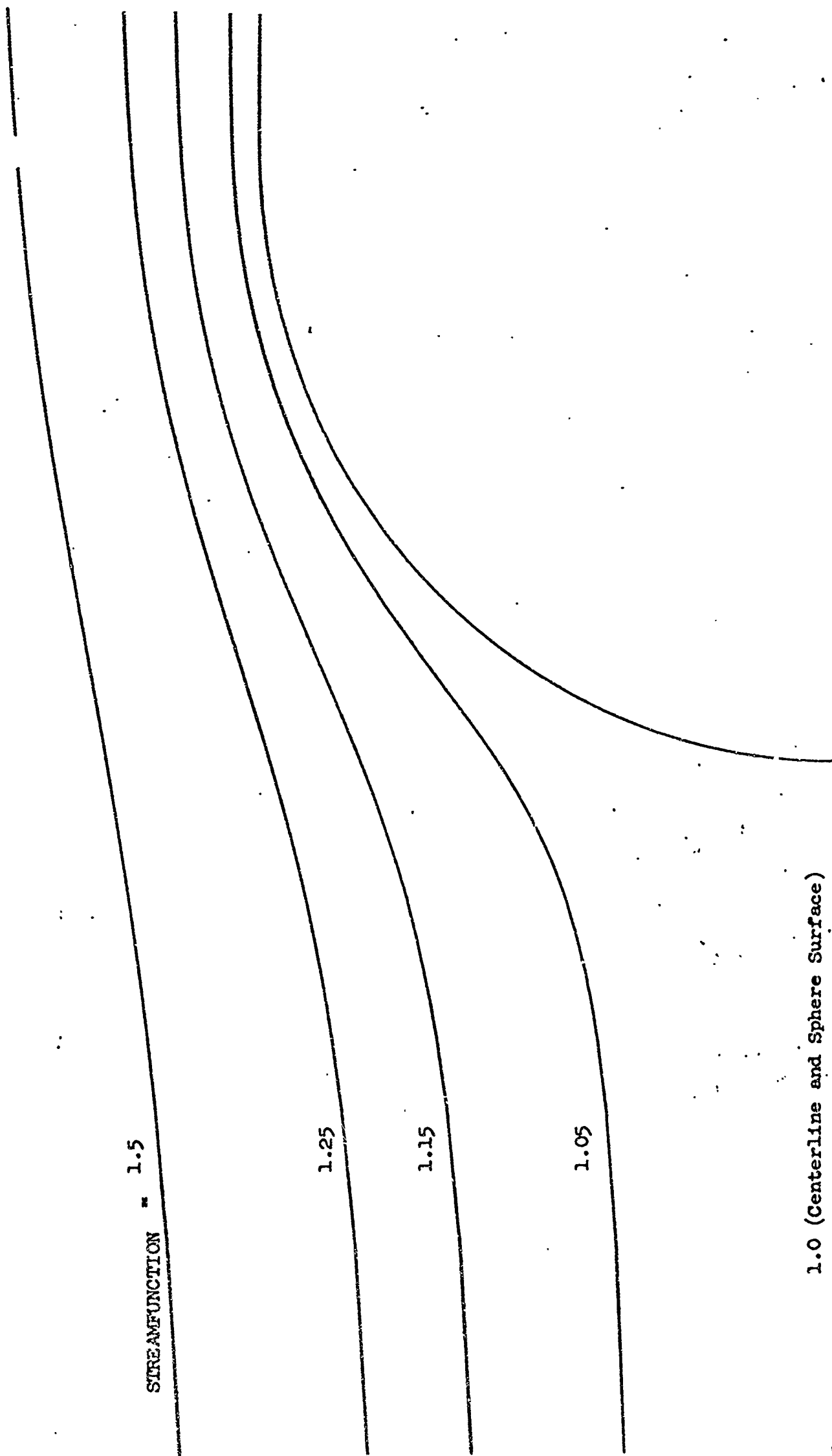


FIGURE 9. POTENTIAL FLOW FIELD FOR 18 INCH DIAMETER SPHERE

WATER DROPLET TRAJECTORIES

Ambient Pressure 28 in. Hg.
Ambient Temperature 50° F
Remote Air Velocity 157 Knots

18 INCH DIAMETER
SPHERE

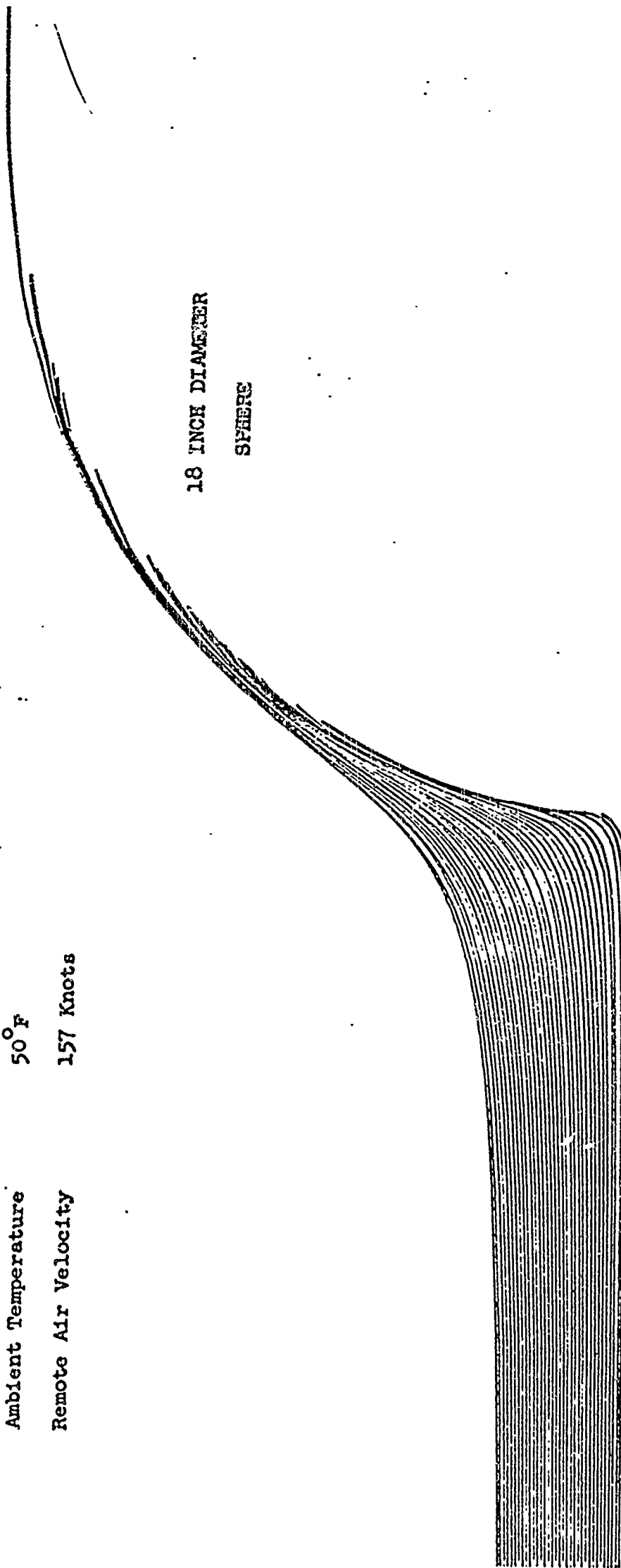


FIGURE 10.

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SPHERE 5.77 MICRON DROP

WATER DROPLET TRAJECTORIES

Ambient Pressure 28 in Hg.
Ambient Temperature 50°F
Remote Air Velocity 157 Knots

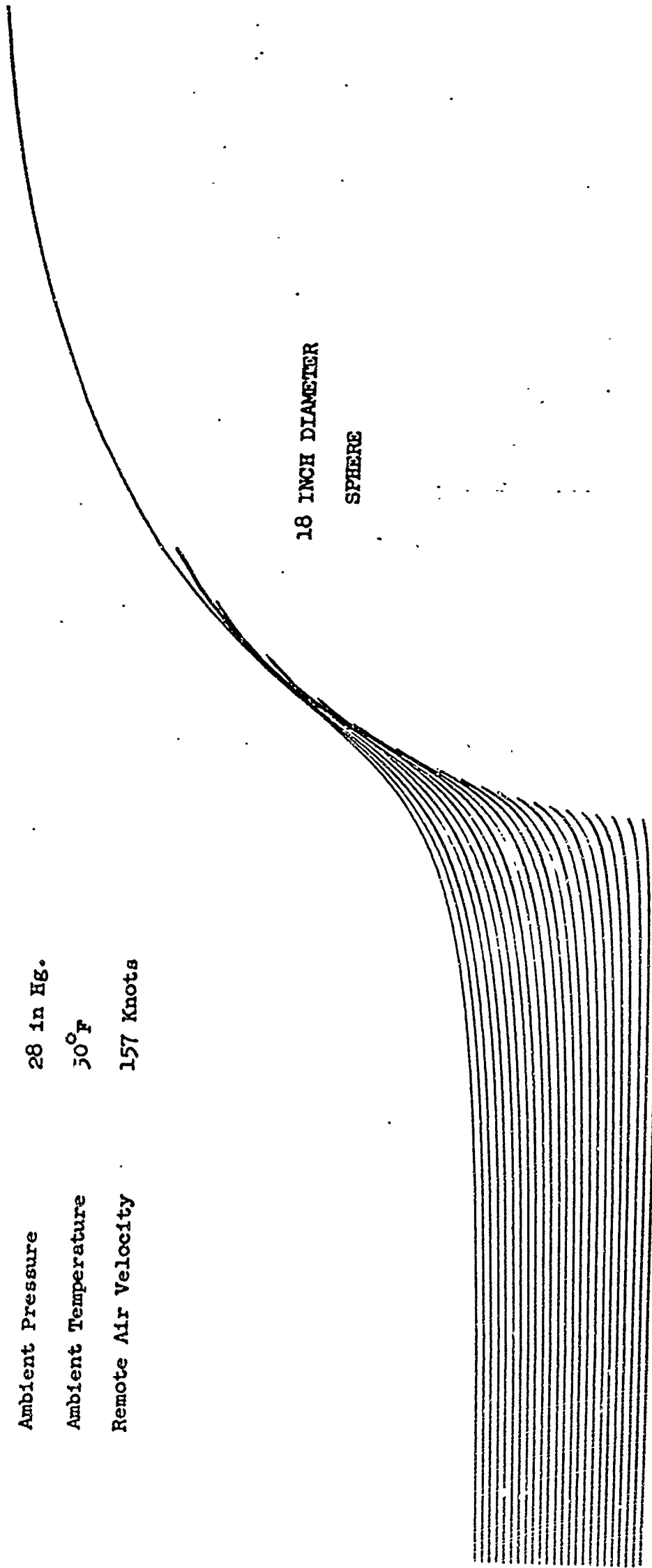


FIGURE 11.

S P H E R E 1 8 . 6 M I C R O N D R O P

10.0 APPENDICES

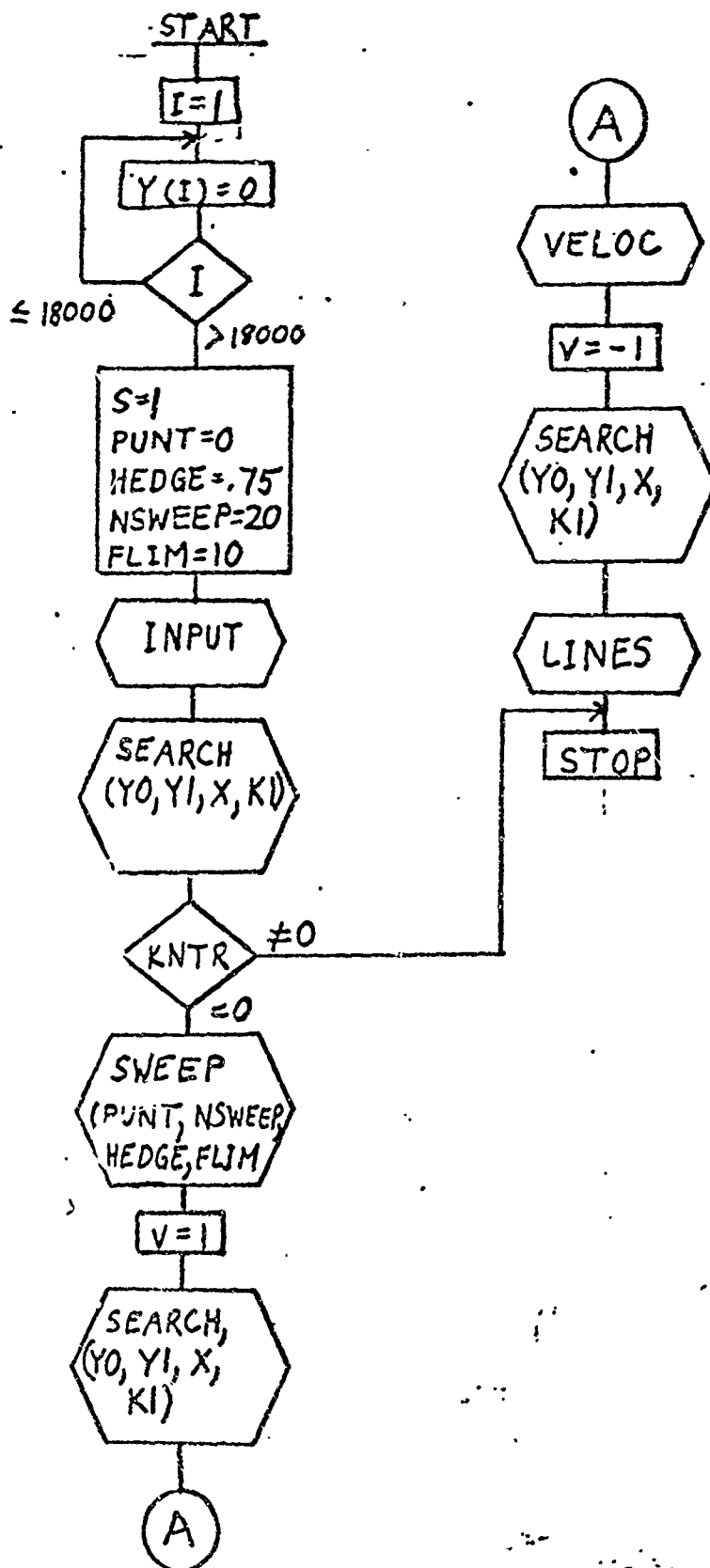
10.1 Appendix 1 - Potential Flow Computer Program Flow Chart

REV LTR:

