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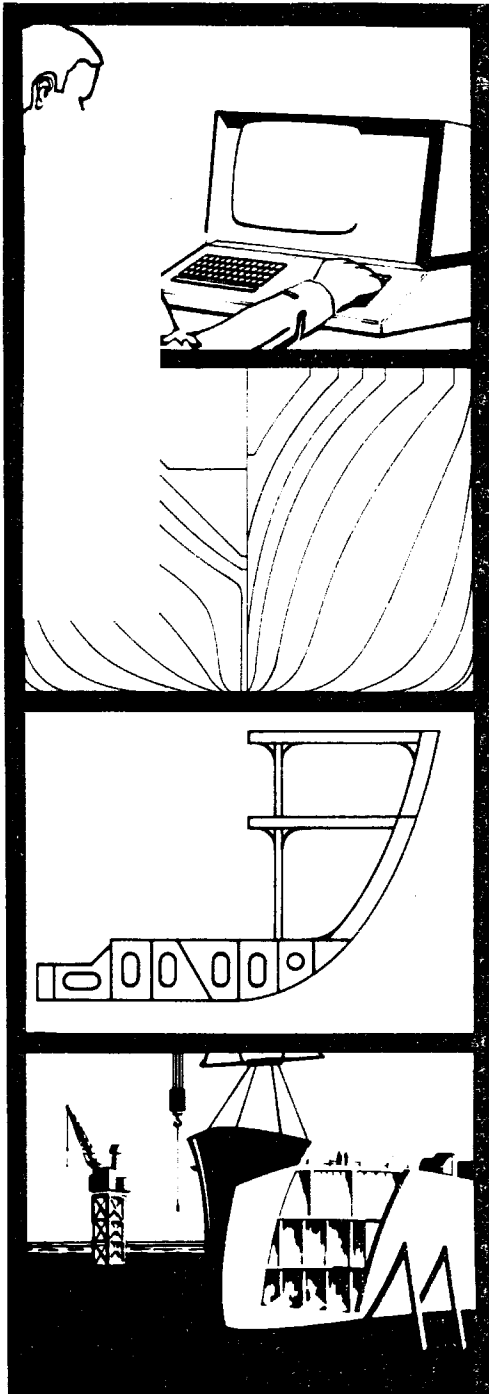
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THE BETHLEHEM DAMAGED STABILITY PROGRAM

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For the last ten years, commercial shipbuilders have had to make frequent and extensive damaged stability investigations. To accomplish this we have developed the program that we are about to describe.

By way of background, passenger vessels have had to meet formal damaged stability requirements for many years. Originally these were not too difficult since the requirements were in terms for which the conventional concepts of statical stability were valid. Subsidized general cargo vessels usually have had to meet similar requirements. Tankers on the other hand, never have had to. Their high survivability after damage was inherent in their extensive subdivision. However, since the early 1960's there has been a trend toward fewer and larger tanks in these vessels. The ability to survive damage has been reduced accordingly.

With the 1966 Load Line Convention there came a new concept to commercial ship design practice. All vessels' are now required to have a degree of survivability after damage. This ability is considered to be implied in vessels with high freeboard. However, it has to be demonstrated on low freeboard ships such as tankers, if they lack extensive subdivision.

There was a new twist to these requirements of particular significance. Submergence of part of the free-board deck after damage was accepted for the first time. The two limitations being a maximum angle of heel at equilibrium and the provision that no openings be submerged through which progressive flooding might take place. If any part of the deck is submerged, the conventional statical stability concepts are invalid. Therefore, we were forced to begin making damaged righting arm calculations. Subsequently, this became a requirement. Recent oil tanker, chemical tanker and liquefied flammable gas carriers all have requirements for minimum range of stability and residual righting arm after damage.

A further complication exists for tankers. These vessels have to be examined for bottom damage to the cargo spaces. This can easily involve four or more tanks, two center and two wing. Further the regulations for tankers have been interpreted to require that all tanks be considered initially empty. This condition generally does not work. Therefore, the amount of liquid cargo that has to be included in any combination of damaged

tanks in order to survive has to be determined. A similar problem exists with pairs of wing tanks particularly on inherently less stable double bottom ships.

As a solution to these new problems, Bethlehem CTD began the development of a damaged righting arm program back in 1969. The data base consists of a mathematical model of the ship and its compartmentation. Calculations are made on the constant displacement principle. In this respect, damaged compartments are considered as no longer part of the buoyant ship. Net Centers of buoyancy after damage are calculated at the equilibrium draft and trim for each angle of heel. From these a righting arm curve can be constructed. Similarly, for a particular combination of damage and vertical center of gravity, an equilibrium condition can be found. Alternatively, to avoid submerging a particular point on the ship, the maximum acceptable KG can be determined.

The "run off" of cargo has been generally ignored to date because in present applications it usually represents an improvement to the damaged condition.

This program was developed over the years with numerous modifications. It has been the basis of all recent Bethlehem submittals for approval.

The Damaged Stability Package consists of several modules, each performing a unique task.

The first Damaged Stability module, DAMAGE 0, performs the following tasks:

1. Given initial displacement and LCG, and compartments to be flooded, the program will compute an initial VCG such that equilibrium after damage will not submerge input limiting points.
2. Similarly, the program may be directed to find an equilibrium waterplane for a fixed VCG and report the status of any input limiting points.
3. A righting arm curve for the damaged ship may be produced either commencing at the equilibrium heel or at a user defined angle and terminating also at a user determined angle. Constant displacement with a zero trimming moment is maintained at all angles.

4. The program can be directed to output, for a single draft, trim and heel, all buoyancy and lost buoyancy values for the damaged ship. This option may be used for producing capacities for any compartment designated to be damaged. With this option and the interim print option, the details of waterplane intersections with a compartment can be made available.

