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SHIP WEIGHT ESTIMATES USING COMPUTERIZED RATIOCINATION

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ABSTRACT

Although the method of ratiocination is well known for use in preparing ship weight estimates during the early design phases, this method when done using hand calculations is cumbersome and does not lend itself well to the rapidly changing and fluid designs characteristic of the early stages of naval ship design. This need to provide a more convenient and rapid method for producing a weight estimate based on minimal ship information, without any loss of accuracy, led to the use of computers and the development of the RATS program to produce these estimates.

The RATS program is an interactive program developed to use a preselected known base ship and certain selected characteristics of the new ship design to produce a complete three-digit SWBS weight estimate containing the weights and vertical and longitudinal centers for the design. This is done by the program through a series of equations which equate the SWBS element weight and centers with certain characteristics of the new ship, which then modify the base ship weight to reflect the new design characteristics. Since this methodology is subject to some inaccuracies if the new design has a somewhat different configuration or mission than the base ship, the program also allows the user to modify the estimate produced by this method to reflect any of the special or unique aspects of the new design. The output of the program is an eleven page estimate which also contains the base and new ship characteristics. Also produced is a summary of all of the modifications made to the estimate by the user. Options also exist to produce a delta summary from the base ship to the new ship, to prepare the estimate in a format compatible for input into the SDWE program, and to use the new ship estimate as a base ship file for sensitivity studies. The estimate may be prepared using either English or metric units.

This program has several applications. Most importantly, it allows the engineer to prepare an accurate weight estimate for a naval ship during the Feasiblity level of design in a very short amount of time. It also allows sensitivity analyses to be performed on a ship at virtually any level of design, again in a very short period of time. These sensitivity analyses would determine the impact of variation in the ship characteristics to the ship weight and centers of gravity.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

BACKGROUND

The Feasibility Study is a crucial step in the design of Naval ships. During this phase the basic ship configuration is defined, and more importantly, the cost of the ship estimated. It is crucial at this early design phase to accurately define all ship parameters, including the cost, so an accurate assessment can be made whether to continue with the procurement process. A crucial factor in this decision is the cost, especially in light of the recent trend in budget reductions and cost overruns. Since the weight estimate is the primary tool in preparing the cost estimate, the weight estimate becomes very important in two ways. First, the weight estimate helps determine the feasibility of the design from a naval architectural standpoint, and secondly, the feasibility from a cost point of view.

It becomes difficult to prepare an accurate and detailed weight estimate to support the requirements of the Feasibilty Study because often times there is a very limited description of the ship which makes any detailed calculations virtually impossible. One technique which has been devised by weight engineers to solve this problem is the use of a known parent ship which has a good, detailed, and preferably verified weight estimate. This parent weight estimate then becomes the basis for the new design weight estimate. Of course, the closer the characteristics of the parent are to the new design the greater the accuracy of the new estimate. This technique assumes that the weights of the various SWBS elements are a function of a set of simple characteristics or parameters of the ship, and that as these parameters change, then so does the weight of all items that are a function of that parameter.

The technique of using these factors to determine the weights for a design from a parent weight estimate is called ratiocination. The name is derived from the fact that a rational and ordered set of ratios of new ship parameters to parent ship parameters are developed which are used to modify the parent ship weight to obtain the new ship weight. The technique of ratiocination has been documented in several sources including References (1), (2), and (3). A good updated set of factors for many of the common SWBS groups used in a naval combatant is also contained in Reference (2).

Preparing a complete weight estimate to the three-digit level of detail using this technique is a fairly lengthy process requiring several days of effort depending upon the complexity of the estimate. One problem is the fact that the design, especially during the Feasibility design, is very fluid and constantly changing. Changes in basic ship parameters can require a significant modification to the weight estimate which requires additional time to prepare. One weight estimate could change six or seven times during the course of a six week Feasibility Study, each requiring major modifications to the weight estimate.

Another problem with this type of analysis is that during a Feasibility Study several options of a design may be studied. These alternative designs inevitably have different parameters and characteristics all of which require a new weight estimate for virtually every alternative studied. For example, a design might trade-off several different cargo capacities or weapon suites depending upon the type of ship. Each alternative will have a diffent length and beam and therefore, will require a complete unique weight estimate. Considering the short time frame under which most Feasibility Studies are done, preparing all the revisions for all of the alternatives under study can become an overwhelming task for the weight engineer.

Given the repetitive nature of all of these alternatives and revisions, this method of ratiocination was seen to lend itself well to the use of computers to streamline and speed up the process of preparing good and accurate weight estimates as a part of the Feasibility design process. From this idea the program RATS was born. All of the equations and factors and methodology used by the weight engineer during Feasibility Studies were transfered into FORTRAN and put onto a computer. The resulting program, RATS, utilizes a library of parent ship weight estimates and the basic ratiocination methodolgy to generate a complete weight estimate to the three digit level of detail in a matter of seconds without any loss of accuracy over the hand method of calculation.

PROGRAM

The RATS program consists of many small subroutines each responsible for performing a small function within the entire weight estimating process. These subroutines are organized into larger functional blocks which make up the program itself. The functional blocks within the program are as follows:

-Data Input
-Calculation of Parametric Ratios
-Weight Calculation
-Vertical Center of Gravity Calculation
-Longitudinal Center of Gravity Calculation
-Estimate Summation
-Estimate Modification
-Output

The interaction and operation of these functional blocks is illustrated in the general flow chart for the RATS program shown in Figure 1. Each of the above functional blocks is described in detail in the following.

Data Input

Two subroutines are used for data input into the program. These two subroutines are READDATA and READBASE which are used to input the new ship and base ship respectively. The operation of these two subroutines is shown in the flow chart shown in Figure 2. The first, READDATA, is an interactive routine which requests all the required information from the user. The routine asks the operator to enter all of the information about the ship geometry and the other required characteristics in small input groups in order to simplify the data entry.

Fifty data entries are required in order to provide the necessary information about the new ship. It would be very awkward to have to reenter all of this data for each run of the program especially when only one or two of the parameters would change. READDATA has the option to read the new ship data from a file as well as from the terminal in order to solve this problem. Once a new ship data file has been established the program can read the data from that file rather than have it entered from the terminal. If small changes are required to the new ship file this can be done most effectively with the system's own file editing program. Consequently there is no means of modifying the new ship data file from the RATS program itself. It is however useful to use the interactive portion of the routine for the initial input of data into the new ship data file. Therefore the option does exist to place all of the new ship data which has been entered from the terminal into a file so it can be used for subsequent runs.

A sample listing of the output from a run of the READDATA subroutine is shown in Figure 3. In this sample case the new ship data has been entered from the terminal and then saved in a file. The other option of

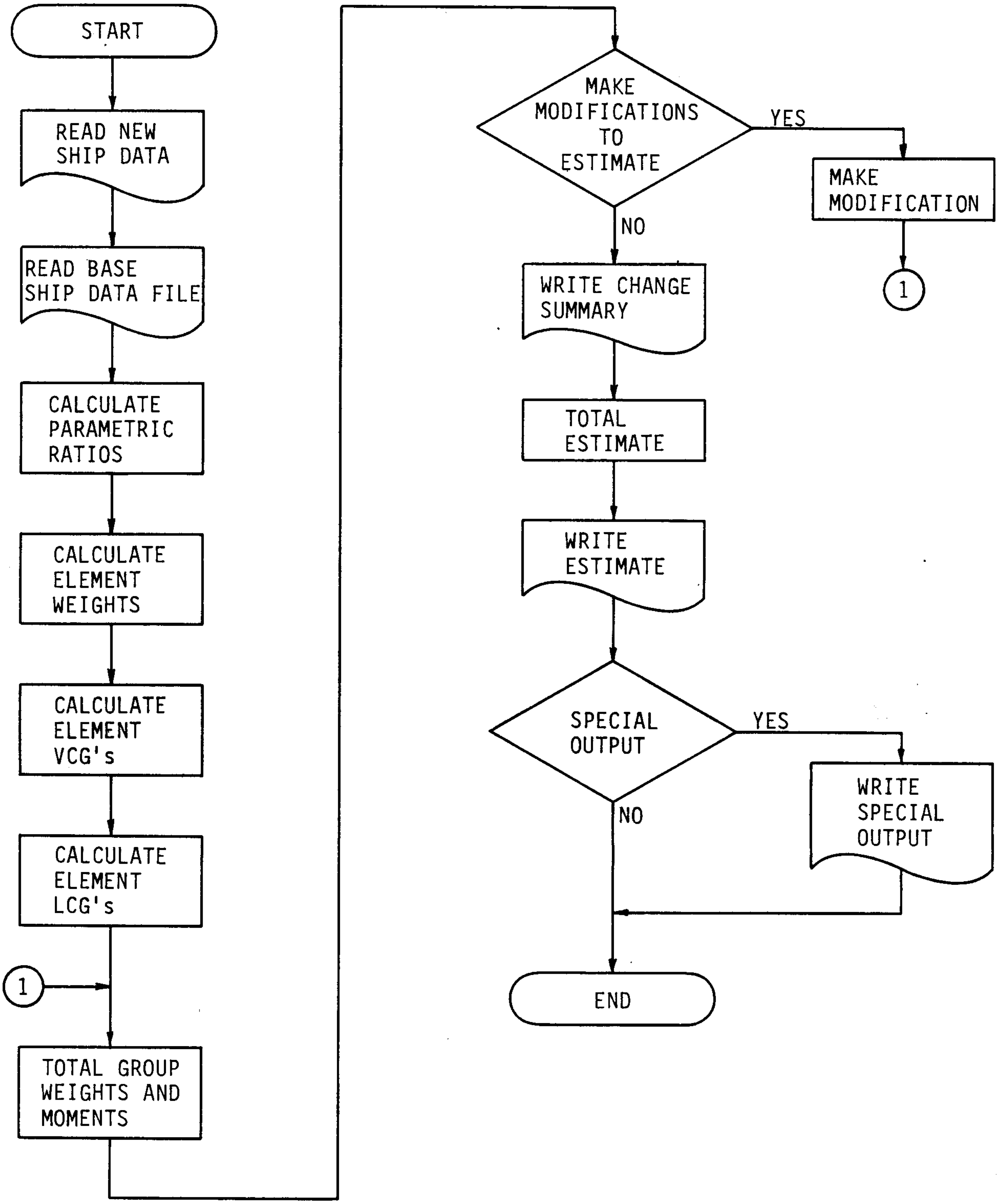


FIGURE 1
FLOW CHART FOR RATS PROGRAM

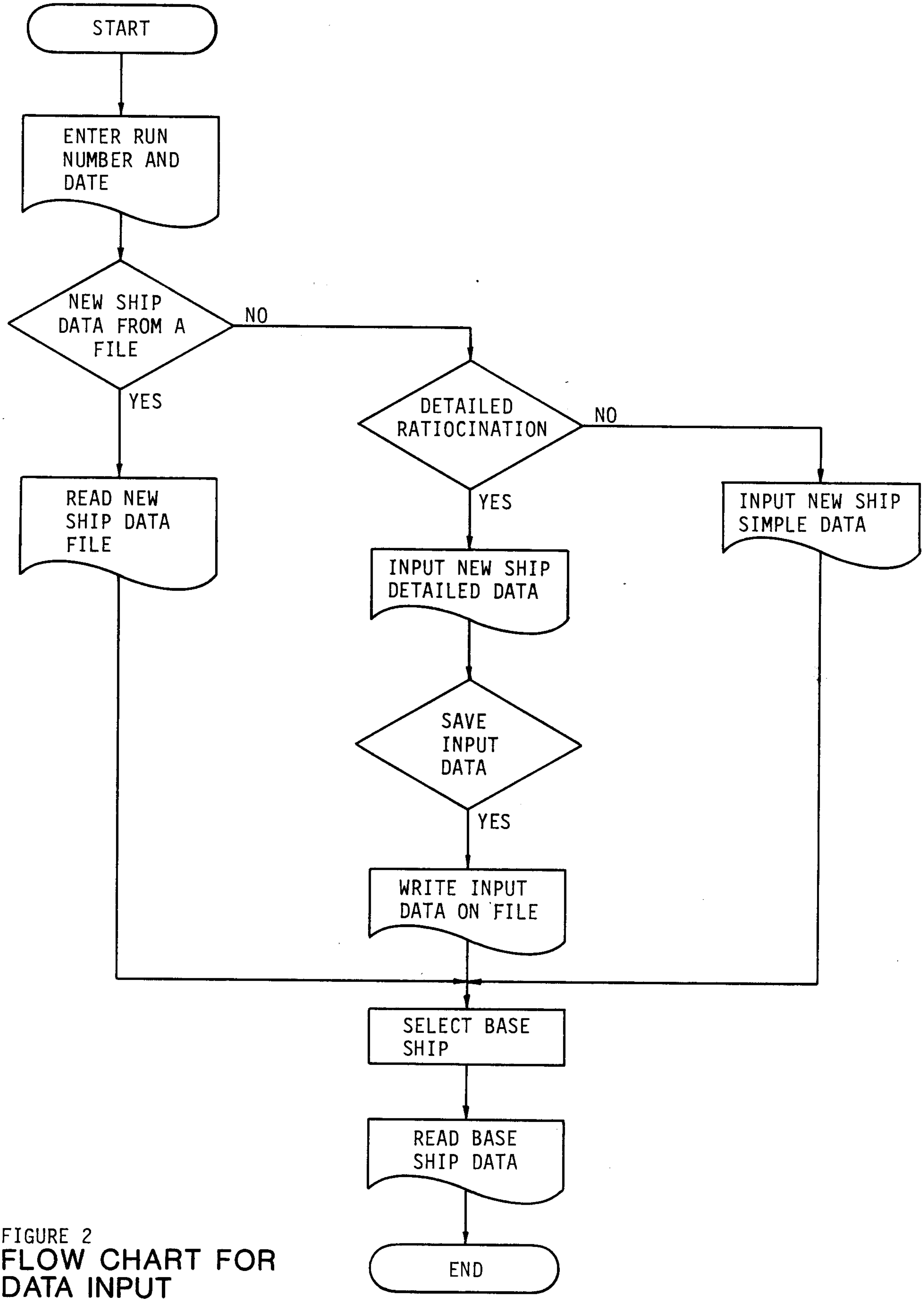
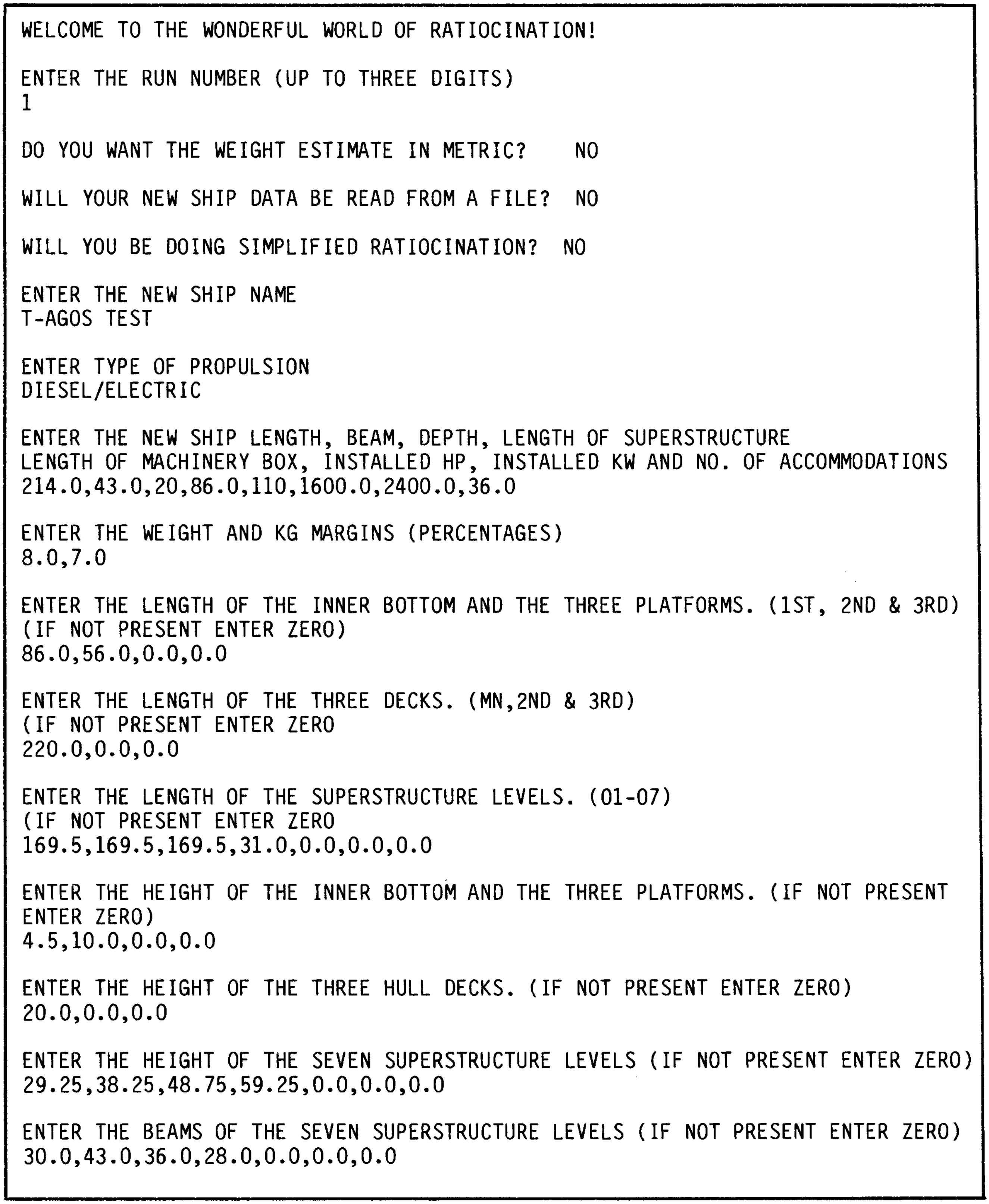