E-3033 R1

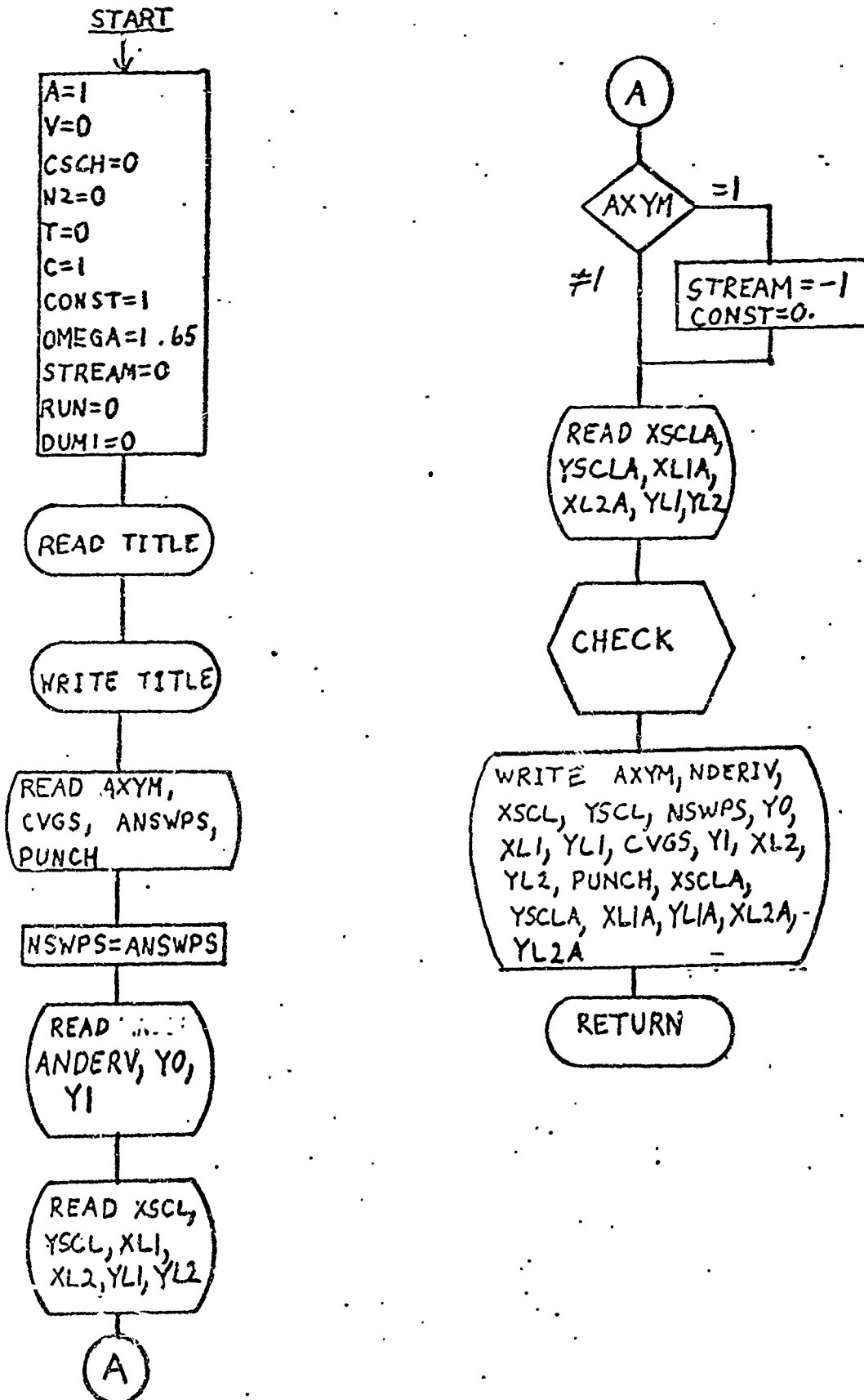
BOEING	NO. D3-6961
SECT	PAGE 56

POTENTIAL FLOW PROGRAM

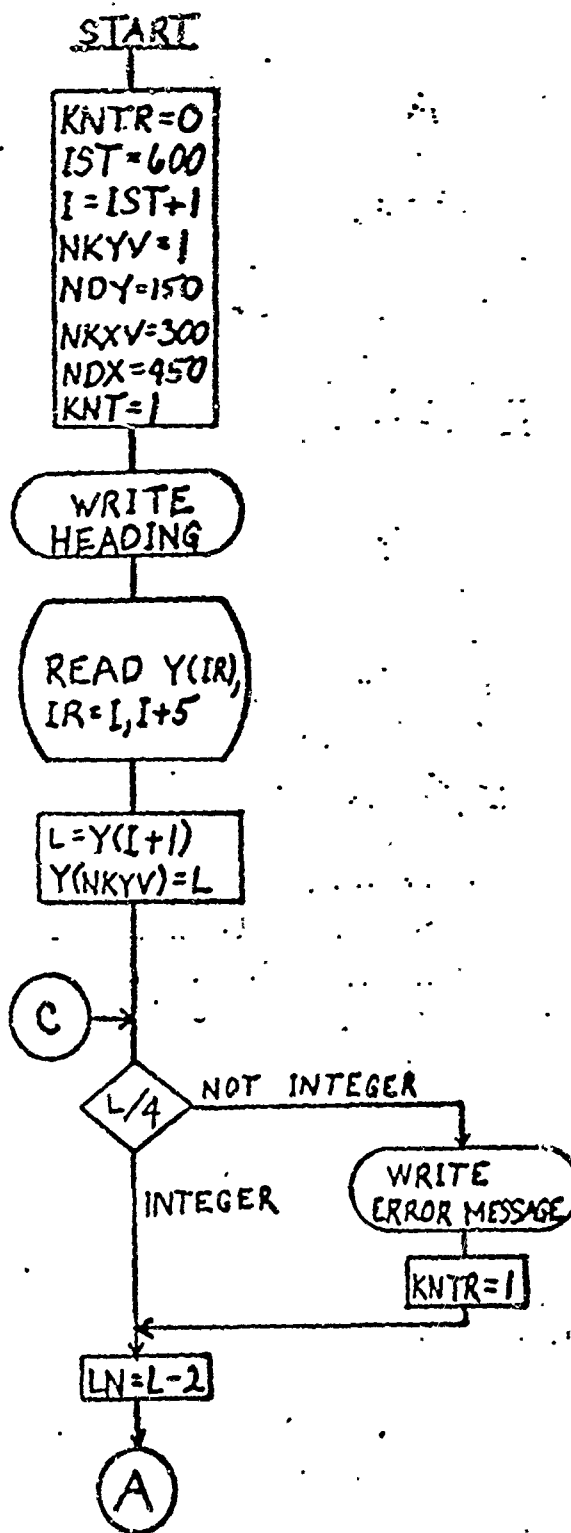


REVISED

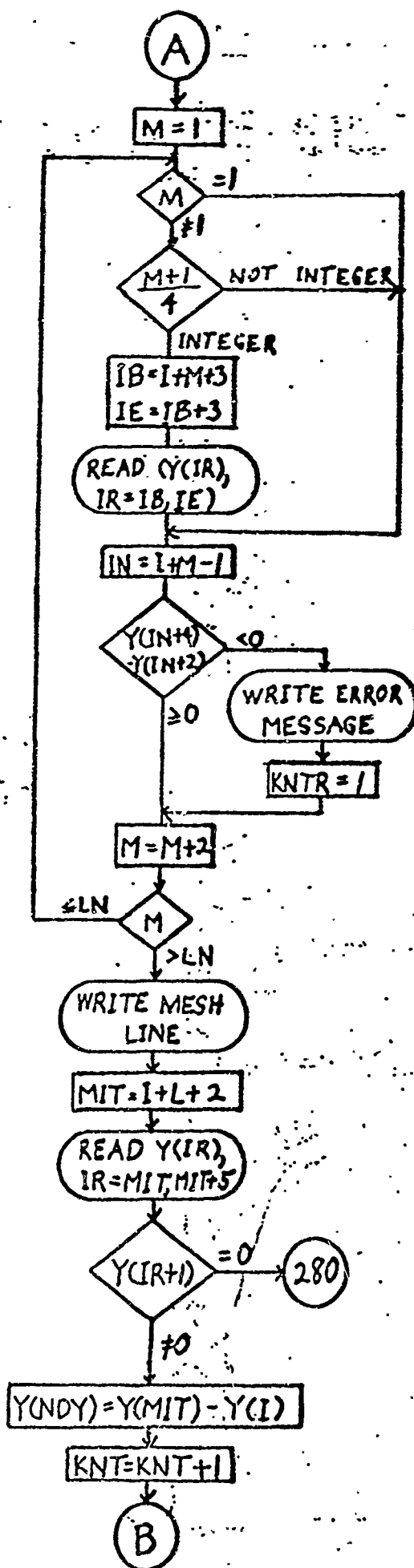
SUBROUTINE INPUT



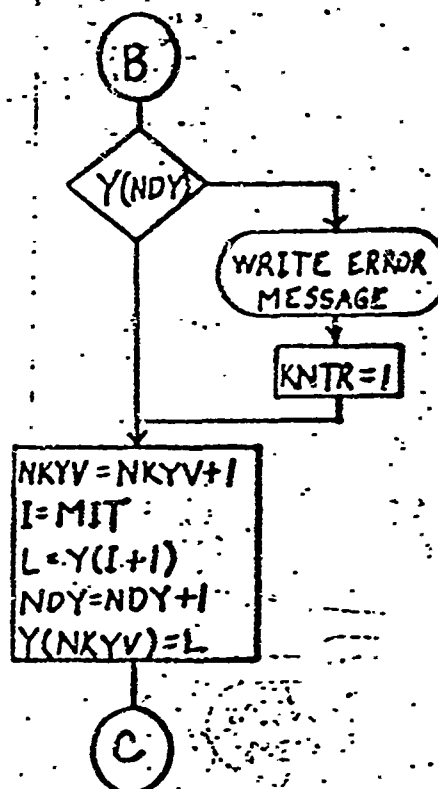
SUBROUTINE CHECK



REVISED

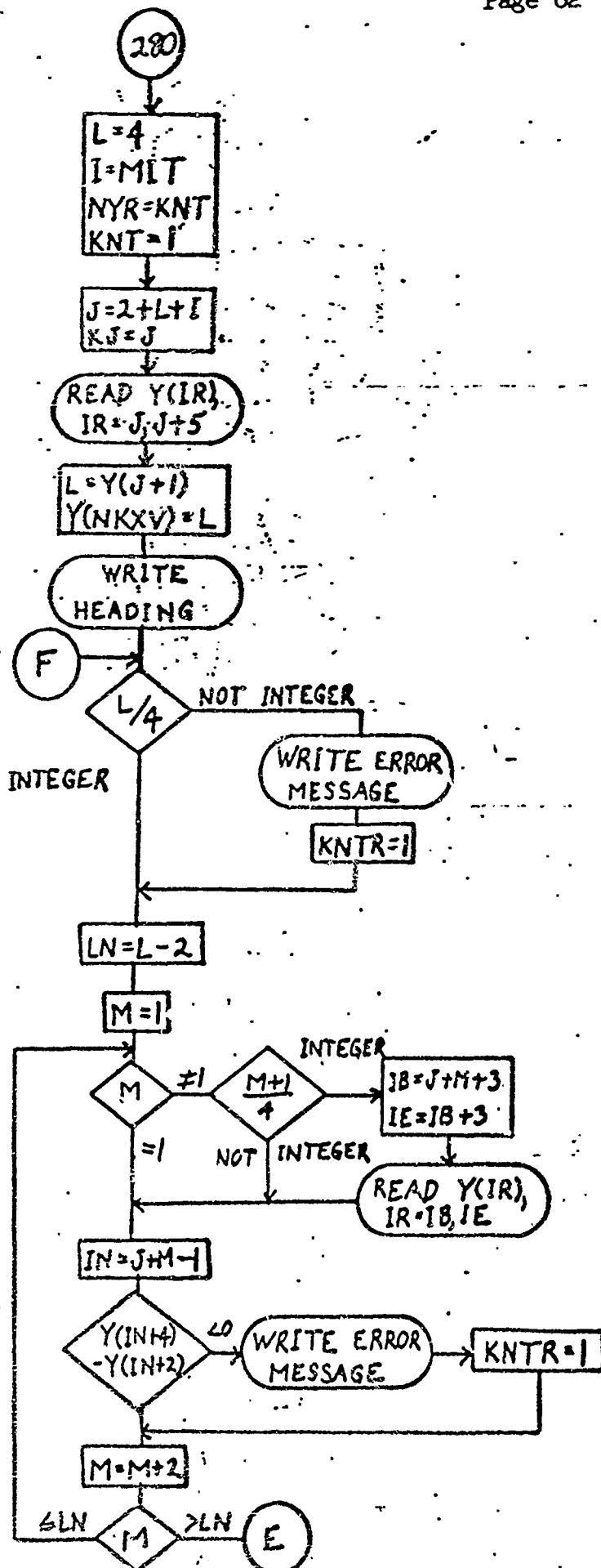


CHECK 2

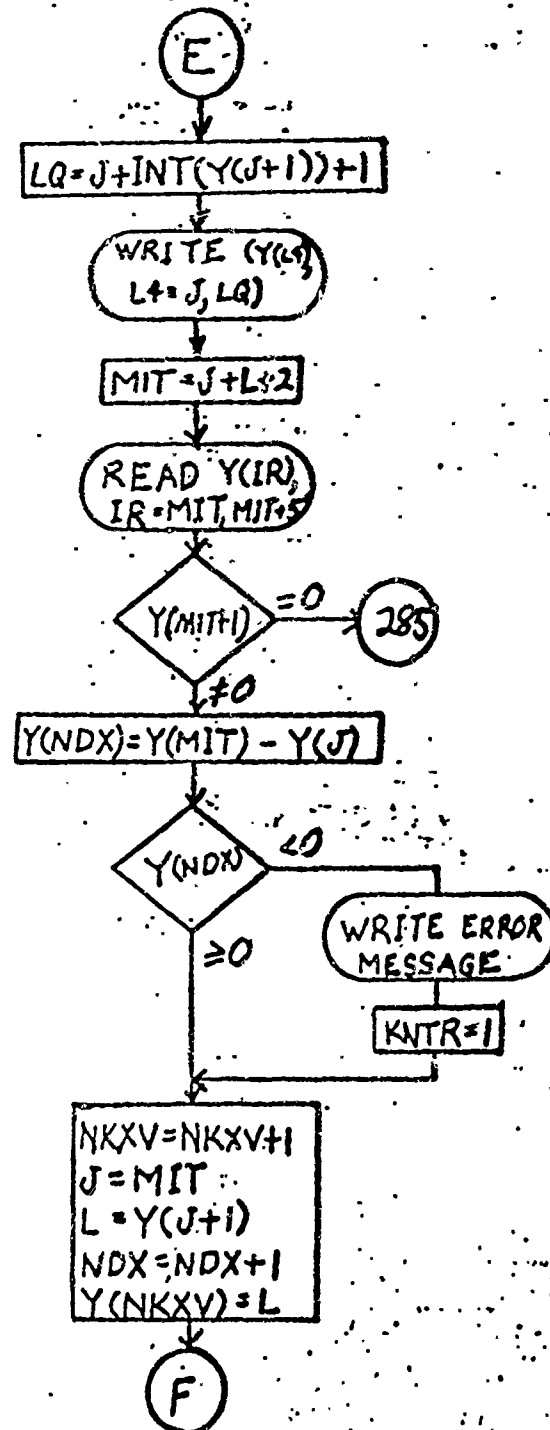


REVISED

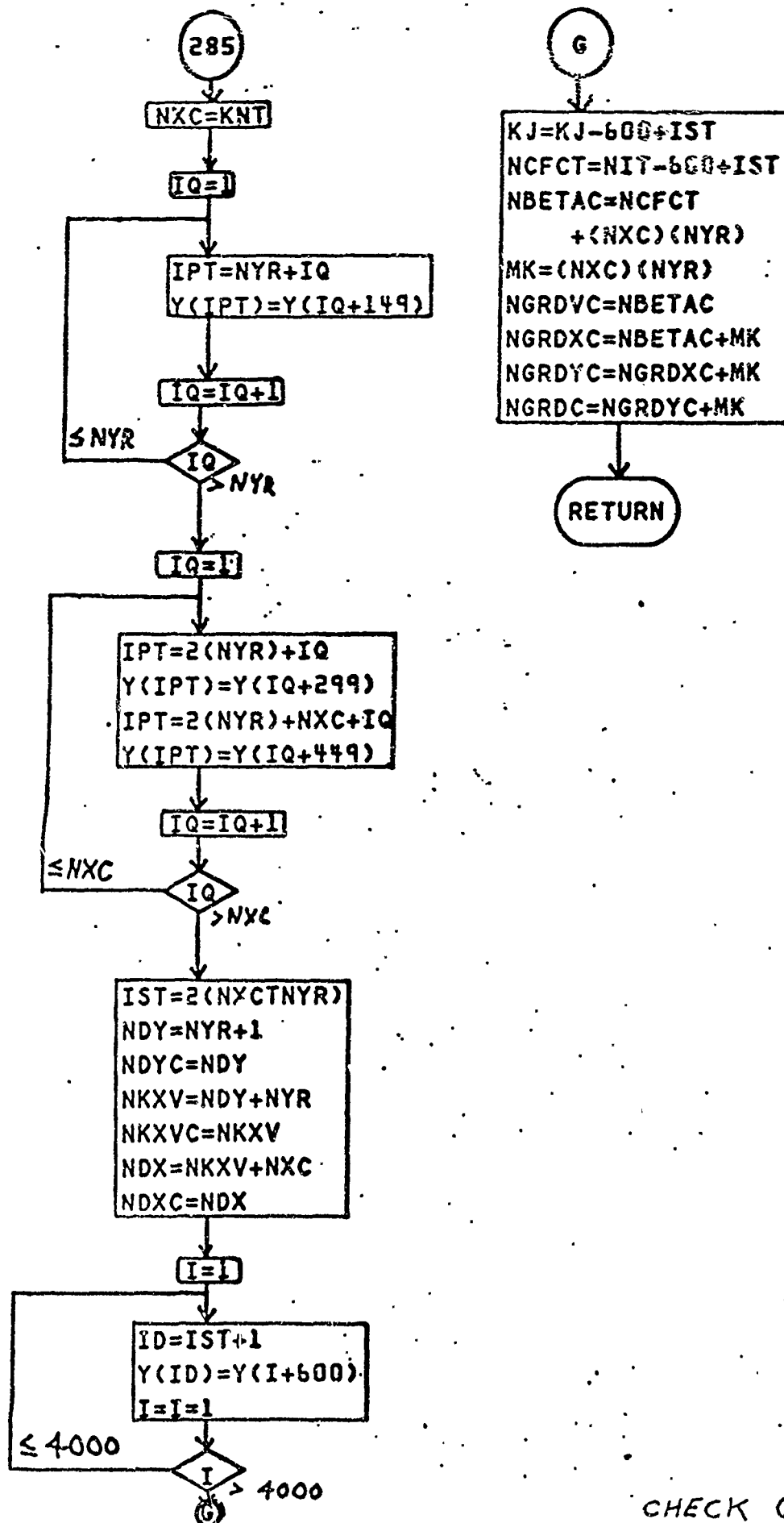
CHECK 3



CHECK 4

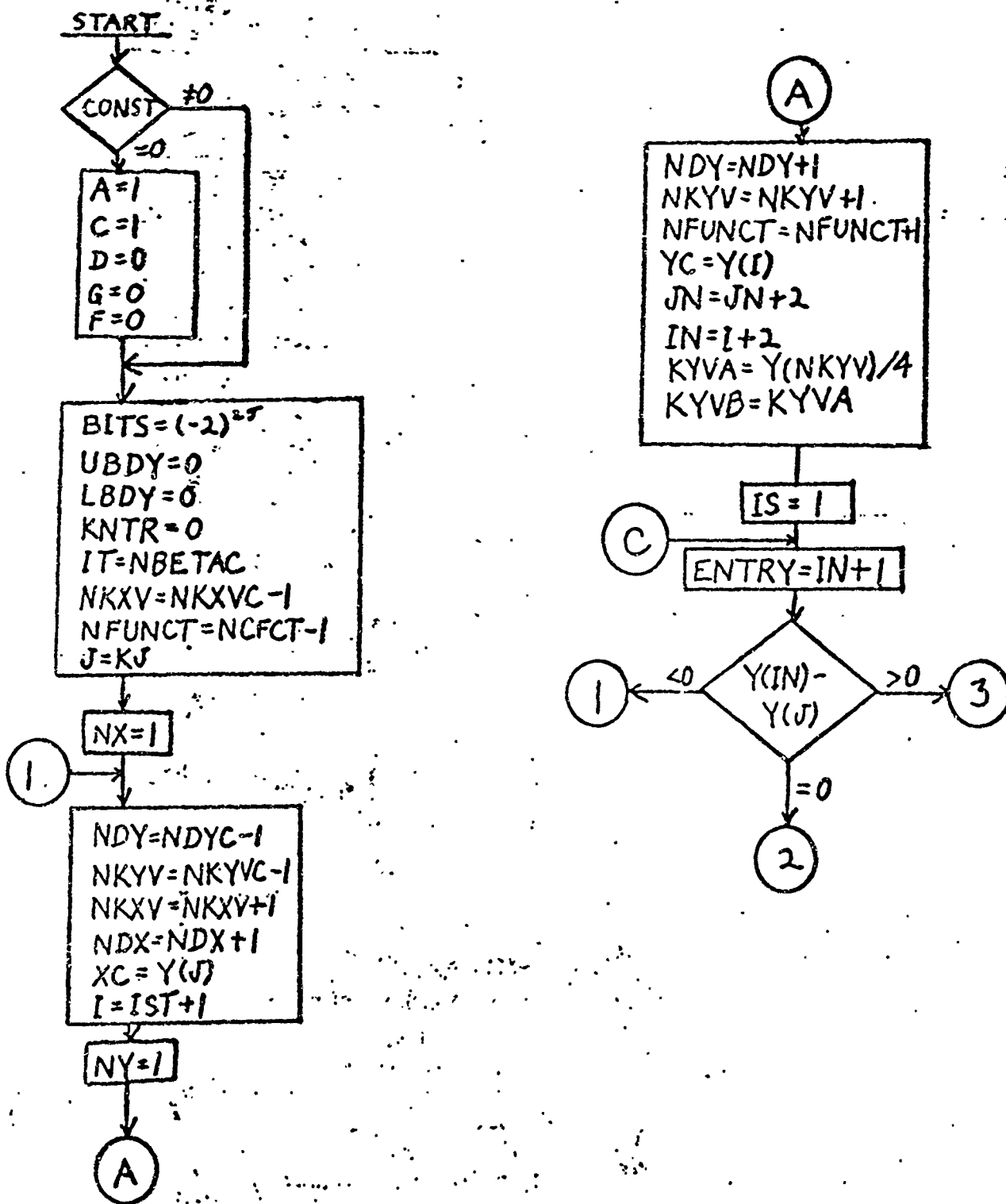


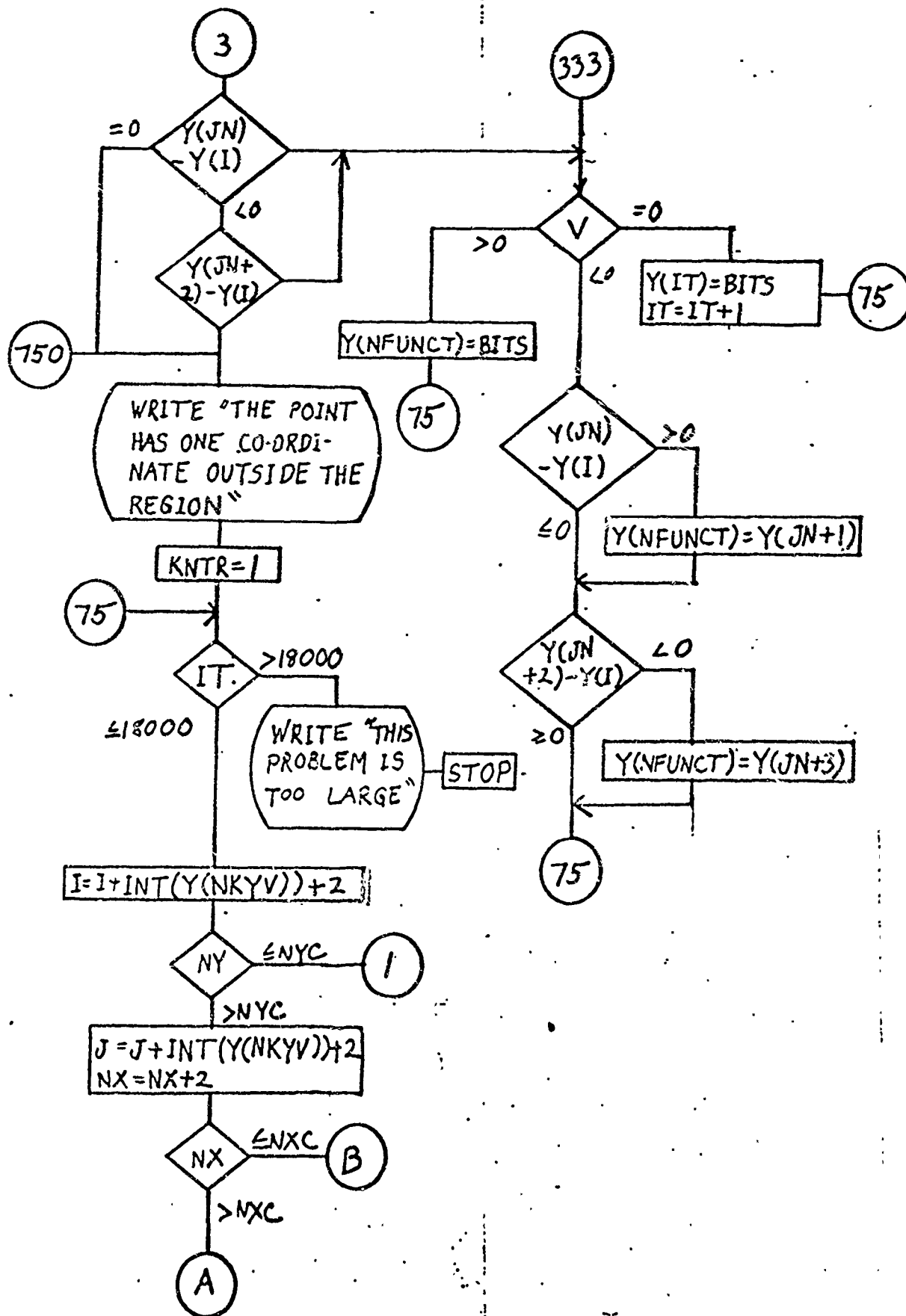
REVISED



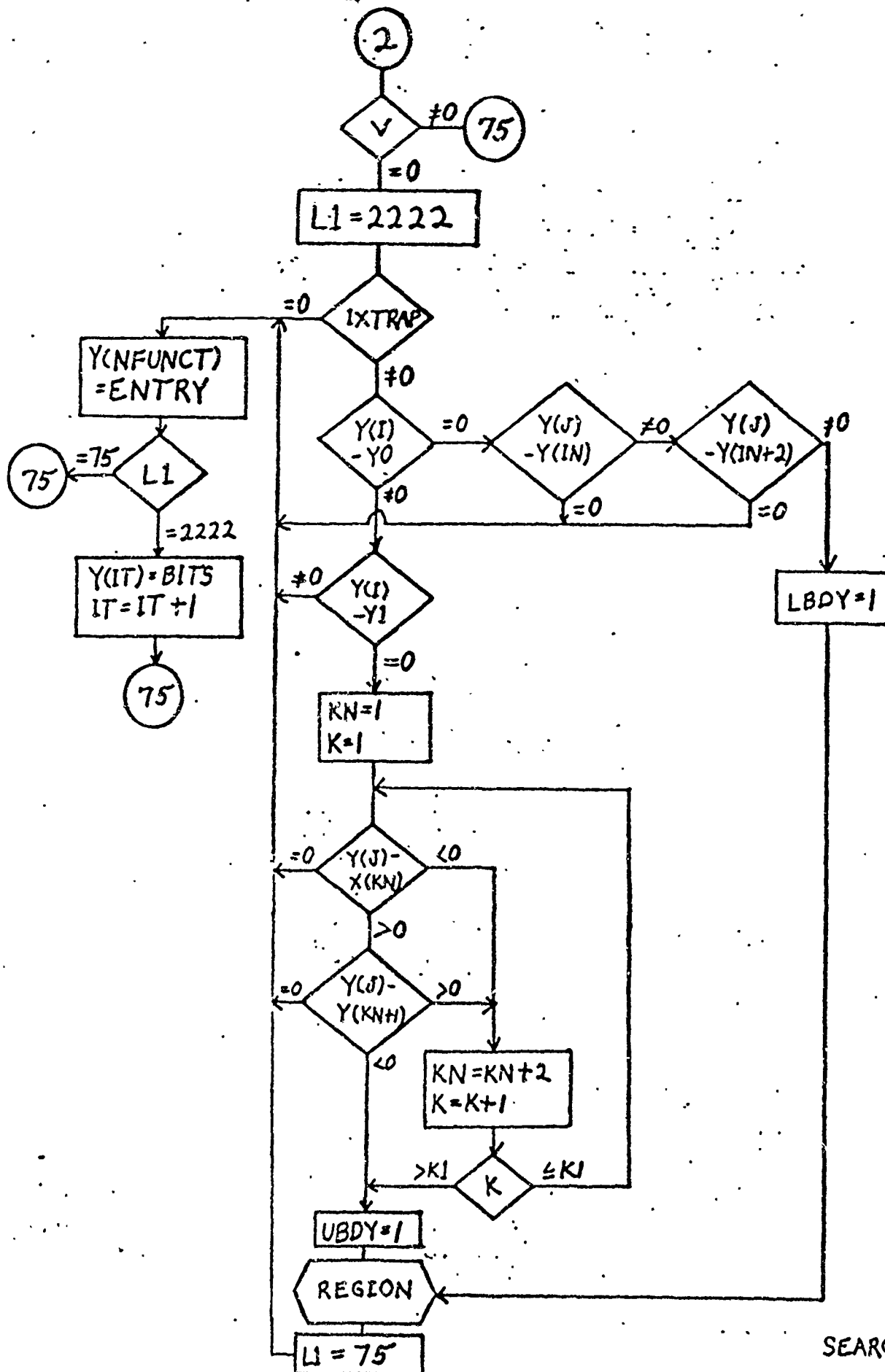
CHECK 6

SUBROUTINE SEARCH

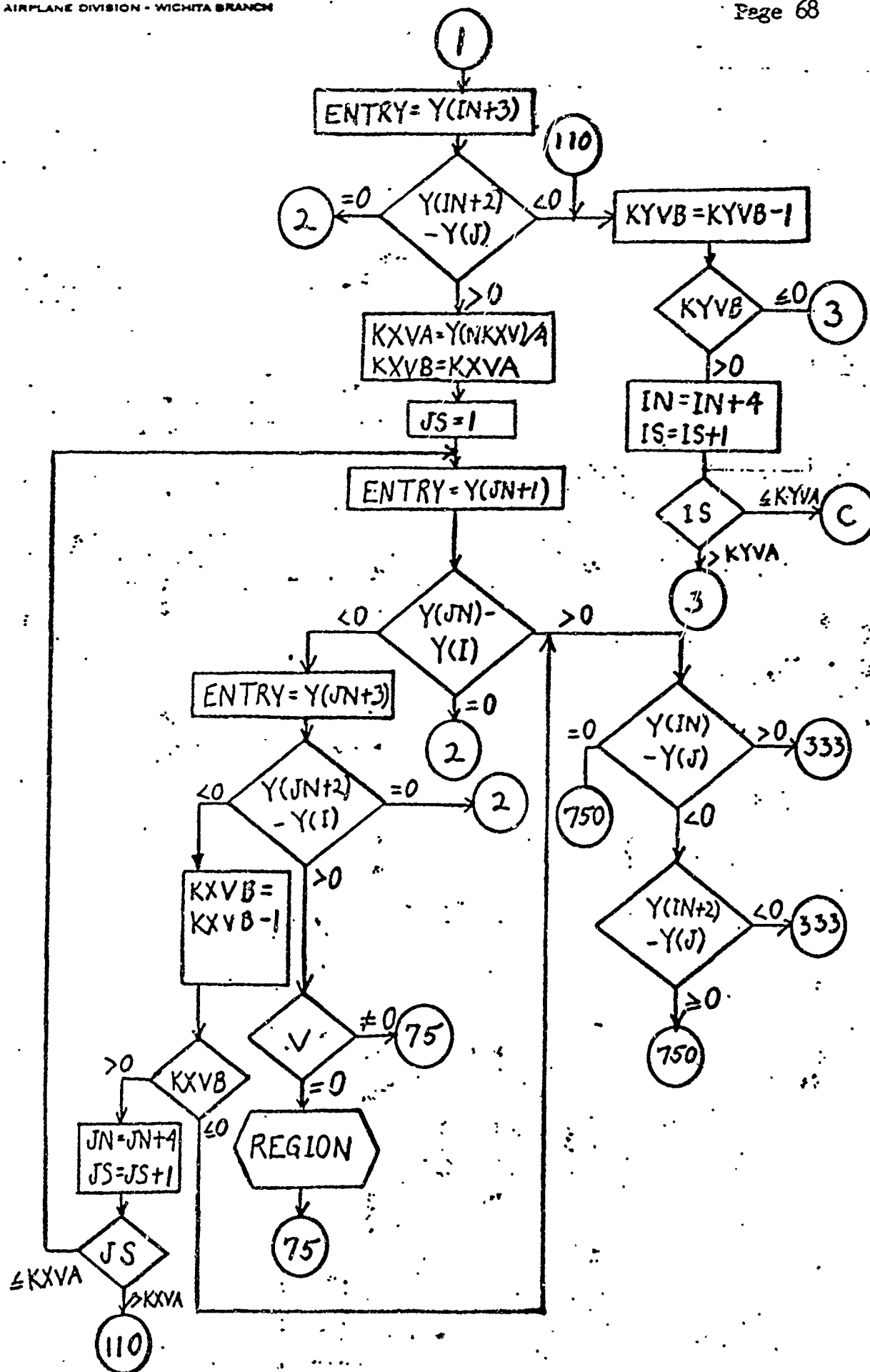




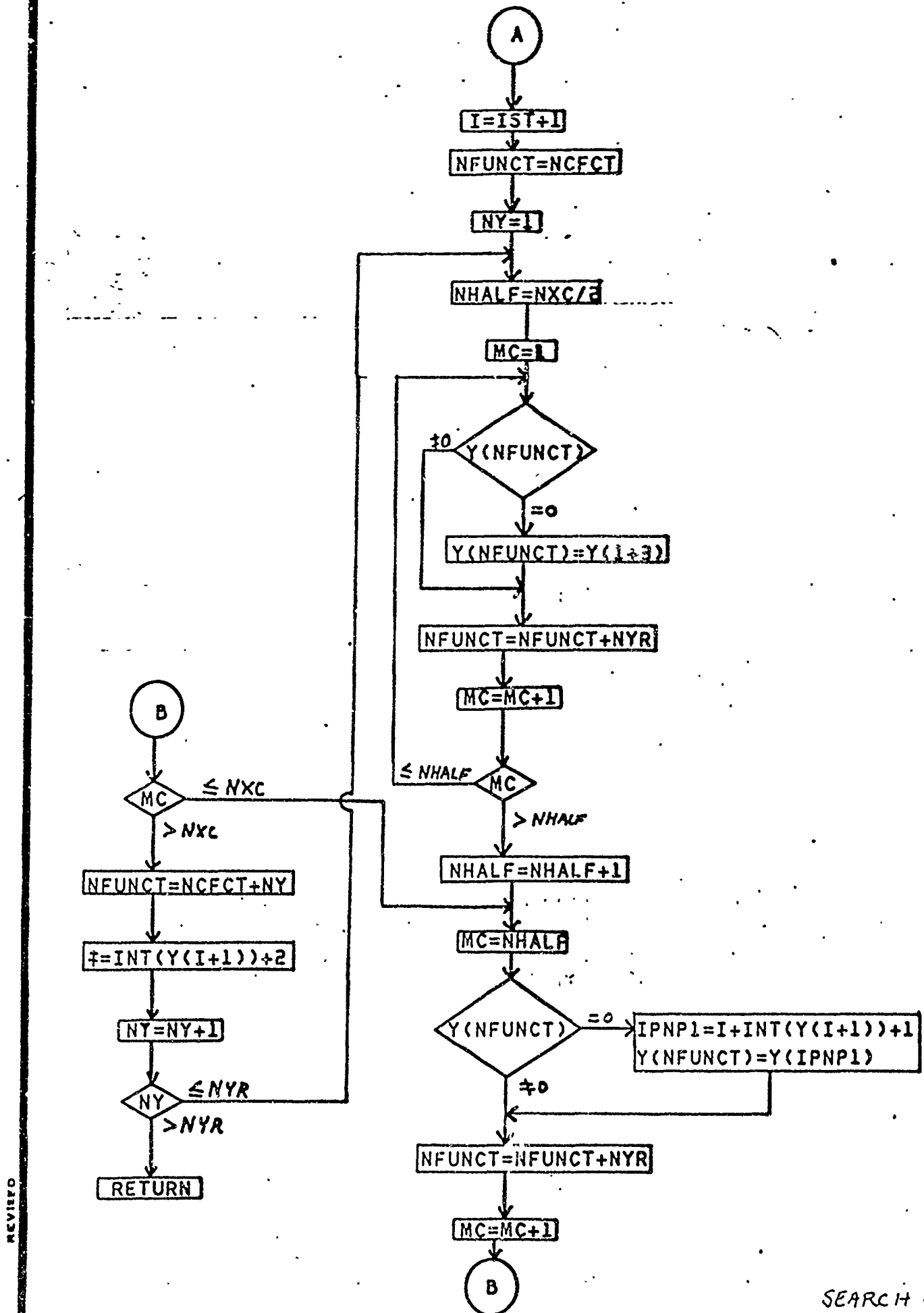
SEARCH 2



SEARCH 3

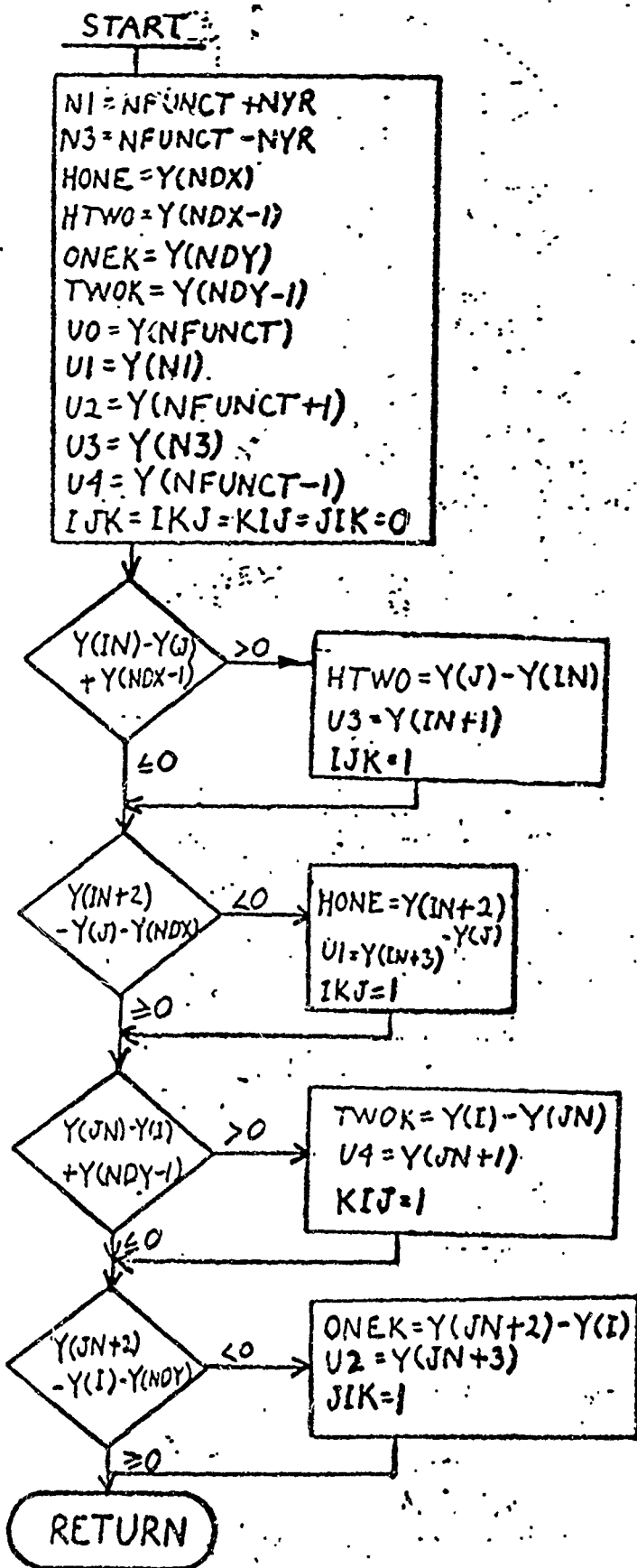


SEARCH 4



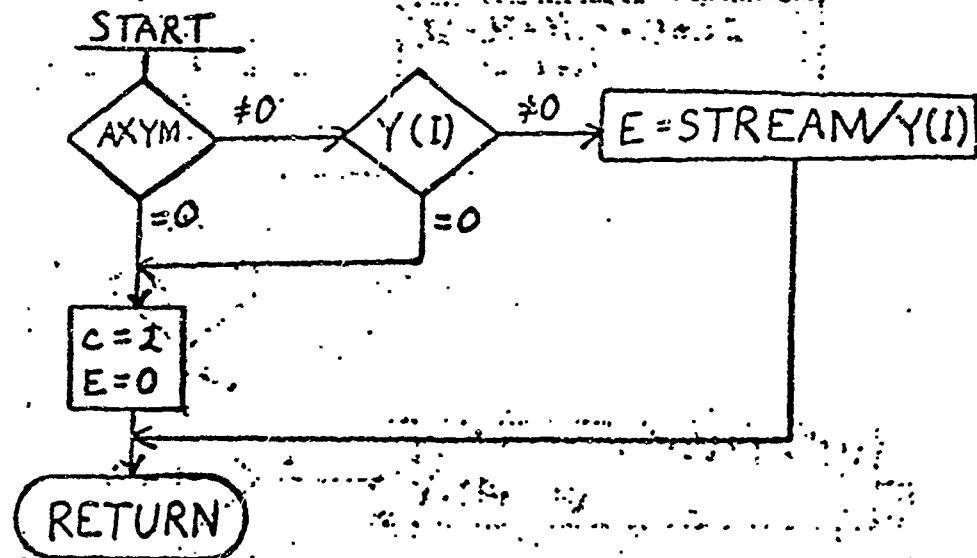
REVISED

SUBROUTINE GRDSTL

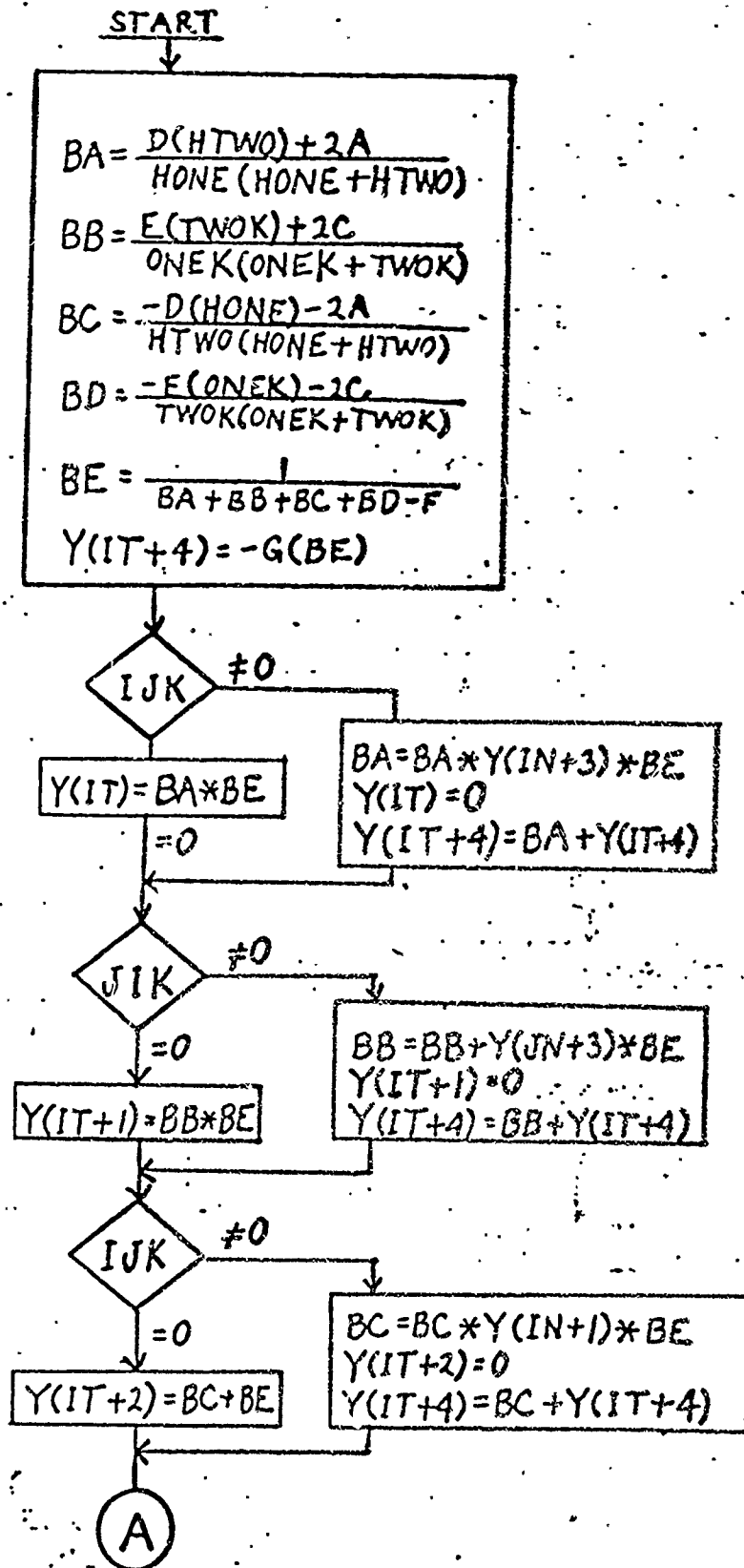


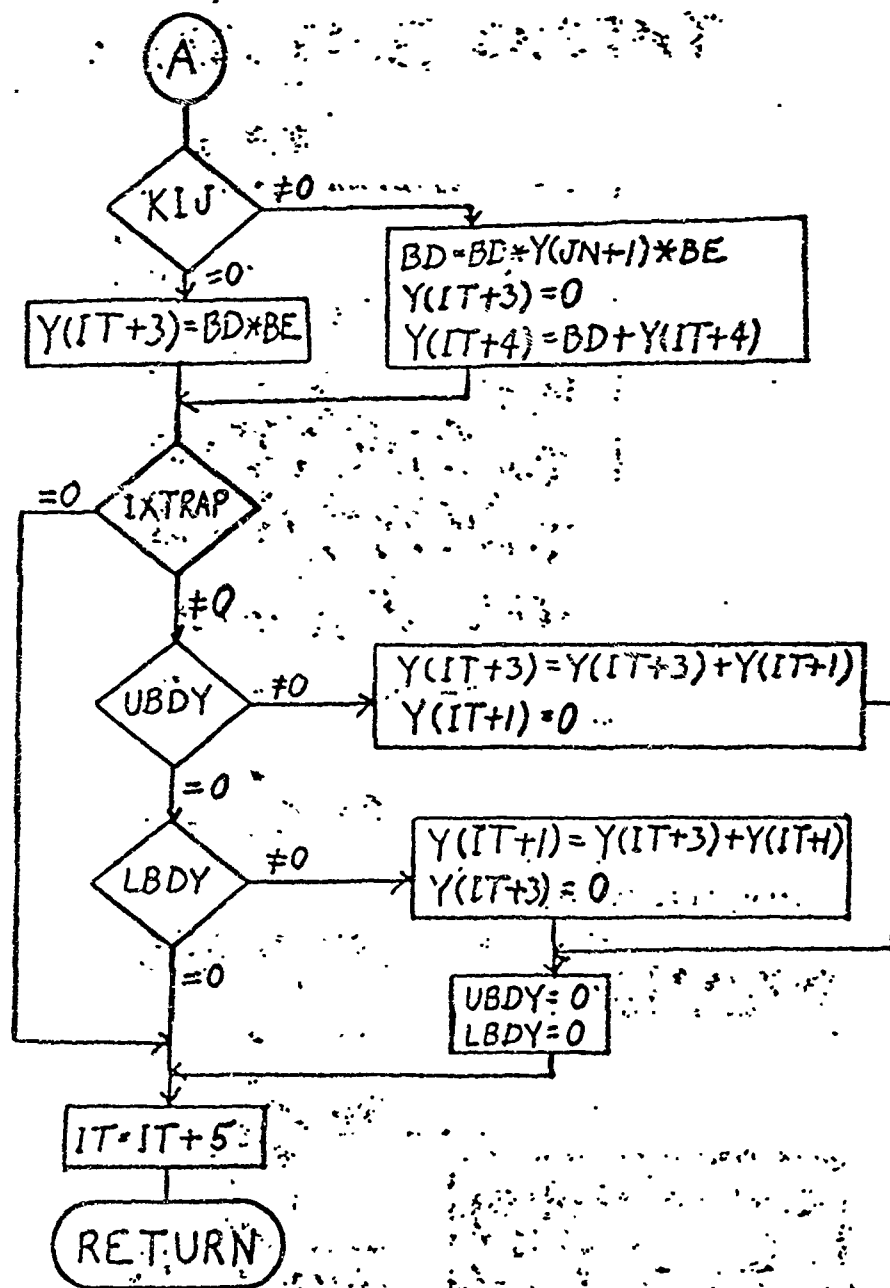
REVISED

SUBROUTINE ACDEFG



SUBROUTINE CNSTNT

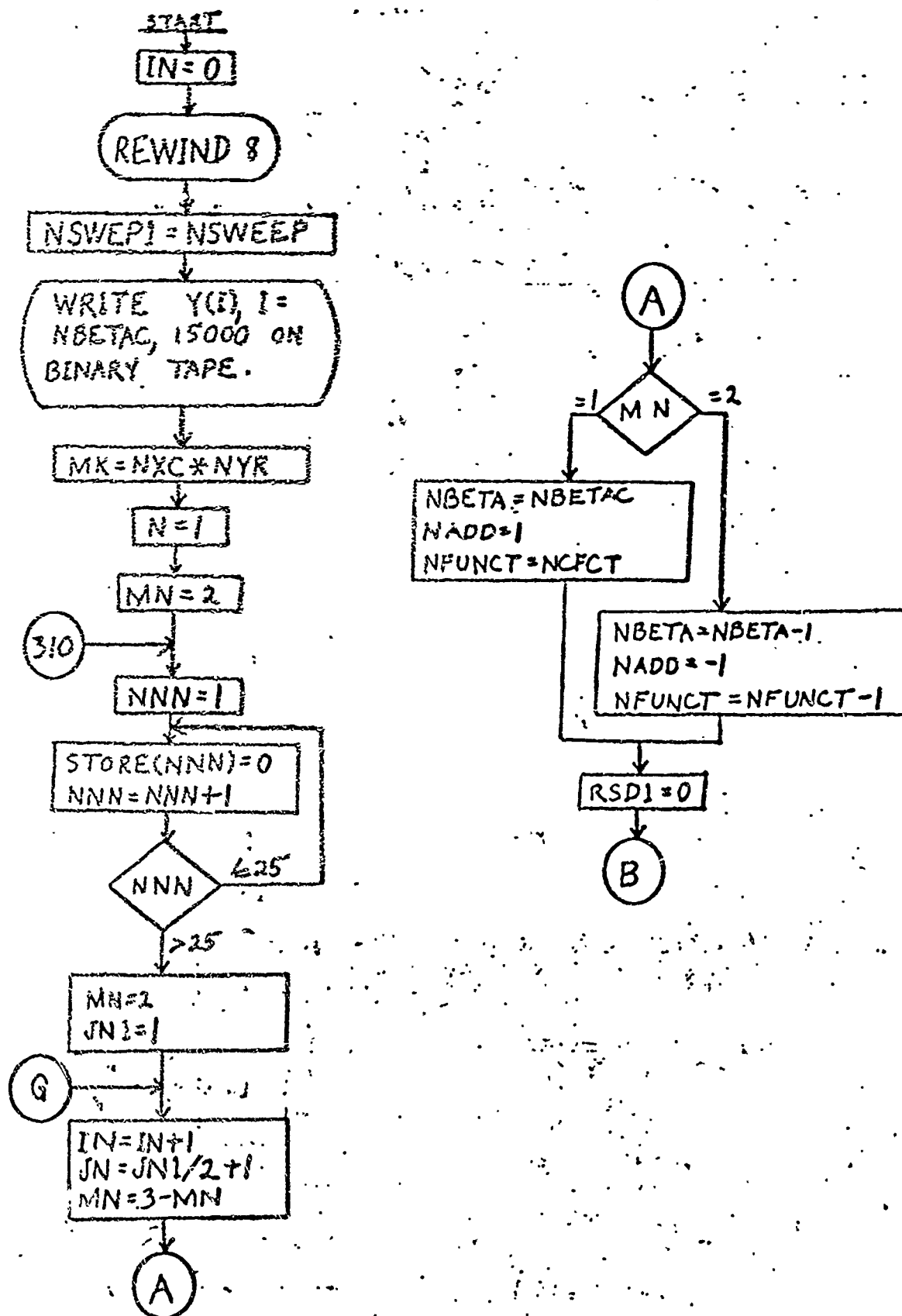


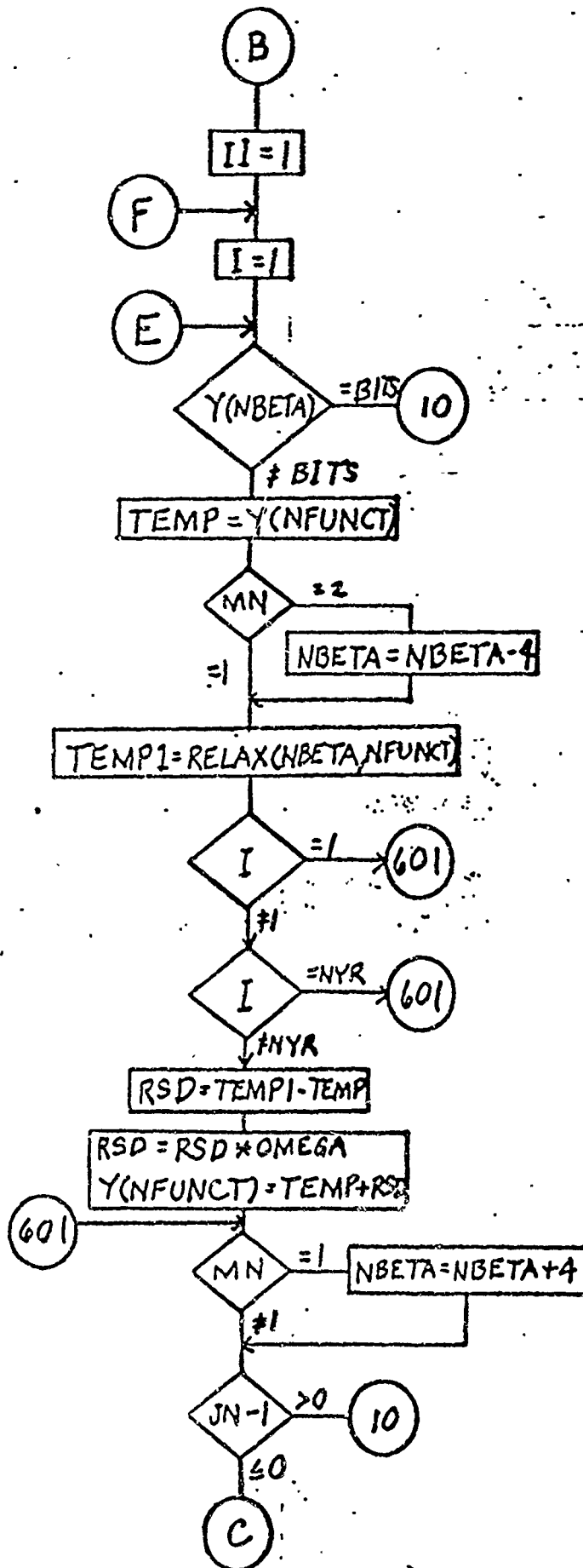


REVISED

CNSTNT 2

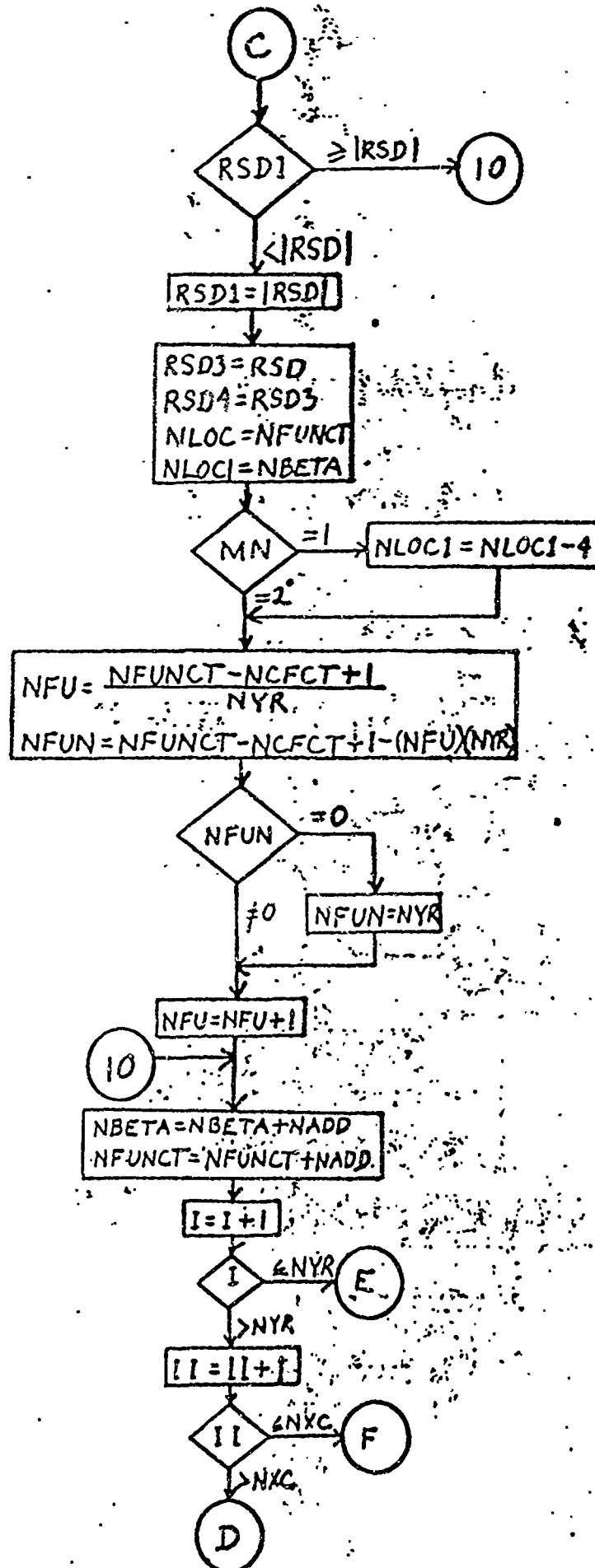
SUBROUTINE SWEEP



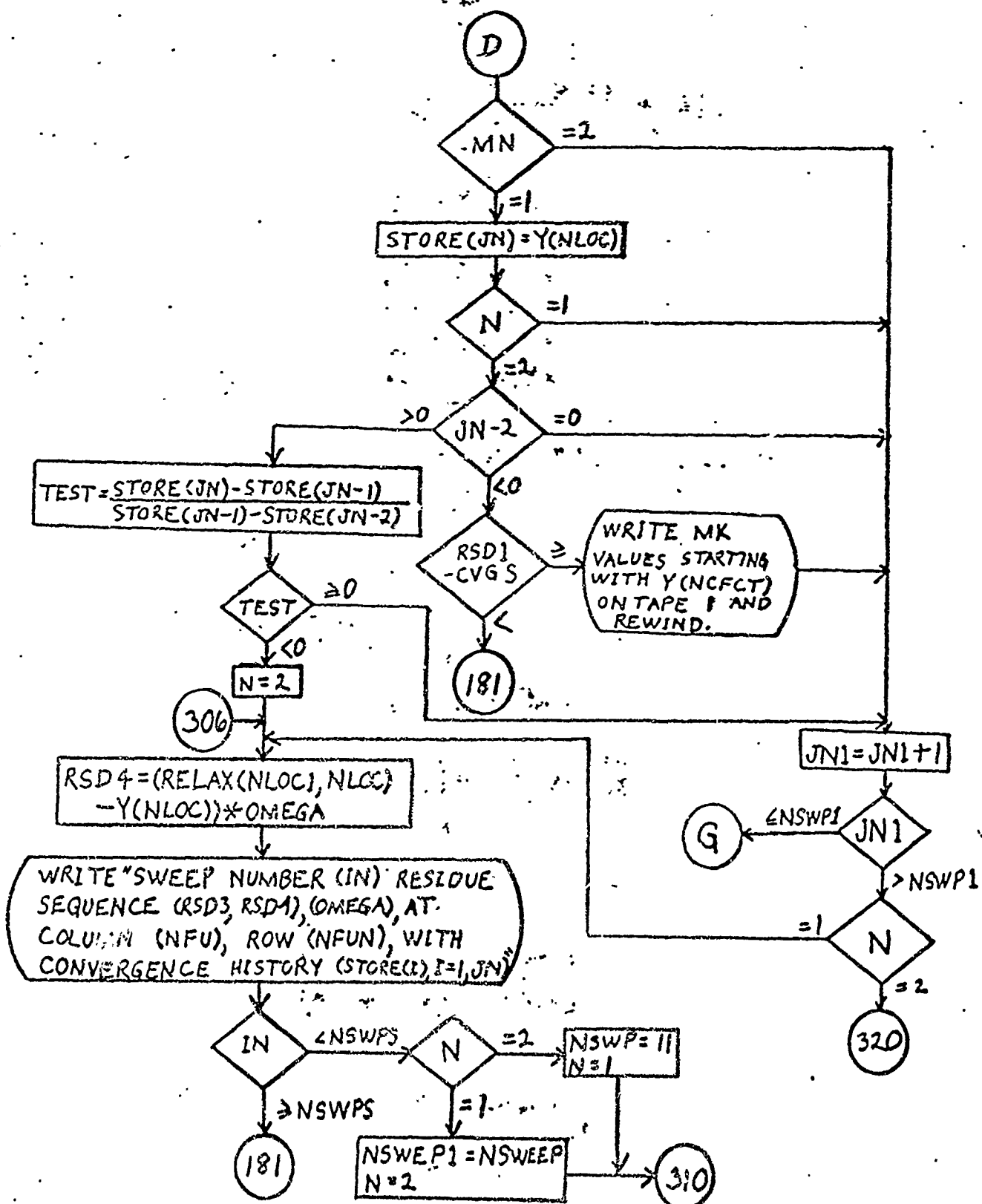


SWEEP 2

REVISED

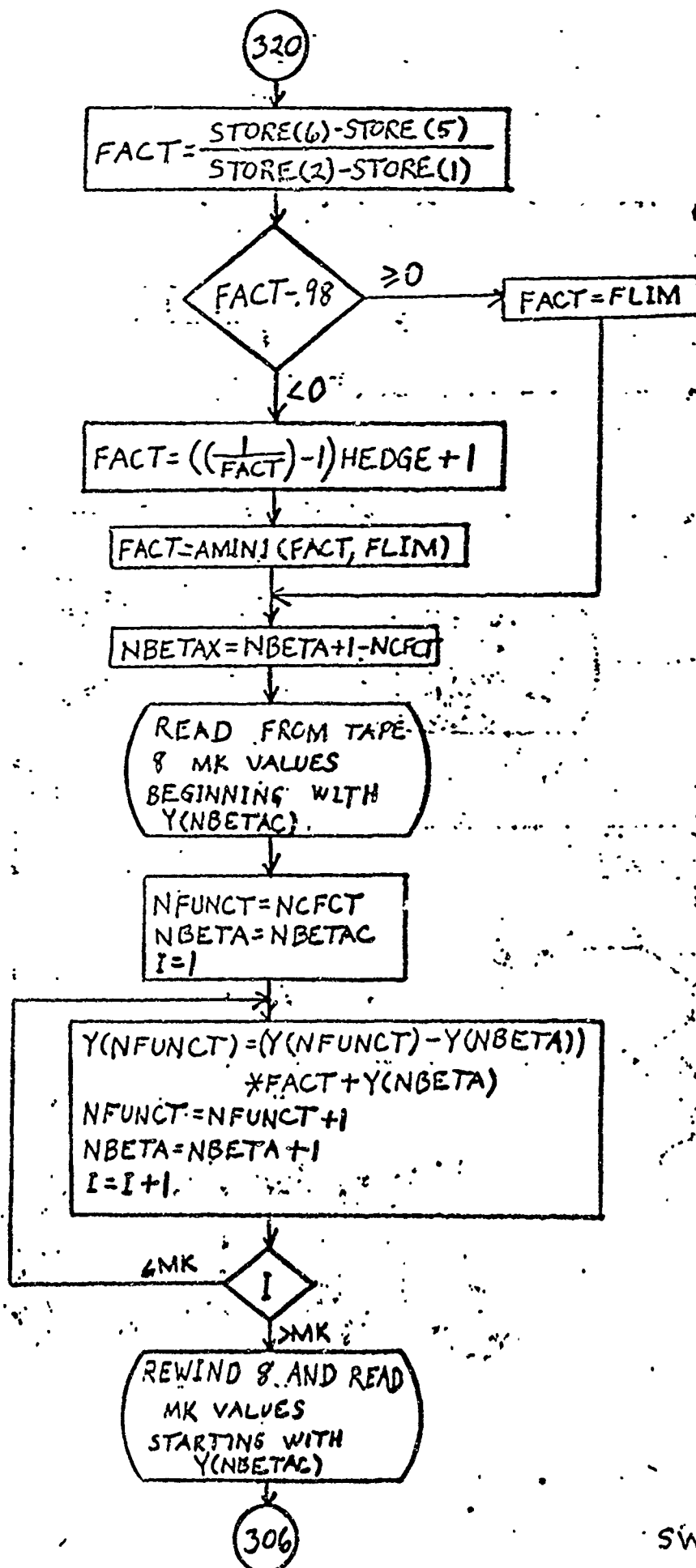


SWEEP 3



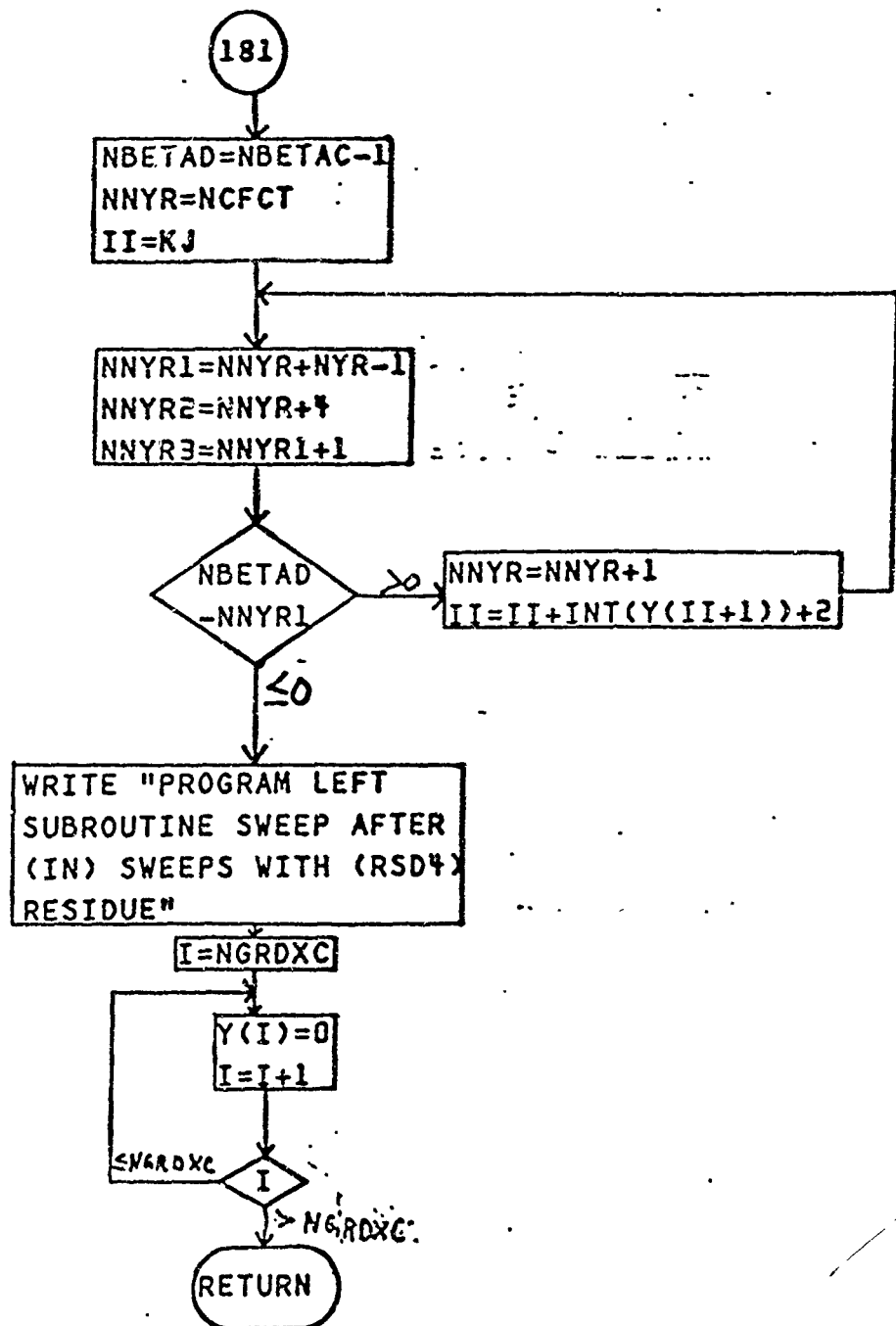
REVISED

SWEEP 4



REVISED

SWEEP: 5



REVISED

SWEEP 6

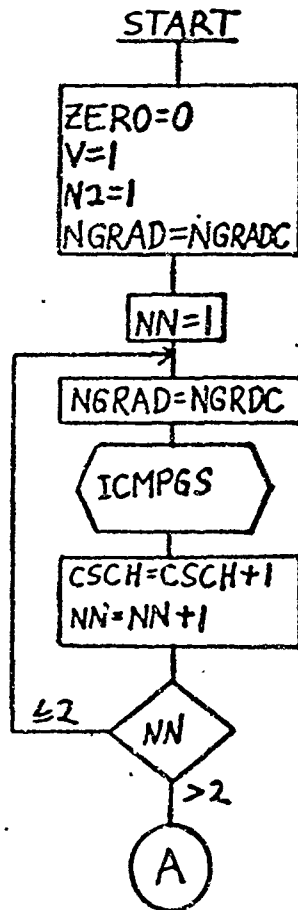
FUNCTION RELAX

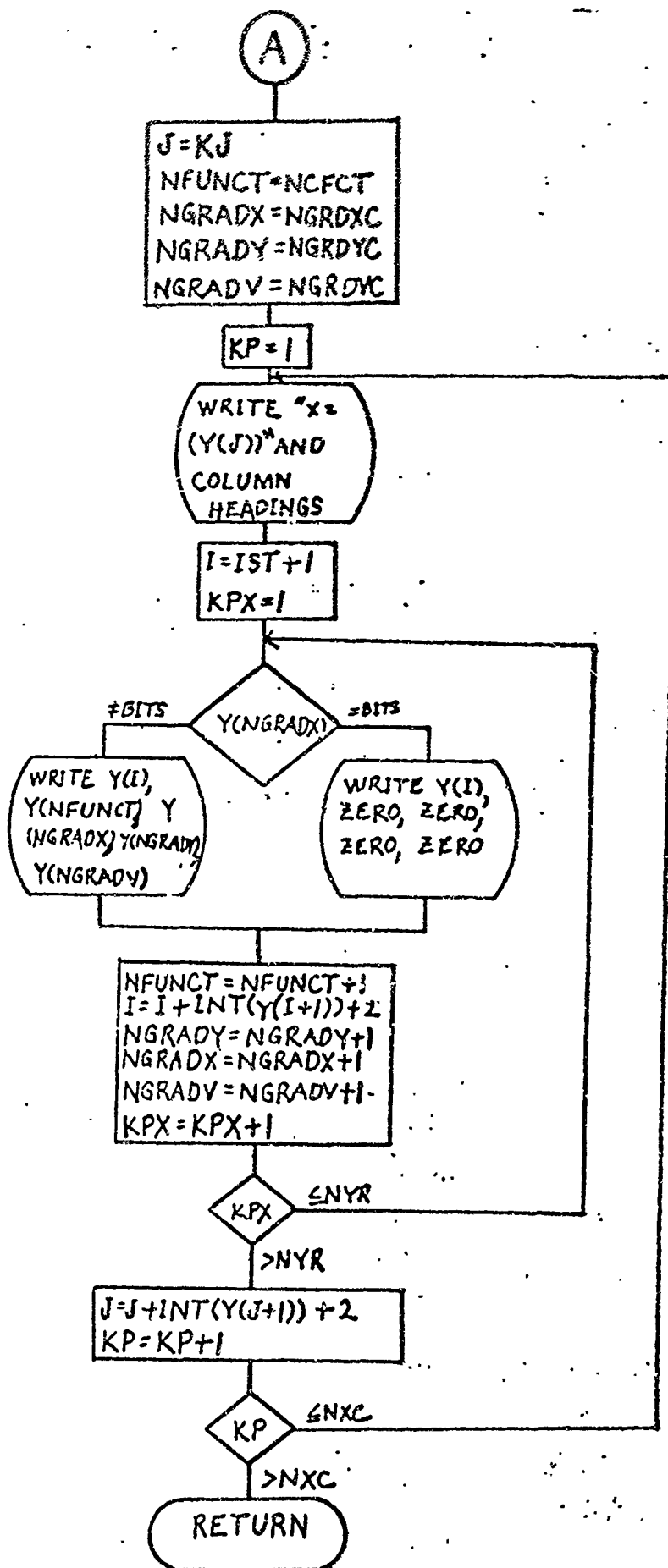
START

NI=NFUNCT+NYR
N3=NFUNCT-NYR
RELAX=Y(NI)*Y(NB)
+Y(NFUNCT+1)*Y(NB+1)
+Y(N3)*Y(NB+2)
+Y(NFUNCT-1)*Y(NB+3)
+Y(NB+4)

RETURN

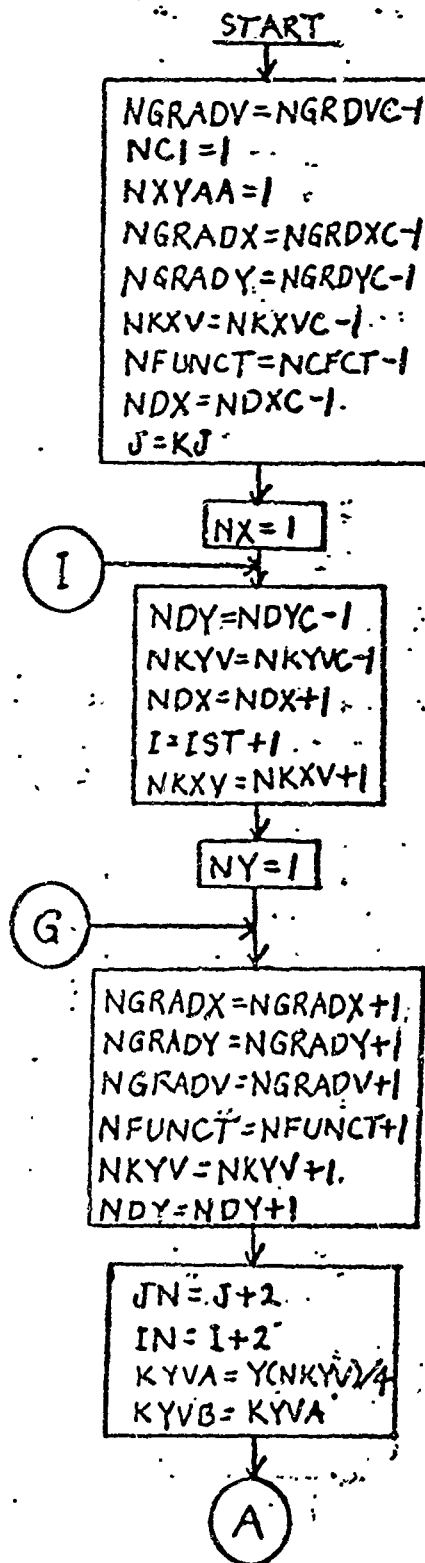
SUBROUTINE VELOC

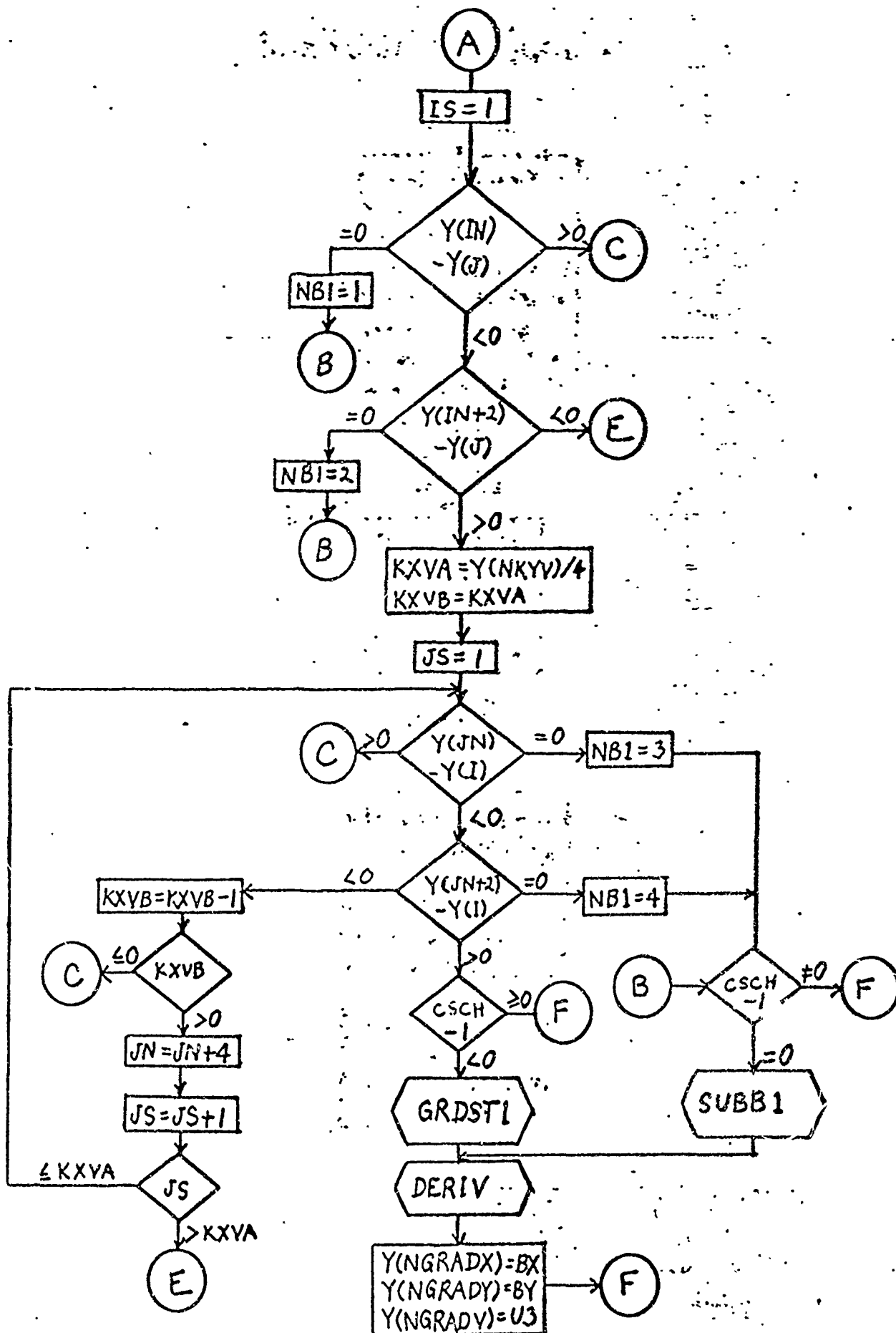


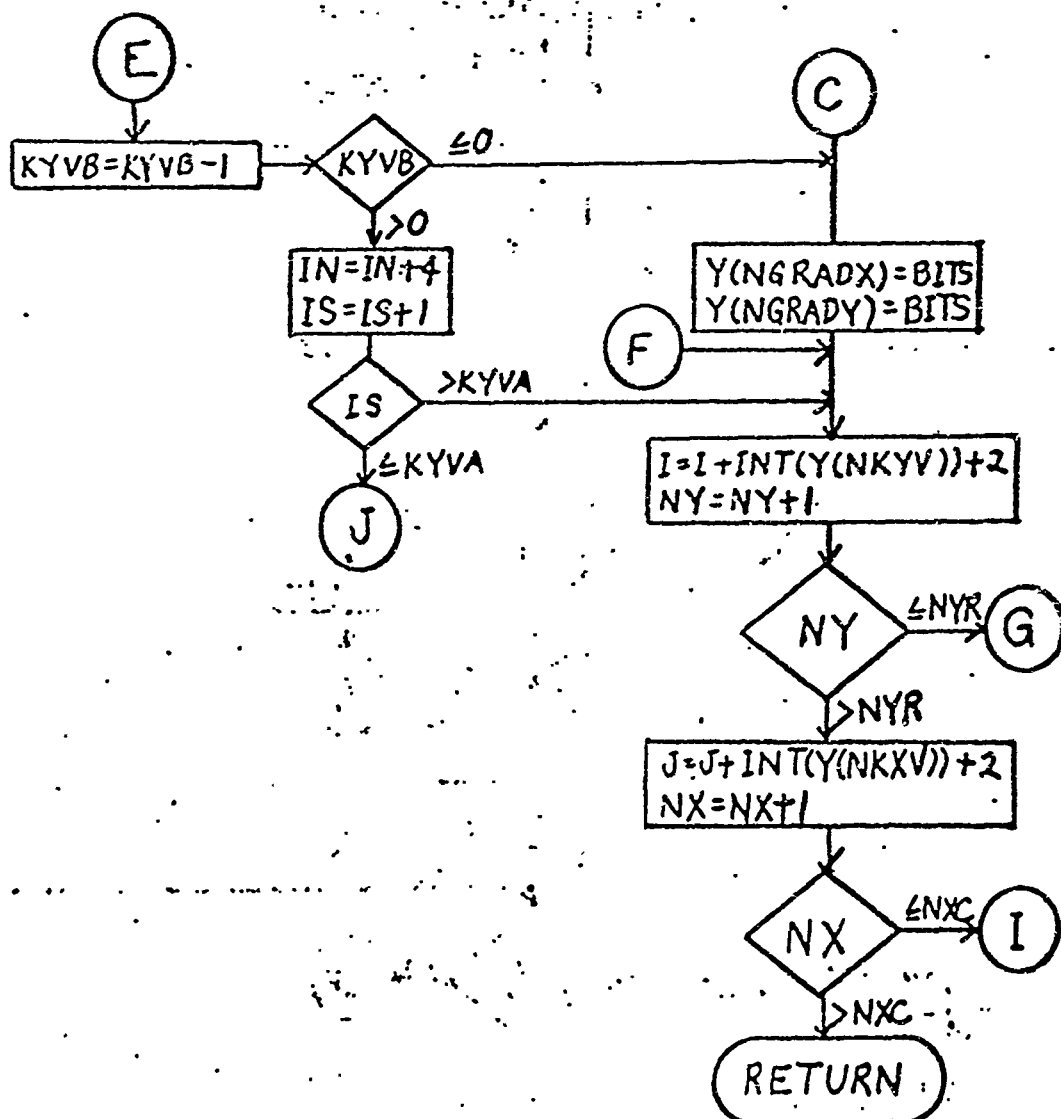


VELQC 2

SUBROUTINE ICMPGS







SUBROUTINE GRDSTI

START

```

NXA=1
NYA=1
NI=NFUNCT+NYR
N3=NFUNCT+NYR
H1=Y(NDX)
H2=Y(NDX-1)
TK1=Y(NDY)
TK2=Y(NDY-1)
U0=Y(NFUNCT)
U1=Y(NI)
U2=Y(NFUNCT+1)
U3=Y(N3)
U4=Y(NFUNCT+1)
IJK=0
IKJ=0
KIJ=0
JIK=0
    
```

$Y(IN) - Y(J) + Y(NDX-1) > 0$

HTWO = $Y(J) - Y(IN)$
U3 = $Y(IN+1)$
IJK = 1

$Y(IN+2) - Y(J) - Y(NDX)$

HONE = $Y(IN+2) - Y(J)$
U1 = $Y(IN+3)$
IKJ = 1

$Y(JN) - Y(I) + Y(NDY-1)$

TWOK = $Y(I) - Y(JN)$
U4 = $Y(JN+1)$
KIJ = 1

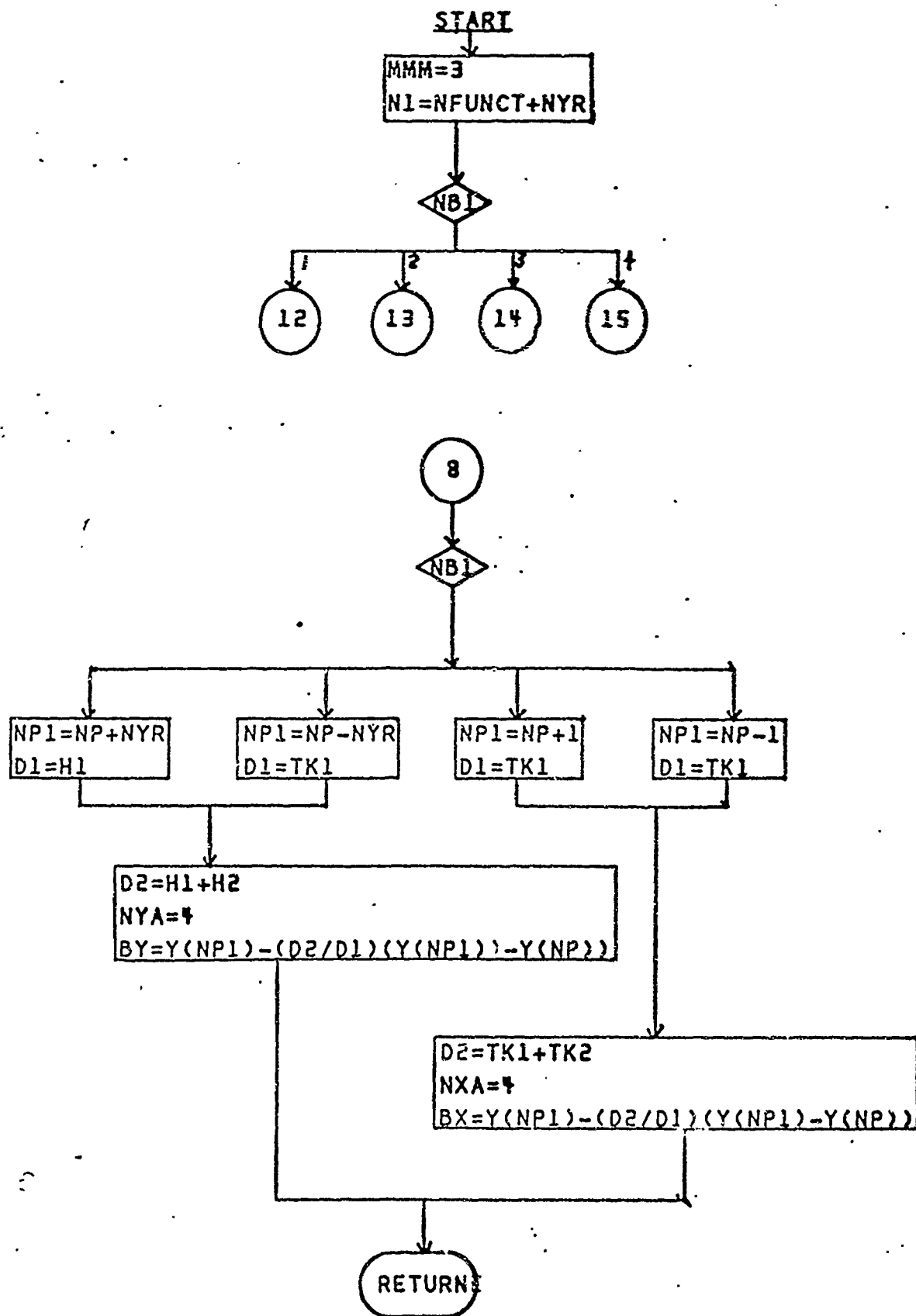
$Y(JN+2) - Y(I) - Y(NDY)$

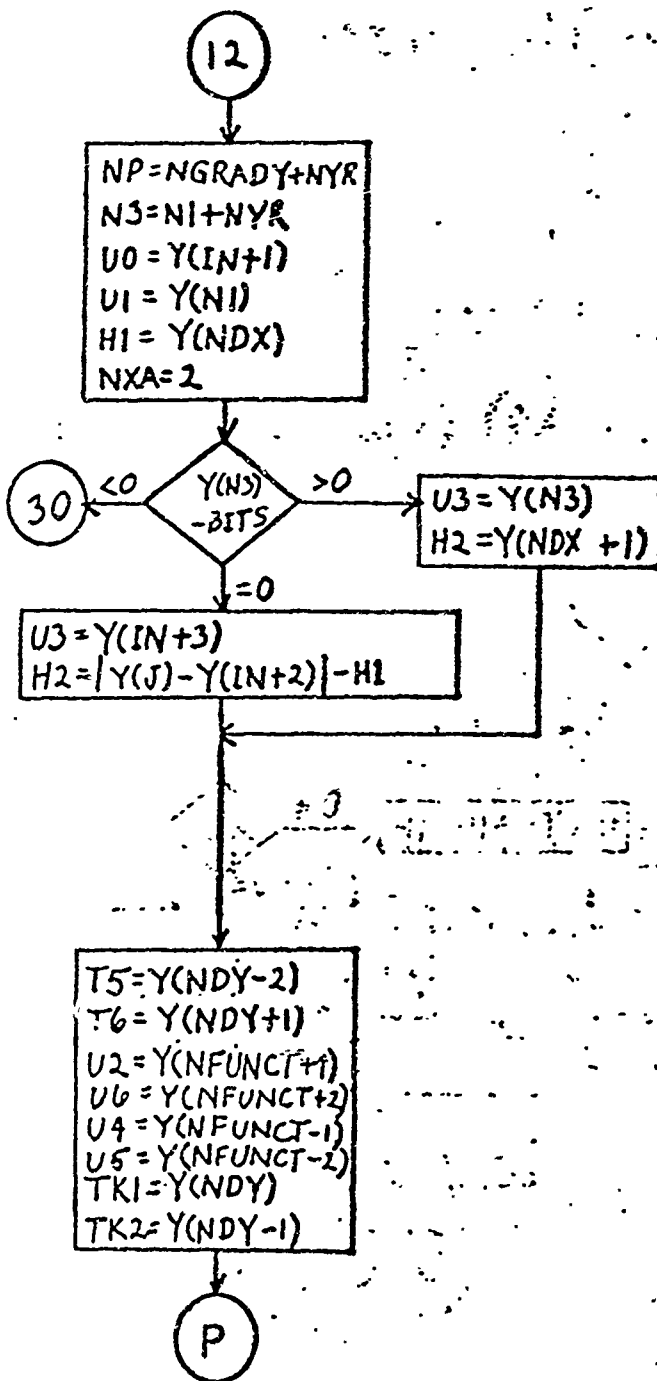
ONEK = $Y(JN+2) - Y(I)$
U2 = $Y(JN+3)$
JIK = 1

