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THESIS

THE EVALUATION OF
DESIGN AND EMPLOYMENT ALTERNATIVES FOR THE LVA:
A MODELLING STRATEGY.

by

David Larkin Chadwick

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The Evaluation of Design and Employment Alternatives for the LVA: A Modelling Strategy

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requirements for the degree of

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I. INTRODUCTION

An explicit statement of desired operational goals is a fundamental first step in the conception of a new weapon system. All subsequent decisions regarding specific design features are based upon these goals. Once the engineering feasibilities of the performance characteristics have been established, it is possible to use an approach similar to that in Figure 1. Such a methodology can provide the decision-maker and the designer information with respect to the impact each of the elements of a design have on the combat effectiveness of the final system.

Essentially then, one may define a system's effectiveness as the degree of success the system realizes in achieving the desired operational goals (i.e. missions) in the context of a particular combat environment. For the purposes of evaluating alternative courses of action (design specification options), it is necessary to quantify the degree of success in attaining the operational goals, and hence the analyst must formulate a measure of effectiveness (MOE). (The reader is referred to Bonder [Ref.2] and also Quade [Ref. 8] for further discussion of the topic of system effectiveness.) This selection of an appropriate criterion by which success can be quantitatively measured is often a difficult procedure requiring the analyst and decision-maker to synthesize the various system objectives into a single variable which may be generated for each alternative by analytic or judgmental means.

It is additionally necessary to "operationally define" system effectiveness in the context of the combat environment. The operating conditions under which the system is to be analyzed is termed the scenario, and

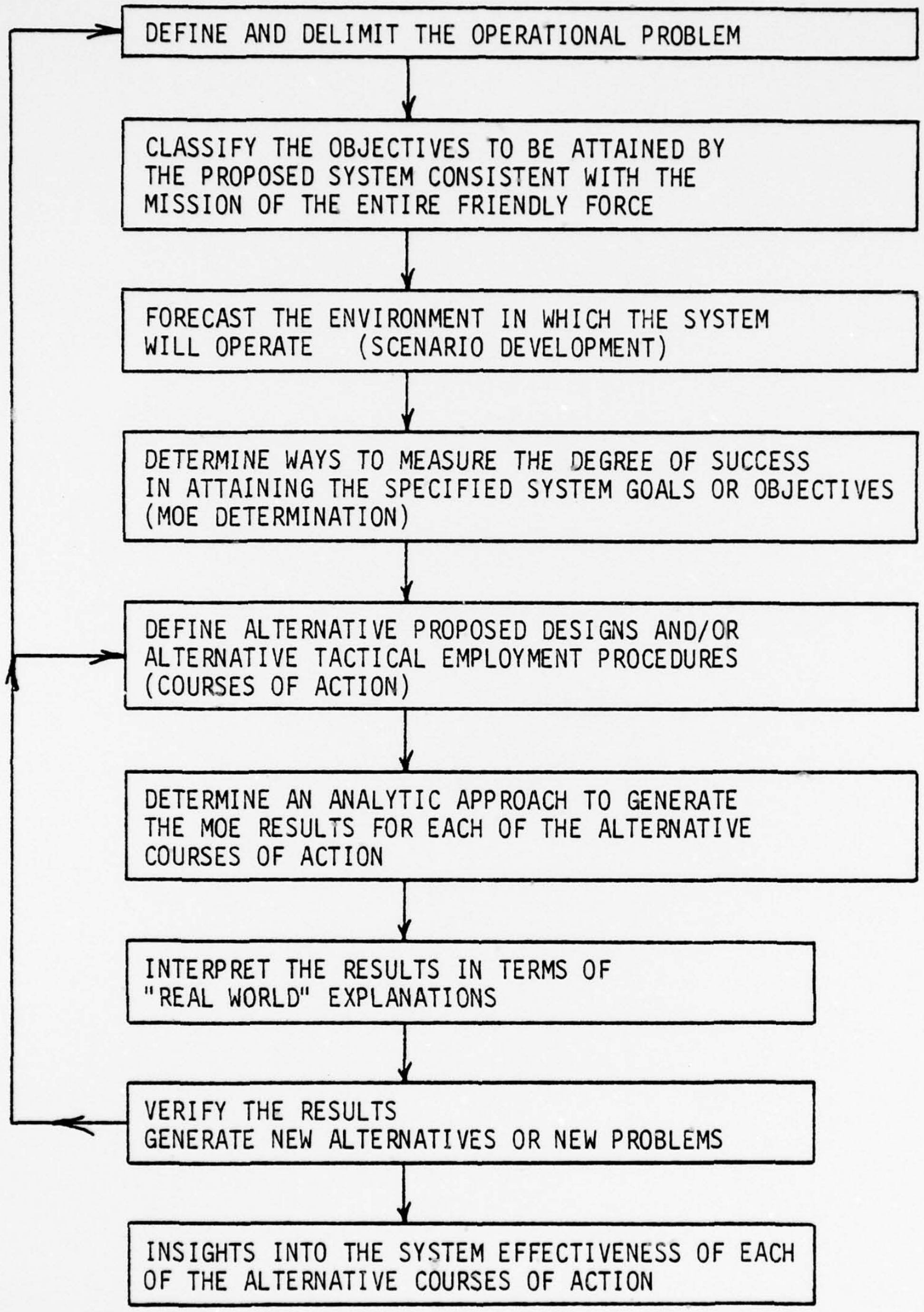


FIGURE (1): GENERALIZED APPLICATION OF ANALYTIC TECHNIQUES TO SYSTEM EFFECTIVENESS EVALUATION may be characterized by the following:

* system performance characteristics,
* system employment procedures,
* a concept of operations and anticipated capability for the remainder of the friendly force, and
* anticipated enemy threat.

Thus, a system's effectiveness is dependent upon the specific combat environment in which it was assessed. This fact emphasizes the responsibility of the military analyst in selecting appropriate scenarios for the evaluation of proposed designs.

A. MODEL DEVELOPMENT FOR THE PURPOSES OF EFFECTIVENESS DETERMINATION

During the conceptual design phase of weapon system acquisition no physical prototype exists and consequently some type of model must be utilized to relate the combat effectiveness of the system (as measured by the MOE) to the independent design parameters. The modelling activity should be directed toward providing cues to the decision-maker as to how the various system design parameters contribute toward the accomplishment of the established system mission, and hence system effectiveness. The inherent complexity of the combat environment has lead to the development of highly sophisticated combat simulations.

The extremely high level of detail characteristic of such models is partially due to the fact that the developers have desired the model to be capable of addressing numerous facets of the combat environment, hence making the model applicable to a broad range of study objectives. The degree of complexity evident in such simulation models reflects a desire to include <u>any</u> factor which may significantly influence the ability of the system to accomplish its operational requirements. It is recognized that such peripheral issues may at times become significant, and since actual combat data is not available, the use of a high resolution model provides a degree of confidence in one's conclusions. There are, however, certain disadvantages with the exclusive use of such a model; these can be summarized by several common full-scale model characteristics. Such models tend to:

* be extremely costly to operate and maintain,
* lack flexibility in tailoring their use to specific problems,
* require an extremely large data base, and
* require the user to perform several replications for each set of input parameters.