FIGURE 2
FLOW CHART FOR DATA INPUT

FIGURE 3

Sample Execution of Subroutine READDATA



```
WELCOME TO THE WONDERFUL WORLD OF RATIOCINATION!

ENTER THE RUN NUMBER (UP TO THREE DIGITS)
1

DO YOU WANT THE WEIGHT ESTIMATE IN METRIC?    NO

WILL YOUR NEW SHIP DATA BE READ FROM A FILE?  NO

WILL YOU BE DOING SIMPLIFIED RATIOCINATION?  NO

ENTER THE NEW SHIP NAME
T-AGOS TEST

ENTER TYPE OF PROPULSION
DIESEL/ELECTRIC

ENTER THE NEW SHIP LENGTH, BEAM, DEPTH, LENGTH OF SUPERSTRUCTURE
LENGTH OF MACHINERY BOX, INSTALLED HP, INSTALLED KW AND NO. OF ACCOMMODATIONS
214.0,43.0,20,86.0,110,1600.0,2400.0,36.0

ENTER THE WEIGHT AND KG MARGINS (PERCENTAGES)
8.0,7.0

ENTER THE LENGTH OF THE INNER BOTTOM AND THE THREE PLATFORMS. (1ST, 2ND & 3RD)
(IF NOT PRESENT ENTER ZERO)
86.0,56.0,0.0,0.0

ENTER THE LENGTH OF THE THREE DECKS. (MN,2ND & 3RD)
(IF NOT PRESENT ENTER ZERO
220.0,0.0,0.0

ENTER THE LENGTH OF THE SUPERSTRUCTURE LEVELS. (01-07)
(IF NOT PRESENT ENTER ZERO
169.5,169.5,169.5,31.0,0.0,0.0,0.0

ENTER THE HEIGHT OF THE INNER BOTTOM AND THE THREE PLATFORMS. (IF NOT PRESENT
ENTER ZERO)
4.5,10.0,0.0,0.0

ENTER THE HEIGHT OF THE THREE HULL DECKS. (IF NOT PRESENT ENTER ZERO)
20.0,0.0,0.0

ENTER THE HEIGHT OF THE SEVEN SUPERSTRUCTURE LEVELS (IF NOT PRESENT ENTER ZERO)
29.25,38.25,48.75,59.25,0.0,0.0,0.0

ENTER THE BEAMS OF THE SEVEN SUPERSTRUCTURE LEVELS (IF NOT PRESENT ENTER ZERO)
30.0,43.0,36.0,28.0,0.0,0.0,0.0
```

FIGURE 3

Sample Execution of Subroutine READDATA (Con't)

```
ENTER THE OFFICER MANNING & ACCOMMODATIONS,
THE CPO MANNING & ACCOMMODATIONS,
AND THE CREW MANNING & ACCOMMODATIONS.
18.0,19.0,2.0,2.0,14.0,15.0

ENTER THE MARINE MANNING & ACCOMODATIONS,
TROOP MANNING & ACCOMODATIONS,
AND THE AIRWING MANNING & ACCOMODATIONS.
0.0,0.0,0.0,0.0,0.0,0.0

DO YOU WANT TO KEEP THE INPUT DATA IN A FILE FOR FUTURE USE? YES

UNDER WHAT FILE NAME DO YOU WANT TO KEEP THIS DATA? TAGOSTEST
```

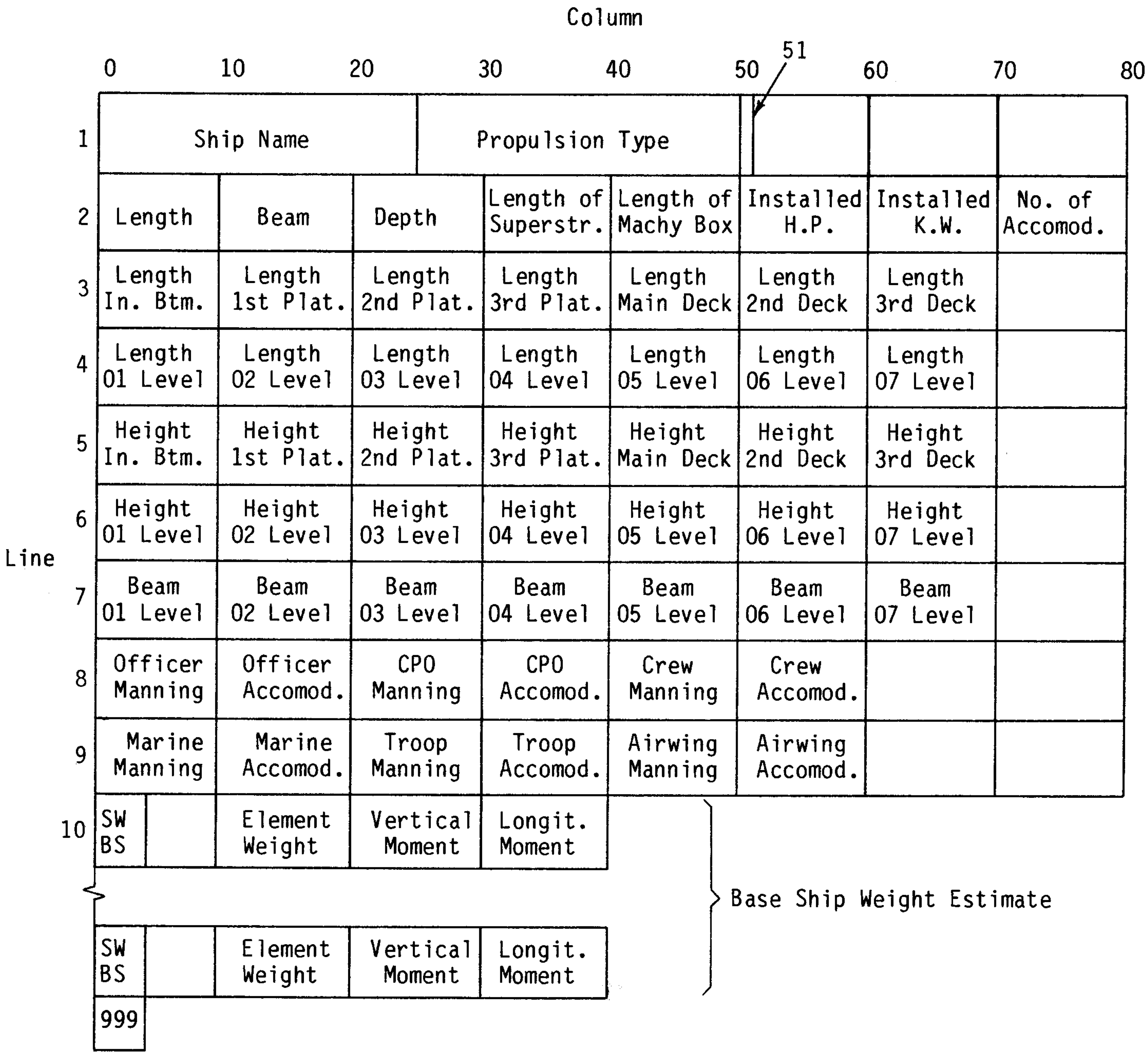
the input of data for the new ship is shown in Figure 4 which is the format for the new ship input data file. After the input of the new ship data has been completed, the program moves to the input of the base ship data.

The second data input subroutine is READBASE which is the subroutine which inputs the base ship data into the program. The required base ship data for the program is much greater than that for the new ship. In addition to the ship characteristics like those required for the new ship, the base ship also requires a complete three-digit SWBS weight estimate with centers to be input. Since all of this information would be too cumbersome to be entered at the terminal during execution of the program it can only be read from a prepared file. In the current operating system for the program there is a library of base ship data files from which the most suitable parent can be selected using the READBASE subroutine.

The required data for the base ship which must be contained in the base ship data file includes the following: ship size and geometry, propulsion plant size, electrical plant size, the accommodations and manning, and the three-digit weight report. The ship data is stored in the file in an identical format to that of the new ship data file. Following this data is the three digit weight summary. It is redundant to store both the center of gravities plus their corresponding moments since one can be derived from the other using the weight. Therefore it was decided that the majority of the moments used in ship weight estimates which are rounded to the nearest whole number contain more significant digits than the centers which are rounded to two decimal places. Consequently, only the vertical and longitudinal moments from the weight estimate are used in the base ship data file. For smaller ships and smaller SWBS elements this method of using the moments is less accurate especially in determining the centers for the individual SWBS elements. These errors should not result in any error in the final ship center of gravity since the final moments should be greater than four significant digits. If the centers were used then there would be inaccuracies in the larger weight groups which would cause errors in the total centers. The sample format for the base ship data file is contained in Figure 5.

In order to aid the engineer in the selection of the best availible base ship from the library, READBASE gives a listing of all of the available base ships and gives him the opportunity to examine the basic ship characteristics of any of the available base ships to aid in the selection of the most appropriate base ship. While this brief look at the base ship characteristics is helpful, it is also desirable to have additional knowledge about the base ship configuration to aid in the selection of the base ship and also to note any differences between the two configurations which may cause errors in the new ship estimate. Figure 6 is a sample listing demonstrating the operation of the READBASE subroutine.

Once a base ship is selected the three-digit weights and moments are read into a 800 x 3 array within the program. The first subscript being the SWBS element and the second subscript identifying it as a weight (subscript=1), vertical moment (subscript=2), and longitudinal moment (subscript=3). For example, the vertical moment for SWBS 555 is stored in



Line	0	10	20	30	40	50	60	70
1	Ship Name		Propulsion Type					
2	Length	Beam	Depth	Length of Superstr.	Length of Machy Box	Installed H.P.	Installed K.W.	No. of Accomod.
3	Length In. Btm.	Length 1st Plat.	Length 2nd Plat.	Length 3rd Plat.	Length Main Deck	Length 2nd Deck	Length 3rd Deck	
4	Length 01 Level	Length 02 Level	Length 03 Level	Length 04 Level	Length 05 Level	Length 06 Level	Length 07 Level	
5	Height In. Btm.	Height 1st Plat.	Height 2nd Plat.	Height 3rd Plat.	Height Main Deck	Height 2nd Deck	Height 3rd Deck	
6	Height 01 Level	Height 02 Level	Height 03 Level	Height 04 Level	Height 05 Level	Height 06 Level	Height 07 Level	
7	Beam 01 Level	Beam 02 Level	Beam 03 Level	Beam 04 Level	Beam 05 Level	Beam 06 Level	Beam 07 Level	
8	Officer Manning	Officer Accomod.	CPO Manning	CPO Accomod.	Crew Manning	Crew Accomod.		
9	Marine Manning	Marine Accomod.	Troop Manning	Troop Accomod.	Airwing Manning	Airwing Accomod.		
10	SW BS	Element Weight	Vertical Moment	Longit. Moment				
	SW BS	Element Weight	Vertical Moment	Longit. Moment				
	999							

Figure 4

SAMPLE FORMAT FOR BASE SHIP DATA FILE

Column

Line	0	10	20	30	40	50	60	70
1	Ship Name			Propulsion Type		51 Simple or Detailed Indicator (0 or 1)		
2	Length	Beam	Depth	Length of Superstr.	Length of Machy Box	Installed H.P.	Installed K.W.	No. of Accomod.
3	Length In. Btm.	Length 1st Plat.	Length 2nd Plat.	Length 3rd Plat.	Length Main Deck	Length 2nd Deck	Length 3rd Deck	
4	Length 01 Level	Length 02 Level	Length 03 Level	Length 04 Level	Length 05 Level	Length 06 Level	Length 07 Level	
5	Height In. Btm.	Height 1st Plat.	Height 2nd Plat.	Height 3rd Plat.	Height Main Deck	Height 2nd Deck	Height 3rd Deck	
6	Height 01 Level	Height 02 Level	Height 03 Level	Height 04 Level	Height 05 Level	Height 06 Level	Height 07 Level	
7	Beam 01 Level	Beam 02 Level	Beam 03 Level	Beam 04 Level	Beam 05 Level	Beam 06 Level	Beam 07 Level	
8	Officer Manning	Officer Accomod.	CPO Manning	CPO Accomod.	Crew Manning	Crew Accomod.		
9	Marine Manning	Marine Accomod.	Troop Manning	Troop Accomod.	Airwing Manning	Airwing Accomod.		
10	Weight Margin	KG Margin						

Column

Figure 5

SAMPLE FORMAT FOR NEW SHIP DATA FILE

FIGURE 6

Sample Execution of Subroutine READBASE

```
THE FOLLOWING BASE SHIPS ARE CURRENTLY AVAILABLE:


   -PCG-612 QUARTERLY 13 (FILE NAME- PCG612)

   -LSD-43 (BASED ON LSD-41 QUARTERLY 8) (FILE NAME- LSD43)

   -T-AGOS 1  QUARTERLY 7 (FILE NAME- TAGOS)



DO YOU WANT MORE INFORMATION ON ANY OF THESE SHIPS
BEFORE YOU SELECT A BASE SHIP?  YES


ABOUT WHICH BASE SHIP DO YOU DESIRE MORE INFORMATION?
(ENTER THE FILE NAME)-  TAGOS


T-AGOS-1  (QUARTERLY 7)
------------------------
PROPULSION TYPE-      DIESEL/ELECTRIC
LENGTH-                   204.00 FT.
BEAM-                      43.00 FT.
DEPTH-                     20.00 FT.
INSTALLED HORSEPOWER-    1600.00 HP.
INSTALLED KW-            2400.00 KW.
NO. OF ACCOMMODATIONS-     30.00

DO YOU WANT INFORMATION ABOUT ANOTHER SHIP?   NO


ENTER BASESHIP FILE NAME - TAGOS
```

