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Correction

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Page 1 of 17

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By: BREVETT
Date: 8 JUNE 1956

Project Whirlwind
Servomechanisms Laboratory
Massachusetts Institute of Technology
Cambridge, Massachusetts

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SUBJECT: DIGITAL COMPUTATION FOR ANTI-SUBMARINE PROBLEM

To: Director, Special Devices Center

From: Jay W. Forrester and Robert R. Everett

Date: October 1, 1947

As an illustration of the use of digital computers as control and simulation devices, we have made a brief study of a simplified version of the anti-submarine problem. The objective of this study has been to estimate the storage capacity and computing time required in a digital machine and no serious attempt has been made to achieve completeness or accuracy. Examples are for the purpose of illustration only. Coding for the control of a surface ship has been worked out in some detail and the results extrapolated to the case of the submarine. Relative radar positions of one surface craft with respect to each other surface craft have been coded using a straightforward but very inefficient method. The radar results have been extrapolated to the sonar problem. Both the radar and sonar codes represent substantially more computation than would probably be used in a large problem. Surface ships have been provided with two types of depth charges. Computing programs have been estimated for charges with pre-set depths as well as charges with proximity-fuses.

Submarines in this particular example have been provided with no armament and only with sonar for communication and information gathering when below the surface and with the added possibility of radar data when on the surface.

Storage capacity and computing speed are compared with the Whirlwind I digital computer, and it is shown that for the simplified problem selected, the Whirlwind I computer is entirely adequate for a problem involving 10 ships, 5 submarines, interconnecting radar and sonar data, and depth charges in any number up to 20 pre-set units and 20 proximity-fuse units in the water at one time.

SUMMARY: In evaluating any simulation problem, it is imperative that the limitations of the particular forms of simulation are understood. There are very few limitations imposed on the

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simulation problem by a digital computer except those dictated by the storage capacity of the machine and the available computing time.

For the purposes of this example, in assumed control panel for a destroyer is illustrated in Fig. 1. The controls and indicators in this sketch represent the only facilities available to the destroyer personnel. It will be noted in Fig. 1 that controls are available for rudder position, propeller r.p.m. and depth charge release and depth setting. Indicators are available for ~~bearing~~ heading, ship's speed, radar data, sonar data, latitude, longitude, rudder position, and propeller r.p.m. As set up in this example, no other features are available in the destroyer, and extension to computation of depth charge release point or for more realistic simulation of the destroyer or data presentation will require additional computing program and computing time.

The submarine in this example would have available the controls for speed, turn and climb angle and indicators for radar and sonar information.

In the following table storage is calculated in numbers of registers, of which there will be approximately 2000 in the Whirlwind I computer. The table is a summary of the storage registers and computing time for the different elements being simulated. A computation time of 20 microseconds for each control order is assumed, and the numerical values are derived from the programs and sketches toward the end of this memorandum.

	Program Storage Registers	Data Registers	Storage Registers for each unit	Computing time per unit
1. Ship Position	100	100	10	2 millisec
2. Submarine Position	100*	30	12	4 millisec
3. Relative Radar Positions	40	10		0.5n millisec
4. Relative Sonar Positions	30**	10		1.0n millisec
5. Pre-set Depth Charge	220	100	6	.5 millisec
6. Proximity Depth Charge	260	100	8	2 millisec
	750	350		

* In addition to the ship program which would be used for submarines also.

** In addition to the radar program which would be used for sonar also.

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[illegible] on course*

It will be observed from the first line of the table that approximately one hundred control orders are required for calculating the X-position, the Y-position, the bearing, and the speed of a ship, and in addition the correction of these control orders for computation of the next ship. Data necessary in the ship computation will require approximately one hundred registers for coefficients, index numbers, and a table of sine and cosine values. The program and data storage is required only once regardless of the number of ships employed in the problem.

In addition to program storage, each ship will require some 10 storage registers for storage of ship's ~~bearing~~ course, speed, X coordinate (longitude), Y coordinate (latitude), turn rate, number of depth charges remaining, damage, etc.

From the last entry of the first line, 2 milliseconds are required for calculating the preceding data about a single ship.

Submarine information in the second line has been estimated to require about one hundred control orders in addition to those used for ships. A ship program would be used for finding X and Y coordinates of the submarine. Additional orders would be used for calculating depth and for the necessary indexing orders. Additional data storage of about 30 entries would be required, and each submarine might require 12 storage registers for retaining ~~bearing~~ course, pitch, speed, X coordinate, Y coordinate, depth, turn rate, pitch rate, and damage. Computing time is estimated at 4 milliseconds per submarine.

The code for the determination of ~~R~~relative radar position for this example has been set up on a rather inefficient basis. As programmed, it requires 40 control orders, 10 data storage registers, no storage for each individual ship since this data is available in the ship storage, and a computing time at each ship equal to 1/2 millisecond times the total number of ships. Sonar information is estimated on a similar basis.

This control code is established on the basis that radar and sonar scopes will write targets at random times and in random order and will not sweep in the normal radial fashion. Additional equipment would be required for production of radial scope sweep.

Computing programs for dep?th charges include automatic selection of any targets within range as well as calculation of damage according to a table of tabular entries.

Proximity and damage computation take into account the cylindrical shape of the submarine. Calculation of pre-set depth charges will require a program of about 220 entries, a table of data of 100

* [illegible] longitudinal [illegible] ship [illegible]

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entries, and a storage of 6 entries for each depth charge which has been launched and which has not yet exploded. An average computing time of 1/2 millisecond will be required for each depth charge which is still sinking. More storage for program and substantially more computing time is required for the proximity-fuse depth charge because the firing location cannot be predicted ahead of time but must be continually examined for proximity of a target.

The tabulation indicates that 750 program orders would be required and about 350 general data entries. Setting up the problem, therefore, requires 1100 of the available 2000 storage registers. The remaining storage registers are therefore available for storing the data of individual ships, submarines, and depth charges.

The table below shows the storage requirement and computing time for a tactical problem involving 10 ships, 5 submarines, and, at any one time, 20 pre-set depth charges, and 20 proximity depth charges having the characteristics summarized previously. If such a problem were set up on the Whirlwind I computer which has a 16 binary digit register length, all quantities would be used at this register length except for latitude and longitude which will require more sensitivity and which would be calculated to 32 binary digits or approximately 10 decimal places. ?

Units	Storage	Computing Time
10 ships	100	20 milliseconds
5 submarines	60.	20 "
20 pre-set depth charges	120	10 "
20 proximity depth charges	160	40 "
Radar	-	50 "
Sonar	-	125 "
Total	440	265 milliseconds
Program and Data	1100	-
Total	1540 registers	0.26 second

2000

It will be seen from the tabulation that the proposed problem will require 1540 storage registers of the available 2000 and will require a computation time of approximately 1/4 second. The assumption has been made in this tabulation that depth charge positions will be calculated at twice the frequency of ship and submarine positions. In other words, the position of each ship and submarine will be calculated each quarter second and the position of each depth charge, each 1/8 second. This computation frequency is probably four times as high as necessary.

DETAILS OF COMPUTING PROGRAMS: Figure 2 illustrates the general

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procedure in solving the control and simulation computation under consideration. Beginning at the point marked "start", the new position of the first ship is computed, based on available data regarding its previous position and its speed and ~~bearing~~ course during the previous time interval. After computation is complete for the first ship, the control orders are indexed ~~to~~ the position of the second ship and the same program of computation is repeated for the second ship. Repetitions of this computing program are continued until all ships have been calculated, after which a conditional program order transfers the computing operation to loop 2 for submarine position. New positions of all submarines are likewise calculated, and the control is shifted to the program for radar relative locations in which each ship is positioned with respect to every other ship and the proper data fed to a radar scope. Computation of relative sonar positions are then calculated and control is shifted to the computing operations required for depth charge location, evaluation, and damage computation. For the problem of 10 ships and 5 submarines, this computing program requires about 1/4 second after which control is returned to the beginning and the entire cycle and all subcycles are repeated.

Figure 2 has shown the overall approach to the computation problem with the major and first minor cycles of computation shown. We will now examine in more detail the computations indicated in the box marked "Ship Position" and the loop 1 circuit. Figure 3 shows the steps required in computing ship position. From the start order, we first calculate a new X (longitude) position for the ship, continue to a Y (latitude) position, then calculate a new ~~bearing~~ course and finally a new ship's speed. At this point, a choice or comparison must be made by means of a conditional program order to determine whether or not all ship positions have been calculated. If all positions have been calculated, control is shifted to the submarine cycle. If all positions have not been calculated, the control orders are reindexed to a new ship ~~location~~ and the cycle ~~completed~~ gone through for another surface ship.

We can now consider in still more detail the exact computer control operations required in each of the boxes indicated in Fig. 3. Before doing this, a definition of flow diagram symbols and a definition of computer control operations will be required. The following computer control operations taken from the Whirlwind I Computer Block Diagram Report No. R-127 by Everett and Swain are included. It is probable that Report R-127 must be studied before the remainder of this memorandum can be effectively understood. A discussion to follow presumes an understanding of the basic computer operations and how they are handled.