The analyst/modeler must keep in mind the fact that the primary purpose of his modelling efforts is "to provide insight, not numbers" [Ref. 4]. The model is a decision aid and as such should be implemented in such a manner as to provide insights into relationships useful to the decision maker. The role of analysis is to augment, stimulate and assist the decision-maker's reasoning ability and as such should not provide the ultimate decision, but only those insights into the dynamics of the problem such that the alternative courses of action may be evaluated and compared. In order that the results of a modelling effort be "acceptable" to the decision maker, there must exist what may be termed "model credibility." The model must provide intuitive, plausible explanations for the numeric results generated. As stated by Geoffrion in Ref. 4:

> "...purely numerical results must be supplemented by intuitively reasonable explanations as to why these results are as they are. Otherwise the validity of a model can only be taken as an act of faith and the end-user will be inclined to revert to intuition or some other more secure mode of analysis."

It must be emphasized that the use of such a complex model is in support of a human decision process. The decision-maker is essentially required to make certain judgments with respect to the final system design specifications, providing a balance between the procurement and maintenance costs inherent in the attainment of a particular set of performance characteristics, and the potential benefit in system effectiveness which may be realized in the combat environment. Factors which may influence this decision process include:

* the individual's personal experiences, intuitions and preferences,
* "external forces," i.e. organizational constraints,
* analytic results tempered by practical judgment.

It is this third source of information which is provided by the high resolution combat simulation modelling effort. Although it should not be inferred that a combat model can generate an accurate point estimate of a system's actual combat effectiveness in a particular scenario, it can provide the decision-maker with a tool which will provide him certain mental cues regarding "gross" differences in effectiveness between various alternative input cases.

Due to the uncertainty in forecasting future operational environments, it is desirable to evaluate the full range of possible effects of a decision by exercising the model over extensive variations in the assumed input parameters. Within each of the four categories of input (see Figure 2) there existscertain ranges over which the input elements of that category may vary. There exist, therefore, numerous feasible model input combinations which conceivably affect the decision criteria. This requirement for detailed sensitivity analysis indicates a need for simulation efficiency which is usually not possible with a high-resolution model.

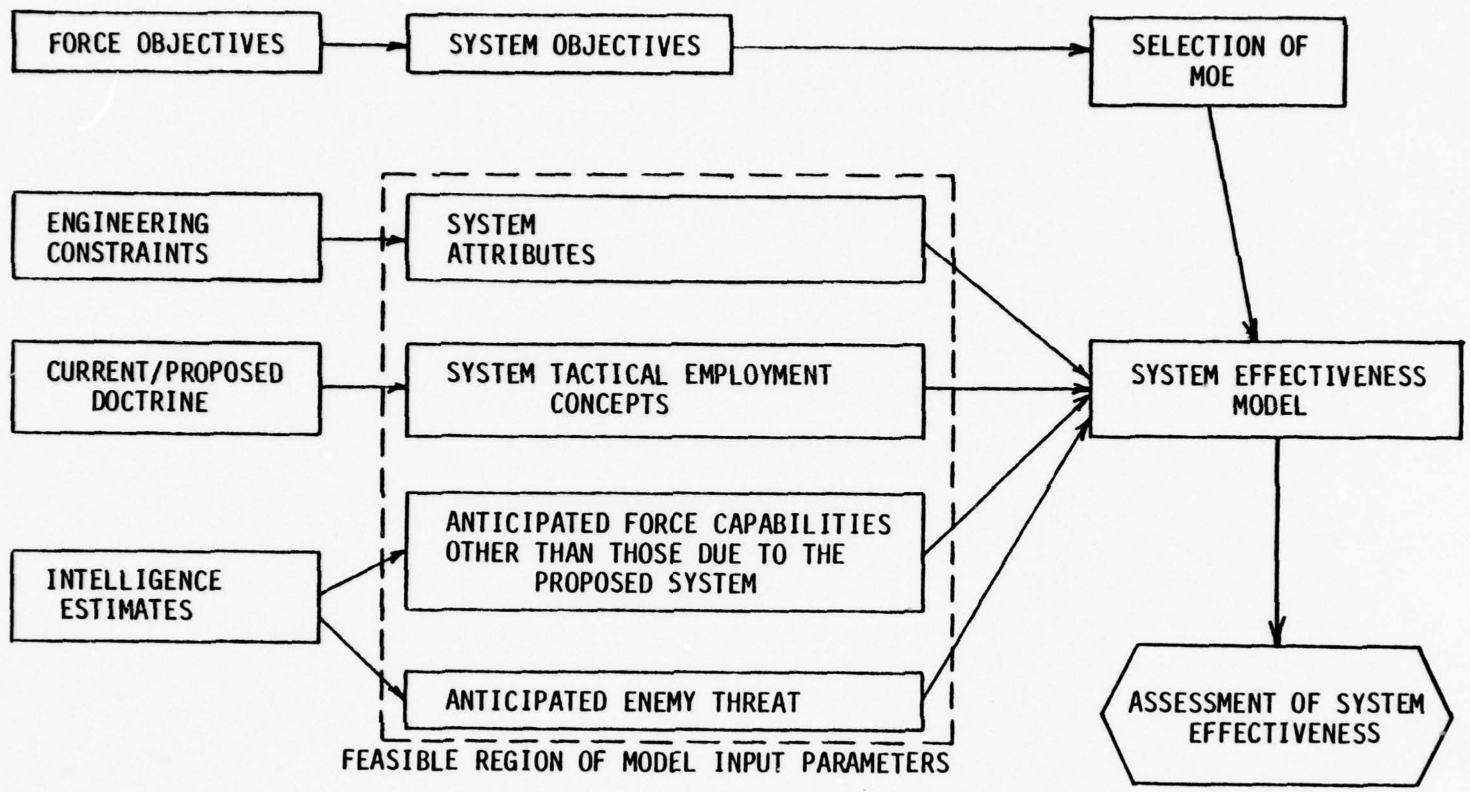


FIGURE (2): MODELING IN THE EVALUATION OF DESIGN AND/OR EMPLOYMENT CRITERIA

B. THE USE OF AN AUXILIARY MODEL IN THE EVALUATION OF SYSTEM EFFECTIVENESS: A MODELLING STRATEGY

The intent of this thesis is to illustrate a methodology which might be applied to such broad based modelling problems as design evaluation. The approach is to develop a specifically tailored simplified model which may be readily exercised over the total realm of input possibilities to assist the analyst in developing certain insights into the behavior of the full-scale model (see [Ref. 4] and [Ref. 11]). Since the results of any simulation are driven by the input parameters, the objective of using this simplified auxiliary model is to be able to process the numerous combinations of input parameters and identify that subset of these combinations which requires further investigation. It is the desire to reduce the entire feasible input region into a manageable number of cases, that is, the auxiliary model is implemented as a mechanism to assist in establishing the initial input case structures which are to be more thoroughly evaluated by means of a large high-resolution simulation. A generalized version of the procedure consists of the following four steps:

* Formulate a simplified auxiliary model, specifically designed to address the primary study objective, simplifying the other peripheral issues as much as possible. Maintain as required the essence of the full-scale model by the use of generalized input parameters defined over certain feasible regions.