RETURN

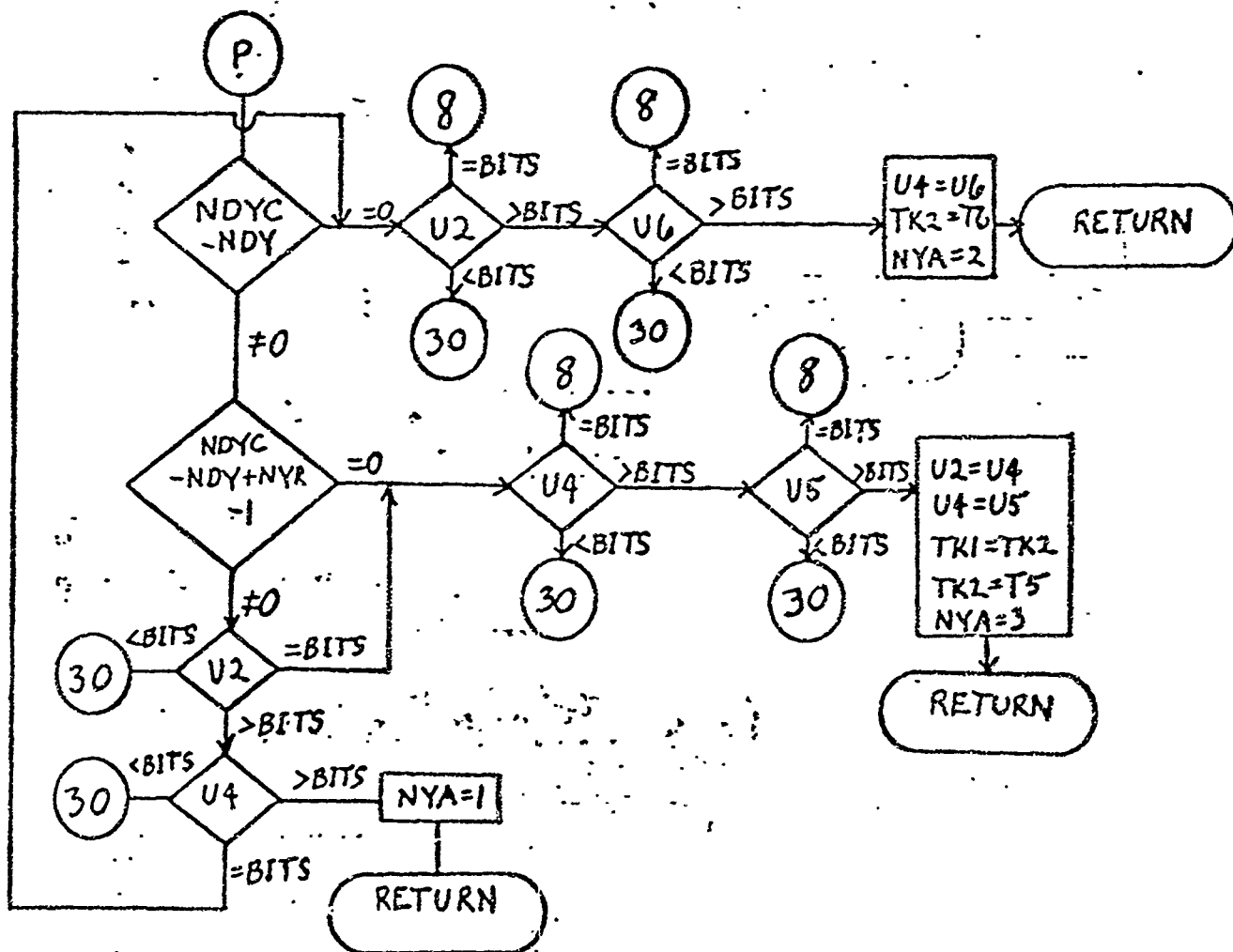
REVISED

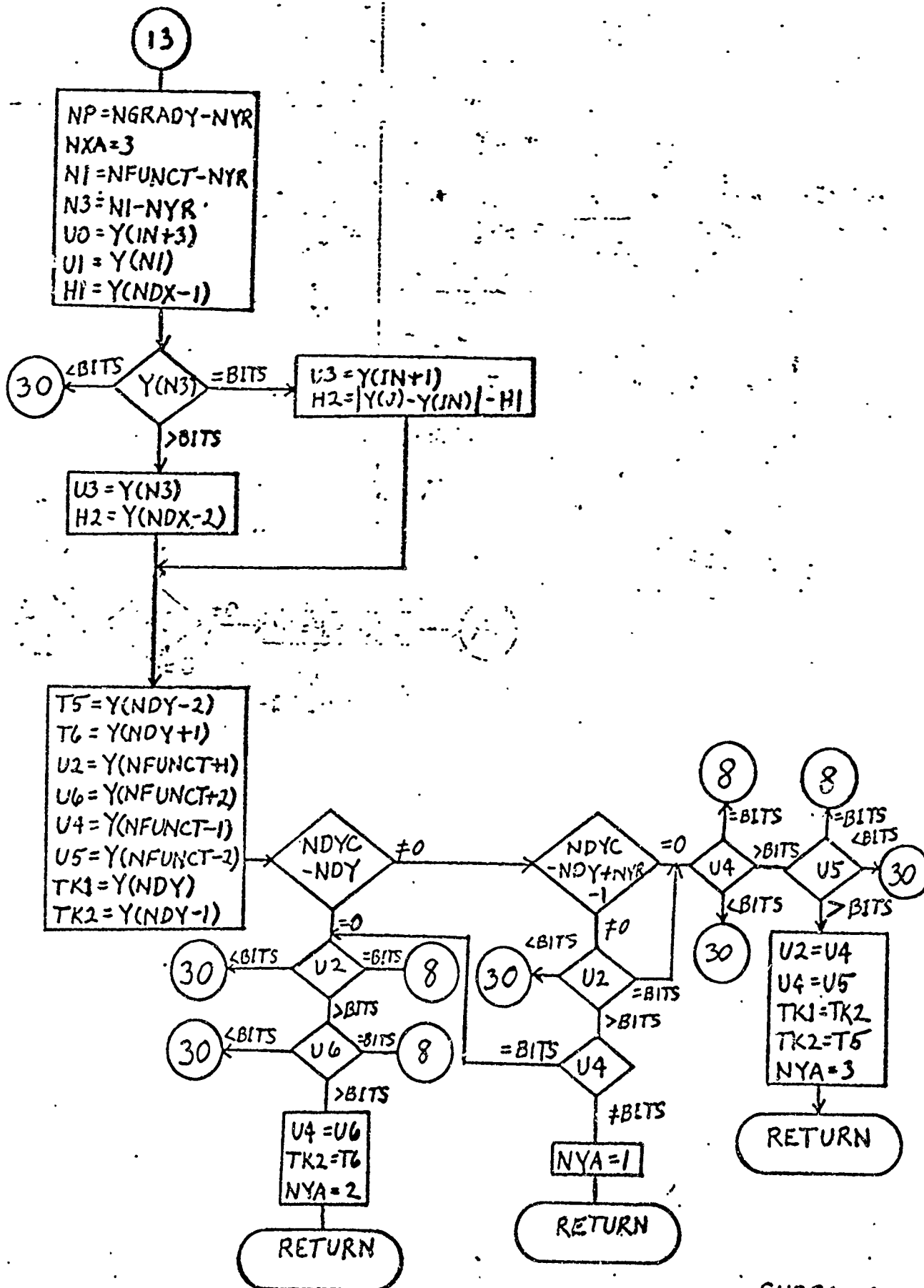
SUBROUTINE SUBB1



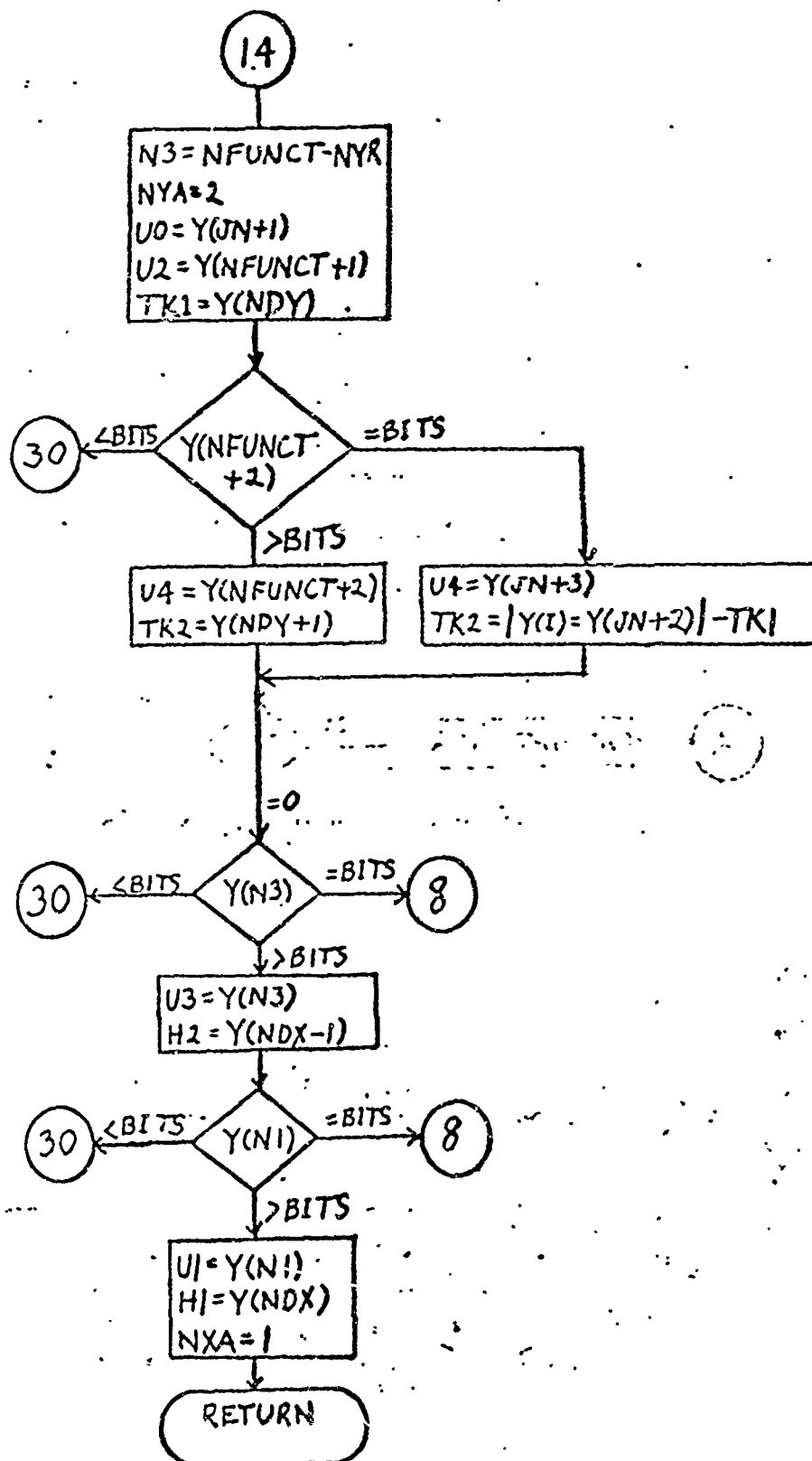


SUBB1 2



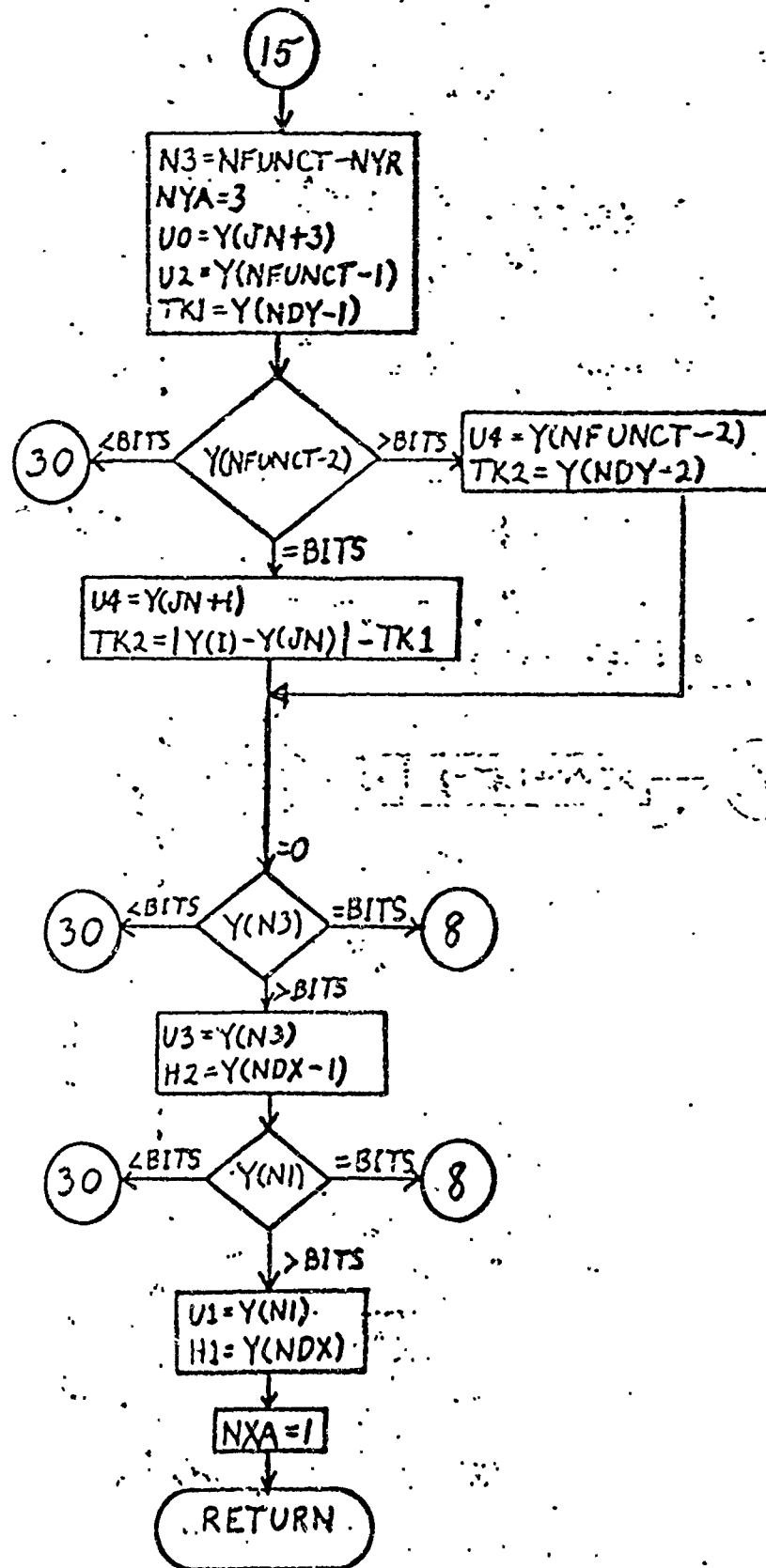


SUBB1 4



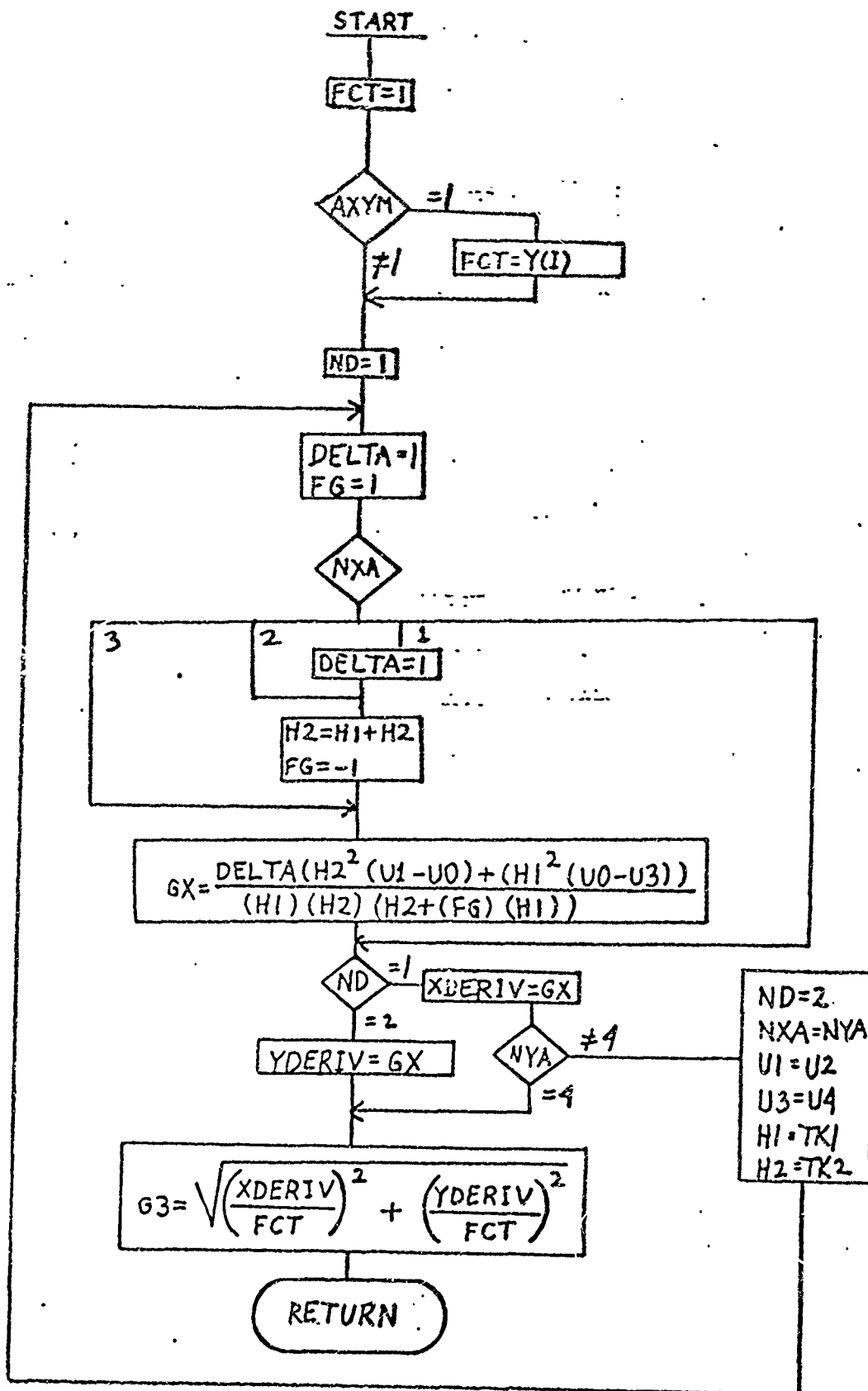
REVISED

SUBB1.5



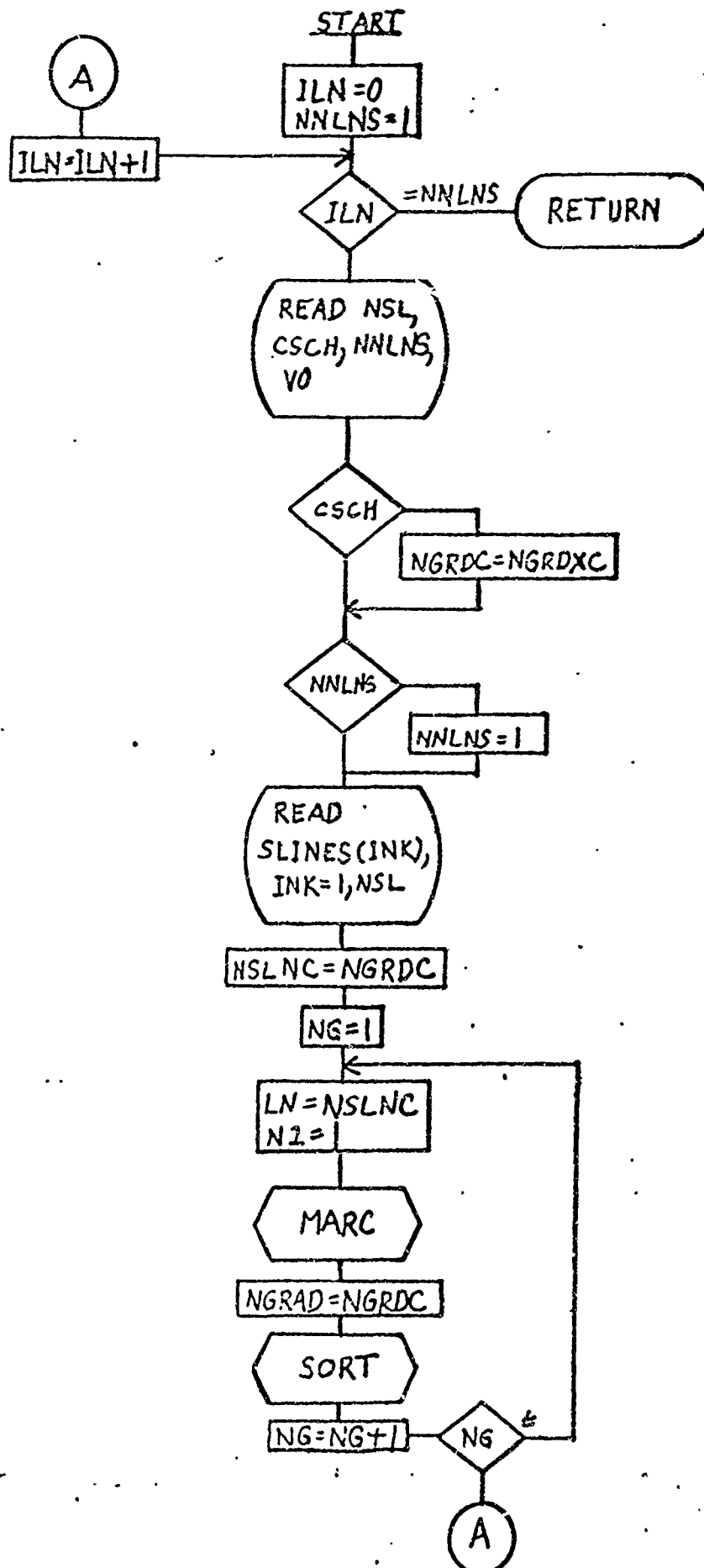
SUBB1 6

SUBROUTINE DERIV

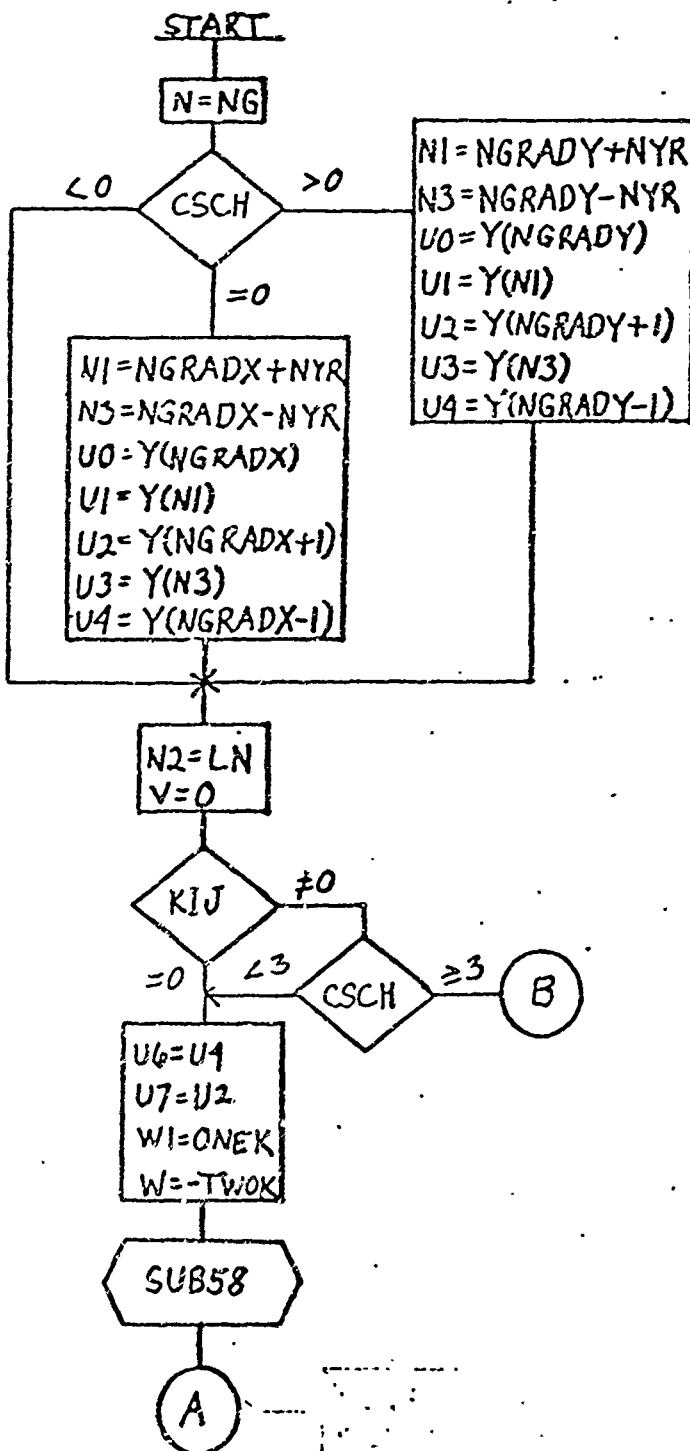


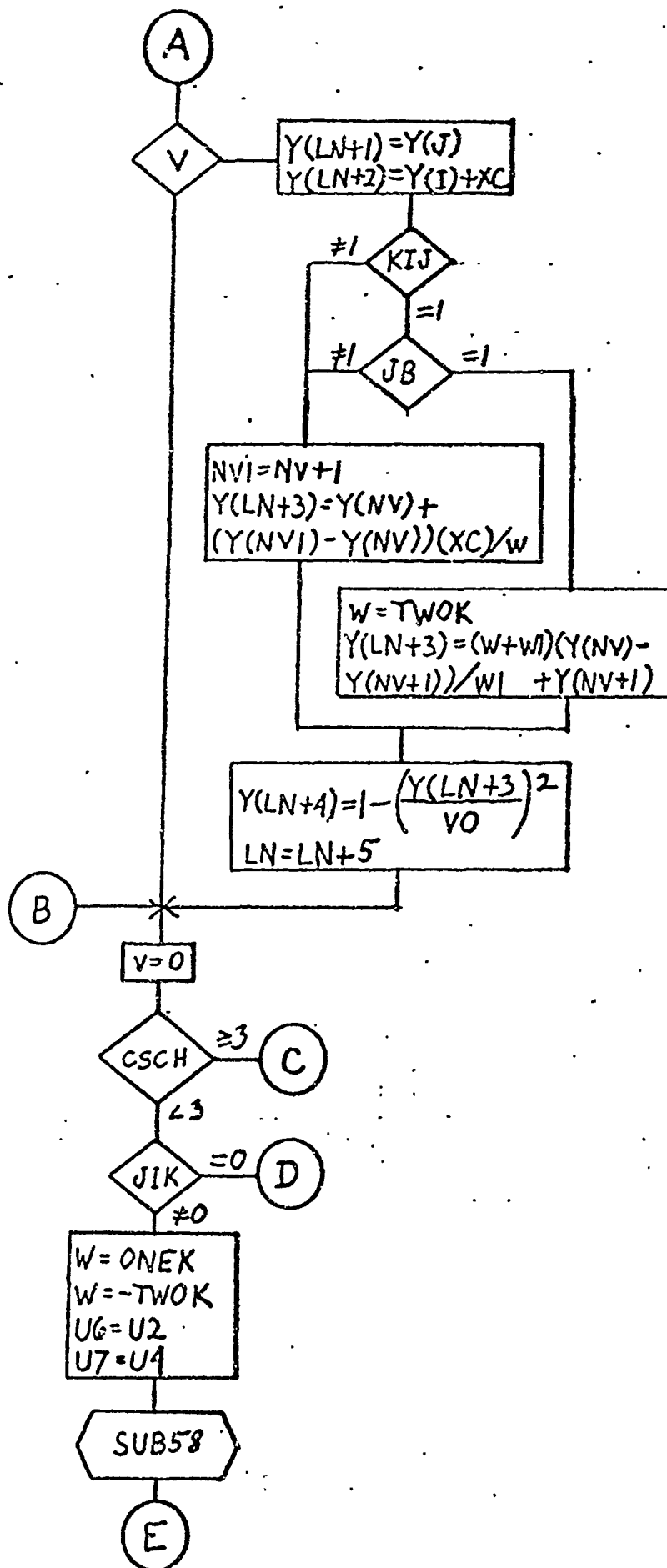
REVISED

SUBROUTINE LINES

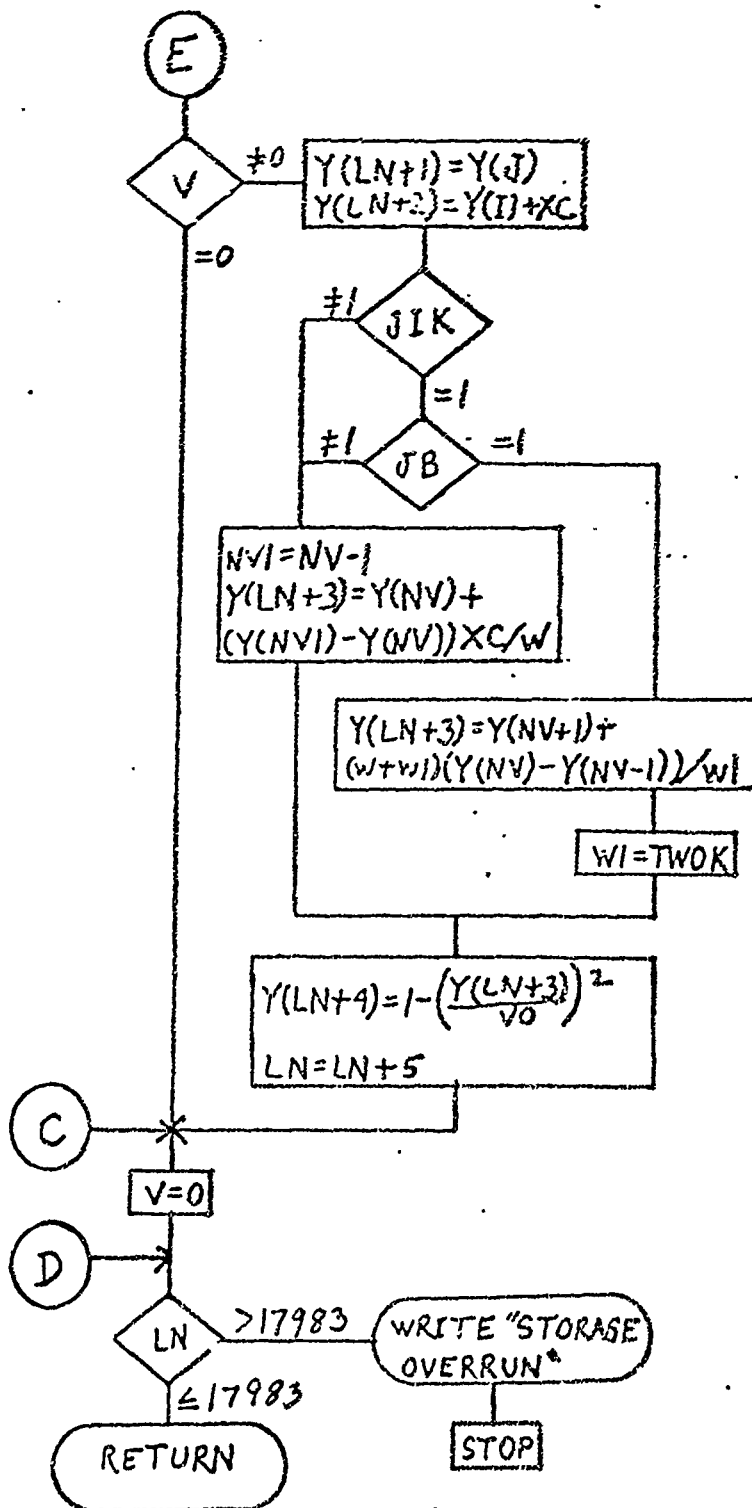


SUBROUTINE SGSRCH



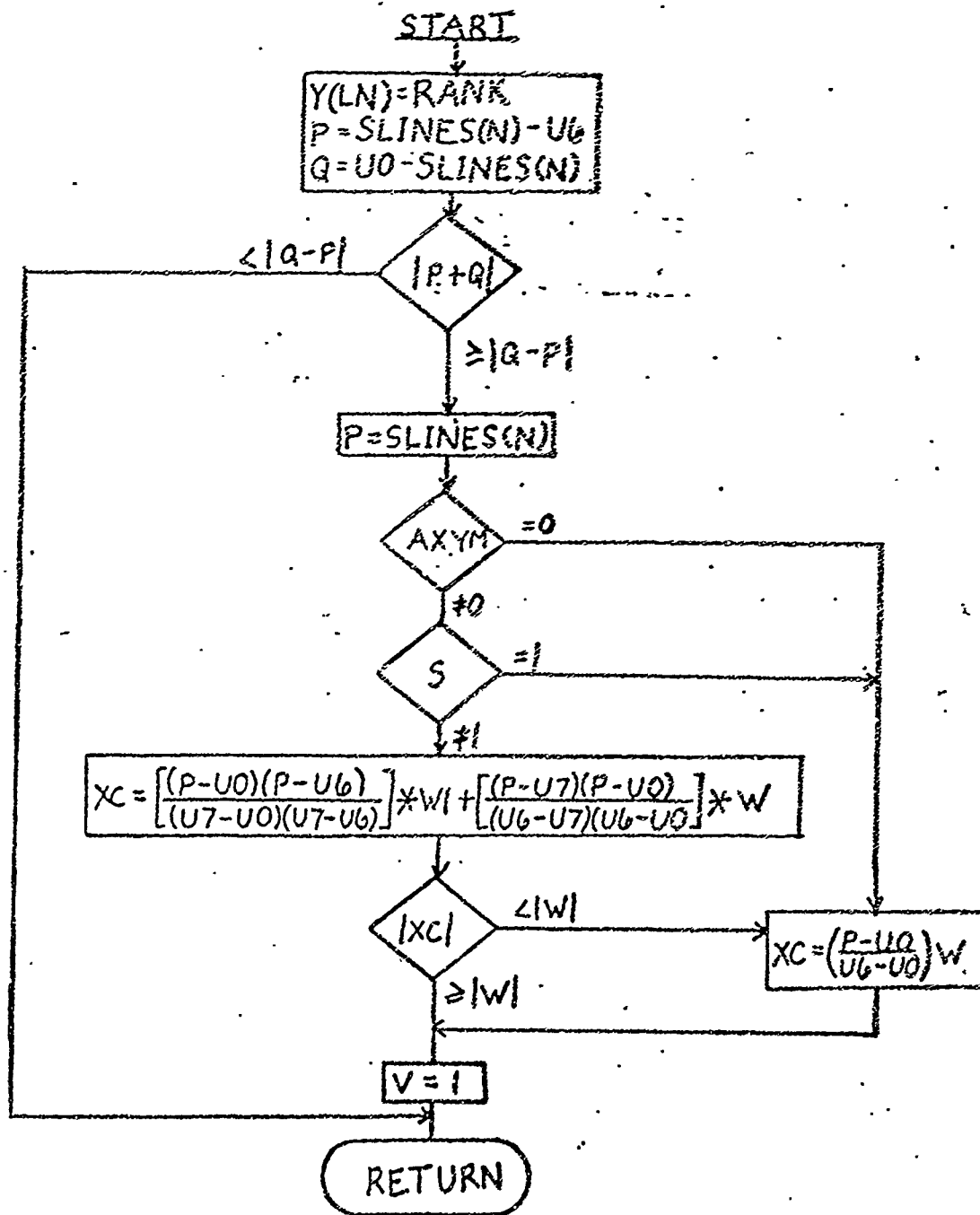


SEARCH 2

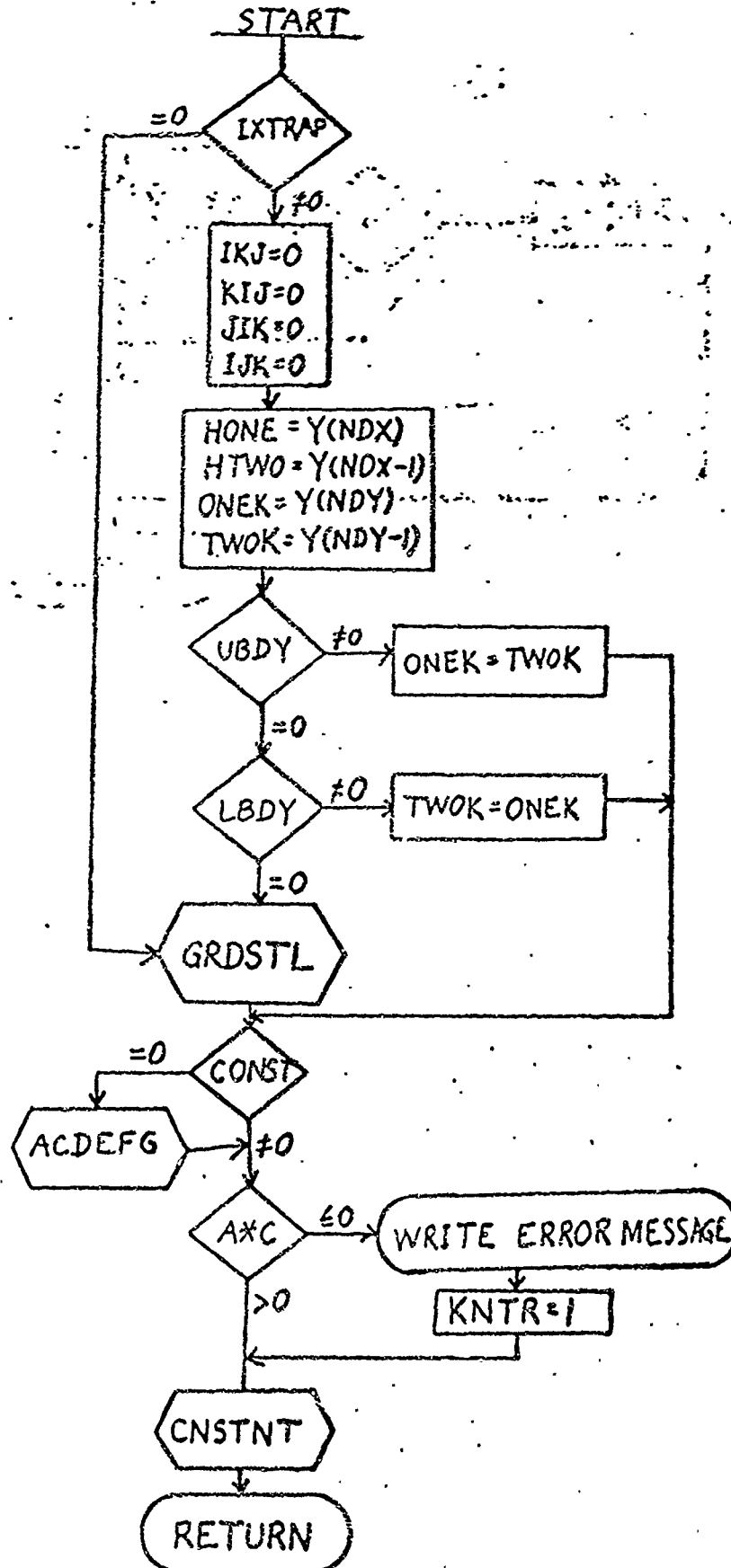


SEARCH 3

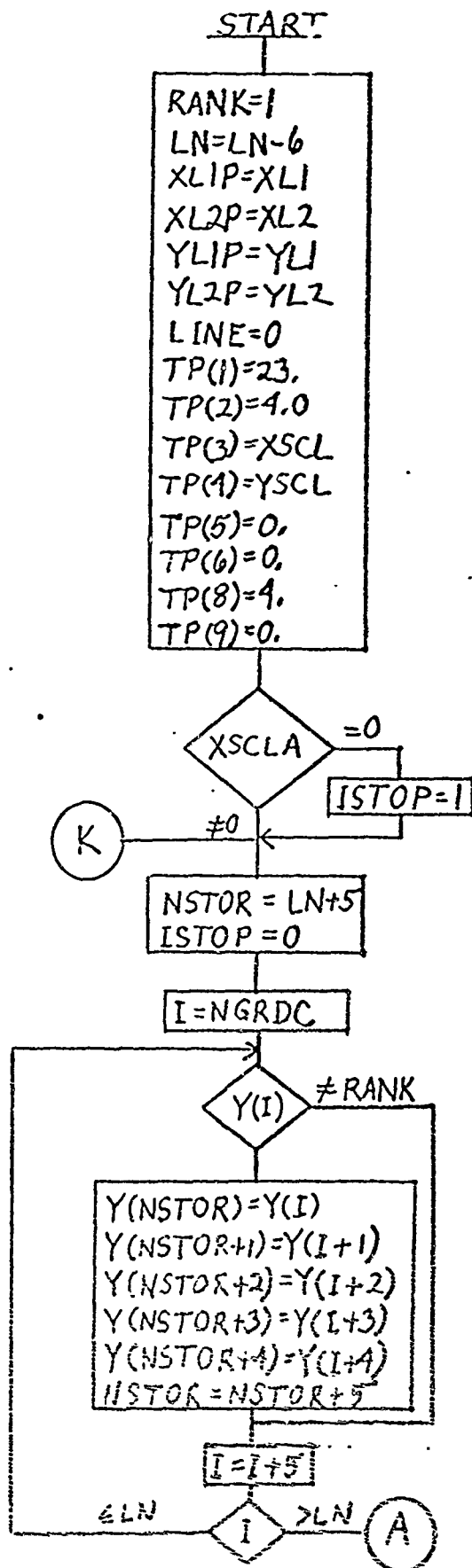
SUBROUTINE SUB58

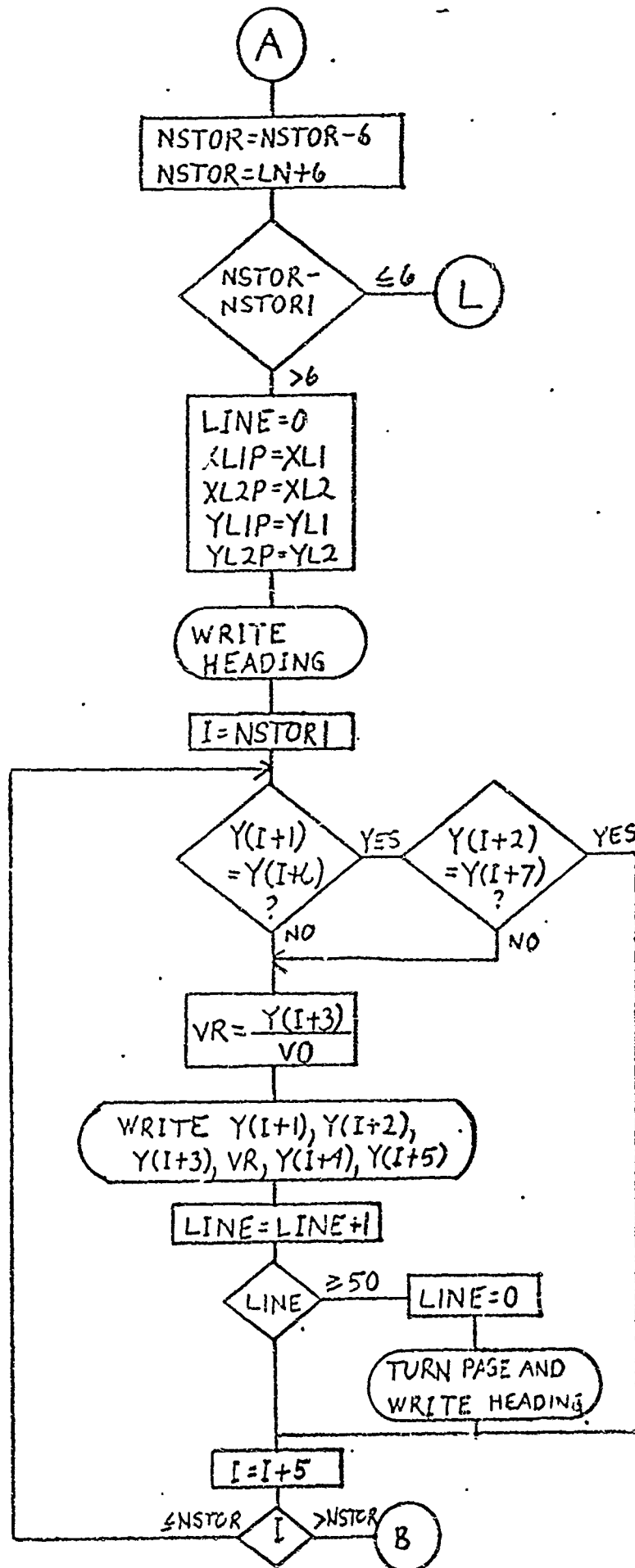


SUBROUTINE REGION

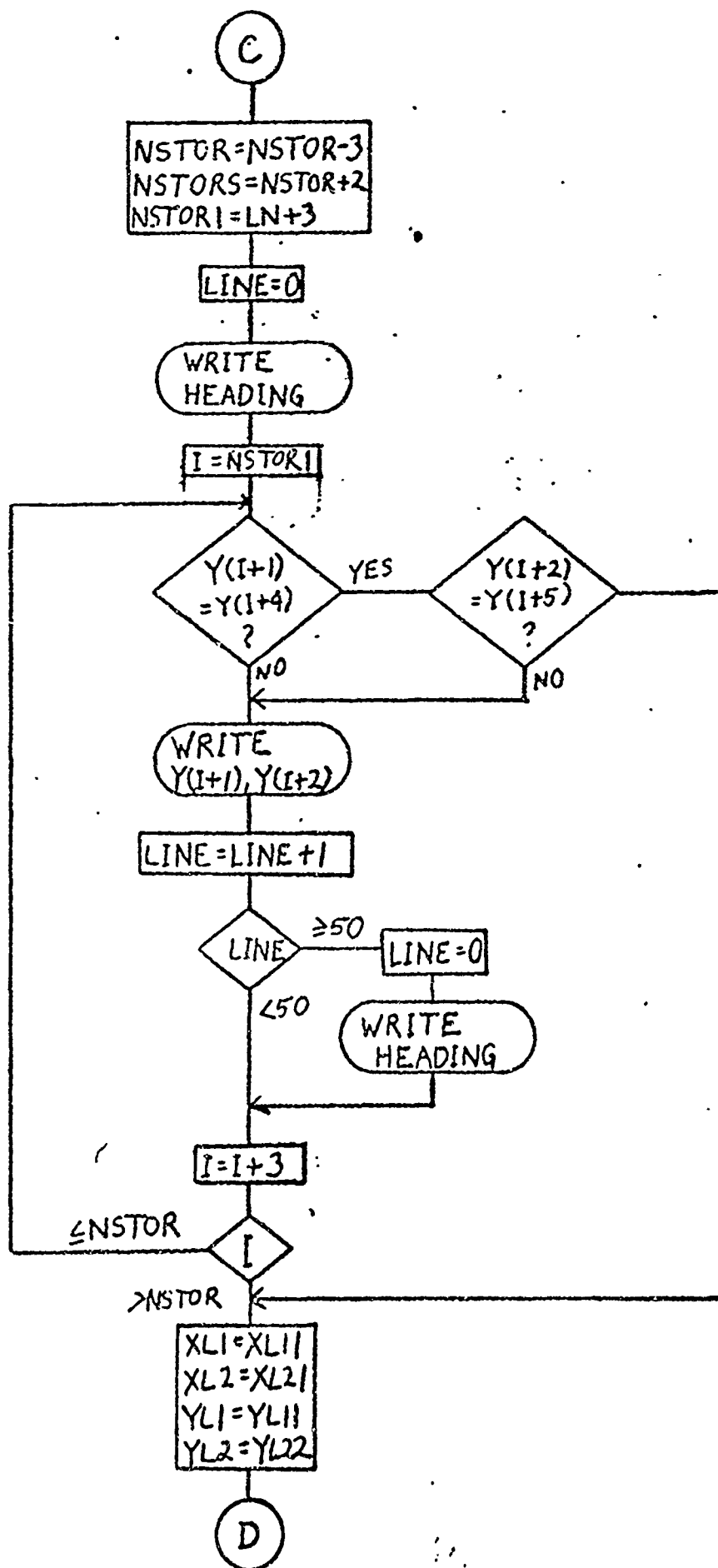


SUBROUTINE SORT

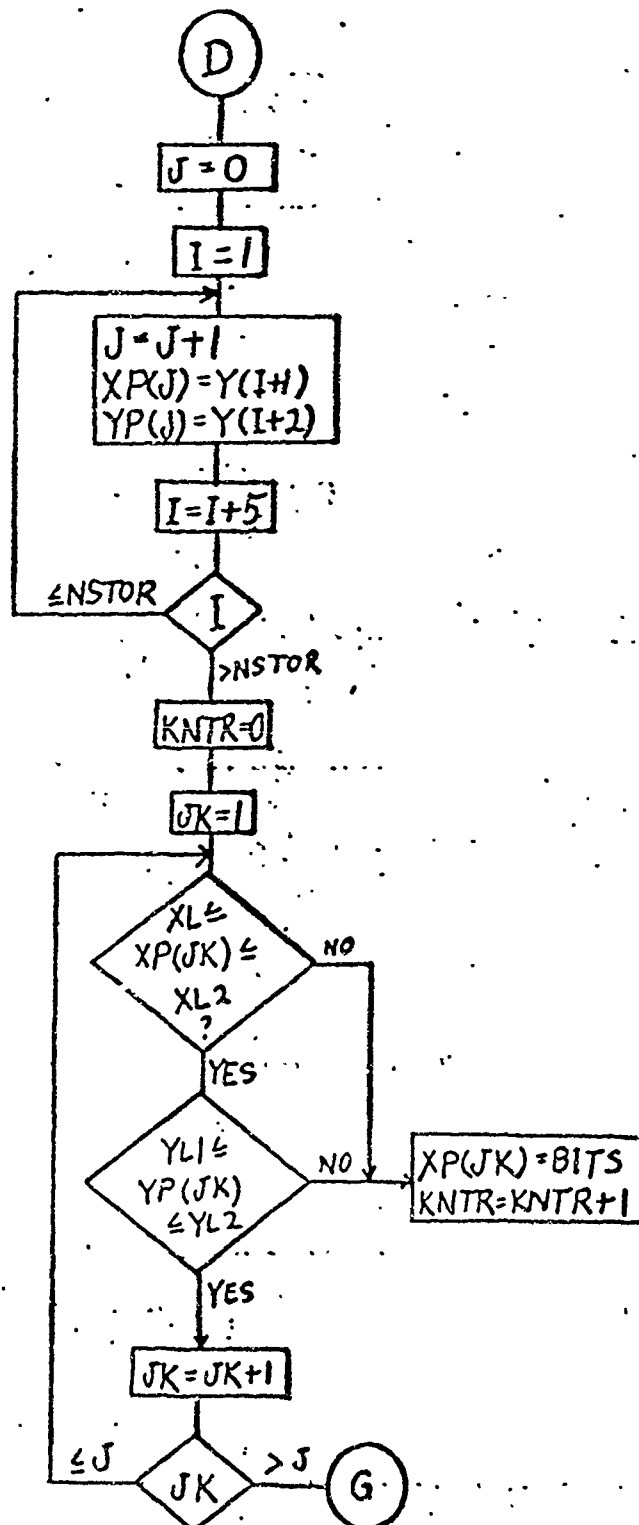




SORT 2

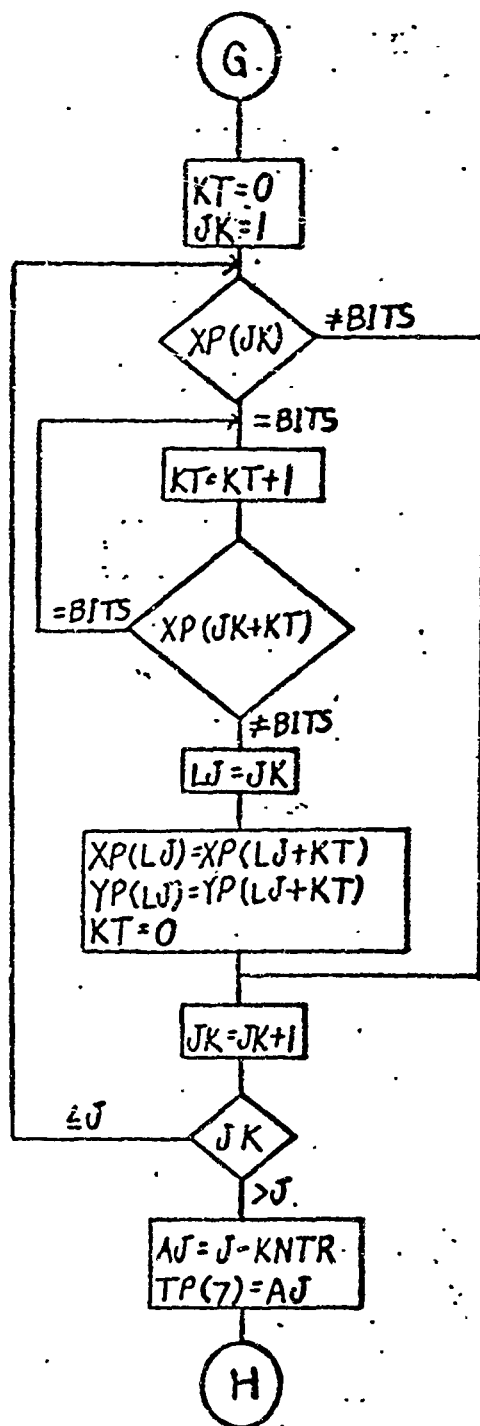


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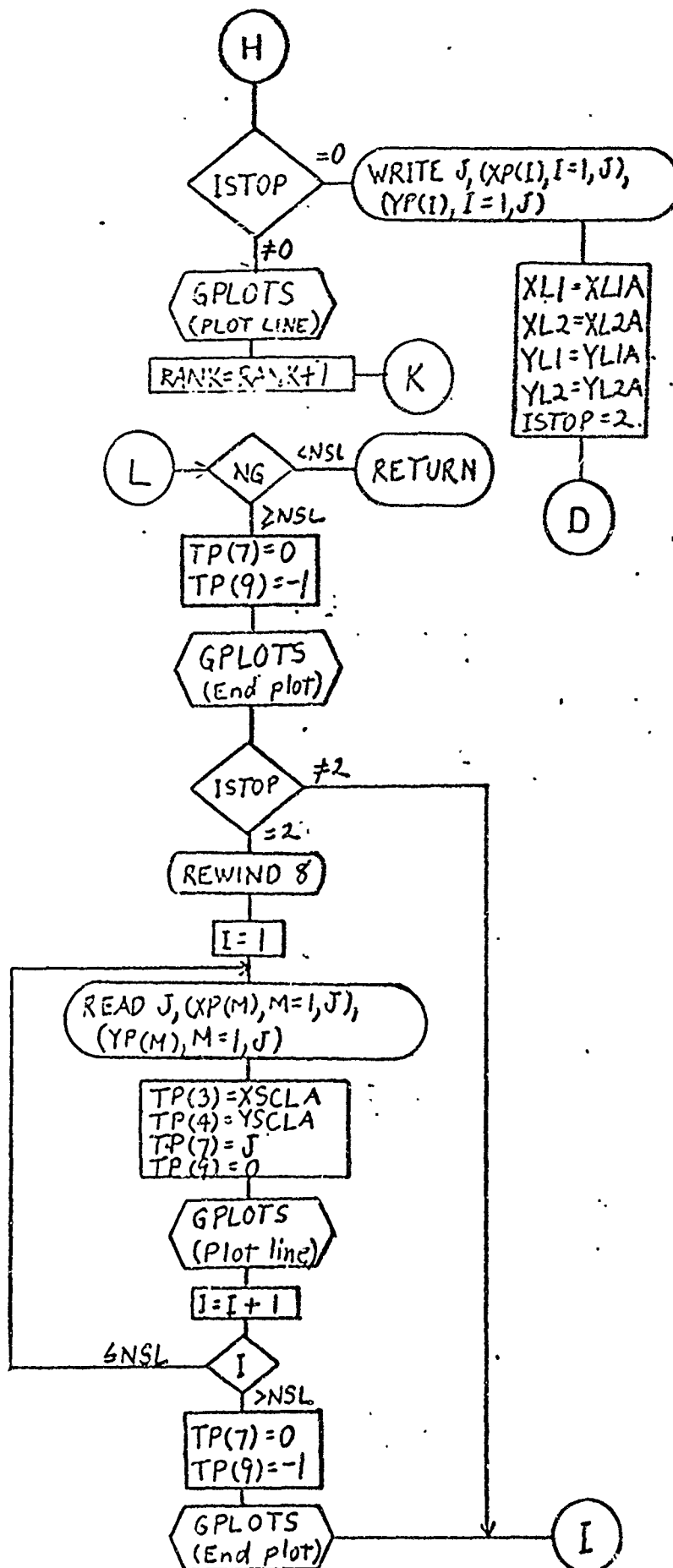
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REVISED



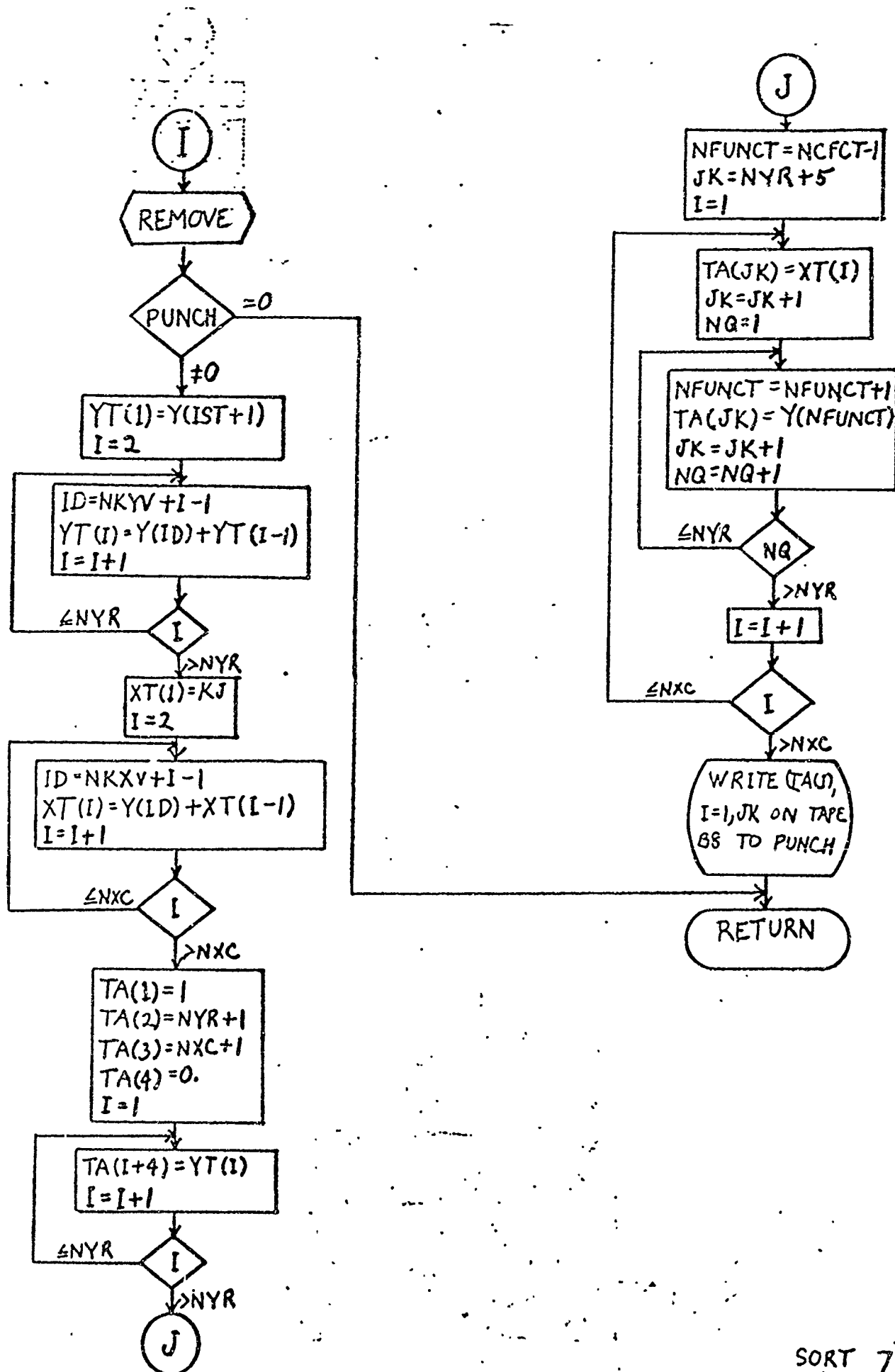
REVISED

SORT 5



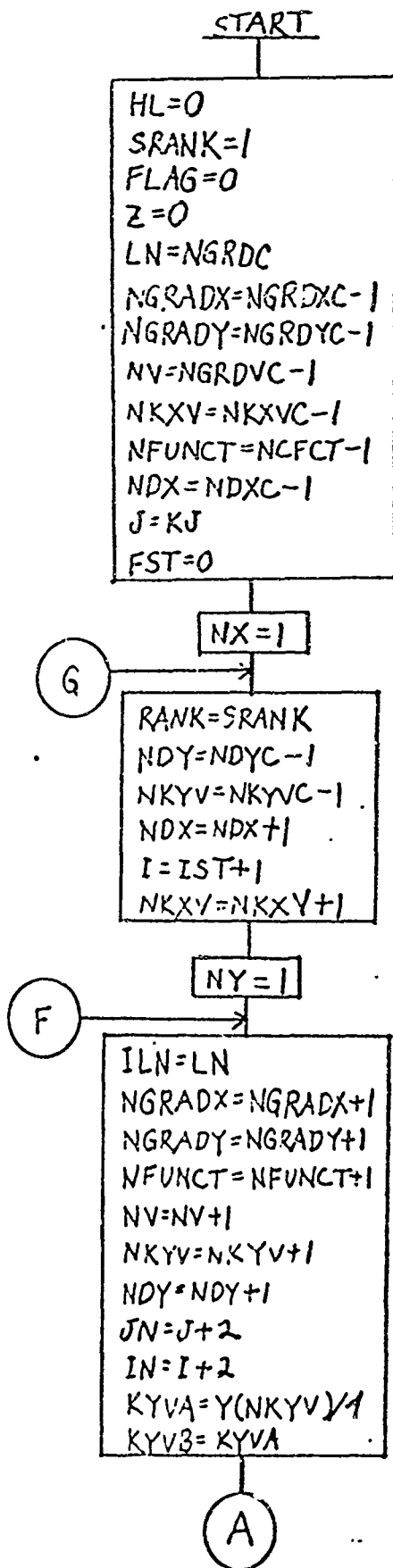
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REVISED



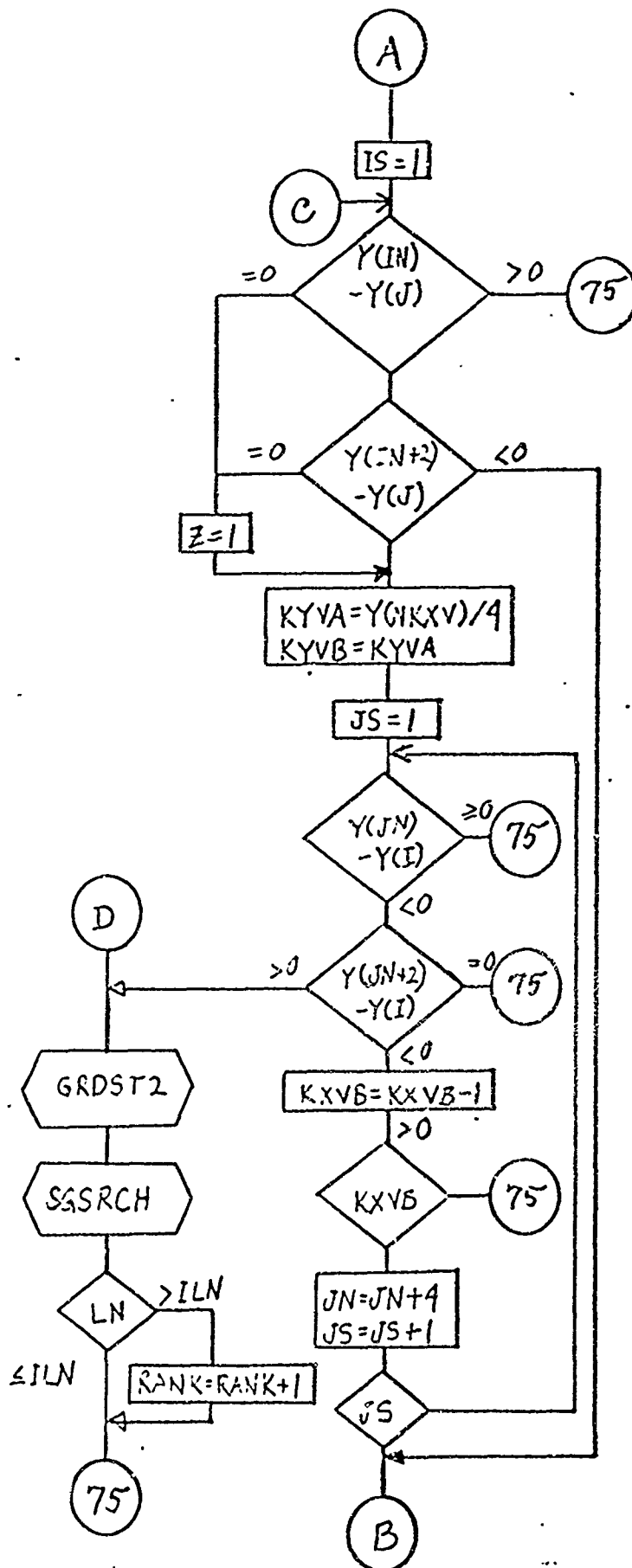
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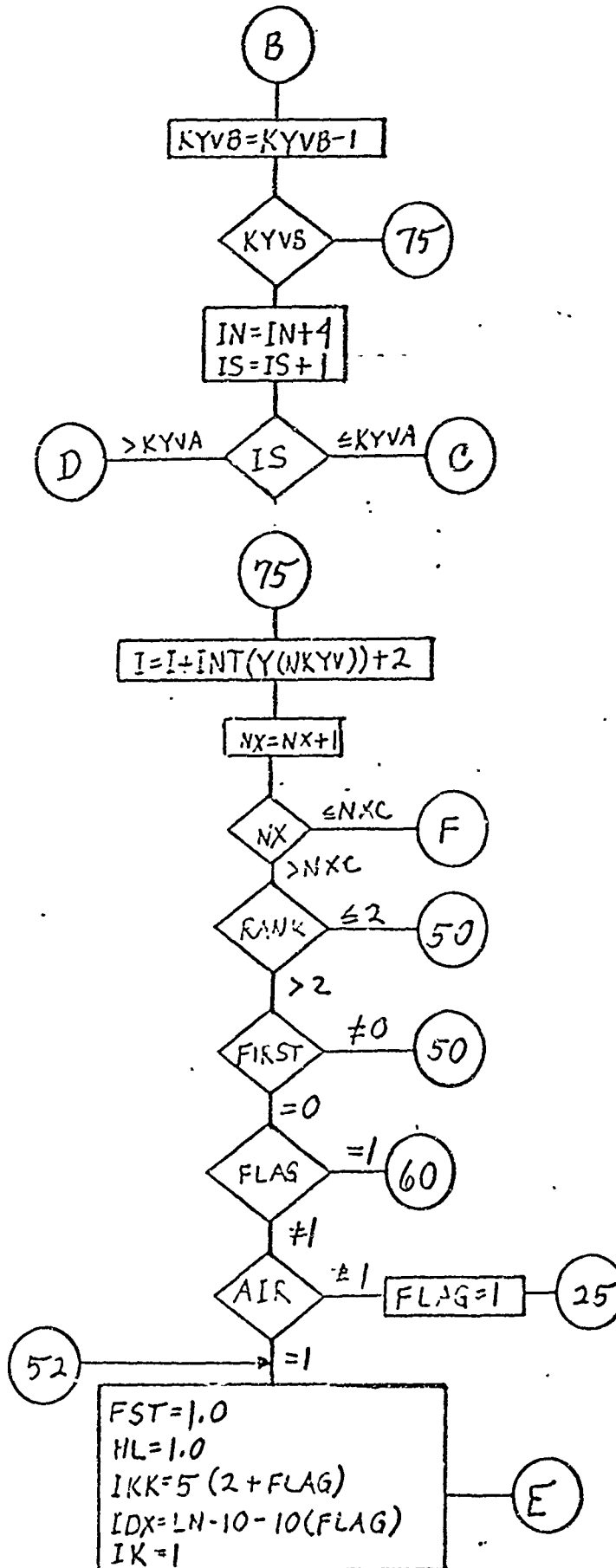
SUBROUTINE MARC