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Symbols

AC	"Accumulator" register of Arithmetic Element
AR	"A-Register" of Arithmetic Element
BR	"B-Register" of Arithmetic Element
S(x)	Storage Register x, where x is identifying number of the storage register to be used in the computing operation.

Operation Code Designation	Description	Meaning
ca	Clear and add.	Clear AC and add the contents of register S(x) into it.
ad	Add.	Add the contents of register S(x) to whatever is already in AC.
Cm cs	Clear and Subtract.	Clear AC and subtract the contents of register S(x) into it.
su	Subtract.	Subtract the contents of register S(x) from whatever is already in AC.
mr	Multiply and round off.	Multiply the contents of register S(x) by whatever is in AC and round off the result to one register length.
mh	Multiply and hold full product.	Multiply the contents of register S(x) by whatever is in AC but do not round off.
dv	Divide.	Divide the contents of AC by Whatever is in register S(x).
ts	Transfer to Storage.	Transfer the contents of AC to register S(x).
sr	Shift right.	Shift the contents of AC and BR to the right the number of digits designated by the number in the register number section of the order.

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Operation Code Designation	Description	Meaning
sl	Shift left.	Shift the contents of AC and BR to the left the number of digits designated by the number in the register section of the order.
sp	Subprogram	Transfer the register number S(x) to the program counter.
cp	Conditional Program	Transfer the register number S(x) to the program counter if the number in AC is non-negative.
td	Transfer digits.	Transfer the left-hand 11 digits in AC to the register position section of the order in S(x).
tx	Transfer externally.	Similar to ts except that the transfer is made to a location external to the computer. These external locations are identified by register numbers as are storage registers.

Figure 4 illustrates the symbols to be used in the detailed flow diagrams that follow.

In Fig. 4a we have a symbol indicating that orders 1 and 2 have been executed by the computer. In general the circle may be thought of as representing the arithmetic element of the computer. In Fig. 4b is shown a storage register as a rectangle with the register identification number in brackets beneath. Text in the box is descriptive of the quantity being stored. Dotted lines extend to and from storage boxes to avoid confusion with flow lines in the computations which are shown solid. Figure 4c shows a symbol indicating transition from one computing operation to the next but without transfer of numerical quantities residing in the arithmetic element. Double lines of Fig. 4d likewise lead to the next operation but indicate that numerical values of the previous computation are carried over into the next cycle. The symbol for a conditional subprogram is shown in Fig. 4e where a choice in computing paths is available. The choice of alternate output channels is made on the basis of positive or negative numbers in the arithmetic element. The broken line of Fig. 4f is used where necessary to indicate the source of a control

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order. In this memorandum such indication is necessary only as a result of the digit transfer order td where the computer generates its own control orders. A transfer operation is shown in Fig. 4g where operations 1 and 2 transfer a number from register 276 to the arithmetic element and thence to register 47. Operations involving incoming arrows always take place before operations involving outgoing arrows. A more complicated operation is shown in Fig. 4h. A number resulting from the previous operation is added by order 1 to the number in register 49 and the resulting sum is stored in register 88. The result of this computation is not used in the next operation as indicated by the single flow line leading from the operation circle. A still more complicated sequence is illustrated in Fig. 4i. Numerical values are not retained from the previous operation. ad represents an add order carried out by operations 1 and 2 bringing the contents of registers 27 and 63 into the arithmetic element and storing the result in register 80. The sum residing in the arithmetic element after this operation is used as the basis of a conditional subprogram as represented by the triangle. A negative number in the arithmetic element results in continuation of the program through orders 4 and 5 while a positive number in the arithmetic element transfers the control to some other order, for example, 28. A td operation involving transfer of digits such as might be required in interpolation is shown in Fig. 4j. Orders 1 and 2 add the contents of registers 99 and 143 and transfer the left-hand or register identification digits to register 4. In this case the order constructed by operation 3 is used immediately as operation 4, for extracting a value from a series of stored functions here referred to as a table of sines. The value of the sine is then carried over to the next operation.

Figure 5 is a detailed operation-by-operation flow diagram for the X-position computation indicated in the ship cycle calculation of Fig. 3.

The following equations are solved to obtain the new X coordinate for the ship:

(Ship Speed)(Sine of ~~Bearing~~ course) = Rate in X direction

(Rate in X)(Solution time Interval) = Increment in X-position

(X Increment) + (Old X-position) = new X-Position

The first twelve operations are required for obtaining the sine of the ship's ~~bearing~~ course angle. Operation 13 multiplies sine bearing by ship's speed. Operation 14 multiplies this quantity by the solution time interval to obtain the increment in X-position. Operation 15 adds the old X-position to obtain the new X-position. Operations 16 and 17 transmit the new X-position to the storage and to the external indicator at the destroyer control.

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Order numbers in the following tabulation agree with those on the flow diagram:

Order Number	Register Number	Operation	Description
1 2 3	S(C) 200 8	ca ad td	These orders combine the ship's bearing angle and the index number to obtain an interpolation order for the first extraction from the sine table.
4 5	201 10	ad td	Linear interpolation is used and the resulting order starts the second entry from the sine table.
6	12	sl	The increment in bearing is stored for interpolation between sine table entries.
7	100	t	
8 9 10	M 101 M+1	cs ts ad	Two entries from the sine table are extracted; the first entry is stored and the difference taken.
11	100	mr	The difference is multiplied by the bearing increment.
12	101	su	The increment in sine value is added to the first table entry, resulting in the final value of sine bearing.
13	S(C+1)	mr	Ship's speed is multiplied by sine bearing.

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Order Number	Register Number	Operation	Description
14	259	mr	X direction rate is multiplied by the time elapsing between consecutive solutions of ship's position.
15	S(C+2)	ad	The X-position increment is added to the old X-position.
16 17	S(C+2) S(C)	ts tx	The new X-position is transmitted to the storage register and to the external indicator at the destroyer control.

A similar computing program is followed for calculating the Y(~~longitude~~)-position of the ship,

Figure 6 illustrates the computing flow diagram for the calculation of turn rate and course ~~bearing~~ of the ship. Course ~~Bearing~~ of a ship is calculated as a double exponential function in which the ship exhibits an exponential approach to the steady state turn rate and in which the turn rate is integrated to obtain the ~~new~~ ship's new course ~~heading~~. The exponentials and integrations are approximated by straight line segments of the curves. The following equations are solved for turn rate and course ~~bearing~~:

$$(TR)_{SS} = D_R \left[\left(A \text{ x speed}\right) + \left(B \text{ x RPM}\right)\right]$$

$$(TR)_1 = (TR)_o + (\text{constant}) \left[(TR)_{SS} - (TR)_o\right]$$

$$\left(\overset{\text{Course}}{\cancel{\text{Bearing}}}\right)_1 = \left(\overset{\text{Course}}{\cancel{\text{Bearing}}}\right)_o + (\text{constant})(TR)_1$$

and rudder position (right rudder being positive, and left, negative)

The first equation defines the steady state turn rate as a function of speed, ~~and~~ propeller RPM, The second equation sets the new turn rate at the old turning rate plus a constant times the difference between the old rate and the steady state rate. Equation three defines the ~~new~~ ship's new course ~~bearing~~ as the old course ~~bearing~~ plus a constant times the new turning rate. ~~Figure 6 shows the flow diagram for this computation and corresponds to the order tabulation below.~~

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Order Number	Register Number	Operation	Description
1	S(C+1)	ca	These orders store the product A times the speed in register 100.
2	261	mr	
3	100	ts	
4	S(C)X	ca	We obtain the product B times RPM.
5	262	mr	
6	100	ad	The quantity A times speed is added.
7	S(C+1)X	mr	Result of the previous computation is multiplied by rudder position to obtain steady state turn rate.
8	S(C+4)	su	Old turn rate is subtracted.
9	263	mr	Difference is multiplied by exponential constant to give increment in turn rate.
10	S(C+4)	ad	Old turn rate is added to obtain new turn rate.
11	S(C+4)	ts	
12	259	mr	The new turn rate is multiplied by the solution time interval factor to obtain bearing increment.
13	S(C)	ad	Bearing increment is added to old bearing position to obtain new ship's bearing.
14	S(C)	ts	

Computation now proceeds to the calculation of ship's speed. Figure 7 shows the computation flow diagram for calculating ship's speed and also the comparison necessary to determine if all ship's positions have been completed and the alteration orders necessary for indexing the ship computation program to the next ship position. The representation for ship speed has been taken as an exponential approach to its steady state value. The following equations have been assumed:

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$$\text{Speed}_{SS} = \text{C(RPM)} - \text{D(absolute Value of Turn Rate)(Speed)}$$

$$\text{Speed}_1 = \text{Speed}_0 + \text{(Constant)}\,(\text{Speed}_{SS} - \text{Speed}_0)$$

The following orders are required for calculation of speed:

Order Number	Register Number	Operation	Description
1	S(C+1)	ca	These orders reult in the storage of quantity D times turn rate times speed.
2	S(C+4)	mr	
3	264	mr	
4	100	ts	
5	265	ca	These orders result in the quantity C times RPM.
6	S(C)X	mr	
7	100	su	This subtract order produces the steady state speed time.
8	S(C+1)	su	Subtracts the previous ship's speed.
9	266	mr	Multiplies by the exponential constant
10	S(C+1)	ad	Result in new ship's speed.
11	S(C+1)	ts	
12	267	ca	These orders add to the index location of the ship under consideration the difference or interval in storage required to reach the next ship storage location. The new index is stored in ship index register 268.
13	268	ad	
14	268	ts	

We next compare the new ship index number with the maximum number of ships being considered to see if the computation has yet reached the last ship in the series.