The basic steps taken to define a damaged stability problem are as follows:

1. Define a hull form as would be necessary to perform hydrostatic calculations.
2. Define a universe of compartments for the ship based on current arrangement or various alternative arrangements.
3. An option in the input is the definition of limiting points. These points, locatable in 3-space, enable the user to define a margin line or other points of interest to the user. The program will provide waterplane information at each of these points indicating if they are submerged.

4. Generally, to specify a damaged condition:
 - A. Indicate an initial draft and trim (heel assumed 0.0) or a displacement and LCG; either combination provides the displacement and longitudinal center which must be 'balanced' by the program.
 - B. Indicate the compartments which must be flooded. A compartment will flood if any of its boundaries are intersected by the waterplane. Specify the permeability of the damage compartment and if applicable, the percentage the tank was initially filled prior to damage. Compartments may be grouped in the input so that their total volume and centers will be output as a single entity in addition to their individual properties.
 - c. Indicate the type of calculation, equilibrium, R.A. curve, etc.
 - D. Indicate the tolerances on displacement and on longitudinal and transverse righting arms with which to "balance" the ship.

- E. Indicate the VCG (if not to be output)
including the free-surface effects.

The output for an equilibria condition or for each heel angle R.A. curve consists of the following items:

1. Final Draft, Trim and Heel
2. Intact Hull Properties (as in hydrostatics)
 - displacement and centers of buoyancy
 - bonjean information at each defined
section of the ship
3. Damage Compartment Properties
 - flooded volume and centers
(if a compartment is partially full initially, the flooded volume is the amount in addition to that already in the tank)
4. Total Flooded Properties
 - sum of all damaged compartment properties
5. Remaining Intact Hull
 - displacement and centers of buoyancy
of damaged ship
 - residual righting arms, give the user a report of 'balance' on the ship with respect to input tolerances.
6. Disposition of Limiting Points
 - position of each point with respect to waterplane.

The second of the two damaged stability programs is DAMAGE 1. It was written with tanker loading restrictions in mind.

DAMAGE 1 has two functions:

The first is to compute the amount of cargo which must be present in a compartment prior to damage. This limits flooding in such a way that at equilibrium the lowest of the input limiting points is tangent to the waterplane.

For this type of problem the user specifies one or a series of compartments, all initially empty, to define the damage condition. The program will, based on the input order, determine which compartment must be partially filled to limit heel.

The second function of DAMAGE 1 is to find the maximum intact draft (or displacement) such that with damage to one or more empty or partially filled tanks, the equilibrium waterplane will be tangent to the 'lowest' input limiting point.

These steps to define a damaged condition for the DAMAGE 1 program are similar to those of DAMAGE 0, only the options have changed. Output is also similar in format and information to that of DAMAGE 0.

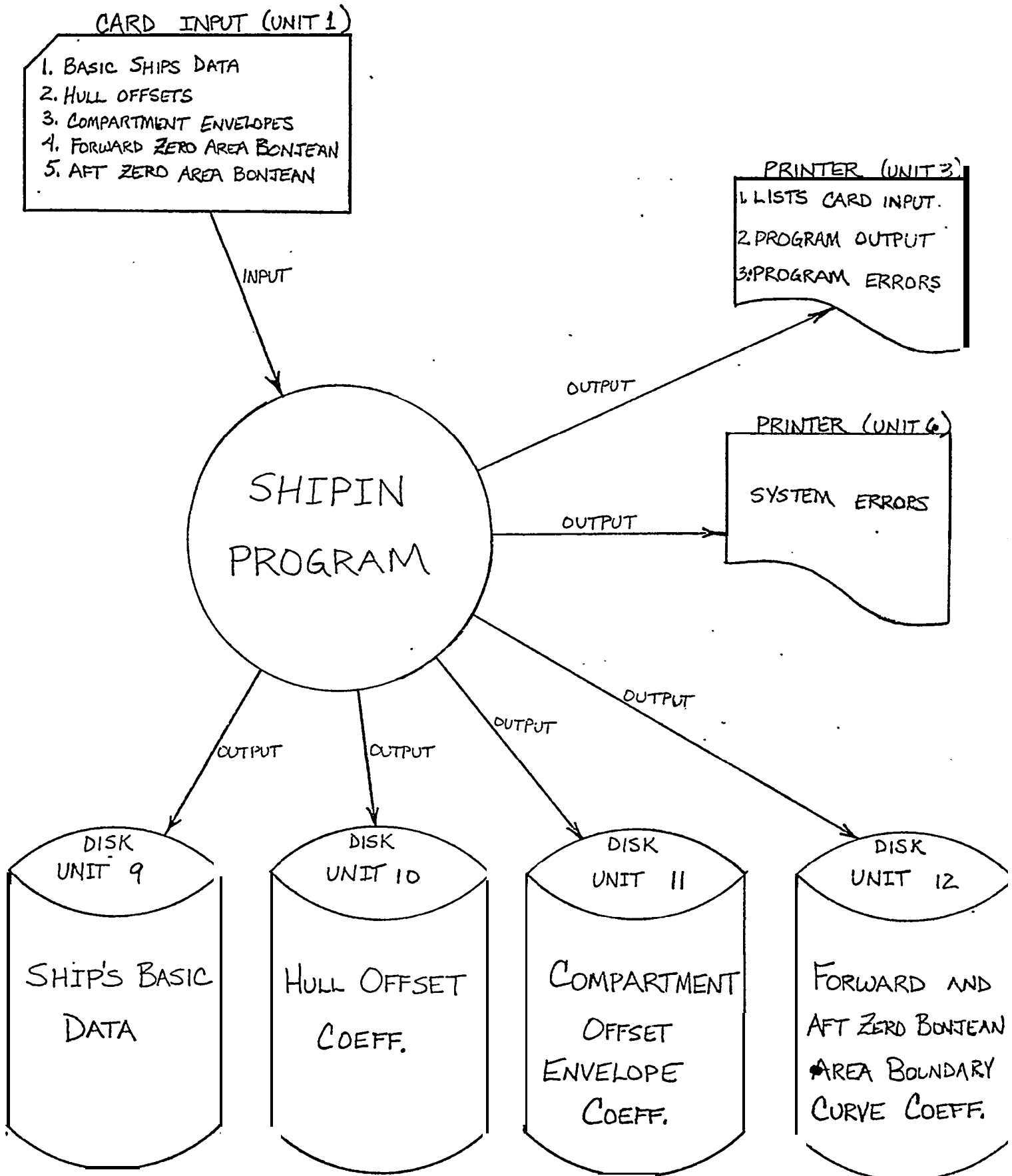
The DAMAGE 0 and DAMAGE 1 programs use files which have been created by other lead modules.