* Calibrate the auxiliary model by comparing its results against full-scale model results over a selected set of input parameters representative of the "typical" case.

* Fully exercise the auxiliary model over the entire range of feasible input combinations reflecting the entire realm of anticipated employment and decision possibilities. From the trends indicated by these runs, formulate tentative hypotheses about the relationships and contributions each of the decision variables makes toward the MOE being investigated.

* Test these hypotheses on the full-scale simulation model. If major discrepancies exist, attempt to determine the underlying explanation. Modify or recalibrate the simplified model as required.

The remainder of this thesis will be devoted to an application of this proposed methodology in the evaluation of proposed designs for the LVA (Landing Vehicle Assault), a high-speed amphibious vehicle currently under development for the United States Marine Corps. The LVA concept provides the means by which various aspects of this modelling strategy are to be illustrated. In addition to an evaluation of the LVA's effectiveness as it relates to specific design specification, the model will also be applied to the assessment of alternative tactical employment concepts. The interrelationships that exist between the physical design and the tactical employment considerations will be examined in detail. The next section will provide certain background with respect to the basic LVA concept.

II. LVA ILLUSTRATION: APPLICATION BACKGROUND

This section shall briefly present certain background information with respect to the proposed LVA vehicle design problem with which the auxiliary modeling methodology will be illustrated. It will also state certain qualifying assumptions which were made in the analysis of this vehicle.

A. LVA CONCEPTUALIZATION

Requirements studies have indicated that in future amphibious operations, due to the increased lethality of anti-ship missiles and long-range artillery, it will be necessary to increase the Amphibious Task Force (ATF) standoff distance to approximately 25 miles from shore in order to reduce the vulnerability of the amphibious shipping against this anticipated threat. The projection of power ashore by both vertical and surface means is expected to remain the concept of operations during this time period. It seems to be necessary therefore to develop an amphibious craft capable of 25MPH in order to transit the much longer distance without significantly increasing troop exposure during the waterborne phase of the operation.

By imposing a minimum of 25 mile standoff from shore, the following tactical advantages may also be realized:

* It causes a significant expansion in the shoreline threatened by the ATF.
* It conceals more effectively the actual landing sites.
* It complicates the emplacement of shore defenses.
* It permits more maneuver area and thus greater flexibility in the sea operations of the ATF.

These advantages may be achieved by developing an amphibious vehicle (LVA) similar in its operating characteristics ashore to those of the present LVTP-7 but with the added requirement that the LVA be capable of water speeds in excess of 25 miles per hour. The following are the general design specifications anticipated for the LVA as specified in Ref. 3:

LVA REQUIREMENTS

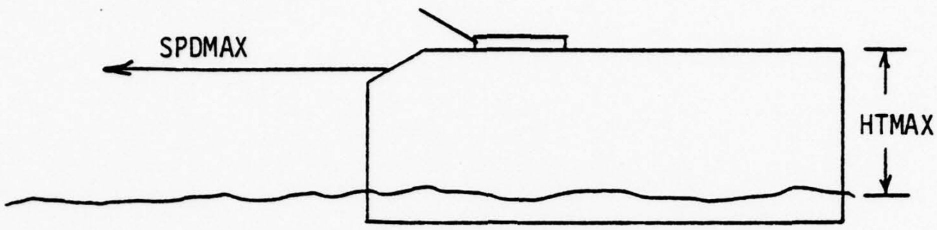
Water Speed	25-40 MPH	(11-18 meters/sec)
Land Speed	40-55 MPH	(18-25 meters/sec)
Water Range	75 Mi.	120 Km
Land Range	250 Mi.	400 Km
Length	33 Ft. (max.)	(8.75 M)
Width	11 Ft. (max.)	(2.9 M)
Height	11 Ft. (max.)	(2.9 M)
Troop Capacity	25-30	
Cargo Capacity	8000 lbs.	

For the purposes of this thesis certain assumptions are to be made with respect to the LVA design. Many proposals have been made regarding the means of achieving the required water speed, however, the current indications are that a planing hull will be used to meet this requirement. It is to be assumed that the LVA to be evaluated is of the planing hull variety for which the following definitions shall apply:

PLANING MODE: An operating mode for the LVA in which the craft is traveling at a water speed high enough (SPDMAX) to sustain a planing configuration (HTMAX). See Figure 3.

DISPLACEMENT MODE: An operating mode for the LVA in which the craft is traveling at such a low rate of speed (SPDMIN) that the vehicle is not capable of maintaining the planing configuration. In the displacement mode the LVA will ride low in the water similar to the conventional LVTP-7. The exposed height in this mode is HTMIN. It is noted that the LVA must be in this particular mode prior to crossing the surfline during its movement ashore. See Figure 3.

PLANING MODE:



DISPLACEMENT MODE:

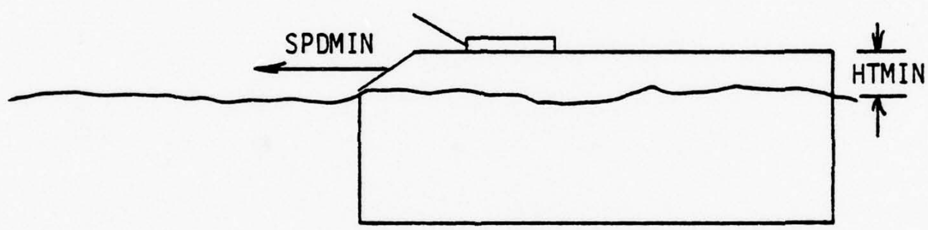


FIGURE (3): LVA WATERBORNE CONFIGURATIONS

The scope of this application of the auxiliary modelling methodology is to be restricted to the waterborne phase of the LVA's employment. This modelling effort will not address the desired capabilities of the vehicle ashore.

B. LVA EMPLOYMENT: CONCEPT OF OPERATIONS

For the purposes of this study, certain broad assumptions have been made as to the exact method of employment for the LVA in the ship-to-shore phase of an amphibious assault. It is envisioned that for command and control purposes as well as mine clearing operations there will exist LVA approach lanes as shown in Figure 4 along which columns of craft will transit the 25 mile distance to shore from the amphibious shipping. It is assumed that there will exist some form of maneuver area within which the columns of LVA form into the conventional landing formation composed of waves of landing craft as prescribed by current doctrine.