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Order Number	Register Number	Operation	Description
15	269	su	Subtract maximum number of ships.
16	271	ad	Compare to see if number in arithmetic element is positive or negative.

Alternate programs in the above comparison lead either to the submarine program, if all ships have been considered, or back to the beginning of the ship computation cycle after the required correction of control orders. If all ships have been considered, the ship index number must be reset to the first ship before continuing with the submarine program. This is accomplished in orders 17 and 18.

Order Number	Register Number	Operation	Description
17	271	td	This transfers first ship index number from register 270 to register number 268.
18	271	td	

Assuming now that the new location and bearing and speed have not been computed for all ships, we follow the other alternate leading to a new order sequence arbitrarily chosen as beginning at 126. In the following set of operations, the ship index number from register 268 is transferred into the operation control orders for the previous sequence. For example, referring back to the orders for calculating the X location of the ship, the number S(C) must be substituted into orders 1 and 17 and into corresponding locations of the other control cycles.

Order Number	Register Number	Operation	Description
126	268	ca	Transfers ship index number to arithmetic element.
127 to 133		td	Transfers numbers S(C) to control order location, such as orders 1 and 17 in the program for X location.
134	371	ad	Adds 1 to ship index number.

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Order Number	Register Number	Operation	Description
135 to 142		td	Transfer number to all program orders requiring S(C+1) such as order 13 of X location program.

Orders 143, 146, and 149 index in a similar manner to the numbers S(C+2), S(C+3) and S(C+4) and place these order numbers in their proper register locations.

Order 154 is a subprogram command returning the machine control back to order 1 of the X-position cycle to start with a new ship.

The previous discussions dispose of the ship's position and bearing computation. Solution of the submarine problem would be similar with extension to the computation of depth. We will consider next the calculation of relative radar position.

RADAR COMPUTATION: This computing program is relatively inefficient. Ships are selected one by one as local ships and the positions of all others calculated with respect to the local ship for presentation on the radar PPI. In Fig. 8 loop 1 is traversed once for each remote ship during the computation of a particular radar scope pattern. When all remote ships have been located, loop 2 is traversed to index the computer to a new local ship for calculation of a second radar scope pattern. Two comparison orders are indicated by triangles, the first to determine if all remote ships have been calculated for a particular PPI pattern and the second conditional program is used to determine if all PPI patterns have been computed. After all patterns are computed, the control is transferred to computation of sonar patterns. Figure 9 is a detailed flow diagram for the radar and control orders tabulated below:

Order Number	Register Number	Operation	Description
1	272	ca	Establish a control order making possible extraction of the remote ship X-coordinate
2	5	td	
3	273	ad	The ship index number is increased by one giving a control order for extraction of the Y-coordinate.
4	8	td	
5	X	ca	The differences in X-position between remote and local ships are calculated and transmitted to the scope deflection circuits.
6	274	su	
7	X deflection	tx	

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Order Number	Register Number	Operation	Description
8	Y	ca	These orders obtain Y axis deflection voltages.
9	275	su	
10	Y deflection	tx	
11	279	ca	These provide a scope write order for the proper local ship.
12	13	td	
13	Z	tx	
14	276	ad	The remote ship index is increased to a new position.
15	272	ts	
16	277	su	This index is compared with the maximum number of ships in the problem.
17	18	cp	A choice is made between continuing with a new remote ship at the same local position by continuing at order 18 or if all remote ships have been completed, control is transferred to the next local ship at order 19.
19	278	ca	The remote ship index is returned to its starting value.
20	272	ts	
21	276	ca	The local index is increased by one.
22	279	ad	
23	279	ts	
24	277	su	The local index is examined to see if all local scope ship patterns have been computed. Control is transferred to sonar beginning at order 35 if local ships are complete.
25	34	cp	

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Order Number	Register Number	Operation	Description
35	278	ca	Local ship index is returned to its beginning value.

If a new local ship is to be calculated, control continues through orders 26 and 27.

Order Number	Register Number	Operation	Description
26	279	ca	Orders are generated for extracting the X coordinate of a new local ship.
27	32	td	
28	273	ad	Orders are generated for extracting the Y coordinate of a new local ship.
29	30	td	
30	Y	ca	
31	275	ts	Y coordinate of a local ship is transferred to register 275.
32	X	ca	The X coordinate of a new local ship is transferred to register 274.
33	274	ts	
34	1	sp	This is a subprogram order returning control to order 1 at the beginning of the radar computing cycle.

<u>SONAR:</u> Sonar computation would be done in a manner similar to radar with such additions as necessary to give depth readings.

<u>DEPTH CHARGES:</u> Fig. 10 shows a solution cycle schematic for pre-set depth charges. This schematic is of the same nature as shown in Fig. 3 for calculation of ship position. Figs. 11 and 12 illustrate the calculation cycle schematic for proximity firing depth charges. Control

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orders for the handling of depth charges have not been worked out in detail. Information is handled in the following general manner.

Consider first the depth charge with pre-set firing depth. When a depth charge key in one of the destroyers is fired, the code number of the destroyer and the depth setting of the charge are transferred into the computer. The computer, knowing the ship position, bearing and speed, and knowing the depth setting of the charge can now compute the X and Y coordinates, the depth, and the time at which explosion will occur. This explosion time is then observed at all subsequent major cycles of the computation until explosion time has occurred.

At the time of explosion each submarine is examined for position to see if it is within the possible region of damage. If a submarine is within the possible region of damage, it is examined more closely as to bearing and is treated as a cylinder in shape to see if it is actually within the damage zone. If no submarine is within the damage zone, the depth charge is removed from the computer storage. If damage can occur the probable damage is observed in a table of values and multiplied by a statistical probability factor to arrive at actual damage. Damage is then added to the damage register of the submarine and the depth charge is removed from the computation.

Depth charges with proximity-fuzes are initiated in the same manner as pre-set charges. The computer initially calculates the time of flight through air and the XY coordinates and the time of impact on the water. On successive computation cycles, the computer observes impact time until the depth charge reaches the water surface. At this time an examination in XY coordinates is made to find if any submarines are close enough that they might possibly reach the path of the sinking depth charge. If no submarines are sufficiently close, the depth charge is removed from the computation at this point. If possible submarines exist in the area, their code numbers are stored along with the depth charge data. At each major cycle of the computation, the new depth of the charge is calculated and its distance from all submarines previously identified is observed. If a submarine lies within the maximum detection sphere, the true distance and cylindrical shape of the submarine are taken into account to see if fuze operation can occur. If the charge is within the detection range, damage is calculated as before. If the proximity controlled charge reaches a maximum specified depth without being fired, it is automatically removed from the computation.

Figure	Drawing	Figure	Drawing
1	B-30977	7	B-30983
2	A-30978	8	B-30984
3	A-30979	9	B-30985
4	B-30980	10	B-30986
5	B-30981	11	B-30987
6	B-30982	12	B-30988