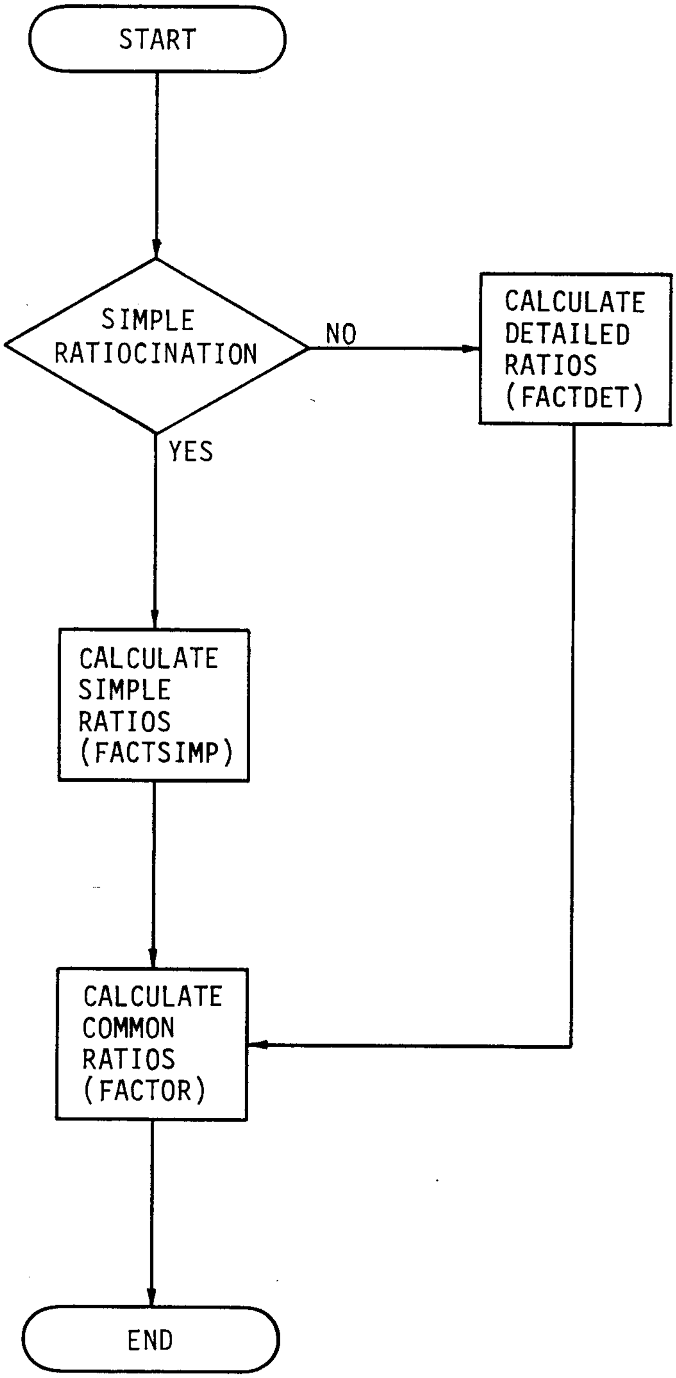


FIGURE 7
FLOW CHART FOR CALCULATION OF PARAMETRIC RATIOS

TABLE 1

Required Parameters for Ratiocination Using the RATS Program

PARAMETER	SIMPLE	DETAILED
Length	X	X
Beam	X	X
Depth	X	X
Length of Superstructure	X	
Length of Machinery Box	X	
Installed Horsepower	X	X
Installed Kilowatts	X	X
Length of Inner Bottom		X
Lengths of All Platforms		X
Lengths of All Hull Decks		X
Lengths of All Superstructure Levels		X
Height of Inner Bottom		X
Heights of All Platforms		X
Heights of All Hull Decks		X
Heights of All Superstructure Levels		X
Total Accommodations	X	
Crew Manning/Accommodations		X
CPO Manning/Accommodations		X
Officer Manning/Accommodations		X
Marine Manning/Accommodations		X
Troop Manning/Accommodations		X
Airwing Manning/Accomodations		X

element (555,2) of the array. This complete array becomes the basis for the calculation of the new ship estimate.

Calculation of Parametric Ratios

The next major function of the program after all of the new ship and base ship data has been entered is to calculate all of the parametric ratios which will be used in the determination of the new ship weights. Figure 7 is a flow chart of the process by which this is done within the program. There are three subroutines that perform this function; FACTOR, FACTSIMP, and FACTDET.

There are two options within this program for the type of ratiocination to be used. The first is called "simple ratiocination" and the second "detailed ratiocination". "Simple ratiocination" is to be used when a very preliminary estimate is needed and there is very little information about the new ship available other than the principal characteristics. In this case some fairly crude factors are used to generate the estimate. FACTSIMP is the routine which calculates these parameters for the "simple ratiocination". FACTSIMP uses only the length, beam, depth, length of machinery box, length of superstructure, installed horsepower, installed kilowatts, and the number of accommodations to calculate the entire weight estimate. While this does produce a fairly crude and potentially inaccurate estimate it is very useful when more detailed information is unavailable.

FACTDET is the routine which is used to calculate the factors to be used for the "detailed ratiocination" which is the more common form of ratiocination normally used in the Feasibility levels of design. It requires that some sort of preliminary arrangement drawing be available from which to obtain details of the ship geometry. Also, a more detailed break-down of the ship's manning and accommodations are required. This routine breaks down the ship characteristics to as much detail as is practicable given the required universitality of a general program of this type and also the level of detail that is generally available during the Feasiblity level of design.

The third subroutine used to determine parametric ratios is FACTOR which is used to calculate those ratios which are common to both the "simple" and the "detailed" ratiocination.

Table 1 contains a summary of the characteristics required of both the new ship and the base ship in order to carry out each of the two types of ratiocination. The actual parametric ratios used to calculate the weights within the RATS program are contained in Appendix A. For clarity in the description of the various ratios used in this paper, the following convention will be used in their description: A ratio such as;

$$\frac{(\text{Length x Beam})_{\text{New Ship}}}{(\text{Length x Beam})_{\text{Base Ship}}}$$

will be simply referred to as LB. All ratios of new ship to base ship will be referred to simply as the characteristics used in the ratio.

Weight Calculation

Once the parametric ratios have been calculated the actual weights for the various three digit elements are calculated. This is done in eight subroutines which are named GRP1WT through GRP7WT plus LOADWT. Each of these routines calculates the weights for all of the elements within the respective SWBS group. The format for these routines is straightforward in that there is an equation for the weight of each element which is simply the base ship weight multiplied by the appropriate parametric ratio which was calculated in the earlier subroutines. If the base ship weight element does not exist (has zero weight) then the new ship element also has zero weight. Only those groups and elements which have a weight will be printed out in the output part of the program.

The actual parametric equations used to determine the weight for the various elements are contained in Appendix A. While these are the parametric ratios currently in use in the program, they are easily changed or modified if analysis indicates that there is some other or more appropriate set of parameters. The majority of these current parameters have been taken from Reference (2) with the remaining groups taken from various sources including Reference (1).

It should be noted that in some instances it is virtually impossible to provide a parametric ratio for some elements which is universal enough to allow it to be applied to all ship types. For example, many of the elements which are related to the payload of the ship and are contained in Groups 4 and 7 are not really a function of ship parameters, but rather the ship's mission requirements. For these elements the new ship weight remains the same as the base ship weight. If the mission of the new ship is similar to the base ship, then this type of calculaltion should be reasonably accurate. If there are different mission requirements, then each of the groups relating to the mission must be examined and revised by using the modification portion of the program. This aspect of retaining a constant payload is very useful when performing a sensitivity analysis of a given design to a single ship parameter which does not affect the payload.

Should the new design require a modified or different payload in any of the elements that are normally held constant, those modifications must be determined prior to the use of the program. The program has the capability to accept modifications to any group, and these modifications to the payload will be input in this way in order to provide accurate weights. A detailed discussion of the methodology for the various payload modifications is contained in the section of this paper entitled "Estimate Modification".

As the various element weights are calculated within these routines, they are stored in an array which is similar in format to the array which contains the base ship estimate. This 800 x 3 array contains the weight for the various elements with the SWBS number being the first subscript and "1" being the second. For example, the weight of SWBS 221 is stored in the position (221,1) within the array. This way there are always two parallel arrays, one containing the base ship weight and one containing the corresponding new ship element weight.

Vertical Center of Gravity Calculation

Calculation of the Vertical Center of Gravity (VCG) for each element is not as straightforward as that for the weights. The center of gravity is not as readily a function of the general ship characteristics or geometry as the element weight. The VCG is a function of the specific new ship configuration and is therefore difficult to express in terms of the general ship characteristics in most cases. For example, it may be very easy to say that the weight of the Officer Living element (SWBS 641) is a function of the number of officer accommodations on the ship, but the vertical center of gravity for that element is a function of where the officer accommodations have been located within the ship. This location may vary greatly depending upon the type of ship and even from one ship configuration to another. For hand calculations the engineer has the ability to examine the general arrangement drawings, if they exist, in order to estimate the VCG. The program however, does not have the ability to examine the drawings.

It is necessary for the program to find a universal method for determining the VCG's for the various elements that is applicable to all ship types, yet one that yields a reasonably accurate estimate. The VCG calculation routines within the RATS program assume that the base ship selected has a similar configuration to that of the new ship. Consequently the VCG for the new ship element is assumed to be the same percentage of the depth as the VCG for the same element on the base ship. This is done for all elements whose location cannot be correlated to some general ship characteristic.

There are, however, elements which can be correlated to some general ship characteristic. The best examples of this are the VCG's of the various decks, platforms, and superstructure levels. In these cases the VCG's for these elements is assumed to be the same height above or below the new ship deck height as the same element on the base ship was above or below its respective deck height. This is very accurate for the hull decks and platforms, but loses some accuracy for the superstructure levels since both the deck and the house sides are included in the element. Once again the closeness of the base ship to the new ship in the superstructure configuration and the deck heights within the superstructure impacts the accuracy of this calculation. Also, many of the elements of the propulsion plant and the electrical plant are not so much a function of the depth of the ship as they are of the height of the inner bottom, since it forms the lower boundary of the machinery spaces which suports much of this equipment. Therefore the VCG's for many of the elements in SWBS groups 2 and 3 are taken to the same height above the inner bottom as the same element in the base ship.

While this method of determining the VCG's for the various elements can lead to gross inaccuracies if the new ship configuration differs greatly from the base ship, it is felt to be the best way to estimate these centers and remain applicable to all ship types. Knowing the method used to determine these VCG's will allow the engineer to review those elements which have been relocated from the base ship and determine that the program has incorrectly estimated the center. If this happens, then the engineer can once again use the Modify portion of the program to input the correct VCG. This Modify portion of the program is discussed in detail in the section entitled "Estimate Modification".

Within the program the VCG's are calculated by a series of subroutines named GRP1VCG through GRP7VCG plus LOADVCG. These subroutines determine the VCG's for all the elements within the respective SWBS group. Each routine simply contains a series of equations for each element which calculates the new VCG whether it be as a function of the depth of one of the other methods. Since the program works with moments rather than with the centers themselves, the output of these routines is a moment for each of the elements. The moments are stored in the same array as the element weights with the first subscript again being the element number and the second subscript being "2". As an example, the vertical moment for element 644 is stored in the (644,2) location within the array.

Longitudinal Center of Gravity Calculation

The same problems that affected the calculation of the VCG's also apply to the calculation of the LCG's for the various elements. Even more so than the VCG's, the LCG's are a function of the ship configuration rather than the general ship characteristics. Very little can be said about the LCG for a given element which is applicable to all ship types, therefore a very general method must be used to calculate the LCG's. Again, it is desirable for the new ship to be similar in configuration to the base ship so the specific arrangement of the base ship can be used to determine the centers for the new ship. Once the assumption of similar configuration between the two ships has been made, the calculation of the LCG's for the various SWBS elements becomes simple. All of the LCG's are simply taken as a percentage of the ship length. The new ship LCG for a given element is calculated to be the same percentage of the ship length as the same element on the base ship.

This type of method of calculation for the LCG's may not be very accurate for many of the groups, but it is felt to be adequate as a starting point for an estimate at the Feasibility level design. First of all, the LCG is the least important center considered by the program. While the weight and VCG are important in ship sizing, cost and stabilty; the LCG contributes only to the trim which can be readily adjusted through modifications to the liquid loading and the location of the LCB as the design becomes more defined. As long as the calculated trim is not extremely excessive at these early design phases there is not a significant problem introduced into the design. Therefore it is not imperative that a very accurate LCG be calculated early in the design. An approximate LCG should suffice to make a preliminary assessment of the trim. Where possible, efforts should be made to make the calculation of the LCG as accurate as possible, however. Therefore, like the weight and VCG, it is possible to adjust any element LCG calculated by the program which does not conform to the new ship configuration. Once again the "modify" portion of the program is used to make these adjustments. Refer to the section entitled "Program Modification" for a detailed discussion of this process.

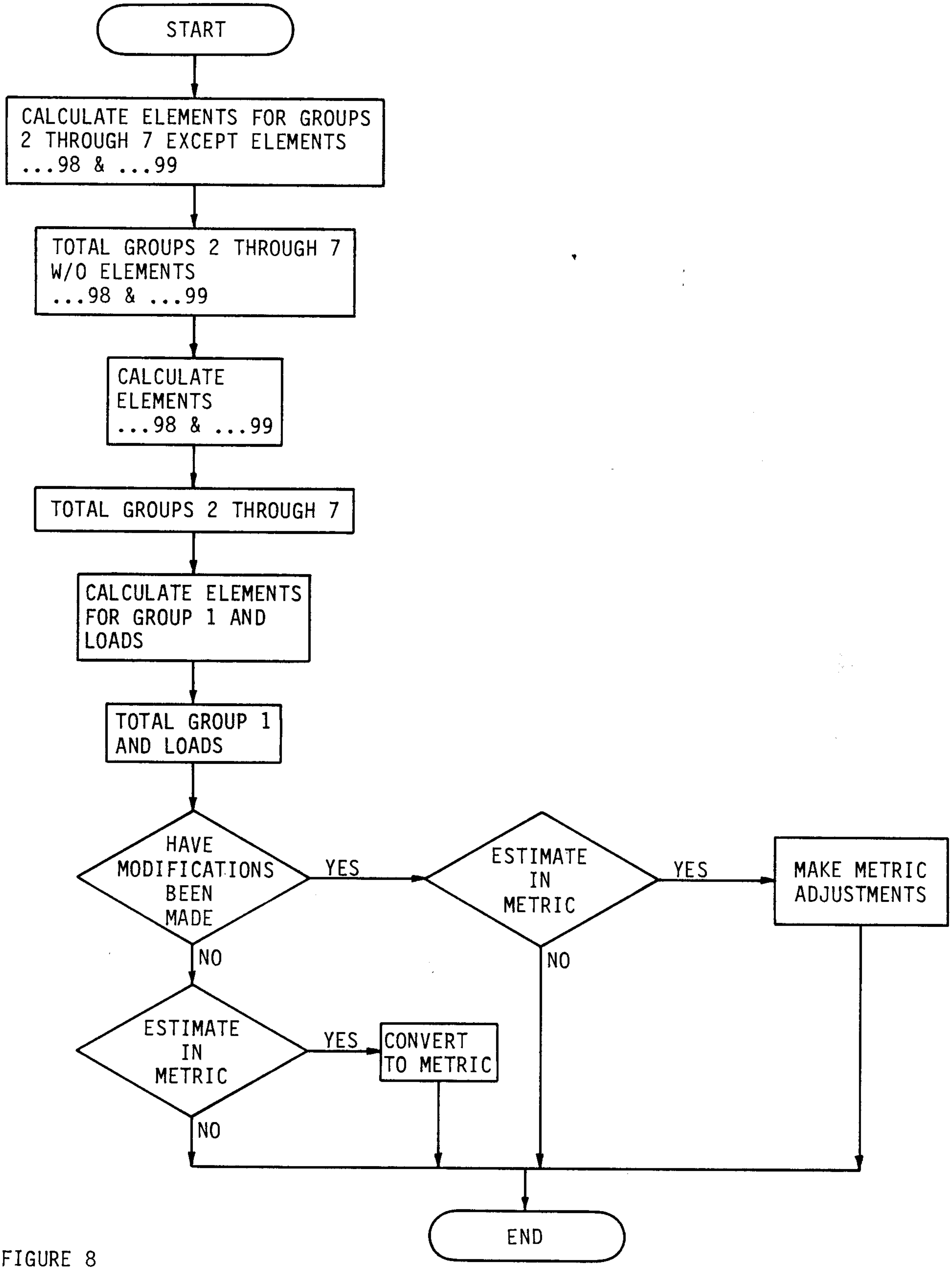


FIGURE 8
FLOW CHART FOR GROUP SUMMATION

Due to the simplicity of the method of calculation for the LCG's, only one subroutine is used to calculate the LCG's for all of the elements for all seven SWBS groups plus the loads. This subroutine, LONGITUDINAL, consists of one equation which sets the LCG as a percentage of the ship length which is then repeated through a "DO" for all possible elements. In reality this subroutine does not determine the LCG itself, but it creates the longitudinal moment for each element which completes the array used to store the new ship estimate. These longitudinal moments occupy the location identified by "3" as the second ordinate with the element number occupying the first position. For example, the longitudinal moment for element 311 is stored in position (311,3).