REVISED

REVISED

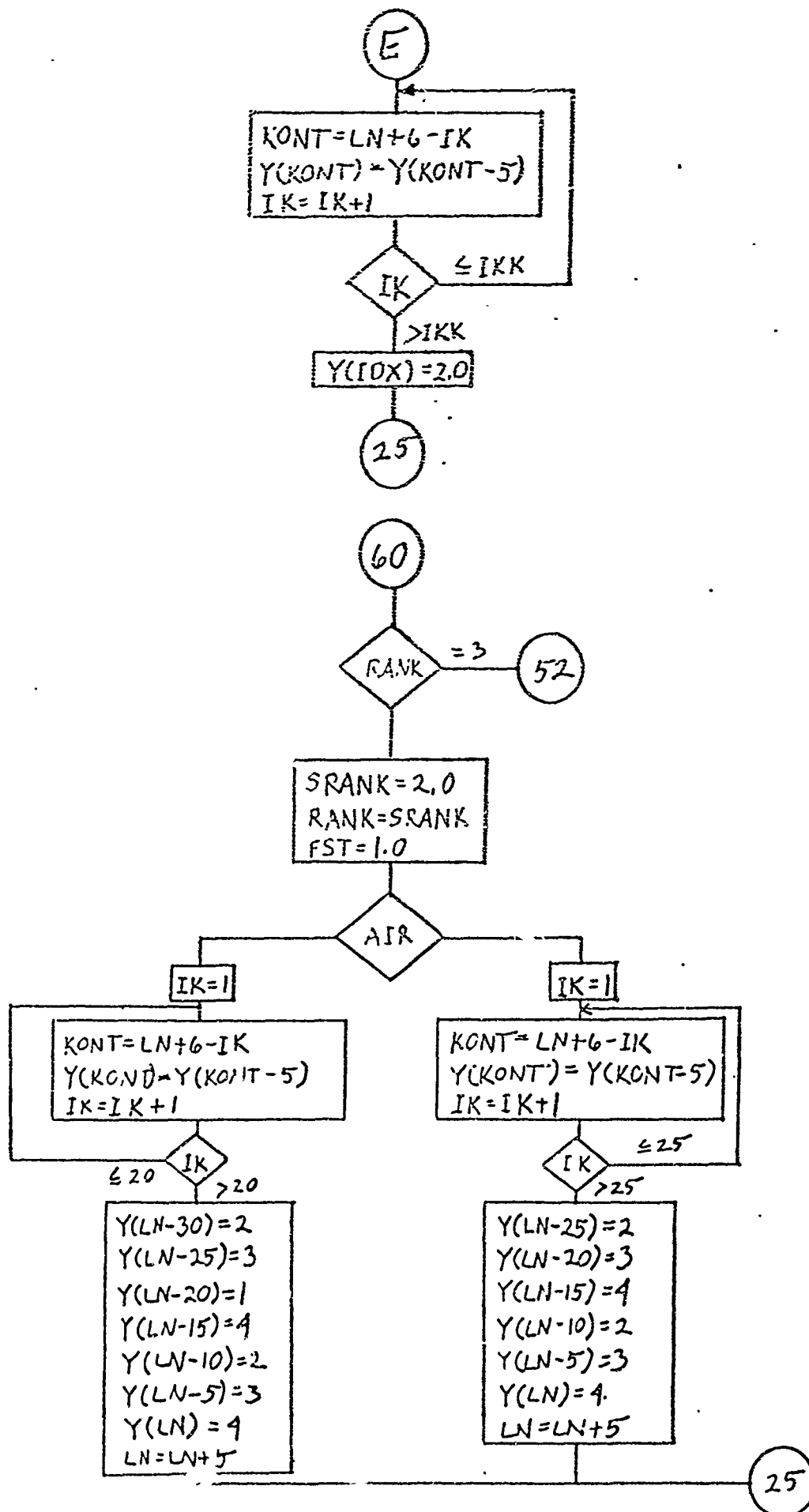




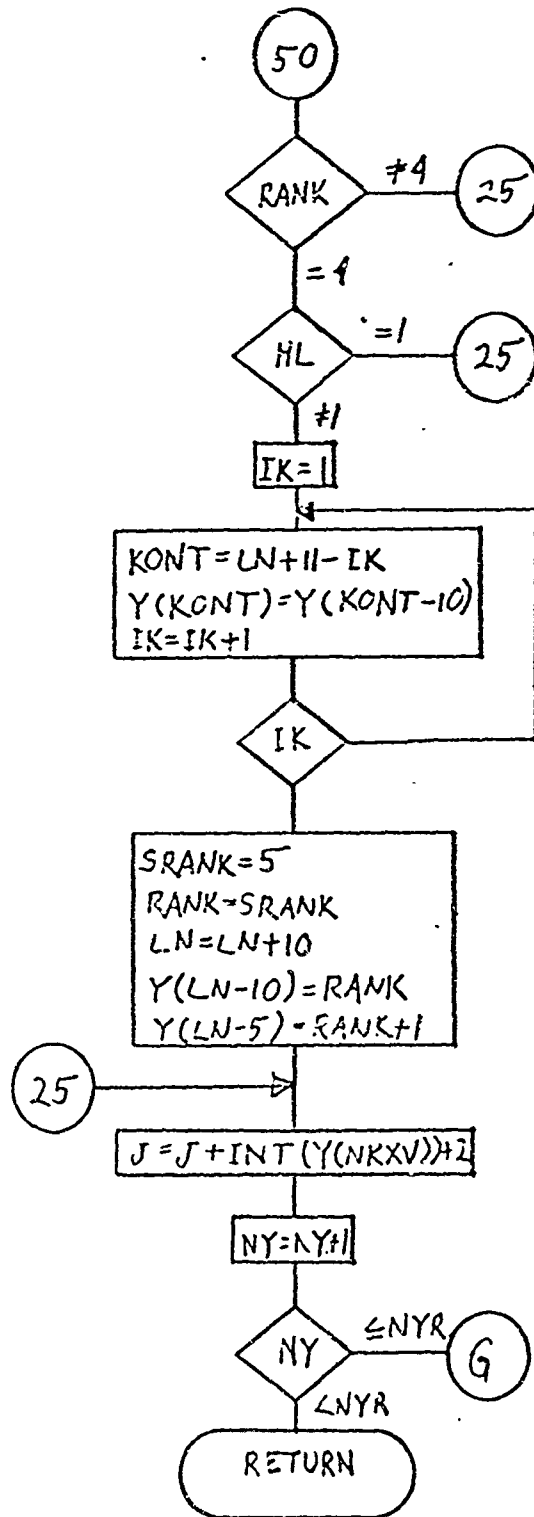
REVISED

REVISED

MARC 3



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10.2 Appendix 2 - Potential Flow Computer Program Listing

REVLTR:

E-3033 R1

BOEING	NO. D3-6961
SECT	PAGE .112

SIDFTC WAMAIN

```
C      MAIN PROGRAM
      DIMENSION B(1),Y(18000),SLINES(30)
      COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JK,IK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRACX,NGRADY,LN,CSCH,NG,NDERIV,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6NLRCAL,Q,R,S,T,V,W,XC,YC,IH,NTAPE
      COMMON /VEL/ NGROVC
      COMMON /COM2/ XSCL,YSCL,PUNCH,ITLE,Y0,Y1,XL1,XL2,YL1,YL2,XSCLA,
1YSCLA,XL1A,YL1A,XL2A,YL2A
      DIMENSION ITLE(24)
      REWIND 23
1 DO 10 I=1,18000
10 Y(I)=0.
   S=1.
   PUNT = 0.
   HEDGE=.75
   NSWEEP=20
   FLIM=10.
   CALL INPUT
902 CALL SEARCH(Y0,Y1,X,K1)
C    THIS ROUTINE ALSO FINDS ERRORS IN THE INPUT DATA,GENERATES THE
C    COEFFICIENTS OF THE DIFFERENCE ANALOGUE, AND ENFOFCES DERIVATIVES.
   IF(KNTR)40,907,40
907 CALL SWEEP(PUNT,NSWEEP,HEDGE,FLIM)
   V=1.
   CALL SEARCH(Y0,Y1,X,K1)
   CALL VELOC
   V=-1.0
   CALL SEARCH (Y0,Y1,X,K1)
   CALL LINES
40 STOP
   END
```

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\$18FTC WALNK1

```
SUBROUTINE INPUT
DIMENSION Y(18000), SLINES(30), X(6)
COMMON B, NXC, NYR, NKXVC, NKYVC, NDXC, NDYC, NCFCT, NBETAC, KJ, BITS, IST,
1HONE, HTWO, ONEK, TWOK, I, IN, J, JN, IKJ, KIJ, JIK, IJK, IT, NDX, NDY, NFUNC, Y,
2SLINES, H1, H2, TK1, TK2, NB1, NB2, NB3, NB4, NC1, NC2, NC3, NC4, N1, N2, UO, U1,
3U3, U2, U4, IPRIN, YRSDUE, NSL, NSLNC, NGRDC, NGRDXC, NGRDYC, AXYM, NGRAD,
4NGRADX, NGRADY, LN, CSCH, NG, NDERIV, SSRCH, NSWPS, OMEGA, CVGS, CONST,
5STREAM, KNTR, A, C, D, E, F, G, HK1, HK12, H12, HK2, BY, BX, NKXV, NKYV, N3,
6NLRCAL, Q, R, S, T, V, W, XC, YC, IH, NTAPE
COMMON /COM2/ XSCL, YSCL, PUNCH, ITLE, YO, Y1, XL1, XL2, YL1, YL2, XSCLA,
1YSCLA, XL1A, YL1A, XL2A, YL2A
COMMON /VEL/ NGRDVC
DIMENSION ITLE(24)
501 FORMAT (6E12.6)
502 FORMAT (6I12)
503 FORMAT (12A6)
600 FORMAT (7H AXYM =F2.0,11X,7HNDERIV=12, 10X,5HXSCL=F8.3,4X,5HYSCL=
1F8.3/ 7H NSWPS=16, 7X,7HYO =F8.3, 4X,5HXL1 =F8.3,4X,5HYL1 =
2F8.3/ 7H CVGS =F9.7, 4X,7HY1 =F8.3, 4X,5HXL2 =F8.3,4X,5HYL2 =
3F8.3/ 7H PUNCH=F2.0,30X,6HXSCLA=F7.3,4X,6HYSCLA=F7.3/
4 39X,5HXL1A=F8.3,4X,5HYL1A=F8.3/ 39X5HXL2A=F8.3,4X,
55HYL2A=F8.3//)
610 FORMAT(1H1,12A6/1X,12A6//)
XSCLA=0.
2 A=1.
V=0.
CSCH=0.
N2=0
T=0.
C=1.
CONST=1.
OMEGA=1.37
STREAM = 0.
RUN = 0.
DUM1=0.
READ (5,503) ITLE
WRITE (6,610) ITLE
READ (5,501) AXYM,CVGS,ANSWPS,PUNCH
NSWPS=ANSWPS
READ (5,501) ANDERV,YO,Y1
NDERIV=ANDERV
READ (5,501) XSCL,YSCL,XL1,XL2,YL1,YL2
READ (5,501) XSCLA,YSCLA,XL1A,XL2A,YL1A,YL2A
IF (AXYM.EQ.1.) STREAM=-1.
IF (AXYM.EQ.1.) CONST=0.
900 CALL CHECK
IF (KNTR.NE.0) STOP
WRITE (6,600) AXYM,NDERIV,XSCL,YSCL,NSWPS,YO,XL1,YL1,CVGS,Y1,XL2,
1YL2,PUNCH,XSCLA,YSCLA, XL1A,YL1A, XL2A,YL2A
42 RETURN
```

END

606

SIBFTC WACHCK

SUBROUTINE CHECK

C THIS ROUTINE READS COORDINATE INPUT, CHECKS FOR ERRORS, AND PRINTS
C COORDINATE INPUT.

DIMENSION B(1),Y(18000),SLINES(30)

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IJK,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,UO,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE

COMMON /VEL/ NGRDVC

227 FORMAT (4H Y1=F12.5/61H CHECK THE INPUT DATA CARD WHICH HAS THIS Y
X AS ITS FIRST TERM/47H EITHER THE CONSTANT TERM IS NOT DIVISIBLE B
XY 4/55H EXACTLY OR THE BOUNDARY COORDINATES ARE NOT MONOTONIC.//)

228 FORMAT (4H Y1=F12.5/4H Y2=F12.5/41H THE COORDINATE VALUES ARE NOT
XMONOTONIC.//)

501 FORMAT (6E12.6)

599 FORMAT (1H1)

600 FORMAT (67H COORDINATES AND FUNCTION VALUES FOR BOUNDARY POINTS ON
1 MESH ROWS //8X,1HY,13X,1HN,13X,1HX,12X,6HF(X,Y),10X,1HX,11X,6HF(
2X,Y)//)

601 FORMAT (68H COORDINATES AND FUNCTION VALUES FOR BOUNDARY POINTS ON
1 MESH COLUMNS//8X,1HX,13X,1HN,13X,1HY,12X,6HF(X,Y),10X,1HY,11X,6HF
2(X,Y)//)

602 FORMAT (1X,6F14.7,/(29X,4F14.7))

620 FORMAT (1X,6F14.7)

686 FORMAT (1X,4I10)

LINE=5

KNTR = 0

IST=600

I = IST+1

C Y(I) IS THE LOCATION OF THE FIRST Y INPUT VALUE.

NKYV=1

NKYVC=NKYV

C NKYV AND NKXV GIVE THE BEGINNING OF KYV AND KXV

C IN Y ARRAY. THESE TWO VECTORS TELL HOW MANY BOUNDARY

C VALUES ARE CONNECTED WITH EACH Y AND X COORDINATE.

NDY=150

NKXV=300

NDX=450

KNT=1

WRITE (6,600)

IE=I+5

READ (5,501)(Y(IR),IR=1,IE)

L = Y(I+1)

Y(NKYV)=L

40 XL=L

IF (AMOD(XL,4.))240,44,240

240 WRITE (6,227) Y(I)

KNTR = 1

```

C 46 LN = L-2
    LOOP 5 CHECKS MONOTONICITY OF X BOUNDARY COORDINATES
    DO 5 M = 1, LN, 2
      IF (M.EQ.1) GO TO 52
      XM=M+1
      IF (AMOD(XM,4.) .NE.0.) GO TO 52
      IB=J+M+3
      IE=IB+3
      READ (5,501) (Y(IR),IR=IB,IE)
52  IN=J+M-1
      IF(Y(IN+4)-Y(IN+2))245,5,5
245 WRITE (6,227) Y(J)
      KNTR = 1
      5 CONTINUE
      LQ=J+INT(Y(J+1))+1
      WRITE (6,602)(Y(L4),L4=J,LQ)
      LINE=LINE+1
      IF (LINE.LT.25) GO TO 62
      LINE=0
      WRITE (6,601)
62  MIT=J+L+2
      IE=MIT+5
      READ (5,501) (Y(IR),IR=MIT,IE)
      IF (Y(MIT+1).EQ.0.) GO TO 285
      KNT=KNT+1
      Y(NDX)=Y(MIT)-Y(J)
      IF(Y(NDX))243,8,8
C  IF STATEMENT CHECKS MONOTONICITY OF X COORDINATES
243 WRITE (6,228) Y(J),Y(MIT)
      KNTR = 1
      8 NKXV = NKXV + 1
      J=MIT
      L=Y(J+1)
      NDX = NDX + 1
26  Y(NKXV)=L
      GO TO 260
285 NXC=KNT
      DO 290 IQ=1,NYR
        IPT=NYR+IQ
        Y(IPT)=Y(IQ+149)
290 CONTINUE
      DO 291 IQ=1,NXC
        IPT=2*NYR+IQ
        Y(IPT)=Y(IQ+299)
        IPT=2*NYR+NXC+IQ
        Y(IPT)=Y(IQ+449)
291 CONTINUE
      IST=2*(NXC+NYR)
      NDY=NYR+1
      NDYC=NDY
C  NDYC GIVES LOCATION OF FIRST Y MESH VALUE IN Y ARRAY.
      NKXV=NDY+NYR

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	44 LN = L-2	0
C	LOOP 16 CHECKS MONOTONICITY OF Y BOUNDARY COORDINATES	0
	DO 16 M=1, LN, 2	0
	IF (M.EQ.1) GO TO 51	
	XM=M+1	
	IF (AMOD(XM,4.) .NE.0.) GO TO 51	
	IB=I+M+3	
	IE=IB+3	
	READ (5,501) (Y(IR),IR=IB,IE)	
51	IN = I+M-1	
	IF(Y(IN+4)-Y(IN+2))241,16,16	0
241	WRITE (6,227) Y(I)	
	KNTR = 1	0
16	CONTINUE	0
	LQ=I+INT(Y(I+1))+1	
	WRITE (6,602)(Y(L4),L4=I,LQ)	
	LINE=LINE+1	
	IF (LINE.LT.25) GO TO 61	
	LINE=0	
	WRITE (6,599)	
	WRITE (6,600)	
61	MIT = I+L+2	0
	IE=MIT+5	
	READ (5,501) (Y(IR),IR=MIT,IE)	
	Y(NDY)=Y(MIT)-Y(I)	0
	IF (Y(MIT+1).EQ.0.) GO TO 280	
	KNT=KNT+1	
	IF(Y(NDY))244,24,24	0
C	IF STATEMENT CHECKS MONOTONICITY OF Y COORDINATES	0
244	WRITE (6,228) Y(I),Y(MIT)	0
	KNTR = 1	0
24	NKYV=NKYV+1	
	I=MIT	0
	L=Y(I+1)	0
	NDY = NDY + 1	0
4	Y(NKYV)=L	0
	GO TO 40	
280	NYR=KNT	
	KNT=1	
	J=2+L+I	0
	KJ=J	0
C	Y(KJ) IS THE LOCATION OF THE FIRST X INPUT VALUE.	0
	LINE=0	
	IE=J+5	
	READ (5,501) (Y(IR),IR=J,IE)	
	L=Y(J+1)	0
	Y(NKXV)=L	0
	WRITE (6,601)	
260	XL=L	
	IF (AMOD(XL,4.))242,46,242	
242	WRITE (6,227) Y(J)	
	KNTR = 1	0

```

      NKXVC=NKXV
      NDX=NKXV+NXC
      NDXC=NDX
C      NDXC GIVES LOCATION OF FIRST X MESH VALUE IN Y ARRAY.
      DO 295 I=1,4000
      ID=IST+I
      Y(ID)=Y(I+600)
295  CONTINUE
      KJ=KJ-600+IST
      NCFCT=MIT-600+IST
C      Y (NCFCT) IS THE FIRST FUNCTION VALUE LOCATION.
      NBETAC=NCFCT+(NXC*NYR)
C      Y(NBETAC) IS THE FIRST CONSTANT VALUE LOCATION.
      MK=NXC*NYR
      NGRDVC=NBETAC
      NGRDXC=NBETAC+MK
      NGRDYC=NGRDXC+MK
      NGRDC=NGRDYC+MK
      IF (LINE.GT.22) WRITE (6,599)
59  RETURN
      END

```

```

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0  C
0  C
0  C

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1)

C

\$IBFTC WASRCH

SUBROUTINE SEARCH(YO,Y1,X,K1)

C THIS ROUTINE PLACES THE INPUT BOUNDARY VALUES IN THE PSI ARRAY
C WHICH BEGINS WITH Y(NFUNCT). IT CHECKS FOR INCONSISTENCY IN INPUT
C AND CALLS REGION FOR EACH MESH POINT INSIDE THE REGION.

DIMENSION B(1),Y(18000),SLINES(30)

DIMENSION X(6)

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,UO,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLYC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,IXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE

COMMON UBDY,LBDY

225 FORMAT (4H Y1=F12.6/4H Y2=F12.6/56H THE POINT (Y1,Y2) HAS ONE COOR
XDINATE OUTSIDE THE REGION//)

620 FORMAT (1X,6F14.7)

621 FORMAT (3I24)

625 FORMAT (120H THIS PROBLEM IS TOO BIG. ELIMINATE AS MANY OF THE MES
1H POINTS FOR WHICH PSI VALUES ARE CALCULATED AS THERE ARE OF SUCH-
2/26H POINTS TO THE RIGHT OF X=F14.7)

626 FORMAT (8F12.5)

630 FORMAT (5F15.4)

631 FORMAT (1H1)

IF (CONST.EQ.1.)GO TO 8

A=1.

C=1.

D=0.

G=0.

F=0.

8 BITS=-2.**15

UBDY=0.

LBDY=0

KNTR = 0

IT=NBETAC

NKXV=NKXVC-1

NFUNCT=NCFCT-i

NOX=NDXC-1

J=KJ

C LOOPS 75 AND 76 PERMIT CHECKING POINTS BY COLUMN

DO 76 NX=1,NXC

NDY=NDYC-1

NKYV=NKYVC-1

NKXV=NKXV+1

9 NOX=NOX+1

XC=Y(J)

I = IST+1

DO 755 NY=1,NYR

NDY=NDY+1

NKYV=NKYV+1

NFUNCT=NFUNCT+1

```

YC=Y(I)
JN=J+2
IN=I+2
KYVA=Y(NKYV)/4.
KYVB = KYVA
C   LOOPS 10 AND 112 CHECK ALL POINTS BETWEEN BOUNDARY COORDINATES
C   TO DETERMINE THEIR LOCATION IN THE FIELD
DO 10 IS=1,KYVA
C   ENTRY PERMITS TRANSFER OF BOUNDARY MESH POINTS TO FUNCTION ARRAY
ENTRY=Y(IN+1)
IF(Y(IN)-Y(J))1,2,3
C   Y(IN) IS THE LOCATION OF THE LEFT X BOUNDARY COORDINATE
1   ENTRY=Y(IN+3)
   IF(Y(IN+2)-Y(J))110,2,7
7   KXVA=Y(NKXV)/4.
   KXVB=KXVA
DO 112 JS=1,KXVA
ENTRY=Y(JN+1)
IF(Y(JN)-Y(I))11,2,33
11 ENTRY=Y(JN+3)
   IF(Y(JN+2)-Y(I))12,2,13
C   SUBROUTINE REGION GENERATES MESH DISTANCES THAT
C   ARE NOT FOUND IN THE CHECK SUBROUTINE. THESE ARE
C   THE SHORT DISTANCES TO THE BOUNDARY.
13 IF (V) 75,113,75
113 CALL REGION
GO TO 75
12 KXVB=KXVB-1
   IF(KXVB) 33,33,112
112 JN=JN+4
110 KYVB = KYVB-1
   IF (KYVB) 3,3,10
10 IN=IN+4
C   Y(JN) IS THE LOCATION OF THE LEFT Y BOUNDARY COORDINATE
C   IF A POINT IS IN THE FIELD IN THE X-DIRECTION
C   AND OUT IN THE Y-DIRECTION, THE ROUTINE GOES
C   TO LOCATION 750 INDICATING INCORRECT INPUT DATA.
3   IF (Y(JN)-Y(I))101,750,333
101 IF (Y(JN+2)-Y(I))333,750,750
750 WRITE (6,225) Y(I),Y(J)
KNTR = 1
GO TO 75
C   MINUS ALL BITS ARE STORED IN COEFFICIENT ARRAY FOR
C   POINTS WHICH ARE NOT IN THE REGION DEFINED.
33 IF (Y(IN)-Y(J))171,750,333
171 IF (Y(IN+2)-Y(J))333,750,750
333 IF (V) 400,633,632
633 Y(IT)=BITS
   IT=IT+1
GO TO 75
400 IF (Y(JN).GT.Y(I)) Y(NFUNCT)=Y(JN+1)
   IF (Y(JN+2).LT.Y(I)) Y(NFUNCT)=Y(JN+3)

```

[illegible]

GO TO 75	0
632 Y(NFUNCT)=BITS	0
GO TO 75	0
2 IF (V) 75,22,75	0
22 ASSIGN 2222 TO L1	0
IF (IXTRAP)222,232,222	0
232 CONTINUE	0
2202 Y(NFUNCT)=ENTRY	0
GO TO L1,(2222,75)	0
2222 Y(IT)=BITS	0
IT =IT+1	0
GO TO 75	0
C CHECK HERE TO FIND WHERE DERIVATIVES ARE TO BE ENFORCED	0
222 IF (Y(I)-Y0)200,15,200	0
15 IF (Y(J)-Y(IN))25,232,25	0
25 IF (Y(J)-Y(IN+2))123,232,123	0
200 IF (Y(I)-Y1)232,321,232	0
321 KN=1	0
DO 201 K=1,K1	0
IF (Y(J)-X(KN))201,232,204	0
204 IF (Y(J)-X(KN+1))206,232,201	0
201 KN=KN+2	0
206 UBDY=1.	0
GO TO 207	0
123 LBDY=1.	0
207 CALL REGION	0
ASSIGN 75 TO L1	0
GO TO 2202	0
75 IF (IT.GT.18000) GO TO 320	0
755 I=I+INT(Y(NKYV))+2	571
76 J=J+INT(Y(NKXV))+2	
IF (V.NE.0.) GO TO 540	
I=IST+1	
NFUNCT=NCFCT	
DO 310 NY=1,NYR	
NHALF=NXC/2	
DO 300 MC=1,NHALF	
IF (Y(NFUNCT).NE.0.)GO TO 300	
Y(NFUNCT)=Y(I+3)	
300 NFUNCT=NFUNCT+NYR	
NHALF=NHALF+1	
DO 305 MC=NHALF,NXC	
IF (Y(NFUNCT).NE.0.)GO TO 305	
IPNP1=I+INT(Y(I+1))+1	
Y(NFUNCT)=Y(IPNP1)	
305 NFUNCT=NFUNCT+NYR	
NFUNCT=NCFCT+NY	
310 I=I+INT(Y(I+1))+2	
540 RETURN	0
320 WRITE (6,625) Y(J)	
STOP	
END	0

\$IBFTC WAGRDS

C THIS ROUTINE GETS PSI VALUES OF THE NEAREST POINTS IN FOUR
C DIRECTIONS FROM THE POINT IN QUESTION AND THE DISTANCES TO THESE
C POINTS

```
    DIMENSION B(1),Y(18000),SLINES(30)
    COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
    1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JIJ,IJK,IT,NDX,NDY,NFUNCT,Y,
    2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,UO,U1,
    3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
    4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
    5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
    6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE
    N1 = NFUNCT+NYR
    N3=NFUNCT-NYR
    HONE=Y(NDX)
    HTWO=Y(NDX-1)
    ONEK=Y(NDY)
    TWOK=Y(NDY-1)
    UO=Y(NFUNCT)
    U1=Y(N1)
    U2=Y(NFUNCT+1)
    U3=Y(N3)
    U4=Y(NFUNCT-1)
    IJK=0
    IKJ=0
    KIJ=0
    JIK=0
    IF (Y(IN)-Y(J)+Y(NDX-1))51,51,150
150 HTWO = Y(J)-Y(IM)
    U3=Y(IN+1)
    IJK=1
    51 IF(Y(IN+2)-Y(J)-Y(NDX))151,52,52
151 HONE = Y(IN+2)-Y(J)
    U1=Y(IN+3)
    IKJ=1
    52 IF(Y(JN)-Y(I)+Y(NDY-1))53,53,152
152 TWOK = Y(I)-Y(JN)
    U4=Y(JN+1)
    KIJ=1
    53 IF(Y(JN+2)-Y(I)-Y(NDY))153,540,540
153 ONEK = Y(JN+2)-Y(I)
    U2=Y(JN+3)
    JIK=1
    540 RETURN
    END
```

\$IBFTC WAACDE

SUBROUTINE ACDEFG

```
DIMENSION B(1),Y(18000),SLINES(30)
```

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,THOK,I,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,UO,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLVC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6NLRCAL,Q,R,S,T,V,W,XC,YC,IH,NTAPE

```
IF (AXYM) 1,2,1
```

```
1 IF (Y(I)) 3,4,3
```

4 C=2.

2 $E \neq 0$.

GOTO 7

```
3 E=STREAM/Y(I)
```

7 RETURN

END

SIBFTC WACNST

* CNSTNT SUBROUTINE FOR CALCULATING CONSTANTS OF DIFFERENCE EQUATIONS
SUBROUTINE CNSTNT

C THIS ROUTINE CALCULATES THE WEIGHTS TO BE GIVEN THE PSI VALUES OF
C THE FOUR SURROUNDING POINTS IN THE RELAXATION. THESE CONSTANTS ARE
C STORED BY SEARCH IN THE ARRAY THAT BEGINS WITH Y(NBETAC).

DIMENSION B(1),Y(18000),SLINES(30)

COMMON B,NXC,NYR,NKXVC,NKYVC,VDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IJK,KIJ,JKI,IJK,IT,NOX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,VSL,NSLVC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,IXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE

COMMON UBDY,LBDY

C THE CONSTANTS IKJ,JKI,IJK,KIJ ARE SET EQUAL TO 1 IF LESS THAN A
C MESH DISTANCE AWAY FROM A BOUNDARY POINT. IN THIS CASE THE FUNCTION
C VALUE AT THE
C BOUNDARY IS INCLUDED IN THE CONSTANT TERM Y(IT+4), AND THE
C CORRESPONDING CONSTANT TERM IS SET EQUAL TO ZERO.

222 BA=(HTWO*D+2.*A)/(HONE*(HONE+HTWO))

BB=(2.*C+TWOK*E)/(ONEK*(ONEK+TWOK))

BC=(2.*A-HONE*D)/(HTWO*(HONE+HTWO))

BD=(2.*C-ONEK*E)/(TWOK*(ONEK+TWOK))

BE=-F+BA+BB+BC+BD

BE=1./BE

Y(IT+4)=-G*BE

IF(IKJ)202,201,202

202 BA = BA*Y(IN+3)*BE

Y(IT)=0.

Y(IT+4)=BA+Y(IT+4)

GO TO 210

201 Y(IT)=BA*BE

210 IF(JKI)204,203,204

204 BB = BB*Y(JN+3)*BE

Y(IT+1)=0.

Y(IT+4)=BB+Y(IT+4)

GO TO 211

203 Y(IT+1)=BB*BE

211 IF(IJK)206,205,206

206 BC=BC*Y(IN+1)*BE

Y(IT+2)=0.

Y(IT+4)=BC+Y(IT+4)

GO TO 212

205 Y(IT+2)=BC*BE

212 IF(KIJ)208,207,208

208 BD=BD*Y(JN+1)*BE

Y(IT+3)=0.

Y(IT+4)=BD+Y(IT+4)

GO TO 213

207 Y(IT+3)=BD*BE

C ANY DERIVATIVE ENFORCEMENT BEGINS WITH STATEMENT 213

```

213 IF (IXTRAP) 217,227,217
217 IF (UBDY) 1,2,1
  1 Y(IT+3)=Y(IT+3)+Y(IT+1)
  Y(IT+1)=0.
  GO TO 225
  2 IF (LBDY) 3,227,3
  3 Y(IT+1)=Y(IT+3)+Y(IT+1)
  Y(IT+3)=0.
225 UBDY=0.
  LBDY=0
227 IT=IT+5
  RETURN
  END

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\$IBFTC WASWEP

```
      SUBROUTINE SWEEP(PUNT,NSWEEP,HEDGE,FLIM)
      DIMENSION STORE(25)
      DIMENSION B(1),Y(18000),SLINES(30)
      COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDY,C,NCFCT,NBETAC,KJ,BITS,IST,
      1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,K(J),JIK,IJK,IT,NDX,NDY,NFUNCT,Y,
      2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
      3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
      4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
      5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
      6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE
      COMMON /VEL/ NGRDYC
253  FORMAT (/13H SWEEP NUMBER15, 9H RESIDUE=E15.7,
      110H AT COLUMN,I4,4H ROW,I4,25H WITH CONVERGENCE HISTORY//16F18.6))
255  FORMAT (36HOPROGRAM LEFT SUBROUTINE SWEEP AFTER,18,12H SWEEPS WITH
      XF12.6,8H RESIDUE//)
686  FORMAT (1X,4I10)
750  FORMAT (1H1)
      WRITE (6,750)
      IN=0
      REWIND 8
      NSWEP1=NSWEEP
      WRITE(8)(Y(INM),INM=NBETAC,18000)
316  MK=NXC*NYR
      N=1
310  DO 311 NNN=1,25
311  STORE(NNN)=0.
      MN=2
      DO 112 JN1=1,NSWEP1
      IN=IN+1
      JN=JN1/2+1
      MN=3-MN
204  GOTO(1,2),MN
      1 NBETA=NBETAC
      NADD=1
      NFUNCT=NCFCT
      GO TO 3
      2 NBETA=NBETA-1
      NADD=-1
      NFUNCT=NFUNCT-1
      3 RSD1=0.
      DO 12 II=1,NXC
      DO 12 I=1,NYR
      IF(Y(NBETA)-BITS)4,10,4
      4 TEMP=Y(NFUNCT)
      GO TO (6,5),MN
      5 NBETA=NBETA-4
      6 TEMPI=RELAX(NBETA,NFUNCT)
      IF((I.EQ.1).OR.(I.GE.NYR)) GO TO 601
      RSD=TEMPI-TEMP
19  RSD=RSD*OMEGA
17  Y(NFUNCT)=TEMP+RSD
```

```

601 GO TO (7,8),MN
7 NBETA=NBETA+4
8 IF(IJN-1)9,9,10
9 IF (RSD1-ABS (RSD)) 99,10,10
99 RSD1=ABS (RSD)
RSD3=RSD
RSD4=RSD3
NLOC=NFUNCT
NLOC1=NBETA
GOTO(20,21),MN
20 NLOC1=NLOC1-4
21 NFU=(NFUNCT-NCFCCT+1)/NYR
NFUN=(NFUNCT-NCFCCT+1)-NFU*NYR
IF(NFUN)97,98,97
98 NFUN=NYR
97 NFU=NFU+1
10 NBETA=NBETA+NADD
12 NFUNCT=NFUNCT+NADD
400 GOTO(301,112),MN
301 STORE(IJN)=Y(NLOC)
GO TO(112,299),N
299 IF(IJN-2)302,112,303
302 IF(RSD1-CVGS)502,304,304
303 IF((STORE(IJN)-STORE(IJN-1))/(STORE(IJN-1)-STORE(IJN-2)))298,112,112
298 N=2
GOTO 306
304 IEND=NCFCCT+MK
WRITE (8) (Y(IJN),IJN=NCFCCT,IEND)
318 BACKSPACE 8
112 CONTINUE
GO TO(306,320),N
320 FACT=(STORE(6)-STORE(5))/(STORE(2)-STORE(1))
IF(FACT-.98)329,330,330
329 FACT=(1./(1.-FACT)-1.)*HEDGE+1.
FACT=AMIN1(FACT,FLIM)
GOTO 331
330 FACT=FLIM
331 NBETAX=NBETA+1-NCFCCT
IEND=NBETAC+MK
READ (8) (Y(IJN),IJN=NBETAC,IEND)
322 NFUNCT=NCFCCT
NBETA=NBETAC
DO 321 I=1,MK
Y(NFUNCT)=(Y(NFUNCT)-Y(NBETA))*FACT+Y(NBETA)
NFUNCT=NFUNCT+1
321 NBETA=NBETA+1
324 REWIND 8
IEND=NBETAC+MK
READ (8) (Y(IJN),IJN=NBETAC,IEND)
306 WRITE (6,253) IN,RSD3, NFU,NFUN,(STORE(I),I=1,IJN)
16 IF(IN-NSWPS)307,502,502
307 GOTO(308,309),N

```

[illegible]

000000

SIBFTC WARELX

FUNCTION RELAX(NB,NFUNCT)	0
DIMENSION B(1),Y(18000),SLINES(30)	
COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,	0
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JIJ,IJK,IT,NDX,NDY,NFUNCT,Y,	0
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,V2,U0,U1,	0
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,	0
4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,	0
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,	0
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE	0
N1=NFUNCT+NYR	0
N3=NFUNCT-NYR	0
RELAX=Y(N1)*Y(NB)+Y(NFUNCT+1)*Y(NB+1)+Y(N3)*Y(NB+2)+	0
1Y(NFUNCT-1)*Y(NB+3)+Y(NB+4)	0
RETURN	0
END	0

\$LBFTC WALNK2

SUBROUTINE VELOC

DIMENSION B(1),Y(18000),SLINES(30)

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,NDERIV,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE
COMMON /COM2/ XSCL,Y9CL,PUNCH,ITLE,Y0,Y1,XL1,XL2,YL1,YL2,XSCLA,
1Y9CLA,XL1A,YL1A,XL2A,YL2A

COMMON /VEL/ NGRDVC

DIMENSION ITLE(24)

650 FORMAT (1H1,3X,2HX=F14.7//)

651 FORMAT (11X,1HY,16X,3HPSI,12X,12HX-DERIVATIVE,6X,12HY-DERIVATIVE,
19X,8HVELOCITY//)

652 FORMAT (1X,5F18.7)

686 FORMAT (1X,4I10)

ZERO=0.

7 V=1.

N2=1

112 DO 1 NN=1,2

NGRAD=NGRDC

CALL ICMPS

1 CSCH=CSCH+1.

16 K=NGRDYC

J=KJ

NFUNCT=NCFCT

NGRADX=NGRDXC

NGRADY=NGRDYC

NGRADV=NGRDVC

DO 250 KP=1,NXC

LINE=0

WRITE (6,650) Y(J)

WRITE (6,651)

I=IST+1

DO 251 KP=1,NYR

IF (Y(NGRADX).NE.BITS) GO TO 200

WRITE (6,652) Y(I),ZERO,ZERO,ZERO,ZERO

LINE=LINE+1

IF (LINE.GT.52) GO TO 101

GO TO 201

200 WRITE (6,652) Y(I),Y(NFUNCT),Y(NGRADX),Y(NGRADY),Y(NGRADV)

LINE=LINE+1

IF (LINE.GT.52) GO TO 101

201 NFUNCT=NFUNCT+1

I=I+INT(Y(I+1))+2

NGRADX=NGRADX+1

NGRADY=NGRADY+1

251 NGRADV=NGRADV+1

250 J=J+INT(Y(J+1))+2

```
331 RETURN
101 LINE=0
    WRITE (6,650) Y(J)
    WRITE (6,651)
    GO TO 201
END
```

01

SIBFTC WAICMP

SUBROUTINE ICMPS

C THIS ROUTINE IS CALLED TWICE. THE FIRST TIME IT CALLS GROST1 AND
C DERIV FOR INTERIOR POINTS. THE SECOND TIME IT CALLS SUBB1 AND
C DERIV FOR BOUNDARY POINTS.

DIMENSION B(1),Y(10000),SLINES(30)

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JIJ,IJK,IT,NOX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,JH,KH

COMMON /VEL/ NGRDVC

* INITIALIZE ALL SUBSCRIPTS TO PICK UP INFORMATION IN Y ARRAY.

NC1=1

NGRADX=NGRDXC-1

NGRADY=NGRDYC-1

NGRADV=NGRDVC-1

NKXV=NKXVC-1

NFUNCT=NCFCT-1

NDX=NDXC-1

J=KJ

* SET LOOP TO PROGRESS FROM COLUMN TO COLUMN.

DO 76 NX=1,NXC

* CHANGE SUBSCRIPTS AFFECTED BY A CHANGE OF COLUMN.

NDY=NDYC-1

NKYV=NKYVC-1

NDX=NDX+1

I = IST+1

NKXV=NKXV+1

* SET LOOP TO PROGRESS ALONG A COLUMN.

DO 75 NY=1,NYR

* CHANGE SUBSCRIPTS AFFECTED BY A CHANGE ALONG A COLUMN

NGRADX=NGRADX+1

NGRADY=NGRADY+1

NFUNCT=NFUNCT+1

NGRADV=NGRADV+1

NKYV=NKYV+1

NDY=NDY+1

* SET SUBSCRIPTS TO FIND BOUNDARY INFORMATION FROM THE INPUT ARRAY.

JN=J+2

IN=I+2

KYVA=Y(NKYV)/4.

KYVB = KYVA

```

* LOOP 10 AND 112 ARE NECESSARY FOR COMPLEX BOUNDARIES.
*
  GO 10 IS=1,KYVA
* LOCATE POSITION OF POINT IN THE ENTIRE SYSTEM.
*
* THE POINT WILL EITHER BE INTERIOR, EXTERIOR OR BOUNDARY.
*
  IF(Y(IN)-Y(J))1,2,3
1 IF(Y(IN+2)-Y(J))110,22,7
7 KXVA=Y(NKXV)/4.
  KXVB=KXVA
  DO 112 JS=1,KXVA
  IF(Y(JN)-Y(I))11,222,3
11 IF(Y(JN+2)-Y(I))12,2222,13
*
* THE DERIVATIVES FOR INTERIOR POINTS ARE COMPUTED ON THE FIRST SWEEP.
13 IF (CSCH-1.) 113,75,75
113 CALL GRDST1(NXA,NYA)
  GO TO 90
12 KXVB=KXVB-1
  IF (KXVB) 3,3,112
112 JN=JN+4
110 KYVB = KYVB-1
  IF (KYVB) 3,3,10
10 IN=IN+4
  GO TO 75
*
* THE DERIVATIVES ON BOUNDARIES ARE COMPUTED ON THE SECOND SWEEP.
*
  2 NB1=1
  GO TO 202
22 NB1=2
  GO TO 202
222 NB1=3
  GO TO 202
2222 NB1=4
202 IF (CSCH-1.) 75,31,75
*
* SUBROUTINE SUBB1 SUPPLIES THE INFORMATION FROM
*
* WHICH THE BOUNDARY DERIVATIVES ARE COMPUTED.
*
  31 CALL SUBB1(NXA,NYA)
*
* DERIVATIVES ARE COMPUTED USING CENTRAL, FORWARD OR BACKWARD DIFFERENCING
*
  90 CALL DERIV (NXA,NYA,NXYAA,BX,BY,G3)
*
* ON RETURN FROM DERIV, BX AND BY ARE THE X AND Y DERIVATIVES .
  Y(NGRADX)=BX
  Y(NGRADY)=BY

```

```

      Y(NGRADY)=G3
      GO TO 75
3    Y(NGRADX)=BITS
      Y(NGRADY)=BITS
*   BITS ARE STORED IN THE X AND Y DERIVATIVE ARRAY FOR EXTRAPOLATION USES
75   I=I+INT(Y(NKYV))+2
76   J=J+INT(Y(NKXV))+2
26  RETURN
     END

```

1073

\$IBFTC WAGRO1

```
1 SUBROUTINE GRDST1(NXA,NYA)
1 DIMENSION B(1),Y(18000),SLINES(30)
1 COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
073 1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JK,IJK,IT,NDX,NDY,NFUNCT,Y,
1 2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGROXC,NGRDYC,AXYM,NGRAD,
1 4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH
NXA=1
NYA=1
N1 = NFUNCT+NYR
N3=NFUNCT-NYR
H1=Y(NDX)
H2=Y(NDX-1)
TK1=Y(NDY)
TK2=Y(NDY-1)
U0=Y(NFUNCT)
U1=Y(N1)
U2=Y(NFUNCT+1)
U3=Y(N3)
U4=Y(NFUNCT-1)
IJK=0
IKJ=0
KIJ=0
JK=0
IF (Y(IN)-Y(J)+Y(NDX-1))51,51,150
150 H2 = Y(J)-Y(IN)
U3=Y(IN+1)
IJK=1
51 IF(Y(IN+2)-Y(J)-Y(NDX))151,52,52
151 H1 = Y(IN+2)-Y(J)
U1=Y(IN+3)
IKJ=1
52 IF(Y(JN)-Y(I)+Y(NDY-1))53,53,152
152 TK2 = Y(I)-Y(JN)
U4=Y(JN+1)
KIJ=1
53 IF(Y(JN+2)-Y(I)-Y(NDY))153,540,540
153 TK1 = Y(JN+2)-Y(I)
U2=Y(JN+3)
JK=1
540 RETURN
END
```

\$IBFTC WASUB1

*SUBB1 00

SUBROUTINE SUBB1(NXA,NYA)

DIMENSION B(1),Y(18000),SLINES(30)

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1H0NE,HTWO,ONEK,TWOK,I,IN,J,JV,I<J,KIJ,JIJ,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH

301 FORMAT (28H THERE IS GARBAGE IN MEMORY//)

* THIS SUBROUTINE FINDS DATA TO COMPUTE DERIVATIVES FOR BOUNDARIES.

* CHOOSE WHICH BOUNDARY IS BEING WORKED ON.

MMM=3

N1=NFUNCT+NYR

GO TO (12,13,14,15),NB1

* LEFT BOUNDARIES ARE IN QUESTION.

12 NP=NGRADY+NYR

N3=N1+NYR

U0=Y(IN+1)

U1=Y(N1)

H1=Y(NDX)

NXA=2

IF (Y(N3)-BITS)30,2,1

1 U3=Y(N3)

H2=Y(NDX+1)

GO TO 100

2 U3=Y(IN+3)

H2=ABS (Y(J)-Y(IN+2))-H1

GO TO 100

* RIGHT BOUNDARIES ARE IN QUESTION.

13 NP=NGRADY-NYR

NXA=3

N1=NFUNCT-NYR

N3=N1-NYR

U0=Y(IN+3)

U1=Y(N1)

H1=Y(NDX-1)

IF (Y(N3)-BITS)30,20,31

31 U3=Y(N3)

H2=Y(NDX-2)

GO TO 100

20 U3=Y(IN+1)

H2=ABS (Y(J)-Y(IN))-H1

* SET UP DATA TO FACILITATE FINDING Y'DERIVATIVES

100 T5=Y(NDY-2)

```

T6=Y(NDY+1)
U2=Y(NFUNCT+1)
U6=Y(NFUNCT+2)
U4=Y(NFUNCT-1)
U5=Y(NFUNCT-2)
TK1=Y(NDY)
TK2=Y(NDY-1)
*
* IS THE BOUNDARY POINT A CORNER OF THE CIRCUMSCRIBED RECTANGULAR REGION
*
  IF(NDYC-NDY) 22,10,22
22 IF(NDYC-NDY+NYR-1)23,7,23
23 IF(U2-BITS)30,7,6
  6 IF(U4-BITS)30,10,90
*
* THE BOUNDARY POINT IS A TOP CORNER.
*
  7 IF(U4-BITS)30,8,11
 11 IF(U5-BITS)30,8,21
21 U2=U4
  U4=U5
  TK1=TK2
  TK2=T5
  NYA=3
  GO TO 9
*
* THE POINT IS A BOTTOM CORNER OF THE RECTANGLE
*
 10 IF (U2-BITS)30,8,18
 18 IF (U6-BITS)30,8,120
120 U4=U6
  TK2=T6
  NYA=2
  GO TO 9
*
* A LINEAR EXTRAPOLATION IS MADE WHEN DATA IS INSUFFICIENT.
*
  8 GO TO (112,113,114,115),NB1
112 NP1=NP+NYR
  D1=H1
  D2=H1+H2
  GO TO 116
113 NP1=NP-NYR
  D1=H2
  D2=H1+H2
116 NYA=4
  BY=Y(NP1)-(D2/D1)*(Y(NP1)-Y(NP))
  GO TO 9
114 NP1=NP+1
  D1=TK1
  D2=TK1+TK2
  GO TO 117

```


\$IBFTC WADERV

SUBROUTINE DERIV (NXA,NYA,NXYAA,XDERIV,YDERIV,G3)

C SUBROUTINE DERIV CALCULATES DERIVATIVES OF PSI WITH RESPECT TO X
C AND Y, AND VELOCITIES.

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,UO,U1,
3U3,U2,U4,IPRIN,NRSDUE,VSL,NSLVC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,VG,NDERIV,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6NLRGAL,Q,R,S,T,V,W,XC,YC,IH,NTAPE

0
0
0
0
0
0

DIMENSION B(1),Y(18000),SLINES(30)

600 FORMAT (1X,6F14.6)

* IF NXA=1 THE X-DERIVATIVE IS FOUND BY CENTRAL DIFFERENCING
* IF NXA=2 THE X-DERIVATIVE IS FOUND BY FORWARD DIFFERENCING
* IF NXA=3 THE X-DERIVATIVE IS FOUND BY BACKWARD DIFFERENCING
* THE ABOVE CONVENTION HOLDS FOR NYA AND Y-DERIVATIVES
* IF NXA=4 NO X-DERIVATIVE IS FOUND.

1
1
1
1
1

FCT=1.

IF (AXYM.EQ.1.) FCT=Y(I)

NO=1

100 DELTA=1.

1
1

FG=1.

GO TO (3,2,1,7),NXA

1
1

1 DELTA=-1.

2 H2=H1+H2

FG=-1.

3 GX=DELTA*(H2**2*(U1-UO)+ H1**2*(UO-U3))/(H1*H2*(H2+FG*H1))

4 GO TO (6,10),NO

1

6 XDERIV=GX

1

IF (NYA-4) 7,15,7

1

7 NO=2

1

NXA=NYA

1

U1=U2

U3=U4

H1=TK1

H2=TK2

GO TO 100

1

* G3=GRADIENT,YDERIV=Y ER CROSS DERIVATIVE,XDERIV=X-DERIVATIVE

1

10 YDERIV=GX

1

15 CONTINUE

G3=SQRT((XDERIV/FCT)**2+(YDERIV/FCT)**2)

13 RETURN

1

END

1

\$1BFTC WALNK3

SUBROUTINE LINES

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,L,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,NDERIV,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE,TITLE1,NCHAIN,MONTH

1!
1!
1!
1!
1!
1!
1!

COMMON /COM2/ XSCL,YSC,PUNCH,ITL,Y0,Y1,XL1,XL2,YL1,YL2,XSCLA,
1YSCLA,XL1A,YL1A,XL2A,YL2A

COMMON /COM3/ YMAX

COMMON /FRSCOF/ FIRST,VO,CO

COMMON /VEL/ NGRDVC,AIR

DIMENSION Y(18000),SLINES(30),ITL(24)

DIMENSION B(1)

501 FORMAT (6E12.6)

686 FORMAT (1X,4I10)

2 ILN=0

1!

NNLNS=1

34 IF (ILN.EQ.NNLNS) RETURN

36 READ (5,501) ANSL,CSCH,NNLNS,CO,VO,AIR

IF (CSCH.EQ.2.) NGRDC=NGRDXC

IF (NNLNS.LT.1) NNLNS=1

NSL=ANSL

READ (5,501) (SLINES(INK),INK=1,NSL)

12 NSLNC=NGRDC

1!

DO 61 NG=1,NSL

LN=NSLNC

1!

111 N2=1

1!

CALL MARC

1!

1111 NGRAD=NGRDC

1!

60 CALL SORT (INT(CSCH)-1)

61 CONTINUE

27 ILN=ILN+1

1!

GO TO 34

1!

END

1!

\$IBFTC HASGSC

*SGSRCH

SUBROUTINE SGSRCH

DIMENSION Y(18000),SLINES(30)

COMMON B,NXC,NYR,NKXVC,NKYVC,NOXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NOX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,VG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE

COMMON /ZCOM/ Z

COMMON /LNK5/ NV

COMMON /COM/ U7,W1

COMMON/BDRY/ JB

COMMON/PRSCOF/ FIRST,VO

600 FORMAT (1X,F14.7)

601 FORMAT (48H STORAGE OVERRUN WHILE CALCULATING STREAM LINES)

602 FORMAT (1X,5F14.5)

N=NG

IF (CSCH-3.) 57,81,82

81 N1=NGRADX+NYR

N3=NGRADX-NYR

U0=Y(NGRADX)

U1=Y(N1)

U2=Y(NGRADX+1)

U3=Y(N3)

U4=Y(NGRADX-1)

GO TO 57

82 N1=NGRADY+NYR

N3=NGRADY-NYR

U0=Y(NGRADY)

U1=Y(N1)

U2=Y(NGRADY+1)

U3=Y(N3)

U4=Y(NGRADY-1)

57 N2=LN

V=0.

IF (KIJ) 84,85,84

84 IF (CSCH-3.) 85,2,2

85 U6=U4

U7=U2

W1=ONEK

W=-TWOK

CALL SUB58 (U6,N)

IF (V) 3,2,3

3 Y(LN+1)=Y(J)

Y(LN+2)=Y(I)+XC

IF (KIJ.EQ.1.AND.JB.EQ.1) GO TO 31

NV1=NV+1

Y(LN+3)=Y(NV)+(Y(NV1)-Y(NV))*XC/W

GO TO 32

```

31 W=TWOK
   Y(LN+3)=(W+W1)*(Y(NV)-Y(NV+1))/W1+Y(NV+1)
32 Y(LN+4)=1.-(Y(LN+3)/VO)**2
   LN=LN+5
   2 V=0.
12 V=0.
   IF (CSCH-3.) 89,90,90
89 IF (JIK) 22,73,22
22 W=ONEK
   W1=-TWOK
   U6=U2
   U7=U4
   CALL SUB58 (U6,N)
   IF (V) 21,73,21
21 Y(LN+1)=Y(J)
   Y(LN+2)=Y(I)+XC
   IF (JIK.EQ.1.AND.JB.EQ.1) GO TO 40
   NV1=NV-1
   Y(LN+3)=Y(NV)+(Y(NV1)-Y(NV))*XC/W
   GO TO 41
40 W1=TWOK
   Y(LN+3)=(W+W1)*(Y(NV)-Y(NV-1))/W1+Y(NV-1)
41 Y(LN+4)=1.-(Y(LN+3)/VO)**2
   LN=LN+5
90 V=0.
73 CONTINUE
58 IF (LN.GT.17983) GO TO 100
   RETURN
100 WRITE (6,601)
   STOP
   END

```

SECRET WASHINGTON

SUBROUTINE SU858 (U6,N)

```
DIMENSION R(1),Y(18000),SLINE(30)
```

COMMON /COM/ U7, W1

COMMON /PLOT/ RANK

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,BIK,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,H1,N2,UO,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,ALYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IN

YILNI=SLAESINA

YOUNG = RANK

P=SLINES(IN)-US

0-00-SLINES:NI

```
IF (ABS(P+Q).LT.ABS(Q-P)) GO TO 2
```

P=SLINES(IN)

IF (AXYH.EQ.0.0.OR.S.EQ.1.) GO TO 20

$$XC = (P-U0) * (P-U6) / ((U7-U0) * (U7-U6)) * W1 + (P-U7) * (P-U0) / ((U6-U7) * (U6-U0)) * W$$

```
IF (ABS(XC).LT.ABS(W)) GO TO 21
```

20 $X_C = (P - U_0) / (U_6 - U_0) \cdot W$

21 $V=1$.

2 RETURN.

END

\$IBFTC WAREGN

```

SUBROUTINE REGION
DIMENSION B(1),Y(18000),SLINES(30)
COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,I,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,IXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE
COMMON UBDY,LBDY
226 FORMAT (3H A=F12.6/3H C=F12.6/3H E=F12.6/4H Y1=F11.6/4H Y2=F11.6/5
X3H THE DIFFERENTIAL EQUATION IS NOT ELLIPTIC AT (Y1,Y2)/57H IF SUB
ROUTINE ACDEFG IS USED. OTHERWISE CHECK A,C,AND F.//)
C STATEMENT 112 TO 4 SET MESH VALUES FOR DERIBATIVE ENFORCEMENT
IF (IXTRAP) 112,113,112
112 IKJ=0
KIJ=0
JKI=0
IJK=0
HONE=Y(NDX)
HTWO=Y(NDX-1)
ONEK=Y(NDY)
TWOK=Y(NDY-1)
IF (UBDY) 1,2,1
1 ONEK=TWOK
GO TO 3
2 IF (LBDY) 4,113,4
4 TWOK=ONEK
GO TO 3
113 CALL GROSTL
3 IF (CONST) 141,149,141
C CONST, AN INPUT VALUE, CONTROLS USAGE OF ACDEFG.
C XC,YC ARE X AND Y COORDINATE VALUES.
149 CALL ACDEFG
141 IF (A*C) 147,147,43
C STATEMENT 141 CHECKS ELLIPTICITY
147 WRITE (3,226) A,C,E,Y(I),Y(J)
KNTR = 1
43 CALL CNSTNT
C SUBROUTINE CNSTNT CALCULATES COEFFICIENTS OF DIFFERENCE ANALOGUE
75 RETURN
END

```

\$LBFTC HASORT

```

SUBROUTINE SORT(KASE)
  DIMENSION XT(250),YT(250)
  DIMENSION XP(250),YP(250)
  DIMENSION TA(4000)
  DIMENSION TP(9)
  DIMENSION B(1),Y(18000),SLINES(30)
  DIMENSION      ITLE(24),HEAD(2,3)
  COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,TWOK,L,IN,J,JN,IKJ,KIJ,JKI,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LV,CSCH,NG,NDERIV,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,NTAPE
  COMMON/PRSCOF/ FIRST,VO
  COMMON /COM2/ XSCL,YSCL,PUNCH, ITLE,Y0,Y1,XL1,XL2,YL1,YL2,XSCLA,
1YSCLA,XL1A,YL1A,XL2A,YL2A
  COMMON /COM3/ YMAX
  EQUIVALENCE (TA(1),Y(11000))
  EQUIVALENCE (XT(1),XP(1)),(YT(1),YP(1))
600 FORMAT (1H1,2A6,1H=F14.7//8X,1HX,13X,1HY,10X,8HVELOCITY,6X,
18HVELOCITY,6X,8HPRESSURE/47X,5HRATIO,9X,11HCOEFFICIENT/)
620 FORMAT (1X,5F14.2)
630 FORMAT (1X,13)
640 FORMAT (1X//)
700 FORMAT (5E14.8)
1001 FORMAT (5F14.7)
  DATA (HEAD(I,1),I=1,2)/6H PSI,6H /,(HEAD(I,2),I=1,2)/6HX-DB
XRI,6HVATIVE/, (HEAD(I,3),I=1,2)/6HY-DER1,6HVATIVE/
  RANK=1.
  LN=LN-5
  XL1P=XL1
  XL2P=XL2
  YL1P=YL1
  YL2P=YL2
  IF (XSCLA.EQ.0.) ISTOP=1
  LINE=0
  TP(1)=23.
  TP(2)=4.
  TP(3)=XSCL
  TP(4)=YSCL
  TP(5)=0.
  TP(6)=0.
  TP(8)=4.
  TP(9)=0.
  2 NSTOR =LN+5
  ISTOP=0
  5 DO 20 I=NGRDC,LN,5
  IF (Y(I).NE.RANK1 GO TO 20
10 Y(NSTOR)=Y(I)
  Y(NSTOR+1)=Y(I+1)

```