The fundamental assumption is that the formation of incoming waves is to be accomplished at a distance offshore which is greater than the effective range of the direct-fire weapon systems which it shall be assumed dominate the primary anti-LVA threat. Although it is to be expected that LVA may be attrited during this seaward portion of the ship-to-shore movement, it is assumed that the critical exposure period will be that portion of the waterborne approach from when the first incoming wave is approximately 5000 meters offshore up to and including the arrival ashore of the last assault wave. It is therefore this portion of the operation which is to be analyzed. Further embellishments to the model could certainly be developed which would encompass the broader aspects of the entire LVA concept.

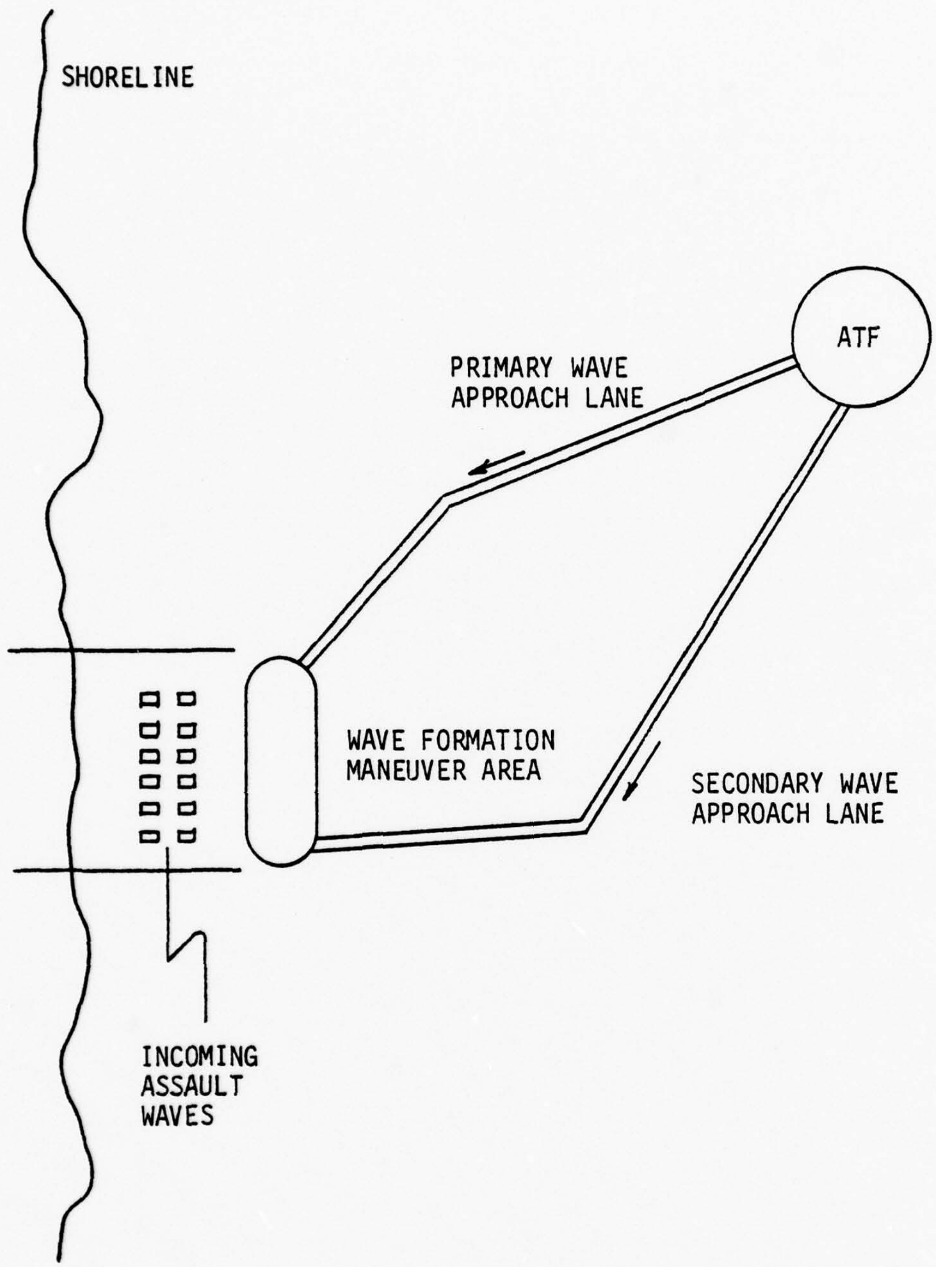


FIGURE (4): LVA CONCEPT OF OPERATIONS SHIP-TO-SHORE

In simplifying the movement of LVA ashore, two tactical decision variables are utilized.

1. TBW

The Landing Force Commander must decide upon the time interval between successive waves of incoming craft arriving at the beach. TBW is the decision variable for the Time Between Waves. As TBW is shortened, coordination problems resulting in confusion at the beach will arise since there is not sufficient time for each wave to move inland prior to the next wave's arrival. This consideration must be balanced against the desire for an initial rapid build-up of offensive power ashore.

2. RD

As each wave of LVA moves toward the shoreline in the planing mode, there must exist a coordination measure to denote that point at which the craft are to slow to the displacement mode. Due to engineering stability requirements it is necessary that this displacement configuration be achieved prior to crossing the surfline. Once the craft has slowed down, the operator also must lower the vehicle tracks in preparation for land movement. At this point it shall be assumed that as each wave passes an imaginary line RD meters off the shoreline, each LVA in that wave will commence the transition from planing to displacement modes. Successive waves likewise upon crossing this RD coordination line will initiate their transition. This process shall be termed a sequential wave transition since each of the assault waves sequentially perform the mode transition. See Figure 5 for a graphic portrayal of the tactical employment criteria.[1]

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[1] It is noted that in this figure and in the remainder of the thesis the character "*" shall be used to designate a multiplication operation between variables.