JWF:RRE/has - vh

B-30977

B-30977

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1

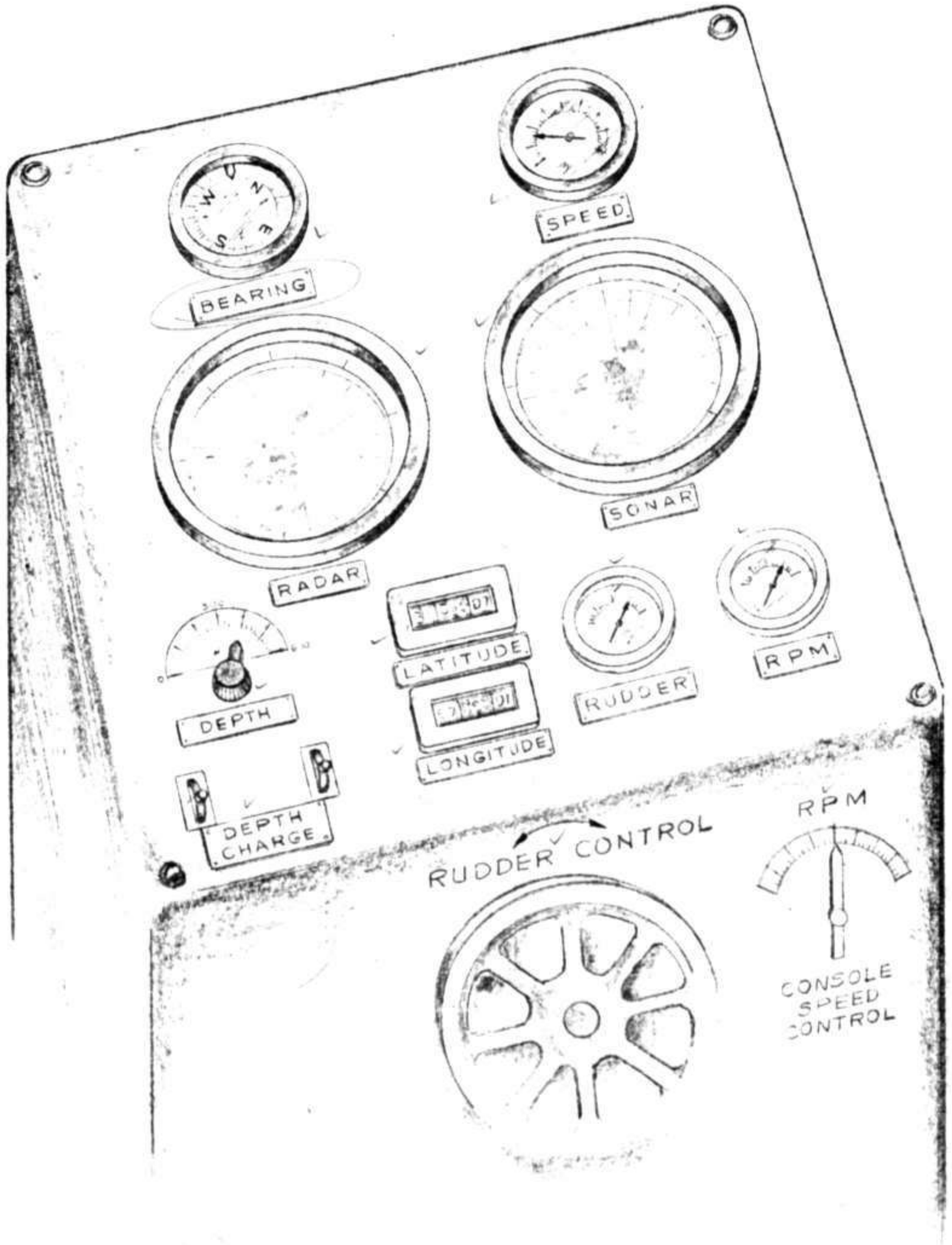

FIG. I

DESTROYER INDICATOR AND CONTROL PANEL

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B-30977

A-30978 USED IN 6345 MEMO M-108
CHANGED TO MEMO L-1

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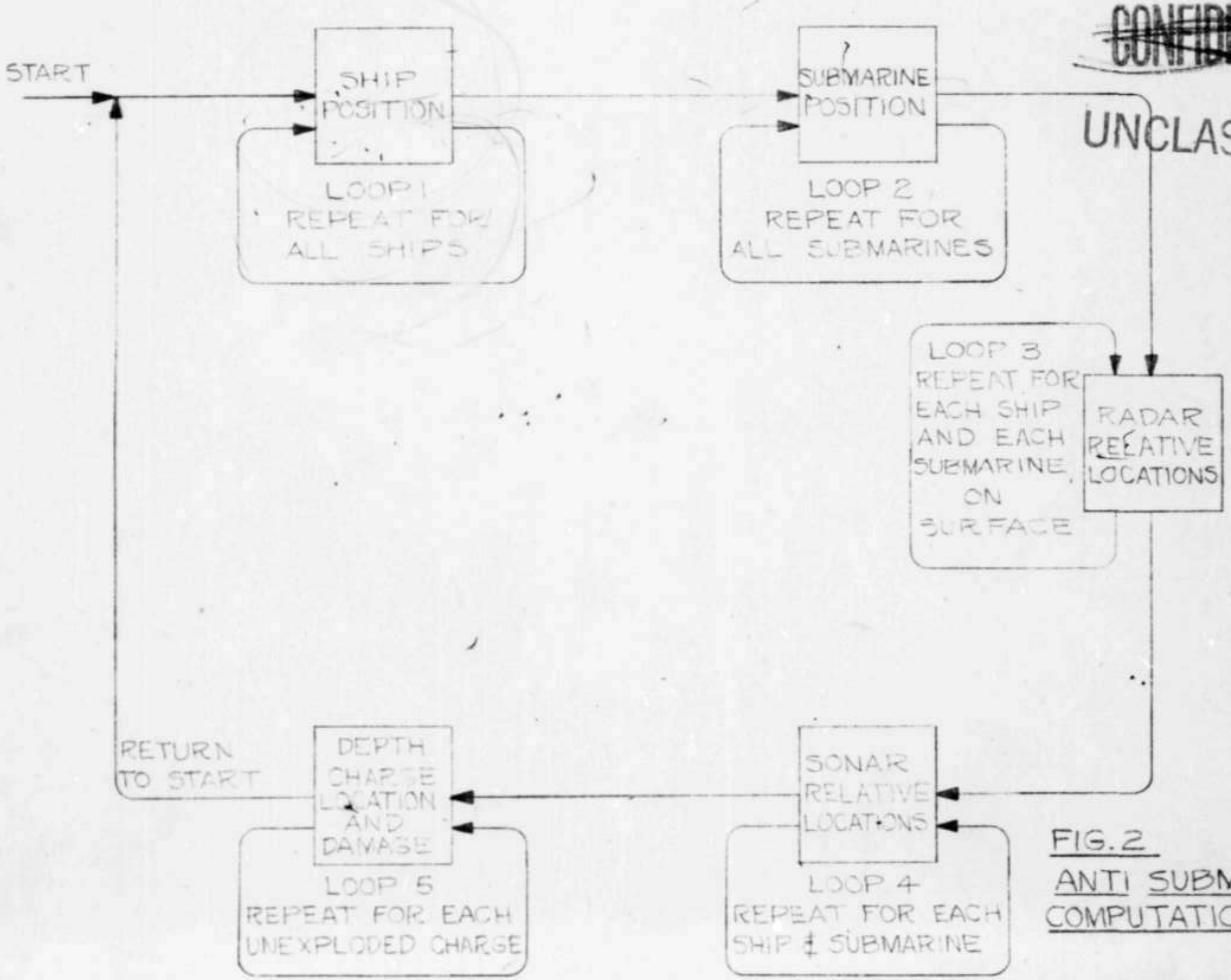