```

Y(NSTOR+2)=Y(I+2)
Y(NSTOR+3)=Y(I+3)
Y(NSTOR+4)=Y(I+4)
NSTOR=NSTOR+5
20 CONTINUE
GO TO 23
22 RANK=RANK-1.0
23 NSTOR=NSTOR-5
NSTOR1=LN+5
IF (NSTOR-NSTOR1.LE.6) GO TO 102
46 LINE=0.
XL1P=XL1
XL2P=XL2
YL1P=YL1
YL2P=YL2
971 WRITE (6,600) (HEAD(I,KASE),I=1,2),SLINES(NG)
DO 775 I=NSTOR1,NSTOR,5
IF (Y(I+1).EQ.Y(I+6).AND.Y(I+2).EQ.Y(I+7)) GO TO 775
VR=Y(I+3)/VO
WRITE (6,1001) Y(I+1),Y(I+2),Y(I+3),VR,Y(I+4)
LINE=LINE+1
IF (LINE.LT.50) GO TO 775
LINE=0
WRITE (6,600) (HEAD(J,KASE),J=1,2),SLINES(NG)
775 CONTINUE
72 J=0
DO 100 I=NSTOR1,NSTOR,5
J=J+1
XP(J)=Y(I+1)
100 YP(J)=Y(I+2)
KNTR=0
DO 65 JK=1,J
IF (XP(JK).LT.XL1P.OR.XP(JK).GT.XL2P.OR.YP(JK).LT.YL1P.OR.YP(JK) .
XGT.YL2P) GO TO 62
GO TO 65
62 XP(JK)=BITS
KNTR=KNTR+1
65 CONTINUE
KT=0
DO 68 JK=1,J
IF (XP(JK).NE.BITS) GO TO 68
66 KT=KT+1
JKT=JK+KT
IF (XP(JKT).EQ.BITS) GO TO 66
DO 67 LJ=JK,J
JKT=LJ+KT
XP(LJ)=XP(JKT)
67 YP(LJ)=YP(JKT)
KT=0
68 CONTINUE
J=J-KNTR
AJ=J

```

```

      TP(7)=AJ
      IF (ISTOP.NE.0) GO TO 80
      WRITE (8) J
      WRITE (8) (XP(I),I=1,J),(YP(I),I=1,J)
      XL1P=XL1A
      XL2P=XL2A
      YL1P=YL1A
      YL2P=YL2A
      ISTOP=2
      GO TO 72
80  IF (ISTOP.EQ.1) GO TO 81
      TP (3)=XSCLA
      TP (4)=YSCLA
      TP(2)=4.
81  CALL GPLOTS(TP,XP,YP)
      RANK=RANK+1.
      GO TO 2
102 IF (NG.LT.NSL) RETURN
      TP(7)=0
      TP(9)=-1.
      TP(2)=4.
      CALL GPLOTS (TP,XP,YP)
      IF (ISTOP.NE.2) GO TO 120
      REWIND 8
      TP (3)=XSCL
      TP (4)=YSCL
      TP(9)=0.
      DO 101 I=1,NSL
      READ (8) J
      READ (8) (XP(M),M=1,J),(YP(M),M=1,J)
      TP(7)=J
      TP(2)=4.
101 CALL GPLOTS (TP,XP,YP)
      TP(7)=0.
      TP(9)=-1.
      TP(2)=4.
      CALL GPLOTS (TP,XP,YP)
120 CALL REMOVE(23,3)
      IF (PUNCH.EQ.0.) GO TO 99
      YT(1)=Y(IST+1)
      DO 123 I=2,NYR
      ID=NKYV+I-1
123 YT(I)=Y(ID)+YT(I-1)
      XT(1)=Y(KJ)
      DO 124 I=2,NXC
      ID=NKXV+I-1
124 XT(I)=Y(ID)+XT(I-1)
      TA(1)=1.
      TA(2)=NYR+1
      TA(3)=NXC+1
      TA(4)=0.
      DO 125 I=1,NYR

```

```

125 TA(I+4)=YT(I)
    NFUNCT=NCFCCT-1
    JK=NYR+5
    DO 256 I=1,NXC
      TA(JK)=XT(I)
      JK=JK+1
    DO 255 NQ=1,NYR
      NFUNCT=NFUNCT+1
      TA(JK)=Y(NFUNCT)
      JK=JK+1
255 CONTINUE
256 CONTINUE
    JK=JK-1
    WRITE (7,700) (TA(I),I=1,3)
    WRITE (7,700) (TA(I),I=4,JK)
99 RETURN
END

```

\$IBFTC WAMARK

*MARC

SUBROUTINE MARC

* THIS SUBROUTINE PERFORMS THE FUNCTION OF SEARCH IN LINK 3.

DIMENSION B(1),Y(18000),SLINES(30)

COMMON B,NXC,NYR,NKXVC,NKYVC,NDXC,NDYC,NCFCT,NBETAC,KJ,BITS,IST,
1HONE,HTWO,ONEK,THOK,I,IN,J,JN,IKJ,KIJ,JIJ,IJK,IT,NDX,NDY,NFUNCT,Y,
2SLINES,H1,H2,TK1,TK2,NB1,NB2,NB3,NB4,NC1,NC2,NC3,NC4,N1,N2,U0,U1,
3U3,U2,U4,IPRIN,NRSDUE,NSL,NSLNC,NGRDC,NGRDXC,NGRDYC,AXYM,NGRAD,
4NGRADX,NGRADY,LN,CSCH,NG,EXTRAP,SSRCH,NSWPS,OMEGA,CVGS,CONST,
5STREAM,KNTR,A,C,D,E,F,G,HK1,HK12,H12,HK2,BY,BX,NKXV,NKYV,N3,
6P,Q,R,S,T,V,W,XC,YC,IH,JH,KH

COMMON /VEL/ NGRDVC,AIR

COMMON/BDRY/ JB

COMMON /ZCOM/ Z

COMMON /LNK5/ NV

COMMON /PLOT/ RANK

600 FORMAT (I12)

620 FORMAT (1X,6F14.2)

* INITIALIZE ALL SUBSCRIPTS TO PICK UP INFORMATION IN Y ARRAY.

HL=0.0

SRANK=1.0

FLAG=0.0

Z=0.

LN=NGRDC

NGRADX=NGRDXC-1

NGRADY=NGRDYC-1

NV=NGRDVC-1

NKXV=NKXVC-1

NFUNCT=NCFCT-1

NDX=NDXC-1

J=KJ

* SET LOOP TO PROGRESS FROM COLUMN TO COLUMN.

FST=0.

DO 76 NX=1,NXC

* CHANGE SUBSCRIPTS AFFECTED BY A CHANGE OF COLUMN.

RANK=SRANK

NDY=NDYC-1

NKYV=NKYVC-1

NDX=NDX+1

I = IST+1

NKXV=NKXV+1

* SET LOOP TO PROGRESS ALONG A COLUMN.

DO 75 NY=1,NYR

* CHANGE SUBSCRIPTS AFFECTED BY A CHANGE ALONG A COLUMN

ILN=LN

```

    NGRADX=NGRADX+1
    NGRACY=NGRADY+1
    NFUNCT=NFUNCT+1
    NV=NV+1
    NKYV=NKYV+1
    NDY=NDY+1
*
* SET SUBSCRIPTS TO FIND BOUNDARY INFORMATION FROM THE INPUT ARRAY.
*
    JN=J+2
    IN=I+2
    KYVA=Y(NKYV)/4.
    KYVB = KYVA
*
* LCCP 10 AND 112 ARE NECESSARY FOR COMPLEX BOUNDARIES.
*
    DO 10 IS=1,KYVA
*
* LOCATE POSITION OF POINT IN THE ENTIRE SYSTEM.
*
* THE POINT WILL EITHER BE INTERIOR, EXTERIOR OR BOUNDARY.
    IF(Y(IN)-Y(J))1,80,75
    1 IF(Y(IN+2)-Y(J))110,80,7
    7 KXVA=Y(NKXV)/4.
    KXVB=KXVA
    DO 112 JS=1,KXVA
    IF(Y(JN)-Y(I))11,75,75
    11 IF(Y(JN+2)-Y(I))12,75,13
    12 KXVB=KXVB-1
    IF (KXVB) 75,75,112
112 JN=JN+4
110 KYVB = KYVB-1
    IF (KYVB) 75,75,10
    10 IN=IN+4
    13 CALL GRDST2
    14 CALL SGSRCH
    IF (LN.GT.ILN) RANK=RANK+1.
    Z=0.
    75 I=I+INT(Y(NKYV))+2
    IF (RANK.LE.2.0.OR.FST.NE.0.) GO TO 50
    IF (FLAG.EQ.1.0) GO TO 60
    IF (AIR.NE.1.0) GO TO 55
    52 FST=1.0
    HL=1.0
    IKK=5.0*(2.0+FLAG)
    IDX=FLOAT(LN)-(10.0+FLAG*10.0)
    DO 57 IK=1,IKK
    KONT=LN+6-IK
    57 Y(KONT)=Y(KONT-5)
    Y(IDX)=2.0
    GO TO 50
    55 FLAG=1.0

```

