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A proposed method for efficient pre-load planning for containerized cargo ships

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A PROPOSED METHOD FOR EFFICIENT PRE-LOAD PLANNING FOR CONTAINERIZED CARGO SHIPS

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THESIS

A PROPOSED METHOD FOR EFFICIENT
PRE-LOAD PLANNING
FOR
CONTAINERIZED CARGO SHIPS

by

Dewey Eldridge Beliech, Jr.

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20.
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The program is presented in flowchart format to promote easy comprehension of the steps involved and allow coding into any programming language desired.

A Proposed Method for Efficient Pre-load Planning for Containerized Cargo Ships

by

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

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LIST OF TERMS, SYMBOLS, AND ABBREVIATIONS

TERMS AND ABBREVIATIONS

1. BOW = the forward end (front) of a ship

2. CELL = volumetric space designated for stowage of a single container

3. CENTER OF BUOYANCY = the geometric center of the under-water volume of the ship's hull

4. CENTER OF GRAVITY = the common point where the weight of the ship's structure and contained load is considered to exert a force downward

5. DECKHOUSE = that part of the ship's structure which houses the crew's living spaces, and the operational control area (bridge) of the ship

6. DISPLACEMENT = the weight of the volume of water which is displaced by the ship's hull under various load conditions.

7. FSC = Free Surface Correction - a correction factor to show the loss of initial stability caused by the shifting of weight when a liquid is free to "slosh" back and forth in a compartment or tank

8. GM = Metacentric Height - the difference between the heights of the metacenter and center of gravity above the keel. Serves as an indication of initial stability.

9. HYDROSTATIC TABLE = a table listing important stability factors of a ship at various drafts and displacements

10. KEEL = the main structural member of the ship. It extends longitudinally along the bottom of the ship's hull

11. KM = height of the metacenter above the keel

12. LCB = Longitudinal Center of Buoyancy - distance of center of buoyancy forward or aft of a stated point in the ships length

13. LCG = Longitudinal Center of Gravity (distance forward or aft of the center of the ship)

14. LIST = a condition of stability in which the ship heels (tilts) to one side due to the action of the forces of gravity acting downward and forces of buoyancy acting upward

15. METACENTER = a common point on the centerline of a ship where the forces of buoyancy act as the ship is tilted through small angles (less than 10^{o})

16. MTI = Moment To Trim One Inch - the amount of moment required to change the ship's trim one inch at a given displacement

17. OVERSTOW = a condition occurring when cargo to be offloaded at a later port is stowed over cargo to be offloaded at an earlier port

18. PORT = the left side of a ship when facing forward

19. REEFER = an electrically refrigerated container for cold storage

20. ROW = a vertical stack of container tiers

21. STARBOARD = the right side of a ship when facing forward

22. STERN = the after end (back) of a ship

23. TCG = Transverse Center of Gravity (distance to left or right of the ships longitudinal centerline)

24. TIER = a horizontal, single layer of container cells

25. TRIM = the measure of how level a ship floats in the water. Indicates whether the bow or stern is sitting lower in the water

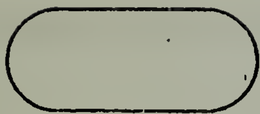
26. TRIM LEVER = the distance between the total LCG of the ship and the total LCB

27. TWENTY-FOOT EQUIVALENT = a measure of the volume occupied by a standard size container with dimensions 8'x8'x20'. Used as the unit of measure of a container ship's cargo carrying capacity.

28. VCG = Vertical Center of Gravity (height above the keel)

SYMBOLS

1.  = MIDDLE PERPENDICULAR - The vertical member of the ship's frame nearest the longitudinal center. Used to mark the center of the ship's length.

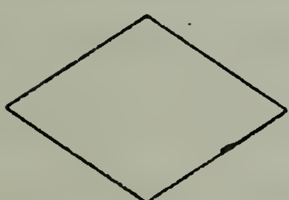
2.  = TERMINAL - The beginning, end, or a point of interruption in a program.

3.  = CONNECTOR - An entry from, or exit to another part of the flowchart.

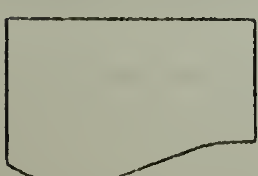
4.  = OFFPAGE CONNECTOR - A connector used to indicate an exit from one page to another.

5.  = PROCESSING INFORMATION - A group of instructions performing a processing function in the program.

6.  = INPUT/OUTPUT - Any function of inputting or outputting information.

7.  = DECISION JUNCTION - Used to indicate a branch based upon variable conditions.

8.  = PREDEFINED PROCESS - A group of operations detailed separately.

9.  = DOCUMENT- Printed output.

I. INTRODUCTION

"The old ways have failed, to the detriment of the seamen, the businessmen, the balance of payments, and the national defense."

Richard M. Nixon

A. BACKGROUND

The above quotation is an excerpt from a statement issued by Richard M. Nixon on September 25, 1968. It was a shocking, but sadly truthful description of the tragic condition of the United States Merchant Marine. The general reaction to that statement was a question as to how such a condition had evolved.

1. The Decline of the U. S. Merchant Marine

For nearly three decades prior to Mr. Nixon's statement the Federal Government had sporadically considered various ideas and programs for providing assistance to the Merchant Marine, but very little action had been taken. In the void between promise and action, maritime progress had virtually halted. The shipyards had suffered under misguided policies which had given them no incentive to increase their productivity, to provide for adequate updating of their plant facilities, or to introduce any new technology. As a result, vessel obsolescence had multiplied. By 1968 over two-thirds of the United States' merchant ships were beyond their economically useful age, and new construction had not significantly improved. (See Figure 1)

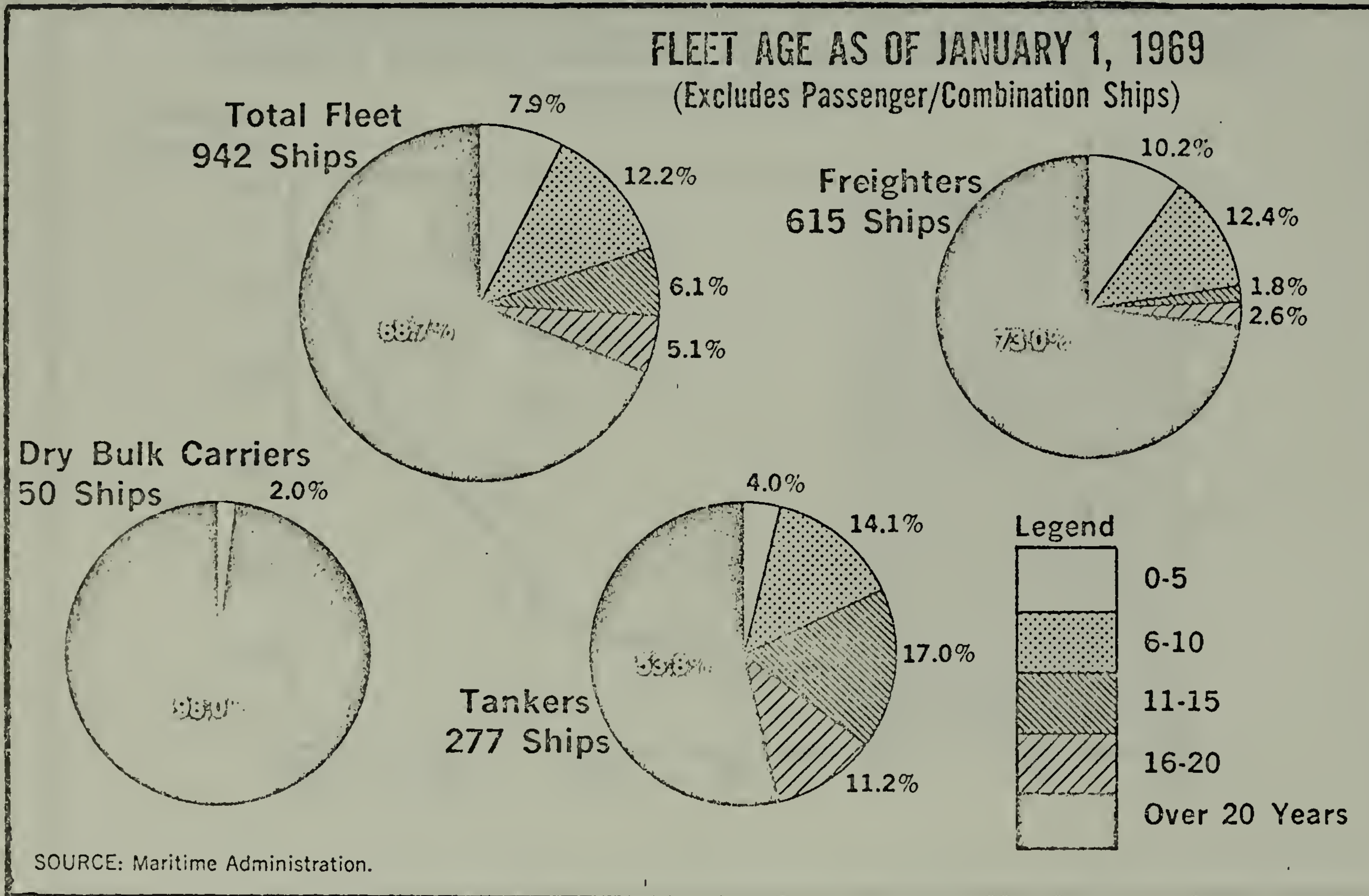


Figure 1
Age of U. S. Merchant Fleet as of 1969

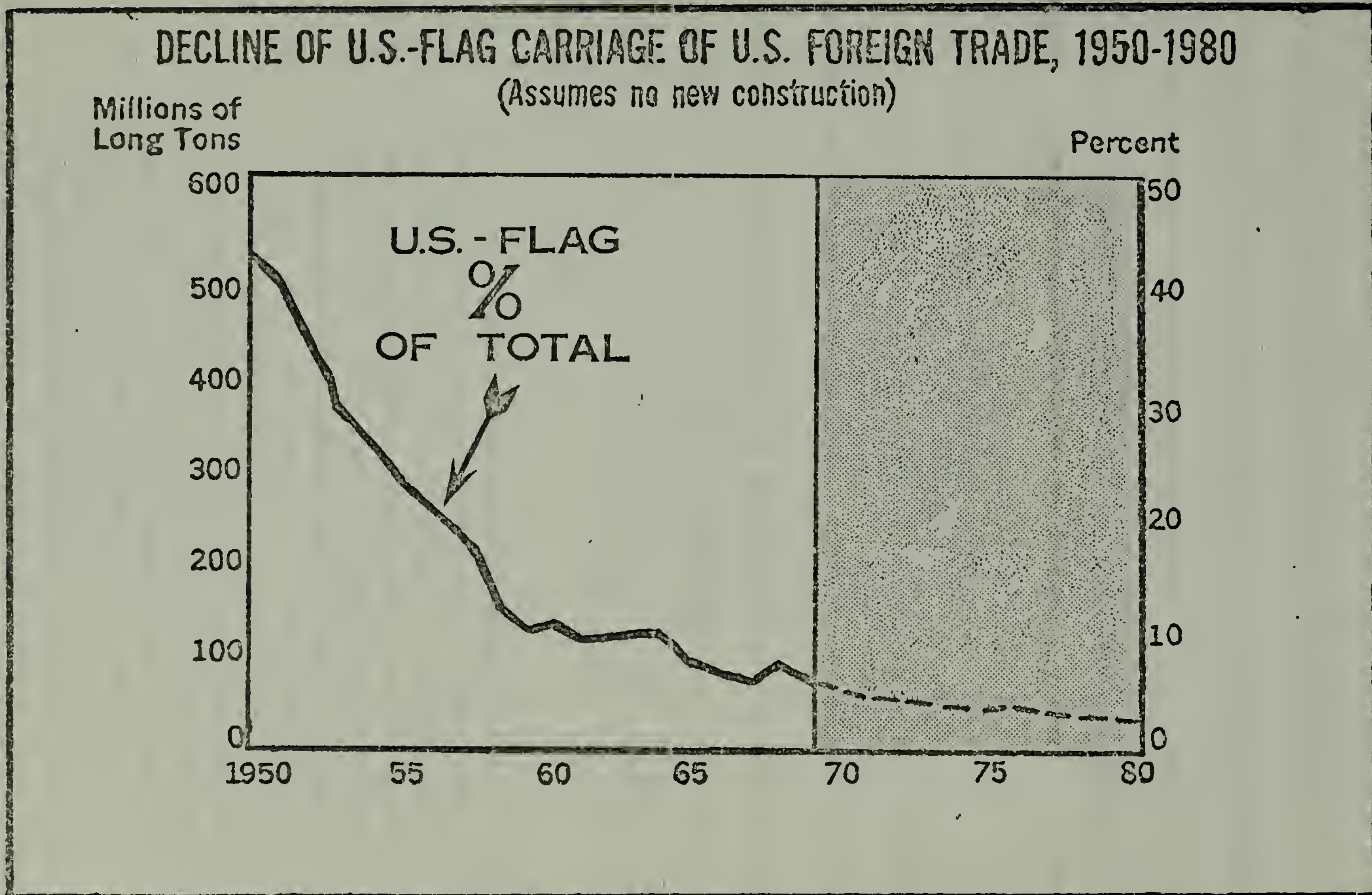


Figure 2
Percentage of U. S. Foreign Trade Carried by U.S.-Flag Ships

The downward trend had inevitably affected our global economic status. As illustrated by Figure 2, the percentage of foreign trade carried by U. S.-flag ships had steadily declined since the late nineteen-forties, and our balance of payments had suffered. By 1968 the percentage had reached a dangerously low level, ". . . and our ability to meet our maritime commitments overseas had decreased alarmingly," [Nixon, 1968].

2. The Need For a New Approach

Once the full scope of the problem had been recognized, it was obvious that some action had to be taken to reverse the trend. The "old methods" had indeed failed. It was time to try a new approach, and the only alternative which appeared to have the potential for much success was to attempt to improve the technology of the maritime industry. As stated by Mr. Nixon:

> "To overcome the present maritime crisis, I recognize that we have an opportunity and an obligation to reverse the gross deficiencies. . . All our goals will not be accomplished overnight. Restoring the U.S. to the role of a first rate maritime power requires the cooperation of management, labor, local port authorities, and government . . . We shall adopt a policy that recognizes the role of government in the well-being of an industry so vital to our national defense, and stimulates private enterprise to revitalize the industry . . . We shall adopt a policy that will enable American flag ships to carry much more American trade at competitive world prices . . . Cooperating with local port authorities, the new administration will encourage further modernization and development of our existing port facilities to meet the needs of the future . . . We shall adopt vigorous research and development programs

designed to harness the latest and best technology to the needs of our maritime fleet . . . Only through new technology can the American Merchant Marine minimize its competitive disadvantages with other merchant fleets . . . The time has come for new departures, new solutions and new vitality for American ships and American crews on the high seas of the world." [Nixon, 1968].

The need for change had been made known, and it gave birth to a new effort to revitalize the maritime industry. Ideas which had been considered before, but never seriously pursued, were once again being investigated with renewed purpose. One of those older ideas was the carrying of cargo in standard size containers aboard special ships.

3. Development of Containerization

The development of fully-containerized cargo ships in the late nineteen-sixties provided a step forward in the search for new technology. The United States had actually been a pioneer in the field since the advent of the first "Seatrain" in 1929. The idea was developed as a means of intermodal transport by carrying loaded railroad freight cars aboard special cargo ships. Unfortunately, the great potential of this concept was not fully developed due to variations in railroad gauges and the failure to recognize that this was a viable concept. It was not until the mid-nineteen-fifties that the next step in the development occurred. At that time, some of the ships operating in coastwise and contiguous trade were specially outfitted to carry the truck trailers which were used to haul cargo inland

This idea slowly evolved into the concept of a common cargo container which would be fully transferable among the various modes of transportation. By the Spring of 1966 the first fully-containerized ship had been completed and entered into the foreign trade market. Finally the potential had been realized and the concept gained widespread acceptance as the promise of a new economic future. New designs emerged, and the American maritime industry began to blossom once again with the introduction of the LANCER-class, the second generation American container-ship which commenced operations in 1968-1969 [Maritime Administration, 1970].

B. REASONS FOR THE STUDY

1. The Military Involvement

The Department of Defense has always been largely dependent on the civilian shipping industry for transportation of the majority of all military cargo, in peacetime as well as in wartime. When commercial operators began converting from break-bulk ships to container ships, it became obvious that in the future the Department of Defense could expect a large part of the shipping services provided to involve containerization. Military interest was stimulated toward the possibility of establishing a container-oriented logistics system as a principle means of supporting forces in the future. The envisioned rewards of such a system would be major improvements in the economy, efficiency, and responsiveness of future logistics operations [Department of

Defense 1972]. This total system concept is currently under investigation by civilian industry and the military, working jointly in a Department of Defense sponsored project to develop a "Surface Container-Supported Distribution System." Some of the stated objectives of that project are to:

-Develop the total system concept

-Develop required hardware, software, and procedures

-Provide for commonality and inter-changeability throughout DOD

-Ensure compatibility of DOD container systems with commercial industry systems

-Documentation development

The model developed in this thesis could prove to be very useful to the military if incorporated as part of the software and procedures of the total system. Possible usage as part of an emergency contingency system is discussed in section IV-B, "Recommendations for Use."

2. <u>Need for Further Improvement</u>

Due to the specialized equipment required, containerized cargo shipping is a highly capital intensive industry. This has been one of the major factors in its success. The rising inflation in labor costs in this country have tended to make the capital intensive systems the more profitable ones in the long run. However, in order to be successful, these systems must have a high rate of through-put to

overcome the effects of the capital investment. The majority of the hardware systems in use today are designed for high-speed handling of containers to allow loading and unloading rates in the range of 20 to 40 containers per hour (400 to 1200 tons per hour). As the industry has grown, so has the size of the ships. Newer classes now in operation are designed to carry approximately 1200 "twenty-foot equivalents." The hardware development has progressed so rapidly in the last few years that the foreseeable restriction to through-put volume appears to be man's ability to handle the planning and controlling aspects of the operation. This is the problem area which requires further improvement to realize the maximum efficiency available, and which is addressed in this thesis.

II. NATURE OF THE PROBLEM

Managerial planning and control are absolutely essential in order to competently handle the large volumes of cargo characteristic of the new containerized systems.

A. DEFINITION

When contracts are arranged for shipping, the various shippers begin to transport their cargo into the shipping company's receiving yard. As containers are received in the yard, the entire operation must be closely controlled and coordinated to reduce the handling required. Containers must be placed in specified holding areas according to which ship they will be loaded into, at which port they are to be unloaded, and who is the designated consignee. Proper arranging in the company's marshalling yard is essential to assist the managers in the Planning Division and the Port Captain in their task of planning and controlling the actual loading process. It is obvious that without close control and coordination among all concerned, unnecessary mistakes and delays will occur, and the loss of a customer may be the unpleasant result.

1. The Concept of Pre-Load Planning

When containers have been assigned to a specific ship the process of pre-load planning begins. The objective of this process is to determine a suitable on-board stowage pattern for all the

containers, and designate specific locations for each container. In determining this suitable stowage arrangement, appropriate consideration must be given to such problems as:

(1) Proper grouping of a consignee's cargo

(2) The order of port calls in the voyage (to avoid "overstow" of cargo for a later port over that for an earlier port)

(3) Special stowage requirements for hazardous types of cargo or "reefer" containers requiring access to electrical outlets

(4) Arrangements of weight to meet the ship's trim and stability requirements

(5) Order of container accessibility in the marshalling yard.

Trying to satisfy all these conditions simultaneously becomes a very complex task requiring knowledge, skill, and experience; and, it must be repeated for each ship that is to be loaded.

To insure success, the personnel selected for the planning process must be chosen carefully. Typically, the group would consist of a mixture of some individuals with advanced education in management and planning combined with others who have had actual operating experience at sea (preferably as a Ship's Master). Assuming that the company can provide adequately qualified personnel, the remaining issue then becomes a question of the procedure to be used in attempting to accomplish the required planning tasks.