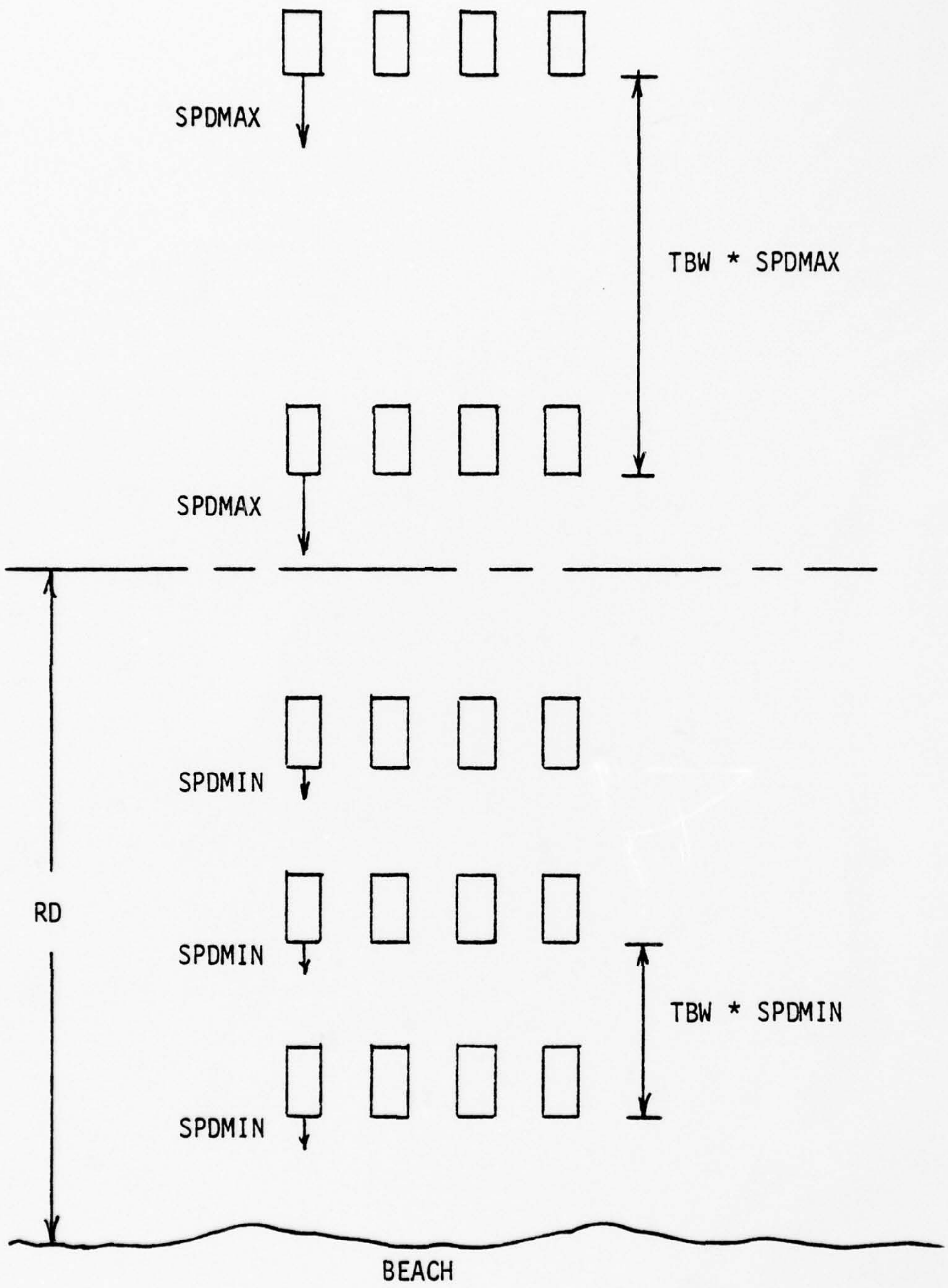


FIGURE (5): TACTICAL EMPLOYMENT PARAMETERS - SEQUENTIAL TRANSITION

C. LVA ILLUSTRATION: AUXILIARY MODEL USAGE

In applying the methodology proposed in the first chapter to the design specifications regarding the LVA, the initial step is to identify a suitable measure of effectiveness (MOE) by which alternative proposed designs might be compared. In this thesis it was decided that the survivability of the craft was the underlying determinant in performing its mission. Since the purpose of the vehicle in the waterborne phase is the transport of men and equipment from the ATF to the beach, the total number of surviving craft arriving ashore (given the same initial number of craft departing the amphibious shipping) is therefore chosen as the MOE.

As indicated by the proposed approach, it is the intent to develop a simplified model specifically tailored to addressing the decision criteria of importance to this problem. The remainder of this section shall briefly delineate the scope of the auxiliary model and formally state the decision variables to be used.

1. Model Considerations

It is an implicit assumption throughout this application that in future amphibious operations the attrition of incoming landing craft shall be dominated by the effects of shore defense direct-fire weapon systems, specifically, modified versions of current tank and anti-tank guided missile (ATGM) assets. The primary modelling effort within the auxiliary model itself is therefore based upon this assumption. It is noted that the model essentially omits the effects of the defensive indirect fire capabilities. The seriousness of this omission would be determined by comparing auxiliary model results with those of the full-scale simulation model.

A secondary consideration which it is felt cannot be ignored is the effect of the ATF's fire support assets against the shore defenses. In developing the auxiliary model the intent is to capture the effect of this peripheral issue without actually implementing the level of detail contained in a high-resolution simulation. It is reiterated that the simplified model to be developed here is a tool to be used in conjunction with a high level combat simulation; it is not intended as a replacement for such a full-scale model.

A final peripheral issue which must be considered is the attrition effects made on the defensive forces by the initial waves arriving ashore. Again it is felt that this aspect of the problem cannot be ignored but also does not require the level of complexity which it would receive within a high-resolution model.

2. Model Objectives

In the development of a new amphibious vehicle, two basic interrelated issues must be resolved: the design specifications and the employment criteria. These two problems lend themselves to the application of this proposed modelling approach. Table I lists the basic decision variables in both these categories which are of interest. The next chapter will describe the basic logic contained in the LVA auxiliary model and will explain the simplifications which were instituted in the course of the model's development. The underlying motivation behind the structure of the model is a desire to focus upon the primary consideration (the direct-fire weapon versus LVA interrelationship), while aggregating the effects of the other peripheral issues. The validity of a model is contained in its ability to accurately reflect the interactions among the decision variables. It is the desire to develop a model which encompasses such interactions without recreating a costly stochastic model.

TABLE I. LVA AUXILIARY MODEL: PRIMARY DECISION VARIABLES

DECISION CATEGORY	VARIABLE	DEFINITION
ENGINEERING DESIGN CRITERIA	SPDMAX	WATER SPEED OF THE LVA IN THE PLANING MODE
	SPDMIN	WATER SPEED OF THE LVA IN THE DISPLACEMENT MODE
	HTMAX	EXPOSED LVA HEIGHT ABOVE THE WATERLINE IN THE PLANING MODE
	HTMIN	EXPOSED LVA HEIGHT ABOVE THE WATERLINE IN THE DISPLACEMENT MODE
TACTICAL EMPLOYMENT CRITERIA	RD	DISTANCE OFF THE BEACH AT WHICH THE LVA COMMENCES ITS TRANSITION FROM A PLANING CONFIGURATION TO THE DISPLACEMENT
	TBW	INTERARRIVAL TIME BETWEEN SUCCESSIVE WAVES OF LVA ARRIVING AT THE BEACHLINE
	WVINT	THE INITIAL NUMBER OF LVA IN EACH OF THE ASSAULT WAVES

III. AUXILIARY MODEL DOCUMENTATION SUMMARY

This chapter contains a description of the basic qualities and logical interrelationships incorporated in the actual model. For complete documentation the reader is referred to the flowchart in Appendix C and to the documented source listing.