The situation regarding the transverse centers of gravity is similar to that of the LCG's in that it is difficult to express them in terms of ship characteristics in a gerneral way. The TCG is also a characteristic of the ship which is really not required to be known in the early design phases. It is even more subtle than the LCG in its impact to the design and it is almost impossible to calculate since detailed arrangements are required as a minimum to make an accurate assessment. In light of these facts it was felt that any TCG's calculated by the computer would have little meaning to the design so it was decided that they be omitted from the program. Consequently, the program only calculates the weight and the vertical and longitudinal centers.

Group Summation

Some SWBS elements are calculated as a percentage of the group total. In Groups 2 through 7 the Operating Fluids and the Repair Parts and Tools are determined as a percentage of their respective group. In Group 1 all of the foundation elements are a function of their corresponding one digit group while the Welding and Mill Tolerence is a function of the Group 1 steel total. In order to determine these element weights the various groups must be totaled.

There are two subroutines which perform the summation function within the program. The first is TOTAL27 which totals Groups 2 through 7 and the second is TOTALGR1 which totals Group 1 plus the loads. The flow chart for these two subroutines is shown in Figure 8. TOTAL27 is the first routine to be utilized. It is called upon completion of the calculation of all of the elements for Groups 2 through 7. It sums all of the elements for each group, calculates the Operating Fluids and the Repair Parts and Tools for each group based on these totals, and then totals the entire completed group. After this has been completed all of the elements for Group 1 are calculated including the foundations which use the group totals from TOTAL27. The exceptions are the Welding and Mill Tolerence and the Repair Parts and Tools which are not yet calculated. TOTALGR2 is then called which totals group one and calculates these last two elements which are a function of the Group 1 total. The final part of the execution of TOTALGR1 is to total the loads.

Once all of the groups have been summed the program moves to the modification portion. After all modifications have been made, execution of the

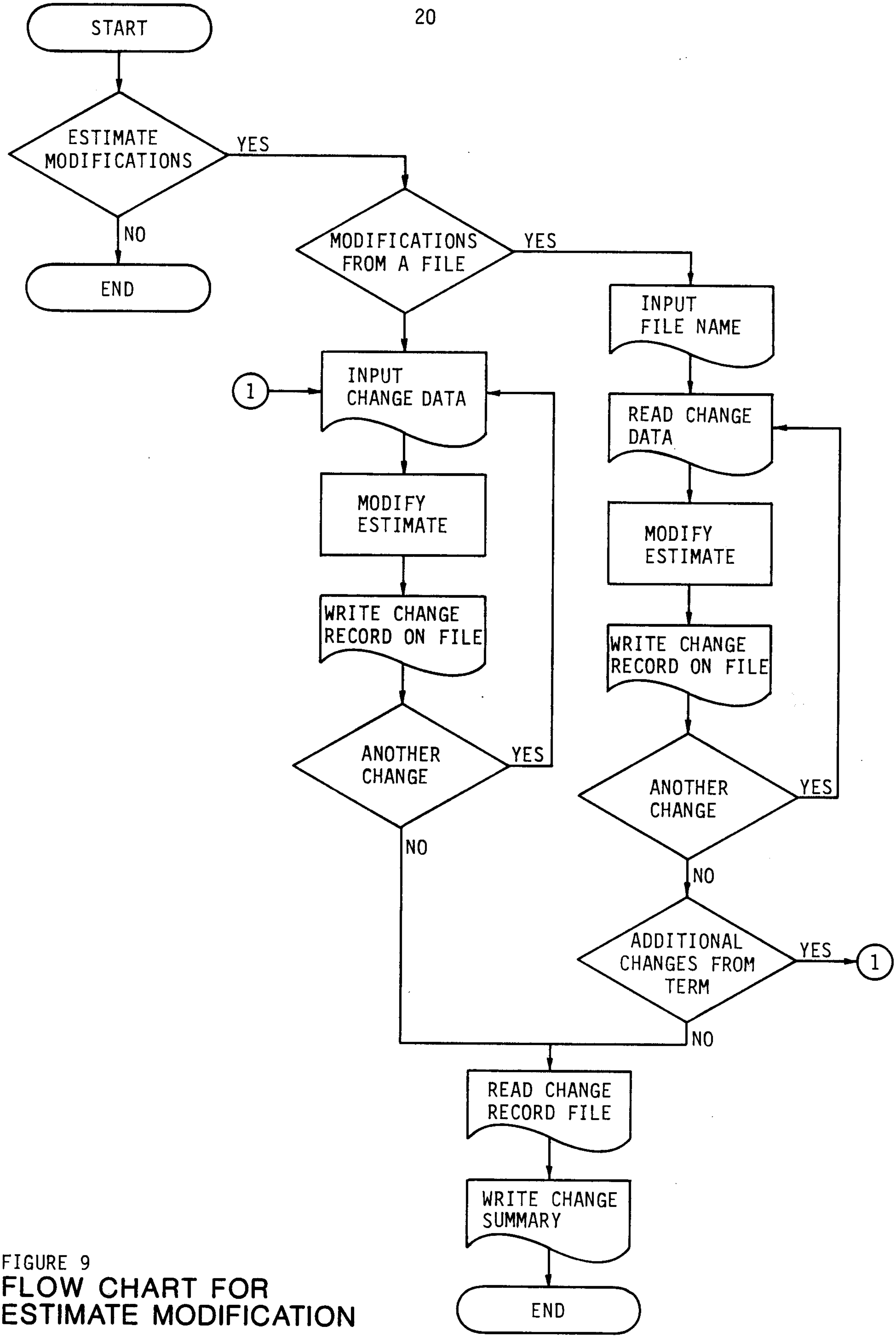


FIGURE 9
FLOW CHART FOR ESTIMATE MODIFICATION

program returns to TOTAL27 and TOTALGR2 to recalculate and retotal all of the groups.

Estimate Modification

If the new ship configuration and mission requirments are identical to the base ship, then the estimate generated by the program is as accurate as can be expected in the early design phases. Rarely is this the case, however, since in reality no two ship designs are identical in configuration and mission. This means that the estimate generated by the program using the paramentric formulas for the weights and centers will have some inaccuracies. The extent of these inaccuracies depends on how close the new ship resembles the base ship. A cursory review of the two designs with the knowledge of how the program calculated the new ship weights and centers should identify those soft spots where the computer generated estimate lacks the accuracy which is attainable at the early stages of the design. For example, if the base ship has a helicopter facility but the new ship does not the weight will still be carried in the new ship estimate because the program assumes identical configuration and mission as the base ship. It is necessary to be able to modify the estimate generated by "pure ratiocination" in the program. This is done through the Estimate Modification portion of the program.

Once the initial estimate has been calculated by "pure ratiocination", the program moves to the Estimate Modification portion which consists of three subroutines: CHANGE, CHANGEFILE and PRINTCHANGE. The interaction of these three files for estimate modification is shown in the flow chart for the Estimate Modification portion of the program in Figure 9. It can be seen that changes can be made to the initial estimate either from the terminal or a prepared file or both. Subroutine CHANGEFILE makes the changes from a prepared file, while subroutine CHANGE accepts modifications only from the operator at the terminal. If one elects to make the modifications from a file, the opportunity is given to make additional changes from the terminal; but changes cannot be made from a file after inputing modifications from the terminal. Since there may be a large number of modifications required for a new design which may have to be used for several runs of the program as the design progresses, those changes which are input from the terminal may also be saved in a file to be used for future runs of the program. In this way a file of changes can be maintained for the design which will be used every time the program is run. This file will contain changes like deleting the helicopter facility which was carried over from the base ship which will be done for every run of the program. As the design progresses the modification file can be appended to include the design development modifications.

The estimate created by the program is stored in an 800 x 3 array, so the modification subroutines, CHANGE and CHANGEFILE, make modifications to that array. All modifications are made to the estimate at the element level within the program. There are five types of changes which can be made to the estimate stored in the array. Each type of change will be discussed in the following:

1) Percentage- This type of change modifies the weight by a percentage. For example, it may be necessary to modify an element by reducing it by 50%. This allows this to be done by simply inputing the element number and the percentage to be used. The input percentage should be input as a whole number rather than a decimal (50. rather than .50). It should be noted also that the centers remain unchanged by this type of modification. The element weight will be reduced by 50% and the moments also will be reduced by 50% resulting in no change to the element's centers.

2) Replacement- This type of change replaces the element weight or centers calculated by the program with any value the engineer would like. For example, if the actual weight of an element is known, that weight could be substituted for the one calculated by the program, either retaining the centers determined by the program of replacing one or both of them with centers determined by the engineer. This type change can also be used simply to correct the centers for an element. Since the centers are subject to error due to differences from the base ship configuration, this type of change is extremely useful in this respect. For the replacement type change the element number and the replacement weight and centers are input. Should either the weight or centers calculated by the program wish to be retained, then "-1" should be entered as the replacement value.

3) Additive- The additive type modification is used to add or delete a known weight from the element calculated by the program. An example of this type of modification would be in the case of a base ship which carries a single helicopter and a new design which carries two. If the weight of the helicopter is known then it could be added to the new ship which would only have the weight of the single helicopter from the base ship estimate. This type of modification requires the element and the added weight with its center to be input. If the input weight is negative then the weight is removed. Should the added weight wish to be added at the center of the element as calculated by the computer, then "-1" should be entered for the center which causes the element center to be substituted. Of course, if an addition or deletion is made with this type modification at a center other than the calculated element center, then the new element center will be recalculated.

4) Deletion - In order to prepare an accurate new ship estimate, it may be required to delete some elements which were carried over from the base ship which do not apply to the new ship. This type of modification is done with the deletion type change. For example, if the base ship has a helicopter and the new does not, a weight will be carried in the new ship for a helicopter which must be deleted with this type of modifica-

tion. The only input required for this modification is the element number. In order to avoid accidental deletion of an element when changes are being made from a terminal, the user will be asked when attempting to delete an element if he really does wish to delete the identified element. Only an affirmative answer to this question will result in the deletion of the identified element.

5) New Group - There may also be cases when the new ship has some characteristic or feature which was not present on the base ship which means that there is no weight in the new ship for that feature. The new group modification allows a new group to be added to account for these unique features of the new design. For the case of a base ship without a helicopter and a new ship with one, it can be added to the new ship estimate with this type modification. The input required is the element number and the element weight and centers.

There is one other noteworthy aspect common to all of these modifications. That is that every time a modification is made a reason must be entered for that change. This reason for change may be up to fifty characters in length and is extremely useful in documenting the final new ship estimate and how it differs from the "pure ratiocination" carried out by the program. This documentation of the modifications is executed by the third subroutine of the Estimate Modification portion of the program, PRINTCHANGE. PRINTCHANGE creates a record of all of the changes made to the initial estimate calculated by the program and places this record in a file which can be printed if a written record is desired. For each element modified this file contains a record of the original element estimate calculated by the program, the new element estimate after the modifications have been made, and finally and most importantly the reason for the modification. The program places this record of changes in a file named CHNGSUM which may be accessed or printed as desired.

A sample output which demonstrates the use of the CHANGE subroutine in making changes from the terminal is contained in Figure 10. A sample listing of the file containing these same modifications to be used by the CHANGEFILE subroutine is shown in Figure 11. The file CHNGSUM which summarizes the modifications shown in Figures 10 and 11 is contained in Appendix C.

It is the ability of the program to allow modification of the estimate which makes it a viable engineering tool. To blindly follow the equations of the program wihout examining the results and correcting the inaccuracies which result from the general nature of this program would be extremely dangerous. This is especially true in light of the fact that this estimate will be used to determine whether the design is feasible and should be continued. It is the responsibility of every engineer who uses this program to understand the methodology used to calculate the weights and centers and to examine the estimate in light of the method and make the required modifications to the estimate so that it reflects the actual ship it is produced for to the greatest extent possible.

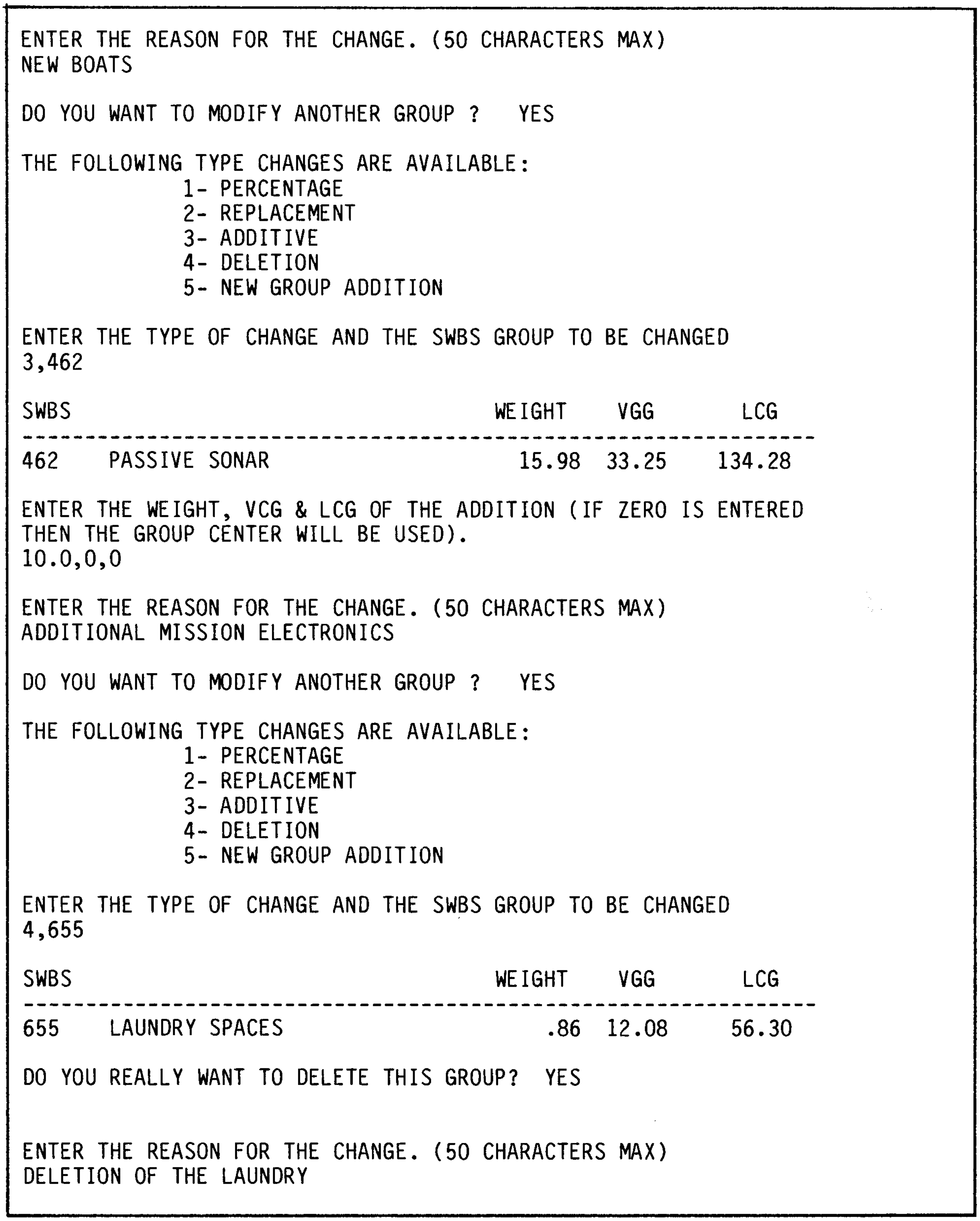
FIGURE 10

Sample Execution of CHANGE Subroutine

```
A WEIGHT ESTIMATE HAS BEEN PREPARED USING PURE
RATIOCINATION FROM T-AGOS-1  (QUARTERLY 7)
DO YOU WISH TO MODIFY, DELETE, OR ADD ANY THREE DIGIT GROUP
FOR ANY SPECIAL ASPECTS OF THE T-AGOS TEST?  YES

DO YOU WANT THE CHANGES READ FROM A FILE?  NO

DO YOU WANT TO SAVE THE CHANGES IN A FILE SO THAT THEY MAY BE USED AGAIN?  YES

ENTER THE FILE NAME FOR THE CHANGES  TESTCHNG

THE FOLLOWING TYPE CHANGES ARE AVAILABLE:
             1- PERCENTAGE
             2- REPLACEMENT
             3- ADDITIVE
             4- DELETION
             5- NEW GROUP ADDITION

ENTER THE TYPE OF CHANGE AND THE SWBS GROUP TO BE CHANGED
1,041

SWBS                                  WEIGHT    VGG       LCG
----------------------------------------------------------------
F41    DIESEL FUEL                     709.26  10.64    105.78

ENTER THE PERCENTAGE TO BE USED (95% = 95).  110.0

ENTER THE REASON FOR THE CHANGE. (50 CHARACTERS MAX)
INCREASED ENDURANCE FUEL REQ'TS

DO YOU WANT TO MODIFY ANOTHER GROUP ?   YES

THE FOLLOWING TYPE CHANGES ARE AVAILABLE:
             1- PERCENTAGE
             2- REPLACEMENT
             3- ADDITIVE
             4- DELETION
             5- NEW GROUP ADDITION

ENTER THE TYPE OF CHANGE AND THE SWBS GROUP TO BE CHANGED
2,583

SWBS                                  WEIGHT    VGG       LCG
----------------------------------------------------------------
583    BOATS & BOAT HNDLG SYS            1.80  42.27    129.94

ENTER THE NEW WEIGHT, VCG & LCG. (IF NO CHANGE ENTER -1)
2.75,-1,-1
```