The SHIPIN program builds the intact hull data file for the damage programs. (See Figure 1.)

The intact hull can be coded by hand or, with the use of another damaged stability module, PRELDAM, can be produced semi-automatically from a PRELIKON Database. This provides a convenient transfer medium from the Autokon E-file. (See Figure 2.)

The intact hull is defined by a series of sections, forward to aft; their spacings determine the type of integration used in the damaged stability programs on the bonjeans over that portion of the ship. There are four types of integration available: trapezoidal for a single unique spacing; Simpsons 1-4-1 for two equal spacings; Simpson's $3/8$'s rule for three equal spacings. The fourth is simply a double Simpson's 1-4-2-4-1 for four equal spacings. The damaged stability programs will 'look-ahead' at the spacings to avoid a trapezoidal; if there are five equal spacings, a $3/8$'s and a 1-4-1 are performed.

In order to provide exact ends at all waterlines for volume integration of sections, a Zero Bonjean Area boundary is defined to physically limit the extent of the hull .



SHIPIN INPUT AND OUTPUT

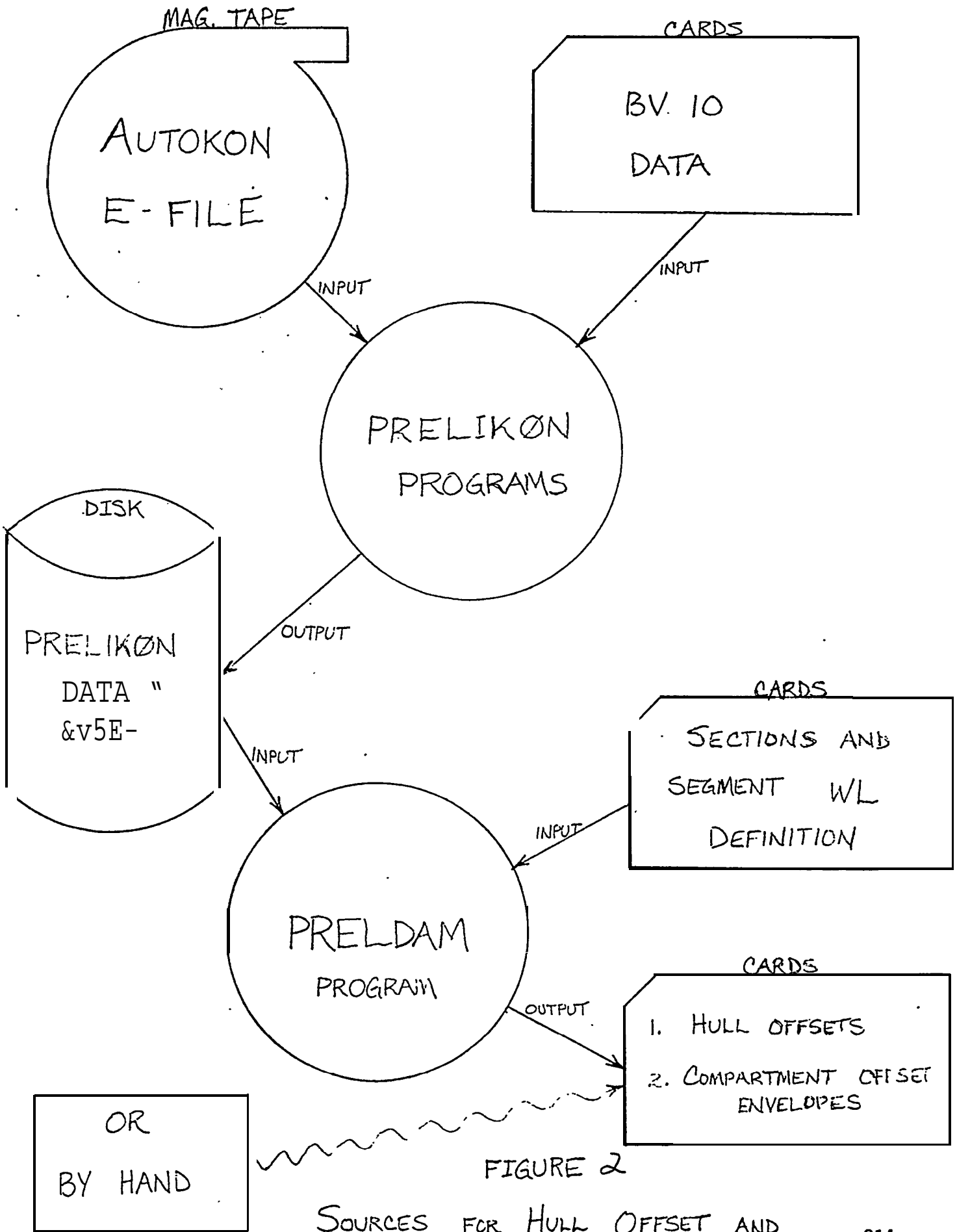


FIGURE 2

SOURCES FOR HULL OFFSET AND
COMPARTMENT OFFSET ENVELOPES

Each section defines a transverse molded hull outline from baseline to above deck at center and is described by several piece-wise continuous polynomials or segments. Although the slope is not guaranteed at each segment boundary, the error is not significant to calculations.