2. Present Planning Methods

The actual methods used in each step of the pre-planning vary among different companies, but one factor is commonly evident -- it is time-consuming. In general, most of the planning is accomplished by manual methods; however, some companies have adopted automated techniques for handling container information and for checking the ship trim and stability requirements after the containers have been arranged and assigned in a pattern which meets the other stowage requirements. An example of such a company is American President Lines of San Francisco. Their "Container Control System" is an effective management information system using automated data processing techniques for stowage and retrieval of such vital information as container identification numbers, container size and type, cargo description, gross weight, designated shipper, carrier, and consignee, and history of movement. This type of system can be an invaluable aid in controlling the handling and stowage of containers in the receiving and marshalling areas; but most companies could probably only use the provided information as input data for the slow and laborious process of manually planning the container stowage arrangement.

To assist in the manual stages, various heuristic techniques have been devised to exploit the human capabilities of pattern recognition. Thumb-rules have been derived from company policies; and individuals have adopted their own methodology from past experiences.

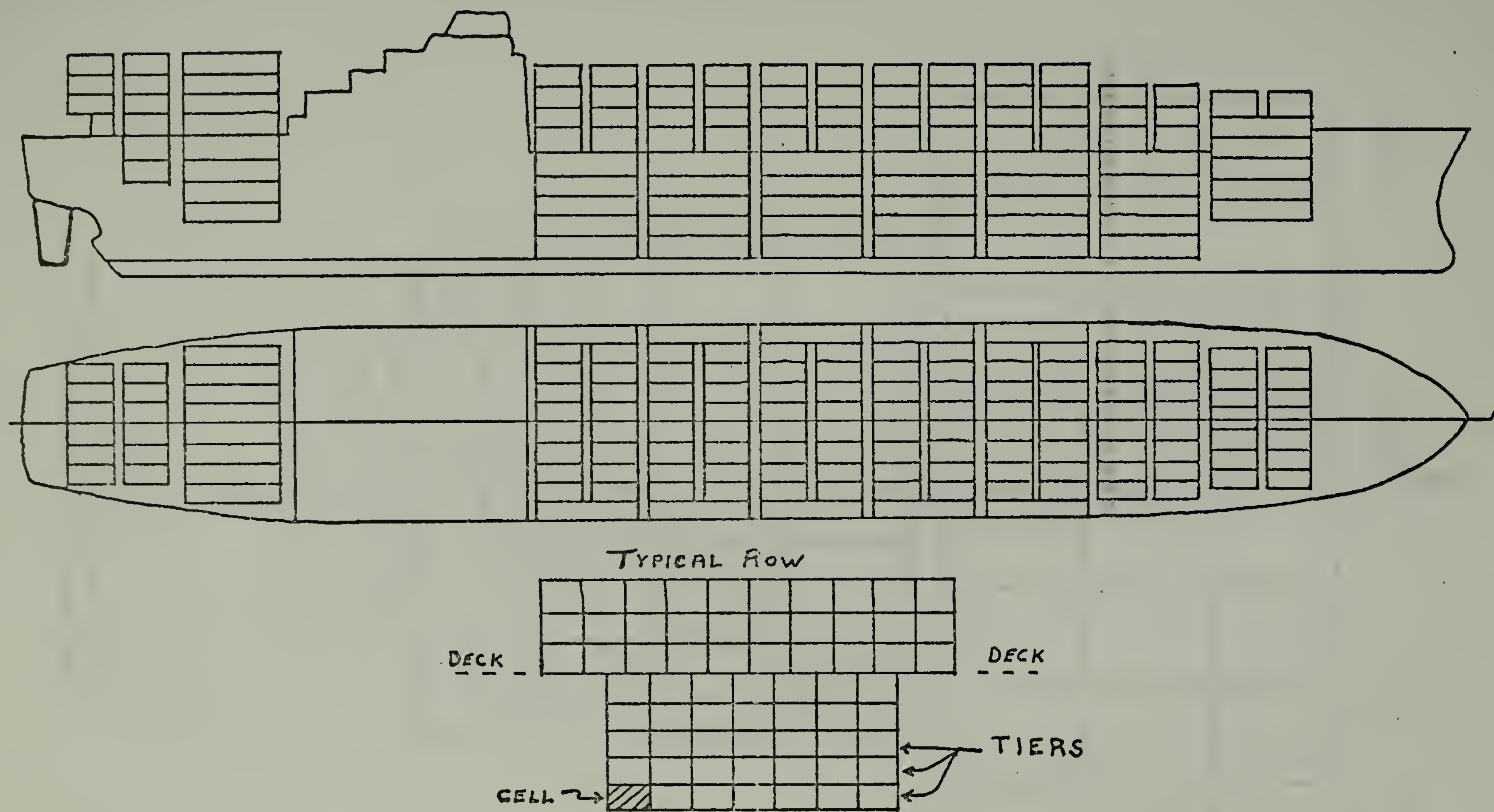


Figure 3
Sample Section of Ship Stowage Diagram

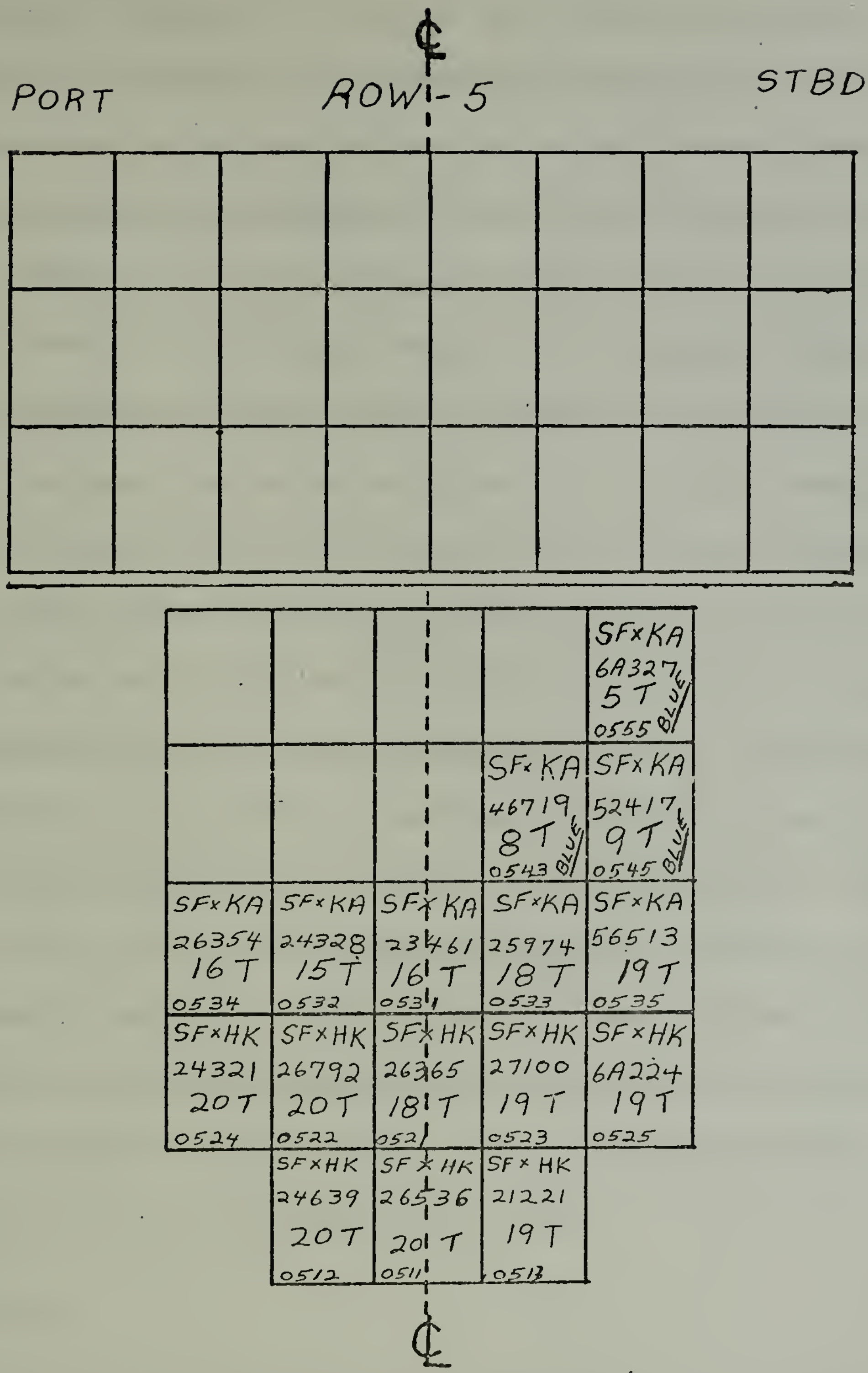


Figure 4
Sample of a Row Stowage Diagram
with Container Information

One popular technique is to color code the containers according to their port of destination. The pre-planning manager can use this color code in conjunction with special charts of the ship's stowage design to tentatively assign blocks of space for certain color containers (destinations). Filling in these blocks of space with their respective colors makes it relatively easy to spot overstow discrepancies and make suitable reassignments of space until an acceptable arrangement is found. Another technique involves the use of "stick-on" decals or other type movable placards. On each individual decal the pertinent information for a single container is manually recorded. By using appropriate status boards and area "layout charts", the decals can be attached to designate their respective locations in any given area. Properly used and controlled, this system can help keep track of each container as it moves from receiving area, to stowage, to marshalling yard. It can then be used to show the designated shipboard cell into which each container is to be loaded. Figure 3 shows an example of one section of a typical ship's stowage-plan chart, and Figure 4 is an example of how a row diagram might look with some of the decals attached for containers which were assigned to that section.

B. SCOPE

The techniques mentioned above were designed to assist in the pre-planning effort, but it is important to note that the actual assignment of containers to specific locations was still a manually performed,

highly time-consuming, trial-and-error process. It would not be unusual to find the load-planning still in progress after as much as half of the cargo had already been loaded aboard. The planners would use the tentative color-coded plan to determine the final assignment for one section of the ship at a time. As each section was assigned, the loading instructions would be prepared for that section and delivered to the stevedoring company. The longshoremen would proceed to load that section while the planners began working on assignment of the next section, keeping ahead of the loading by only a relatively small margin of time. This situation obviously poses a tentative threat of delay and unnecessary handling. There is little room for any type of error in judgment, and a question arises as to the efficiency of such a crash-basis operation.

1. Proposed Improvements

In the past, the old trial-and-error methods somehow managed to suffice. Now, larger ships are being built, and still larger ones are being designed and planned for the future. The economics of the industry require less cargo handling and shorter turn-around times for ships. If these goals are to be met, changes must be made in the load-planning to develop a more efficient process.

The objective of this study is to formulate an improved method for assigning containers to specific shipboard locations. A repetitive type of algorithm has been designed which will lend itself to automated processing techniques.

By using an automated method, the time required for the planning process should be greatly reduced. Whereas the old method required two or three days of effort, the new one should be capable of producing results in a matter of minutes or a few hours at the most (including the time for preparation and set-up). This will greatly increase management's flexibility and control capabilities. Managers can compare several different alternatives of cargo-mix or ship type to find the optimum choices. More time will be available to make arrangements for any special services required (carpenters, etc.), or for adjusting to any unusual conditions encountered (such as labor strikes, weather conditions, or procurement of materials and provisions).

Probably the most promising of the suggested improvements is the development of a total system concept incorporating an automated container control system, a container assignment program, and a stability calculation program. This planning and control package can cover all movements of containers from receipt at the receiving yard until the loaded ship sailed. Such a system would be an invaluable aid to managing and documenting the operations of a container shipping company, would make the planning process far more efficient, and would provide an increased capability for handling the larger "super-ships" envisioned for the near future.

2. Constraints and Requirements

Trying to solve such a problem naturally posed some difficulties. The task to be performed was of a very specific nature requiring some specific techniques, but the method used had to be made as general and flexible as possible due to the variations in the types of ships in use. A single model was desired which could handle the pre-planning process for a large variety of stowage plans aboard many different ships. A repetitive pattern had to be developed which would assign containers to shipboard locations in a manner which would evenly distribute the total weight for the various stowage patterns which might be encountered.

Weight distribution was of major concern, for it posed a three-dimensional problem. Total weight on a ship must be balanced with respect to the longitudinal axis to avoid listing moments, with respect to the athwartship axis to insure proper trim of the vessel, and with respect to vertical height above the keel to provide the righting moments required for roll stability. Finding a repetitive pattern to meet these requirements was a major task in itself, but there were still other requirements to be met.

In addition to satisfying the weight constraints, the order of loading containers for various ports had to be considered. When there are multiple ports to visit in a single voyage, care must be taken not to overstow a later port's containers over those of a port to be visited earlier. This overstow condition causes excessive handling of cargo

which in turn results in schedule delays and unnecessary cost increases. A typical voyage may average from three to five visits to major ports-of-call. With the advent of larger ships, it would be reasonable to expect a possible increase in the number of port visits per voyage. This required that the model remain flexible enough to handle a varying number of port calls, and still eliminate or satisfactorily minimize any overstowage of cargo.

The final set of constraints on the model proved to be the most complex of all. The problem was to find a method of assignment that not only met the above requirements, but simultaneously satisfied all of the multivariate operational safety requirements for stowage of hazardous cargo.

Chapter 46 of the Code of Federal Regulations and the United States Coast Guard Regulations have set the rules governing the classification and labeling of dangerous types of cargo, as well as establishing special stowage requirements for the various types. Basically there are eight major categories of dangerous cargo, each identified by a specific type of label:

1. EXPLOSIVES - (labeled as such)
2. INFLAMMABLE COMPRESSED GAS - (Red Gas)
3. INFLAMMABLE LIQUIDS - (Red Label)
4. INFLAMMABLE SOLIDS, OXIDIZING MATERIALS - (Yellow Label)
5. CORROSIVE LIQUIDS - (White Label)
6. NON-INFLAMMABLE COMPRESSED GAS - (Green Label)
7. POISONOUS ARTICLES - (Blue Label)
8. HAZARDOUS ARTICLES - (Labeled according to contents).

A resume of the basic stowage requirements is shown in Appendix A. The requirement to satisfy these rules greatly increased the complexity of the problem, especially in light of the fact that they were designed for use with bulk cargo. The Coast Guard Regulations for hazardous cargo have not yet been modified to apply specifically to containerized cargo; therefore, bulk rules had to be applied in determining what would constitute safe stowage rules with containerization. In developing the model, the rules of separation were followed as listed in Appendix A; and, additionally, all containers labeled "Explosive", "Red Gas", "Red Label", "White Label", or "Yellow Inflammable Solids" were required to be stowed on deck for easy access in case of emergency.

III. DISCUSSION

A. INVESTIGATION AND MODEL DEVELOPMENT

The initial phases of research in this problem consisted of a literature search to investigate any past work in this area. Contact with the civilian shipping industry and a computer search of the Defense Documentation Center's catalog files produced no results. Apparently no past work had been conducted in the area of improving the pre-planning process, at least in the sense of developing any type of algorithm or standardized method. The process was considered to be more of an art than a science, and each group of individuals had its own methods for accomplishing the task. With no past research available for assistance, it became evident that working in a new area would be a trial-and-error process of investigating various methods which might be used.

Since one of the prime constraints to be met was to satisfy the trim and stability requirements of the loaded ship, it was decided that a stability calculating program should be incorporated as a final check on any cargo assignment plan. Development of this program was undertaken first since the calculating techniques were readily available in standard texts on ship stability. Using these texts, and ideas gained from a study of a calculating routine presently used by a shipping company, a routine was developed which would calculate the trim and

stability conditions of a loaded ship and provide the required information as part of the output of the assignment routine. The Stability Calculation routine is included in Appendix C.

Once the stability routine had been developed, the problem of how to assign the cargo could be investigated. The first attempts at finding a solution were based on using mathematical techniques.

1. Attempted Mathematical Techniques

At first it was thought that this problem might well be resolved using one of the more sophisticated types of mathematical techniques such as Linear Programming. It was quickly realized that this method was not really appropriate because the obtained solutions involved non-integer quantities. Since only whole containers (integer quantities) were physically feasible, the use of conventional Linear Programming was discounted and Integer Programming methods were then investigated as possible solution techniques. Two major problems evolved in this area - one involving the problem set-up, the other concerning the time required for solution.

The first major problem was encountered in trying to describe the problem in a format appropriate for Integer Programming use. The constraints could be described well, but the objective function could not be readily formulated. The nature of the problem did not lend itself to an objective of maximizing the weight to be carried because the containers were normally pre-designated for any given ship. There was no leeway in choosing which containers to put aboard, only

in how to go about doing it. The most reasonable objective appeared to be minimizing the number of over-stowed containers, but difficulties were encountered in expressing this as a mathematical function.

The second major difficulty with Integer Programming techniques was the time required for solving the problem even if it could be determined how to do it. In the present state of the art, the solution algorithms (such as the Branch and Bound Method, or the Cutting Plane Algorithm) work on the principle of solving a set of Linear Programming problems. Constraints are continuously added or altered to cause the feasible answer to converge into integer quantities. For problems involving a large number of variables, the number of solution iterations grows tremendously as does the time required to find the final solution. In this problem each container would essentially be a separate variable. Since the total problem would involve over 1,000 variables, such a method could conceivably take years to reach a solution, even using the fastest electronic computers available. For this reason, the use of Integer Programming techniques was considered non-feasible with presently known algorithms.

2. <u>The Heuristic Approach</u>

After discounting more sophisticated mathematical techniques, it was decided to try to find a pattern of loading which would follow some of the thumb-rules used in manual planning. If a repetitive method could be developed which would assign containers in a pattern which met the given constraints, it could be coded for efficient

electronic processing. The problem then became one of attempting to satisfy the constraints.

The first two factors considered were weight distribution and overstowage of cargo. Past experience and common sense indicated that overstowage could best be avoided by sorting the containers according to their destination ports and using a "last-in-first-out" (LIFO) policy for loading order. This method would load all the containers for the last port first, followed by all containers for the next-to-last port, and would be repeated in inverse order of succession until all containers for the first port were loaded. In this manner overstow could be completely eliminated. The method could not be used exactly in this manner due to the requirement to satisfy the other constraints, but it formed the basis for the final pattern developed.

Weight distribution was the next factor incorporated into the basic pattern described above. The containers for each port were to be sorted into descending order of weights so that the heaviest would be loaded first. This facilitated developing a pattern which would tend to equalize the distribution of weight on either side of the longitudinal axis (to avoid a list condition) and simultaneously provide sufficient vertical distribution to give satisfactory roll moments. The longitudinal distribution could then be controlled by adjusting the order of loading for the rows in the ship. In general, longitudinal equilibrium would be obtained by beginning at the row at the center of balance of the ship,

then loading a row at the extreme forward end, and then extreme after end. Following this alternating pattern would spread the load evenly across the ship's length, giving the desired trim conditions.

Having found a suitable method for handling overstowage and weight distribution, the problem of incorporating the rules for separation of labeled cargo was investigated next. This proved to be a major problem area because it was necessary to restrict stowage of several types of labels (explosives, inflammables, and corrosives) to on-deck stowage in order to keep them readily accessible in case of emergency. Stowing labeled cargo on deck tended to upset the "last-in-first-out" order of loading each port, and threatened to produce overstow conditions if large mixtures of labeled cargo were encountered. To accommodate the myriad of rules governing separation of labeled cargo, a method was adopted indicating the rows in which certain types of labels had been stowed, and those rows which subsequently were to be excluded from stowage of other specific types of labels. By checking the suitability of a row prior to loading each container, the necessary separation could be maintained.

Using these basic ideas, further refinement of the details involved was pursued. The major constraint factors and the methods for handling them were combined; and the pattern of each was altered to accommodate the others simultaneously. Finally, a method was devised which incorporated all the requirements and was repetitive in nature. This method then became the basis of the final load-planning model.