A. MODEL FUNCTIONAL FORM

In formulating this model a fundamental self-imposed limitation was the anticipated execution time. The level of modelling sophistication was purposely constrained so as to keep the execution time (CPU) less than ten seconds (IBM 360/67) per set of parameters. This was done in order that extensive sensitivity analysis would be possible. The model finally developed incorporates several substantial simplifications over a full-scale combat simulation; the most significant of these is that the model handles unit attrition in a deterministic fashion. The primary advantage achieved by the use of such a deterministic model is the ability to generate in a single execution of the model an "average" LVA survivor outcome for a particular input case in contrast with the multiple replications required if a stochastic model were used. It should be noted that although the decision was made not to develop a stochastic model, the LVA auxiliary model developed here does require most of the same input data that a Monte-Carlo combat simulation would. The primary modelling simplifications arise from the approximation of discrete force sizes by continuous variables. This is in contrast with the discrete event/discrete entity approach used within a stochastic simulation. Since the model's primary function is in establishing the dynamics involved in the employment of a proposed LVA craft, that is, the basic interrelationships that exist between the various decision criteria, the decision was made to utilize a deterministic analysis.

The classical LANCHESTER hypothesis for aimed fire attrition ("modern conditions") is that the casualty rate of a unit is proportional to the "size" of the opposing force. If unit "A" is being engaged by "D", this may be expressed by the differential equation

$$\frac{dA}{dt} = - BETA_{DA} * D .$$

The proportionality constant $BETA_{DA}$ is called the Lanchester attrition rate coefficient. It is assumed that this functional relationship holds for each (firing unit, target unit) pairing over a small time interval dt. The ability of a differential combat model to accurately reflect the inherent complexities of the combat environment is determined by the level of sophistication associated with the computation of each of the attrition rate coefficients within each time interval. The credibility of the model is determined by the manner in which the model transforms the performance characteristic data with the tactical and physical configurations for each of the combat units to generate the numerous attrition rate coefficients.

Although more complicated models exist (the reader is referred to the work of Taylor in Refs. 11 and 12), it was decided to express these coefficients as the product of the rate of fire (ROF) and the kill probability per round (P(K)). Therefore

$$BETA_{DA} = P(K)_{DA} * ROF_{DA} .$$

The subscript DA refers to the tactical relationship of "D" engaging "A". The strength of the model rests in its ability to express $P(K)_{DA}$ and ROF_{DA} as functions of the physical combat environment each pair of units being modeled are face with as the simulated operation progresses each time interval. The bulk of the modelling effort is involved in the computation of these instantaneous attrition coefficient factors reflecting the tactical situation at each instant of time. Numerical methods must be used to generate combat results because of the well-known analytical intractability of variable-coefficient differential-equation models.

The remainder of this chapter describes in detail the logical process by which each of these variable factors is determined for each weapon-target pair.

B. FORCE STRUCTURE

This model aggregates the various actual combat organizations involved in the waterborne phase of the amphibious operation into several homogeneous combat units. Each of these units is characterized by certain offensive and defensive capabilities in comparison to each of the other units.

The following table illustrates the combat organizations which were explicitly modeled. The combat strength of each unit was represented by the state variables indicated. An exact interpretation of these strength variables will be presented in a later section.

COMBAT ORGANIZATION	STATE VARIABLE
Shore Defenses - TANK assets	DT
Shore Defenses - ATGM assets	DS
Incoming assault waves of LVA representing waves 1 through 5	WV(I) I = 1,2,3,4,5
A cumulative combat force comprised of those Marine ground units which have arrived at the beach and have debarked the LVA	TLF
Fire Support Assets of the Amphibious Task Force	ATFFS

The initial strength in each of the above force units is input data to the model. This permits the user to investigate alternative wave composition options and also various defensive scenarios without modifications to the model logic. The tactical interrelationships which exist between the nine combat units within the force structure are illustrated in Figure 6.

C. SHORE DEFENSES CONCEPTUALIZATION

The defensive scenario postulated for the purposes of this model includes a force comprised of tanks (DT) and anti-tank guided missiles (DS). Both the tank unit and the ATGM unit are assumed to be emplaced approximately 75 meters inland of the waterline at an elevation of approximately 5-10 meters. The model does not explicitly maneuver or emplace individual tanks or ATGM systems within each unit as a high-resolution simulation would but aggregates the cumulative effects of the individual vehicles and weapons within each category.