The segments are allowed to be of 1st to 3rd order, using equal vertical spacings within each segment. Choosing the right type of polynomial for a given area of the ship assists the accuracy of the mathematical model.

The bonjeans for each section are computed by integrating the segments which are of the form:

$$Y=A_0 + A_1 X + A_2 X^2 + A_3 X^3$$

Adjustments are then made for trim and heel at each section. The result is an underwater plane bonjean curve for the molded hull at the current draft, trim and heel. This curve is integrated in the damaged stability programs, according to the previously mentioned method, to produce a molded volume.

Program CMPRTMNT is the final program which provides files for the damaged stability programs. (See Figure 3.)

Several types of compartments are allowed.

The first is geometric shapes: CYLINDERS & SPHERES which are defined by their axis of rotation or center point, radius and, in the case of cylinders, the ends.

Another way of defining a compartment is using the PLANE method. This method allows for the most generalized compartment description, the simplest being a cube. These compartments may be defined port or starboard, symmetric or non-symmetric crossing the centerlines. See Figure 4. This type uses cross-section area integration similar to that used in intact hull with the boundaries of the compartment being defined as follows:

1. Fore and aft bulkheads are restricted to be perpendicular to the baseline and centerline planes.
2. The remaining four sides may be defined by skewed planes, the hull or special offsets.

See Figures 4, 5 and 6.

The cross-sections are formed by the intersection of the planes with a waterplane and a defined offset envelope. The offset envelope is necessary to the PLANE type of compartment - it normally becomes one or more sides used in the boundary of the compartment. For this reason