FIG. 2
ANTI SUBMARINE COMPUTATION LOOP

✓

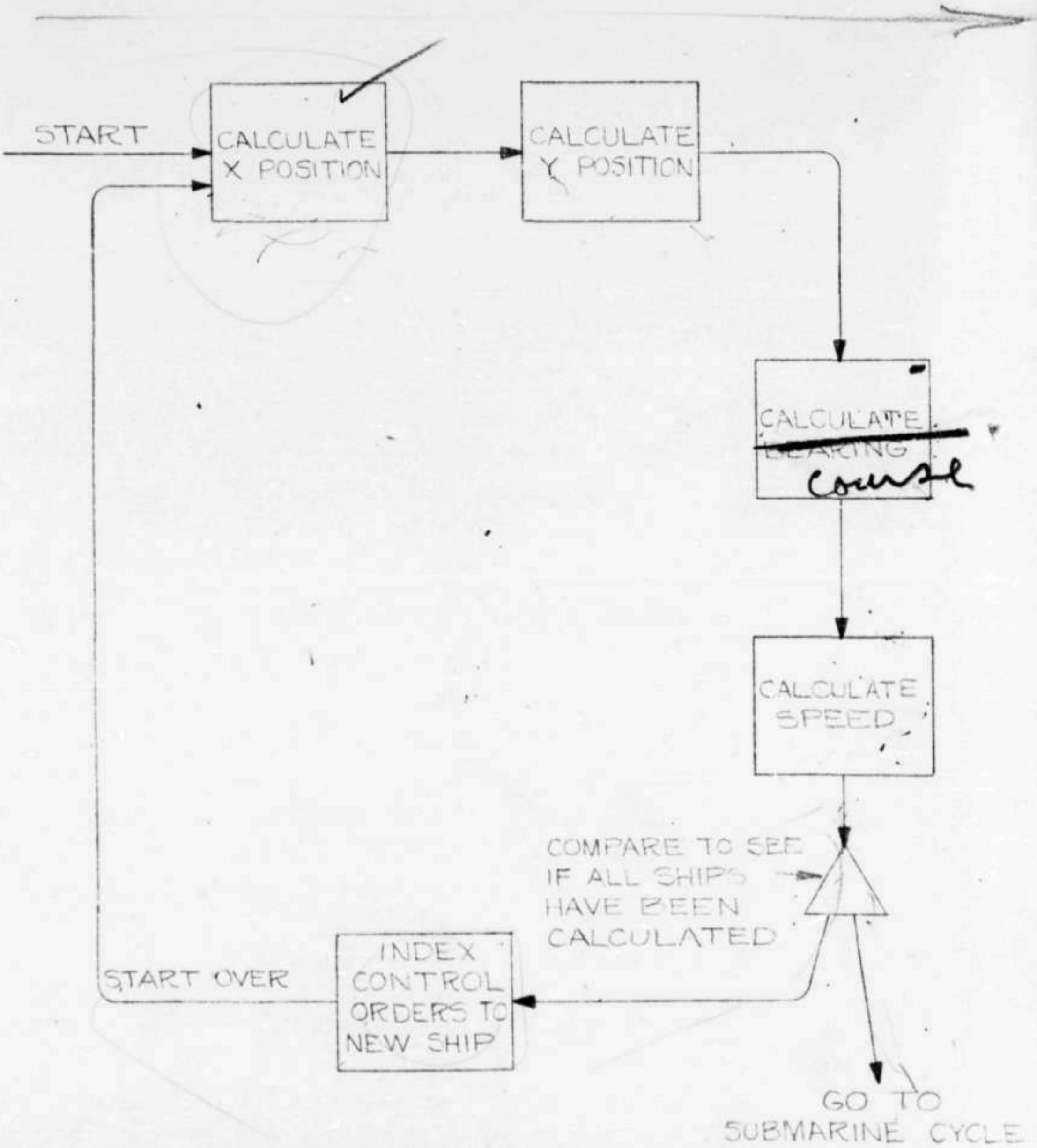

FIG. 3. SHIP CYCLE SCHEMATIC

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A-30979

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1

A-30979

B-30980

B-30980

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1

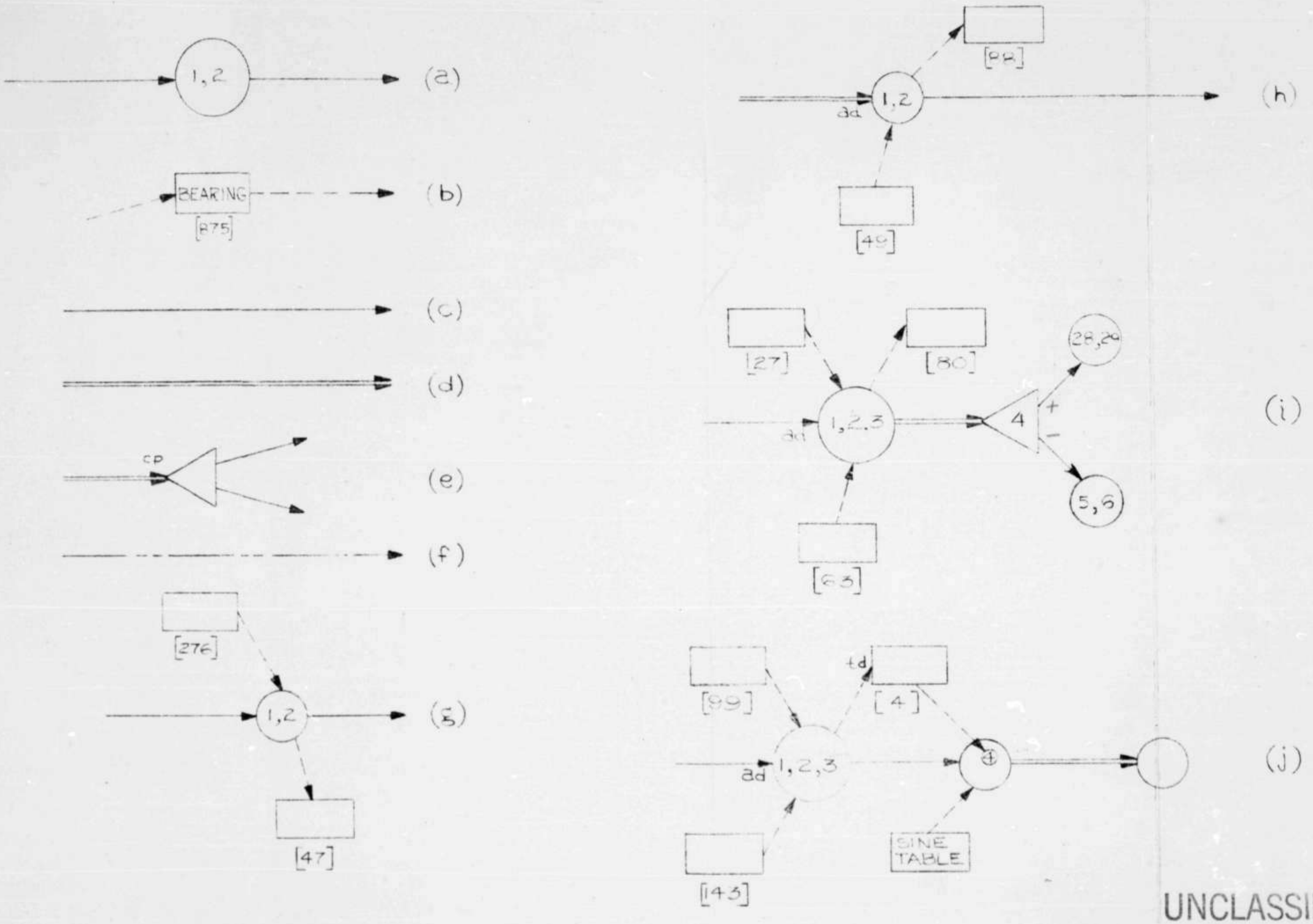

FIG. 4. FLOW DIAGRAM SYMBOLS

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B-30980F

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B-30981

B-30981

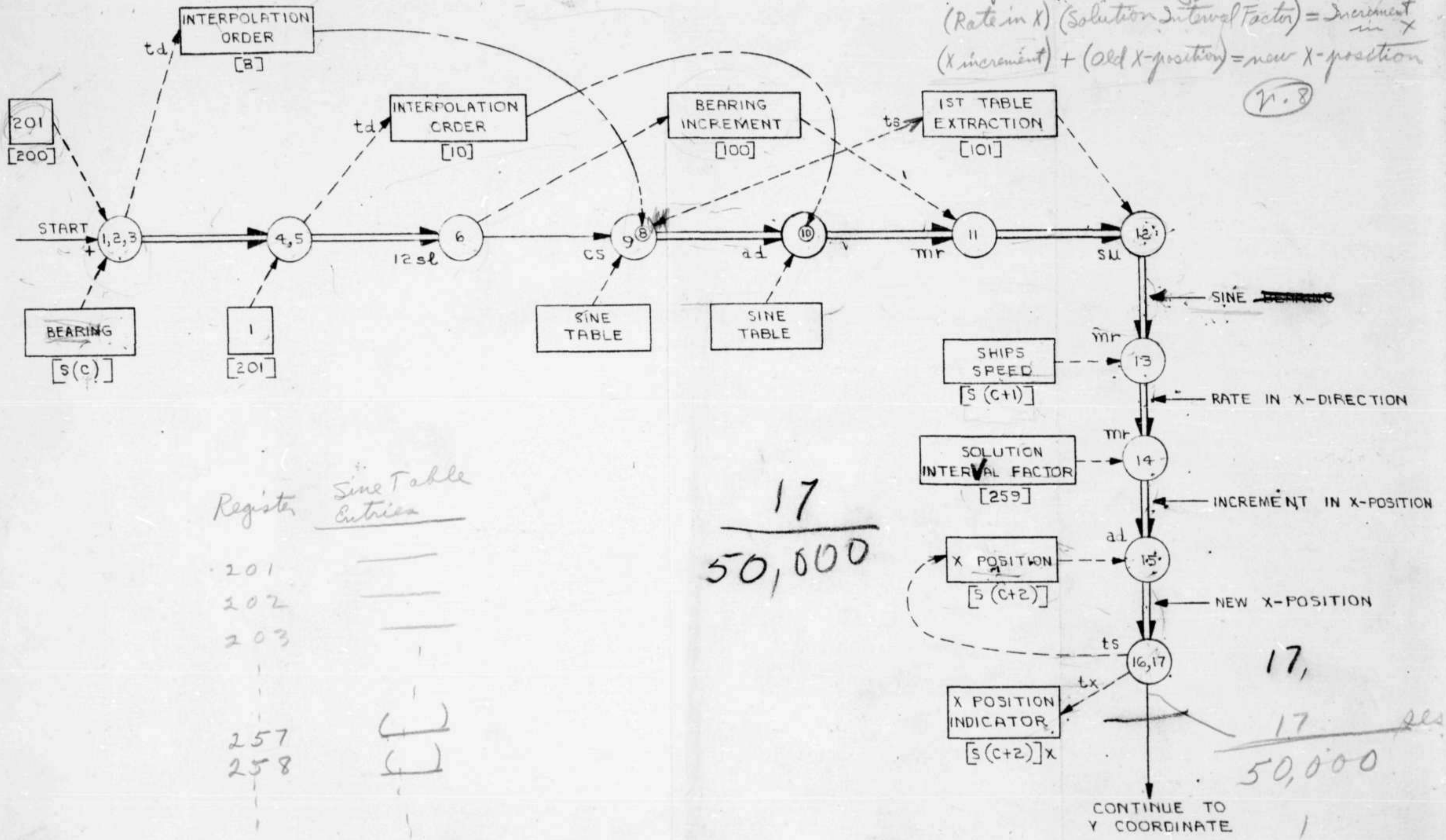
USED IN 6345 MEMO M-108
CHANGED TO MEMO L-1

(Ships Speed)(Sine Brg) = Rate in X dir

(Rate in X)(Solution Interval Factor) = Increment in X

(X increment) + (Old X-position) = new X-position

V.8



Register	Sine Table Entries
201	
202	
203	
257	( )
258	( )