```

GO TO 25
60 CONTINUE
  IF (RANK.EQ.3.) GO TO 52
  SRANK=2.0
  RANK=SRANK
  FST=1.0
  IF (AIR.LT.1.0) GO TO 74
  DO 65 IK=1,20
  KONT=LN+6-1K
65 Y(KONT)=Y(KONT-5)
  Y(LN-30)=2.0
  Y(LN-25)=3.0
  Y(LN-20)=1.0
  Y(LN-15)=4.0
  Y(LN-10)=2.0
  Y(LN-5)=3.0
  Y(LN)=4.0
  LN=LN+5
  GO TO 25
74 DO 745 IK=1,25
  KONT=LN+6-1K
745 Y(KONT)=Y(KONT-5)
  Y(LN-25)=2.0
  Y(LN-20)=3.0
  Y(LN-15)=4.0
  Y(LN-10)=2.0
  Y(LN-5)=3.0
  Y(LN)=4.0
  LN=LN+5
  GO TO 25
50 CONTINUE
  IF (RANK.NE.4.0) GO TO 25
  IF (HL.EQ.1.0) GO TO 25
  SRANK=5.0
  RANK=SRANK
  DO 24 IK=1,10
  KONT=LN+11-1K
24 Y(KONT)=Y(KONT-10)
  LN=LN+10
  Y(LN-10)=RANK
  Y(LN-5)=RANK+1.0
25 CONTINUE
76 J=J+INT(Y(NKXV))+2
26 RETURN
80 Z=1.
GO TO 7
END

```

1686

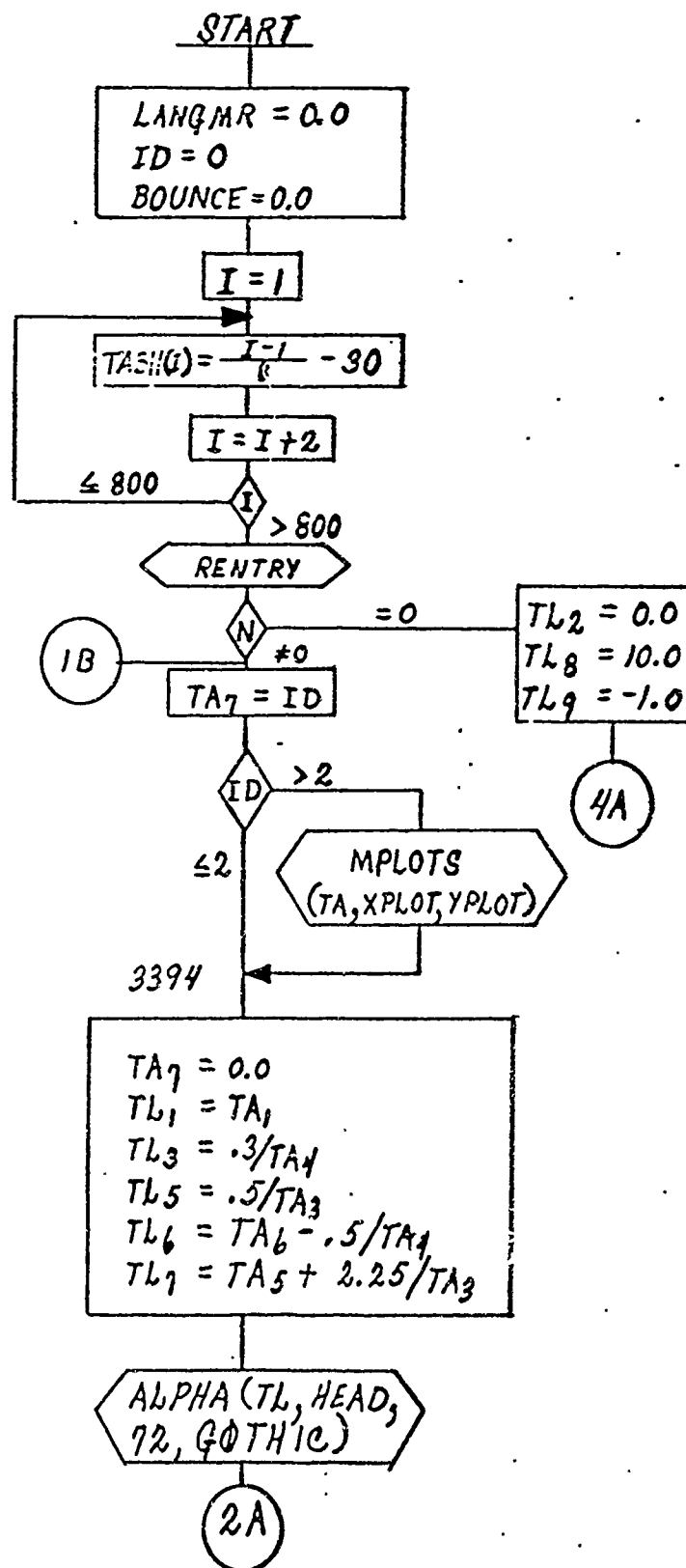
10.3 Appendix 3 - Water Droplet Trajectory Computer Program Flow Chart

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E-3033 D1

BOEING	NO. D3-6961
SECT	PAGE 153

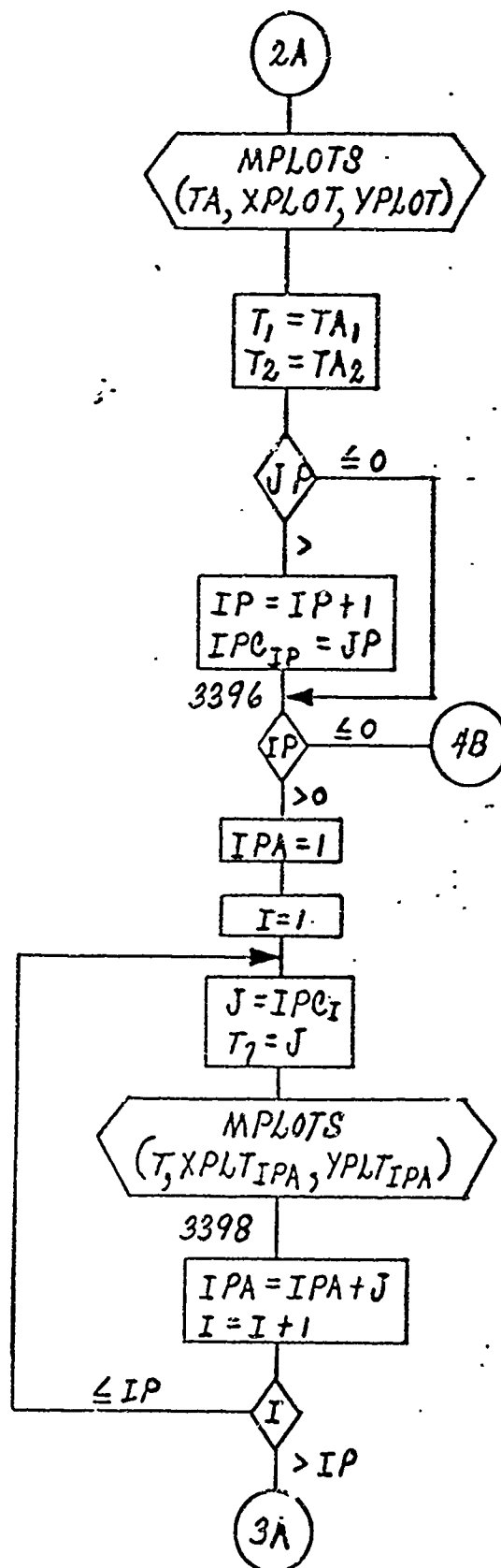
Water Droplet Trajectory Program



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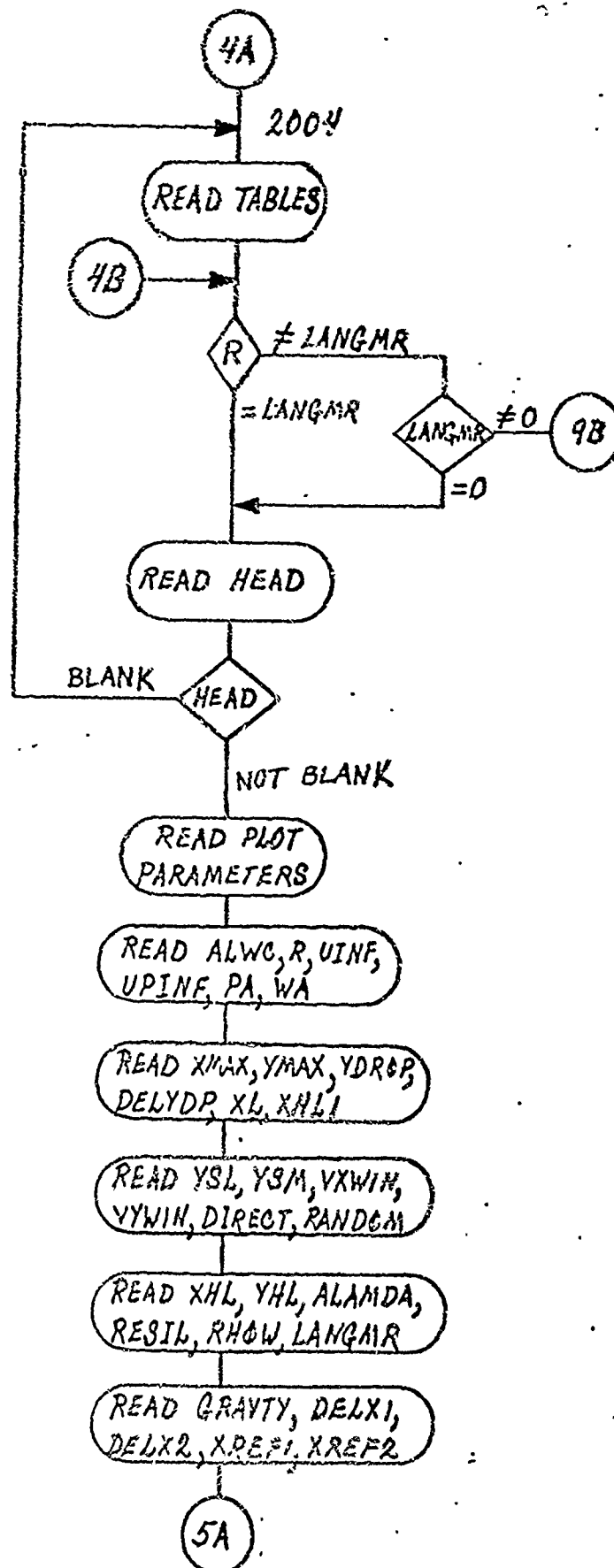
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 SECT PAGE 154



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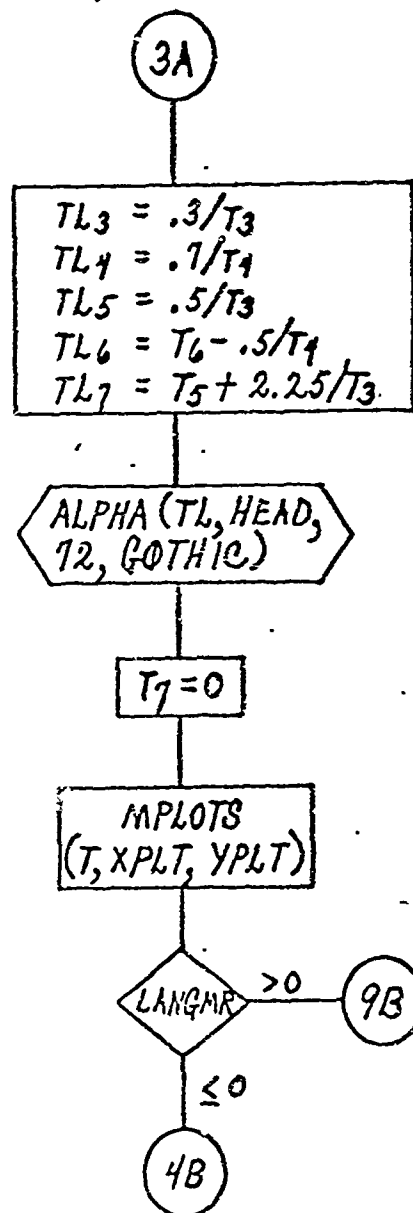
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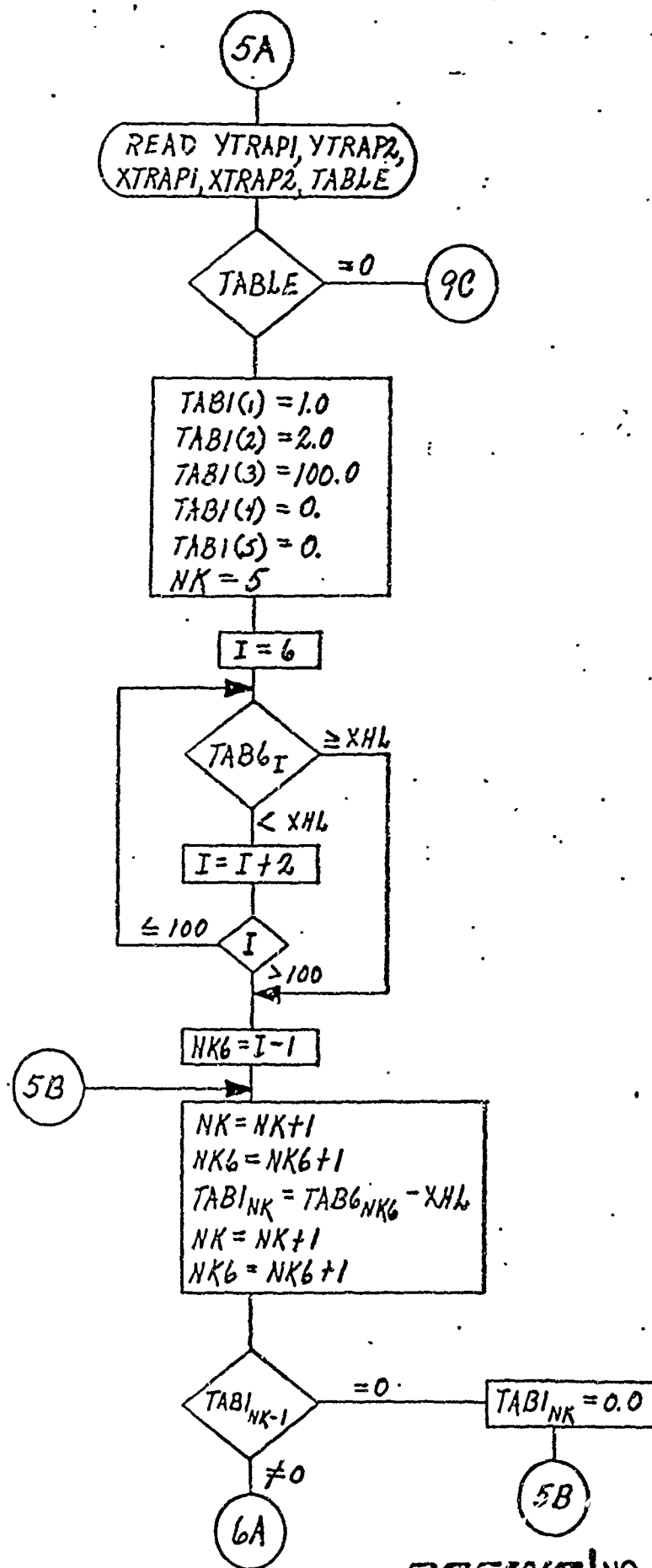
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SECT	PAGE 136	



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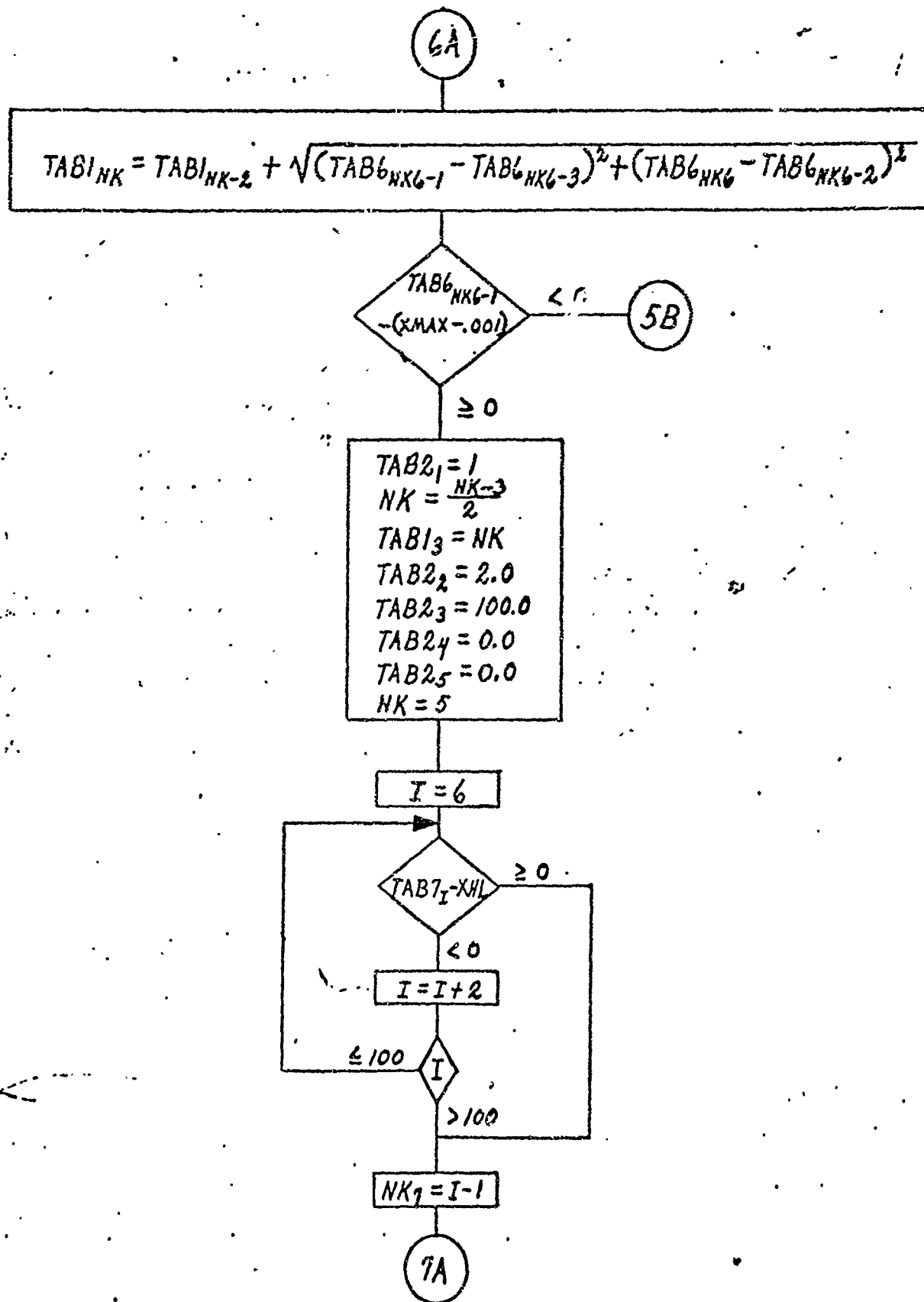
BOEING		NO. D3-1961
SECT	PAGE 157	



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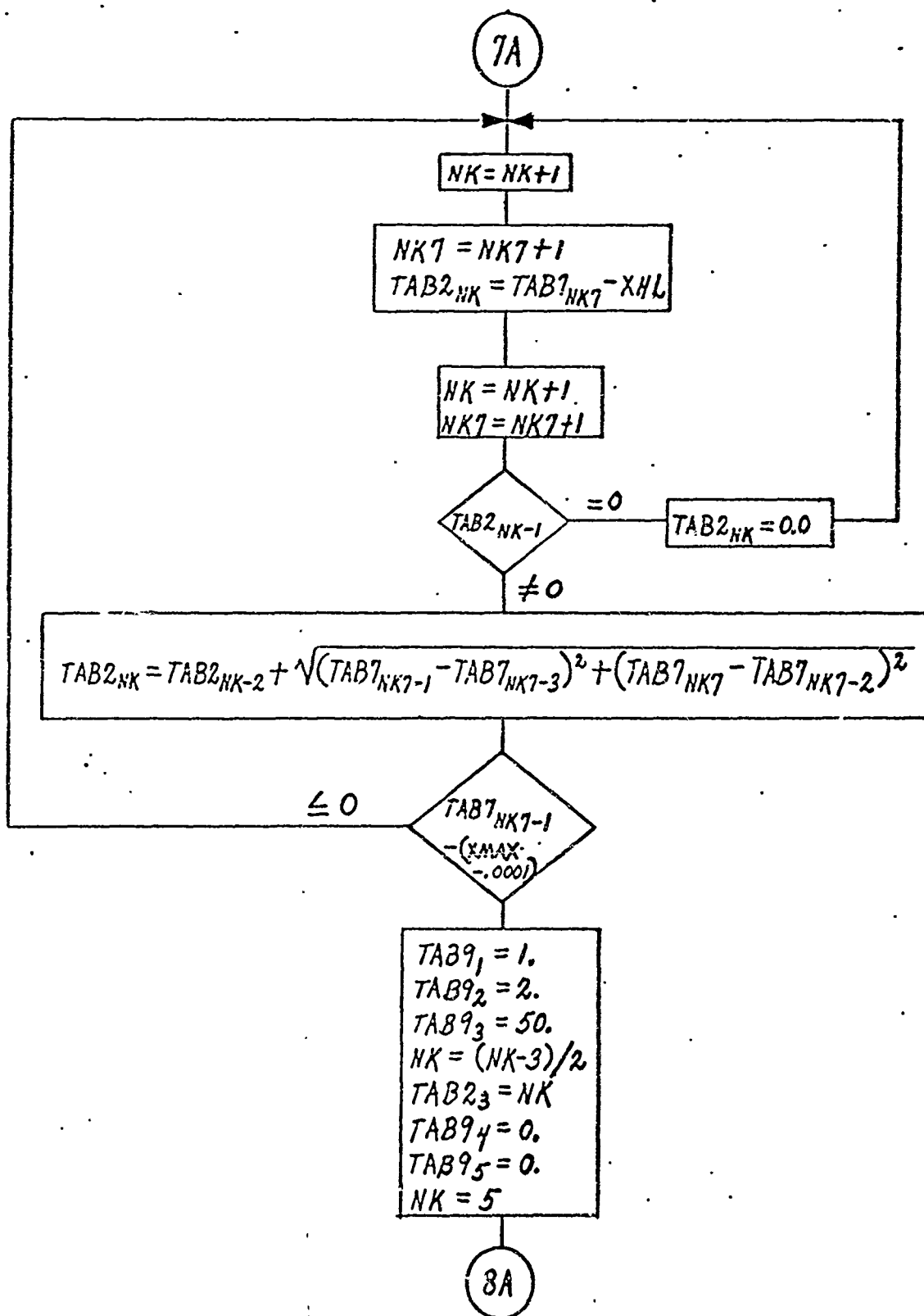
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SECT	PAGE	158



REVLTR:

K-2032 R1

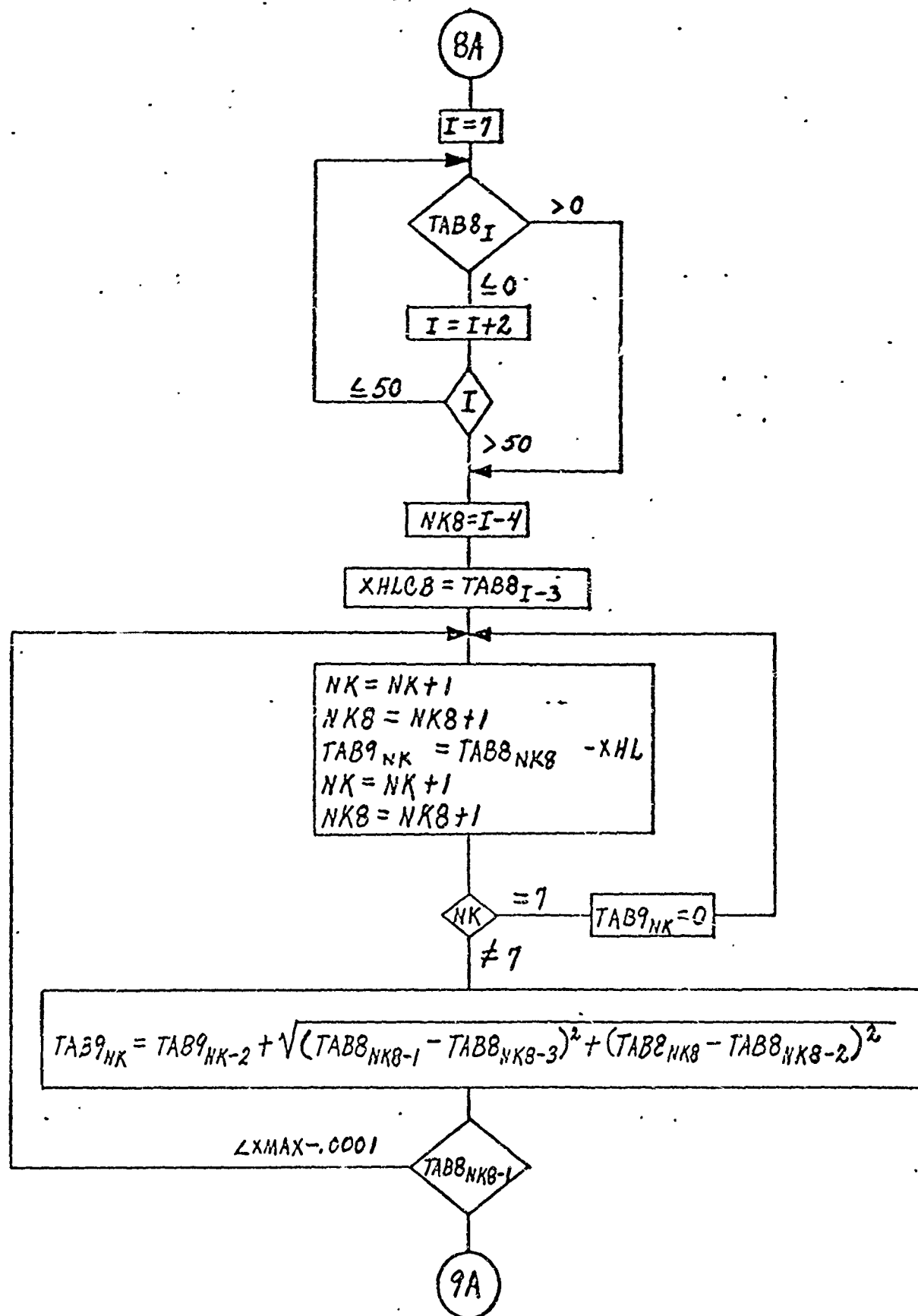
BOEING	NO. D3-6961
SECT	PAGE 159



REVLTR:

E-3032 R1

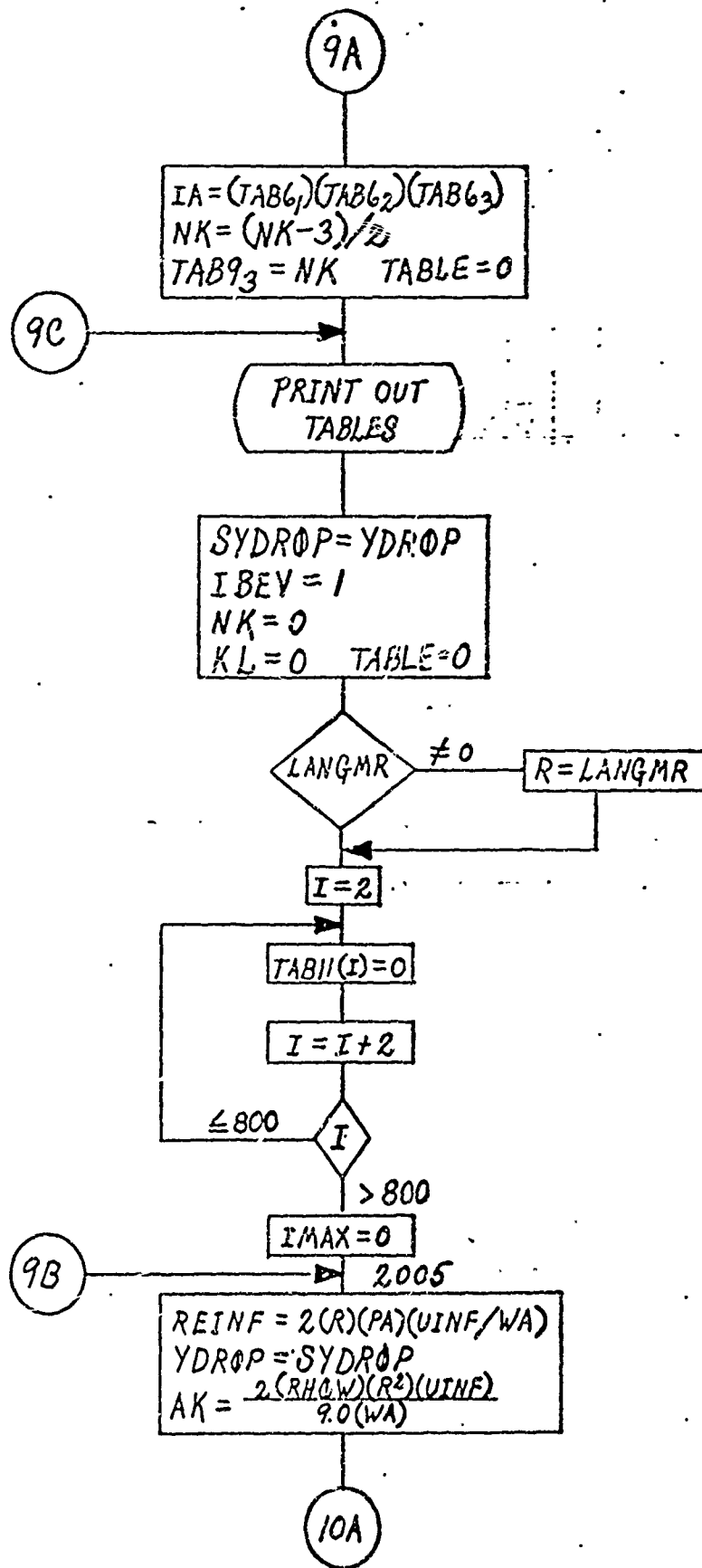
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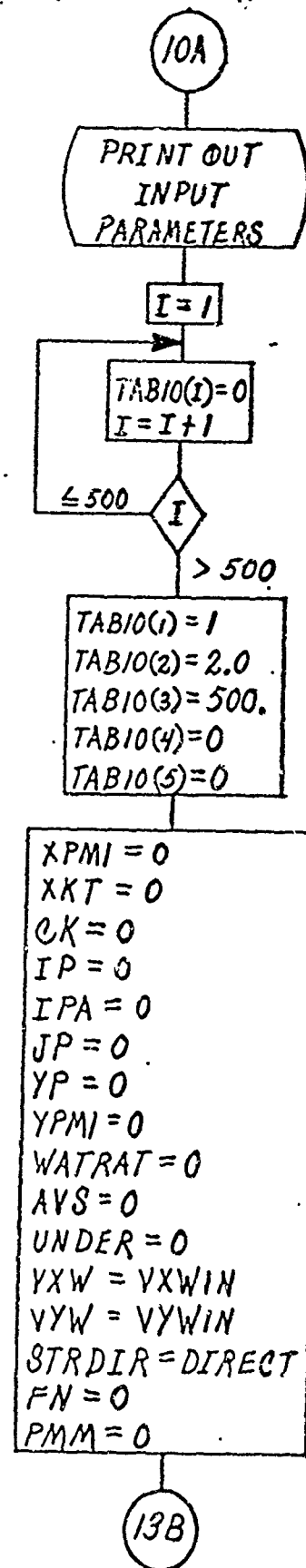


REVLTR:

E-3033 R1

BOEING NO. D3-6961
 SECT PAGE 161

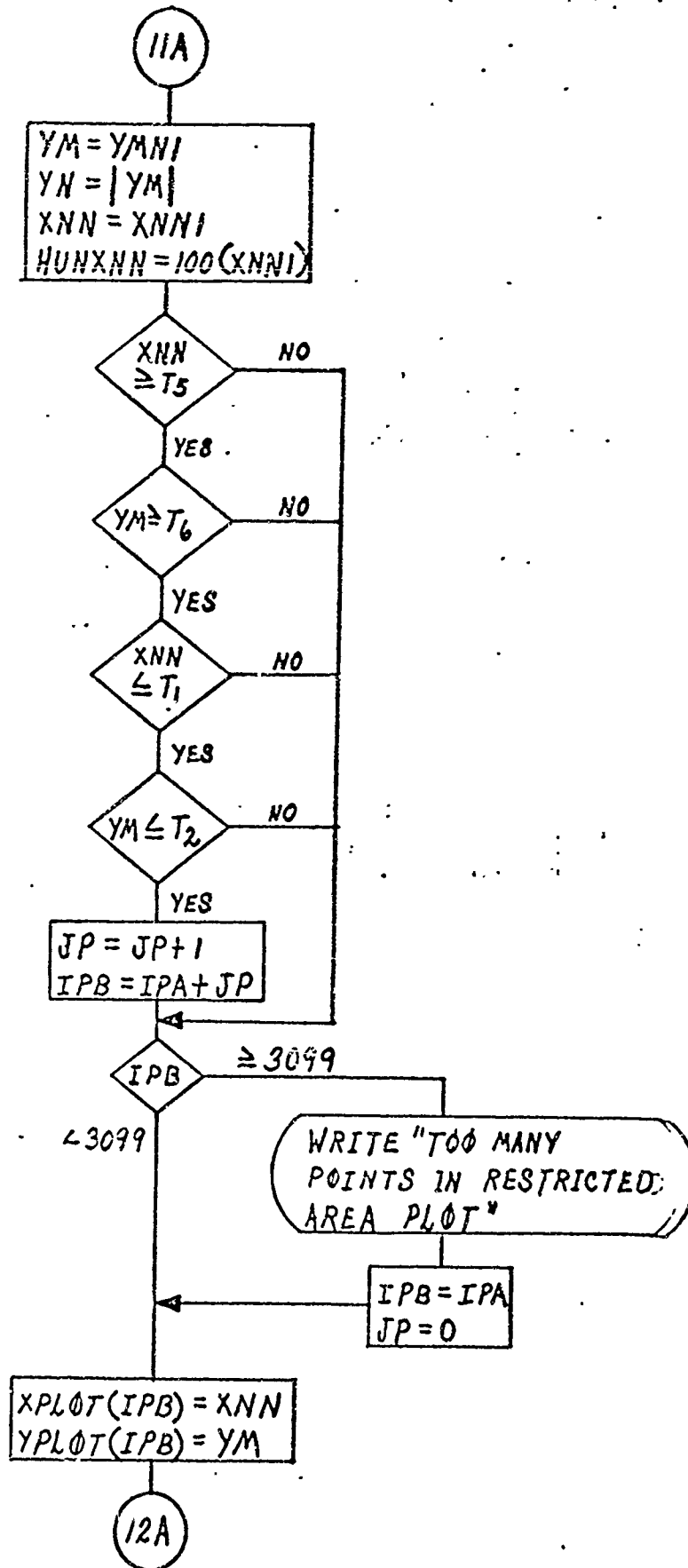




REVLTR:

E-3032 R3

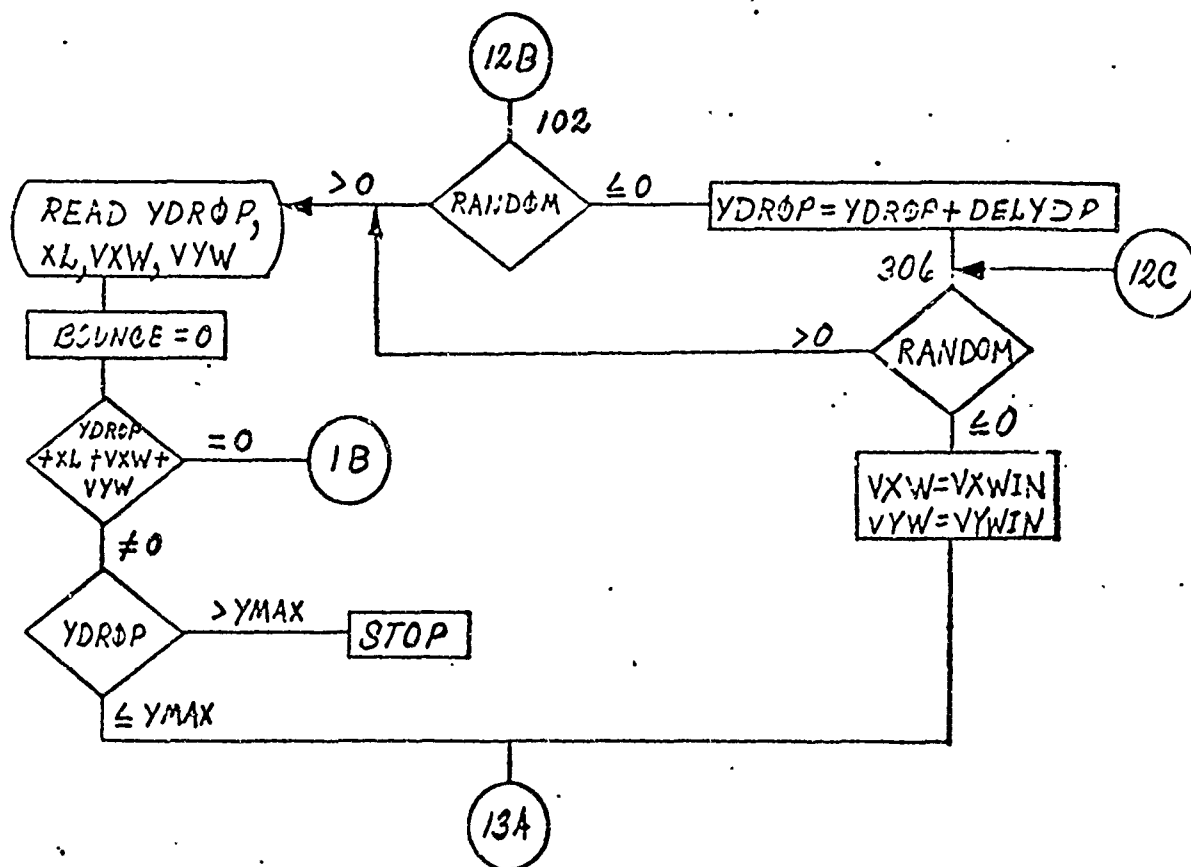
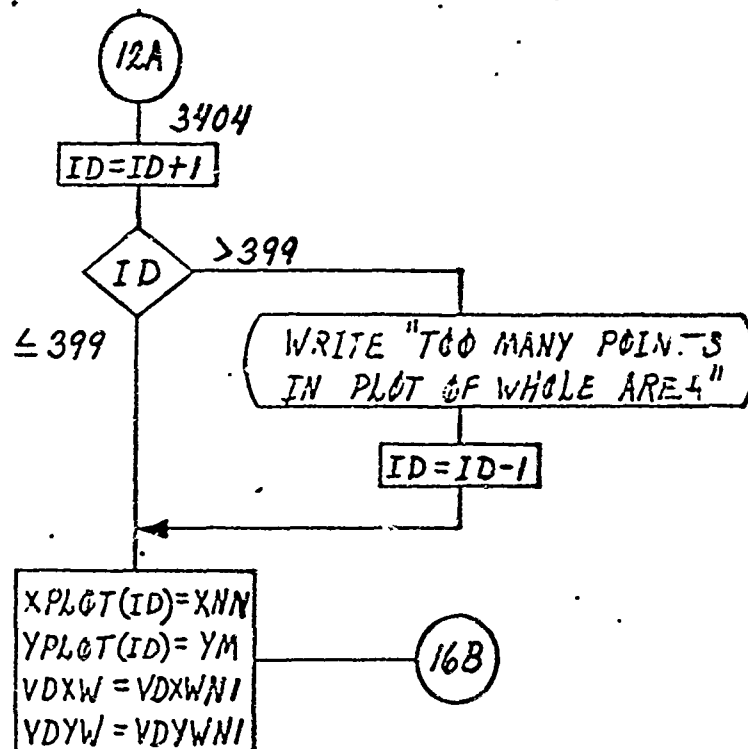
BOEING	NO. D3-6961
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REVLTR:

E-3023 R1

~~INDEX~~	NO.	D3-6961
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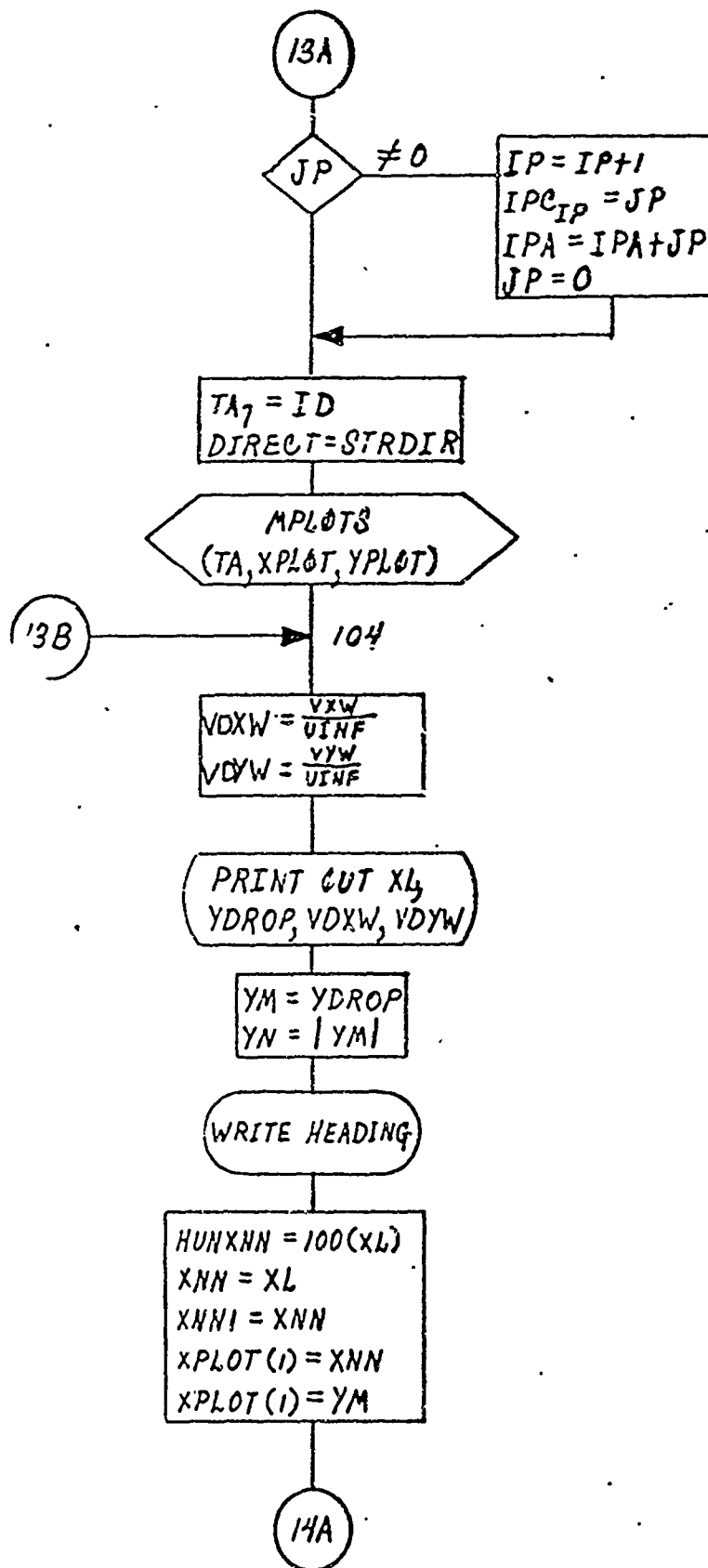


REVLTR:

E-3033 R1

BOEING NO. D3-6961

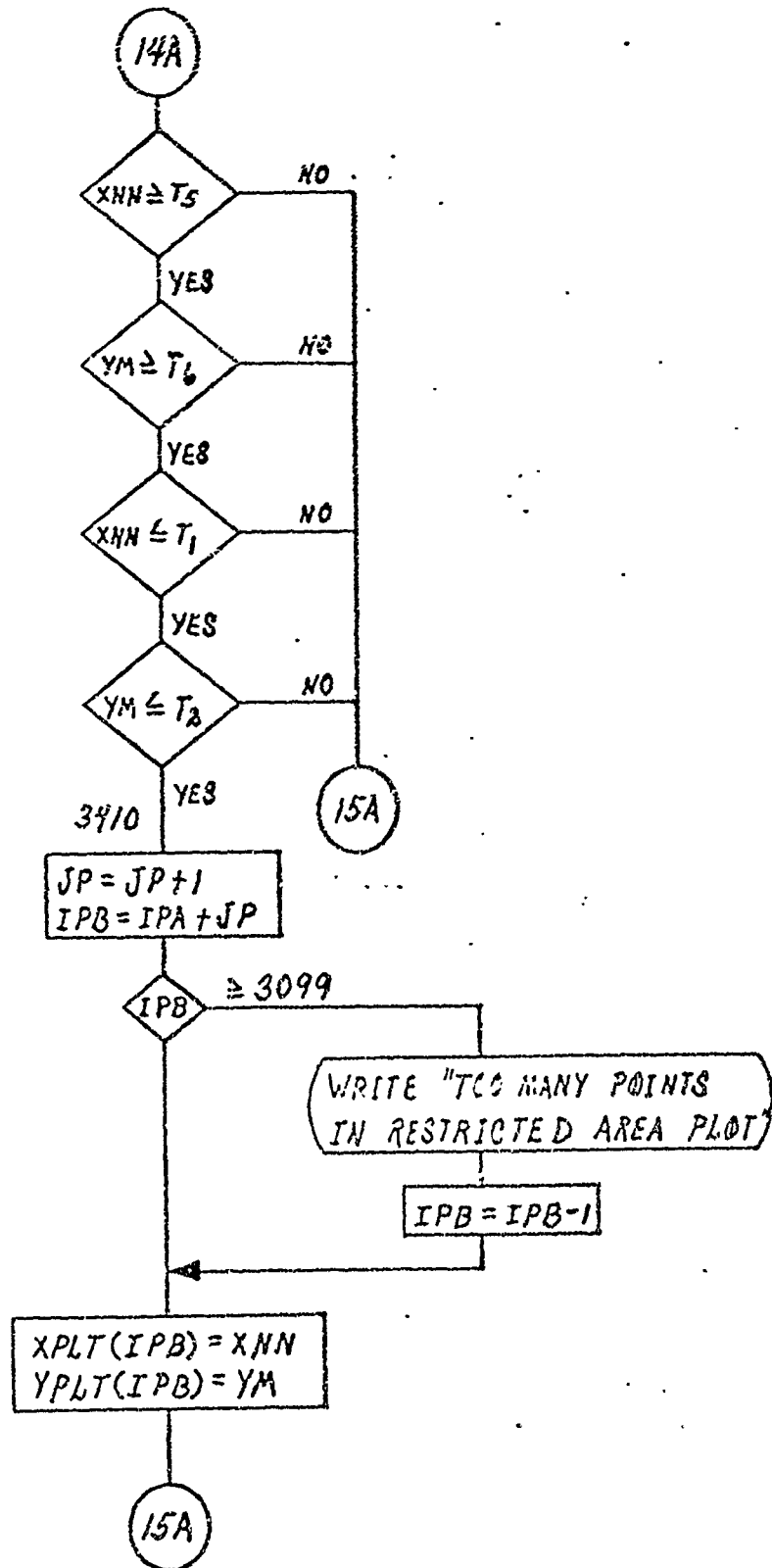
SECT	PAGE 165
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REVLTR:

E-3033 R1

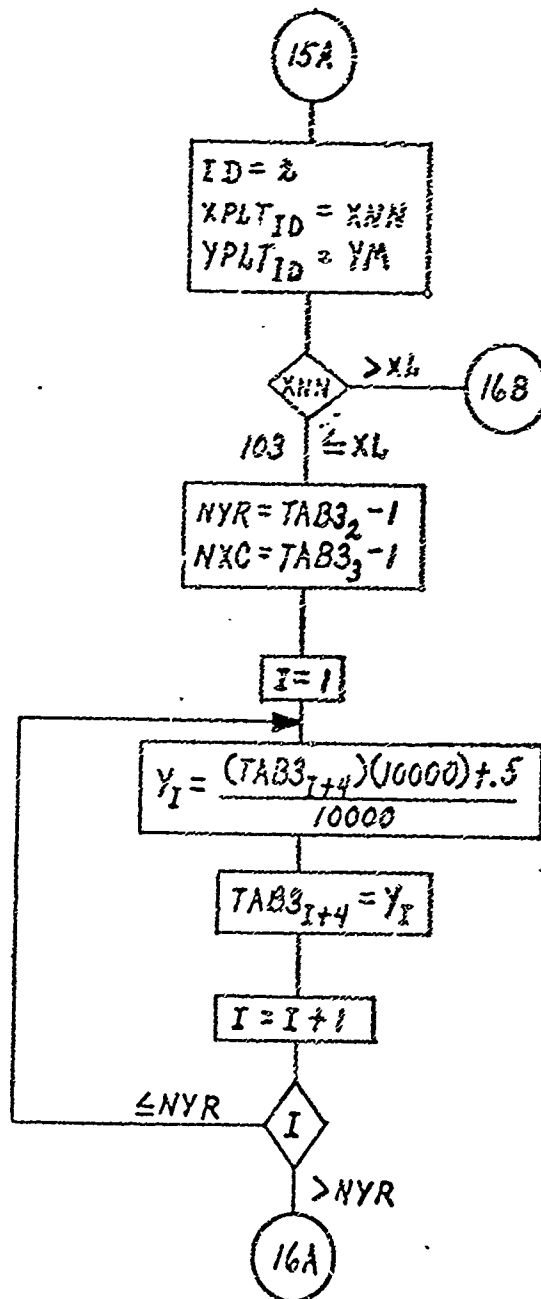
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REVLTR:

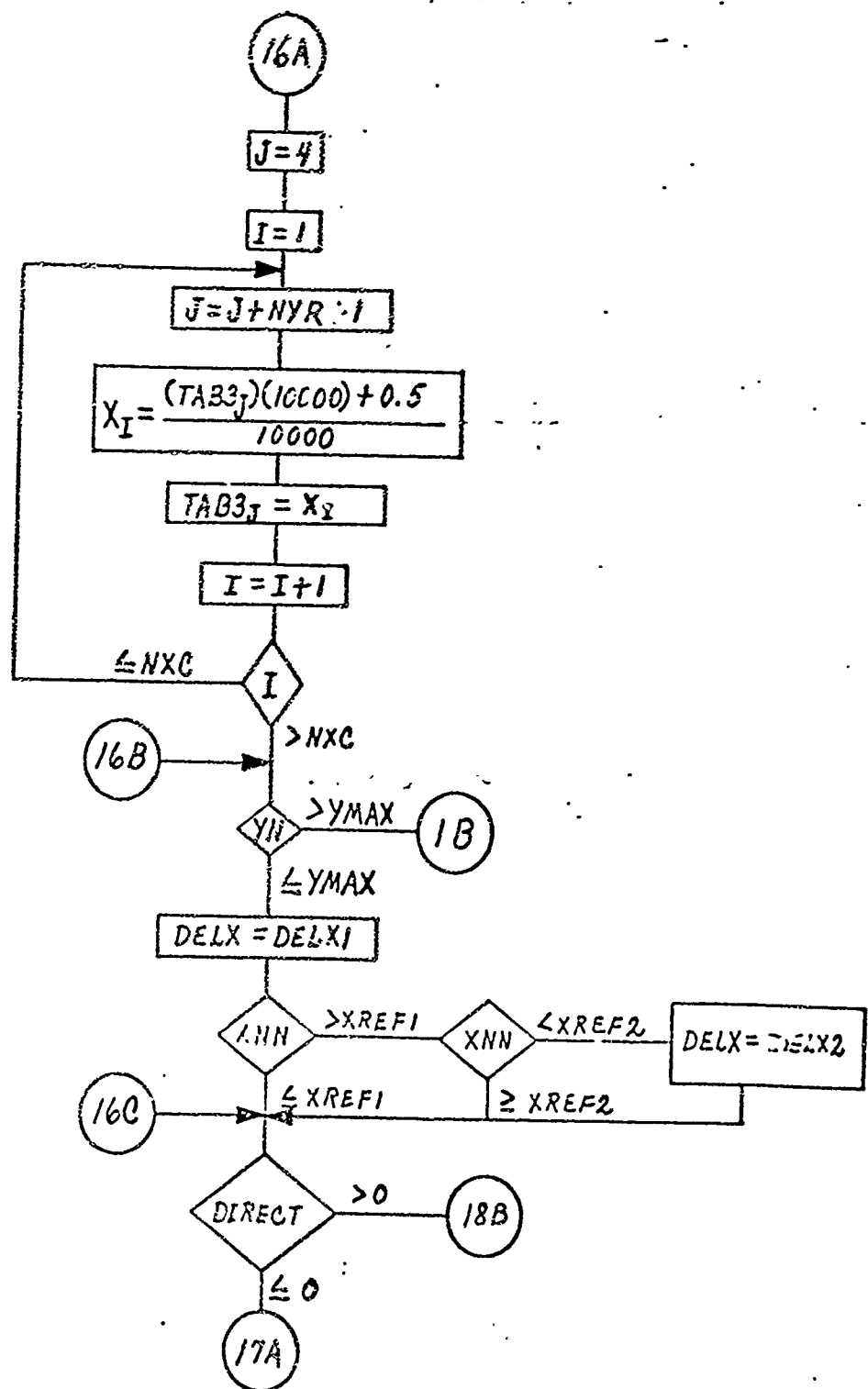
E-3033 Rf.

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REVLTR:

E-3033 R1



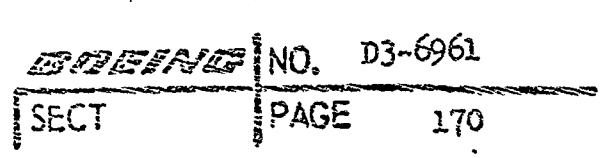
REVLTR:

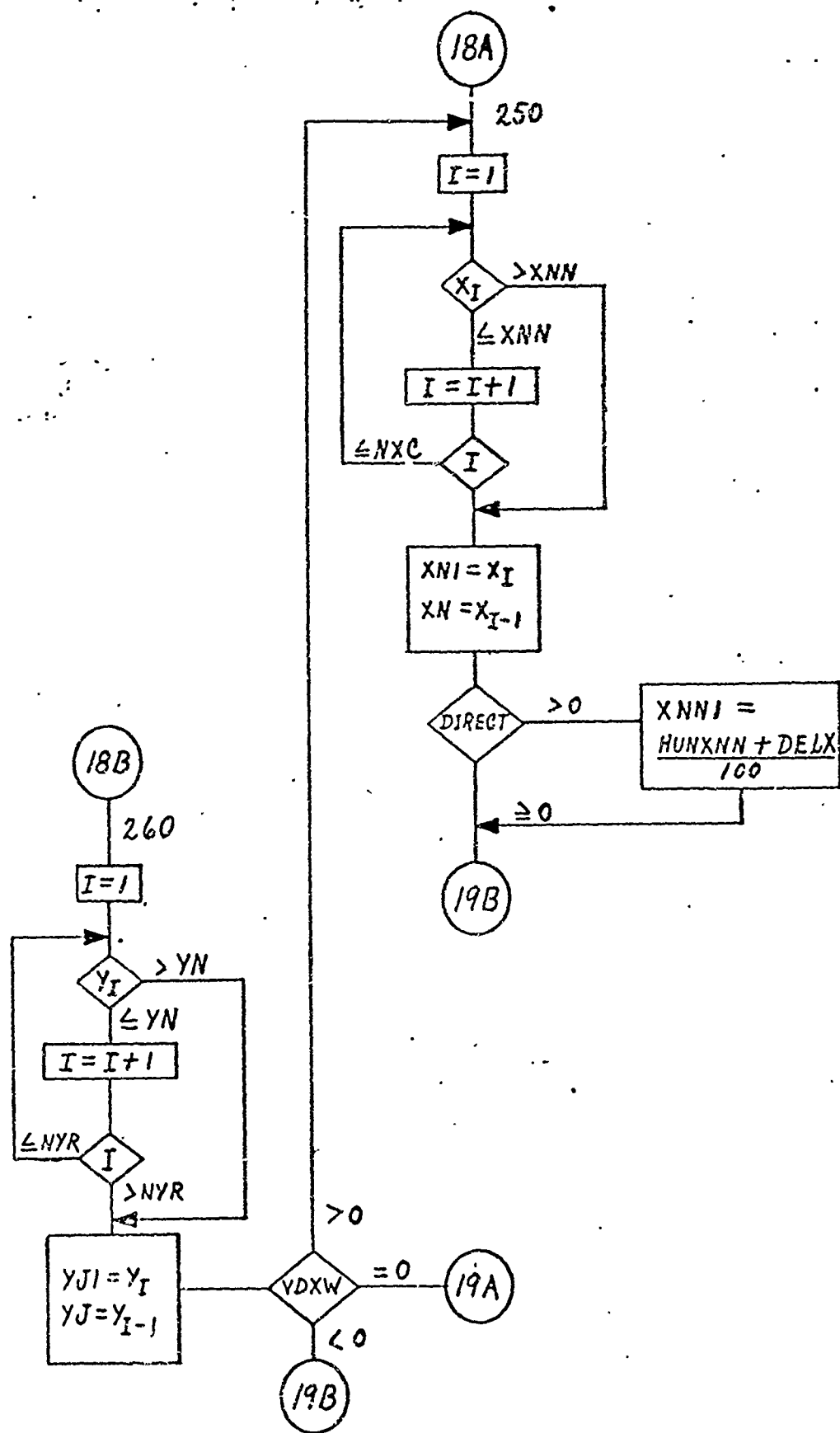
E-3032 R1

BOEING NO. D3-6961

SECT

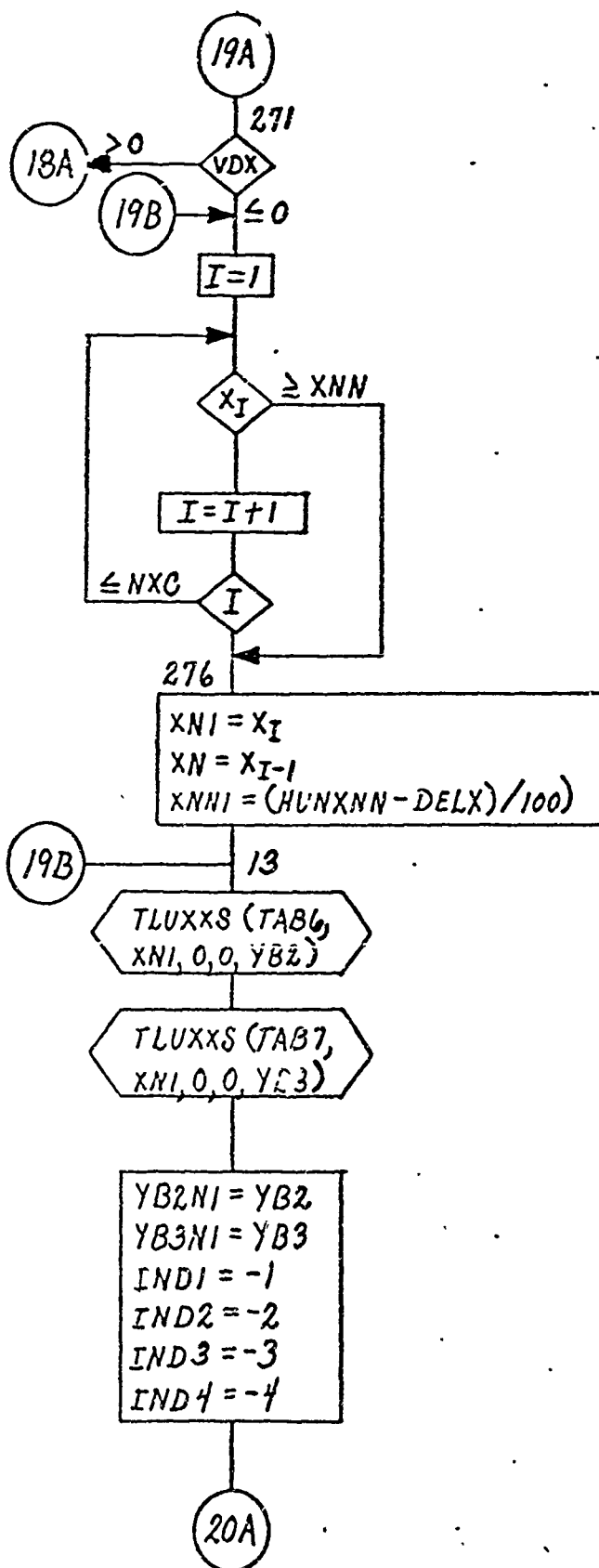
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REVLTR:

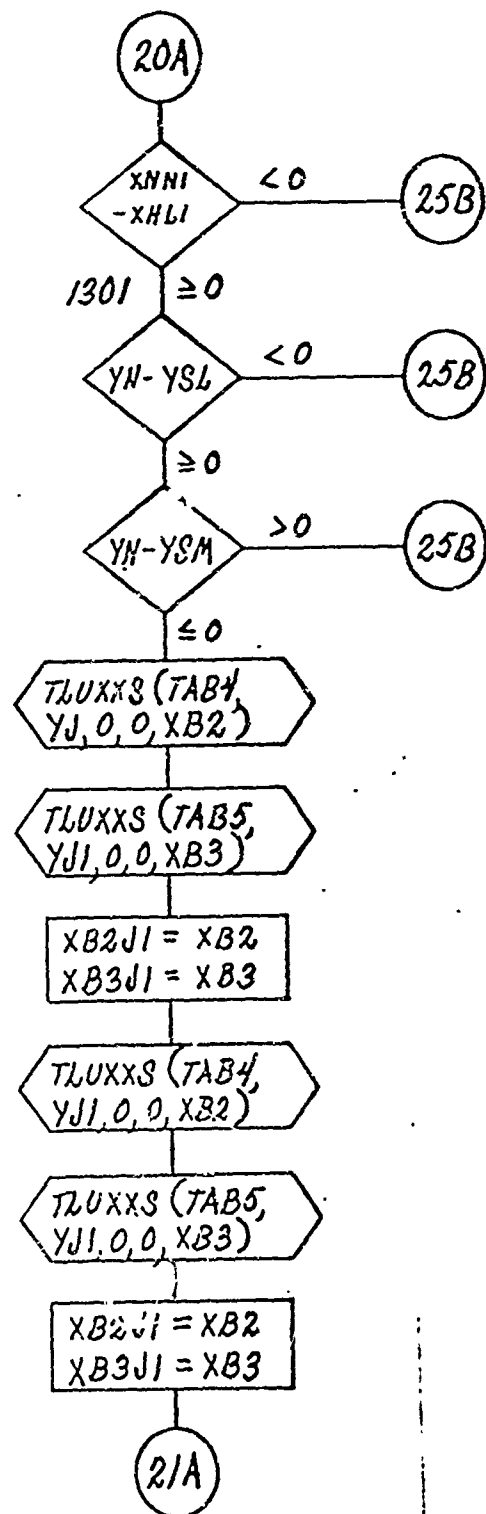
2-3038 RS



REVLTR:

E-5033 R1

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REVLTR:

E-2033 R1

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21A

TLUXXS (TAB6,
XN, 0, 0, YB2)

TLUXXS (TAB7,
XN, 0, 0, YB3)

YB2N = YB2
YB3N = YB3

TLUXXS (TAB6,
XN1, 0, 0, YB2)

TLUXXS (TAB7,
XN1, 0, 0, YB3)

TLUXXS (TAB9,
XN, 0, 0, YB1)

YBIN = YB1

TLUXXS (TAB8,
XN1, 0, 0, YB1)

YBIN1 = YB1
YB2N1 = YB2
YB3N1 = YB3
IND1 = -1.0
IND2 = -1.0
IND4 = -1.0
IND4 = -1.0

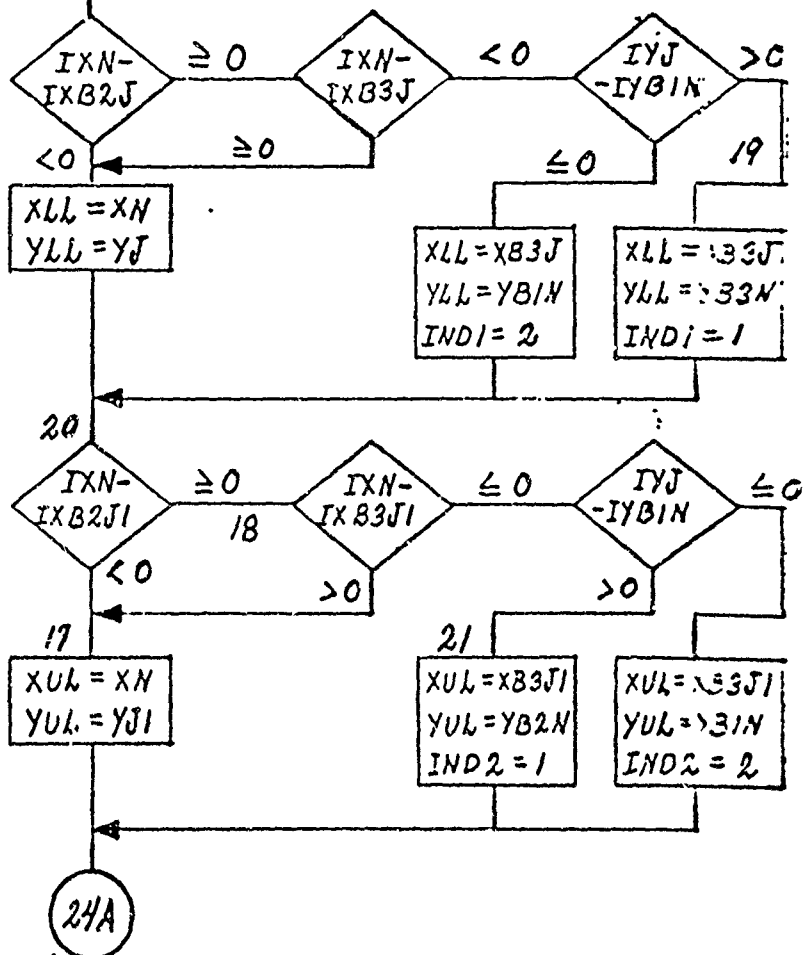
22A

REVLTR:

E-3033 R1

23A

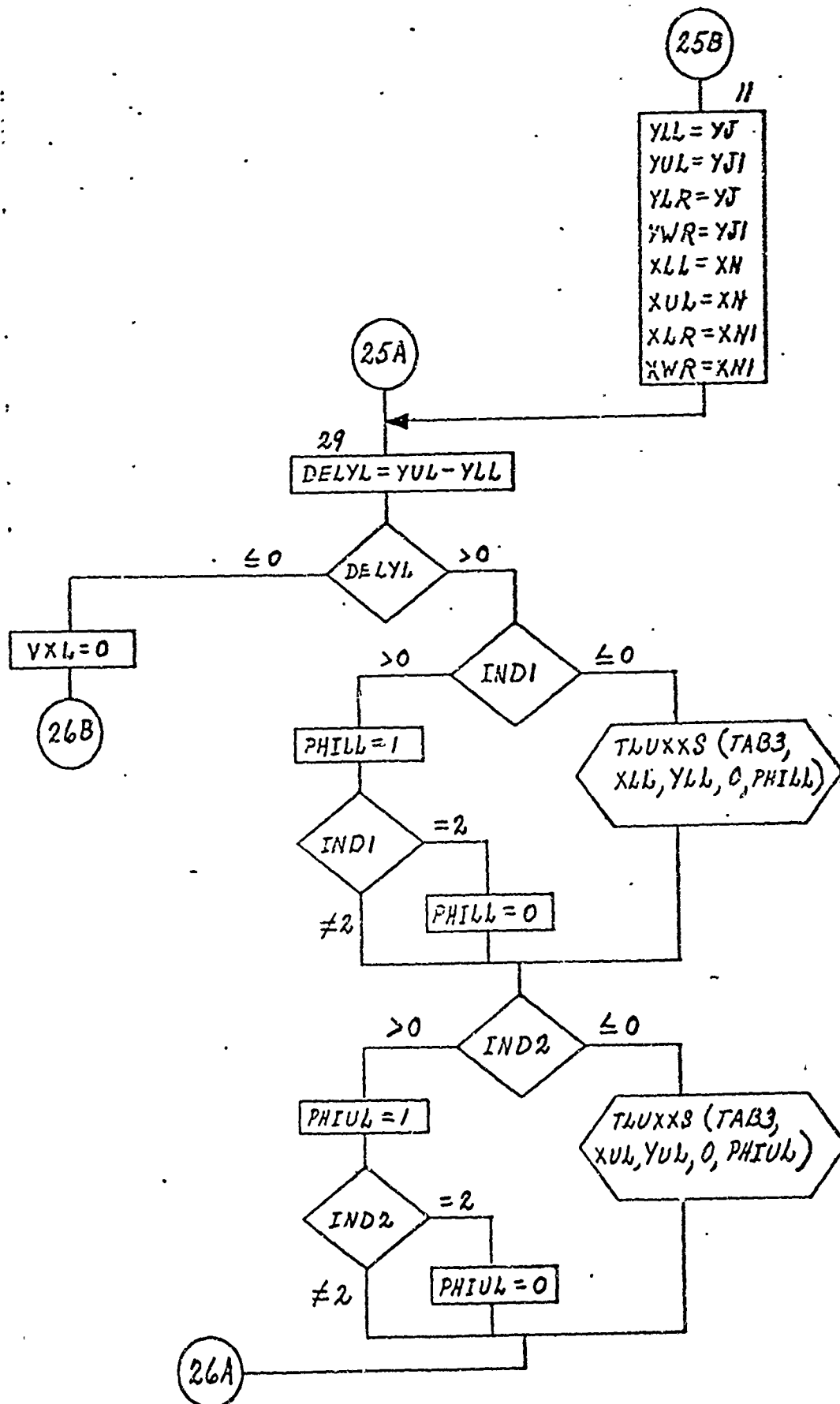
$IXB2J = 10000(XB2J + .00001)$
 $IXB3J = 10000(XB3J + .00001)$
 $IXB2J1 = 10000(XB2J1 + .00001)$
 $IXB3J1 = 10000(XB3J1 + .00001)$
 $IXB2N = 10000(XB2N + .00001)$
 $IXB3N = 10000(XB3N + .00001)$
 $IXB2N1 = 10000(XB2N1 + .00001)$
 $IXB3N1 = 10000(XB3N1 + .00001)$
 $IYBIN = 10000(YBIN + .00001)$
 $IYBIN1 = 10000(YBIN1 + .00001)$
 $IXN = 10000(XN + .00001)$
 $IXN1 = 10000(XN1 + .00001)$
 $IYJ = 10000(YJ + .00001)$
 $IYJ1 = 10000(YJ1 + .00001)$



24A

REVLTR:

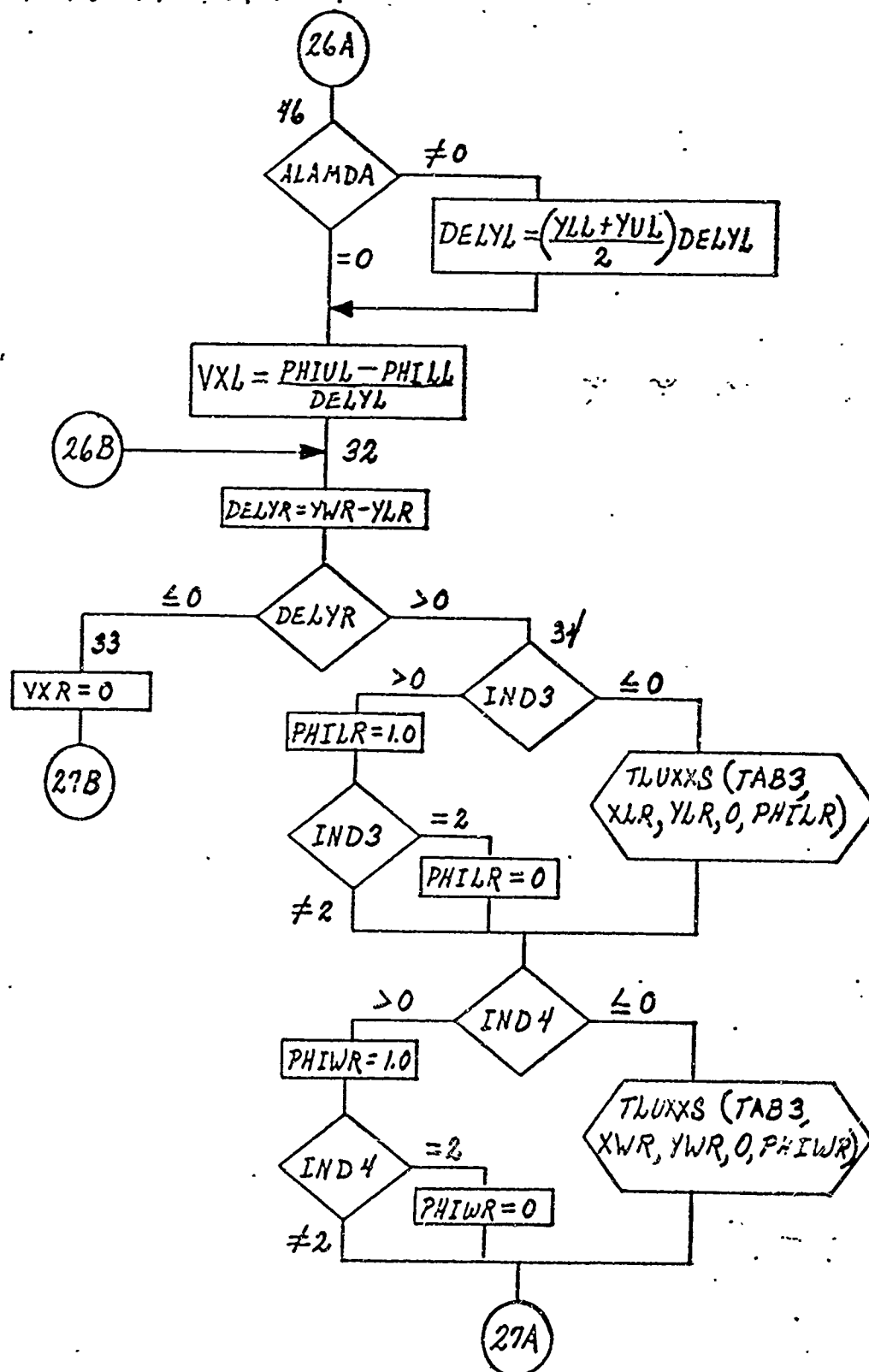
E-3033 R1



REVLTR:

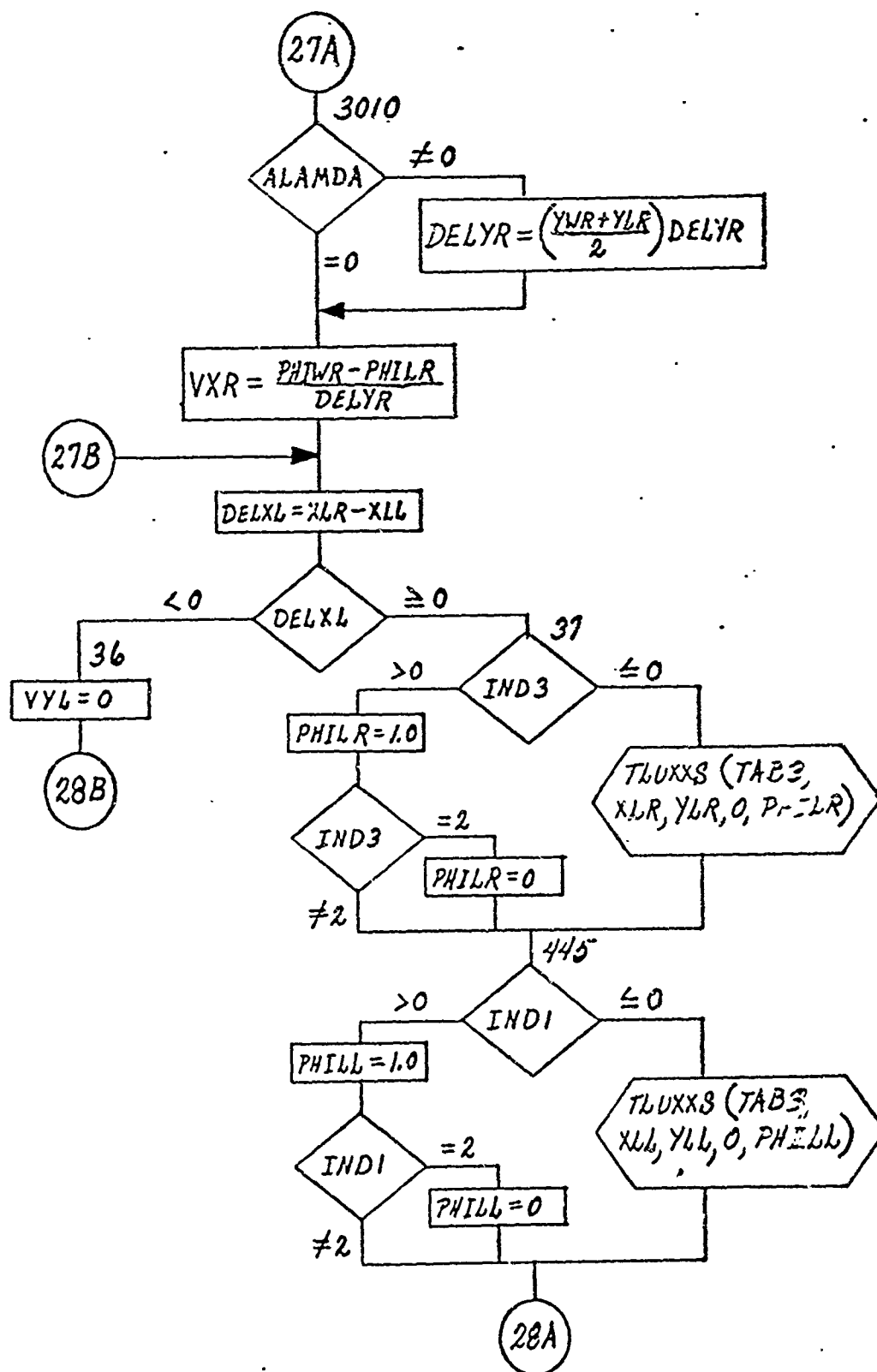
E-3033 R1

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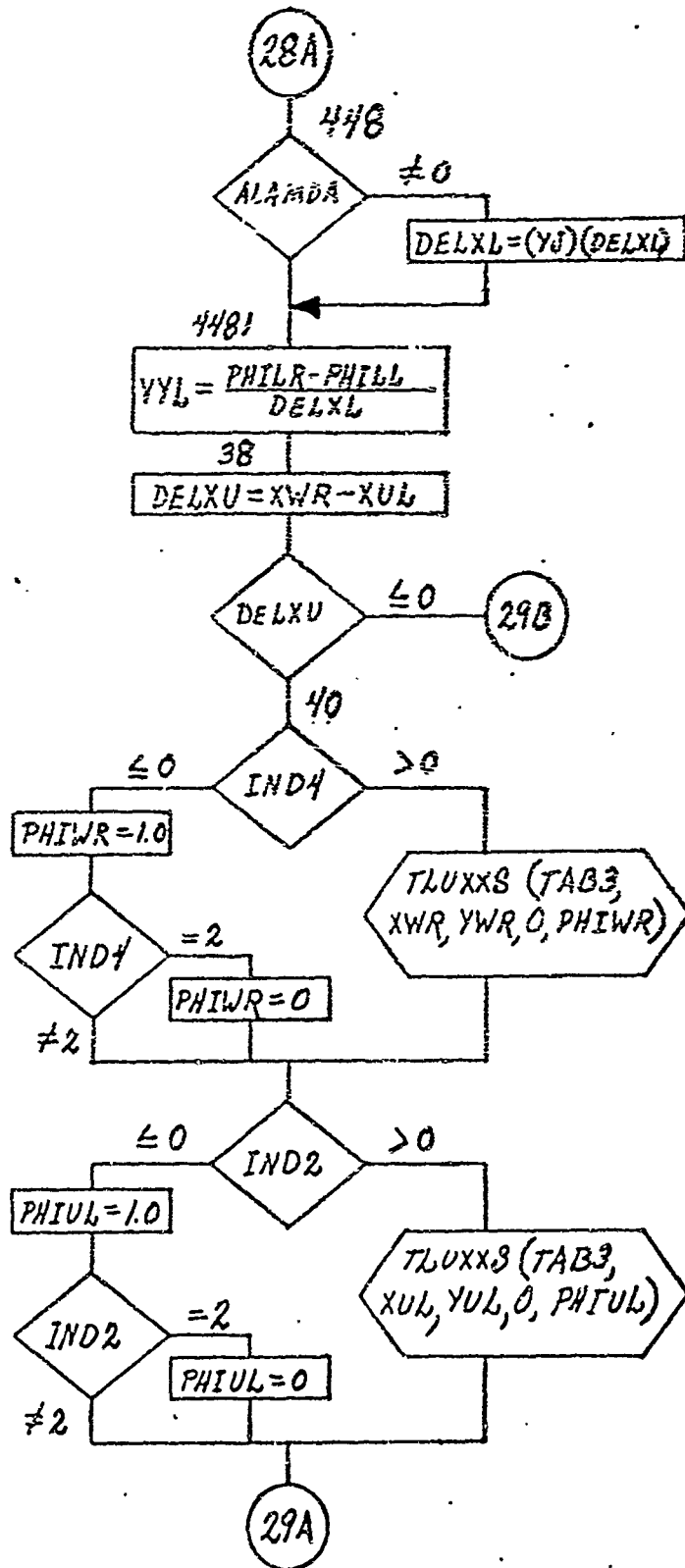
REV LTR:

E-3033 R1



REVLTR:

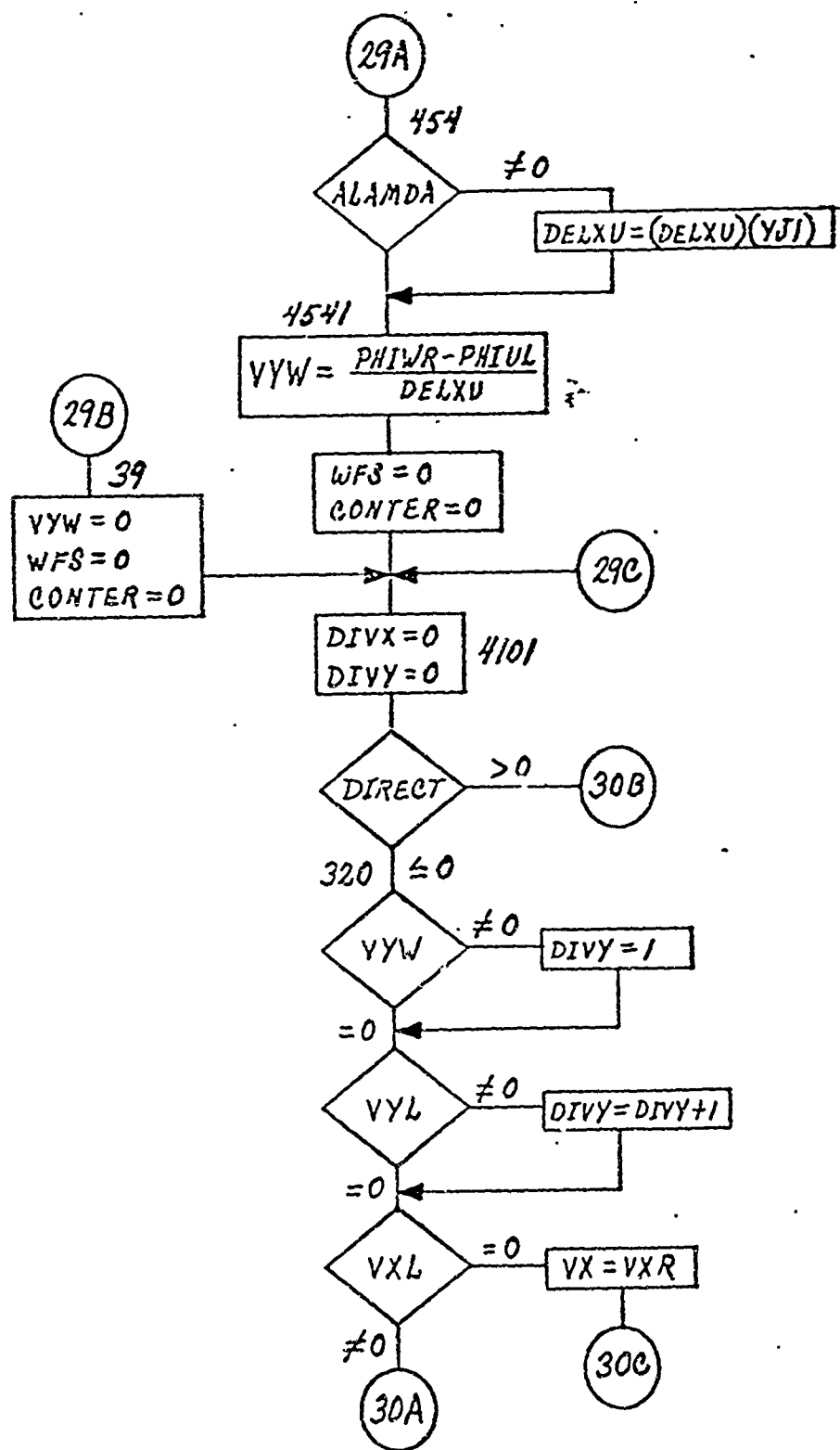
E-3023 R1



REVLTR:

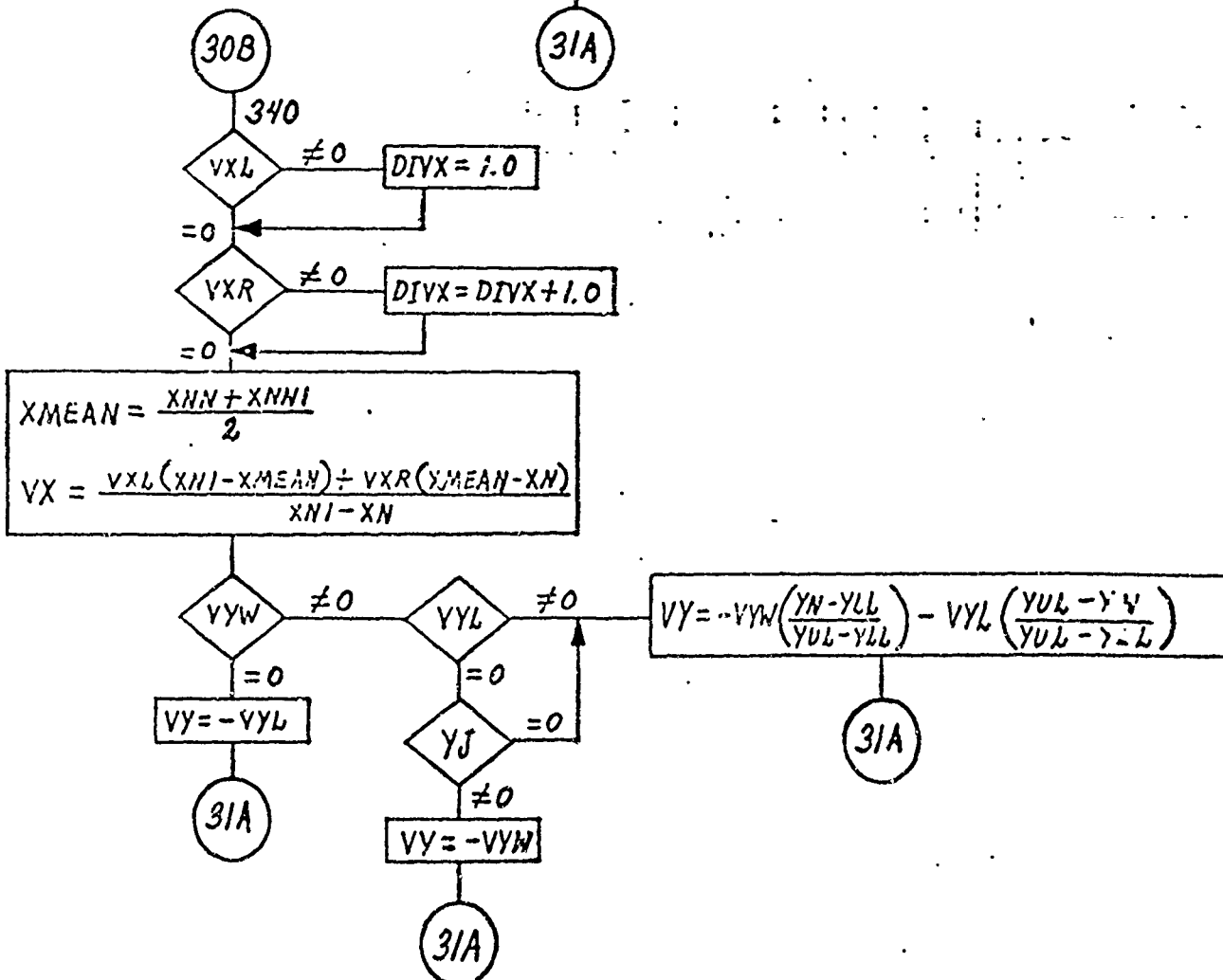
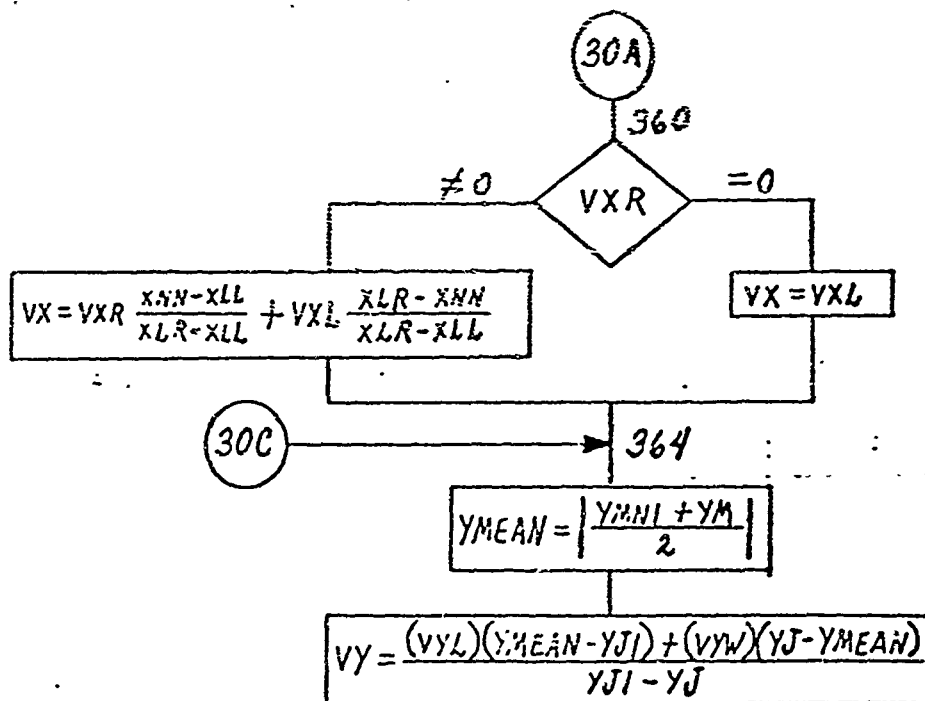
E-2033 R8

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REVLTR:

K-3033 R1

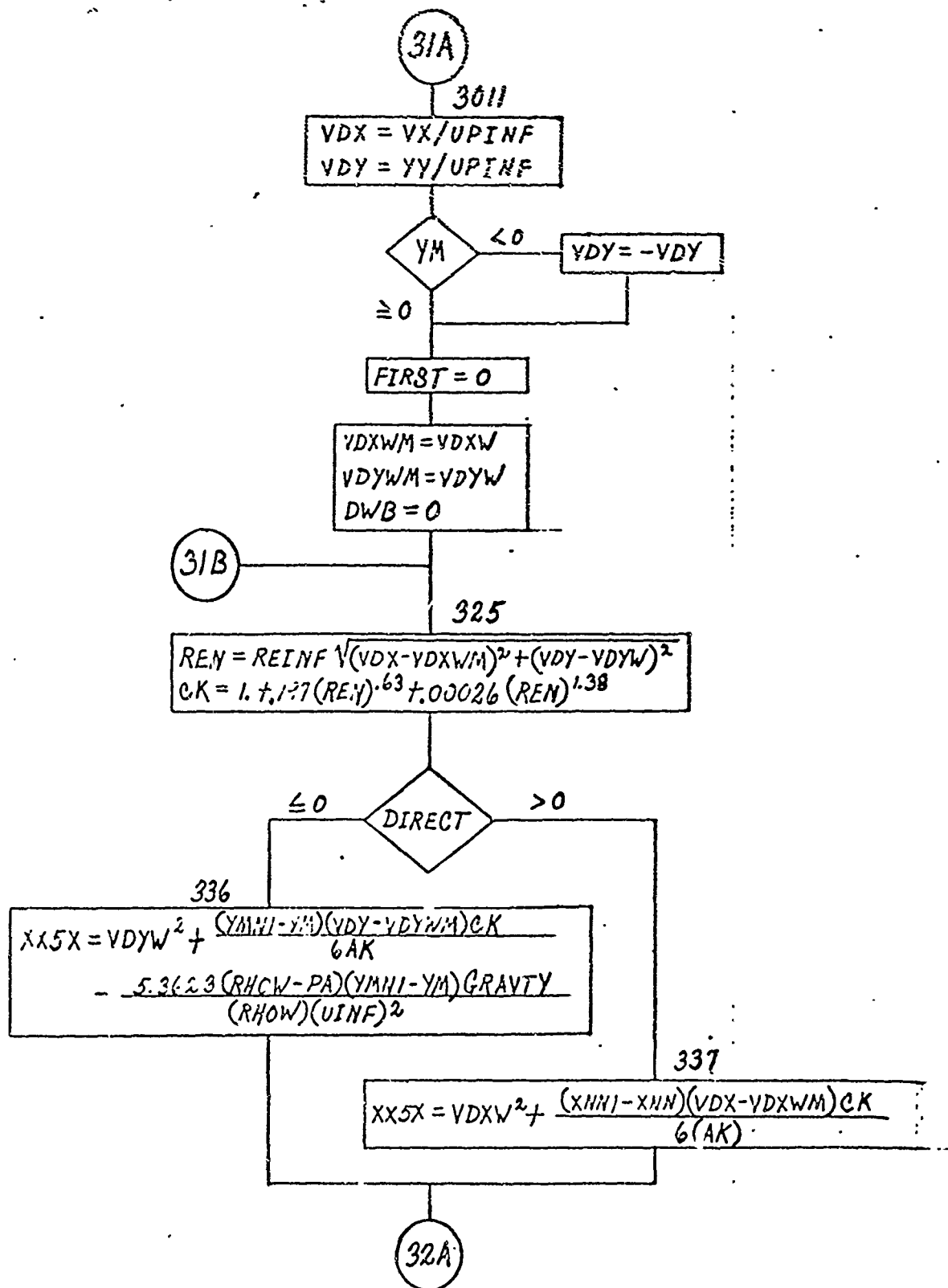


REVLTR:

E-3033 R1

BOEING NO. D3-6961

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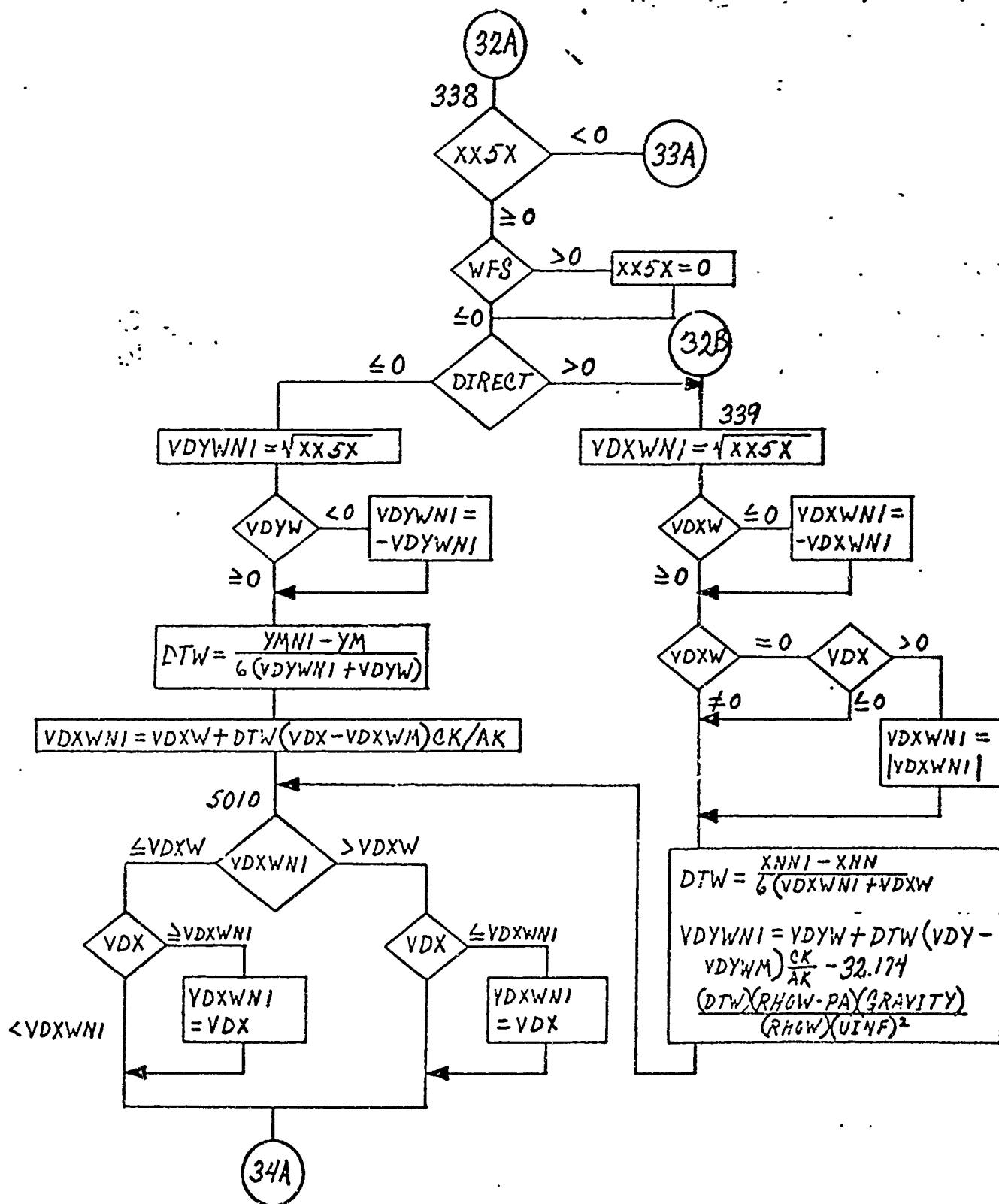


REVLTR:

E-3033 RI

BOEING NO. D3-6961

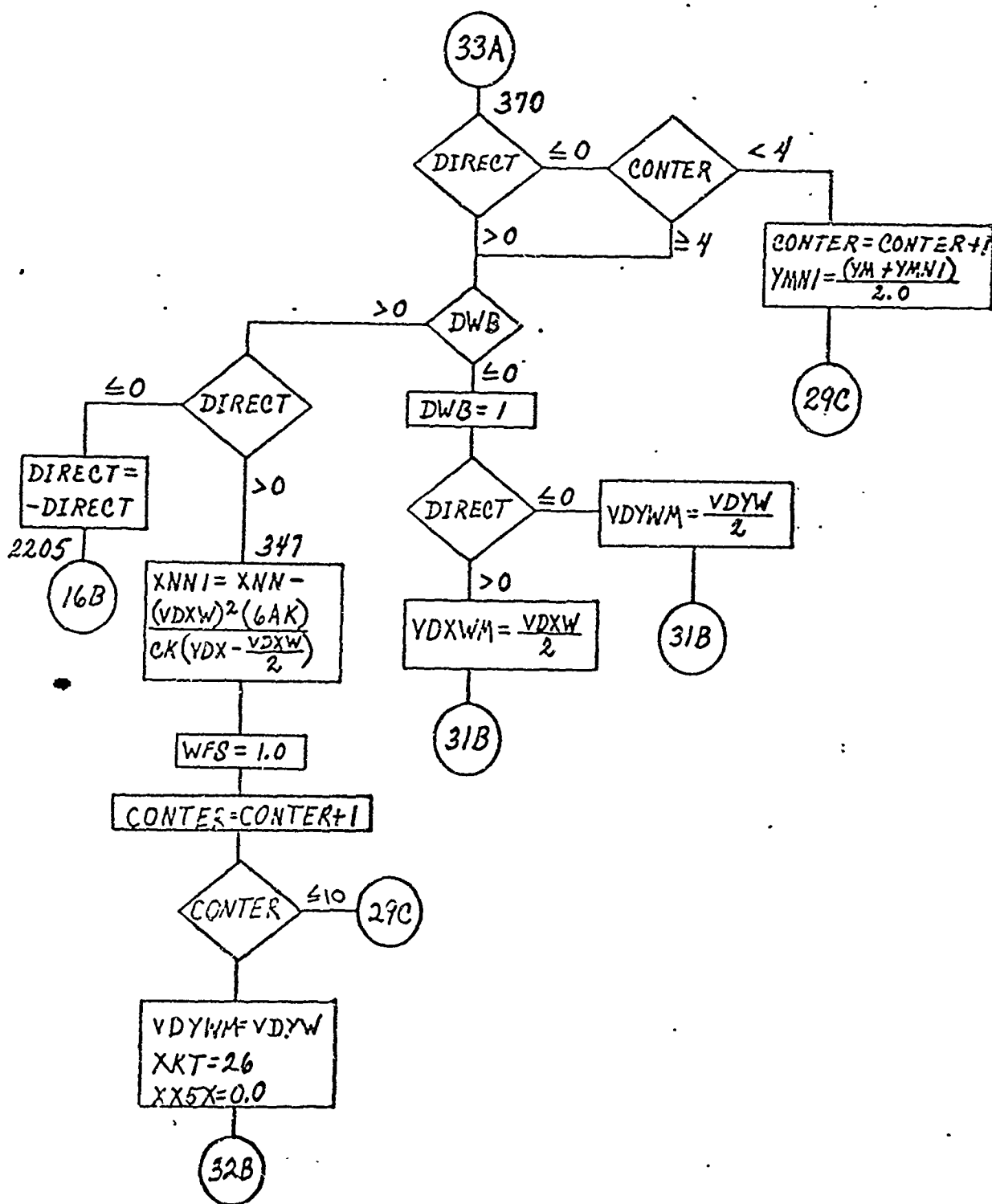
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REVLTR:

E-3032 R1

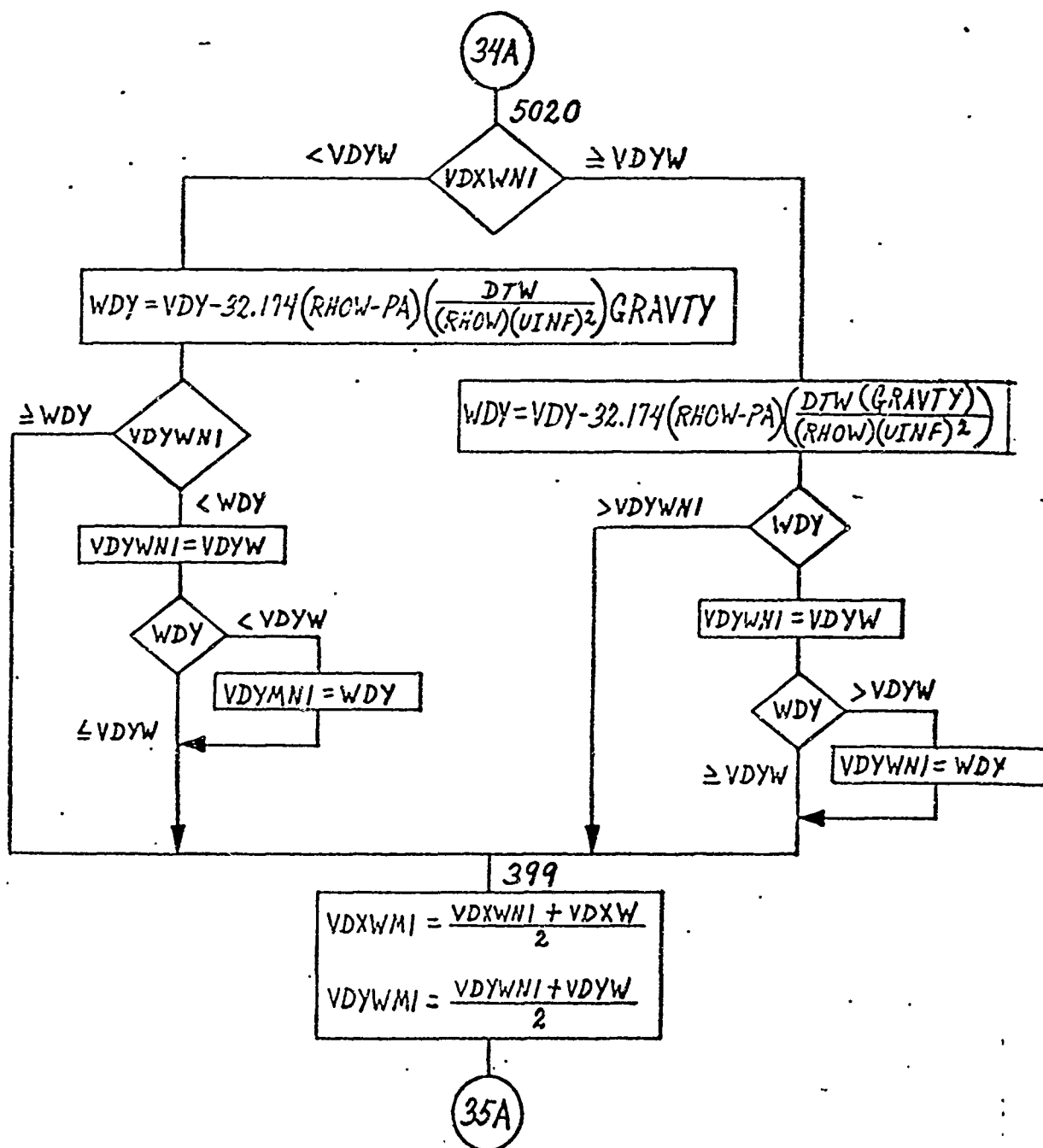
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REVLTR:

E-3033 R1

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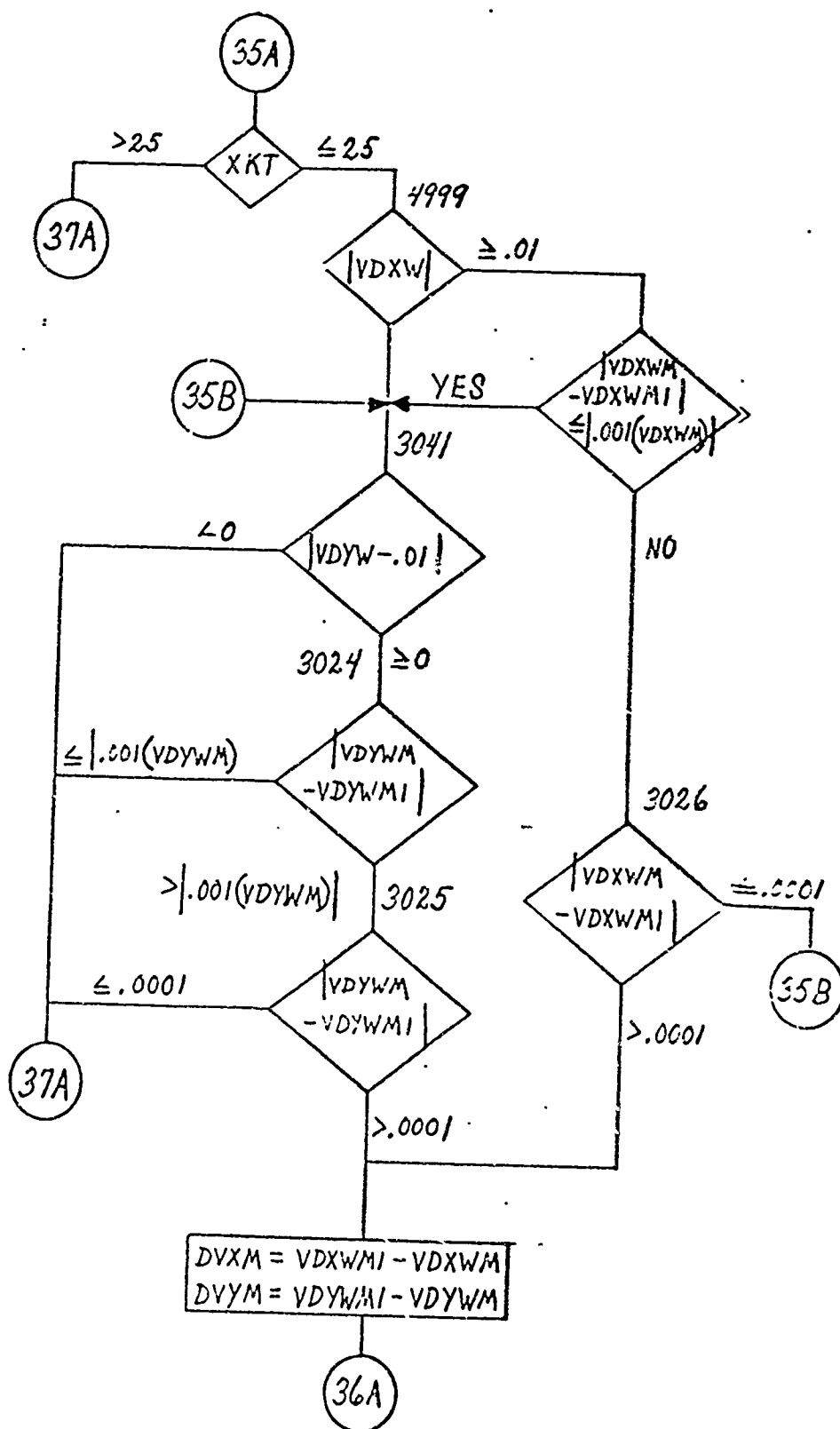


REVLTR:

E-3033 R1

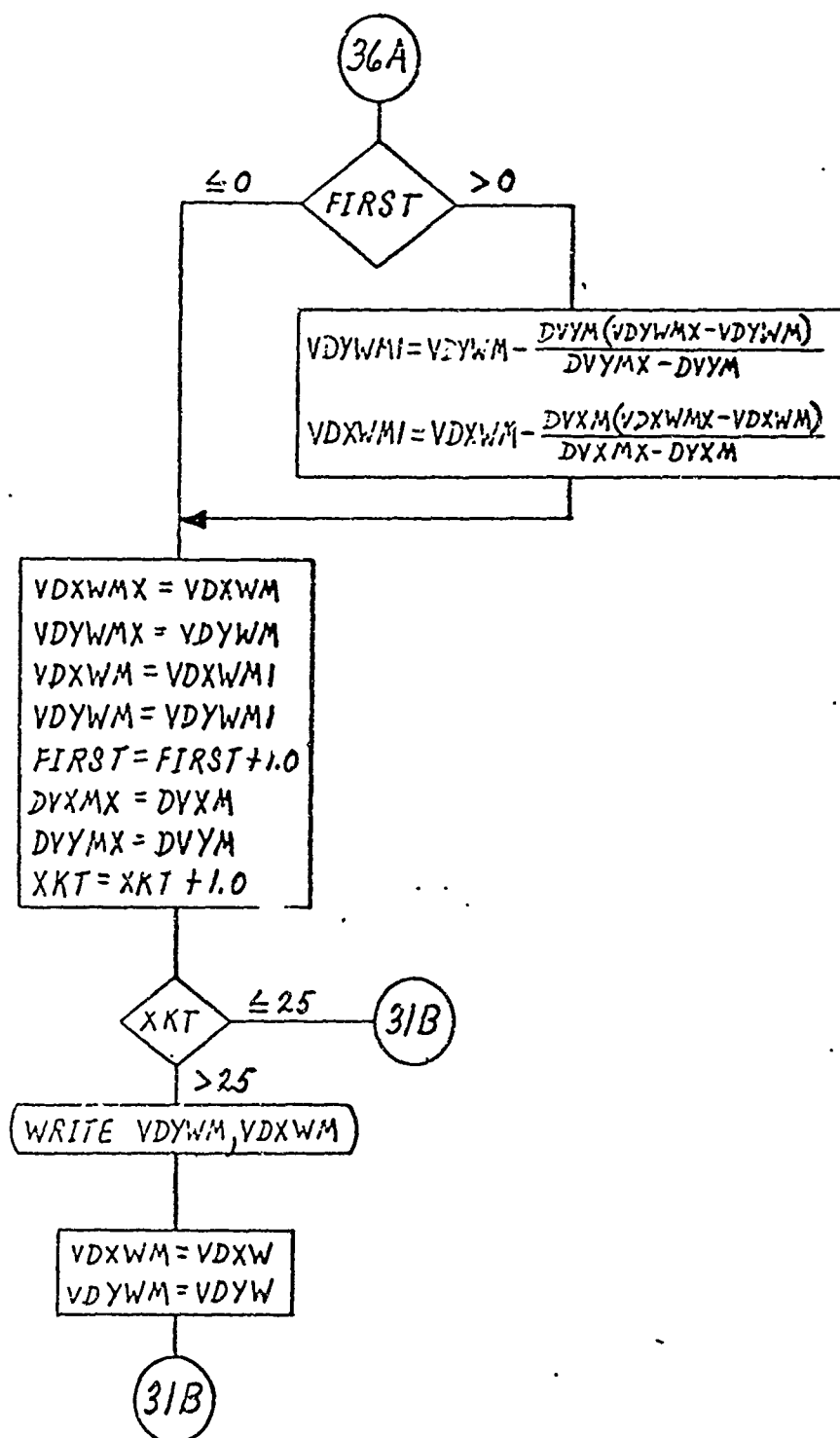
BOEING NO. D3-6961

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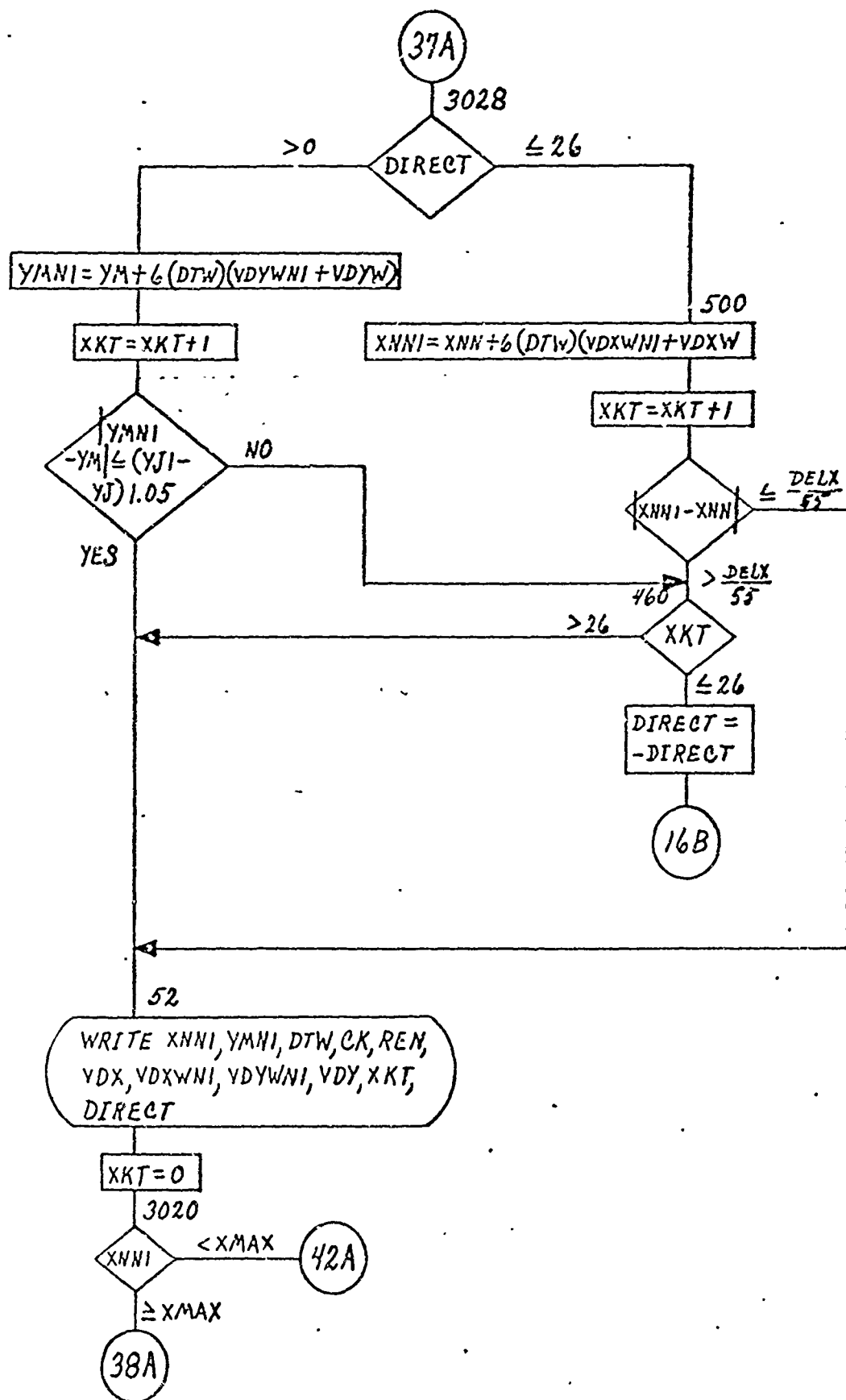
REVLTR:

E-3033 R1



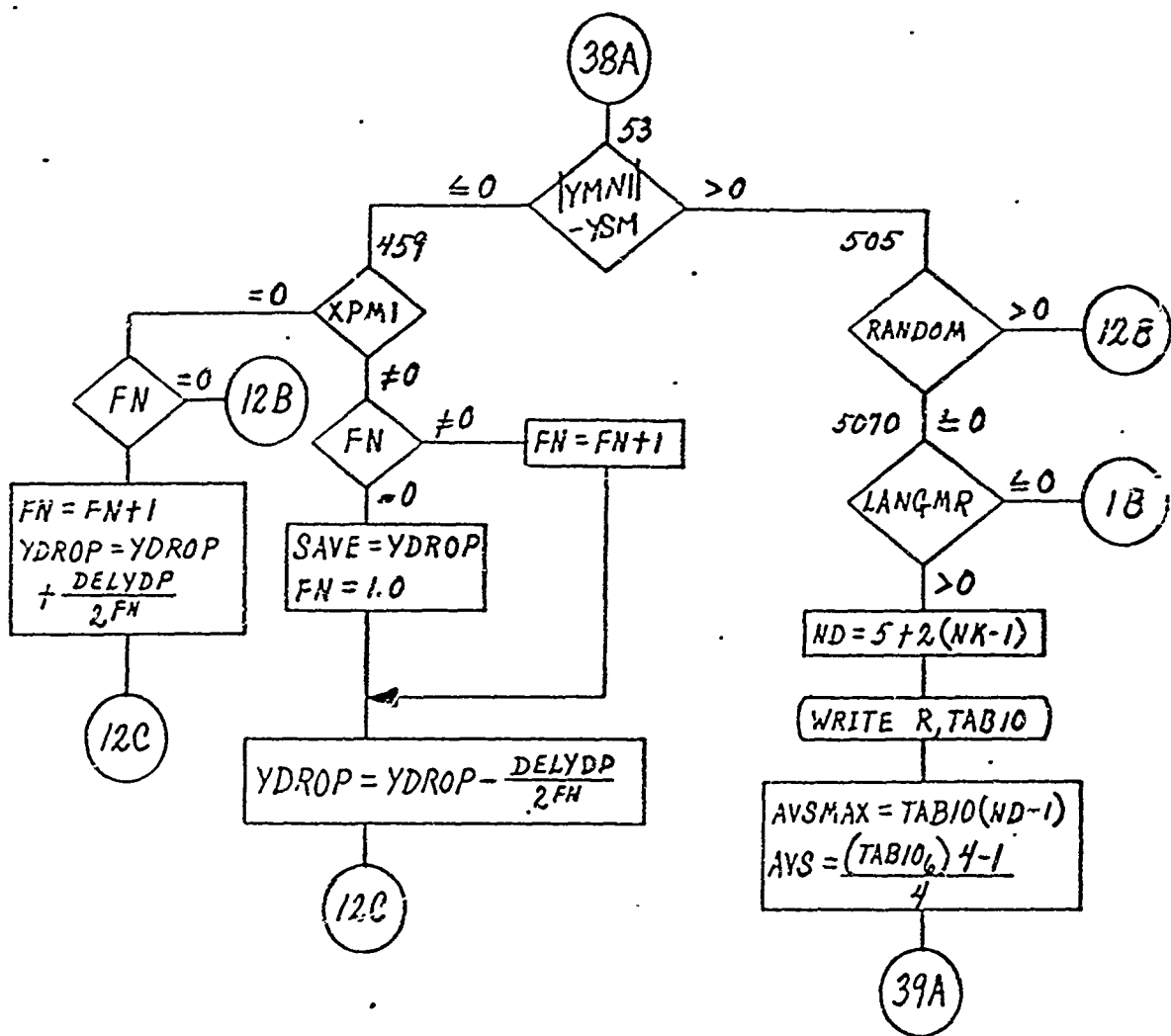
REVLTR:

E-3033 R1



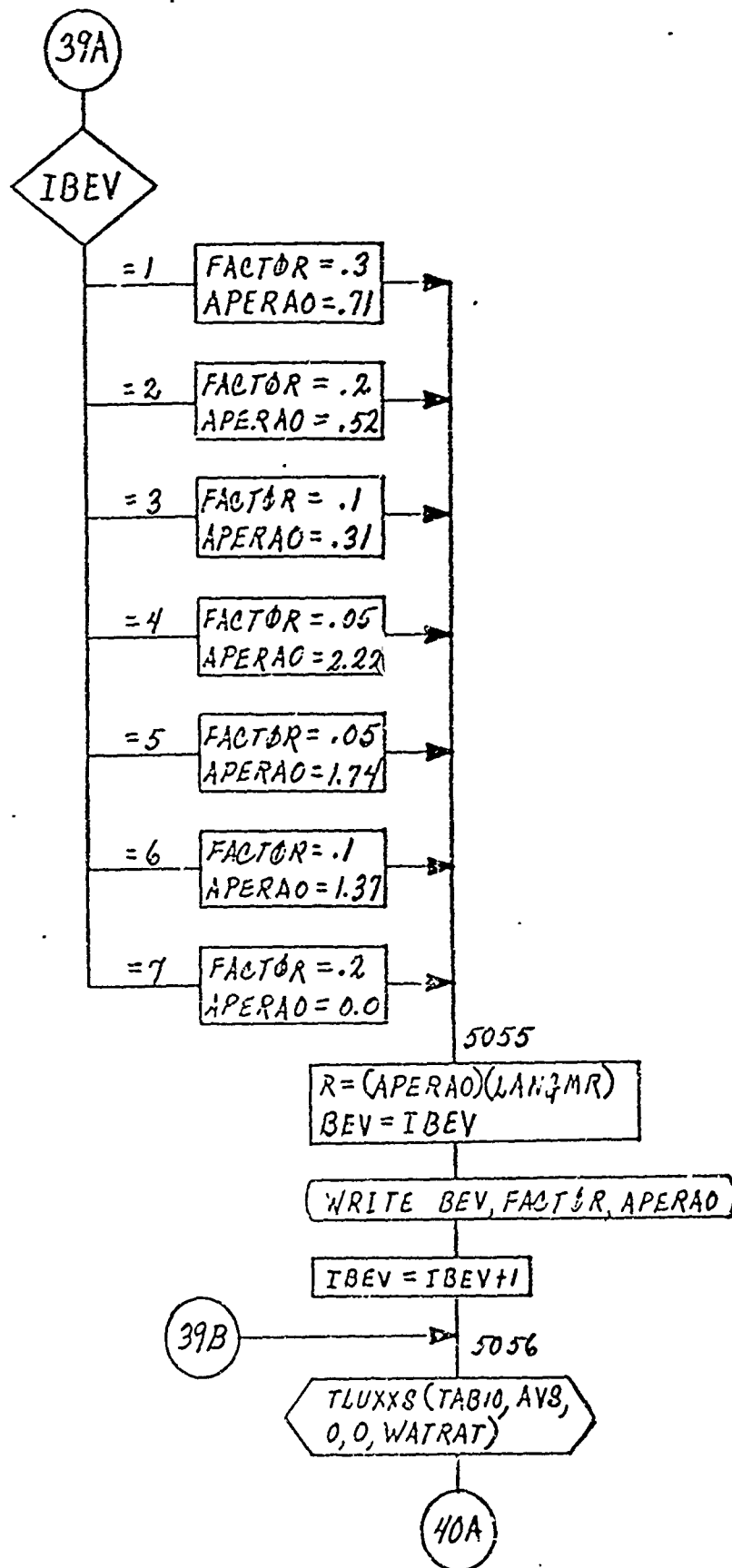
REVLTR:

E-3033 R1



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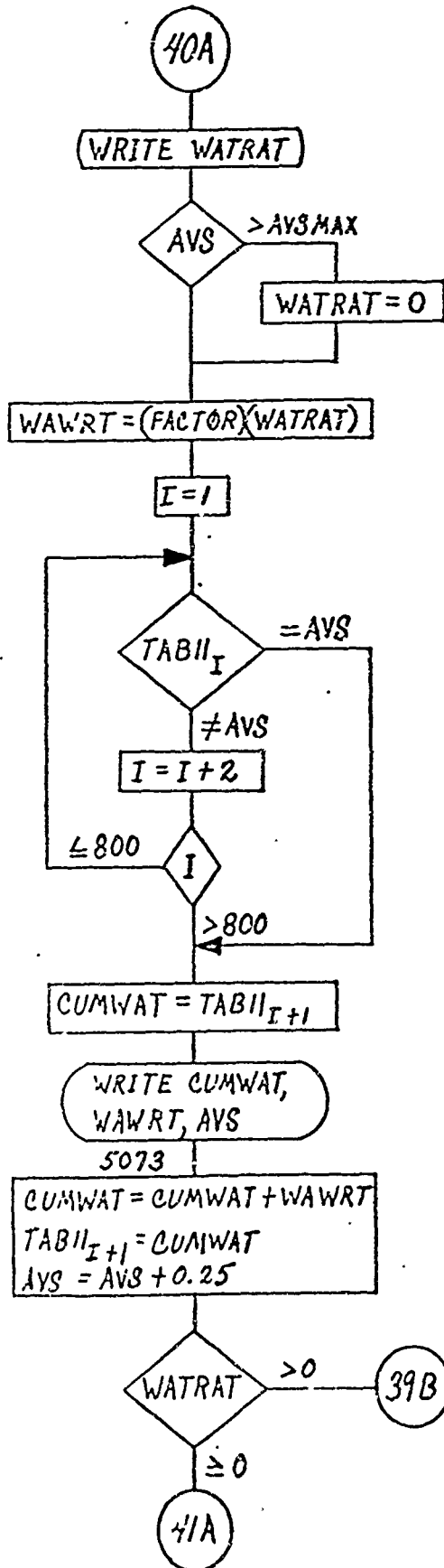
E-3033 R1



REV LTR:

E-3033 R1

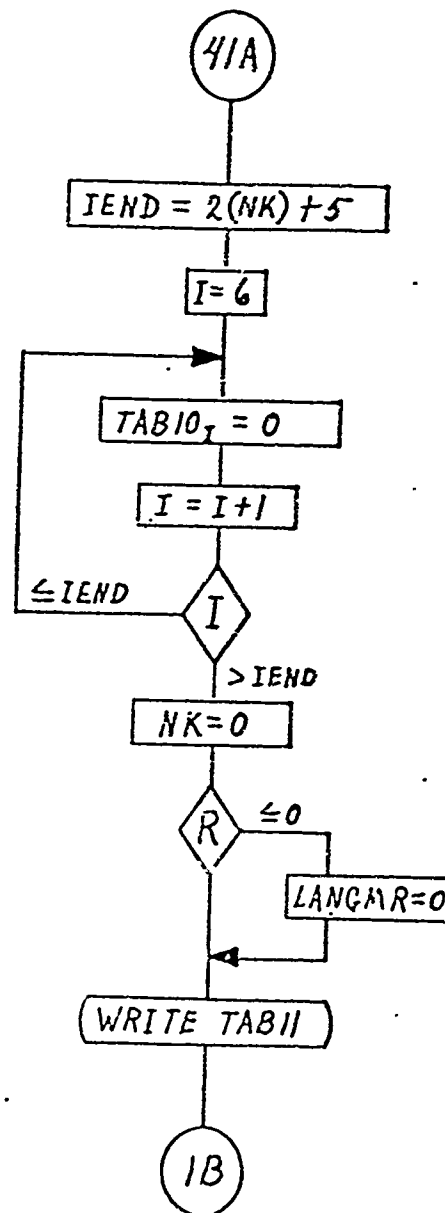
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REVLTR:

E-3033 R1

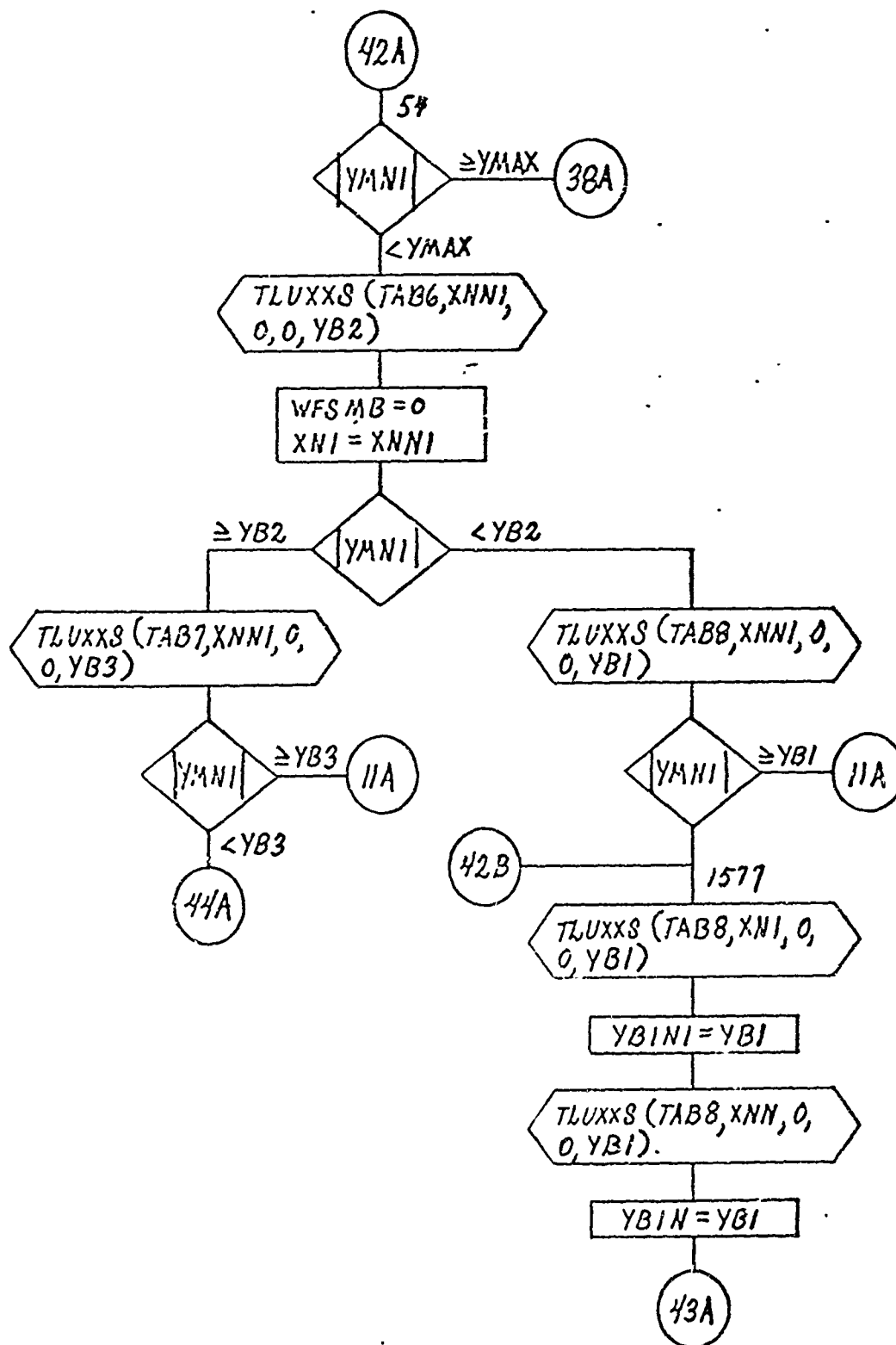
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REVLTR:

E-3033 R1

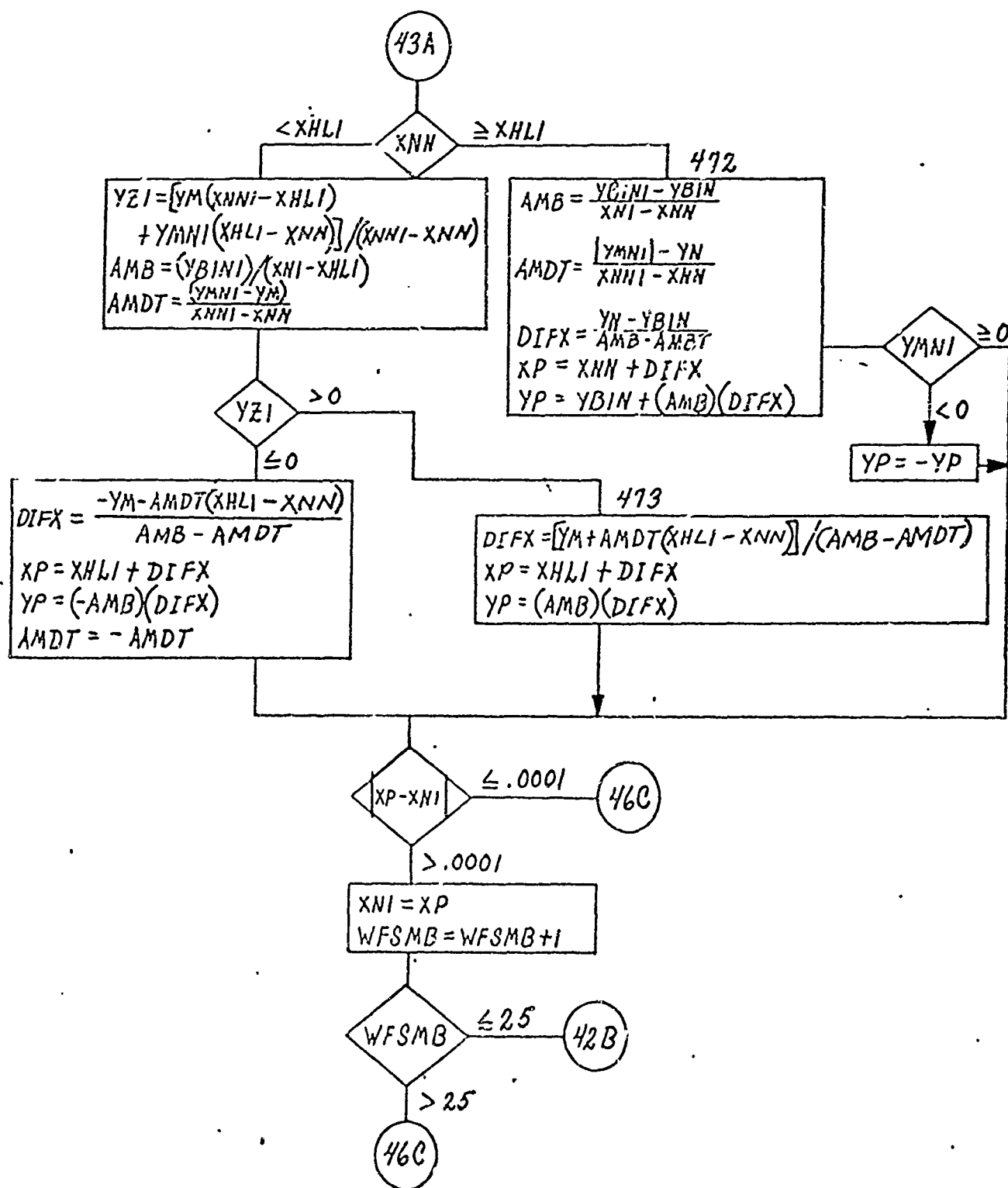
~~SECRET~~ NC. 03-6961
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REVLTR:

E-3033 R1

BOEING	NO. D3-6961
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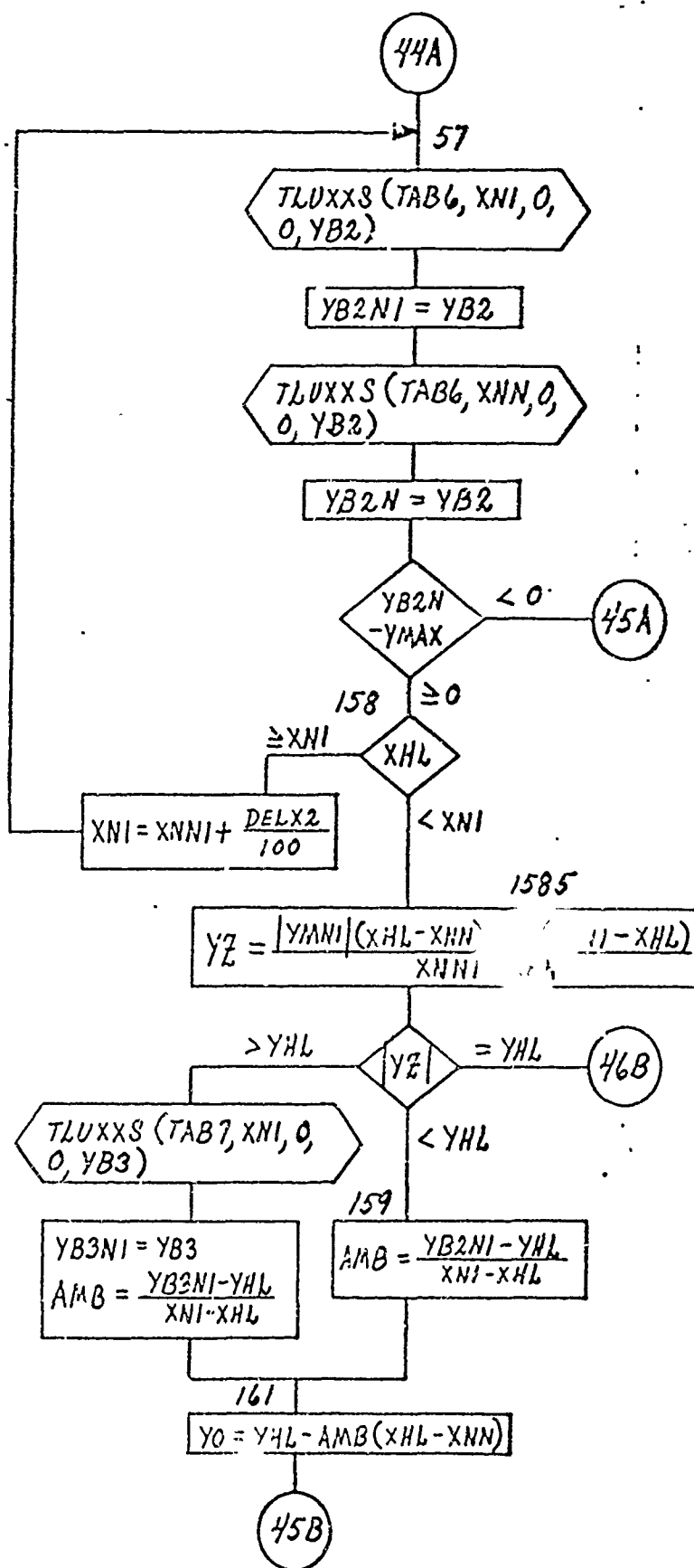


REV LTR:

E-2033 R1

NO. 03-6061

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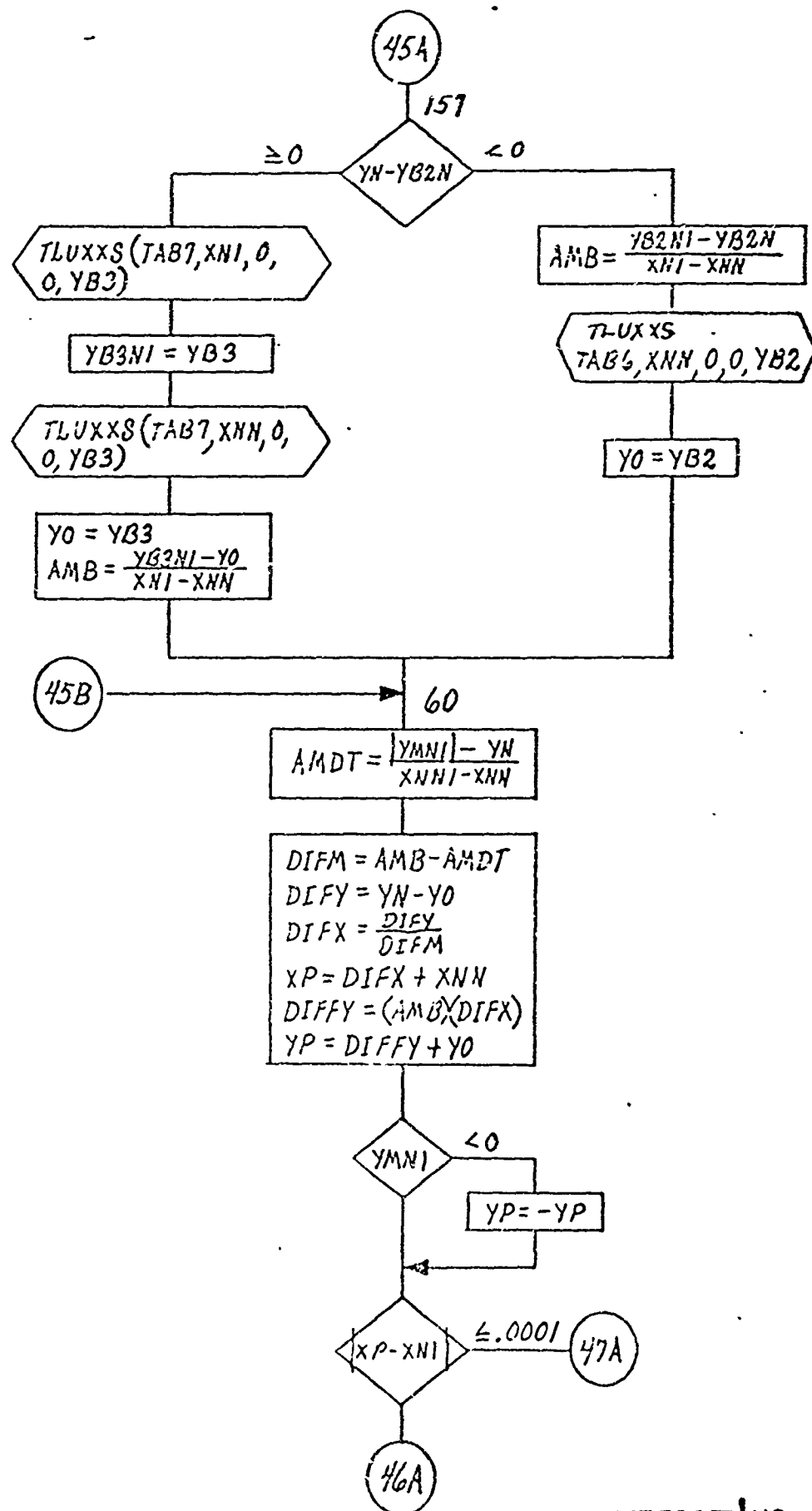


REV LTR:

E-3033 R1

NO. D3-6961

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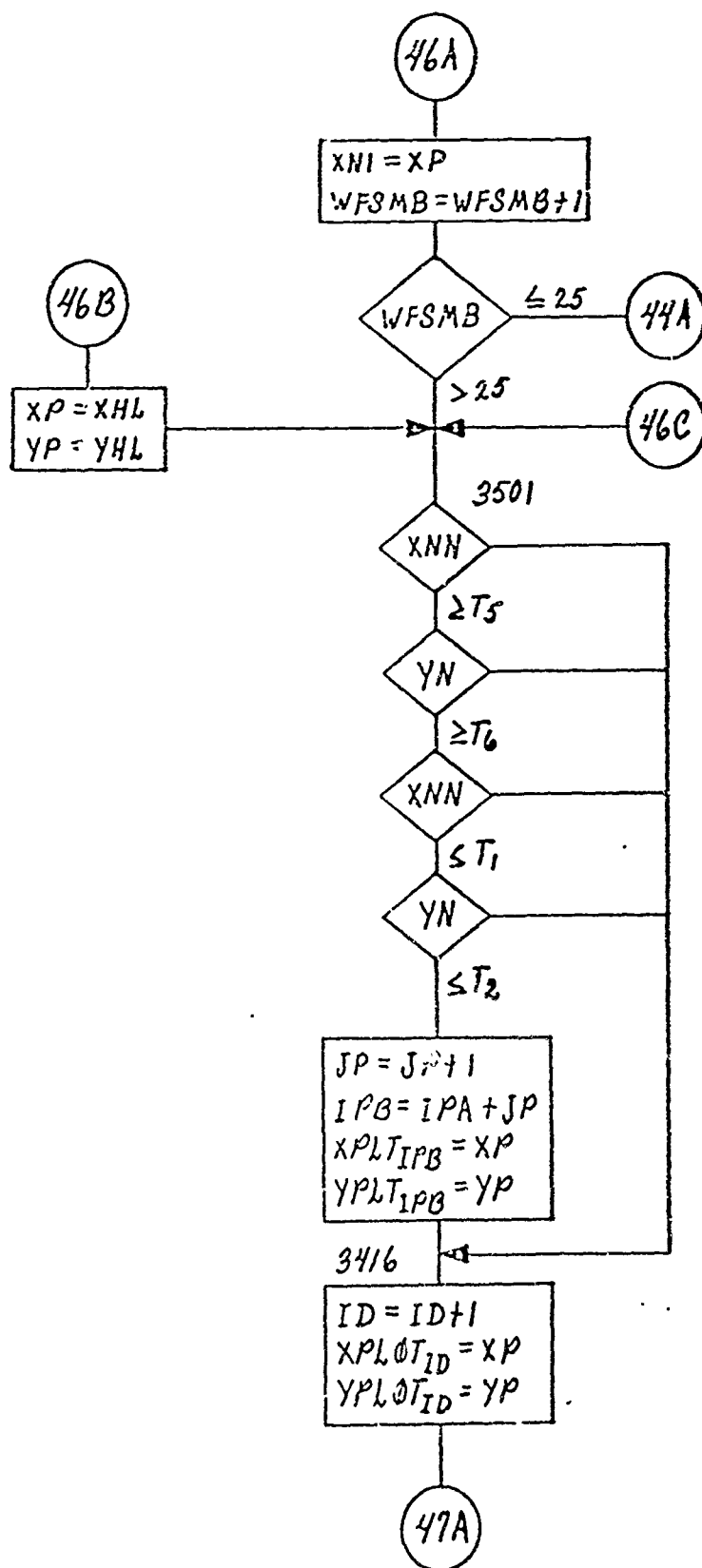


REVLTR:

E-3039 R1

NO. D3-6961

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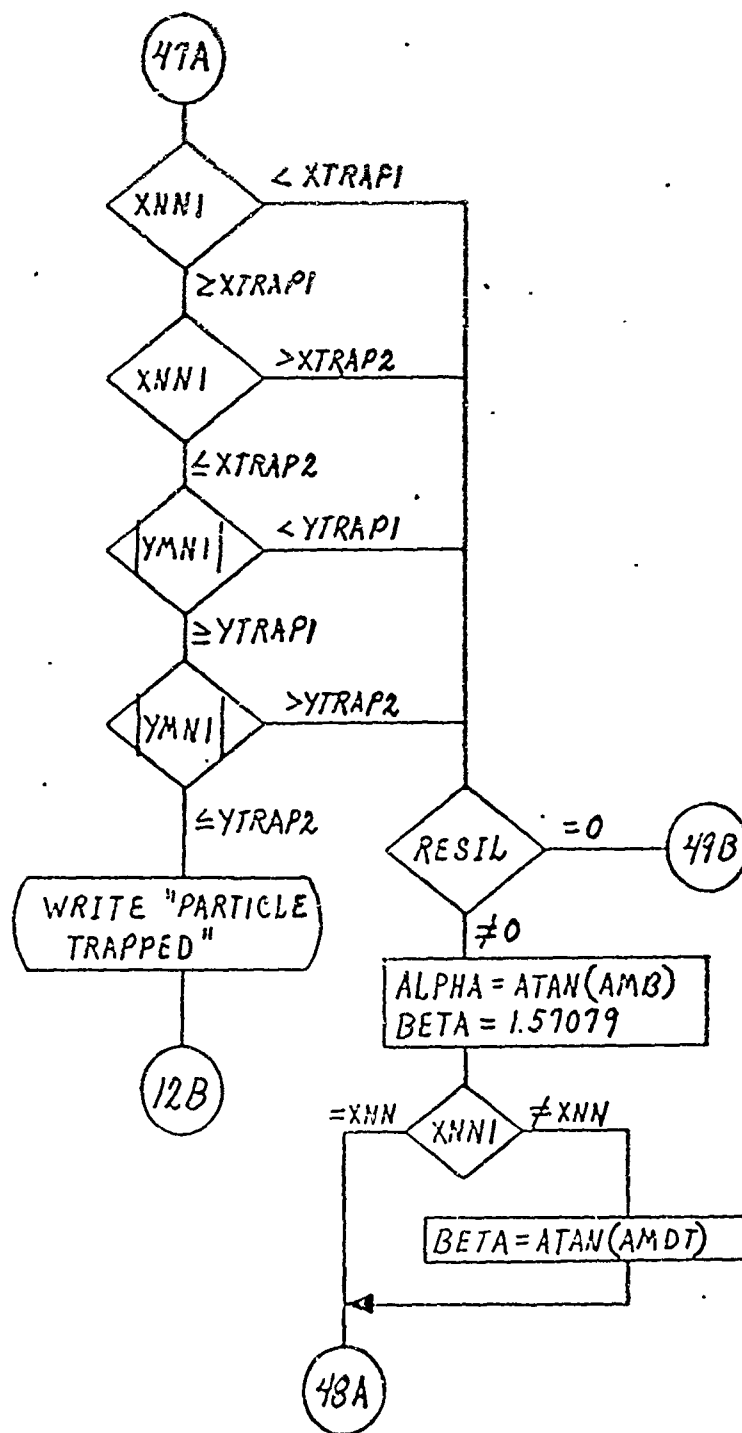


REVLTR:

E-3033 RV

~~BOEING~~ NO. D3-6961

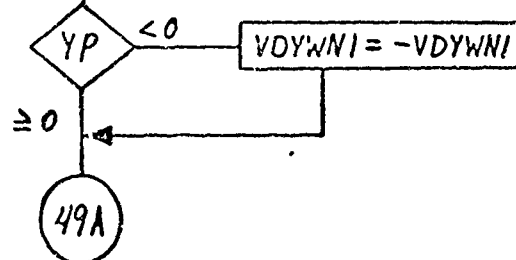
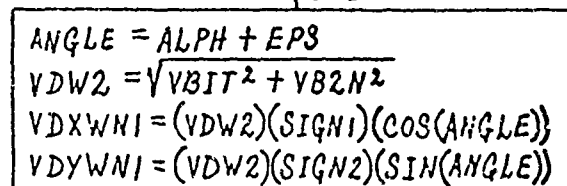
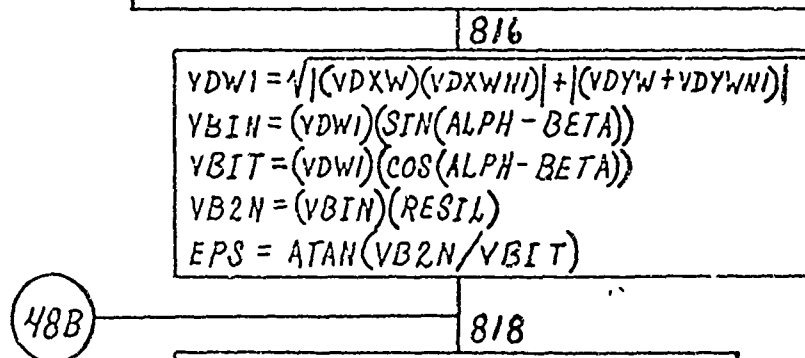
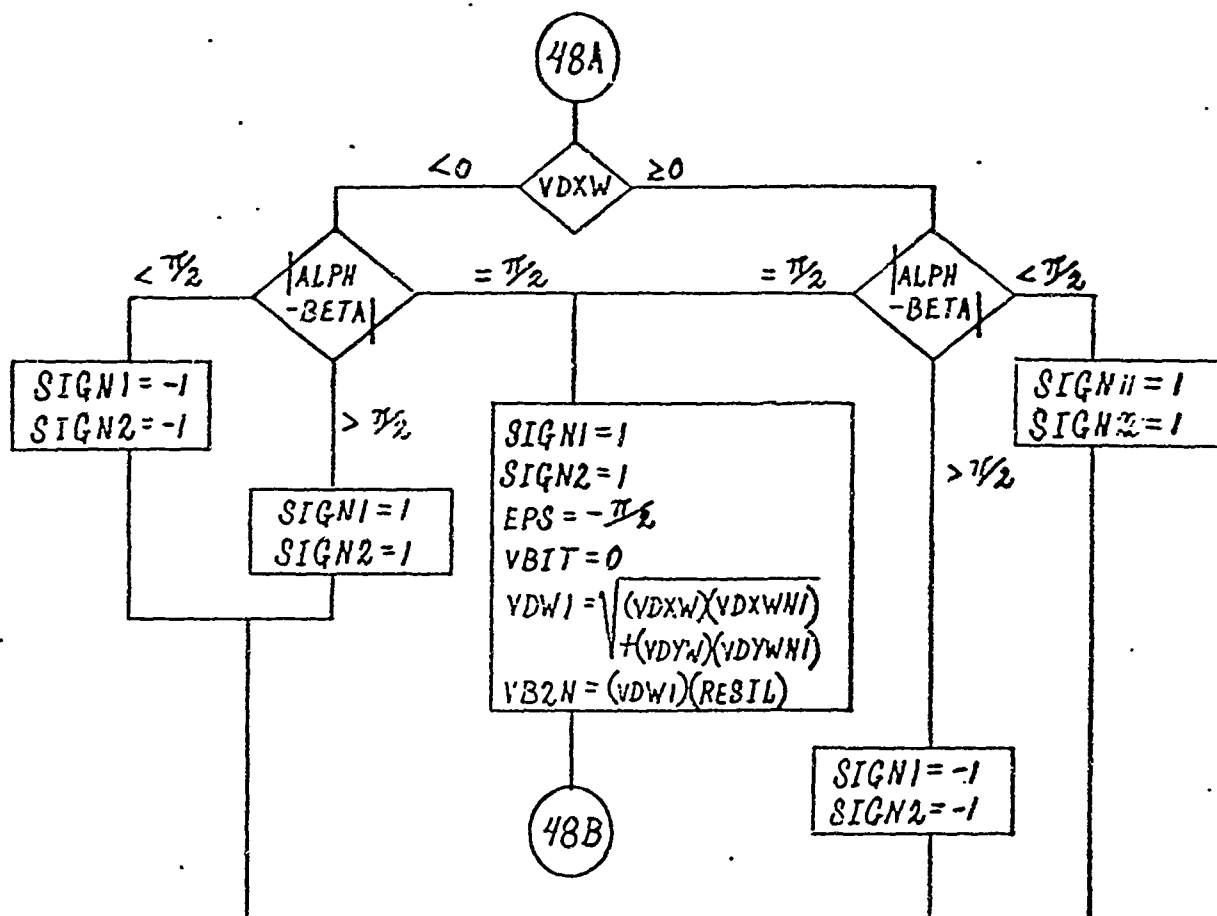
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REVLTR:

E-3033 R1

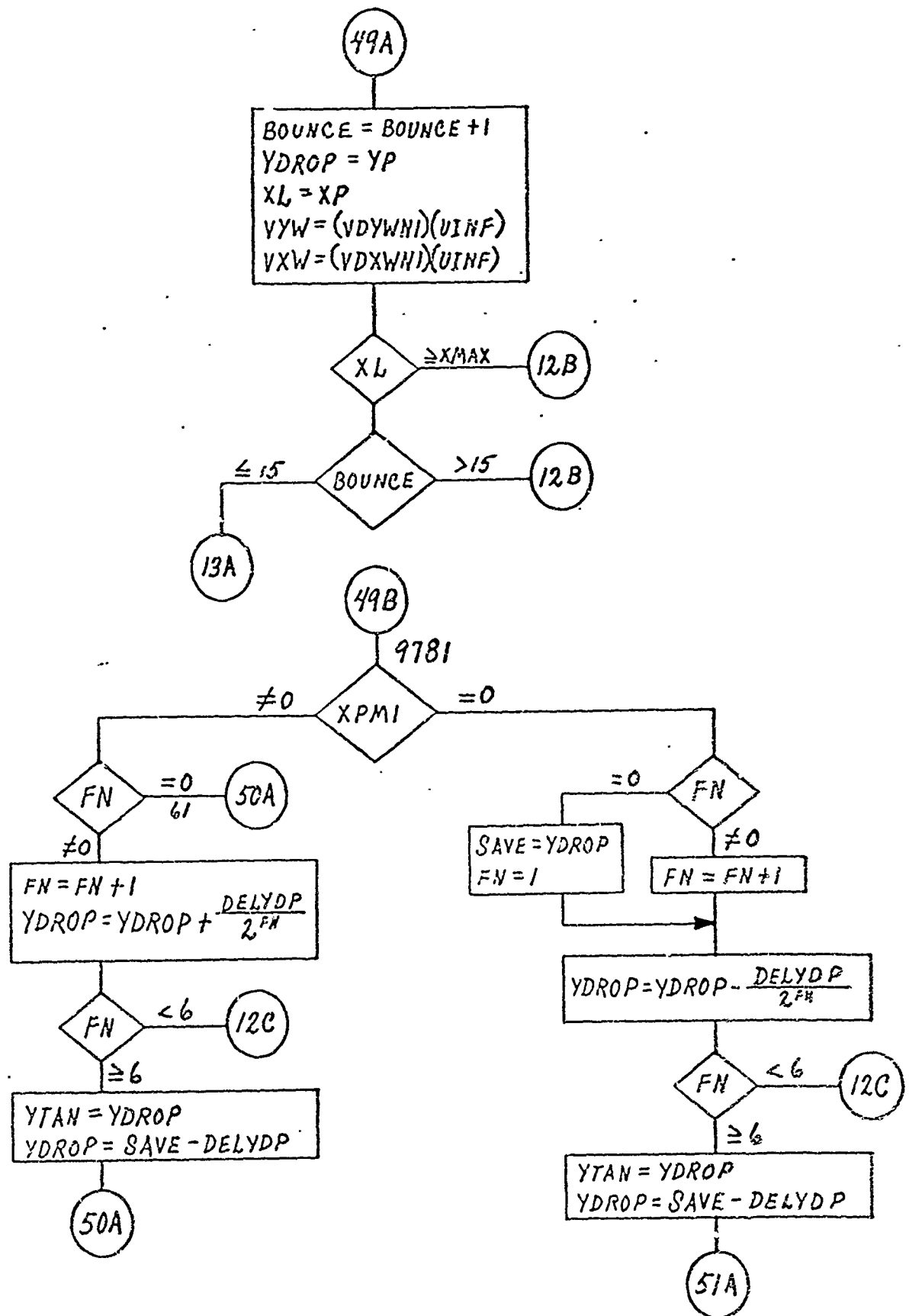
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REVLTR:

E-3033 R1

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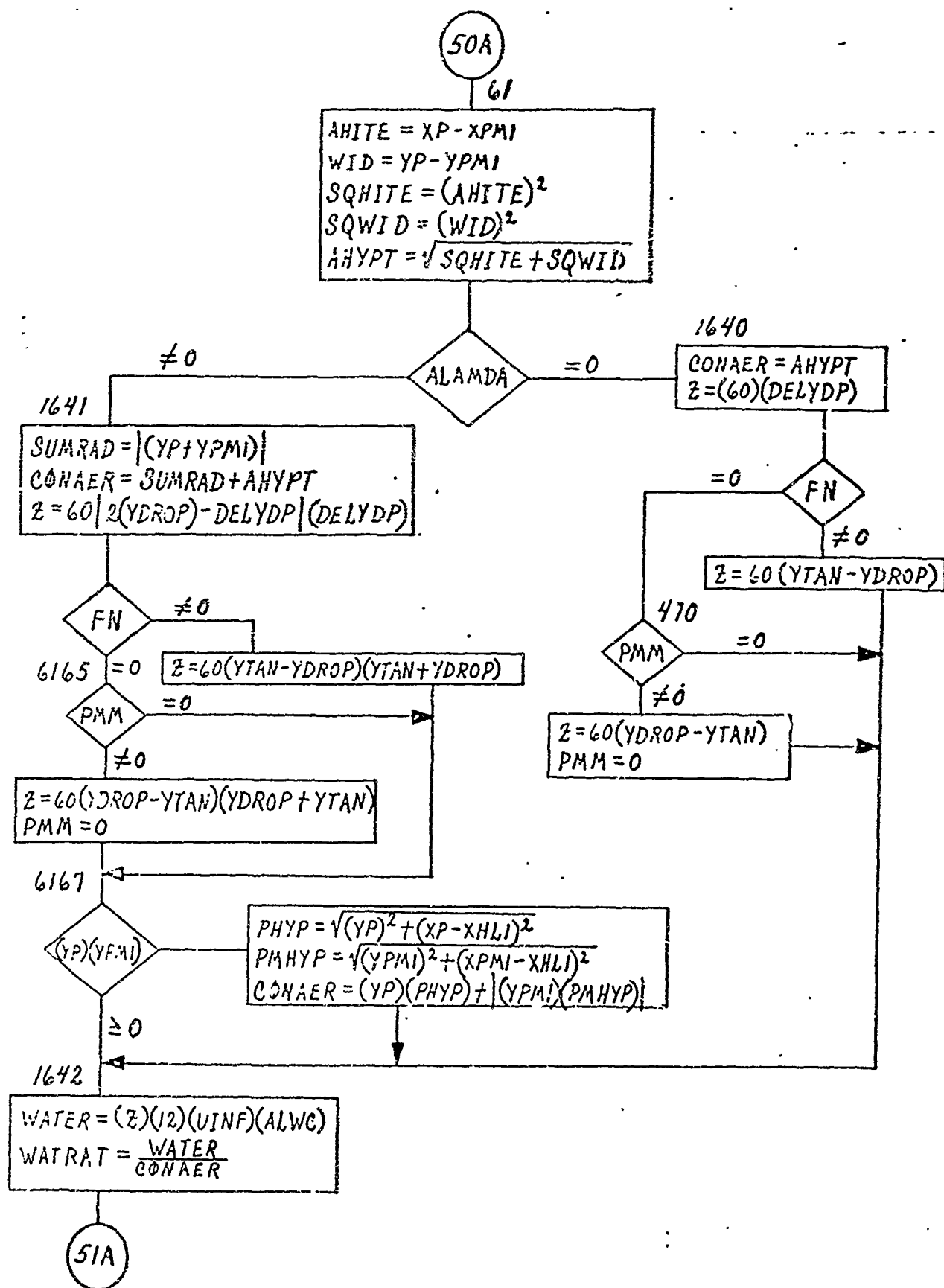
REVLTR:

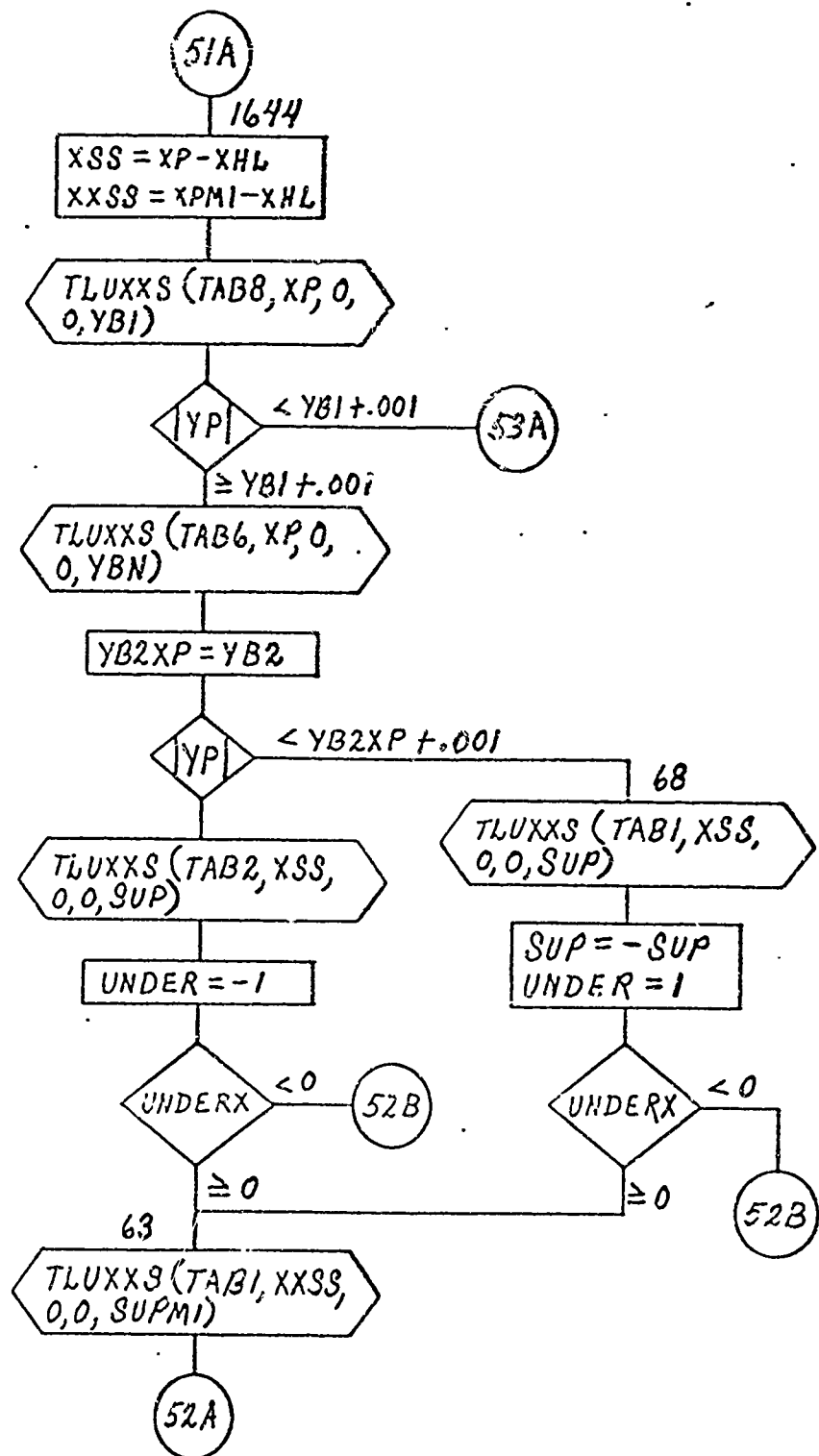
E-3033 R1

BOEING NO. D3-6961

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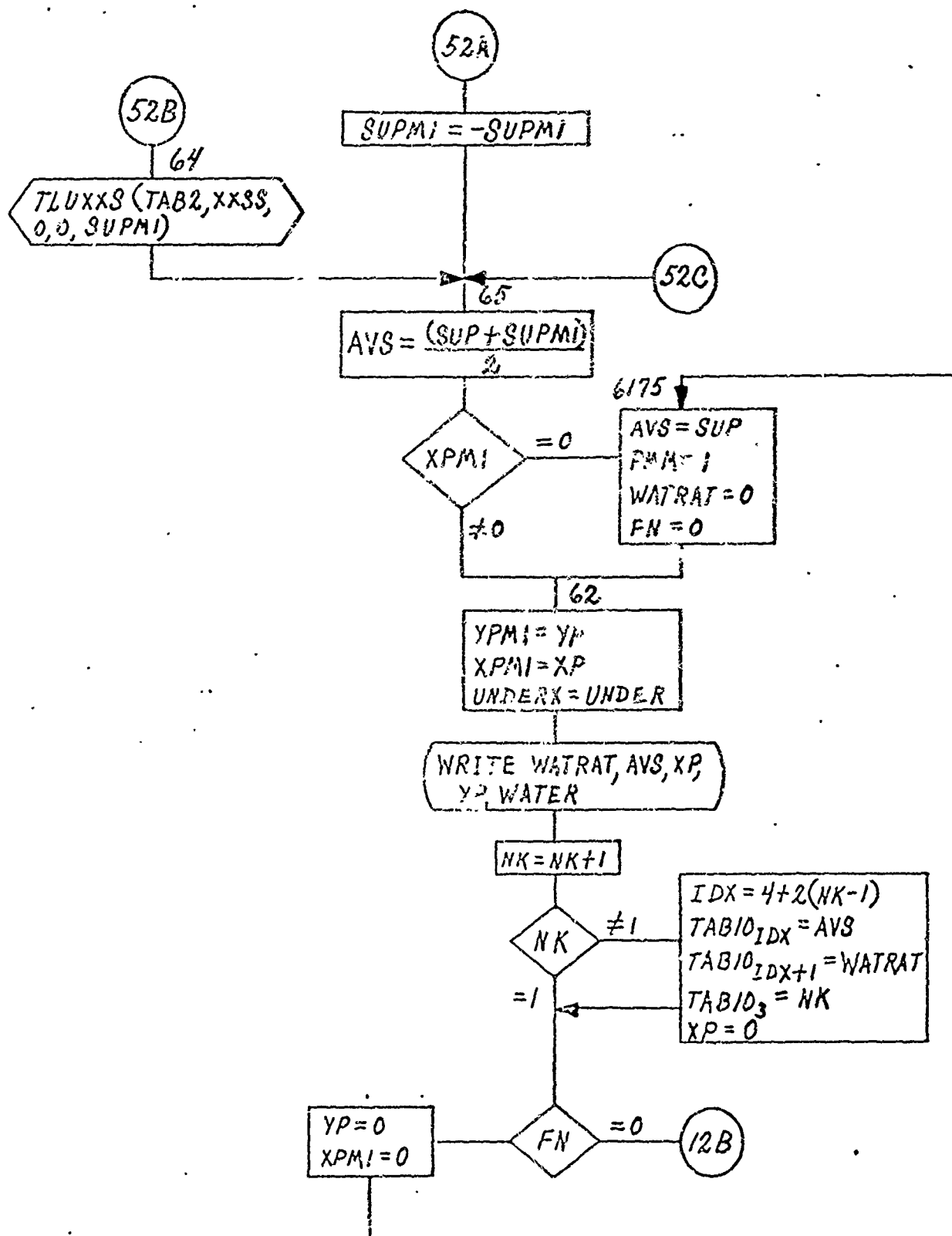




REVLTR:

E-3053 RE

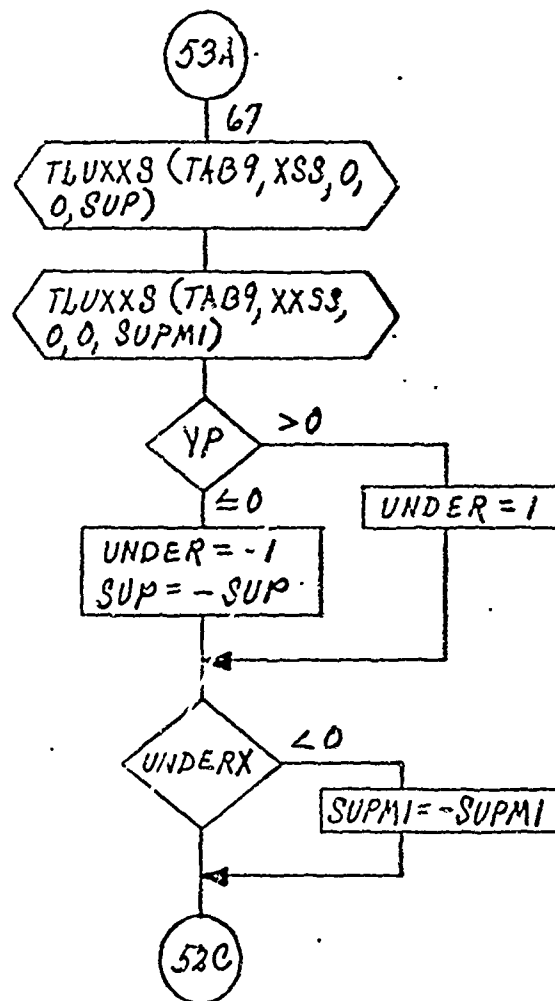
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REVLTR:

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10.4 Appendix 4 - Water Droplet Trajectory Computer Program Listing

REVLTR:

E-3033 R1

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\$IBFTC DRCP

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      DIMENSION T(7),XPLT(550),YPLT(550),XPLT(3100),YPLT(3100)
      DIMENSION TAB1(100),TAB2(100),TAB3( 500),TAB4(200),TAB5(200)
      DIMENSION TAB6(200),TAB7(200)
      DIMENSION HEAD(12),TA(7),IPC(100)
      DIMENSION TL(9)
      EXTERNAL GOTHIC
      COMMON TAB3
C     DIMENSION TAB6(200),TAB7(200)
C     DIMENSION T(7),XPLT(200),YPLT(200),XPLT(2000),YPLT(2000)
C     DIMENSION HEAD(12),TA(7),IPC(100)
      DIMENSION TAB8(100),TAB9(100)
      INTEGER HEAD
      DIMENSION TAB10(500),TAB11(800)
C     DIMENSION TL(9)
      REAL MB,MDT,LANGMR
C     COMMON TAB3
C     GOTHIC
1000 FORMAT(6E12.6)
8787 FORMAT(4X,4HDTW=E12.4,4X,5HVDYW=E12.4,4X,7HVDYWN1=E12.4/4X,5HVDXW=
1E12.4,4X,7HVDXWN1=E12.4,4X,3HAK=E12.4/4X,3HCK=E12.4,4X,4HREN=E12.4
2,4X,6HREINF=E12.4/4X,4HVDX=E12.4,4X,4HVDY=E12.4,4X,3HVS=E12.4/4X,
33HVS=E12.4)
1240 FORMAT(4X,7HWATRAT=E20.8,7X,4HAVS=E20.8/4X,3HXP=E20.8,11X,3HYP=E20
1.8,9X,5HWATER ,F14.6)
      DIMENSION Y(150),X(150)
600 FORMAT (6E18.5)
601 FORMAT (1X)
603 FORMAT (1X,4F14.5)
604 FORMAT(1/4H XP=F12.6/5H XN1=F11.6/)
610 FORMAT (9H AHLSTEDT)
630 FORMAT (1X,2HR=F12.6//6X,3HAVS,11X,6HWATRAT//((F14.6,2X,F14.6)))
635 FORMAT (1/6X,3HAVS,11X,6HCUMWAT//((F14.6,2X,F14.6)))
640 FORMAT (1X,6F14.6)
650 FORMAT (1X,8F9.3)
660 FORMAT (17H PARTICLE TRAPPED)
661 FORMAT (38H TOO MANY POINTS IN PLOT OF WHOLE AREA)
662 FORMAT (40H TOO MANY POINTS IN RESTRICTED AREA PLOT)
670 FORMAT (8H1TABLE 1/33H X=DISTANCE TO RIGHT OF HIGHLIGHT/45H Y=LOWE
XR CCWL SURFACE DISTANCE FROM HIGHLIGHT//10X,1HX,20X,1HY/)