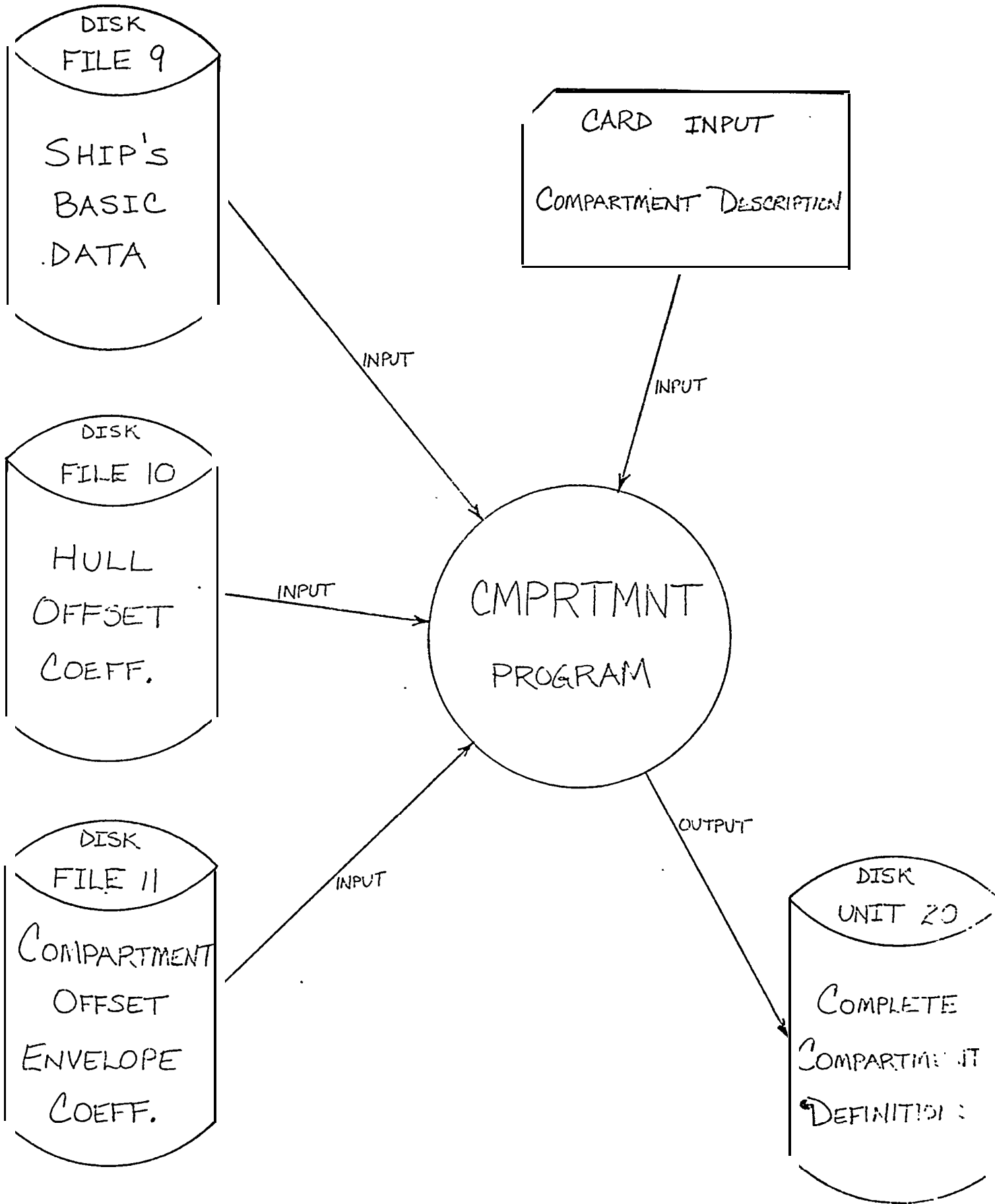


FIGURE 3
CMPRTMNT INPUT AND OUTPUT

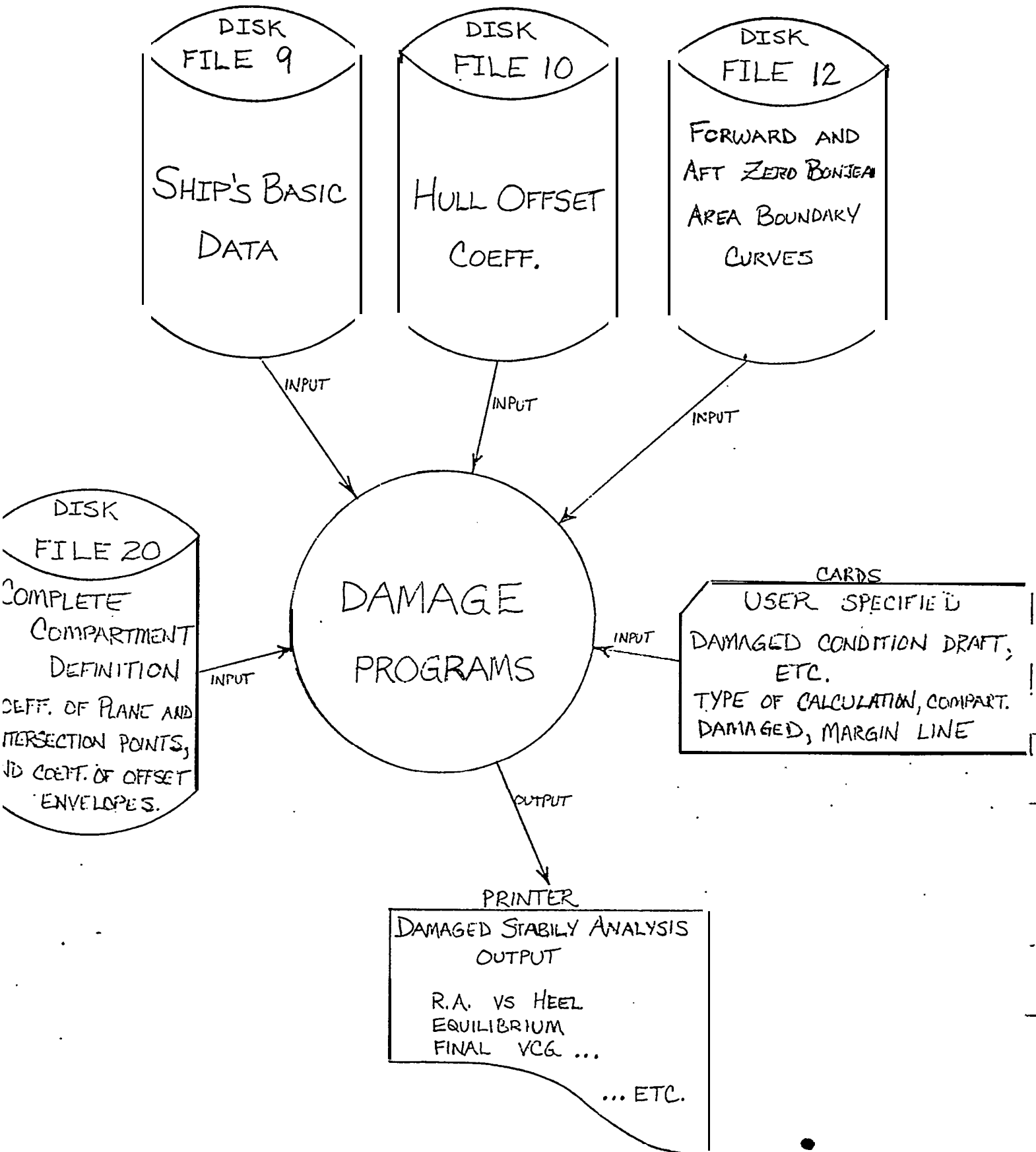