17
50,000

17,

17
50,000

CYCLE FOR X-POSITION COMPUTATION
FIGURE 5

1
3

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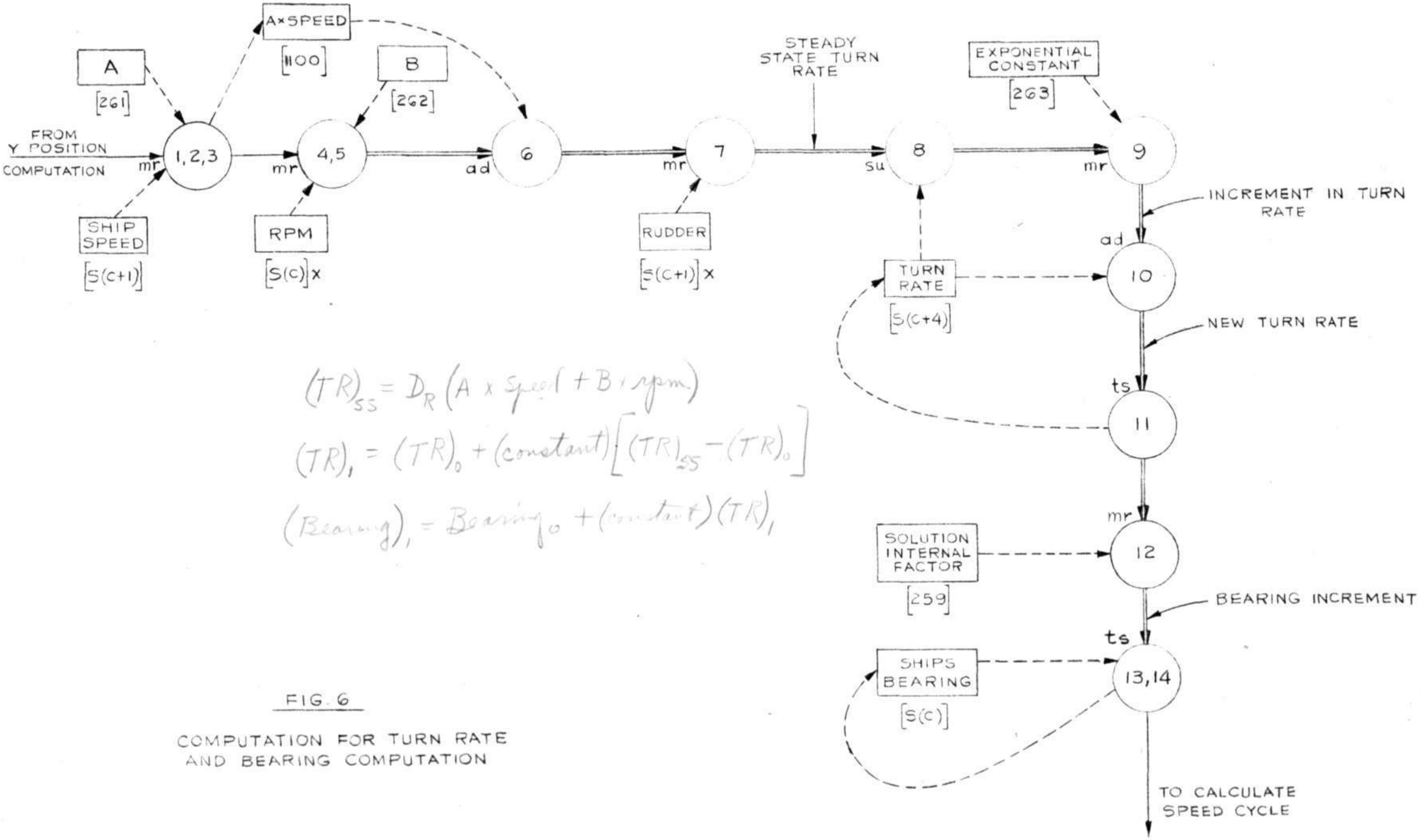
B-30982

B-30982

USED IN 6345 MEMO M-108, CHANGED TO MEMO L-1



$$(TR)_{ss} = D_R\,(A \times \text{Speed} + B \times \text{rpm})$$

$$(TR)_1 = (TR)_0 + (\text{constant})\left[(TR)_{ss} - (TR)_0\right]$$

$$(\text{Bearing})_1 = \text{Bearing}_0 + (\text{constant})(TR)_1$$

FIG. 6

COMPUTATION FOR TURN RATE AND BEARING COMPUTATION

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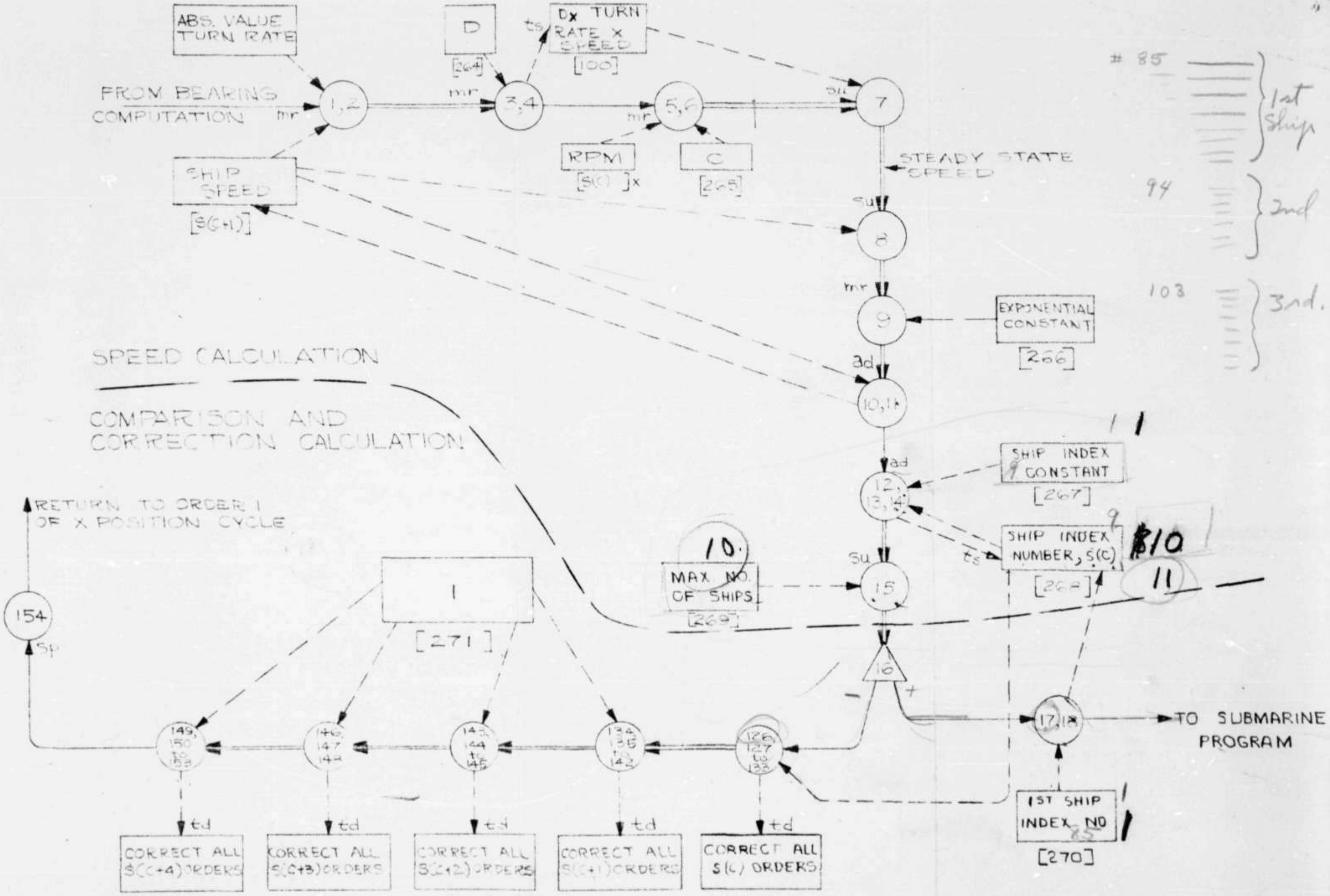
B-30982

B-30983

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1



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SHIP'S SPEED CALCULATION CHECK ON END OF SHIP CYCLE CORRECTION OF SHIP ORDERS.

FIGURE 7.