671 FORMAT (8H2TABLE 2/33H X=DISTANCE TO RIGHT OF HIGHLIGHT/46H Y=UPPE
XR CCWL SURFACE DISTANCE FROM HIGHLIGHT//10X,1HX,20X,1HY/)
605 FORMAT(1X////)
673 FORMAT (8H TABLE 4/34H X=Y VALUE OF POTENTIAL FLOW FIELD/53H Y=FIR
XST BCUNDARY VALUE OF X AFTER LEFT HAND BOUNDARY//10X,1HX,20X,1HY/)
674 FORMAT (8H TABLE 5/34H X=Y VALUE OF POTENTIAL FLOW FIELD/54H Y=SEC
XOND BCUNDARY VALUE OF X AFTER LEFT HAND BOUNDARY//10X,1HX,20X,1HY/)
675 FORMAT (8H TABLE 6/34H X=X VALUE OF POTENTIAL FLOW FIELD/50H Y=FIR
XST BOUNDARY VALUE OF Y ABOVE LOWER BOUNDARY//10X,1HX,20X,1HY/)
676 FORMAT (8H TABLE 7/34H X=X VALUE OF POTENTIAL FLOW FIELD/50H Y=SEC
XOND BOUNDARY VALUE OF Y ABOVE LOWER BOUNDARY//10X,1HX,20X,1HY/)
677 FORMAT (8H TABLE 8/34H X=X VALUE OF POTENTIAL FLOW FIELD/41H CENTE

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XRLINE OR LOWEST BOUNDARY VALUE OF Y//10X,1HX,20X,1HY)
078 FORMAT (8H TABLE 9/39H X=DISTANCE TO RIGHT OF HIGHLIGHT (XHL)/63H
1Y=CENTERBODY SURFACE DISTANCE FROM CENTERBODY HIGHLIGHT (XHL1)//10
2X,1HX,20X,1HY)
680 FORMAT (10X,F10.5,10X,F10.5)
3100 FORMAT(12A6)
3101 FORMAT(1H1,12A6)
3102 FORMAT(1H0,10X4HALWC17X1HR14X4HUIINF13X5HUPIINF16X2HPA16X2HWA;
3104 FORMAT (1H0,11X,3HYSL,15X,3HYSM,13X,5HVXWIN,13X,5HVVWIN,13X,
16HDIRECT,13X,6HRANDOM)
3105 FORMAT (1H0,11X,3HXHL,15X,3HYHL,12X,6HALAMDA,13X,5HRESIL,14X,4HRHO
XW,12X,6HLANGMR)
3165 FORMAT (1H0,9X,5HREINF,16X,2HAK)
3106 FORMAT (1X,6(E15.7,3X))
3107 FORMAT(1H0)
3108 FORMAT (1H0,10X,4HMAX,14X,4HYMAX,13X,5HYDROP,12X,6HDELYDP,16X,
12HXL,14X,4HXHL1)
3109 FORMAT (2X,4HXNN1,5X,4HYMN1,6X,3HOTW,6X,2HCK,7X,3HREN,9X,3HVUX,
17X,6HVDXWN1,6X,6HVDYWN1,8X,3HVDY,6X,3HXKT,3X,6HDIRECT)
3110 FORMAT (1H ,F7.3,F10.4,1X,F8.5,1X,E8.1,1X,E11.3,1X,E11.3,1X,E11.3,
11X,E11.3,1X,E11.3,1X,3F5.1)
3111 FORMAT(8HVDYWM =E12.4,5X7HVDXWM =E12.4)
3112 FORMAT (6E12.6)
3113 FORMAT (5E14.6)
3114 FORMAT (1H0,8X,6HGRAVITY,13X,5HDELX1,13X,5HDELX2,13X,5HXREF1,13X,
15HXREF2)
3115 FORMAT (1H0,8X,6HYTRAP1,12X,6HYTRAP2,12X,6HXTRAP1,12X,6HXTRAP2,12X
X,5HTABLE)
DATA IBLANK/6H /
LANGMR=0.
REWIND 23
WRITE (23,610)
ID=0
DO 2009 I=1,800,2
FILL=FLOAT(I-1)/8.-30.
2009 TAB11(I)=FILL
BCUTCE=0.0
2001 CALL RENTRY (N)
IF (N.NE.0) GO TO 6041
2000 CONTINUE
CALL REMOVE (23,3)
TL(2) = 0.0
TL(5) = 10.0
TL(9) = -1.0
GO TO 2004
6041 X55=X55
2003 TA(7) = ID
IF(IC - 2)3394,3394,3393
3393 CALL MPLOTS(TA,XPLOT,YPLOT)
3394 TA(7) = 0.0
TL(1) = TA(1)
TL(3) = .3/TA(3)

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      TL(4) = .7/TA(4)
      TL(5) = .5/TA(3)
      TL(6) = TA(6) - .5/TA(4)
      TL(7) = TA(5) + 2.25/TA(3)
      CALL ALPHA(TL,HEAD,72,GOTHIC)
      CALL MPLOTS(TA,XPLOT,YPLOT)
      I(1) = TA(1)
      T(2) = TA(2)
      IF(JP)3396,3396,3395
3395  IP = IP + 1
      IPC(IP) = JP
3396  IF(IP)2002,2002,3397
3397  IPA = 1
      DO 3398 I=1,IP
      J = IPC(I)
      T(7) = J
      CALL MPLOTS(T,XPLT(IPA),YPLT(IPA))
3398  IPA = IPA + J
      TL(3) = .3/T(3)
      TL(4) = .7/T(4)
      TL(5) = .5/T(3)
      TL(6) = T(6) - .5/T(4)
      TL(7) = T(5) + 2.25/T(3)
      CALL ALPHA(TL,HEAD,72,GOTHIC)
      T(7) = 0
      CALL MPLOTS(T,XPLT,YPLT)
      IF (LANGMR.GT.0.) GO TO 2005
      GO TO 2002
2004  READ (5,3112) (TAB1(J),J=1,3)
      IA=TAB1(1)*TAB1(2)*TAB1(3)+3.0
      READ (5,3112) (TAB1(J),J=4,IA)
      READ (5,3112) (TAB2(J),J=1,3)
      IA=TAB2(1)*TAB2(2)*TAB2(3)+3.0
      READ (5,3112) (TAB2(J),J=4,IA)
      READ (5,3113) (TAB3(J),J=1,3)
      IA=TAB3(1)*TAB3(2)*TAB3(3)+3.0
      READ (5,3113) (TAB3(J),J=4,IA)
      READ (5,3112) (TAB4(J),J=1,3)
      IA=TAB4(1)*TAB4(2)*TAB4(3)+3.0
      READ (5,3112) (TAB4(J),J=4,IA)
      READ (5,3112) (TAB5(J),J=1,3)
      IA=TAB5(1)*TAB5(2)*TAB5(3)+3.0
      READ (5,3112) (TAB5(J),J=4,IA)
      READ (5,3112) (TAB6(J),J=1,3)
      IA=TAB6(1)*TAB6(2)*TAB6(3)+3.0
      READ (5,3112) (TAB6(J),J=4,IA)
      READ (5,3112) (TAB7(J),J=1,3)
      IA=TAB7(1)*TAB7(2)*TAB7(3)+3.0
      READ (5,3112) (TAB7(J),J=4,IA)
      READ (5,3112) (TAB8(J),J=1,3)
      IA=TAB8(1)*TAB8(2)*TAB8(3)+3.0
      READ (5,3112) (TAB8(J),J=4,IA)

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```

      READ (5,3112)(TAB9(J),J=1,3)
      IA=TAB9(1)*TAB9(2)*TAB9(3)+3.0
      READ (5,3112)(TAB9(J),J=4,IA)
2002 IF (R.NE.LANGMR.AND.LANGMR.NE.0.) GO TO 2005
      READ (5,3100) HEAD
      IF (HEAD(1).EQ.IBLANK) GO TO 2004
      READ (5,1000)(TA(I),I=1,6)
      READ (5,1000)(T(I),I=1,6)
      TA(1)=-23.
      READ (5,1000) ALWC,R,UINF,UPINF,PA,WA
      READ (5,1000) XMAX,YMAX,YDROP,DELYDP,XL,XHL1
      READ (5,1000) YSL,YSM,VXWIN,VYWIN,DIRECT,RANDCM
      READ (5,1000) XHL,YHL,ALAMDA,RESIL,RHOW,LANGMR
      READ (5,1000) GRAVITY,DELX1,DELX2,XREF1,XREF2
      READ (5,1000) YTRAP1,YTRAP2,XTRAP1,XTRAP2,TABLE
      SYDROP=YDROP
      IBEV=1
      NK=0
      KL=0
      IF (LANGMR.NE.0.) R=LANGMR
      DO 2007 I=2,800,2
2007 TAB1(I)=0.
      IMAX=0
2005 REINF=2.0*R*PA*UINF/WA
      IF (TABLE.EQ.0.0) GO TO 6055
      TAB1(1)=1.
      TAB1(2)=2.
      TAB1(3)=100.
      TAB1(4)=0.
      TAB1(5)=0.
      NK=5
      DO 701 I=6,100,2
701 IF (TAB6(I).GE.XHL) GO TO 702
702 NK6=I-1
703 NK=NK+1
      NK6=NK6+1
      TAB1(NK)=TAB6(NK6)-XHL
      NK=NK+1
      NK6=NK6+1
      IF (TAB1(NK-1).EQ.0.) GO TO 705
      TAB1(NK)=TAB1(NK-2)+SQRT((TAB6(NK6-1)-TAB6(NK6-3))**2+(TAB6(NK6)-
XTAB6(NK6-2))**2)
      IF (TAB6(NK6-1).LT.XMAX-.C01) GO TO 703
      GO TO 706
705 TAB1(NK)=0.
      GO TO 703
706 TAB2(1)=1.
      NK=(NK-3)/2
      TAB1(3)=NK
      TAB2(2)=2.
      TAB2(3)=100.
      TAB2(4)=0.

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```

      TAB2(5)=0.
      NK=5
      DO 710 I=6,100,2
710  IF (TAB7(I).GE.XHL) GO TO 712
712  NK7=I-1
713  NK=NK+1
      NK7=NK7+1
      TAB2(NK)=TAB7(NK7)-XHL
      NK=NK+1
      NK7=NK7+1
      IF (TAB2(NK-1).EQ.0.) GO TO 715
      TAB2(NK)=TAB2(NK-2)+SQRT((TAB7(NK7-1)-TAB7(NK7-3))**2+(TAB7(NK7)-
xTAB7(NK7-2))**2)
      IF (TAB7(NK7-1).LT.XMAX-.0001) GO TO 713
      GO TO 716
715  TAB2(NK)=0.
      GO TO 713
716  TAB9(1)=1.
      TAB9(2)=2.
      TAB9(3)=50
      NK=(NK-3)/2
      TAB2(3)=NK
      TAB9(4)=0.
      TAB9(5)=0.
      NK=5
      DO 720 I=7,50,2
720  IF (TAB8(I).GT.0.) GO TO 722
722  NK8=I-4
      XHLC8=TAB8(I-3)
723  NK=NK+1
      NK8=NK8+1
      TAB9(NK)=TAB8(NK8)-XHL
      NK=NK+1
      NK8=NK8+1
      IF (NK.EQ.7) GO TO 725
      TAB9(NK)=TAB9(NK-2)+SQRT((TAB8(NK8-1)-TAB8(NK8-3))**2+(TAB8(NK8)-
xTAB9(NK8-2))**2)
      IF (TAB8(NK8-1).LT.XMAX-.0001) GO TO 723
      GO TO 726
725  TAB9(NK)=0.
      GO TO 723
726  NK=(NK-3)/2
      TAB9(3)=NK
6055  IA=TAB6(1)*TAB6(2)*TAB6(3)
      WRITE (6,670)
      IA=TAB1(1)*TAB1(2)*TAB1(3)+3.0
      WRITE (6,680) (TAB1(I),I=6,IA)
      WRITE(6,605)
      WRITE (6,671)
      IA=TAB2(1)*TAB2(2)*TAB2(3)+3.0
      WRITE(6,680) (TAB2(I),I=6,IA)
      WRITE(6,605)

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```

WRITE(6,673)
IA=TAB4(1)*TAB4(2)*TAB4(3)+3.0
WRITE (6,680) (TAB4(I),I=6,IA)
WRITE (6,605)
WRITE (6,674)
IA=TAB5(1)*TAB5(2)*TAB5(3)+3.0
WRITE (6,680) (TAB5(I),I=6,IA)
WRITE (6,605)
WRITE (6,675)
IA=TAB6(1)*TAB6(2)*TAB6(3)+3.0
WRITE (6,680) (TAB6(I),I=6,IA)
WRITE (6,605)
WRITE (6,676)
IA=TAB7(1)*TAB7(2)*TAB7(3)+3.0
WRITE (6,680) (TAB7(I),I=6,IA)
WRITE (6,605)
WRITE (6,677)
IA=TAB8(1)*TAB8(2)*TAB8(3)+3.0
WRITE (6,680) (TAB8(I),I=6,IA)
WRITE (6,605)
WRITE (6,678)
IA=TAB9(1)*TAB9(2)*TAB9(3)+3.0
WRITE (6,680) (TAB9(I),I=6,IA)
WRITE (6,605)
TABLE=0.0
YDRCP=SYDRCP
AK=2.0*RHOW*R**2*UINF/(9.0*WA)
WRITE (6,3101)HEAD
WRITE (6,3102)
WRITE (6,3106)ALWC,R,UINF,UPINF,PA,WA
WRITE (6,3108)
WRITE (6,3106) XMAX,YMAX,YDROP,DELYDP,XL,XHL1
WRITE (6,3104)
WRITE (6,3106) YSL,YSH,VXWIN,VYWIN,DIRECT,RANDOM
WRITE (6,3105)
WRITE (6,3106) XHL,YHL,ALAMDA,RESIL,RHOW,LANGMR
WRITE (6,3114)
WRITE (6,3106) GRAVITY,DELX1,DELX2,XREF1,XREF2
WRITE (6,3115)
WRITE (6,3106) YTRAP1,YTRAP2,XTRAP1,XTRAP2,TABLE
WRITE (6,3165)
WRITE (6,3106) REINF,AK
WRITE (6,3107)
DO 2010 I=1,500
2010 TAB10(I)=0.
TAB10(1)=1.
TAB10(2)=2.
TAB10(3)=500.
TAB10(4)=0.
TAB10(5)=0.
XPM1=0.
XKT = 0.0

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```

      CK = 0.0
      IP = 0
      IPA = 0
      JP = 0
      YP=0.0
      YPM1 = 0.0
      WATRAT = 0.0
      AVS = 0.0
      UNDER=1.0
      VXW=VXWIN
      VYW=VYWIN
      STRCIR=CIRECT
      FN=0.0
      PMM=0.0
      GO TO 104
100  YM=YMNI
      YN=ABS(YM)
      XNN=XNN1
      HUNXAN=100.*XNN1
      IF (T(5) -XNN)3400,3400,3404
3400 IF (T(6) - YM)3401,3401,3404
3401 IF (T(1) -XNN)3404,3402,3402
3402 IF (T(2) - YM)3404,3403,3403
3403 JP = JP + 1
      IPB = IPA + JP

      IF (IPB.LT.3099) GO TO 6064
      WRITE(6,662)
      IPB=IPA
      JP=0
6064 XPLT(IPB)= XNN
      YPLT(IPB)= YM
3404 ID = ID + 1

      IF (ID.LT.549) GO TO 6065
      WRITE (6,661)
      ID=ID-1
6065 XPLCT(ID) = XNN
      YPLCT(ID) = YM
      VDXW=VDXWN1
      VDYW=VDYWN1
      GO TO 2205
102 IF (RANDOM) 305,305,310
305 YDRCP=YDROP+DELYDP
306 IF (RANDOM.GT.0.0) GO TO 310
      VXW=VXWIN
      VYW=VYWIN
      GO TO 315
310 READ (5,1000) YDROP,XL,VXW,VYW
      SCUNCE=0.0
      IF (YDROP+XL+VXW+VYW.EQ.0.0) GO TO 2003
      IF (YDROP.GT.YMAX) STOP