B. THE RESULTING MODEL

The total load-planning model consists of a charted procedure to: (1) obtain the information on the containers and the ship to be loaded, (2) assign each container to a specific cell within the ship (while meeting the constraint requirements), (3) calculate the trim and stability conditions which would result from such an assignment pattern, and (4) provide information on the resulting conditions within a short time span. The procedure is in flowchart format to facilitate comprehension on a step-by-step basis, and to allow coding into any computer programming language which may be desired. The model has been designed with the specific intention of being run by computer, and it should be borne in mind that this is the only way it would be fully effective for producing rapid results.

To account for the varying ship designs in the industry, the model was designed to be as general as possible. It can be used for any size ship of varying design, for voyages to a varying number of ports, and for a varying number of containers. Limits on the maximum ship size and design would be determined by the specific programming techniques employed, and described by the input parameters. This allows the basic model to be programmed to cover whatever range is desired by the user.

1. Input Requirements

Because of the ability to cover a range of parameters, specific data would have to be provided on the particular type of ship used, the

containers to be loaded, and the voyage to be made.

The data required for a specific type of ship would be prepared by the user and should be established as a standard data file which could be easily and quickly called-up for use by the computer system. When the program was to be run, the user would simply designate which input file should be called to describe the design characteristics of the particular ship to be loaded. Specific data required as standard input is shown in Appendix B.

It is envisioned that the input data required for the containers would be obtained from the data bank used in a container control system. Such a system would contain a comprehensive file of information on all containers received by the company. For using this planning model, only a few of these items are actually required. These are listed in Appendix B.

Only two items of information are required concerning the voyage: (1) The total number of port calls, and (2) The order of visiting the ports. (These items are also listed in Appendix B for continuity). With this information the containers can be sorted into respective destination categories for proper order of loading.

2. Internal Manipulations

Once the input data has been entered the internal model essentially completes two tasks - it assigns the containers to stowage cells, and then calculates the trim and stability which results from that stowage plan.

a. Container Assignment

With the receipt of the ship description data, the parameters governing the assignment process are set to the proper quantities. This transforms the general model into a program for solving the specific problem at hand. The program collects all the containers and sorts them into their respective destination ports, then arranges these port groups into inverse order of port visits. This step sets up the proper arrangement for the last-in-first-out assignment. To complete the arranging steps, each port's respective group of containers is then sorted into decreasing order of gross weights. This facilitates obtaining proper weight distribution as discussed previously.

To insure proper assignment of labeled cargo requiring on-deck stowage, those containers are selected first (by searching the array of containers in its arranged order) and immediately assigned to deck areas. A method of flagging the affected stowage areas where other types of labeled cargo may not be assigned insures the proper separation as required by safety regulations. As each labeled container is assigned, the appropriate rows are flagged accordingly. The next labeled container is then not assigned to a cell until an ordered search locates an area suitable for that type label. This process is repeated for each container until the required on-deck stowage is completed. The order of selection for these labels is: "Explosives," "White Label," "Red Gas," "Red Label," and "Yellow Inflammable Solids."

When the labels listed above have all been assigned, the remaining cargo is handled by a more generalized program designed for non-labeled containers, refrigerated units, and other type labels not specifically requiring on-deck stowage. This program follows the same pattern as the previous sections for weight distribution and inverse order of port calls. As each container is taken in turn, a series of checks are made to determine whether or not it has labeled cargo or is a refrigerated unit. Following the designated order, the program checks each row until it finds a row which is suitable for that particular type container. If it is a refrigerated unit, it is stored on the deck in the first available cell which has no restrictions and has access to an electrical outlet. If it is a labelled container, it is placed in the first suitable cell and the appropriate areas are then flagged for any subsequent restrictions required by that specific type of label.

Finding a suitable row for a labeled container may well require jumping to a row different from the one which was previously being filled with non-labeled containers. A register is used to keep track of the previously filled cell number in the regular non-label loading process. After assigning a labeled container to the first suitable space found by the search, the program then returns to the next cell which would have been used in the regular loading process as indicated by the register. The next container is chosen and the search begins from that cell to find a suitable area. By using this technique, all non-labeled

containers (which also are not "reefer" units) will be stowed in a continuous fashion, filling all cells in one row before proceeding to the next row. This prevents having to begin the search for an empty cell at the first row each time and repeatedly searching through many filled areas before finding an empty, suitable cell.

The requirement to load special labels on deck increased the chance of getting an overstow situation with the assignment routine used. To avoid this, the regular program jumps to the next ordered row when it finds the first cell on deck previously filled by the assignment of labeled cargo. This jump causes all cells above the filled ones to be initially left empty while loading the remainder of the cargo. If a ship is to carry a less-than-capacity load (approximately less than 95%) this would cause no problem; but for a near-capacity load those cells which would have been left empty may well be needed. To account for this situation, a "switch" technique is used to slightly alter the program from its "regular" mode to a "full ship" mode. When the last ordered row is filled, and more containers remain to be assigned, the mode is switched from "regular" to "full ship." In the latter mode, the program begins again at the first ordered row, this time starting with on-deck stowage only. It then proceeds to assign the remaining containers to suitable cells found empty on top of the already loaded cells. Due to the inverse port order, by this time the remaining containers should all be the last or next-to-last port. This greatly decreases the chances of overstowage.

If for any reason this routine is unsuccessful in assigning all containers, a warning will be printed out to the operator indicating this condition. The program will then stop and wait for further instructions. The options in this case are to print out the present assignment plan for manual inspection, or drop the remaining containers, print out a list of those not loaded, and proceed to the Stability Calculation Program. The Container Assignment Program is given in flowchart form in Appendix C.

b. Stability Calculation

When all containers have been assigned stowage cells (or when the overload condition described above occurs) the next step in the model is to proceed to the Stability Calculation Program.

The first part of this program calculates the stability factors of the ship which are independent of any cargo to be loaded. These include standard light-ship conditions, ship's stores, fuel oil tanks, fresh water tanks, and any miscellaneous tanks or compartments (such as lube oil stowage). To calculate the stability factors of these areas, data must be provided giving the weights contained in each compartment or tank. When this data has been entered, the program will calculate the total weight, the longitudinal moment (forward or aft), the transverse moment (port or starboard), the vertical moment, and total free surface correction for each area. Ballast is considered to be zero because the program is designed to show the conditions which would exist with no ballasting. This method was chosen because ballast would continually be shifted as

required during the actual loading process, and also because it gives the ship's crew the choice of how much and where to add or subtract ballast if it is required when the load is completed.

The second section of this program calculates the stability factors of the cargo resulting from loading in accordance with the assignment plan determined in the Container Assignment Program. Beginning at row-1, cell-1, the transverse center of gravity (port or starboard) and the transverse moment (port or starboard) are computed for each cell in a tier. As each tier is completed, its total weight, total transverse moment (port or starboard), longitudinal moment (forward or aft), and vertical moment are computed. Since the vertical and longitudinal centers of gravity remain unchanged for each cell in any particular tier, it is only necessary to calculate these two moments for the tier as an entity rather than for each cell. The final steps in this stage of the program determine the sub-totals of each category factor. These subtotals are then combined to produce the total weight and moment factors for the entire ship.

The last section of this program performs the final trim and stability calculations for the loaded ship with no ballast aboard. The most important results of these calculations are the ship's total displacement (weight in tons), the metacentric height (GM) corrected for total free-surface effects, mean draft, the change in draft forward and aft, and any list angle (port or starboard) which might develop from

these conditions. The Stability Calculating Program is given in flowchart form in Appendix D.

It should be mentioned here that, for planning purposes, it would not be necessary to use the entire Stability Calculating Program. A shorter version could be used to provide more rapid information with less input required. By eliminating the first section (pre-load conditions) except for the light-ship conditions, the program could be used to calculate the stability of the ship due to the cargo assignment itself. In this manner, the model could easily be used to obtain a tentative load plan without having to wait for knowledge of the ship's pre-load condition. This would allow use of the model as soon as the container information was available.

3. Output

The basic information available from the model has been previously described. The actual output is completely variable. The format and scope of information provided are at the discretion of the user depending on how the program were coded and the type of hardware to be used. It is envisioned that the container stowage plan and the final GM and list conditions would be the minimum information desired in order for the model to serve its purpose. It is also suggested that the most readily useful format for the assignment plan print-out would be one similar to that produced manually on a lay-out chart (as shown in Figure 4). A suggested format for the stability output is shown in Appendix E.

IV. CONCLUSIONS

Having discussed the development of the model and its internal working scheme, some comment should be made concerning its worth as a useable management tool.

A. FEASIBILITY OF THE MODEL

The author does not contend that the model proposed here is a panacea for all container load-planning problems. The basic ideas and the methods described here are totally feasible concepts; but in developing the details involved, some assumptions had to be made. As a result, the overall capabilities of the model are subject to some limitations.

The wide diversity of present container sizes made it extremely difficult to determine any method suitable for general use throughout the shipping industry. To avoid this problem, the method developed was based on the assumption that all containers would be of a single, standard size. Implementation and use of the model as presently described would require that this standardization constraint be upheld. All containers would have to be the same, but no limitations are set as to what the dimensions could be. This is not considered an unreasonable requirement, for the idea of a standard size, inter-model capability was one of the primary advantages inherent in the containerization concept. That capability has been obtainable for some time, but container size

has continued to vary due to competition among shipping companies. The military is presently investigating various sizes of containers in an effort to move into standardization; and it should be safe to assume that the industry as a whole would follow suit sometime in the near future. As a bare minimum, the sizes could be narrowed down to two standards (a large container and a small one) to maintain flexibility in the sizes of shipments handled.

A second limitation of the model is found in its capability to handle various cargo mixes which involve safety regulations requiring separation of labeled cargo. Due to the conservative nature of the routine used to establish that separation, more space is flagged as "non-useable" than may be absolutely necessary. This could possibly lead to a potential shortage of "useable" stowage cells in cases where mixed loads contain large quantities of various types of labels. Since no statistics are presently available on use of the model, the exact nature of this limitation cannot yet be quantitatively described. With normal loads involving mixtures of the labeled cargo, there should be no problem, but the possibility of a problem is mentioned for the information of future potential users of the model.

Another factor which should be considered as a potential problem area is container accessibility. The design of the model does not account for container locations in the receiving or marshalling yard prior to loading. To maintain the repetitious assignment pattern desired for

electronic processing equipment, the assumption had to be made that any container could be chosen at random for assignment. During the actual loading process, this could become a problem if all containers are not readily accessible when required. In port facilities where enough room is available to stow containers in a single layer, there would be no problem. In those ports where land is at a premium, containers must be stacked two or three high to make efficient use of the area available. To obtain the bottom container, the others would have to be moved, resulting in excess handling. A possible solution to the access problem might be to store containers in a frame-work structure which has individual, readily accessible cells similar to a honey comb structure. Each container could then be stowed or removed at will without disturbing the others.

If standard size containers are used, each is accessible, and unusual load mixes are not encountered, the proposed model is a feasible one for present implementation and actual use as a management tool in the shipping industry of today.

B. RECOMMENDATIONS FOR USE

The described model was developed for the primary purpose of improving the pre-planning process, but its maximum efficiency would be obtained by incorporating it as part of a total planning system.

1. Total System Concept

The system envisioned would consist of an automated method of collecting and handling container information, the planning model proposed here, and an automated report generating program. The data collection program would maintain all information files required and would serve as the input mechanism for providing the rest of the system with required data. The assignment program would plan the stowage arrangement of the containers in accordance with its designated parameters and provide that assignment plan as input for the stability calculating program. When stability conditions have been calculated for the designated load plan, all information would be available in the data files. From there, it could be retrieved at will, in any format desired, by specifying that format in the report generating program. Documentation could be prepared by machine to serve the needs of management, or for other areas such as customs documents and loading instructions for the stevedoring company. Access to such a system would greatly enhance the shipping company's planning and control capabilities and would assist in providing information for further investigation in other areas of the container shipping industry.

2. Emergency Contingency System

Use of a total system concept could also prove beneficial for governmental or military purposes. With an automated planning system as an aid, a contingency supply system could be established to provide the capability of rapid response to an emergency situation. Containers

could be pre-loaded with specified materials and sealed for long periods of stowage. Sets of these containers could be grouped at designated locations and by specific types of materials needed during various types of emergencies. (Military emergencies, floods, earthquakes, hurricanes, or other disasters). Various cargo mixes and types of ships could be compared, and guidelines established on how best to respond to any given type of situation. With these contingency supplies available at strategic locations, the information on the containers could be kept in a central data file. Groups of containers could be quickly designated for use as required and all necessary documentation and instructions could be produced within a very short time span. This would allow the actual loading and shipping of the contingency supplies to begin immediately without the usual delays due to the time required for load planning and producing the necessary documents. This rapid response capability could certainly prove to be a valuable asset in a future time of need.

C. IMPLICATIONS FOR FURTHER STUDY

In order to implement the proposed planning model, the charted process must first be coded and programmed for use on electronic computing equipment. Trial runs should be made using various mixtures of different quantities and types of labeled cargo to investigate the model's capabilities and limitations in handling those mixtures. Statistics should be collected to verify and document its performance.

1. Expanded Input/Output Capabilities

The first logical extension of the model's capabilities would be to enable it to simultaneously handle two different size containers. This would make the model readily useable to industry now, since most shipping companies are presently using both large and small containers.

To make the uses suggested in the previous section totally feasible and obtainable, the use of various types of electronic input/output hardware and techniques should be explored. Which types of equipment would provide the most rapid input and access capability? Which would be most suitable for outputting information and preparing desired documents? These questions should be answered empirically. With selection of the proper equipment, the output capabilities of the model could be expanded to include:

(1) Loading diagrams

(2) Stevedore loading instructions

(3) Manifests and other cargo documentation

(4) Hazardous cargo lists

(5) Customs documents

Further development of the model's internal processes could also lead to uses in areas such as cost/benefit analysis. As an example, it should be feasible to have the model determine the number of containers which may have been overstowed, and calculate the costs involved in moving those containers the required number of times to get to the

cargo beneath them. This could be of great assistance to the booking department in determining whether it is worth the effort to try to get a late arriving customer's cargo included on a ship already being loaded. Perhaps a program could be developed to help determine when the cut-off point had been reached for changing the input list of containers, and what the costs would be if changes were made beyond that point. These financial areas deserve further investigation.

2. Automated Port Facility

An important extension of the total system previously described might be the development of an automated container port facility. This concept offers the potential for a vast increase in the through-put volume which a single port is capable of handling. The importance of high volume trade in a capital intensive industry has already been discussed. Various ideas for automated ports are presently under consideration by the shipping industry, and it would appear that the total system suggested in this thesis could serve as the heart of such a facility.

The envisioned port would utilize large framework structures for storing each container in its own individual cell to allow ready access when required. (See example of facility in Figure 5). A crane system would work within this structure for stowing and removing containers. After a suitable assignment plan was determined and checked for stability, the computer system would instruct the crane to remove containers for loading in the required order. As each container was removed from

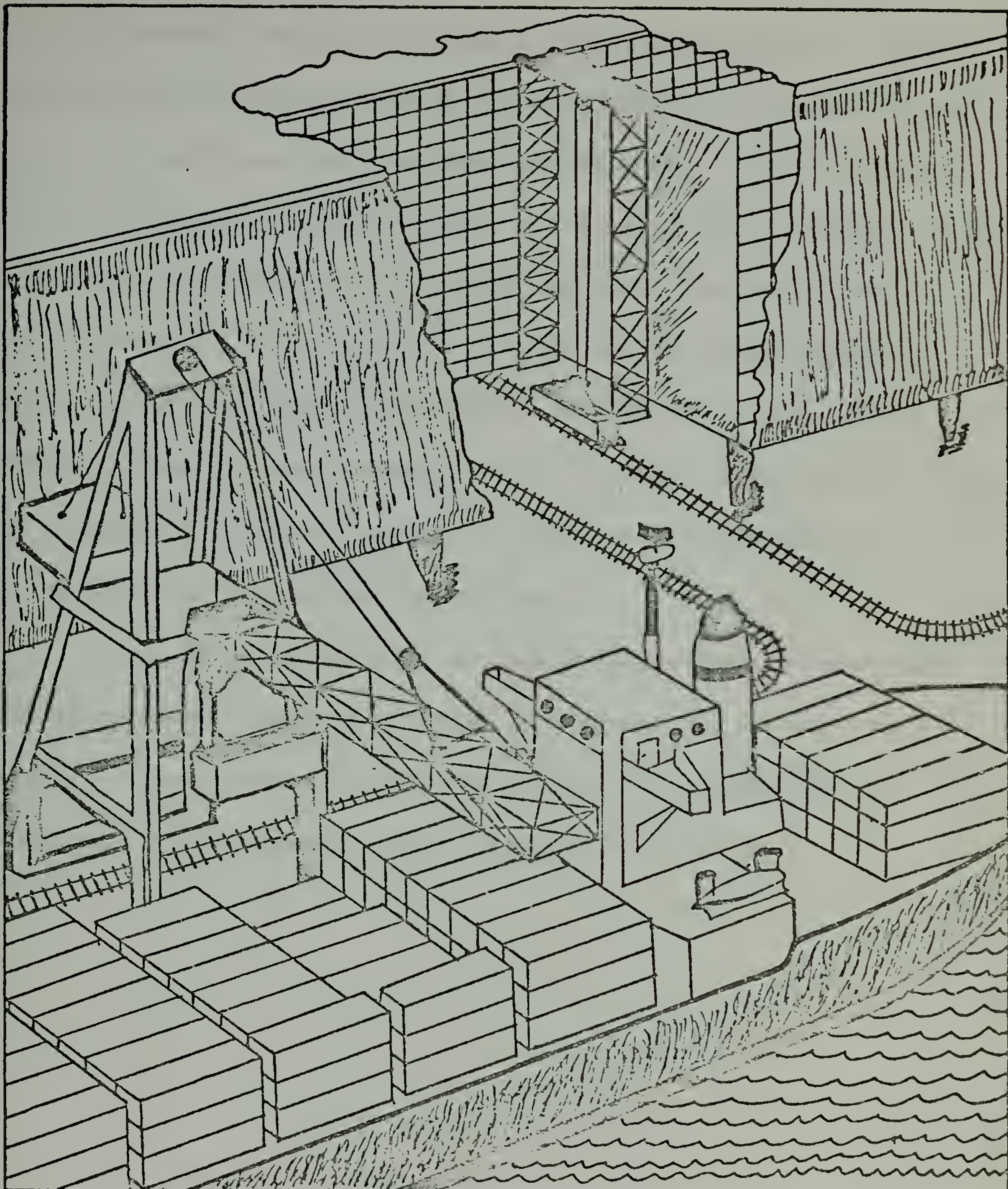


Figure 5
Artist's Concept of an Automated
Port Facility

its cell it would be placed on a remotely controlled "dolly-car" which would move on rail tracks from the stowage area out to the loading quay area and be positioned under the ship loading crane. The crane would remove the container from the "dolly" and place it into its assigned shipboard cell as designated by the assignment plan. The empty "dolly" would then return to the storage area to be loaded with another container. With an oval "race-track" layout for the rail tracks, three or four "dollies" could be spaced so that all were working simultaneously. This would provide a continuous supply of containers to the loading crane in the correct order for loading aboard ship.

This concept is not only feasible, but appears to be obtainable with only a small amount of hardware development for the machinery required. It is strongly suggested as an area for investigation and incorporation of the planning model proposed in this thesis.

APPENDIX A: BASIC RULES FOR STOWAGE OF LABELED CARGO

EXPLOSIVES

1. Must not be stowed with any other labels.

INFLAMMABLE COMPRESSED GAS - (RED GAS)

EXAMPLES: BUTANE, LPG, ACETYLENE

1. Must be stowed on deck.
2. Cannot be stowed over a red label hatch.
3. Must be 25 feet from any other hazardous cargo.
4. Must have the deck house between it and explosives.