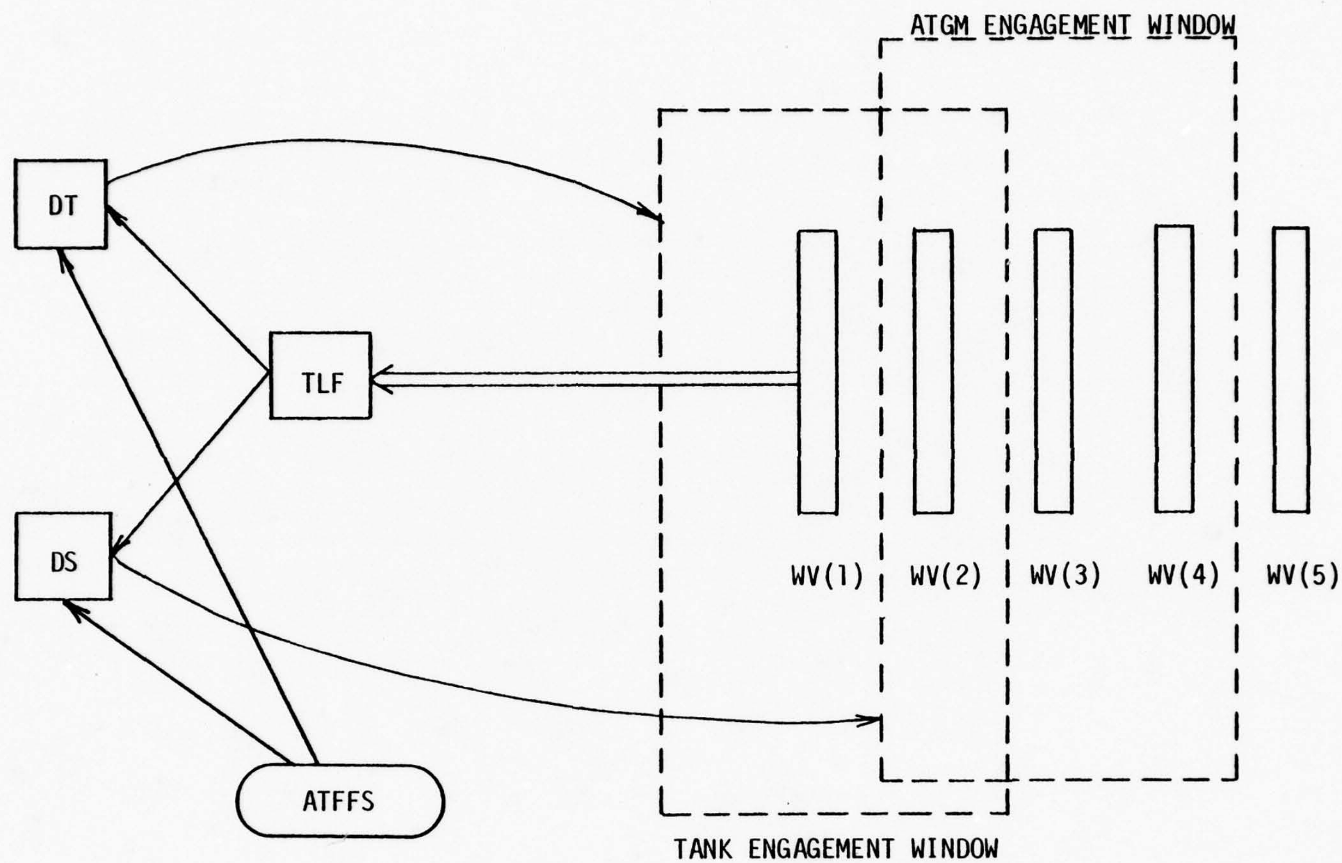


FIGURE (6): AUXILIARY MODEL FORCE INTERRELATIONSHIPS

1. Defensive Unit Strengths

The state variables DT and DS represent the total unit "strengths" in each of these defensive weapon categories. The term unit strength may be best explained by means of the following example. DT = 3 indicates that within the shore defenses there exists a unit of tanks having a total combat effectiveness equivalent to 3 continuously firing individual weapon systems. A similar interpretation is applicable to the state variable DS.

2. Defensive Fire Allocation

It was assumed that each of the two categories of direct-fire weapons would engage targets (incoming LVA) according to a pre-assault determined tactical scheme. The defensive "plan" was parameterized as follows:

Each weapon category was assigned an engagement window as illustrated in Figure 7. Only those LVA located within this range window could be fired upon by the shore defenses. The windows are designated by the following input parameters:

	TANK	ATGM
MAXIMUM ENGAGEMENT RANGE	TENGMX	SENGMX
MINIMUM ENGAGEMENT RANGE	TENGMN	SENGMN

Additional defensive tactical criteria are implemented into the model logic by adherence to the following rules:

* A defensive weapon only engages the two closest incoming waves if more than two waves of LVA are at any time located within the weapon's engagement window.

* If only one wave of LVA is present in a weapon's engagement window, defensive fires of that particular weapon type will be distributed uniformly against the surviving LVA in that wave.

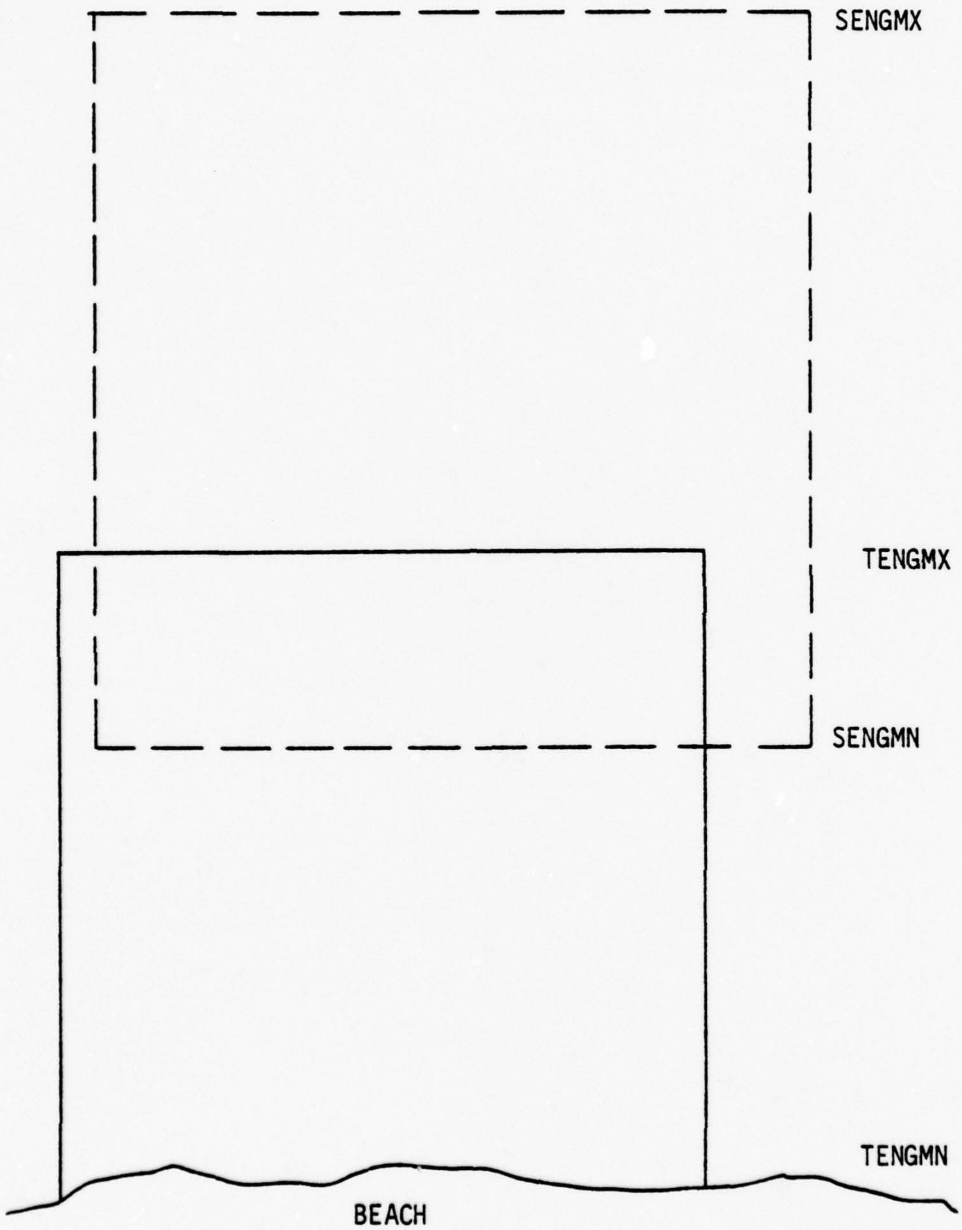


FIGURE (7): DEFENSIVE ENGAGEMENT WINDOW PARAMETERS

* If two waves of LVA are both contained within the engagement window, defensive fires of that particular weapon type will be distributed according to a tactical allocation submodel. A weighting factor (DEFWT) is utilized in establishing the proportion of the total weapon strength to be allocated against the surviving LVA's in each of the two waves. As an example, if DEFWT(1) = 2 and DEFWT(2) = 1, then each surviving LVA in the closer of the two incoming waves would be allocated twice as much fire as surviving LVA in the seaward wave. For the purposes of this example, if waves 3 and 4 were both located within the tank engagement window, then the proportion of DT's fire allocated to surviving LVA in wave 3 would be

$$\frac{DEFWT(1)*WV(3)}{DEFWT(1)*WV(3) + DEFWT(2)*WV(4)} * DT ,$$

where WV(3) is the state variable for the current number of survivors in wave 3.