FIGURE 10

Sample Execution of CHANGE Subroutine (Con't)



```
ENTER THE REASON FOR THE CHANGE. (50 CHARACTERS MAX)
NEW BOATS

DO YOU WANT TO MODIFY ANOTHER GROUP ?   YES

THE FOLLOWING TYPE CHANGES ARE AVAILABLE:
             1- PERCENTAGE
             2- REPLACEMENT
             3- ADDITIVE
             4- DELETION
             5- NEW GROUP ADDITION

ENTER THE TYPE OF CHANGE AND THE SWBS GROUP TO BE CHANGED
3,462

SWBS                                  WEIGHT    VGG       LCG
----------------------------------------------------------------
462    PASSIVE SONAR                    15.98  33.25    134.28

ENTER THE WEIGHT, VCG & LCG OF THE ADDITION (IF ZERO IS ENTERED
THEN THE GROUP CENTER WILL BE USED).
10.0,0,0

ENTER THE REASON FOR THE CHANGE. (50 CHARACTERS MAX)
ADDITIONAL MISSION ELECTRONICS

DO YOU WANT TO MODIFY ANOTHER GROUP ?   YES

THE FOLLOWING TYPE CHANGES ARE AVAILABLE:
             1- PERCENTAGE
             2- REPLACEMENT
             3- ADDITIVE
             4- DELETION
             5- NEW GROUP ADDITION

ENTER THE TYPE OF CHANGE AND THE SWBS GROUP TO BE CHANGED
4,655

SWBS                                  WEIGHT    VGG       LCG
----------------------------------------------------------------
655    LAUNDRY SPACES                     .86  12.08     56.30

DO YOU REALLY WANT TO DELETE THIS GROUP?  YES


ENTER THE REASON FOR THE CHANGE. (50 CHARACTERS MAX)
DELETION OF THE LAUNDRY
```

FIGURE 10

Sample Execution of CHANGE Subroutine (Con't)

```
DO YOU WANT TO MODIFY ANOTHER GROUP ?   YES

THE FOLLOWING TYPE CHANGES ARE AVAILABLE:
             1- PERCENTAGE
             2- REPLACEMENT
             3- ADDITIVE
             4- DELETION
             5- NEW GROUP ADDITION

ENTER THE TYPE OF CHANGE AND THE SWBS GROUP TO BE CHANGED
5,573

ENTER THE NEW GROUP WEIGHT, VCG, AND LCG IN L. TONS AND FEET
2.5,37,115.0

ENTER THE REASON FOR THE CHANGE. (50 CHARACTERS MAX)
ADDITION OF CRANE

DO YOU WANT TO MODIFY ANOTHER GROUP ?   N

THE WEIGHT ESTIMATE HAS BEEN PLACED IN THE FILE "NEWEST"
AND THE CHANGE FILE (IF CREATED) IS IN FILE "CHNGSUM"
```

FIGURE 11

SAMPLE LISTING OF MODIFICATION FILE

```
1   41     110.00                    INCREASED ENDURANCE FUEL REQ'TS

2  583       2.75     -1.00     -1.00NEW BOATS

3  462      10.00       .00       .00ADDITIONAL MISSION ELECTRONICS

4  655                               DELETION OF THE LAUNDRY

5  573       2.50     37.00    110.00ADDITION OF CRANE

9
```

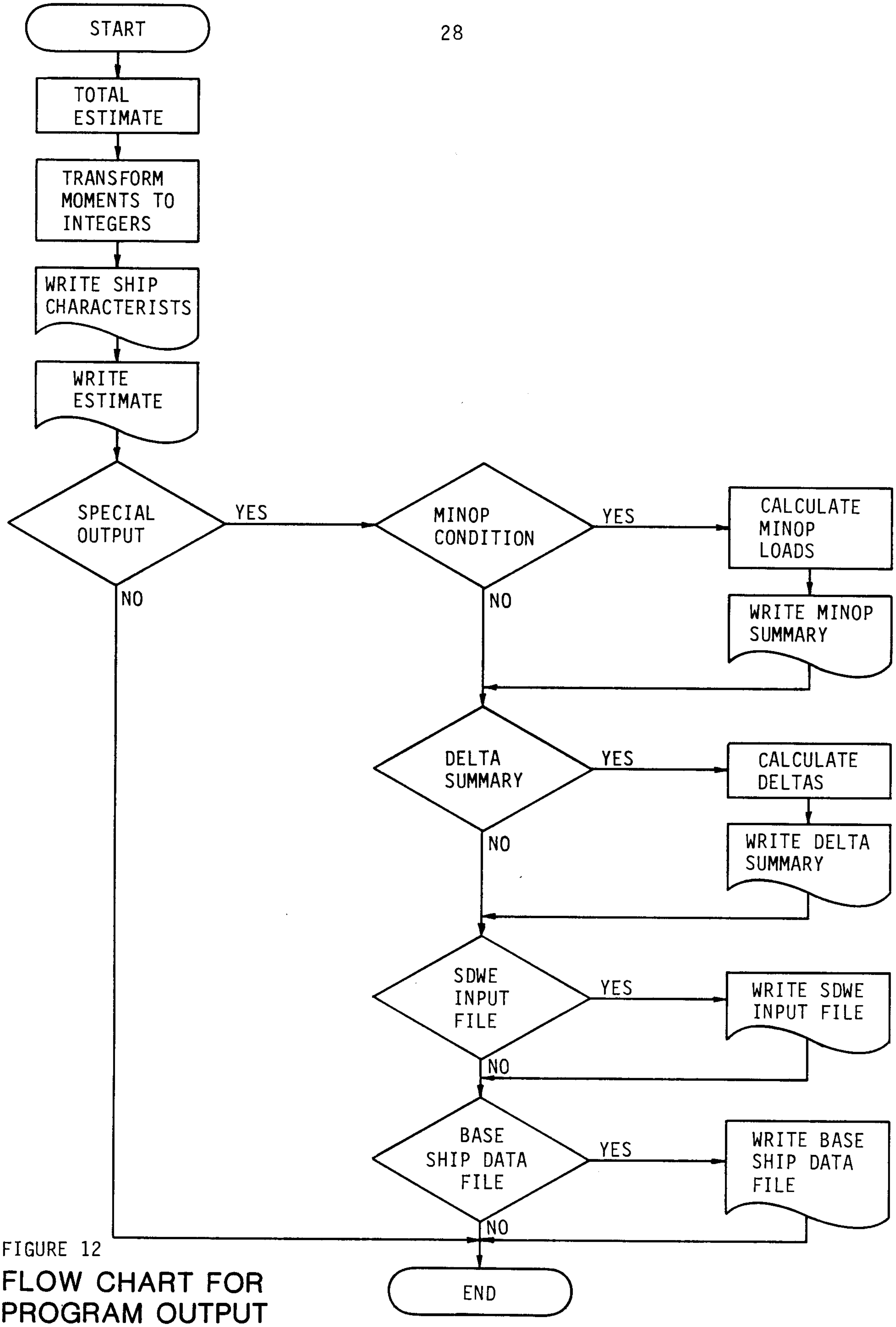


FIGURE 12

FLOW CHART FOR PROGRAM OUTPUT

Output

Following the completion of all of the modifications to the estimate it is time to print the results. This is done through the use of two subroutines, PRINTWT and SPECIALOUT. PRINTWT is the subroutine which actually creates and prints out the final estimate while SPECIALOUT, which is called from PRINTWT, is used to produce some special output options of the data generated by the program. The flow chart for the complete program output produced by these two subroutines is shown in Figure 12.

The first step in the output process is to total the final estimate. While the previous routines TOTAL27 and TOTALGRP1 totaled the one digit groups, they did not total the rest of the estimate. The first portion of the PRINTWT subroutine totals the lightship, calculates the margins, and then totals the full load condition. Once everything has been totaled, all of the moments are transformed into integer variables with the appropriate roundoff taken into account. This is done to clean up the final printed output. All moments are always rounded to nearest whole number but if they are left as truncated real variables the decimal point will still be printed. Elimination of the decimal point through the transformation to integer variables not only improves the appearance of the printed estimate but allows the estimate to be printed two columns narrower which is significant as will be seen later.

After the estimate has been totaled and the moments transformed to integers, the estimate is ready for printing. Since the program is an interactive program designed to be run from a terminal which may or may not give a printed record, the estimate is printed into a file rather than to the terminal. This allows it to be printed on a device selected by the user. The program currently prints all estimates into a file named NEWEST. In this way only the latest estimate is kept within the computer available for printing at one time. This avoids a large backlog of old estimates which have been printed from cluttering up the file storage. After using this method for some time it has been found to work very well as opposed to allowing the output file to be selected by the user. No need has been found to go back and find a previous estimate within the file storage. This is probably due to the fact that the designs at these early phases are constantly changing which causes an estimate to be outdated and superseded in a very short period of time.

The first page of the estimate to be output to NEWEST is a page which summarizes and compares the major characteristics of both the base ship and the new ship. This page serves two purposes. The first is to allow a check of the input data for the new ship and also the base ship to insure that there are no errors and that the intended data has in reality been used by the program. The second is to have a summary of the characteristics used to produce the estimate with the estimate itself. This allows the engineer to trace the origins of the estimate at a later time and to have a record of the parameters used in its preparation. The characteristics printed out on this page are the basic ship dimensions, type of propulsion, installed horsepower, installed kilowatts, and the manning and accommodations.

The second page of the estimate is the full load summary. It summarizes the lightship, the margins, and the loads and totals them to show the calculated full load condition. As is common in U.S. Navy practice, all of the weights are carried to two decimal places, the centers are carried to two decimal places, and all moments are carried to the nearest whole number. This convention is carried throughout all of the output for the estimate. This full load summary page is then followed by the lightship summary. This page contains the summaries for the seven SWBS groups and their summation which is the lightship without margins. This is then followed by seven pages, one each for each one digit SWBS group. These contain the breakdown of each group by SWBS element plus the group total. An additional feature shown on these three digit group summaries is that each group which has been modified from the basic ratiocination carried out by the program is designated with an asterisk which refers to the bottom of the page to a comment which so indicates. The final page of the estimate is similar to the group summaries, except it summarizes the loads.

One goal in the formating of the output of the program was to keep it within an 8½" x 11" format. One very real fact of modern naval ship design is that large quantities of paper are generated by the process. Most of this is in the form of written reports documenting the design work. In order to allow the output of this program to easily be included in reports and reproduced without undue difficulties, it was a self-imposed requirement to keep all output within the size of an 8½ x 11 piece of paper. This has been accomplished for all output and the first page of each output even contains guides for cutting the larger computer paper down to 8½ x 11 with the proper margins around the output.

A sample printout of the estimate which reflects all of the sample data and information contained in Figures 3, 6 and 10 is contained in Appendix B.

While there are two output files always created by the program, CHNGSUM (if modifications were made) and NEWEST, there are several other options which may be selected by the the user. These are carried out by the SPECIALOUT subroutine and are described in the following:

> MINOP Loading Condition- For stability calculations and other analyses it may be required to know the MINOP displacement and centers of gravity. For this output option the MINOP loads are calculated from the previously determined full loads including any modifications that were made in accordance with the standard U.S. Navy definition of MINOP as desribed in Reference (4). While the weights for the various load elements have been modified from the full load condition all of the full load centers have been retained. This is a valid assumption for all of the elements with the exception of the ship's fuel. In reality the VCG of the fuel will be lower in the MINOP condition than in the full load since the higher fuel tanks are generally consumed first. It was impossible however, to determine a reduction in the vertical center that

was universal for all ships. The conservative approach which was to use the higher full load center was used in the absence of a more realistic solution. The LCG of the fuel is also subject to possible error since the ship's fuel is normally consumed in a manner which produces the optimum trim in the various loading conditions. This may lead to an LCG for the fuel in the MINOP condition which is significantly different from the full load case. Again, since there is no general way to estimate this shifting of the LCG for MINOP, the full load LCG was retained for the fuel. Since the lightship does not change for this condition, only the detailed load summary and the whole ship summary sheet are printed out. These two pages have the same format as the corresponding sheets of the complete full load estimate. The MINOP estimate is written into the file named MINOPEST. A sample of this file for the sample estimate is contained in Appendix D.

Weight Deltas- The first special output option is a listing of the weight deltas from the base ship to the new ship. These deltas are printed in a summary report in a format similar to the weight estimate. There is a page for the full load summary which shows the weight deltas from the base ship, a lightship delta summary, and the deltas for each element by SWBS group. This delta summary is useful when comparing the differences between the base ship and the new ship, especially when performing sensitivity studies for a certain ship parameter.

SDWE Input- Assuming the design continues on into the Preliminary Design phase it will be necessary to continue the development of the estimate in much greater detail. This more detailed estimate would be prepared with the aid of the SDWE computer program. In order to allow the final estimate prepared by the RATS program to be input into SDWE, which will serve as a starting point for more detailed analysis, the RATS program has the ability to produce an the estimate in the form of an SDWE input file. This file can then be directly input into SDWE using the UPDATE program, which results in the complete transfer of the estimate.