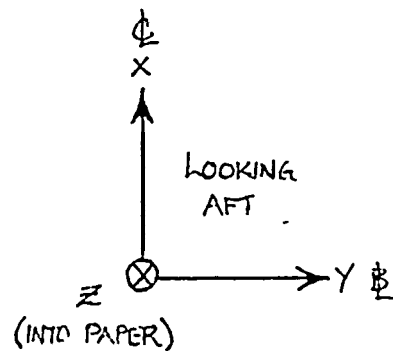
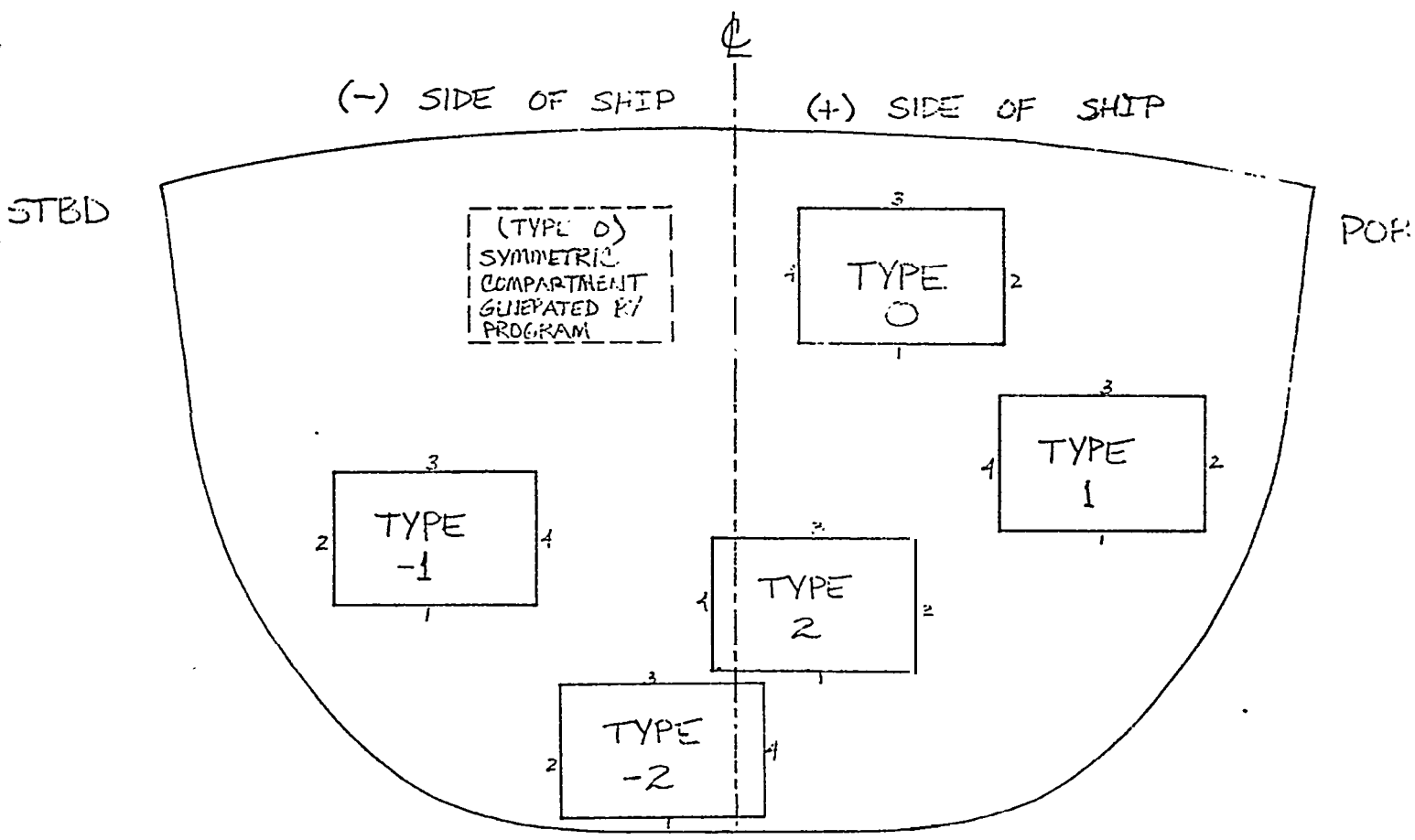