```

```

315 IF(JP) 3405,3406,3405
3405 IP = IP + 1
      IPC(IP) = JP
      IPA = IPA + JP
      JP = 0
3406 TA(7) = ID
      DIRECT=STRDIR
      CALL MPLOTS(TA,XPLOT,YPLOT)
104 VDXW=VXW/UINF
      VDYW=VYW/UINF
      WRITE (6,603) XL,YDROP,VDXW,VDYW
      YP=YDROP
      YN=ABS(YM)
      WRITE (6,3109)
      HUNXAN=100.*XL
      XAN=XL
      XNN1=XNN
      XPLOT(1) = XNN
      YPLOT(1) = YM
      IF(T(5) -XNN)3407,3407,3411
3407 IF(T(6) - YM)3408,3408,3411
3408 IF(T(1) -XNN)3411,3409,3409
3409 IF(T(2) - YM)3411,3410,3410
3410 JP = JP + 1
      IPB = IPA + JP
      XPLOT(IPB) = XNN
      YPLOT(IPB) = YM
3411 ID = 2
      XPLOT(ID) = XNN
      YPLOT(ID) = YM
      IF (XNN.GT.XL) GO TO 2205
103 NYR=TAB3(2)-1.
      NYC=TAB3(3)-1.
      DO 210 I=1,NYR
      Y(I)=FLOAT(INT(TAB3(I+4)*10000.0+.5))/10000.0
      TAB3(I+4)=Y(I)
210 CONTINUE
      J=4
      DO 220 I=1,NYC
      J=J+NYR+1
      X(I)=FLOAT(INT(TAB3(J) *10000.0+.5))/10000.0
      TAB3(J)=X(I)
220 CONTINUE
2205 IF (YN.GT.YMAX) GO TO 2003
      DELX=DELX1
      IF (XAN.GT.XREF1.AND.XNN.LT.XREF2) DELX=DELX2
221 IF (DIRECT) 225,225,260
225 IF (VDYW)226,226,235
226 IF (YM.LE.0.) GO TO 231
232 DO 228 I=1,NYR
      IF (Y(I).GE.YN) GO TO 229
228 CONTINUE

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```

229 YMN1=Y(I-1)
230 YJ=Y(I-1)
    IF(YM.LE.-Y(1)) YMN1=-YMN1
    IF (ABS(YMN1).EQ.Y(2).AND.VDYW.GT.0.0) YMN1=ABS(YMN1)
    YJ1=Y(I)
    GO TO 250
235 IF (YM.LT.0.) GO TO 232
231 DO 236 I=1,NYR
    IF (Y(I).GT.YN) GO TO 237
236 CONTINUE
237 YMN1=Y(I)
    GO TO 230
250 DO 255 I=1,NXC
    IF (X(I).GT.XNN) GO TO 256
255 CONTINUE
256 XN1=X(I)
    XN=X(I-1)
    IF (DIRECT.GT.0.) XNN1=(HUNXNN+DELX)/100.
    GO TO 13
260 DO 265 I=1,NYR
    IF (Y(I).GE.YN) GO TO 266
265 CONTINUE
266 IF (YV.EQ.Y(1)) I=2
    YJ1=Y(I)
    YJ=Y(I-1)
    IF (VDCW) 270,271,250
271 IF (VDC) 270,270,250
270 DO 275 I=1,NXC
    IF (X(I).GE.XNN) GO TO 276
275 CONTINUE
276 XN1=X(I)
    XN=X(I-1)
    XNN1=(HUNXNN-DELX)/100.
13 CALL TLUXXS(TAB6,XN1,0,0,YB2)
    CALL TLUXXS(TAB7,XN1,0,0,YB3)
    YB2N1=YB2
    YB3N1=YB3
    IND1=-1
    IND2=-2
    IND3=-3
    IND4=-4
    IF (XNN1-XHL1) 11,12,12
12 IF(YN-YSL) 11,1301,1301
1301 IF(YN-YSM) 14, 14, 11
14 CALL TLUXXS(TAB4, YJ,0,0,XB2)
    CALL TLUXXS(TAB5, YJ,C,0,XB3)
    XB2J=XB2
    XB3J=XB3
    CALL TLUXXS(TAB4,YJ1,0,0,XB2)
    CALL TLUXXS(TAB5,YJ1,0,0,XB3)
    XB2J1=XB2
    XB3J1=XB3

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CALL TLUXXS(TAB6,XN,C,O,YB2)
CALL TLUXXS(TAB7,XN,C,O,YB3)
YB2N=YB2
YB3N=YB3
CALL TLUXXS(TAB6,XN1,O,O,YB2)
CALL TLUXXS(TAB7,XN1,O,O,YB3)
CALL TLUXXS(TAB8,XN,O,O,YB1)
YB1N=YB1
CALL TLUXXS(TAB8,XN1,O,O,YB1)
YB1N1=YB1
YB2N1=YB2
YB3N1=YB3
IND1= -1.0
IND2= -1.0
INC3= -1.0
INC4= -1.0
IXB2J=10000.0*(XB2J+.00001)
IXB3J=10000.0*(XB3J+.00001)
IXB2J1=10000.0*(XB2J1+0.00001)
IXB3J1=10000.0*(XB3J1+0.00001)
IYB2N=10000.0*(YB2N+0.00001)
IYB3N=10000.0*(YB3N+0.00001)
IYB2N1=10000.0*(YB2N1+0.00001)
IYB3N1=10000.0*(YB3N1+0.00001)
IYB1N=10000.0*(YB1N+0.00001)
IYB1N1=10000.0*(YB1N1+0.00001)
IXN=10000.0*(XN+0.00001)
IXN1=10000.0*(XN1+0.00001)
IYJ=10000.0*(YJ+0.00001)
IYJ1=10000.0*(YJ1+0.00001)
IF (IXN-IXB2J) 15,16,16
15 XLL=XN
YLL=YJ
20 IF (IXN-IXB2J1) 17,18,18
16 IF (IXN.GE.IXB3J)GO TO 15
IF (IYJ.GT.IYB1N) GO TO 19
XLL=XB3J
YLL=YB1N
INC1=2
GO TO 20
19 XLL=XB3J
YLL=YB3N
INC1= 1.0
GO TO 20
17 XUL=XN
YUL=YJ1
22 IF (IXN1-IXB2J) 23,24,24
18 IF (IXN.GT.IXB3J1) GO TO 17
IF (IYJ.GT.IYB1N) GO TO 21
XUL=XB3J1
YUL=YB1N
IND2=2

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```

      GO TO 22
21  XUL=X83J1
      YUL=Y82N
      IND2= 1.0
      GO TO 22
23  XLR=XN1
      YLR=YJ
281 IF (IXN1-IX82J1) 25,26,26
24  IF (IXN1.GT.IX83J1) GO TO 23
      IF (IYJ.GT.IYB1N1)GO TO 27
      XLR=X82J
      YLR=YB1N1
      INC3=2
      GO TO 281
27  XLR=X82J
      YLR=Y83N1
      INC3= 1.0
      GO TO 281
25  XWR=XN1
      YWR=YJ1
      GO TO 29
26  IF (IXN1.GT.IX83J1) GO TO 25
      IF (IYJ.GT.IYB1N1) GO TO 28
      XWR=X82J1
      YWR=YB1N1
      INC4=2
      GO TO 29
28  XWR=X82J1
      YWR=Y82N1
      INC4= 1.0
      GO TO 29
11  YLL=YJ
      YUL=YJ1
      YLR=YJ
      YWR=YJ1
      XLL=XN
      XUL=XN
      XLR=XN1
      XWR=XN1
29  DELYL=YUL-YLL
      IF(DELYL) 30,30,31
30  VXL=0
32  DELYR=YWR-YLR
      IF(DELYR) 33,33,34
31  IF(IND1) 431, 431, 432
432 PHILL = 1.0
      IF (IND1.EQ.2) PHILL=0.
      GO TO 433
431 CALL TLUXXS(TAB3,XLL, YLL,0, PHILL)
433 IF(IND2) 434, 434, 435
435 PHIUL = 1.0
      IF (IND2.EQ.2) PHIUL=0.

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GO TO 46
434 CALL TLUXXS(TAB3, XUL, YUL, 0, PHIUL)
46 IF (ALAMDA.EQ.0.0) GO TO 436
DELYL=((YLL+YUL)/2.)*DELYL
436 VXL=(PHIUL-PHILL)/DELYL
GO TO 32
33 VXR=0
35 CONTINUE
3221 DELXL = XLR - XLL
IF(DELXL) 36,36,37
34 IF(IND3) 437, 437, 438
438 PHILR =1.0
IF (INC3.EQ.2) PHILR=0.
GO TO 439
437 CALL TLUXXS(TAB3,XLR,YLR,0, PHILR)
439 IF(IND4) 440, 440, 441
441 PHIWR =1.0
IF (INC4.EQ.2) PHIWR=0.
GO TO 3010
440 CALL TLUXXS(TAB3,XWR,YWR,0,PHIWR)
3010 IF (ALAMDA.EQ.0.0) GO TO 442
DELYR=((YWR+YLR)/2.)*DELYR
442 VXR = (PHIWR-PHILR)/DELYR
GO TO 35
36 VYL=0.0
38 DELXU=XWR-XUL
IF(DELXU) 39,39,40
37 IF(IND3) 443, 443, 444
444 PHILR =1.0
IF (INC3.EQ.2) PHILR=0.
GO TO 445
443 CALL TLUXXS(TAB3,XLR,YLR,0,PHILR)
445 IF(IND1) 446, 446, 447
447 PHILL =1.0
IF (INC1.EQ.2) PHILL=0.
GO TO 448
446 CALL TLUXXS(TAB3,XLL,YLL,0,PHILL)
448 IF (ALAMDA.EQ.0.) GO TO 4481
DELXL=YJ*DELXL
4481 VYL= (PHILR-PHILL)/DELXL
GO TO 38
40 IF(IND4) 449, 449, 450
450 PHIWR= 1.0
IF (INC4.EQ.2) PHIWR=0.
GO TO 451
449 CALL TLUXXS(TAB3,XWR,YWR,0,PHIWR)
451 IF(IND2) 452, 452, 453
453 PHIUL= 1.0
IF (INC2.EQ.2) PHIUL=0.
GO TO 454
452 CALL TLUXXS(TAB3,XUL,YUL,0,PHIUL)
454 IF (ALAMDA.EQ.0.) GO TO 4541

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      DELXU=DELXU*YJ1
4541 VYW= (PHIWR-PHIUL)/DELXU
      WFS=0.0
      CONTER=0.0
      GO TO 4101
39 VYW=0.0
      WFS=0.0
      CONTER=0.0
4101 CIVX=0.0
      CIVY=0.0
      IF (CIRECT) 320,320,340
320 IF (VYW.NE.0.) CIVY=1.
      IF (VYL.NE.0.) CIVY=CIVY+1.
      IF (VXL) 360,361,360
361 VX=VXR
      GO TO 364
360 IF (VXR) 363,362,363
362 VX=VXL
      GO TO 364
363 VX=VXR*((XNN-XLL)/(XLR-XLL))+VXL*((XLR-XNN)/(XLR-XLL))
364 YMEAN=ABS((YMN1+YM)/2.0)
      VY=(VYL*(YMEAN-YJ1)+VYW*(YJ-YMEAN))/(YJ1-YJ)
      GO TO 3011
340 IF (VXL) 42,43,42
42 DIVX=1.0
43 IF (VXR) 44,45,44
44 CIVX=CIVX+1.0
45 XMEAN=(XNN+XNN1)/2.
      VX=(VXL*(XN1-XMEAN)+VXR*(XMEAN-XN))/(XN1-XN)
      IF (VYW.NE.0.0.AND.VYL.NE.0.0) GO TO 365
      IF (VYW.NE.0.) GO TO 7001
      VY=-VYL
      GO TO 3011
7001 IF (YJ.EQ.0.) GO TO 365
      VY=-VYW
      GO TO 3011
365 VY = -VYH*((YN-YLL)/(YUL-YLL))-VYL*((YUL-YN)/(YUL-YLL))
3011 VDX = VX/UPINF
      VDY=VY/UPINF
      IF (YM.LT.0.) VDY=-VDY
      FIRST=0.
      DWB=0.0
      VDXWM=VDXW
      VDYWM=VDYW
325 REN=REINF*SQRT((VDX-VDXWM)**2+(VDY-VDYWM)**2)
      CK=1.+0.197*REN**0.63+0.00026*REN**1.38
      IF (DIRECT) 336,336,337
336 XX5X=VDYWM**2+(YMN1-YM)*(VDY-VDYWM)*CK/(6.0*AK)-5.3623/(RHOW*UINF**
      X2)*(RFCW-PA)*(YMN1-YM)*GRAVTY
      GO TO 338
337 XX5X=VDXWM**2+(XNN1-XNN)*(VDX-VDXWM)*CK/(6.0*AK)
339 IF (XX5X.LT.0.) GO TO 370

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IF (WFS.GT.0.0) XX5X=0.0
IF (DIRECT.GT.0.0) GO TO 339
VDYWN1=SQRT(XX5X)
IF (VDYW.LT.0.0) VDYWN1=-VDYWN1
DTW=(YMN1-YM)/(6.0*(VDYWN1+VDYW))
VDXWN1=VDXW+DTW*(VDX-VDXWM)*CK/AK
GO TO 5010
370 IF (DIRECT.GT.0.0) GO TO 348
IF (CCNTER.GE.4.0) GO TO 348
CONTER=CONTER+1.0
YMN1=(YM+YMN1)/2.0
GO TO 4101
348 IF (CWB.GT.0.0) GO TO 345
DWB=1.0
IF (DIRECT.GT.0.0) GO TO 346
VDYWM=VDYW/2.0
GO TO 325
346 VDXWM=VDXW/2.0
GO TO 325
345 IF (DIRECT.GT.0.0) GO TO 347
DIRECT=-DIRECT
GO TO 2205
347 XNN1=XNN-(VDXW*VDXW*6.0*AK)/(CK*(VDX-VDXW/2.0))
CONTER=CONTER+1.0
WFS=1.0
IF (CCNTER.LE.10.0) GO TO 4101
VDYWM=VDYW
XKT=26.0
XX5X=0.0
GO TO 339
339 VDXWN1=SQRT(XX5X)
IF (VDXW.LE.0.0) VDXWN1=-VDXWN1
IF (VDXW.EQ.0.0.AND.VDX.GT.0.0) VDXWN1=ABS(VDXWN1)
DTW=(XNN1-XNN)/(6.0*(VDXWN1+VDXW))
VDYWN1=VDYW+DTW*(VDY-VDYWM)*CK/AK-32.174*DTW*(RHOW-PA)/(RHOW*UINF*
X*2)*GRAVITY
5010 IF (VDXWN1.GT.VDXW) GO TO 4200
IF (VDX.GE.VDXWN1) VDXWN1=VDX
GO TO 5020
4200 IF (VDX.LE.VDXWN1) VDXWN1=VDX
5020 IF (VDYWN1.GE.VDYW) GO TO 4100
WDY=VDY-32.174*(RHOW-PA)*(DTW)/(RHOW*UINF**2)*GRAVITY
IF (VDYWN1.GE.WDY) GO TO 399
VDYWN1=VDYW
IF (WDY.LT.VDYW) VDYWN1=WDY
GO TO 399
4100 WDY=VDY-32.174*(RHOW-PA)*(DTW)/(RHOW*UINF**2)*GRAVITY
IF (WDY.GT.VDYWN1) GO TO 399
VDYWN1=VDYW
IF (WDY.GT.VDYW) VDYWN1=WDY
399 VDXWM1 = (VDXWN1 + VDXW)/2.0
VDYWM1 = (VDYWN1 + VDYW)/2.0

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      IF(XKT - 25.0)4999,4999,3028
4999 IF(ABS(VDXW) - .01)3041,3040,3040
3040 IF(ABS(VDXWM - VDXWM1) - ABS(.001 * VDXWM))3041,3041,3026
3041 IF(ABS(VDYW) - .01)3028,3024,3024
3024 IF(ABS(VDYWM - VDYWM1) - ABS(.001 * VDYWM))3028,3028,3025
3025 IF(ABS(VDYWM - VDYWM1) - .0001)3028,3028,3027
3026 IF(ABS(VDXWM - VDXWM1) - .0001)3041,3041,3027
3027 DVXM=VDXWM1-VDXWM
      DVYM=VDYWM1-VDYWM
      IF (FIRST.LE.0.) GO TO 750
      VDYWM1=VDYWM-DVYM*((VDYWMX-VDYWM)/(DVYMX-DVYM))
      VDXWM1=VDXWM-DVXM*((VDXWMX-VDXWM)/(DVXMX-DVXM))
750 VDXWMX=VDXWM
      VDYWMX=VDYWM
      VDXWM=VDXWM1
      VDYWM=VDYWM1
      FIRST=FIRST+1.
      DVXM=DVXM
      DVYM=DVYM
      XKT = XKT + 1.0
      IF(XKT-25.)325,325,5000
5000 WRITE (6,3111)VDYWM,VDXWM
      VDXWM = VDXW
      VDYWM = VDYW
      GO TO 325
3028 IF (DIRECT) 500,500,502
500 XNN1=XNN+6.0*DTW*(VDXWN1+VDXW)
      XKT=XKT+1.0
      IF (ABS(XNN1-XNN).LE.DELX/55.0) GO TO 52
460 IF (XKT.GT.26.0) GO TO 52
      DIRECT=-DIRECT
      GO TO 2205
502 YMN1=YM+6.0*DTW*(VDYWN1+VDYW)
      XKT=XKT+1.0
      IF (ABS(YMN1-YM).LE.(YJ1-YJ)*1.05) GO TO 52
      GO TO 460
52 WRITE (6,3110) XNN1,YMN1,DTW,CK,REN,VDX,VDXW1,VDYWN1,VDY,XKT,
      XDIRECT
      XKT = 0.0
3020 IF (XNN1-XMAX)54,53,53
53 IF (ABS(YMN1)-YSM) 459,459,505
459 IF (XPM1.EQ.0.0) GO TO 462
      IF (FN.NE.0.0) GO TO 471
      SAVE=YCROP
      FN=1.0
      GO TO 461
471 FN=FN+1.0
461 YCROP=YCROP-DELYCP/2.0**FN
      GO TO 306
462 IF (FN.EQ.0.0) GO TO 102
      FN=FN+1.0
      YDROP=YDROP+DELYCP/2.0**FN

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      GO TC 306
505  IF (RANDOM) 5070,5070,102
5070 IF (LANGMR.LE.0.) GO TO 2003
      ND=5+2*(NK-1)
      WRITE (6,630) R,(TAB10(I),I=6,ND)
      AVSMAX=TAB10(ND-1)
      AVS=FLCAT(INT(TAB10(6)*4.)-1)/4.
      GO TC(5040,5041,5042,5043,5044,5045,5046),IBEV
5040 FACTOR=.3
5048 APERAC=.71
      GO TC 5055
5041 FACTOR=.2
5049 APERAC=.52
      GO TC 5055
5042 FACTOR=.1
5050 APERAC=.31
      GO TC 5055
5043 FACTOR=.05
5051 APERAC=2.22
      GO TC 5055
5044 FACTOR=.05
5052 APERAC=1.74
      GO TC 5055
5045 FACTOR=.1
5053 APERAC=1.37
      GO TC 5055
5046 FACTOR=.2
5054 APERAC=0.0
5055 R=APERAC*LANGMR
      BEV=IBEV
      WRITE (6,640) BEV,FACTOR,APERAC
      IBEV=IBEV+1
5056 CALL TLUXXS (TAB10,AVS,0,0,WATRAT)
      WRITE (6,640) WATRAT
      IF (AVS.GT.AVSMAX) WATRAT=0.
      WAWRT=FACTOR*WATRAT
      DO 5072 I=1,800,2
5072 IF (TAB11(I).EQ.AVS) GO TO 5073
5073 CUMWAT=TAB11(I+1)
      WRITE (6,640) CUMWAT,WAWRT,AVS
      CUMWAT=CUMWAT+WAWRT
      TAB11(I+1)=CUMWAT
      AVS=AVS+0.25
      IF (WATRAT.GT.0.0) GO TO 5056
      IEND=2*NK+5
      DO 5060 I=6,IEND
5060 TAB10 (I)=0.
      NK=0
      IF (R.LE.0.) LANGMR=0.
      IF (I.GT.IMAX) IMAX=I
      WRITE (6,635) (TAB11(J),J=1,IMAX)
      GO TC 6041

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54 IF (ABS(YMN1)-YMAX)55,53,53
55 CALL TLUXXS(TAB6,XNN1,0,0,YB2)
   WFSMB=0.
   XN1=XNN1
   IF (ABS(YMN1).LT.YB2) GO TO 1575
   CALL TLUXXS(TAB7,XNN1,0,0,YB3)
   IF (ABS(YMN1)-YB3) 57,100,100
1575 CALL TLUXXS(TAB8,XNN1,0,0,YB1)
   IF (ABS(YMN1).GE.YB1) GO TO 100
1577 CALL TLUXXS(TAB8,XN1,0,0,YB1)
   YB1N1=YB1
   CALL TLUXXS(TAB8,XNN,0,0,YB1)
   YB1N=YB1
   IF (XNN.GE.XHL1) GO TO 472
   YZ1=(YM*(XNN1-XHL1)+YMN1*(XHL1-XNN))/(XNN1-XNN)
   AMB=YB1N1/(XN1-XHL1)
   AMDT=(YMN1-YM)/(XNN1-XNN)
   IF (YZ1.GT.0.0) GO TO 473
   DIFX=(0.0-YM-AMDT*(XHL1-XNN))/(AMB+AMDT)
   XP=XHL1+DIFX
   YP=-AMB*DIFX
   AMDT=-AMDT
   GO TO 474
473 DIFX=(YM+AMDT*(XHL1-XNN))/(AMB-AMDT)
   XP=XHL1+DIFX
   YP=AMB*DIFX
   GO TO 474
472 AMB=(YB1N1-YB1N)/(XN1-XNN)
   AMDT=(ABS(YMN1)-YN)/(XNN1-XNN)
   DIFX=(YN-YB1N)/(AMB-AMDT)
   XP=XNN+DIFX
   YP=YB1N+AMB*DIFX
   IF (YMN1.LT.0.0) YP=-YP
474 CONTINUE
   IF (ABS(XP-XN1).LE.0.0001) GO TO 3501
   XN1=XP
   WFSMB=WFSMB+1.0
   IF (WFSMB.LE.25.0) GO TO 1577
   GO TO 3501
57 CALL TLUXXS(TAB6,XN1,0,0,YB2)
   YB2N1=YB2
   CALL TLUXXS(TAB6,XNN,0,0,YB2)
   YB2N=YB2
   IF(YB2N-YMAX) 157,158,158
158 IF (XFL.LT.XN1) GO TO 1585
   XN1=XNN1+DELX2/100.
   GO TO 57
1585 YZ=(ABS(YMN1)*(XFL-XNN)+YNN*(XNN1-XFL))/(XNN1-XNN)
   IF (ABS(YZ)-YHL) 159,3500,160
159 AMB=(YB2N1-YFL)/(XN1-XHL)
   GO TO 161
160 CALL TLUXXS(TAB7,XN1,0,0,YB3)

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      YB3N1=YB3
      AMB=(YB3N1-YHL)/(XN1-XHL)
161  YO=YHL-AMB*(XHL-XNN)
      GO TO 60
157  IF(YN-YB2N) 58, 59, 59
      58  AMP=(YB2N1-YB2N)/(XN1-XNN)
      CALL TLUXXS(TAB6,XNN,0,0,YB2)
      YO=YB2
      GO TO 60
      59  CALL TLUXXS (TAB7,XN1,0,0,YB3)
      YB3N1=YB3
      CALL TLUXXS(TAB7,XNN,0,0,YB3)
      YO=YB3
      AMB=(YB3N1-YO)/(XN1-XNN)
      60  AMDT=(ABS(YMN1)-YN)/(XNN1-XNN)
      DIFM=AMB-AMDT
      DIFY=YN-YO
      DIFX=DIFY/DIFM
      XP=DIFX+XNN
      DIFFY=AMB*DIFX
      YP=DIFFY+YO
      IF (YMN1.LT.0.) YP=-YP
      IF (ABS(XP-XN1).LE.0.0001) GO TO 3501
      XN1=XP
      WFSMB=WFSMB+1.
      IF (WFSMB.LE.25.) GO TO 57
      GO TO 3501
3500  CONTINUE
      XP=XHL
      YP=YHL
3501  IF(T(5) -XNN)3412,3412,3416
3412  IF(T(6) - YN)3413,3413,3416
3413  IF(T(1) -XNN)3416,3414,3414
3414  IF(T(2) - YN)3416,3415,3415
3415  JP = JP + 1
      IPB = IPA + JP
      XPLT(IPB) = XP
      YPLT(IPB) = YP
      IF (IPB.LT.3099) GO TO 3416
      JP=0
3416  IC=IC+1
      XPLCT(IC)=XP
      YPLCT(IC) = YP
      IF (XANN1.LT.XTRAP1) GO TO 802
      IF (XANN1.GT.XTRAP2)GO TO 802
      IF (ABS(YMN1).LT.YTRAP1) GO TO 802
      IF (ABS(YMN1).GT.YTRAP2) GO TO 802
      WRITE (6,660)
      GO TO 102
      802  IF (RESIL.EQ.0.0) GO TO 9781
      ALPH=ATAN(AMB)
      BETA=1.57079

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      IF (XNN1.NE.XNN) BETA=ATAN(AMDT)
      IF (VCXW.GE.0.0) GO TO 812
      IF (ABS(ALPHA-BETA)-1.57079) 810,804,808
804 SIGN1=1.0
      SIGN2=1.0
      EPS=-1.57079
806 VBIT=0.
      VDW1=SQRT(VDXW*VCXWN1+VDYW*VDYWN1)
      VB2N=VCW1*RESIL
      GO TO 818
808 SIGN1=1.0
      SIGN2=1.0
      GO TO 816
810 SIGN1=-1.0
      SIGN2=-1.0
      GO TO 816
812 IF (ABS(ALPH-BETA)-1.57079) 808,814,810
814 SIGN1=1.0
      SIGN2=1.0
      EPS=-1.57079
      GO TO 806
816 VDW1=SQRT(ABS(VCXW*VCXWN1)+ABS(VDYW*VDYWN1))
      VBIN=VDW1*SIN(ALPH-BETA)
      VBIT=VDW1*COS(ALPH-BETA)
      VB2N=VBIN*RESIL
      EPS=ATAN(VB2N/VBIT)
818 ANGLE=ALPH+EPS
      VDW2=SQRT(VBIT*VBIT+VB2N*VB2N)
      VDXWN1=VDW2*SIGN1*COS(ANGLE)
      VDYWN1=VDW2*SIGN2*SIN(ANGLE)
      IF (YP.LT.0.0) VDYWN1=-VDYWN1
      BOUNCE=BOUNCE+1.0
      YDROP=YP
      XL=XP
      VYW=VDYWN1*UINF
      VXW=VDXWN1*UINF
      IF (XL.GE.XMAX) GO TO 102
      IF (BOUNCE.GT.15.0) GO TO 102
      GO TO 315
9781 X66=X66
      IF (XPM1.NE.0.0) GO TO 468
      IF (FN.EQ.0.0) GO TO 463
      FN=FN+1.0
      GO TO 464
463 SAVE=YDROP
      FN=1.0
464 YDROP=YDROP-DELYCP/2.0**FN
      IF (FN.LT.6.0) GO TO 306
      YTA=YDROP
      YDROP=SAVE-DELYDP
      GO TO 1644
468 IF (FN.EQ.0.0) GO TO 61

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      FN=FN+1.0
      YDROP=YDROP+C.LYDP/2.0**FN
      IF (FN.LT.6.) GO TO 306
      YTAN=YDROP
      YDROP=SAVE-DELYDP
      GO TO 61
62  YPM1=YP
      XPM1=XP
      UNDERX=UNDER
      WRITE (6,3107)
      WRITE (6,1240)WATRAT,AVS,XP,YP,WATER
      WRITE (6,3107)
      NK=NK+1
      IF (NK.EQ.1) GO TO 475
      IDX=4+2*(NK-1)
      TAB10(IDX)=AVS
      TAB10(IDX+1)=WATRAT
      TAB10(3)=NK
      XP=0.0
475  IF (FN.EQ.0.0) GO TO 102
      YP=0.0
      XPM1=0.0
      GO TO 6175
61  AHITE=XP-XPM1
      WID=YP-YPM1
      SQHITE=AHITE**2
      SQWID=WID**2
      AHYPT=SQRT(SQHITE+SQWID)
      IF (ALAMDA) 1641, 1640, 1641
1640 CCNAER=AHYPT
      Z = 60.0* DELYDP
      IF (FN.EQ.0.0) GO TO 470
      Z=60.0*(YTAN-YDROP)
      GO TO 1642
470  IF (PMM.EQ.0.0) GO TO 1642
      Z=60.0*(YDROP-YTAN)
      PMM=0
      GO TO 1642
1641 SUMRAC=ABS((YP)+(YPM1))
      CCNAER=SUMRAC*AHYPT
      Z=60.*(ABS(2.*YDROP-DELYDP))*DELYDP
      IF (FN.EQ.0.0) GO TO 6165
      Z=60.0*(YTAN-YDROP)*(YTAN+YDROP)
      GO TO 6167
6165 IF (PMM.EQ.0.0) GO TO 6167
      Z=60.0*(YDROP-YTAN)*(YDROP+YTAN)
      PMM=0.0
6167 IF (YP*YPM1.GE.0.0) GO TO 1642
      PHYP=SQRT(YP*YP+(XP-XHL1)**2)
      PMHYP=SQRT(YPM1**2+(XPM1-XHL1)**2)
      CCNAER=(YP*PHYP)+ABS(YPM1*PMHYP)
1642 WATER=Z*12.0*UINF*ALWC

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      WATRAT=WATER/CONAER
1644 XSS=XP-XHL
      XXSS = XPM1 - XHL
      CALL TLUXXS (TAB8,XP,0,0,YB1)
      IF (ABS(YP).LT.(YB1+.001)) GO TO 67
      CALL TLUXXS (TAB6,XP,0,0,YB2)
      YB2XP=YB2
      IF (ABS(YP).LT.(YB2XP+.001)) GO TO 68
      CALL TLUXXS (TAB2,XSS,0,0,SUP)
      UNDER=-1.0
      IF (UNDERX.LT.0.) GO TO 64
      GO TO 63
68  CALL TLUXXS (TAB1,XSS,0,0,SUP)
      SUP=-SUP
      UNDER=1.0
      IF (UNDERX.LT.0.0) GO TO 64
63  CALL TLUXXS(TAB1,XXSS,0,0,SUPM1)
      SUPM1=-SUPM1
      GO TO 65
64  CALL TLUXXS (TAB2,XXSS,0,0,SUPM1)
65  AVS = (SUP + SUPM1)/2.0
      IF (XPM1.NE.0.0) GO TO 62
6175 AVS=SUP
      PMM=1.0
      WATRAT=0.0
      FV=0.0
      GO TO 62
67  CALL TLUXXS (TAB9,XSS,0,0,SUP)
      CALL TLUXXS (TAB9,XXSS,0,0,SUPM1)
      IF (YP.GT.0.) GO TO 70
      UNDER=-1.
      SUP=-SUP
      GO TO 71
70  UNDER=1.
71  IF (UNDERX.LT.0.0) SUPM1=-SUPM1
      GO TO 65
      END

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