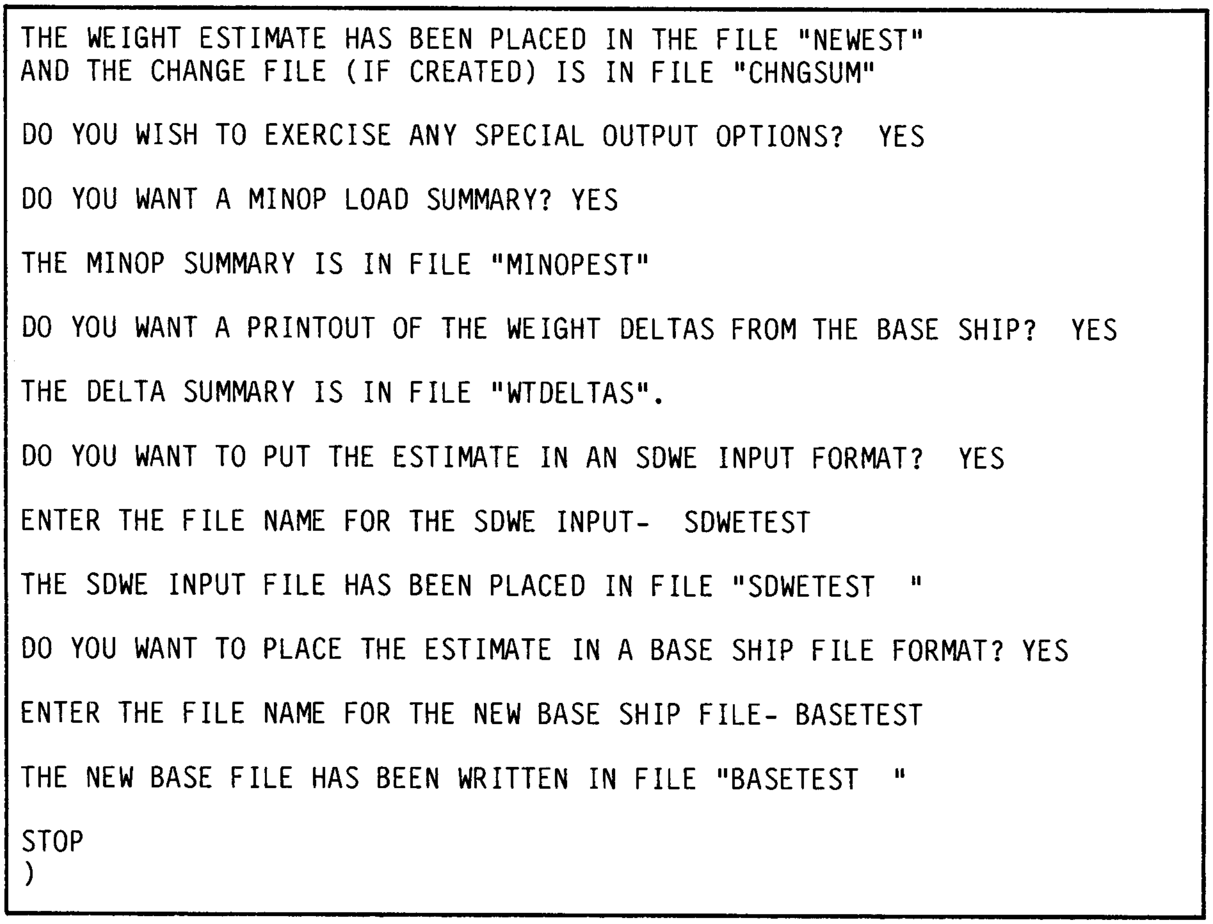
Base Ship Data File- Another useful aspect of this program is to generate an estimate from a known base ship and then modify it to exactly reflect a new ship. Once this has been done it may be necessary to perform sensitivity analyses on this new ship with regard to its principal characteristics. For example a new ship estimate may be prepared which indicates that the design has excess stability and a study is undertaken to determine the impact of reducing the beam on the ship's KG and displacement. Rather than running the program on the original base ship with all of the modifications for the various beams under study, the original new ship can be made into the base ship and the studies on the beam can be made directly onto the new ship estimate. This output option allows the new ship estimate to be placed into a file with the proper format to be used as a base ship for any required studies. Caution should be taken when using a new ship as a base ship since any errors or inaccuracies within the original new ship estimate will be carried over and magnified in subsequent runs using it as the base ship. This method should only be used for sensitivity type studies on the principal characteristic of the design.

All of the output from these special options is placed into a file designated by the user. This is done rather than assigning a file name since these output options are used less frequently and the output files may be used as input to other programs.

Once all of the desired output options have be placed in the proper files, the program gives a summary listing of the locations of all of the output files on the terminal. This is followed by the termination of the execution of the program. A sample listing of the output portion of the program from a run which creates all of the output files including the special output is shown in Figure 13.

Metrification

The program is equipped with the option to select whether the estimate should be produced using English or metric units. When the program first begins the question is asked whether the estimate is to be done in metric units or not. If the answer is affirmative then all of the program output will be produced using metric units with all appropriate units shown. The default is English units which produces an estimate entirely in those units which are also indicated on all output. All base ships however, must be in English units in order to provide the correct units for the output whether they be English or metric. Should any modificications be made to the estimate they must me made in the units that will be used for the final estimate. This means that if the metric option is selected all of the modifications made must also be in metric units. Of course for an estimate in English units the changes must be in English units also.



```
THE WEIGHT ESTIMATE HAS BEEN PLACED IN THE FILE "NEWEST"
AND THE CHANGE FILE (IF CREATED) IS IN FILE "CHNGSUM"

DO YOU WISH TO EXERCISE ANY SPECIAL OUTPUT OPTIONS?  YES

DO YOU WANT A MINOP LOAD SUMMARY? YES

THE MINOP SUMMARY IS IN FILE "MINOPEST"

DO YOU WANT A PRINTOUT OF THE WEIGHT DELTAS FROM THE BASE SHIP?  YES

THE DELTA SUMMARY IS IN FILE "WTDELTAS".

DO YOU WANT TO PUT THE ESTIMATE IN AN SDWE INPUT FORMAT?  YES

ENTER THE FILE NAME FOR THE SDWE INPUT-  SDWETEST

THE SDWE INPUT FILE HAS BEEN PLACED IN FILE "SDWETEST  "

DO YOU WANT TO PLACE THE ESTIMATE IN A BASE SHIP FILE FORMAT? YES

ENTER THE FILE NAME FOR THE NEW BASE SHIP FILE- BASETEST

THE NEW BASE FILE HAS BEEN WRITTEN IN FILE "BASETEST  "

STOP
)
```

FIGURE 13

Sample Execution of Program Output

SUMMARY

While the RATS program is not a perfect means for calculating ship weight estimates during the early design stages, it is still an excellent tool for the preparation of these estimates. A knowlegeable weight engineer must still be responsible for the preparation of the estimate, but this program when used properly will reduce considerably the amount of time the engineer spends in producing that estimate. It is essential for the engineer to completely understand the methodology used and also the assumptions and limitations inherent to the program. If these are understood then the engineer can use this program to the maximum extent possible without any loss of accuracy within the estimate. To blindly use the results of the program without consideration of the sources is not good engineering practice and can produce faulty results.

This program is intended to be constantly evolving with modifications and improvements being as program usage warrants them. For example as better parametric equations are determined for the various elements they can be incorporated with ease. Even more complex logic can be employed to compare and analyse the base ship versus the new ship in order to provide better determination of the element centers of gravity. The program is intended to be extremely "user friendly" so input from the people who use the program is of great value in order improve the operation of the program. It must be realized that while the program as it now stands is a useful and functioning engineering tool, it is not perfect and improvements must continue to be made.

ACKNOWLEDGEMENTS

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APPENDIX A

Parametric Equations Used to Calculate the Weights of the Various SWBS Elements

Explanation of Abbreviations

The following shorthand scheme has been used in describing the parametric ratios: For example, the ratio indicated by the symbol "LB" actually describes the following equation:

$$(\text{Weight})_{\text{New}}=(\text{Weight})_{\text{Base}} \times \frac{(\text{Length x Beam})_{\text{New Ship}}}{(\text{Length x Beam})_{\text{Base Ship}}}$$

A symbol such as (½Lx½ACC) is the abbreviated form of the equation:

$$(\text{Weight})_{\text{New}}= \tfrac{1}{2}(\text{Weight})_{\text{Base}} \times \frac{(\text{Length})_{\text{New}}}{(\text{Length})_{\text{Base}}} + \tfrac{1}{2}(\text{Weight})_{\text{Base}} \times \frac{(\text{Accomm.})_{\text{New}}}{(\text{Accomm.})_{\text{Base}}}$$

The following abbreviations are also used for the various ship characteristics:

L = Length
B = Beam
D = Depth
HP = Installed Horsepower
KW = Installed Kilowatts
ACC = Accommodations
MAN = Manning
K = Constant

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 1

SWBS	TITLE	SIMPLE	DETAILED
111	Shell Plating	(B+2D)L	(B+2D)L
113	Inner Bottom	LB	$(LB)_{\text{Inner Bottom}}$
114	Shell Appendages	(B+2D)L	(B+2D)L
115	Stanchions	LD	LD
116	Longitudinal Framing	(B+2D)L	(B+2D)L
117	Transverse Framing	LD^2	LD^2
121	Longitudinal Bulkheads	DL^2	DL^2
122	Transverse Bulkheads	LBD^2	LBD^2
123	Trunks and Enclosures	LBD	LBD
131	Main Deck	LB	$(LB)_{\text{Main Deck}}$
132	Second Deck	LB	$(LB)_{\text{Second Deck}}$
133	Third Deck	LB	$(LB)_{\text{Third Deck}}$
136	01 Hull Deck	LB	$(LB)_{\text{01 Level}}$
137	02 Hull Deck	LB	$(LB)_{\text{02 Level}}$
141	First Platform	LB	$(LB)_{\text{1st Platform}}$
142	Second Platform	LB	$(LB)_{\text{2nd Platform}}$
143	Third Platform	LB	$(LB)_{\text{3rd Platform}}$
149	Flats	LBD	LBD
151	Deckhouse to First Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{01 Level}}$
152	1st Deckhouse Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{01 Level}}$
153	2nd Deckhouse Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{02 Level}}$
154	3rd Deckhouse Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{03 Level}}$
155	4th Deckhouse Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{04 Level}}$
156	5th Deckhouse Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{05 Level}}$
157	6th Deckhouse Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{06 Level}}$
158	7th Deckhouse Level	$B(L)_{\text{Superstructure}}$	$(LB)_{\text{07 Level}}$

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 1 (Con't)

SWBS	TITLE	SIMPLE	DETAILED
161	Structural Castings	LBD	LBD
162	Stacks and Macks	LBD	LBD
163	Sea Chests	$(\frac{1}{2}K+\frac{1}{2}HP)$	$(\frac{1}{2}K+\frac{1}{2}HP)$
164	Ballistic Plating	LBD	LBD
165	Sonar Domes	LBD	LBD
166	Sponsons	LBD	LBD
167	Hull Structural Closures	LD	LD
168	Deckhouse Struct. Closures	$(L)_{\text{Superstructure}}$	$(L)_{\text{Superstructure}}$
169	Special Purpose Structures	LBD	LBD
171	Masts, Towers, Tetrapods	LBD	LBD
172	Kingposts and Supp. Frms.	LBD	LBD
181	Hull Structural Fdns.	% Group 1	% Group 1
182	Propulsion Fdns.	% Group 2	% Group 2
183	Electric Plant Fdns.	% Group 3	% Group 3
184	Comm. & Surv. Fdns.	% Group 4	% Group 4
185	Auxiliary Sys. Fnds.	% Group 5	% Group 5
186	Outfit & Furn. Fnds.	% Group 6	% Group 6
187	Armament Fnds.	% Group 7	% Group 7
197	Welding & Mill Tolerance	2.5% Group 1	2.5% Group 1
198	Free Flooding Liquids	K	K
199	Hull Repair Parts & Tools	% Group 1	% Group 1

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 2

SWBS	TITLE	SIMPLE	DETAILED
221	Propulsion Boilers	HP	HP
231	Steam Turbines	HP	HP
233	Internal Comb. Engines	HP	HP
234	Gas Turbines	HP	HP
235	Electric Propulsion	HP	HP
237	Auxiliary Propulsion	$(\frac{1}{2}K+\frac{1}{2}HP)$	$(\frac{1}{2}K+\frac{1}{2}HP)$
241	Reduction Gears	HP	HP
242	Clutches & Couplings	$(\frac{1}{2}\sqrt{HP}+\frac{1}{2}L)$	$(\frac{1}{2}\sqrt{HP}+\frac{1}{2}L)$
243	Propulsion Shafting	$(\frac{1}{2}\sqrt{HP}+\frac{1}{2}L)$	$(\frac{1}{2}\sqrt{HP}+\frac{1}{2}L)$
244	Shaft Bearings	$(\frac{1}{2}\sqrt{HP}+\frac{1}{2}L)$	$(\frac{1}{2}\sqrt{HP}+\frac{1}{2}L)$
245	Propulsors	HP^2	HP^2
251	Combustion Air Sys.	$\sqrt{HP}$	$\sqrt{HP}$
252	Prop. Control Sys.	$(\frac{1}{2}K+\frac{1}{2}\sqrt{HP})$	$(\frac{1}{2}K+\frac{1}{2}\sqrt{HP})$
253	Main Steam Piping	$\sqrt{HP}$	$\sqrt{HP}$
254	Condensers	$\sqrt{HP}$	$\sqrt{HP}$
255	Feed & Condensate Sys.	$\sqrt{HP}$	$\sqrt{HP}$
256	Circ. & Cooling Water	$\sqrt{HP}$	$\sqrt{HP}$
258	HP Steam Drain Sys.	$\sqrt{HP}$	$\sqrt{HP}$
259	Uptakes	$\sqrt{HP}$	$\sqrt{HP}$
261	Fuel Service System	$\sqrt{HP}$	$\sqrt{HP}$
262	Main Prop. Lube Oil Sys.	$\sqrt{HP}$	$\sqrt{HP}$
264	Lube Oil Fill & Xfer.	$(\frac{1}{2}HP+\frac{1}{2}LBD)$	$(\frac{1}{2}HP+\frac{1}{2}LBD)$
298	Prop. Operating Fluids	% Group 2	% Group 2
299	Prop. Repair Parts	% Group 2	% Group 2

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 3

SWBS	TITLE	SIMPLE	DETAILED
311	S. S. Power Generation	KW	KW
312	Emergency Generators	KW	KW
313	Batteries & Service Facil.	KWxL	KWxL
314	Power Conversion Equipment	KW	KW
321	Ship Service Power Cable	KWxL	KWxL
322	Emergency Power Cable	KWxL	KWxL
323	Casualty Power Cable	KWxL	KWxL
324	Switchgear and Panels	KW	KW
331	Lighting Distribution	LBDxACC	LBDxACC
332	Lighting Fixtures	LBDxACC	LBDxACC
341	SSTG Lube Oil	KW	KW
342	Diesel Support Systems	KW	KW
343	Turbine Support Systems	KW	KW
398	Electric Plant Op. Fluids	% Group 3	% Group 3
399	Electric Plant Repair Parts	% Group 3	% Group 3

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 4

SWBS	TITLE	SIMPLE	DETAILED
411	Data Display Group	LBD	LBD
412	Data Processing Group	LBD	LBD
413	Digital Data Swbds.	K	K
414	Interface Equipment	K	K
415	Digital Data Comm.	K	K
417	Analog Switchboards	K	K
421	Non-Elect. Nav. Aids	(½K+½LBD)	(½K+½LBD)
422	Electrical Nav. Aids	(½K+½LBD)	(½K+½LBD)
423	Nav. Sys., Radio	LBD	LBD
424	Nav. Sys., Acoustical	LBD	LBD
426	Electrical Nav. Sys.	LBD	LBD
427	Inertial Nav. Sys.	LBD	LBD
428	Nav. Cntl. Monitoring	LBD	LBD
431	Swbds. for IC Sys.	LBD	LBD
432	Telephone Systems	LBD	LBD
433	Announcing Systems	LBD	LBD
434	Entertainment Sys.	(½ACC+½LBD)	(½ACC+½LBD)
435	Voice Tubes	LD	LD
436	Alarm & Warning Sys.	LBD	LBD
437	Indic. Order. & Meter.	LBD	LBD
438	Integrated Control Sys.	LBD	LBD
439	Recording & TV Sy.	(½ACC+½LBD)	(½ACC+½LBD)
441	Radio Systems	LBD	LBD
442	Underwater Systems	LBD	LBD
443	Visual & Audible Sys.	(½K+½LBD)	(½K+½LBD)
444	Telemetry Systems	K	K
445	TTY & Facsimile Sys.	LBD	LBD
446	Security Equipment	LBD	LBD

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 4 (Con't)

SWBS	TITLE	SIMPLE	DETAILED
451	Surface Search Radar	K	K
452	Air Search Radar (2D)	K	K
453	Air Search Radar (3D)	K	K
454	Aircraft Control Radar	K	K
455	Identification Systems	K	K
456	Multiple Mode Sonar	K	K
461	Active Sonar	K	K
462	Passive Sonar	K	K
463	Multiple Mode Sonar	K	K
464	Classification Sonar	K	K
465	Bathythermograph	K	K
471	Active ECM	K	K
472	Passive ECM	K	K
473	Torpedo Decoys	K	K
474	Decoys	K	K
475	Degaussing	LBD	LBD
476	Mine Countermeasures	K	K
481	Gun Fire Control Sys.	K	K
482	Missile Fire Control	K	K
483	Underwater Fire Control	K	K
484	Integrated Fire Control	K	K
491	Elex. Test & Monit. Eqpt.	K	K
492	Flight Cntl & Inst. Lndg.	K	K
493	Non Combat Data Processing	K	K
494	Meteorological Systems	K	K
495	Special Purpose Intel. Sys.	K	K
498	Command & Cntl. Op. Fluids	% Group 4	% Group 4
499	Command & Cntl. Repair Parts	% Group 4	% Group 4