INFLAMMABLE LIQUIDS - (RED LABEL)

1. Must not be stowed in the same hatch with inflammable solids, oxidizing materials, corrosive liquids, poisons, or cotton.
2. Must not be stowed in the same hold over non-inflammable compressed gases.
3. Many red label items require between deck stowage therefore no red label is to be stowed in a lower hold or deep tank without checking the regulations.
4. Must have a full hatch or midship house intervene between it and explosives.

INFLAMMABLE SOLIDS/OXIDIZING MATERIAL - (YELLOW LABEL)

BOTH ARE YELLOW LABEL BUT HAVE SOME VARIATION IN STOWAGE. CHECK CLOSELY BEFORE LOADING

1. They must not be stowed in the same compartment or hold.

2. Must not be stowed in the same hold or compartment as red label, corrosive liquids, poisons, or cotton.

3. Must not be stowed in the same compartment over non-inflammable compressed gases.

4. Must have a full hatch or midship house intervene between it and explosives.

CORROSIVE LIQUIDS -(WHITE LABEL)

EXAMPLES: ALL CORROSIVE ACIDS AND WET BATTERIES, SODIUM HYDROXIDE SOLUTION, LIQUID CAUSTICS.

1. Some are permitted under deck stowage. General policy is to stow on deck at all times.

2. Must not be stowed adjacent to, or over, any compressed gases.

3. Must not be stowed adjacent to or over any poisonous articles or hazardous items.

4. Must not be stowed on the square of the hatch.

5. Must have a full hatch or midship house intervene between it and explosives.

NON-INFLAMMABLE COMPRESSED GASES - (GREEN LABEL)

EXAMPLES: OXYGEN, FREON, HELIUM

1. Must not be stowed with explosives.

2. Must not be over stowed with corrosive liquids, inflammable liquids, inflammable solids, oxidizing material, poison, or hazardous articles.

POISONOUS ARTICLES - (BLUE LABEL)

1. Must not be stowed in the same compartment with explosives, inflammable liquids, inflammable solids, refrigerated cargo, or cotton.

2. Must not be stowed adjacent to corrosive liquids.

3. Must not be stowed over compressed gases.

HAZARDOUS ARTICLES

EXAMPLES: COTTON, OLD NEWS, CALCIUM CARBIDE, SOLID CAUSTICS, AND BLEACHING POWDERS.

1. Hazardous articles <u>must not</u> be stowed in any compartment with explosives.

APPENDIX B: DATA REQUIRED AS INPUT

SHIP DATA

1. Cargo Area Data

   a. Total number of rows in the ship

   b. The number of the first row aft of the deckhouse

   c. Dimensions of largest row

      (1) Maximum number of containers across a tier

      (2) Maximum number of tiers in a row

      (3) The number of the first tier on deck

   d. For each row:

      (1) Row number

      (2) Its designated order of loading

      (3) Code to indicate whether or not it has outlets for reefers

   e. For each tier:

      (1) Tier number

      (2) Total number of cells in that tier

      (3) Vertical center of gravity (VCG) (ft)

      (4) Longitudinal center of gravity (LCG) (ft fwd/aft of ⊗)

2. Light Ship Data

   a. Displacement (tons)

   b. Vertical moment (ft-tons)

c. Longitudinal moment (ft-tons, Fwd/aft)

d. Distance from forward perpendicular (FP) to after perpendicular (AP)

e. Distance from   to forward draft marks

f. Distance from   to after draft marks

3. Crew, stores data

a. Total number of crew, stores compartments

b. For each compartment

(1) Compartment number

(2) VCG (ft)

(3) LCG (ft fwd/aft of ⊗)

(4) Transverse center of gravity (TCG) (ft port/stbd)

4. Fuel-oil tanks data

a. Total number of tanks

b. For each tank:

(1) Tank number

(2) VCG (ft)

(3) LCG (ft fwd/aft of ⊗)

(4) TCG (ft port/stbd)

(5) Free surface correction factor (FSC) (ft)

5. Ballast Tanks and Fresh Water Tanks Data

a. Total number of ballast, fresh water tanks

b. For each tank:

(1) Tank number

(2) VDG (ft)

(3) LCG (ft fwd/aft of ⊗)

(4) TCG (ft port/stbd)

(5) FSC (ft)

6. Miscellaneous Compartments/Tanks Data

   a. Total number of compartments or tanks

   b. For each compartment or tank:

      (1) Compartment or tank number

      (2) VCG (ft)

      (3) LCG (ft fwd/aft of ⊗)

      (4) TCG (ft port/stbd)

      (5) FSC (ft)

7. Hydrostatic Table Data

   a. Displacement (tons)

   b. Mean Draft (ft., in.)

   c. Metacentric height (KM) (ft)

   d. Moment to trim one inch (MTI) (ft-tons)

   e. Longitudinal center of buoyancy (LCB) (ft fdw/aft of ⊗).

   f. Longitudinal center of flotation (LCF) (ft fwd/aft of ⊗).

CONTAINER DATA

1. An input of the total number of containers to be loaded.

2. For each container:

a. Identification number

b. Port of destination

c. Gross weight (tons)

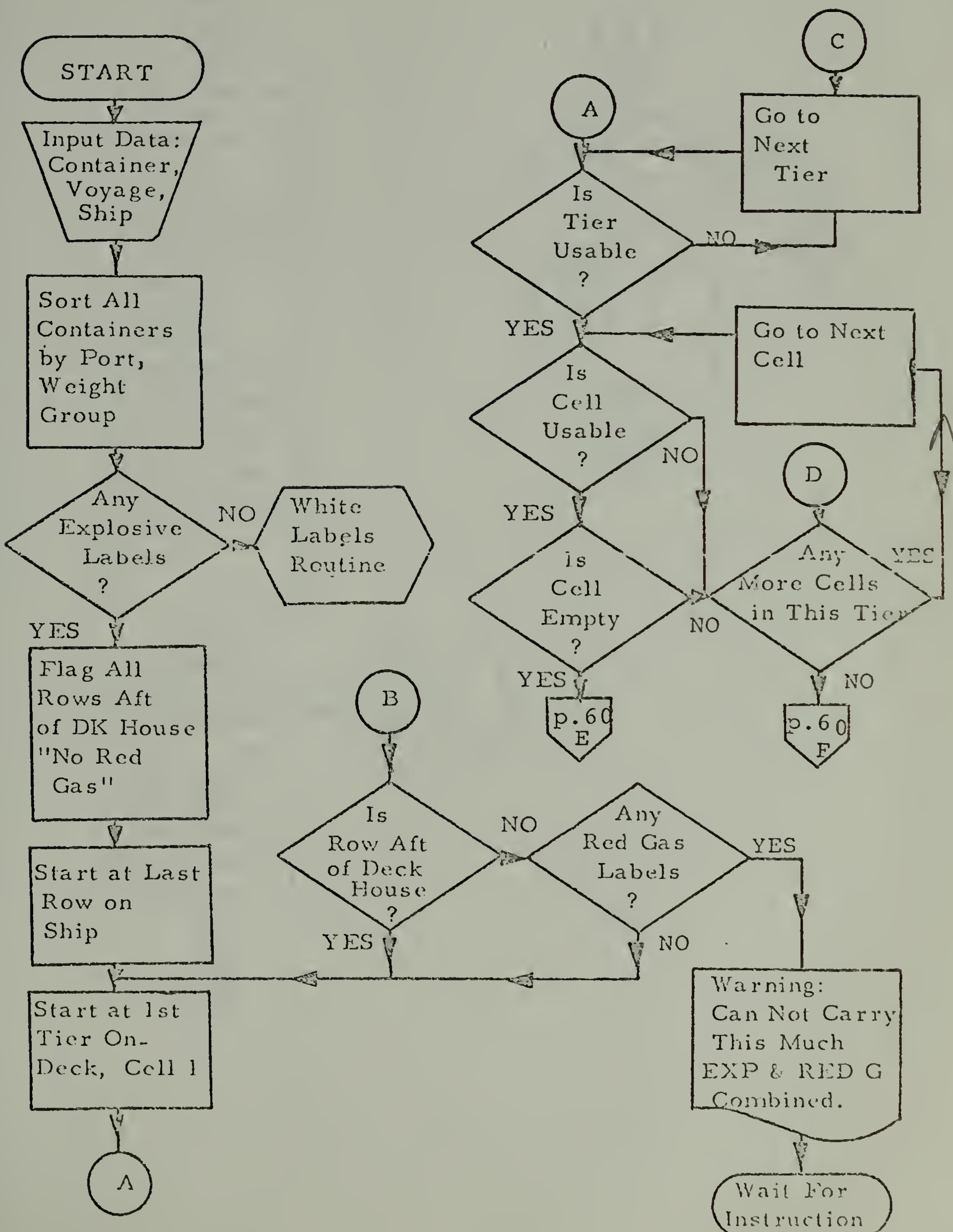
d. Label category of the cargo

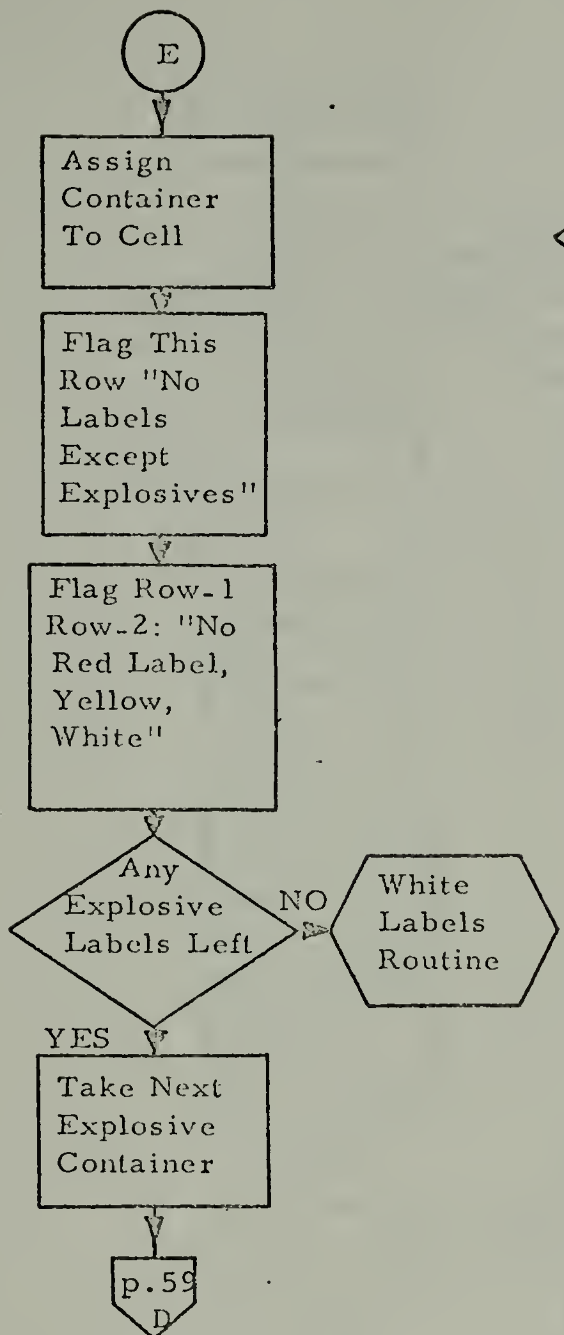
VOYAGE INPUT DATA REQUIRED

1. Total number of port calls

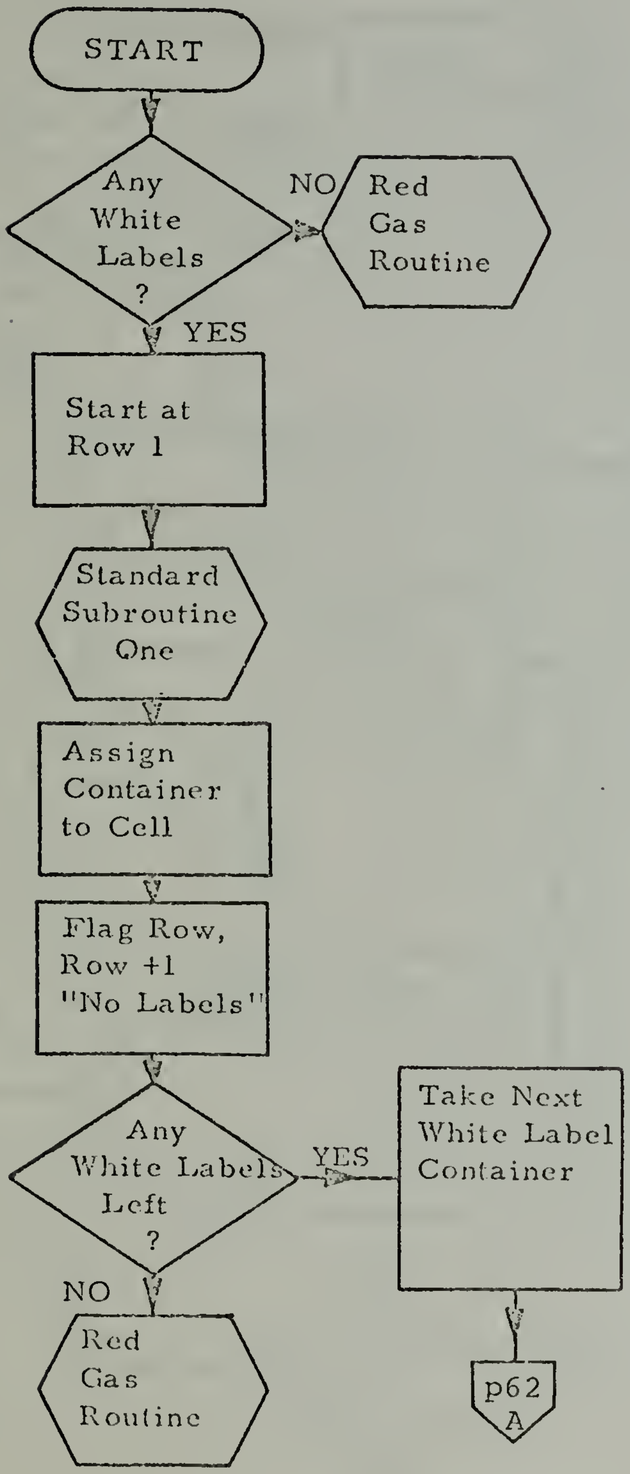
2. The order of visiting the ports.

APPENDIX C:
FLOWCHART OF CONTAINER ASSIGNMENT PROGRAM
(Explosive Label Routine)

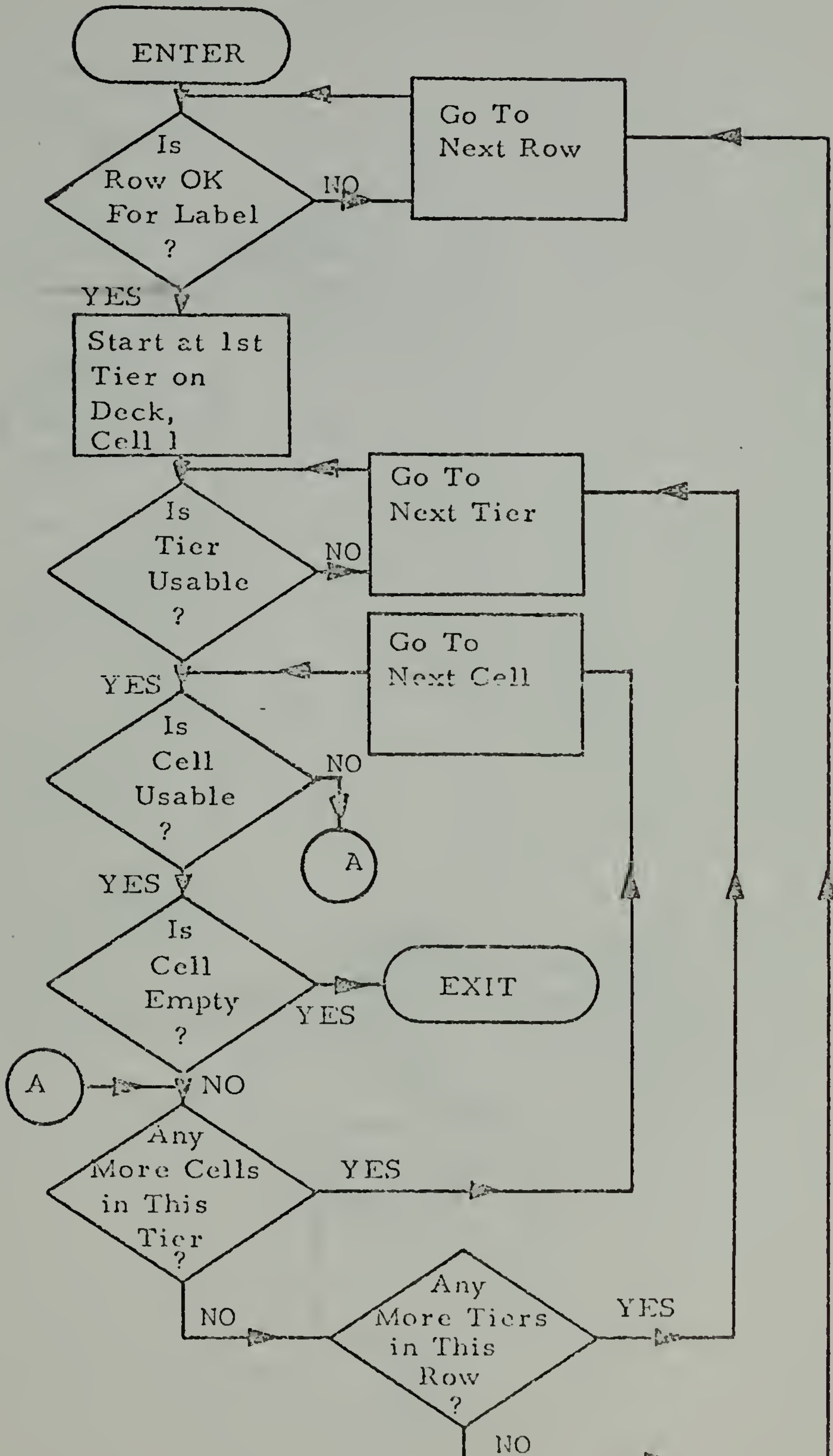



E
Assign Container To Cell
Flag This Row "No Labels Except Explosives"
Flag Row-1 Row-2: "No Red Label, Yellow, White"
Any Explosive Labels Left
NO
White Labels Routine
YES
Take Next Explosive Container
p.59 D
F
Any More Tiers in This Row ?
YES
p.59 C
NO
Move Forward 1 Row
p.59 B