FIGURE 4
DAMAGE-0 AND DAMAGE-1 INPUT AND OUTPUT

- TYPE 0 COMPARTMENT HAS BEEN DESCRIBED ON PORT SIDE - PROGRAM WILL GENERATE A SYMMETRIC COMPARTMENT ON STARBOARD SIDE
- TYPE 1 COMPARTMENT COMPLETELY ON PORT SIDE
- TYPE -1 COMPARTMENT COMPLETELY ON STARBOARD SIDE
- TYPE 2 MAJORITY OF COMPARTMENT ON PORT SIDE
- TYPE -2 MAJORITY OF COMPARTMENT ON STARBOARD SIDE



NUMBERS OUTSIDE EACH OF THE COMPARTMENT ARE THE VARIOUS SIDES.

FIGURE 5
PLANE METHOD COMPARTMENTS

- SIDE 1 - LOWER
- SIDE 2 - OUTBOARD
- SIDE 3 - UPPER
- SIDE 4 - INBOARD

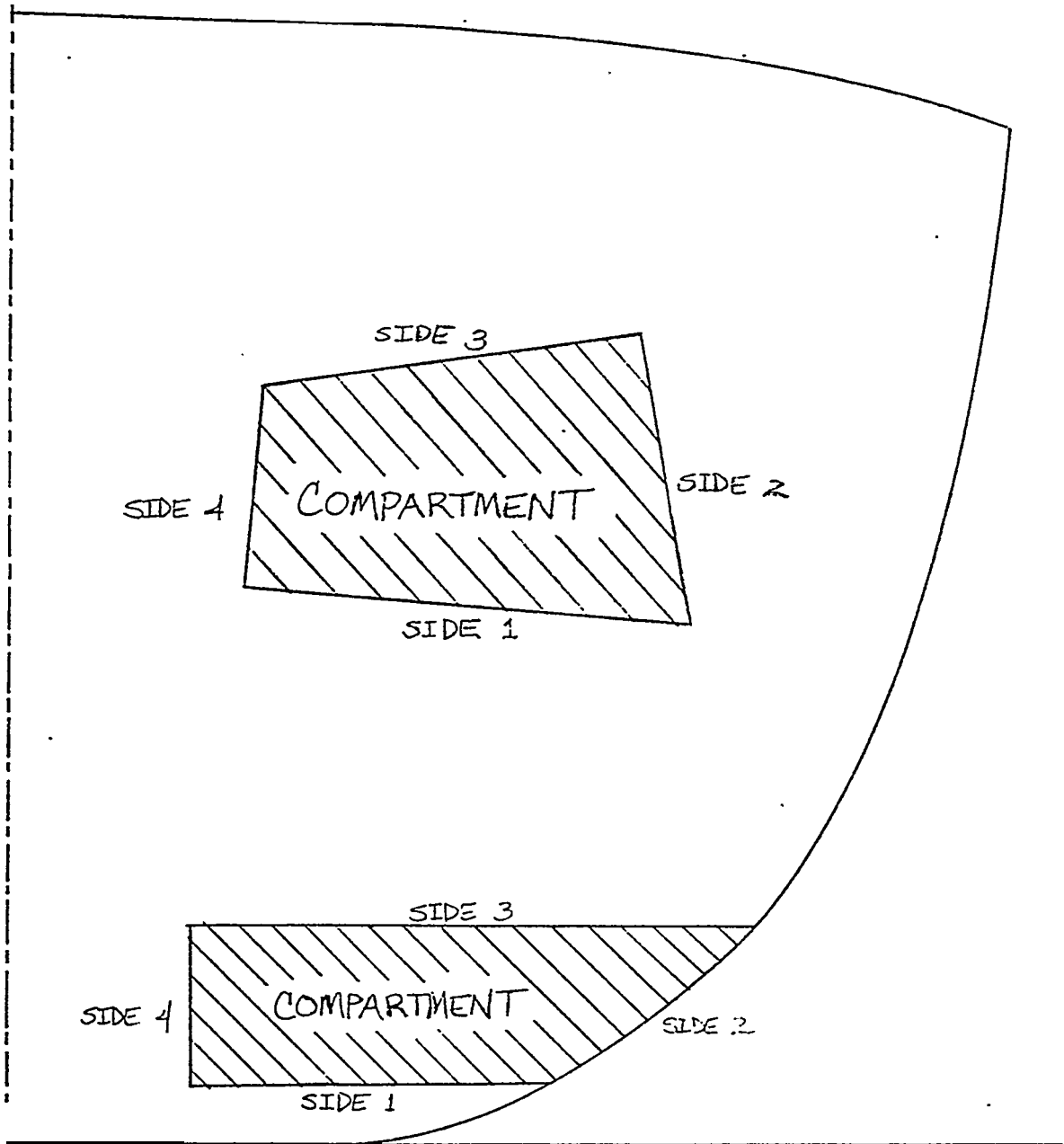


FIGURE 6
NUMBERING OF COMPARTMENT SIDES

the offset envelope is usually a description of a section of the molded hull and is coded in a similar manner. (See Figure 7.)

However, the offset envelope may describe shapes other than that of the molded hull. This would be necessary for a compartment which is unable to be described by any of the types already mentioned. See Figure 8, for example.

There is also available the ability to define a flooded compartment by its volume and center. This implies that the compartment is flooded at all times during the analysis. The volume may be entered as negative; this provides the capability to the program for analyzing a run-off problem.