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 5

SWBS	TITLE	SIMPLE	DETAILED
511	Compartment Heating Sys.	LBDxACC	LBDxACC
512	Ventilation System	LBDxACC	LBDxACC
513	Machinery Space Vent.	(L)Machinery	(L)Machinery
514	Air Conditioning Sys.	LBDxACC	LBDxACC
516	Refrigeration System	ACC	ACC
517	Auxiliary Boilers	LBDxACC	LBDxACC
521	Firemain & Flushing	LBD	LBD
522	Sprinkler System	LBD	LBD
523	Washdown System	LB	LB
524	Auxiliary Seawater Sys.	LBD	LBD
526	Scuppers & Deck Drains	LB	LB
527	Firemain Actuated Sys.	LBD	LBD
528	Plumbing Drainage	LBxACC	LBxACC
529	Drainage & Ballasting	LB	LB
531	Distilling Plant	ACC	ACC
532	Cooling Water	LBD	LBD
533	Potable Water	(½L+½ACC)	(½L+½ACC)
534	Steam Drns. In Machy. Box	(½HP+½LBD)	(½HP+½LBD)
535	Steam Drns. Out Machy. Box	(½HP+½LBD)	(½HP+½LBD)
536	Aux. Fresh Water Cooling	LD	LD
541	Ship Fuel System	(½LD+½HP)	(½LD+½HP)
542	Aviation Fuels	LD	LD
543	Aviation Lube Oil	LD	LD
544	Liquid Cargo	LBD	LBD
545	Tank Heating	LB	LB
549	Special Fuel & Lube Hndlg.	K	K
551	Compressed Air Systems	(½HP+½LB)	(½HP+½LB)
552	Compressed Gases	LBD	LBD
553	O_2 N_2 Systems	LBD	LBD

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 5 (Con't)

SWBS	TITLE	SIMPLE	DETAILED
555	Fire Extinguishing Sys.	LD	LD
556	Hydraulic Fluid Systems	LBD	LBD
558	Special Piping Systems	LB	LB
561	Steering & Diving Cntl.	BDL^2	BDL^2
562	Rudder	LD	LD
565	Trim & Heel Systems	LBD	LBD
568	Maneuvering Systems	LBD	LBD
571	Replenishment at Sea Sys.	LBD	LBD
572	Ship Stores Handling Eqpt.	L	L
573	Cargo Handling Systems	LBD	LBD
575	Vertical Handling Sys.	LBD	LBD
581	Anchor Handling Sys.	LBD	LBD
582	Mooring & Towing Sys.	LBD	LBD
583	Boats & Boat Hndlg. Sys.	ACC	ACC
584	Landing Craft Hndlng. Sys.	K	K
585	Elevating & Retracting Gr.	K	K
586	Aircraft Recovery Systems	K	K
587	Aircraft Launch Systems	K	K
588	Aircraft Handling Systems	K	K
589	Misc. Mech. Handling Sys.	K	K
591	Scientific & Ocean Systems	K	K
592	Swimmer & Diver Support	K	K
593	Pollution Control Systems	ACCxLBD	ACCxLBD
594	Submarine Rescue Systems	K	K
595	Underwater Vehicle Hndlg.	K	K
596	Diver Handling Systems	K	K
597	Salvage Support Systems	K	K
598	Aux Sys. Operating Fluids	% Group 5	% Group 5
599	Aux Sys. Repair Parts	% Group 5	% Group 6

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 6

SWBS	TITLE	SIMPLE	DETAILED
611	Hull Fittings	L	L
612	Rails, Stan. & Lifelines	L	L
613	Rigging & Canvas	L	L
621	Non-Structural Bulkheads	LBD	LBD
622	Floor Plates & Gratings	LB	LB
623	Ladders	LD	LD
624	Non-Structural Closures	LBD	LBD
625	Airports & Windows	LB	LB
631	Painting	LBD	LBD
632	Zinc Coating	LBD	LBD
633	Cathodic Protection	(B+2D)L	(B+2D)L
634	Deck Covering	LB	LB
635	Hull Insulation	LBD	LBD
636	Hull Damping	$(\frac{1}{2}LBD+\frac{1}{2}HP)$	$(\frac{1}{2}LBD+\frac{1}{2}HP)$
637	Sheathing	LBD	LBD
638	Refrigerated Spaces	ACC	ACC
639	Radiation Shielding	LBD	LBD
641	Officer Berthing	ACC	$(ACC)_{Officer}$
642	Noncomm Officer Berthing	ACC	$(ACC)_{CPO}$
643	Enlisted Berthing	ACC	$(ACC)_{Enlisted}$
644	Sanitary Spaces	ACC	ACC
645	Leisure & Comm. Spaces	ACC	ACC
651	Commissary Spaces	ACC	ACC
652	Medical Spaces	ACC	ACC
653	Dental Spaces	ACC	ACC
654	Utility Spaces	$(\frac{1}{2}K+\frac{1}{2}ACC)$	$(\frac{1}{2}K+\frac{1}{2}ACC)$
655	Laundry Spaces	ACC	ACC
656	Trash Disposal Spaces	$(\frac{1}{2}K+\frac{1}{2}ACC)$	$(\frac{1}{2}K+\frac{1}{2}ACC)$
661	Offices	LBDxACC	LBDxACC

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 6 (Con't)

SWBS	TITLE	SIMPLE	DETAILED
662	Machy. Cntl. Ctr. Furn.	LBDxACC	LBDxACC
663	Elex. Cntl. Ctr. Furn.	LBDxACC	LBDxACC
664	Damage Control Stations	LBD	LBD
665	Workshops & Labs	(½LBD+½K)	(½LBD+½K)
671	Lockers & Special Stow.	LBDxACC	LBDxACC
672	Storerooms & Issue Rms	(½LBD+½ACC)	(½LBD+½ACC)
673	Cargo Stowage	LBD	LBD
698	Outfit & Furn. Op. Fluids	% Group 6	% Group 6
699	Outfit & Furn. Rep. Parts	% Group 6	% Group 6

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 7

SWBS	TITLE	SIMPLE	DETAILED
711	Guns	K	K
712	Ammunition Handling	K	K
713	Ammunition Stowage	K	K
721	Missile Launchers	K	K
722	Missile Handling	K	K
723	Missile Stowage	K	K
724	Missile Hydraulics	K	K
725	Missile Gas	K	K
726	Missile Compensating	K	K
727	Missile Launcher Control	K	K
728	Missile Temperature Cntl.	K	K
729	Missile Monitoring	K	K
731	Mine Launching Devices	K	K
732	Mine Handling	K	K
733	Mine Stowage	K	K
741	Depth Charge Launchers	K	K
742	Depth Charge Handling	K	K
743	Depth Charge Stowage	K	K
751	Torpedo Tubes	K	K
752	Torpedo Handling	K	K
753	Torpedo Stowage	K	K
761	Small Arms & Pyrotechnics	K	K
762	Small Arms & Pyro. Hndlg.	K	K
763	SmaLL Arms & Pyro. Stow.	K	K
772	Cargo Munitions Handling	K	K
773	Cargo Munitions Stowage	K	K
782	Aircraft Weapons Handling	K	K
783	Aircraft Weapons Stowage	K	K
792	Special Weapons Handling	K	K

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Group 7 (Con't)

SWBS	TITLE	SIMPLE	DETAILED
793	Special Weapons Stowage	K	K
797	Misc. Ordnance Spaces	K	K
798	Armament Operating Fluids	% Group 7	% Group 7
799	Armament Repair Parts	% Group 7	% Group 7

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Loads

SWBS	TITLE	SIMPLE	DETAILED
F11	Ship's Officers	ACC	(MAN)Officer
F12	Ship's Noncomm. Off.	ACC	(MAN)CPO
F13	Ship's Enlisted Men	ACC	(MAN)Enlisted
F14	Marines	ACC	(MAN)Marine
F15	Troops	ACC	(MAN)Troop
F16	Air Wing Personnel	ACC	(MAN)Air Wing
F19	Other Personnel	ACC	MAN
F21	Ship Ammunition	K	K
F22	Ord. Del. Sys. Ammo.	K	K
F23	Ordnance Delivery Sys.	K	K
F24	Ordnance Repair Parts	K	K
F25	Repair Parts Ord. Del. Sys.	K	K
F26	Ord. Del. Sys. Support Eqpt.	K	K
F29	Special Mission Sys.	K	K
F31	Provisions & Pers. Stores	ACC	MAN
F32	General Stores	ACC	MAN
F33	Marine's Stores	ACC	(MAN)Marine
F39	Special Stores	K	K
F41	Diesel Fuel	HP	HP
F42	JP-5	K	K
F43	Gasoline	K	K
F44	Distillate Fuel	HP	HP
F45	N.S.F.O.	HP	HP
F46	Lubricating Oil	HP	HP
F49	Special Fuels & Lubes	K	K
F51	Sea Water	K	K
F52	Fresh Water	ACC	MAN
F53	Reserve Feed Water	HP	HP
F54	Hydraulic Fluid	K	K

PARAMETRIC FACTORS USED IN THE RATS PROGRAM

Loads (Con't)

SWBS	TITLE	SIMPLE	DETAILED
F55	Sanitary Tank Liquid	ACC	MAN
F56	Gas	K	K
F59	Miscellaneous Liquids	K	K
F61	Cargo Ordnance	LBD	LBD
F62	Cargo Stores	LBD	LBD
F63	Cargo Fuels & Lubes	LBD	LBD
F64	Cargo Liquids	LBD	LBD
F65	Cargo, Liquid Gases	LBD	LBD
F66	Cargo, Amphib. Assault Sys.	K	K
F67	Cargo Gases	LBD	LBD
F69	Miscellaneous Cargo	LBD	LBD

APPENDIX B

Sample Weight Estimate Generated by the RATS Program

```
     WEIGHT ESTIMATE FOR T-AGOS TEST                              PAGE 1
                                                                ----------
     USING RATIOCINATION FROM T-AGOS-1  (QUARTERLY 7)           RUN NO.  1
                                                                 5/12/84


                    SHIP CHARACTERISTICS
                    --------------------

                                   BASE SHIP           NEW SHIP
                                 (T-AGOS-1   )       (T-AGOS TEST     )


LENGTH BETWEEN PERPENDICULARS         204.0 FT.           214.0 FT.
BEAM                                   43.0 FT.            43.0 FT.
DEPTH TO UPPER HULL DECK               20.0 FT.            20.0 FT.
INSTALLED SHAFT HORSEPOWER           1600.               1600.

TYPE OF PROPULSION                  DIESEL/ELECT        DIESEL/ELECT

INSTALLED KW                         2400.               2400.

NUMBER OF ACCOMADATIONS:

                    OFFICER-           16.                 19.
                    CPO-                1.                  2.
                    CREW-              13.                 15.


MANNING:

                    OFFICER-           16.                 18.
                    CPO-                1.                  2.
                    CREW-              13.                 14.
```

```
FULL LOAD SUMMARY FOR T-AGOS TEST                          ----------
-----------------------------------------------            RUN NO.  1
                                                            5/12/84



                                                 VERTICAL          LONGITUDINAL
                                              ---------------    ---------------
                               WEIGHT         VCG     MOMENT      LCG     MOMENT
                              (L TONS)       (FT)   (FT-TONS)    (FT)   (FT-TONS)
                              -------------------------------------------------


LIGHTSHIP                     1538.86       20.19    31072      105.91   162985

MARGINS                        123.11       39.27     4835      105.91    13039

--------------------          --------              -------             --------


LIGHTSHIP W/MARGINS           1661.97       21.60    35907      105.91   176024

FULL LOADS                     862.42       11.16     9625      105.27    90788

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TOTAL FULL LOAD               2524.38       18.04    45531      105.69   266812
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                                                                      ----------
      ONE-DIGIT SUMMARY FOR T-AGOS TEST                               RUN NO.   1
      -----------------------------------------------                  5/12/84



                                                    VERTICAL          LONGITUDINAL
                                                 ---------------    ---------------
                                      WEIGHT     VCG    MOMENT       LCG    MOMENT
                                     (L TONS)   (FT)  (FT-TONS)     (FT)  (FT-TONS)
                                     ---------------------------------------------

    1  HULL STRUCTURE                852.56    18.76    15994     100.22     85440

    2  PROPULSION PLANT               70.35    11.91      838     137.03      9640

    3  ELECTRIC PLANT                100.07    16.77     1678      93.79      9385

    4  COMMAND & SURVEILLENCE         48.37    26.59     1286      96.84      4684

    5  AUXILIARY SYSTEMS             299.77    22.28     6677     128.11     38404

    6  OUTFIT & FURNISHINGS          167.62    27.39     4591      92.01     15423

    7  ARMAMENT                         .12    50.00        6      57.17         6

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       TOTAL LIGHTSHIP              1538.86    20.19    31072     105.91    162985
```

T-AGOS TEST

RUN NO. 1
5/12/84

GROUP 1 - HULL STRUCTURE

SWBS	TITLE	WEIGHT (L TONS)	VERTICAL VCG (FT)	VERTICAL MOMENT (FT-TONS)	LONGITUDINAL LCG (FT)	LONGITUDINAL MOMENT (FT-TONS)
111	SHELL PLATING	139.72	13.89	1940	101.31	14155
113	INNER BOTTOM	45.25	3.50	158	111.34	5039
114	SHELL APPENDAGES	9.73	5.20	51	186.26	1813
115	STANCHIONS	2.92	22.37	65	87.98	257
116	LONGIT. FRAMING	34.92	7.40	258	99.18	3463
117	TRANS. FRAMING	79.73	11.43	911	97.69	7788
121	LONGITUDINAL STRUCT. BHDS	69.52	14.18	986	106.75	7421
122	TRANSVERSE STRUCT. BHDS	74.97	16.06	1204	96.76	7255
123	TRUNKS & ENCLOSURES	17.82	11.93	213	120.93	2155
131	MAIN DECK	62.72	19.97	1253	122.03	7654
136	01 HULL DECK	33.53	28.93	970	87.62	2938
141	1ST PLATFORM	37.57	10.70	402	103.79	3900
151	DECKHSE STRUCT TO 1ST LVL	31.18	33.37	1040	97.31	3034
152	1ST DECKHOUSE LEVEL	42.45	39.19	1663	76.92	3265
153	2ND DECKHOUSE LEVEL	21.93	48.58	1065	53.96	1183
154	3RD DECKHOUSE LEVEL	20.59	57.03	1174	43.88	903
161	STRUCT CASTINGS & FORGING	5.32	34.40	183	9.47	50
162	STACKS AND MACKS	5.90	55.87	329	88.69	523
163	SEA CHESTS	.17	2.35	0	101.75	18
167	HULL STRUC CLOSURES	10.40	21.76	226	121.70	1265
168	DECKHOUSE STRUCT CLOSURES	2.70	36.46	98	114.65	309
169	SPECIAL PURPOSE STRUCTURE	5.51	30.80	170	181.68	1001
171	MAST,TOWER & TETRAPODS	6.08	61.07	372	101.83	620
182	PROP. PLANT FOUNDATIONS	16.12	11.19	180	135.26	2180
183	ELEC. PLANT FOUNDATIONS	34.21	7.79	266	91.34	3124
184	COMMAND & SURV. FNDS	4.66	33.08	154	118.01	550
185	AUX SYSTEM FOUNDATIONS	12.44	15.24	190	95.51	1188
186	OUTFIT & FURN. FNDS	2.28	26.45	60	86.98	198
197	WELDING & MILL TOL.	20.76	18.77	390	100.98	2096
198	FREE FLOODING LIQUIDS	.92	2.95	3	101.75	94
199	HULL REPAIR PARTS	.57	31.67	18	2.88	2
	TOTAL HULL STRUCTURE	852.56	18.76	15994	100.22	85440