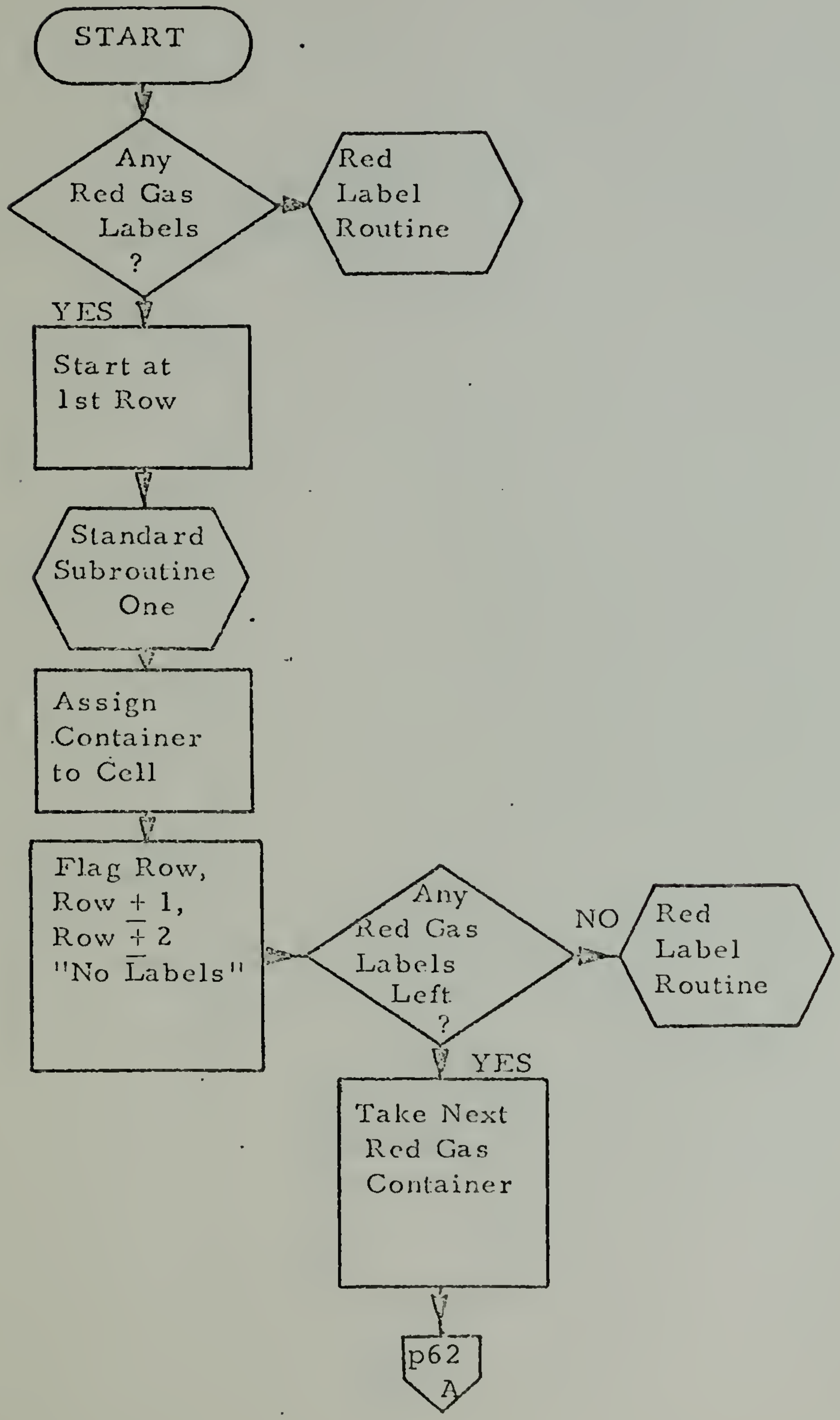
(WHITE LABEL ROUTINE)

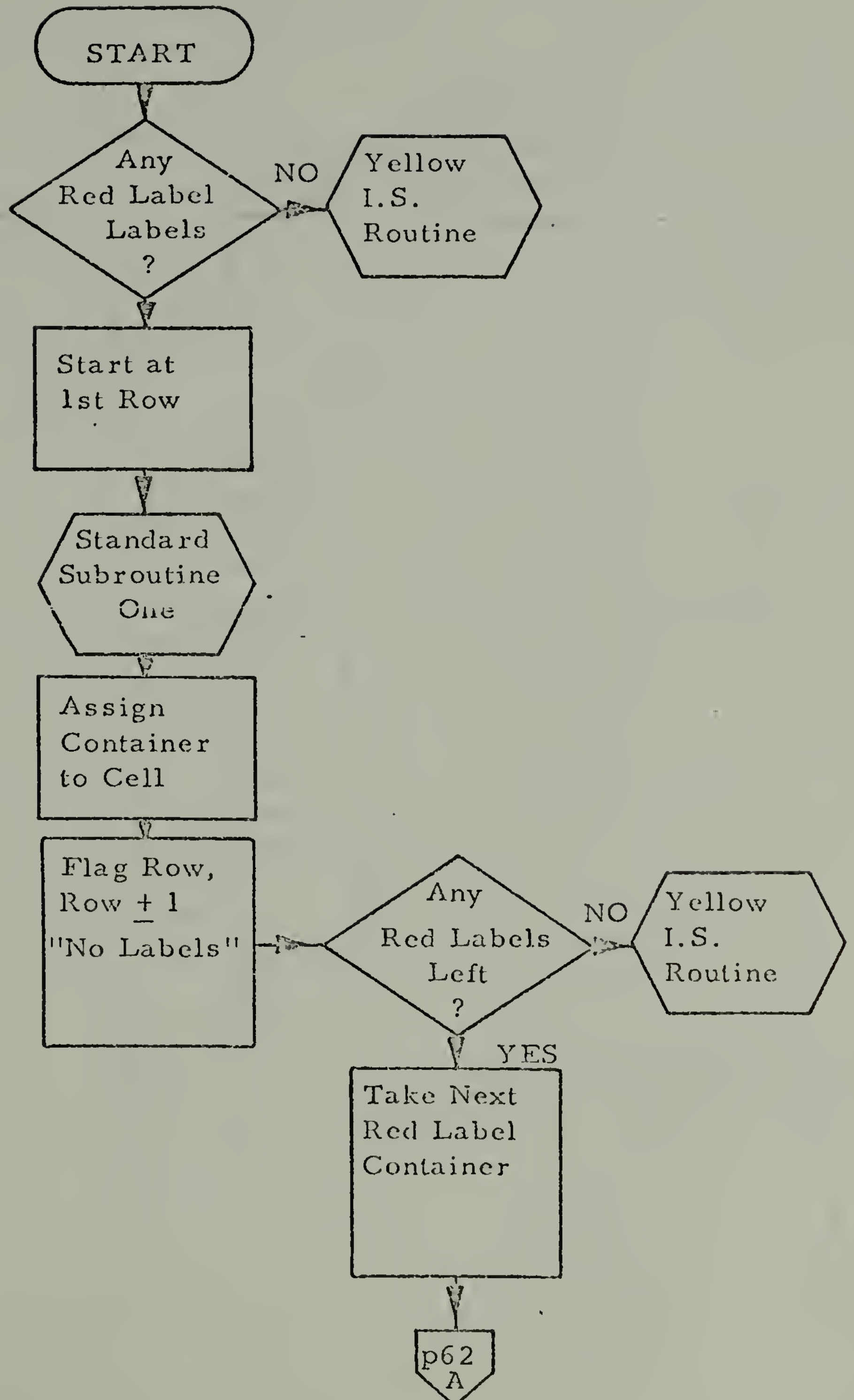


(STANDARD SUBROUTINE ONE)

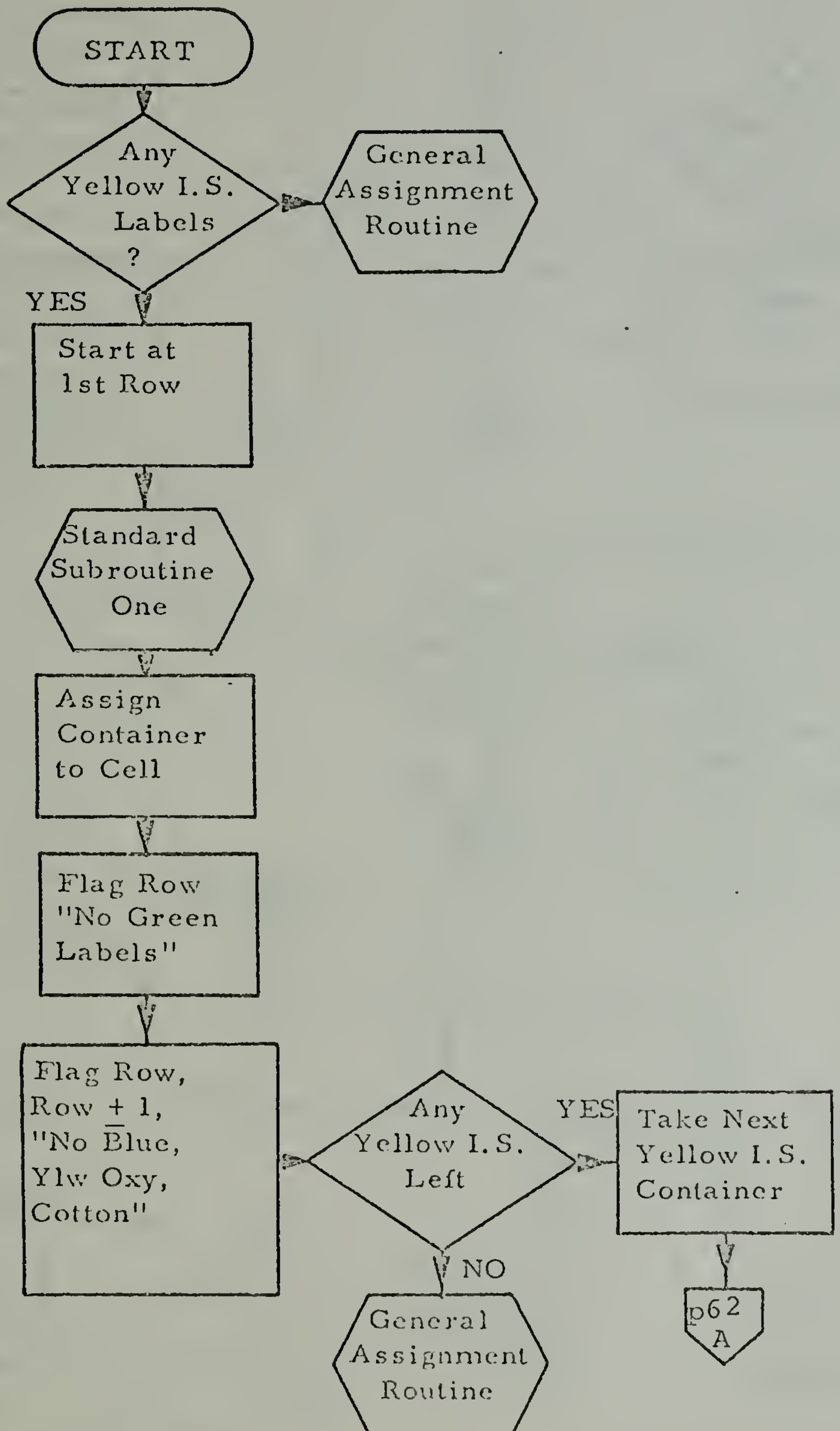


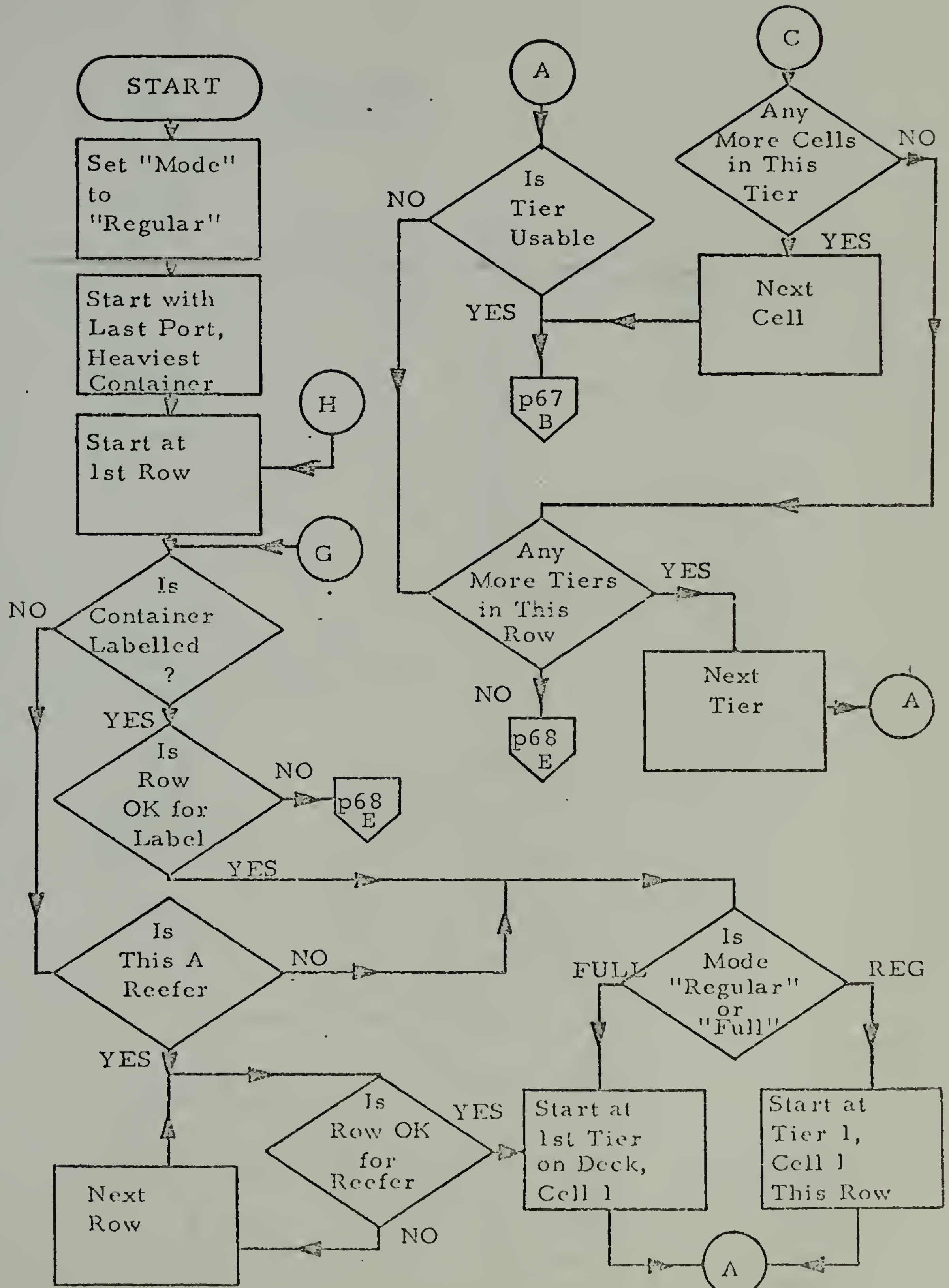
RED GAS ROUTINE

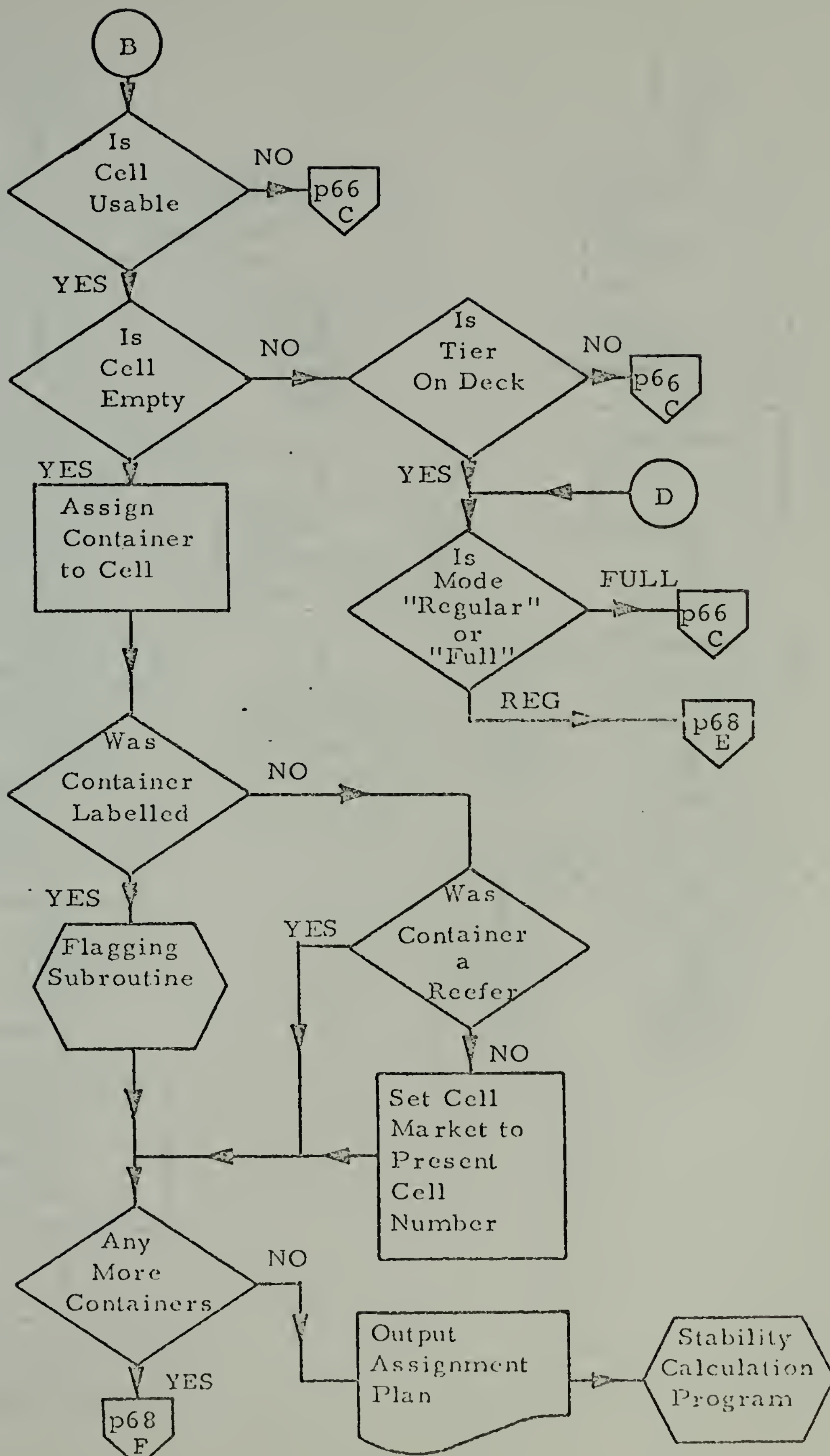


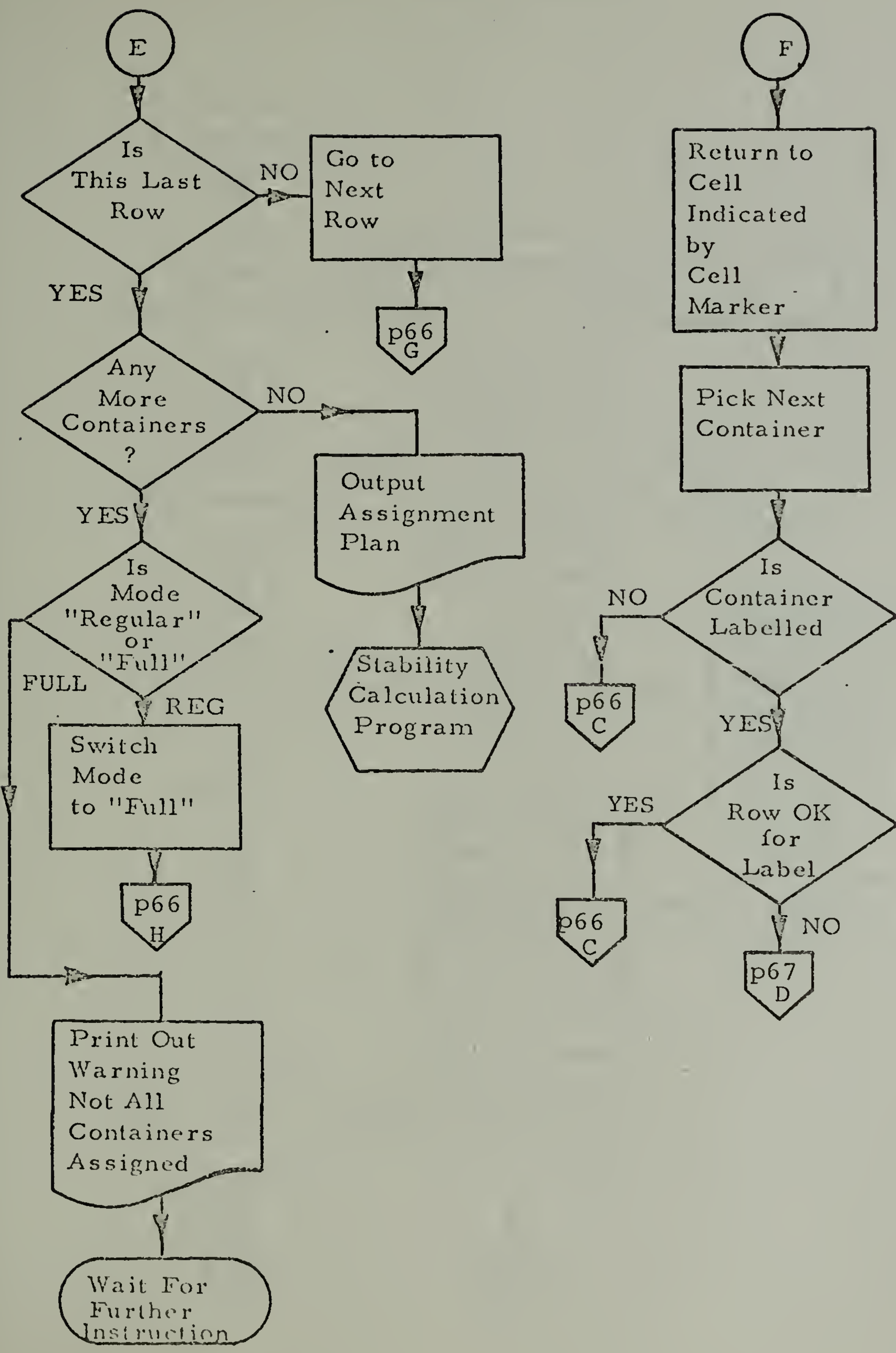

START
Any Red Label Labels ?
NO
Yellow I.S. Routine
Start at 1st Row
Standard Subroutine One
Assign Container to Cell
Flag Row, Row + 1 "No Labels"
Any Red Labels Left ?
NO
Yellow I.S. Routine
YES
Take Next Red Label Container
p62 A