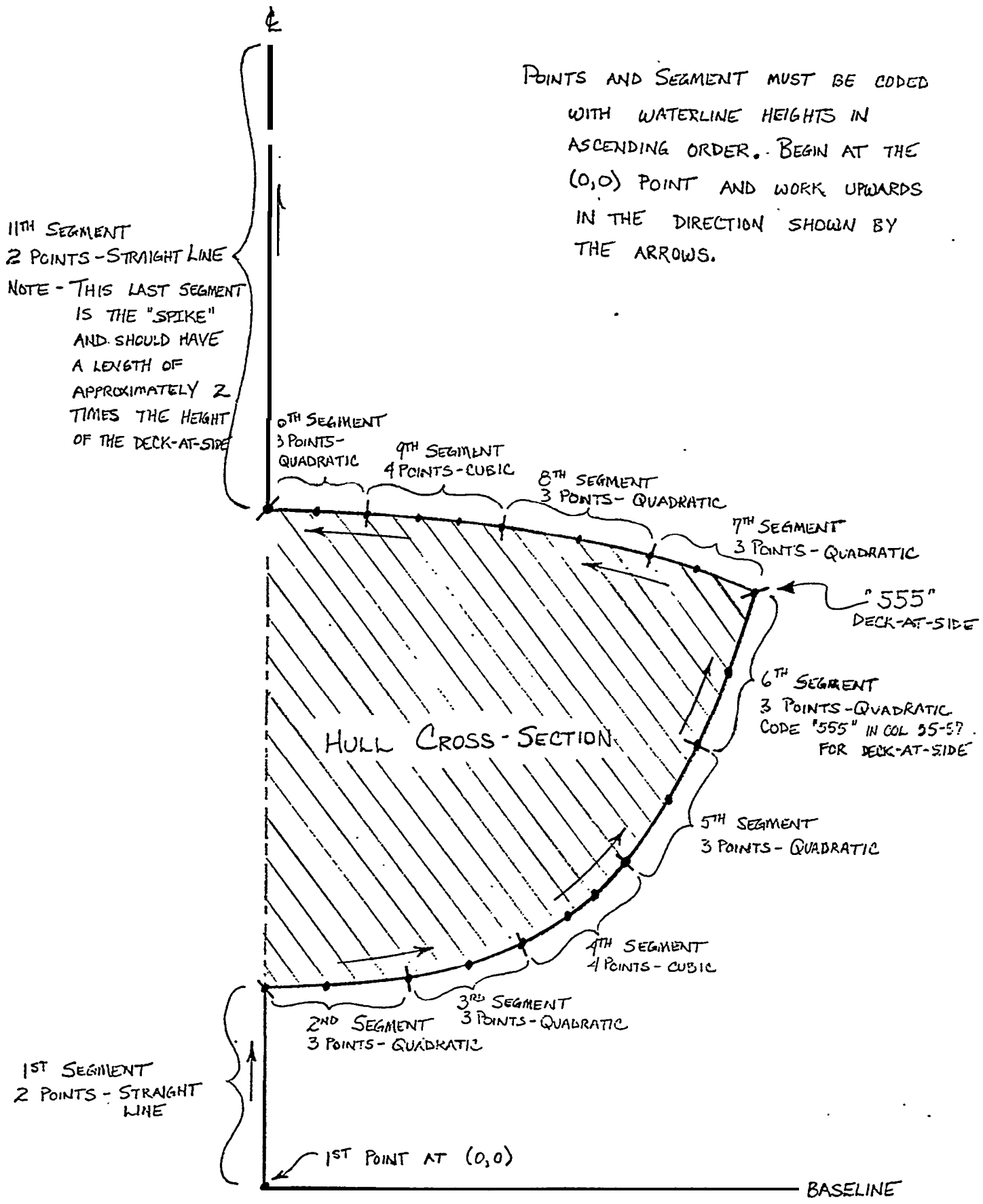
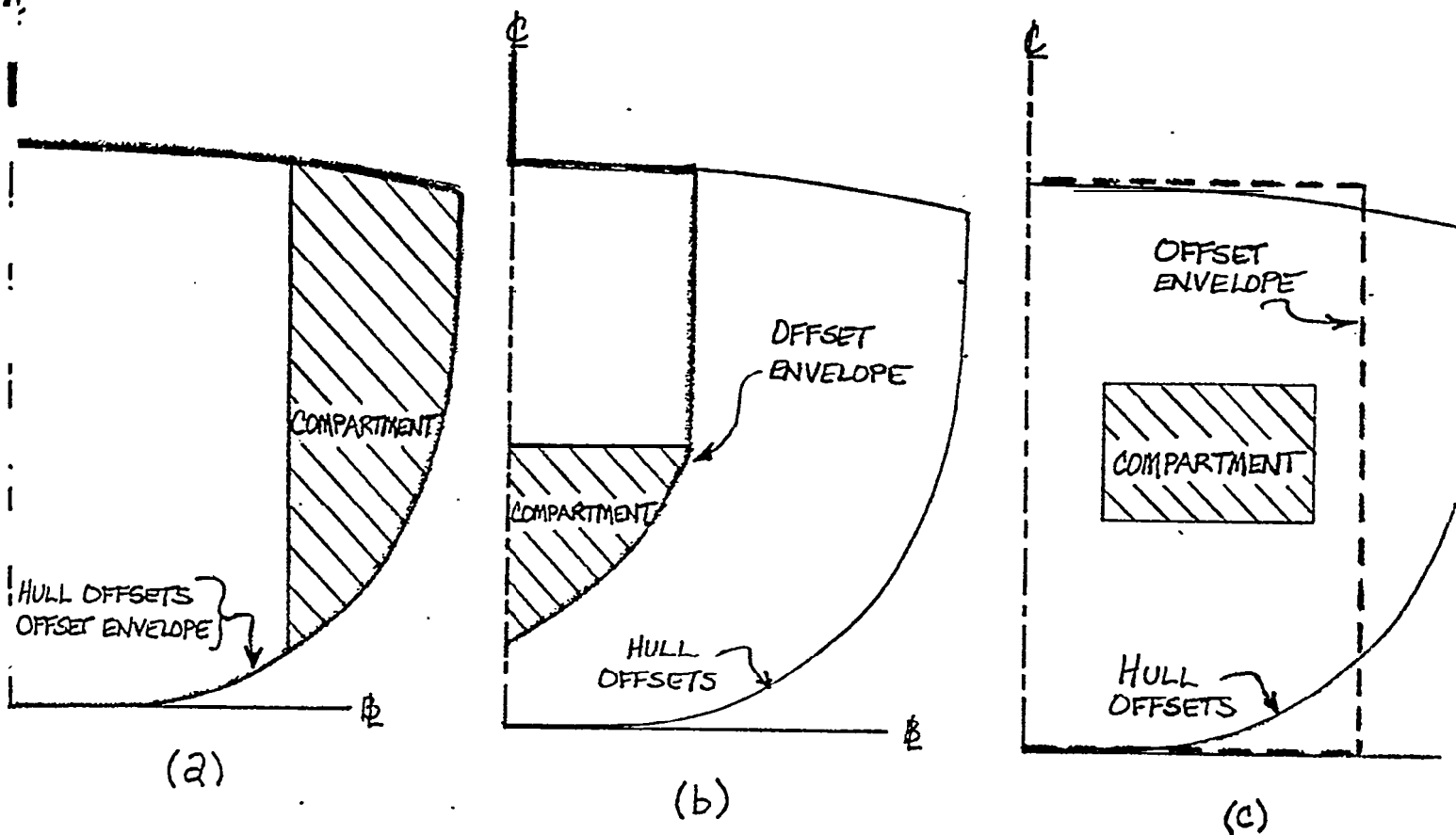


FIGURE 7
SECTION SEGMENT DEFINITION 222



- (a) OFFSET ENVELOPE IS THE SAME AS THE HULL OFFSETS. USED WHEN COMPARTMENT HAS PORTION OF THE HULL AS ITS BOUNDARY.
- (b) OFFSET ENVELOPE HAS SAME SHAPE AS PORTION OF THE COMPARTMENT'S BOUNDARY. USED WHEN COMPARTMENT REQUIRES OFFSETS TO DESCRIBE IT.
- (c) OFFSET ENVELOPE IS ANY SHAPE. USED WHEN OFFSETS ARE NOT NEEDED TO DESCRIBE THE COMPARTMENT. NOTE: HULL OFFSETS MAY BE USED.

FIGURE 8
 USE OF OFFSET ENVELOPES
 FOR DEFINING PLANE TYPE COMPARTMENTS

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