T-AGOS TEST

GROUP 2 - PROPULSION PLANT

RUN NO. 1
5/12/84

SWBS	TITLE	WEIGHT (L TONS)	VERTICAL		LONGITUDINAL	
			VCG (FT)	MOMENT (FT-TONS)	LCG (FT)	MOMENT (FT-TONS)
235	ELECTRIC PROPULSION	32.32	9.67	313	140.57	4543
243	PROPULSION SHAFTING	12.74	7.01	89	173.51	2211
244	PROP. SHAFT BEARINGS	.59	6.38	4	183.33	109
245	PROPULSORS	2.24	4.51	10	199.12	446
252	PROPULSION CONTROL SYS.	3.51	12.74	45	111.62	392
256	CIRC & COOLING WTR. SYS.	2.39	8.54	20	87.23	208
259	UPTAKES	4.69	42.20	198	84.04	394
262	MAIN PROP. LUBE OIL SYS.	6.39	12.54	80	122.49	783
264	L.O. FILL, XFER & PURIF.	1.21	8.84	11	133.31	161
298	PROP. PLANT OPER. FLUIDS	2.24	13.18	30	115.77	259
299	PROP. REP. PARTS & TOOLS	2.02	19.30	39	65.74	133
	TOTAL PROPULSION PLANT	70.35	11.91	838	137.03	9640

T-AGOS TEST

GROUP 3 - ELECTRIC PLANT

RUN NO. 1
5/12/84

SWBS	TITLE	WEIGHT (L TONS)	VERTICAL		LONGITUDINAL	
			VCG (FT)	MOMENT (FT-TONS)	LCG (FT)	MOMENT (FT-TONS)
311	SHIP SERV PWR GENERATION	41.75	10.31	430	91.22	3809
312	EMERGENCY GENERATORS	3.13	32.04	100	18.81	59
313	BATTERIES & SERV. FACIL.	.71	38.53	27	37.12	26
314	POWER CONVERSION EQPT.	12.20	18.61	227	113.36	1383
321	SHIP SERV. POWER CABLE	12.44	27.76	345	95.95	1193
324	SWITCHGEAR & PANELS	16.55	17.48	289	106.64	1765
331	LIGHTING DISTRIBUTION	3.30	16.11	53	103.28	341
332	LIGHTING FIXTURES	3.85	30.62	118	93.15	359
398	ELECT. PLANT OPER. FLUIDS	3.68	11.11	41	88.53	326
399	ELEC. REPAIR PTS. & TOOLS	2.46	19.00	47	51.05	125
	TOTAL ELECTRIC PLANT	100.07	16.77	1678	93.79	9386

T-AGOS TEST

RUN NO. 1
5/12/84

GROUP 4 - COMMAND & SURVEILLENCE

SWBS	TITLE	WEIGHT (L TONS)	VERTICAL		LONGITUDINAL	
			VCG (FT)	MOMENT (FT-TONS)	LCG (FT)	MOMENT (FT-TONS)
411	DATA DISPLAY GROUP	.04	30.00	1	159.45	7
421	NON-ELECT. NAV. AIDS	.05	62.00	3	34.62	2
422	ELECTRICAL NAV. AIDS	.79	49.48	39	111.70	88
423	ELEC. NAV. SYS., RADIO	.08	48.75	4	53.24	4
424	ELEC NAV SYS, ACOUSTIC	.15	.71	0	54.55	8
426	ELECTRICAL NAV. SYSTEMS	1.04	20.30	21	68.27	71
432	TELEPHONE SYSTEM	.84	27.12	23	108.97	91
433	ANNOUNCING SYSTEM	.35	38.18	13	77.91	27
434	ENTER. & TRAINING SYSTEM	.29	26.54	8	33.97	10
436	ALARM,SAFETY & WARN SYS	2.37	16.95	40	113.36	269
437	INDIC.,ORDER. & METER.	.69	14.55	10	111.13	77
441	RADIO SYSTEMS	2.63	57.41	151	71.62	189
443	VISUAL & AUDIBLE SYSTEMS	.10	59.00	6	30.42	3
445	TTY & FACSIMILE EQPT	.45	43.02	19	49.30	22
451	SURFACE SEARCH RADAR	.75	57.47	43	38.95	29
462*	PASSIVE SONAR	25.98	20.45	531	82.59	2146
491	ELECT. TEST & MONITORING	11.19	33.28	372	146.72	1642
499	COMM & SURV REPAIR PARTS	.58	.00	0	.00	0
	TOTAL COMMAND & SURVEILLENCE	48.37	26.59	1286	96.84	4685

* -GROUPS WHICH HAVE BEEN MODIFIED AND DO NOT REFLECT PURE RATIOCINATION.
(SEE CHANGE SUMMARY FOR DETAILS)

T-AGOS TEST

GROUP 5 - AUXILIARY SYSTEMS

RUN NO. 1
5/12/84

SWBS	TITLE	WEIGHT (L TONS)	VERTICAL		LONGITUDINAL	
			VCG (FT)	MOMENT (FT-TONS)	LCG (FT)	MOMENT (FT-TONS)
511	COMPARTMENT HEATING SYS.	.72	29.65	21	94.21	68
512	VENTILATION SYSTEM	33.46	29.43	985	103.82	3474
514	AIR CONDITIONING SYSTEM	16.68	20.05	334	78.52	1310
516	REFRIGERATION SYSTEM	.92	17.01	16	51.48	48
521	FIREMAIN & FLUSHING SYS	4.15	19.24	80	104.43	434
524	AUX SEAWATER SYSTEMS	5.21	11.03	57	92.95	485
526	SCUPPERS & DECK DRAINS	.02	20.00	0	49.30	1
528	PLUMBING DRAINAGE	12.30	21.95	270	86.97	1070
529	DRAINAGE & BALLASTING SYS	5.71	8.20	47	102.74	586
531	DISTILLING PLANT	4.06	13.43	54	75.00	304
532	COOLING WATER	3.24	10.23	33	88.48	287
533	POTABLE WATER	4.64	24.50	114	102.49	476
541	SHIP FUEL SYSTEM	6.51	7.39	48	119.33	776
551	COMPRESSED AIR SYSTEM	3.27	11.63	38	95.47	312
555	FIRE EXTINGUISHING SYS	2.41	24.83	60	108.51	262
556	HYDRAULIC FLUID SYS	1.11	29.06	32	58.61	65
558	SPECIAL PIPING SYSTEMS	5.69	20.41	116	93.12	529
561	STEERING CONTROL SYSTEM	2.94	17.94	53	202.34	594
562	RUDDERS	7.19	11.04	79	204.50	1469
568	MANEUVERING SYSTEM	9.18	11.07	102	18.82	173
571	REPLENISHMENT AT SEA	.91	19.20	18	96.81	88
573*	CARGO HANDLING SYS	2.50	37.00	93	110.00	275
581	ANCHOR HANDLING & STOWAGE	19.72	24.03	474	15.38	303
582	MOORING & TOWING SYSTEMS	2.19	30.67	67	99.55	218
583*	BOATS & BOAT HNDLG SYS	2.75	42.27	116	129.94	357
591	SCIENTIFIC & OCEAN ENG SY	75.01	28.70	2153	194.67	14602
593	ENVIRON. POLLUTION CNTL	.81	10.78	9	76.51	62
598	AUX SYS OPERATING FLUIDS	48.24	15.97	771	145.67	7027
599	AUX SYS REPAIR PTS & TOOL	18.23	24.01	438	150.80	2749
	TOTAL AUXILIARY SYSTEMS	299.77	22.28	6678	128.11	38404

* -GROUPS WHICH HAVE BEEN MODIFIED AND DO NOT REFLECT PURE RATIOCINATION.
(SEE CHANGE SUMMARY FOR DETAILS)

T-AGOS TEST

GROUP 6 - OUTFIT & FURNISHINGS

RUN NO. 1
5/12/84

SWBS	TITLE	WEIGHT (L TONS)	VERTICAL VCG (FT)	VERTICAL MOMENT (FT-TONS)	LONGITUDINAL LCG (FT)	LONGITUDINAL MOMENT (FT-TONS)
611	HULL FITTINGS	.82	20.64	17	143.45	117
612	RAILS, STANS. & LIFELINES	4.20	32.90	138	110.07	462
613	RIGGING & CANVAS	.28	46.67	13	83.88	24
621	NON-STRUCTURAL BULKHEADS	22.42	31.78	712	66.89	1499
622	FLOOR PLTS & GRATINGS	16.93	21.38	362	147.10	2491
623	LADDERS	6.17	23.57	145	108.16	667
624	NON-STRUCT. CLOSURES	5.25	28.86	151	78.76	413
625	AIRPORTS & WINDOWS	2.69	40.59	109	78.81	212
631	PAINTING	12.55	19.01	238	100.70	1263
633	CATHODIC PROTECTION	.97	6.85	7	120.68	116
634	DECK COVERING	8.65	28.19	244	76.91	666
635	HULL INSULATION	23.57	26.72	630	93.63	2207
636	HULL DAMPING	.89	2.64	2	91.26	81
637	SHEATHING	6.47	29.81	193	82.58	534
641	OFFICER BERTHING	8.11	35.45	287	67.75	549
642	CPO BERTHING	4.92	31.79	156	74.25	365
643	CREW BERTHING	5.46	24.84	136	87.54	478
644	SANITARY SPACES	10.74	32.08	345	76.41	821
645	LEISURE & COMM. SPACES	1.20	23.50	28	53.08	64
651	COMMISSARY SPACES	2.34	22.67	53	100.63	235
652	MEDICAL SPACES	.24	24.00	6	72.91	17
654	UTILITY SPACES	.70	24.06	17	24.23	17
661	OFFICES	.72	30.88	22	86.85	62
663	ELEX CNTL CTR FURNISH.	3.45	33.25	115	116.84	403
665	WORKSHOPS & LABS	7.83	26.14	205	145.28	1137
671	LKRS & SPECIAL STOW.	4.25	28.96	123	70.10	298
672	STRMS & ISSUE RMS	5.81	23.46	136	38.23	222
	TOTAL OUTFIT & FURNISHINGS	167.62	27.39	4591	92.01	15423

T-AGOS TEST

GROUP 7 - ARMAMENT

SWBS	TITLE	WEIGHT (L TONS)	VERTICAL		LONGITUDINAL	
			VCG (FT)	MOMENT (FT-TONS)	LCG (FT)	MOMENT (FT-TONS)
761	SMALL ARMS & PYRO	.12	50.00	6	57.17	7
	TOTAL ARMAMENT	.12	50.00	6	57.17	7

```
                                                                     PAGE 11
                            T-AGOS TEST                             ---------
                            -------------------------               RUN NO.  1
                            FULL LOADS                               5/12/84


                                                 VERTICAL              LONGITUDINAL
                                              ---------------        ---------------
SWBS          TITLE                WEIGHT      VCG    MOMENT        LCG     MOMENT
                                  (L TONS)    (FT)  (FT-TONS)      (FT)   (FT-TONS)
--------------------------------------------------------------------------------------


F11   SHIPS OFFICERS                  3.66    31.45       115      80.86        296
F12   SHIPS NONCOMM OFFICERS           .38    31.58        12      81.16         31
F13   SHIPS ENLISTED MEN              2.67    31.53        84      81.09        217
F31   PROV & PERSONNEL STORES        12.07    23.00       278      29.44        355
F32   GENERAL STORES                  7.29    31.99       233       2.12         15
F41*  DIESEL FUEL                   780.19    10.64      8300     105.78      82527
F46   LUBRICATING OIL                34.49    12.15       419     138.28       4769
F49   SPECIAL FUELS & LUBES            .63    38.89        25     180.02        113
F52   FRESH WATER                    21.05     7.56       159     117.07       2464
-----------------------------    --------           -------               --------

   TOTAL FULL LOADS                 862.42    11.16      9625     105.27      90788

* -GROUPS WHICH HAVE BEEN MODIFIED AND DO NOT REFLECT PURE RATIOCINATION.
   (SEE CHANGE SUMMARY FOR DETAILS)
```

APPENDIX C

Sample Change Summary Generated by the RATS Program

```
                                                                 RUN NO.  1
                                                                  5/12/84

                 CHANGE SUMMARY FOR T-AGOS TEST
                 -------------------------------------------

           THESE CHANGES REPRESENT SPECIAL CHANGES FROM THE PURE
           RATIONCINATION VALUES CALCULATED BY THE PROGRAM
           WHICH WERE REQUIRED DUE TO SPECIAL ASPECTS OF THE
           T-AGOS TEST                 .

     SWBS GROUP  41   DIESEL FUEL
     -----------------------------------------

     CHANGED:            WEIGHT   VCG      V. MOM.   LCG      L. MOM.
     --------            -------- ---      -------   ---      -------
     FROM:               709.26  10.64      7546.  105.78      75025.

     TO:                 780.19  10.64      8300.  105.78      82527.

     REASON: INCREASED ENDURANCE FUEL REQ'TS

     SWBS GROUP 583   BOATS & BOAT HNDLG SYS
     -----------------------------------------

     CHANGED:            WEIGHT   VCG      V. MOM.   LCG      L. MOM.
     --------            -------- ---      -------   ---      -------
     FROM:                 1.80  42.27        76.  129.94        234.

     TO:                   2.75  42.27       116.  129.94        357.

     REASON: NEW BOATS

     SWBS GROUP 462   PASSIVE SONAR
     -----------------------------------------

     CHANGED:            WEIGHT   VCG      V. MOM.   LCG      L. MOM.
     --------            -------- ---      -------   ---      -------
     FROM:                15.98  33.25       531.  134.28       2146.

     TO:                  25.98  20.45       531.   82.59       2146.

     REASON: ADDITIONAL MISSION ELECTRONICS
```

```
     CHANGE SUMMARY FOR T-AGOS TEST                   (CON`T)
     ---------------------------------------------------

SWBS GROUP 655   LAUNDRY SPACES
------------------------------------------

                 WEIGHT   VCG     V.MOM.   LCG     L. MOM.
                 -------- ---     -------  ---     -------
DELETED:             .86  12.14       10.  56.56       49.

REASON:DELETION OF THE LAUNDRY

SWBS GROUP 573   CARGO HANDLING SYS
------------------------------------------

                 WEIGHT   VCG     V.MOM.   LCG     L. MOM.
ADDED            -------- ---     -------  ---     -------
NEW GROUP           2.50  37.00       93. 110.00      275.

REASON:ADDITION OF CRANE
```

APPENDIX D

MINOP Load Summary Generated by the RATS Program

```
                                                                 PAGE 1
     MINOP SUMMARY FOR T-AGOS TEST                              ----------
     --------------------------------------------------          RUN NO.  1
                                                                  5/12/84



                                                       VERTICAL          LONGITUDINAL
                                                 ---------------   ----------------
                                    WEIGHT      VCG    MOMENT      LCG      MOMENT
                                   (L TONS)    (FT)  (FT-TONS)    (FT)   (FT-TONS)
                                   ------------------------------------------------


 LIGHTSHIP                         1538.86     20.19   31072     105.91    162985

 MARGINS                            123.11     39.27    4835     105.91     13039
 --------------------              --------            -------             --------


 LIGHTSHIP W/MARGINS               1661.97     21.60   35907     105.91    176024

 MINOP LOADS                        299.38     11.42    3418     105.29     31522
 --------------------              --------            -------             --------


 TOTAL MINOP CONDITION             1961.35     20.05   39325     105.82    207546
```

```
                                                                    PAGE 2
                          T-AGOS TEST                             ----------
                          -------------------------               RUN NO.  1
                          MINOP LOADS                              5/12/84

                                                    VERTICAL      .   LONGITUDINAL
                                              ---------------   ---------------
SWBS          TITLE                WEIGHT     VCG   MOMENT      LCG     MOMENT
                                  (L TONS)   (FT)  (FT-TONS)   (FT)   (FT-TONS)
-----------------------------------------------------------------------------

F11  SHIPS OFFICERS                   3.66   31.45       115   80.86        296
F12  SHIPS NONCOMM OFFICERS            .38   31.58        12   81.16         31
F13  SHIPS ENLISTED MEN               2.67   31.53        84   81.09        217
F31  PROV & PERSONNEL STORES          4.02   23.00        93   29.44        118
F32  GENERAL STORES                   2.43   31.99        78    2.12          5
F41  DIESEL FUEL                    260.06   10.64      2767  105.78      27509
F46  LUBRICATING OIL                 11.50   12.15       140  138.28       1590
F49  SPECIAL FUELS & LUBES             .63   38.89        25  180.02        113
F52  FRESH WATER                     14.03    7.56       106  117.07       1643
------------------------------    --------          -------            --------

   TOTAL MINOP LOADS                299.38   11.42      3418  105.29      31522
```