YELLOW INFLAMMABLE SOLIDS ROUTINE

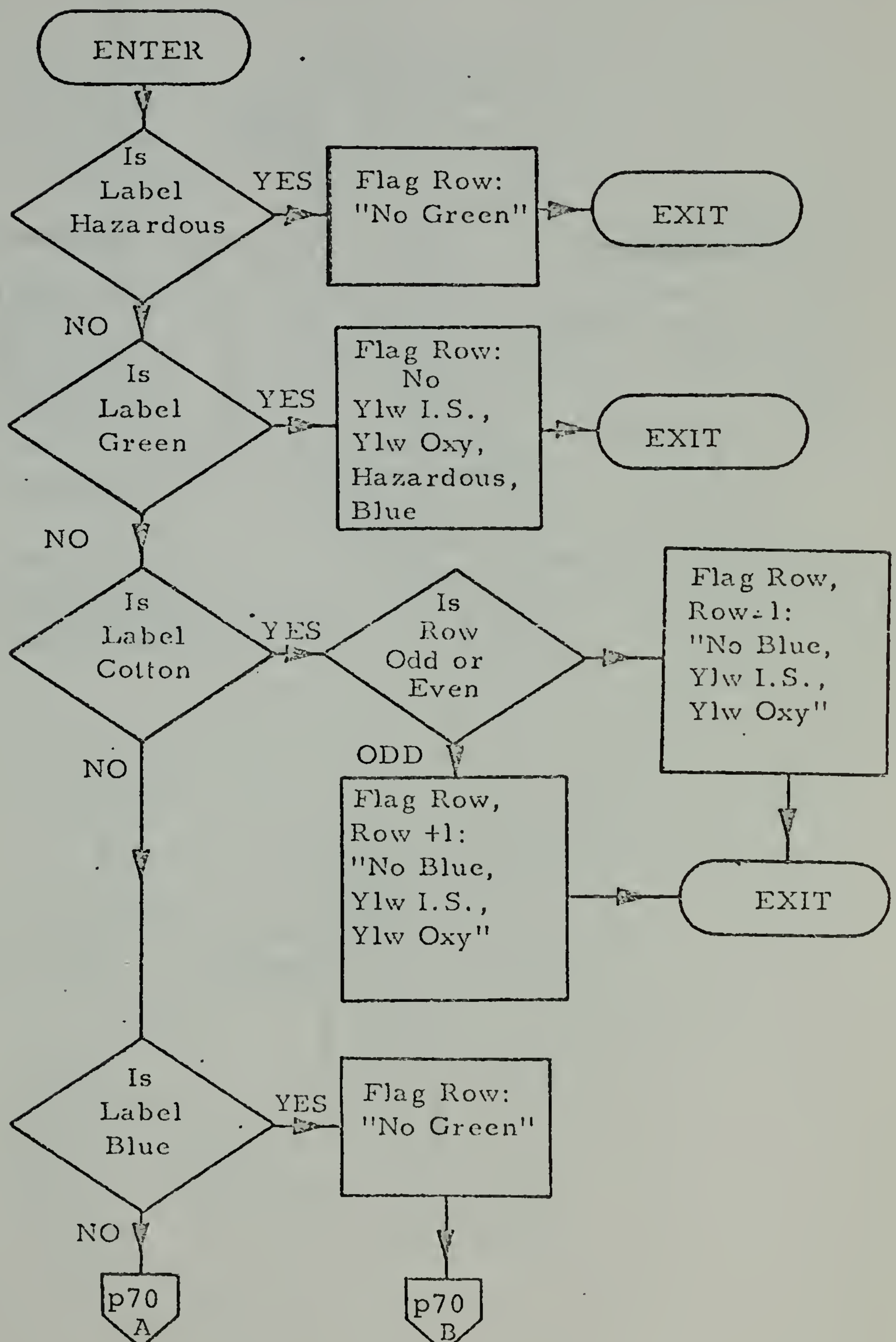


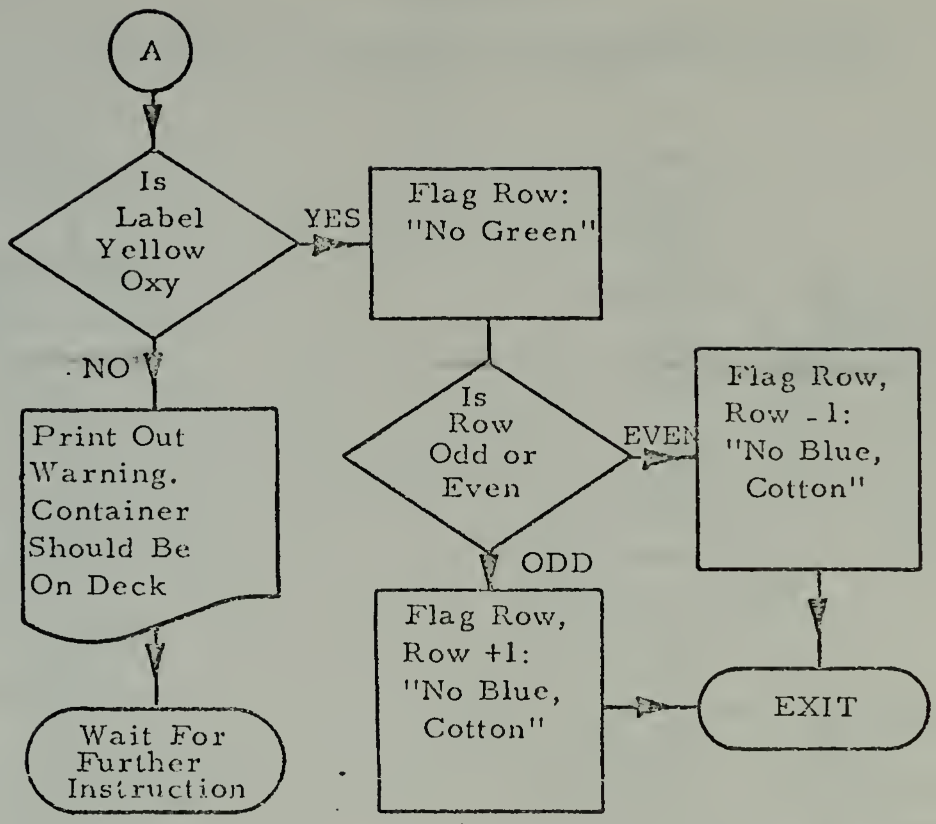

START
Set "Mode" to "Regular"
Start with Last Port, Heaviest Container
Start at 1st Row
H
G
Is Container Labelled ?
NO
YES
Is Row OK for Label
NO
p68 E
YES
Is This A Reefer
NO
YES
Is Row OK for Reefer
YES
NO
Next Row
A
Is Tier Usable
NO
YES
p67 B
C
Any More Cells in This Tier
NO
YES
Next Cell
Any More Tiers in This Row
YES
NO
p68 E
Next Tier
A
Is Mode "Regular" or "Full"
FULL
REG
Start at 1st Tier on Deck, Cell 1
Start at Tier 1, Cell 1 This Row
A


B
Is Cell Usable
NO
p66 C
YES
Is Cell Empty
NO
Is Tier On Deck
NO
p66 C
YES
Assign Container to Cell
YES
D
Is Mode "Regular" or "Full"
FULL
p66 C
REG
p68 E
Was Container Labelled
NO
YES
Flagging Subroutine
Was Container a Reefer
YES
NO
Set Cell Market to Present Cell Number
Any More Containers
NO
YES
p68 F
Output Assignment Plan
Stability Calculation Program

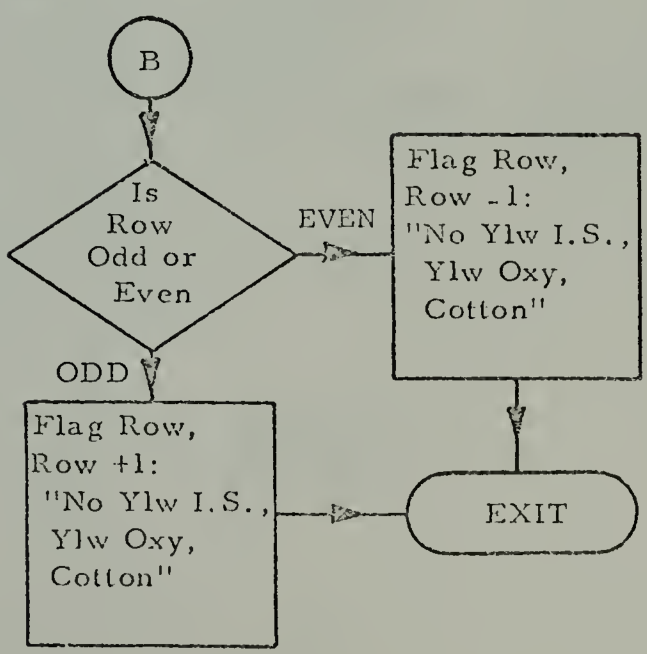

E
Is This Last Row
NO
Go to Next Row
p66 G
YES
Any More Containers ?
NO
Output Assignment Plan
Stability Calculation Program
YES
Is Mode "Regular" or "Full"
FULL
REG
Switch Mode to "Full"
p66 H
Print Out Warning Not All Containers Assigned
Wait For Further Instruction
F
Return to Cell Indicated by Cell Marker
Pick Next Container
Is Container Labelled
NO
p66 C
YES
Is Row OK for Label
YES
p66 C
NO
p67 D

FLAGGING SUBROUTINE





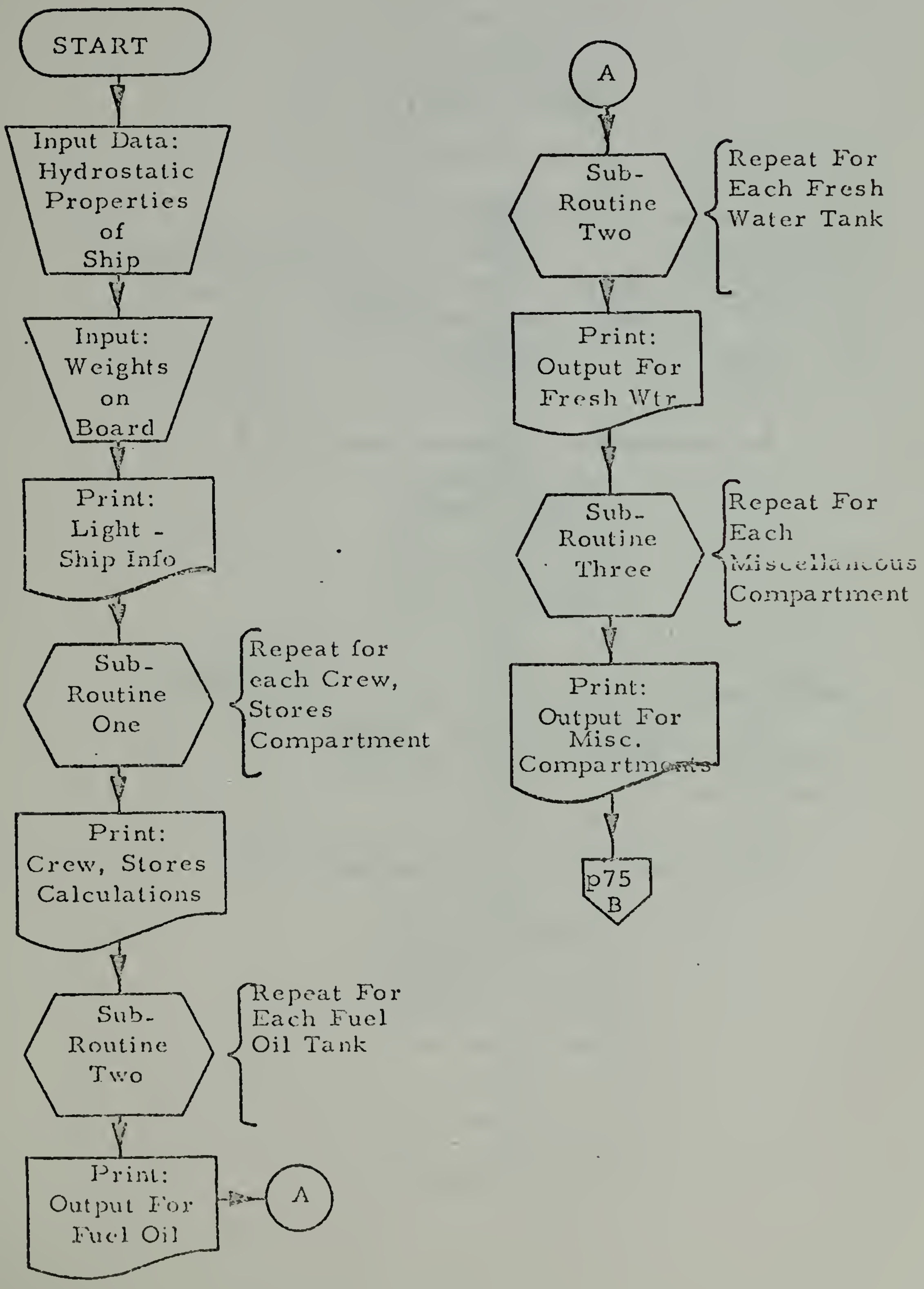
A
Is Label Yellow Oxy
YES
Flag Row: "No Green"
NO
Print Out Warning. Container Should Be On Deck
Wait For Further Instruction
Is Row Odd or Even
EVEN
Flag Row, Row -1: "No Blue, Cotton"
ODD
Flag Row, Row +1: "No Blue, Cotton"
EXIT



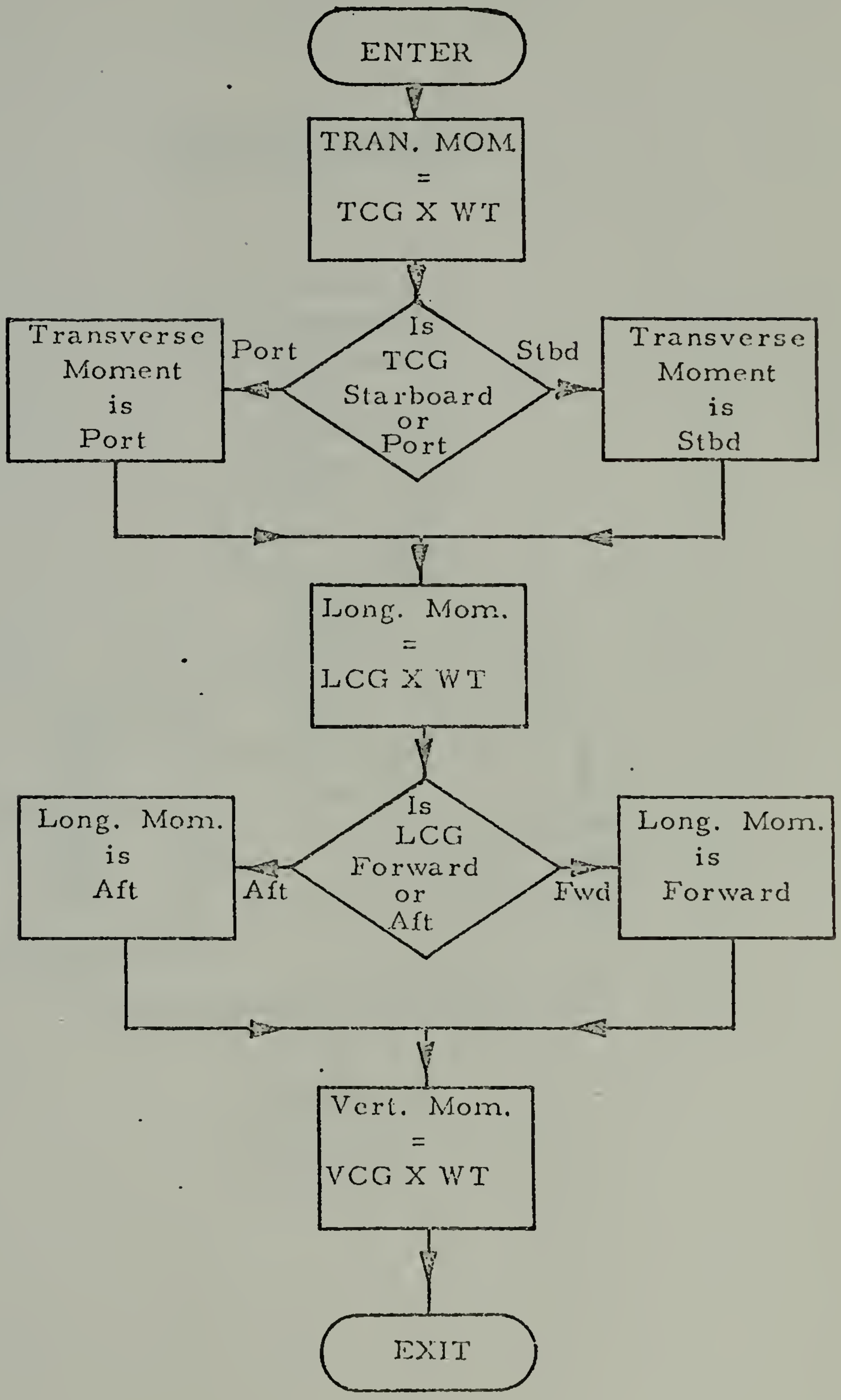
B
Is Row Odd or Even
EVEN
Flag Row, Row -1: "No Ylw I.S., Ylw Oxy, Cotton"
ODD
Flag Row, Row +1: "No Ylw I.S., Ylw Oxy, Cotton"
EXIT
EXIT

APPENDIX D:

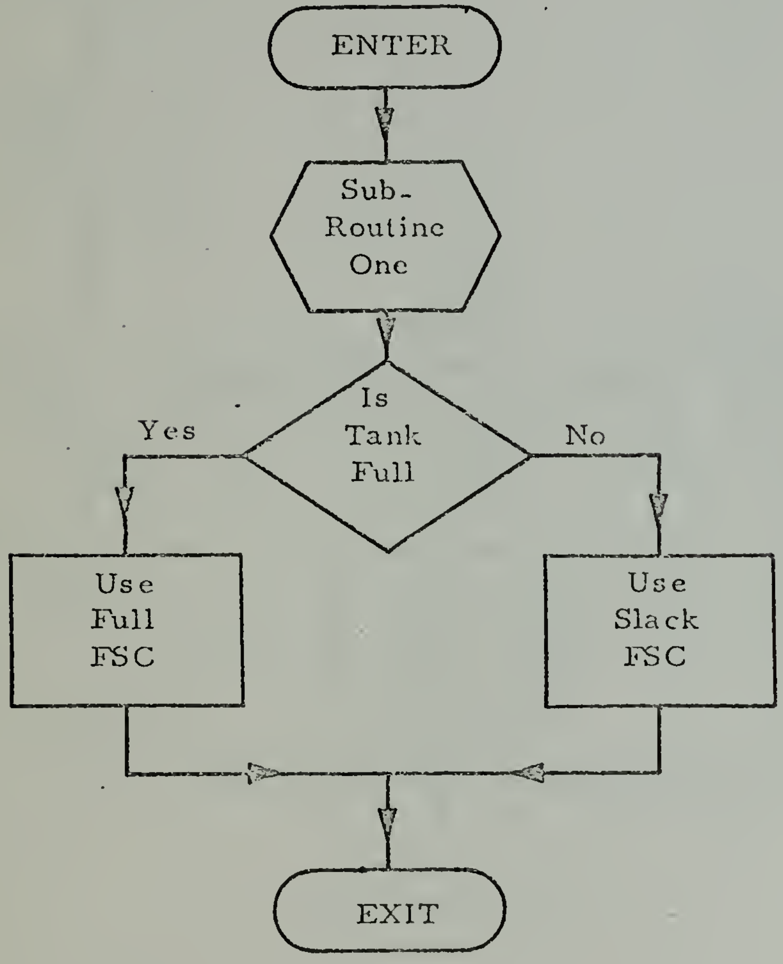
FLOWCHART OF STABILITY CALCULATING PROGRAM



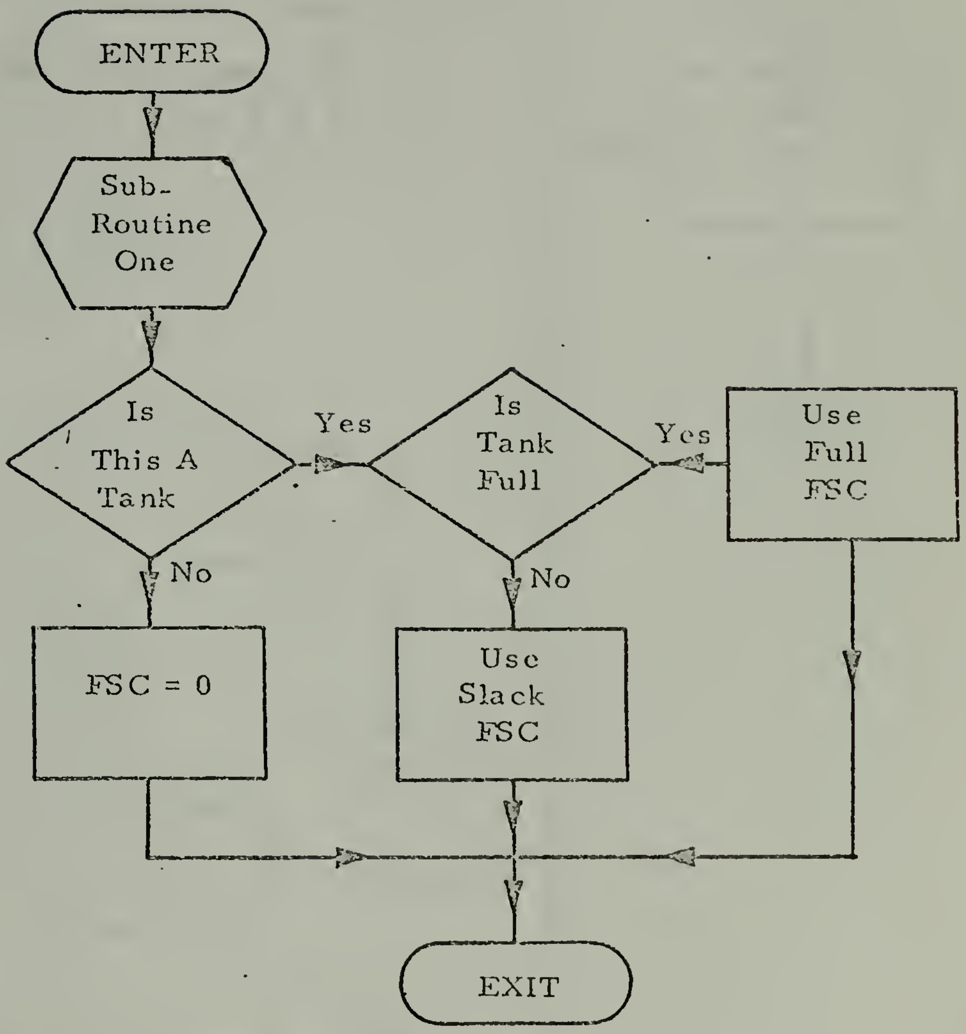
(SUBROUTINE ONE)

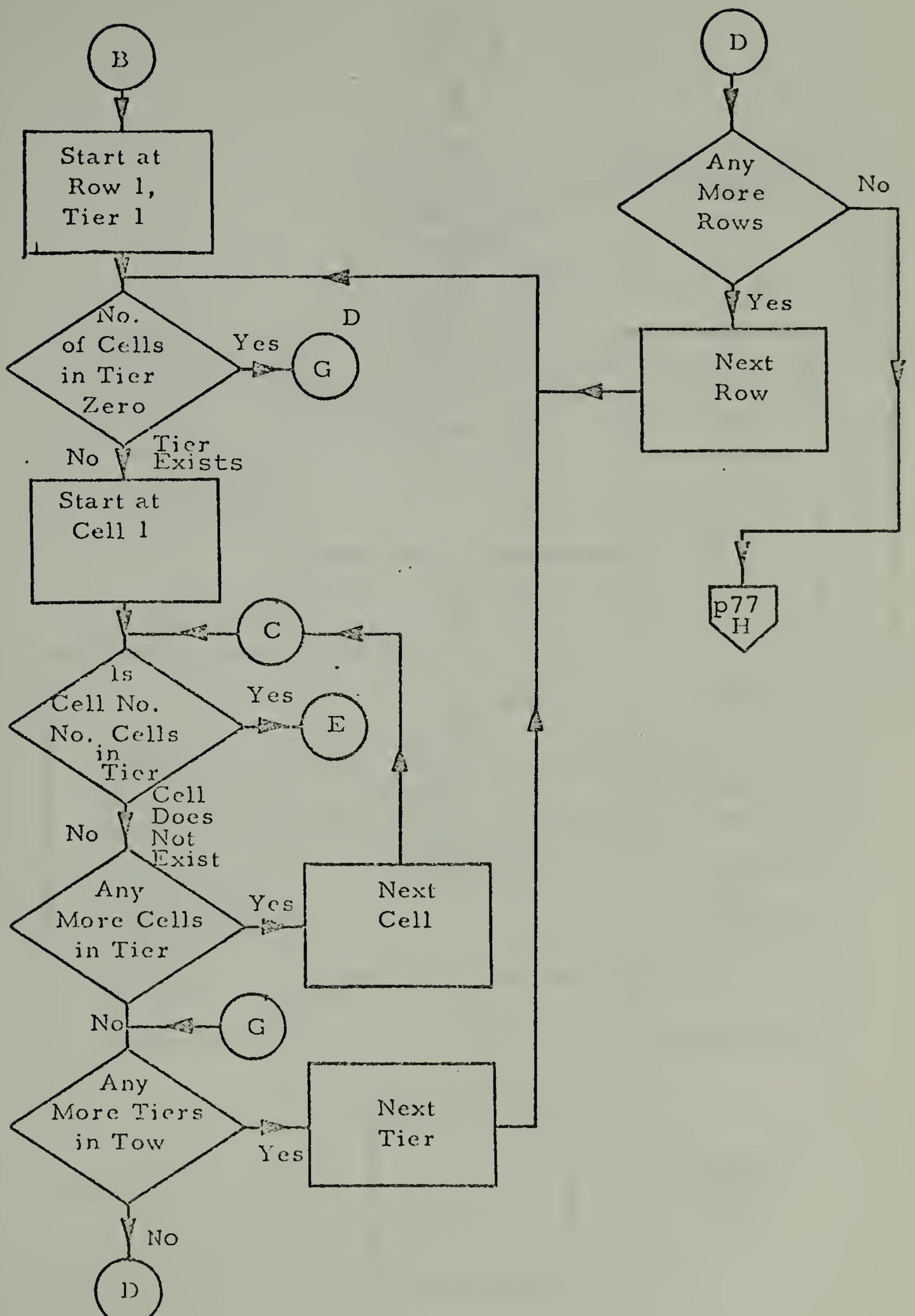


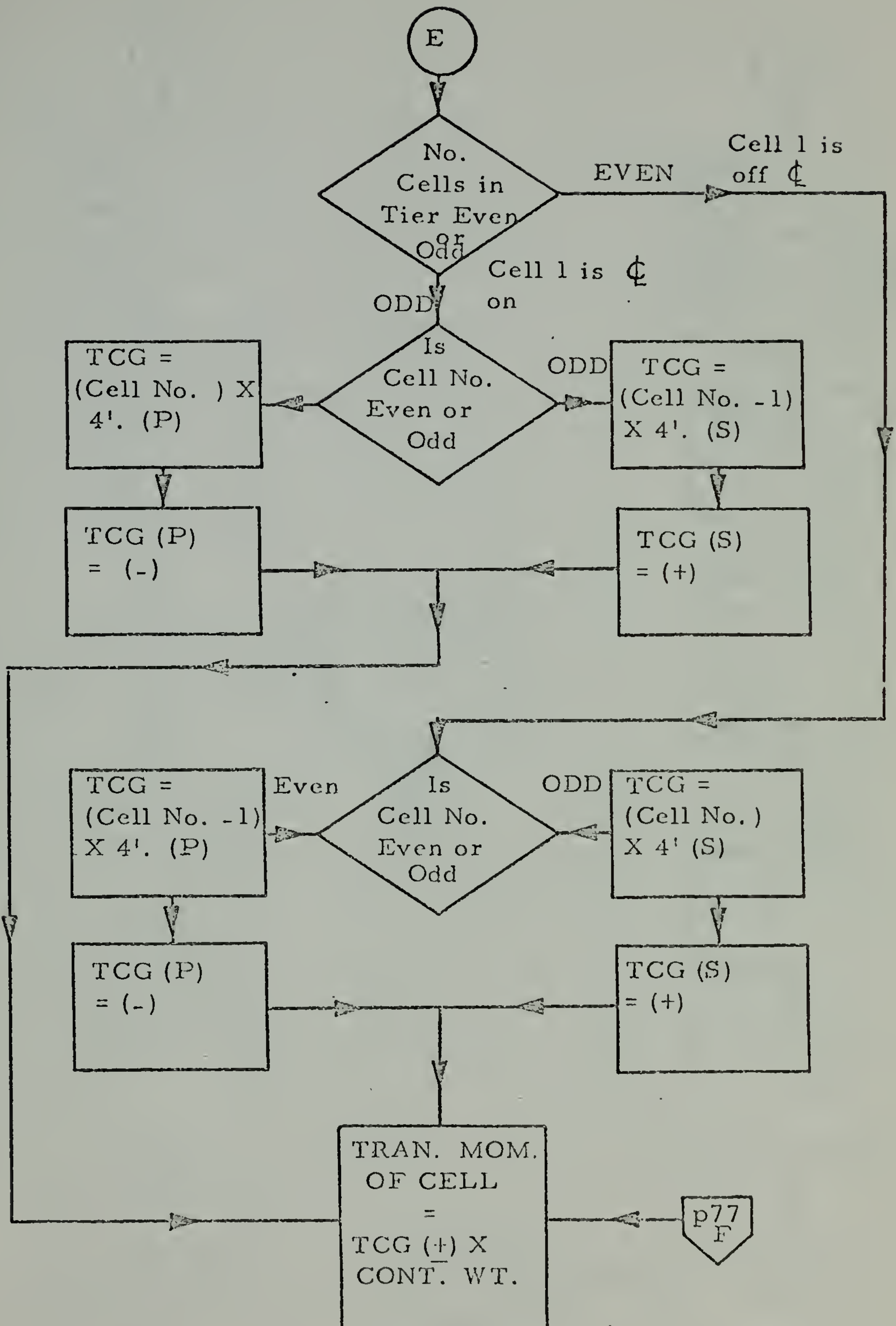
(SUBROUTINE TWO)

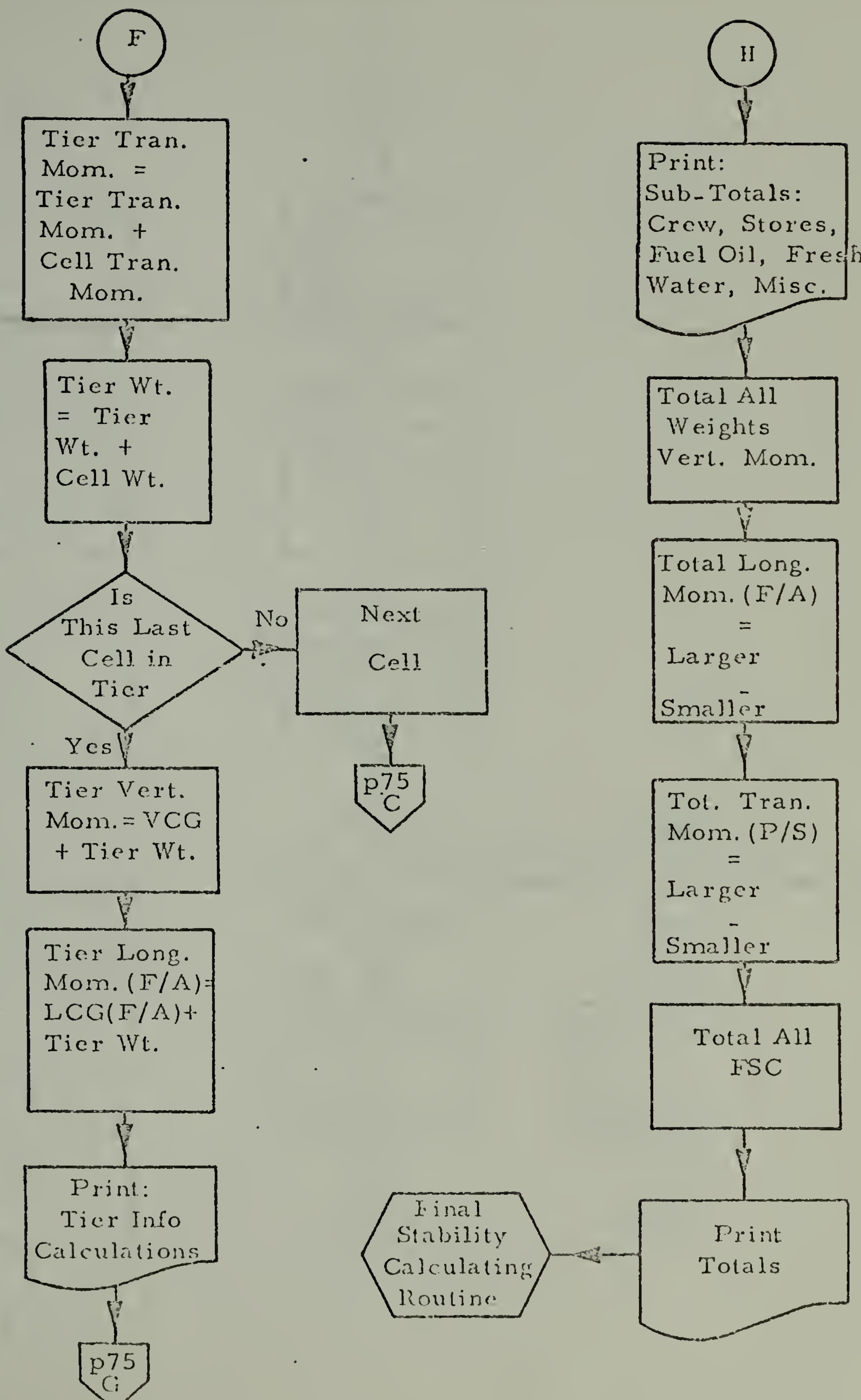


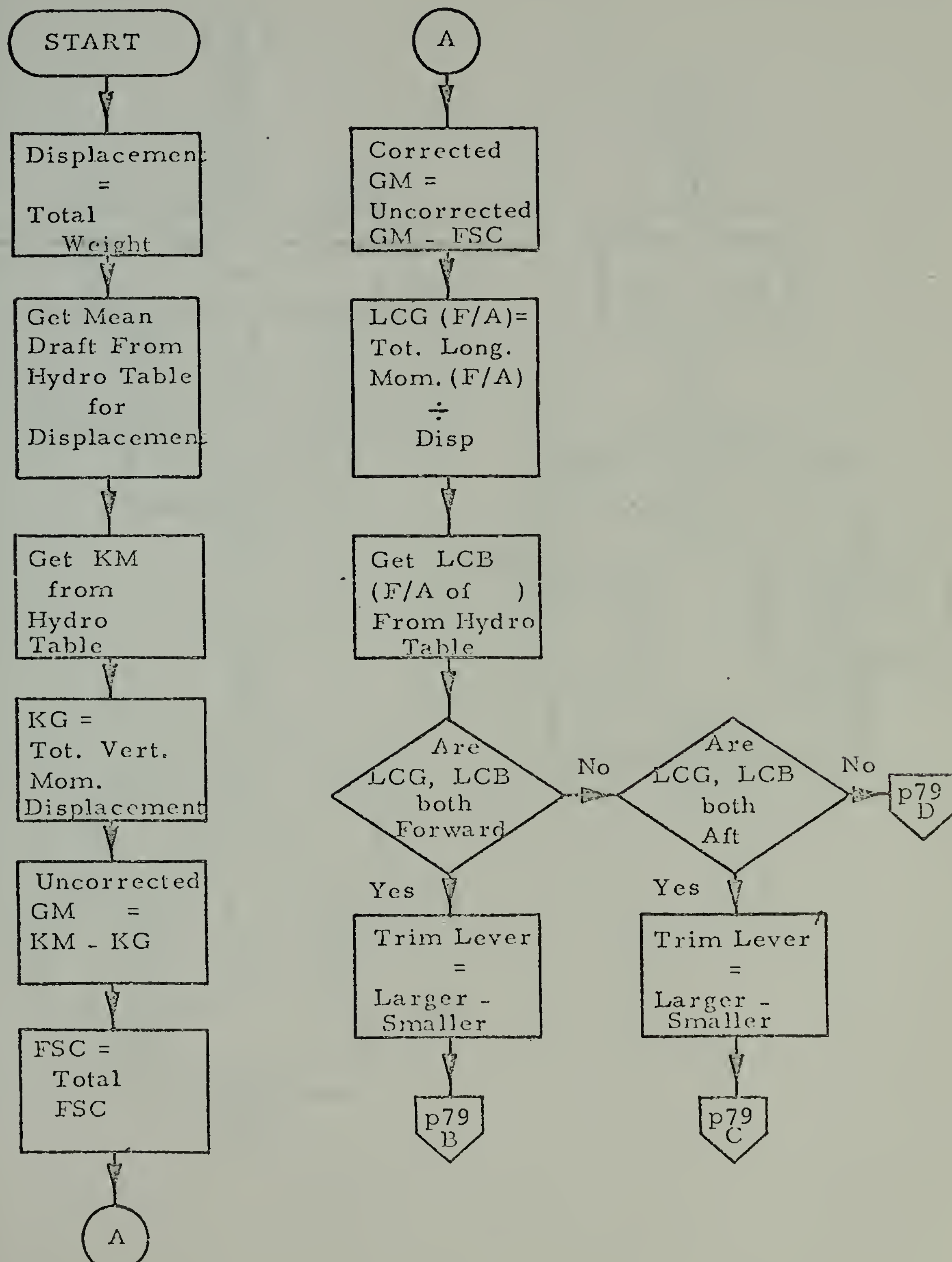
(SUBROUTINE THREE)