B-30983

B-30984

B-30984

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1

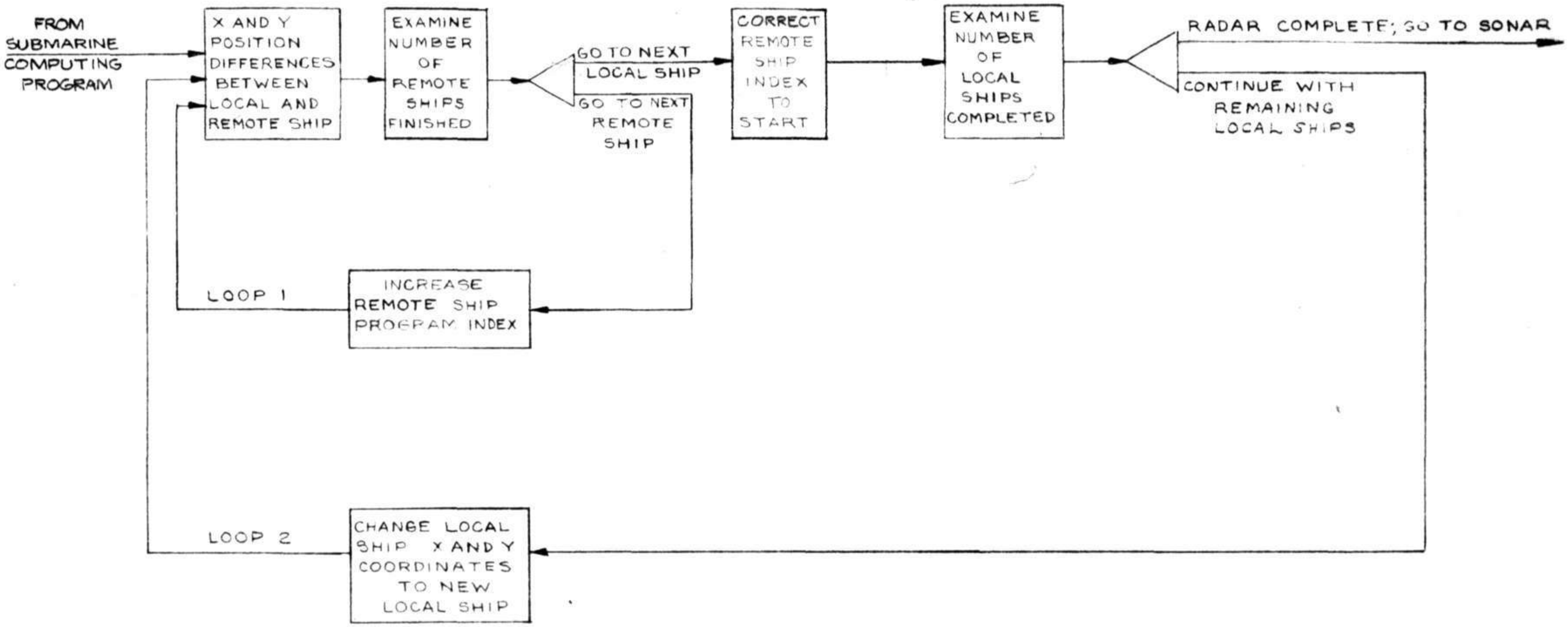

FIG. 8
SCHEMATIC SOLUTION OF
SHIP TO SHIP RADAR PROBLEM

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B-30984

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B-30985

B-30985

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1

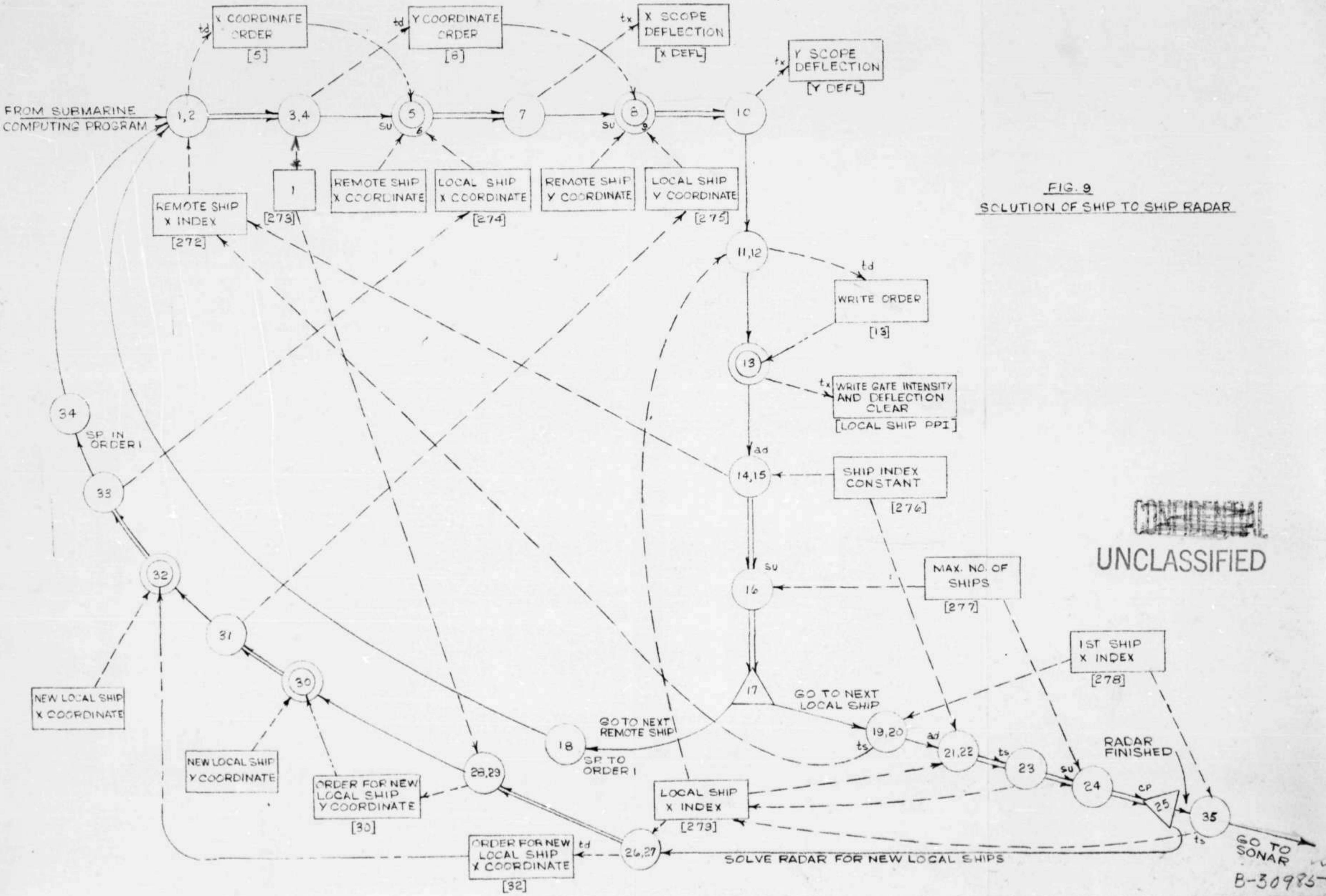

FIG. 9
SOLUTION OF SHIP TO SHIP RADAR

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B-30985

B-30986

B-30986

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1