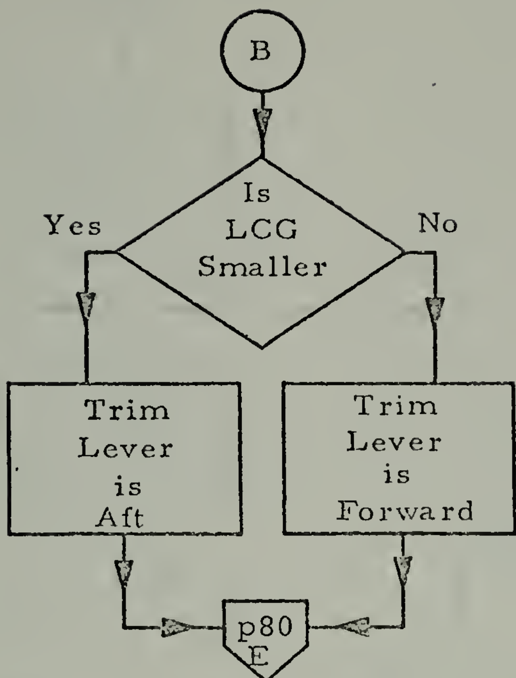

B
Start at Row 1, Tier 1
No. of Cells in Tier Zero
Yes
D
G
No
Tier Exists
Start at Cell 1
C
Is Cell No. No. Cells in Tier
Yes
E
No
Cell Does Not Exist
Any More Cells in Tier
Yes
Next Cell
No
G
Any More Tiers in Tow
Yes
Next Tier
No
D
D
Any More Rows
No
Yes
Next Row
p77 H

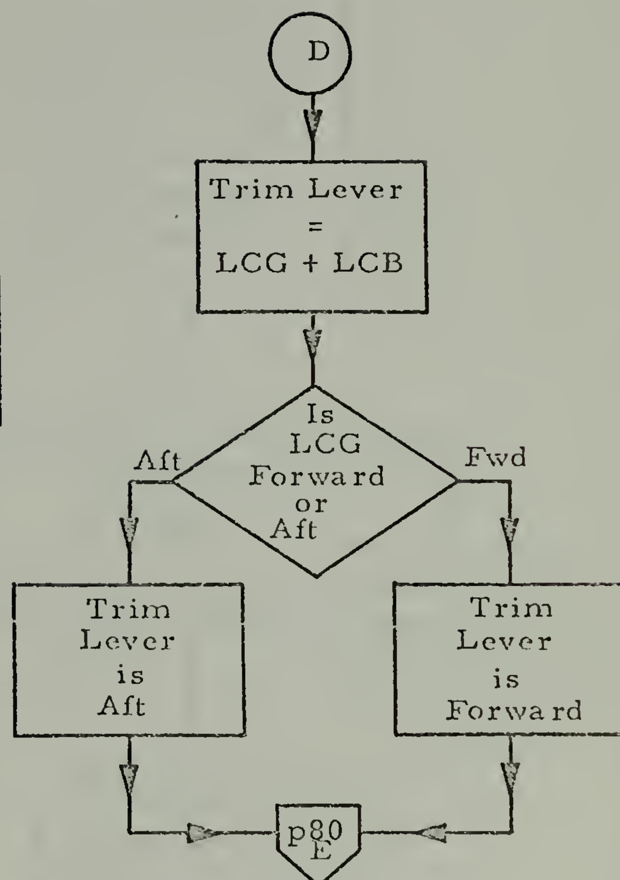

E
No. Cells in Tier Even or Odd
EVEN
Cell 1 is off ℄
ODD
Cell 1 is ℄ on
Is Cell No. Even or Odd
TCG = (Cell No.) X 4'. (P)
ODD
TCG = (Cell No. -1) X 4'. (S)
TCG (P) = (-)
TCG (S) = (+)
Even
Is Cell No. Even or Odd
ODD
TCG = (Cell No. -1) X 4'. (P)
TCG = (Cell No.) X 4' (S)
TCG (P) = (-)
TCG (S) = (+)
TRAN. MOM. OF CELL = TCG (+) X CONT. WT.
p77 F

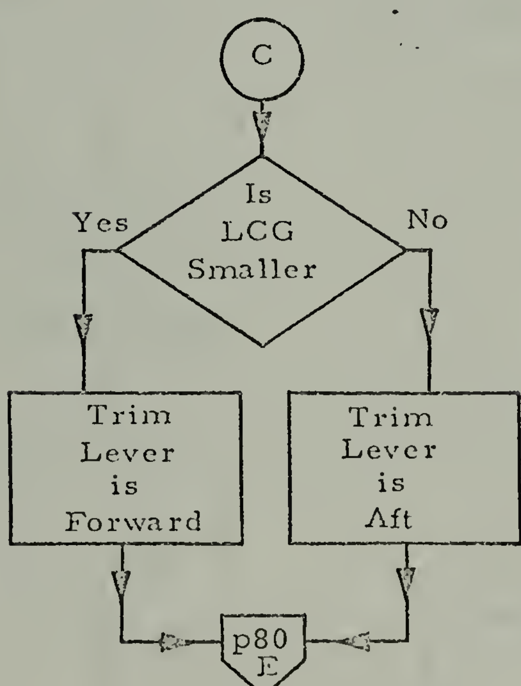

F
Tier Tran. Mom. = Tier Tran. Mom. + Cell Tran. Mom.
Tier Wt. = Tier Wt. + Cell Wt.
Is This Last Cell in Tier
No
Next Cell
p75 C
Yes
Tier Vert. Mom. = VCG + Tier Wt.
Tier Long. Mom. (F/A)= LCG(F/A)+ Tier Wt.
Print: Tier Info Calculations
p75 G
H
Print: Sub-Totals: Crew, Stores, Fuel Oil, Fresh Water, Misc.
Total All Weights Vert. Mom.
Total Long. Mom. (F/A) = Larger - Smaller
Tot. Tran. Mom. (P/S) = Larger - Smaller
Total All FSC
Print Totals
Final Stability Calculating Routine

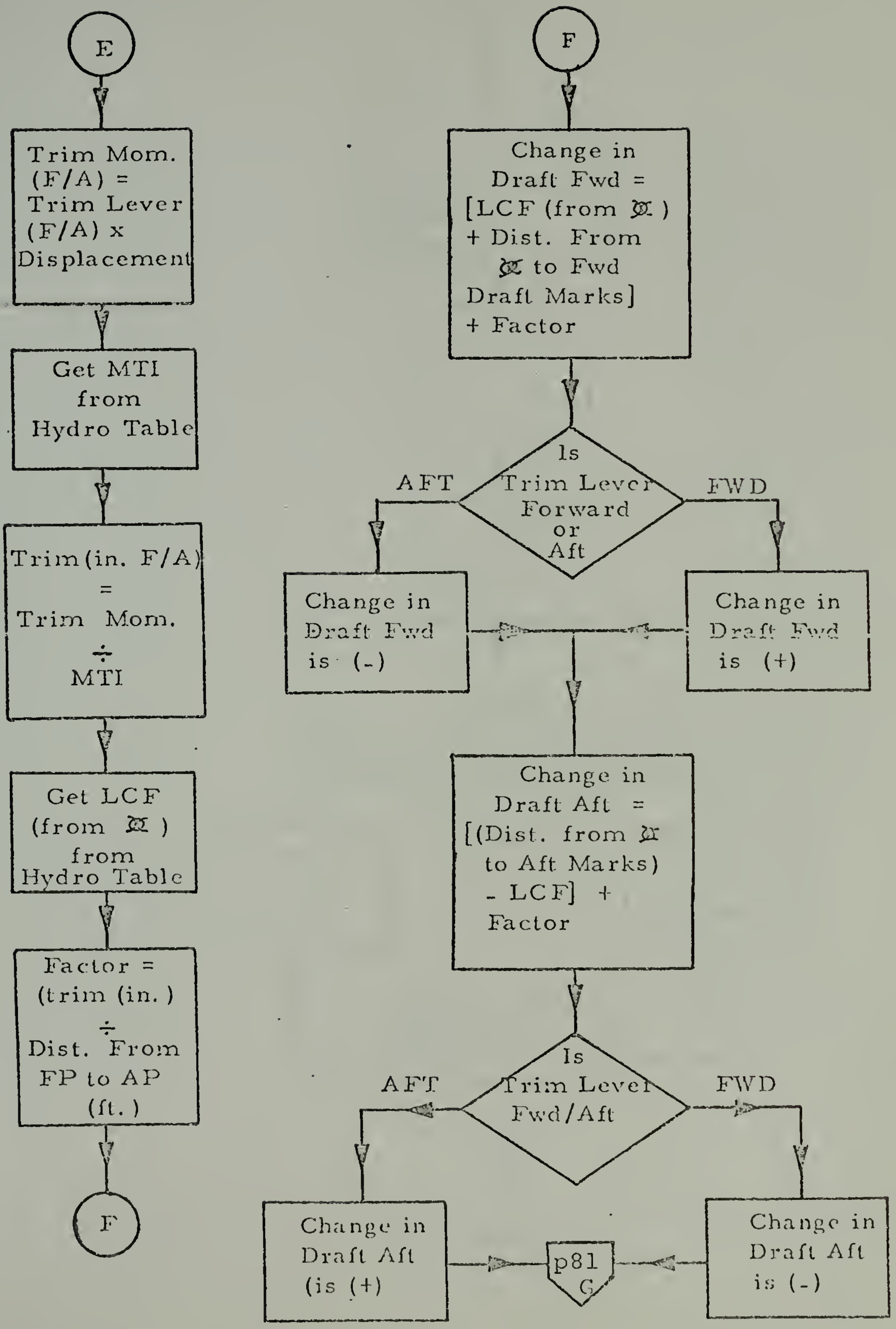


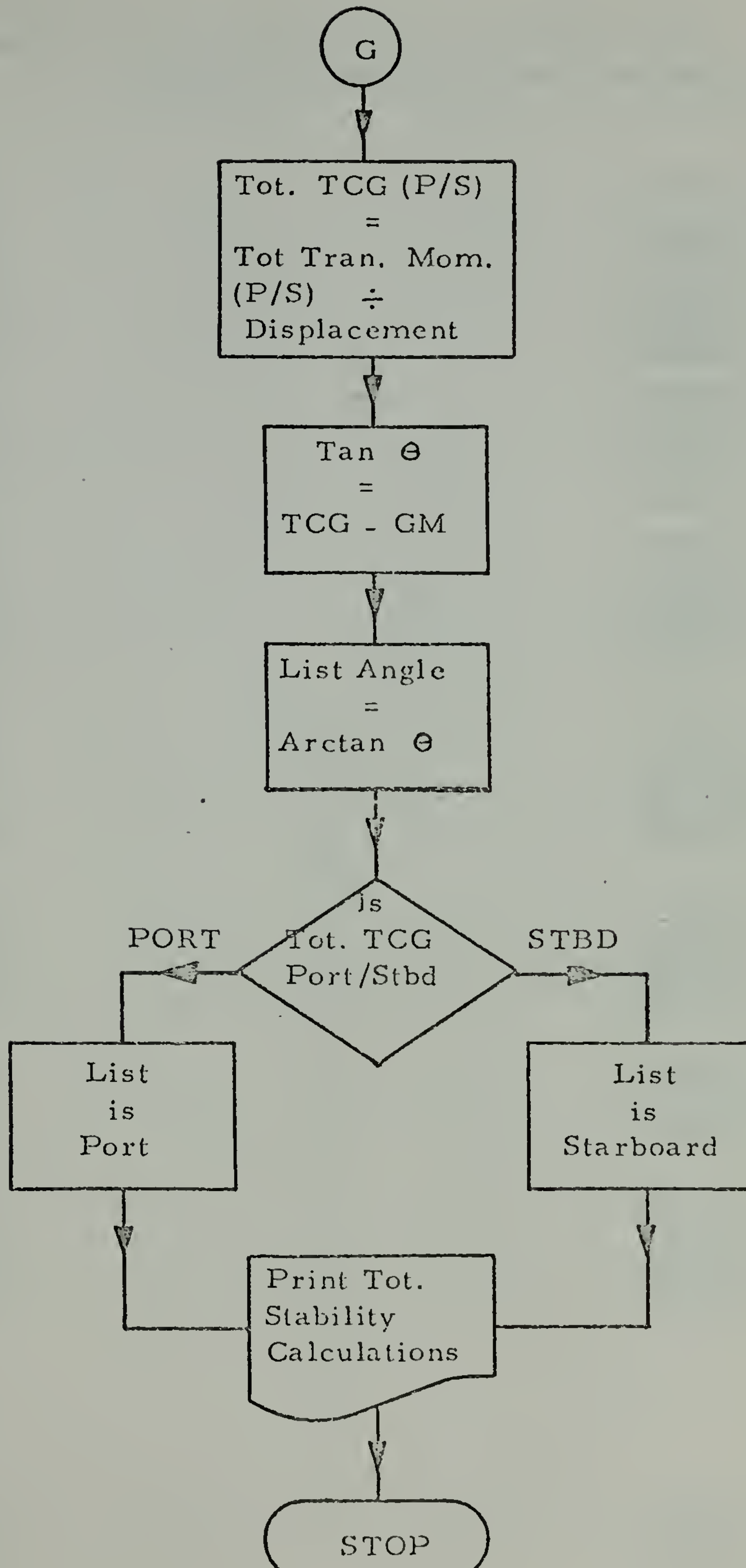
START
Displacement = Total Weight
Get Mean Draft From Hydro Table for Displacement
Get KM from Hydro Table
KG = Tot. Vert. Mom. Displacement
Uncorrected GM = KM - KG
FSC = Total FSC
A
A
Corrected GM = Uncorrected GM - FSC
LCG (F/A)= Tot. Long. Mom. (F/A) ÷ Disp
Get LCB (F/A of) From Hydro Table
Are LCG, LCB both Forward
No
Are LCG, LCB both Aft
No
p79 D
Yes
Trim Lever = Larger - Smaller
p79 B
Yes
Trim Lever = Larger - Smaller
p79 C


B
Is
LCG
Smaller
Yes
No
Trim
Lever
is
Aft
Trim
Lever
is
Forward
p80
E


D
Trim Lever
=
LCG + LCB
Is
LCG
Forward
or
Aft
Aft
Fwd
Trim
Lever
is
Aft
Trim
Lever
is
Forward
p80
E


C
Is
LCG
Smaller
Yes
No
Trim
Lever
is
Forward
Trim
Lever
is
Aft
p80
E


E
Trim Mom. (F/A) = Trim Lever (F/A) x Displacement
Get MTI from Hydro Table
Trim (in. F/A) = Trim Mom. ÷ MTI
Get LCF (from ⊠) from Hydro Table
Factor = (trim (in.) ÷ Dist. From FP to AP (ft.)
F
F
Change in Draft Fwd = [LCF (from ⊠) + Dist. From ⊠ to Fwd Draft Marks] + Factor
Is Trim Lever Forward or Aft
AFT
FWD
Change in Draft Fwd is (-)
Change in Draft Fwd is (+)
Change in Draft Aft = [(Dist. from ⊠ to Aft Marks) - LCF] + Factor
Is Trim Lever Fwd/Aft
AFT
FWD
Change in Draft Aft (is (+)
p81 G
Change in Draft Aft is (-)


G
Tot. TCG (P/S) = Tot Tran. Mom. (P/S) ÷ Displacement
Tan Θ = TCG - GM
List Angle = Arctan Θ
Is Tot. TCG Port/Stbd
PORT
STBD
List is Port
List is Starboard
Print Tot. Stability Calculations
STOP

APPENDIX E: SUGGESTED OUTPUT FORMAT FOR STABILITY CALCULATING PROGRAM

```
                 TRIM AND STABILITY CONDITIONS WITH NO BALLAST

TYPE OF SHIP---LANCER

CONTAINER TIER___TONS___VCG___VERT MOM____LCG___LONG MOM____TCG___TRAN MOM

0120             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
0130             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
0140             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
0150             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
0160             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
  .                 .       .       .        .        .        .       .
  .                 .       .       .        .        .        .       .
  .                 .       .       .        .        .        .       .

   NOTE:  ONE ENTRY FOR EACH TIER OF CONTAINERS

  .                 .       .       .        .        .        .       .
  .                 .       .       .        .        .        .       .
  .                 .       .       .        .        .        .       .
2010             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S
2020             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S
2030             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
2040             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
2050             XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S

SUBTOTALS         XXXXX.XX      XXXXXXX.XX      XXXXXXX.XX F    XXXXXXX.XX P
```

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--

CREW & STORES____TONS___VCG___VERT MOM____LCG___LONG MOM____TCG___TRAN MOM

XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P

SUBTCTALS        XXXXX.XX        XXXXXXX.XX        XXXXXXX.XX F     XXXXXXX.XX P

FUEL OIL_________TONS___VCG___VERT MOM____LCG___LONG MOM____TCG___TRAN MOM___FSC

XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P  XXX

SUBTCTALS        XXXXX.XX        XXXXXXX.XX        XXXXXXX.XX F     XXXXXXX.XX P   XXXX

FRESH WATER______TONS___VCG___VERT MOM____LCG___LONG MOM____TCG___TRAN MOM___FSC

XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX S  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX A XX.XX XXXXX.XX P  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX A XX.XX XXXXX.XX P  XXX

SUBTCTALS        XXXXX.XX        XXXXXXX.XX        XXXXXXX.XX F     XXXXXXX.XX P   XXXX

MISCELLANEOUS____TONS___VCG___VERT MOM____LCG___LONG MOM____TCG___TRAN MOM___FSC

XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX A XX.XX XXXXX.XX S  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX A XX.XX XXXXX.XX S  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX F XX.XX XXXXX.XX P  XXX
XXXXXX          XXXX.XX  XX.XX  XXXX.XX  XXXX.XX  XXXXX.XX A XX.XX XXXXX.XX P  XXX

SUBTCTALS        XXXXX.XX        XXXXXXX.XX        XXXXXXX.XX F     XXXXXXX.XX P   XXXX

NOTE: ONE ENTRY FOR EACH TANK OR COMPARTMENT IN EACH CATEGORY
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TOTALS              TONS          VERT MOM          LCNG MOM            TRAN MOM    FSC

LIGHT SHIP        XXXXX.XX      XXXXXXX.XX       XXXXXXX.XX F      XXXXXXX.XX P
CREW & STORES     XXXXX.XX      XXXXXXX.XX       XXXXXXX.XX F      XXXXXXX.XX P
CONTAINERS        XXXXX.XX      XXXXXXX.XX       XXXXXXX.XX F      XXXXXXX.XX P
FUEL OIL          XXXXX.XX      XXXXXXX.XX       XXXXXXX.XX F      XXXXXXX.XX P   XXXX
FRESH WATER       XXXXX.XX      XXXXXXX.XX       XXXXXXX.XX F      XXXXXXX.XX P   XXXX
MISCELLANEOUS     XXXXX.XX      XXXXXXX.XX       XXXXXXX.XX F      XXXXXXX.XX P   XXXX

TOTALS            XXXXX.XX      XXXXXXX.XX       XXXXXXX.XX F      XXXXXXX.XX P   XXXX


KG= XX.XX

MEAN DRAFT IS XX' XX"

KM= XX.XX

UNCORRECTED AVAILABLE GM = X.XX

TOTAL FSC = X.XX

**** CORRECTED AVAILABLE GM = X.XX ****

LCG = X.XX F

LCB = X.XX F

TRIM LEVER = X.XX A

MOMENT TO TRIM 1" = XXXXX

**** TRIM IN INCHES = XX.XX F ****

LCF = XX.XX A

**** FWD DRAFT =XX' XX"      AFT DRAFT = XX' XX" ****

**** LIST ANGLE = XX P ****

END OF STABILITY PROGRAM
```

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