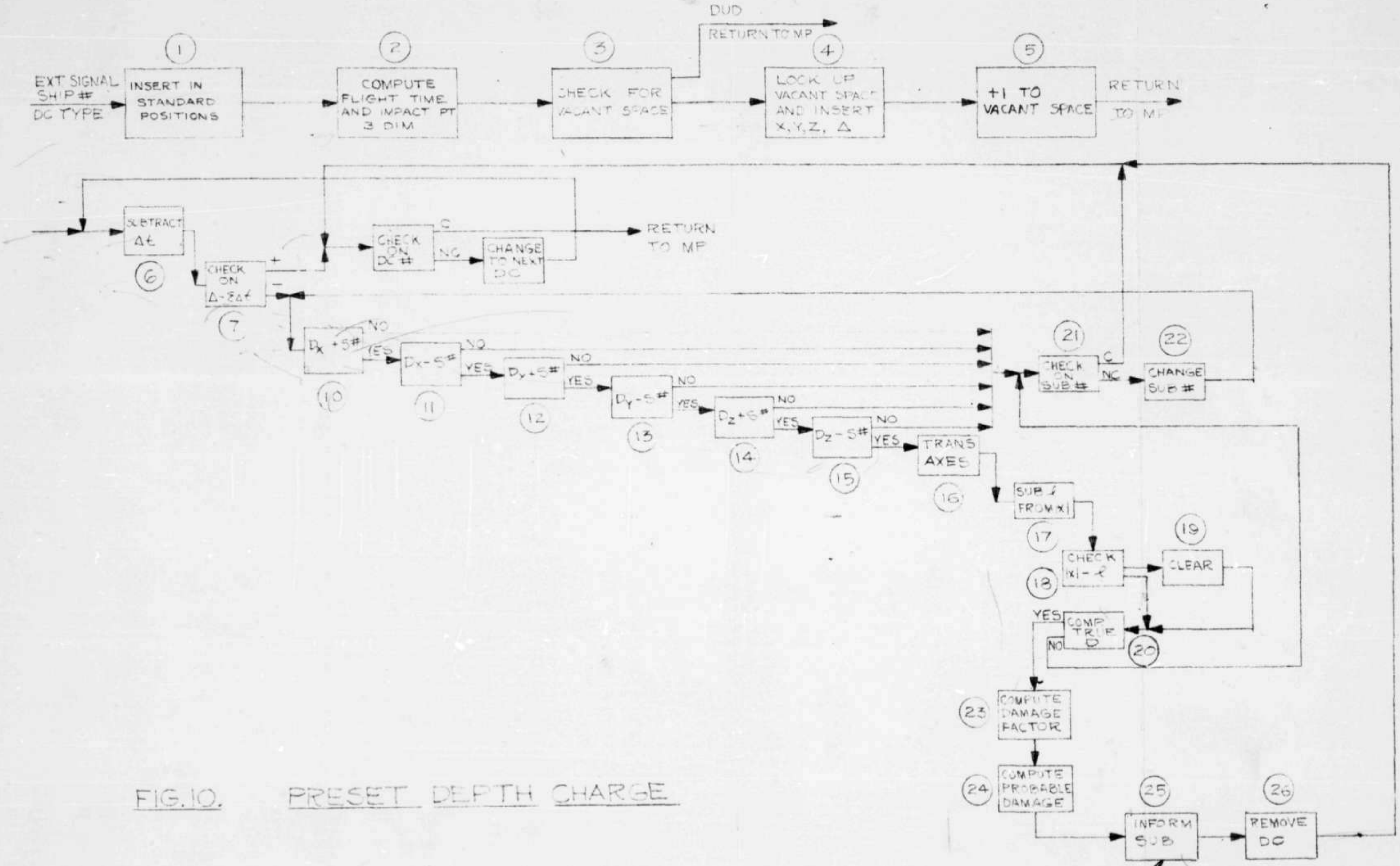

FIG. 10. PRESET DEPTH CHARGE

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B-30986

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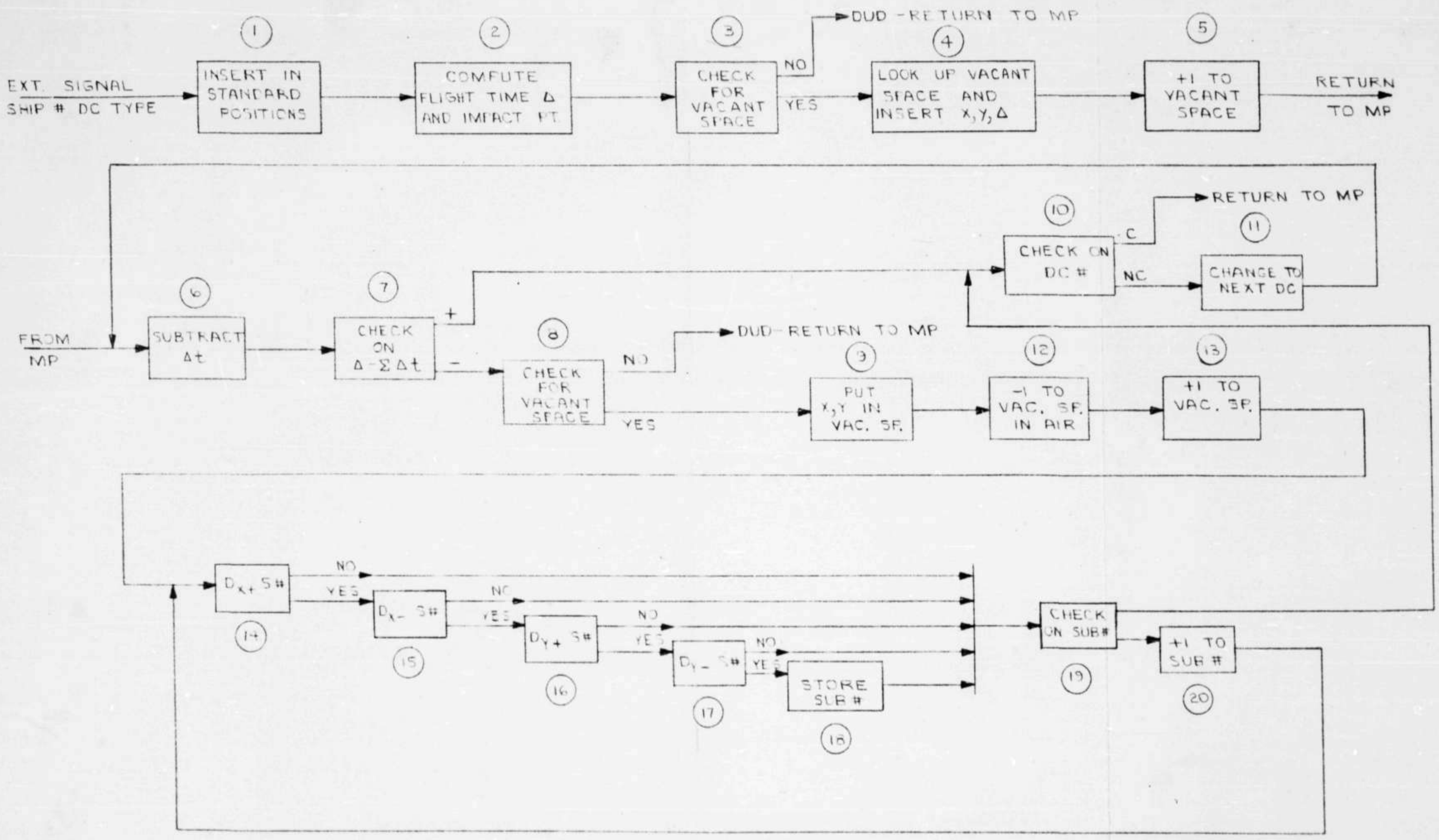
B-30987

B-30987

USED IN 6345 MEMO M-105,
CHANGED TO MEMO L-1



PROXIMITY DEPTH CHARGE
IN AIR
FIGURE

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B-30987

B-30988

B-30988

USED IN 6345 MEMO M-108,
CHANGED TO MEMO L-1

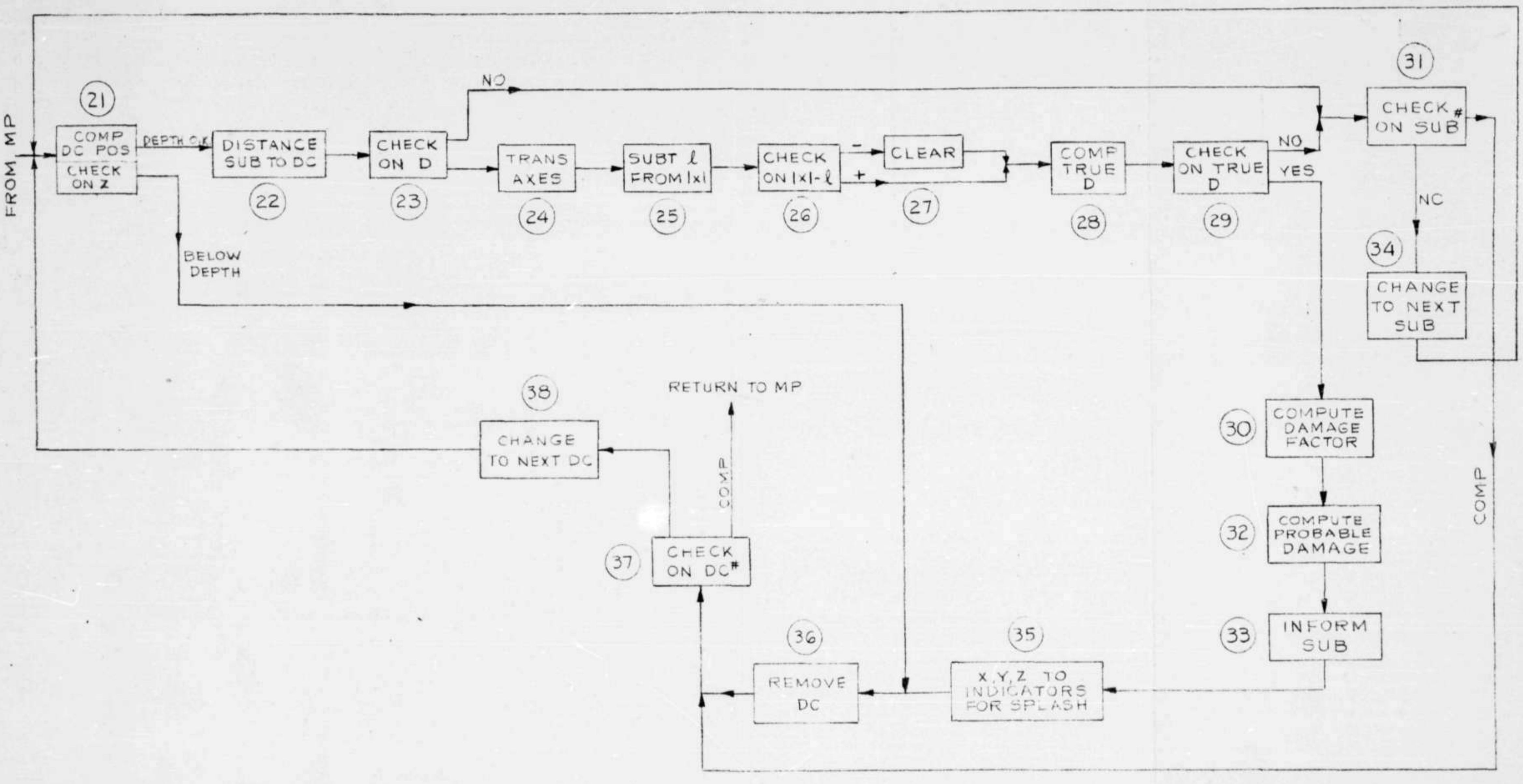

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FIG. 12

PROXIMITY DEPTH CHARGE IN WATER

B-30988