3. Attrition Rate Coefficient Computation

It has been stated that the primary modeling devise is the Lanchester attrition rate coefficient. Such a coefficient exists for each (defensive weapon, target) pairing yielding the ten variables:

$$BETA_{DT-WV(I)} = ROF_{DT-WV(I)} * P(K)_{DT-WV(I)} \quad I = 1,2,3,4,5$$

$$BETA_{DS-WV(I)} = ROF_{DS-WV(I)} * P(K)_{DS-WV(I)} \quad I = 1,2,3,4,5 .$$

The rate of fire (ROF) factor conveniently serves as a switch mechanism by implementing the functional relationship:

$$ROF_{D\_-WV(I)} = \begin{cases} 0 & \text{if WV(I) is located outside the engagement window} \\ \frac{1}{TBF} & \text{if WV(I) is located within the engagement window} \end{cases} ,$$

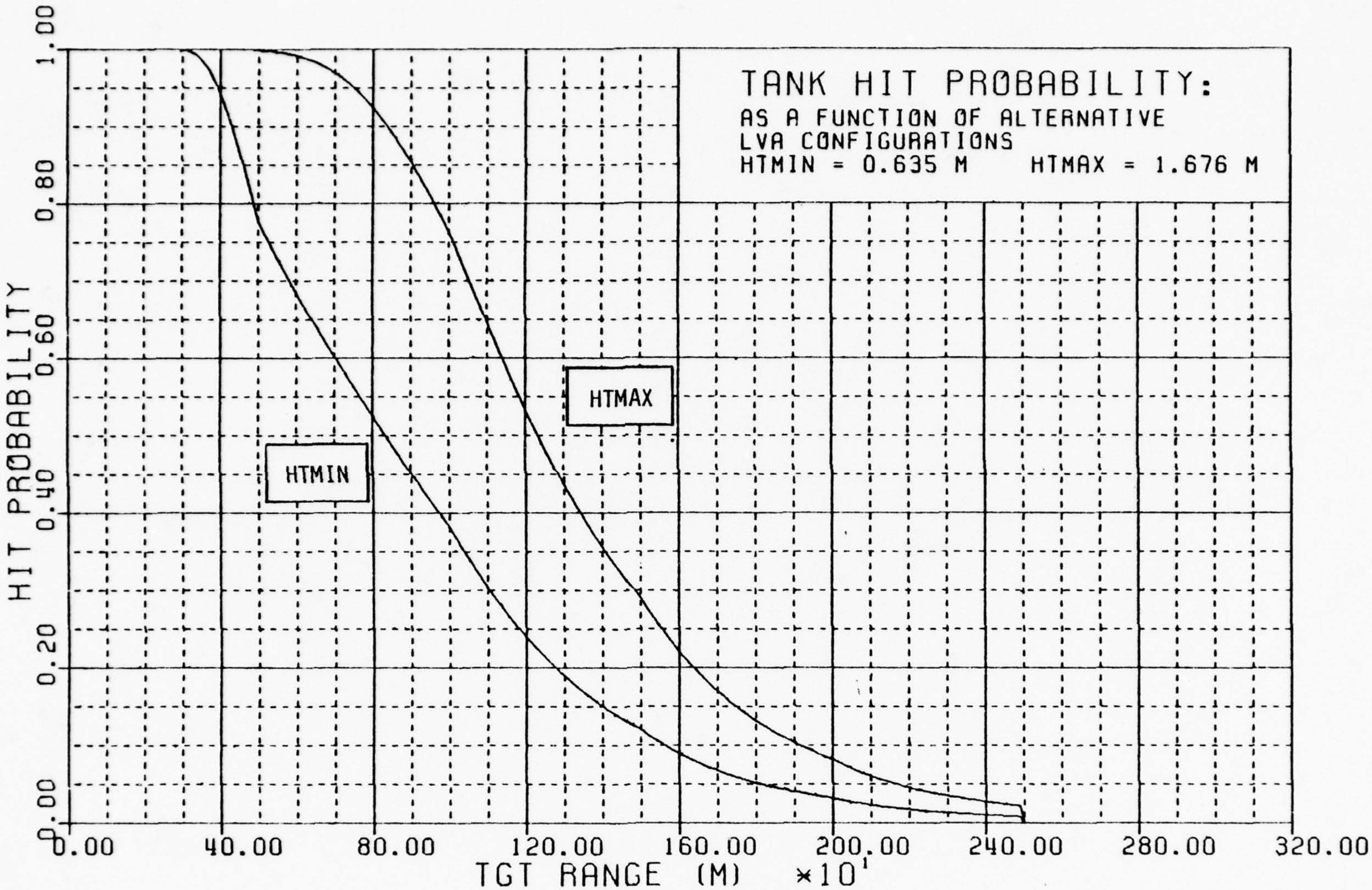
where TBF (Time Between Firings) can be evaluated by

$$TBF = \text{AIM-RELOAD TIME} + \frac{\text{TARGET RANGE}}{\text{TARGET SPEED + PROJECTILE VELOCITY}} .$$

The relatively slow projectile velocities representative of anticipated ATGM assets in the future does cause such velocities to become significant in this computation.

The second factor in determining each attrition rate coefficient is the probability of a vehicle "kill" per round: P(K). It is assumed that a hit by a large caliber projectile would constitute a "kill" in that it would most likely inflict serious enough damage to either sink the LVA or render the craft immobile and hence eliminate it from contributing to the build-up of forces ashore. A second assumption is that the two defensive weapon systems addressed would exhibit normal, uncorrelated horizontal and vertical errors. Typical dispersion data, both mean and standard deviation, for the tank and ATGM weapons is required as input data for the hit probability computations. Figure 8 and 9 illustrate the hit probability versus range characteristics for the representative tank and ATGM data hypothesized for this application. It may be observed that the configuration of the LVA (planing or displacement mode) is a predominant factor in the vulnerability of the craft to direct fire.

The suppressive effects of incoming fire upon each of the defensive units was considered a significant factor with respect to its effect upon the survivability of the incoming assault waves of LVA. It was assumed that this suppressive effect would significantly reduce a unit's rate of fire and also increase the error standard deviation. The modelling of these suppressive effects is accomplished by the assignment of a relative suppression factor (SUPFAC) in the interval [1,2] for both the tank and ATGM units. This factor is determined subject to the following somewhat arbitrary guidelines.



FIGURE(8): HEIGHT EFFECTS ON TANK HIT PROBABILITY

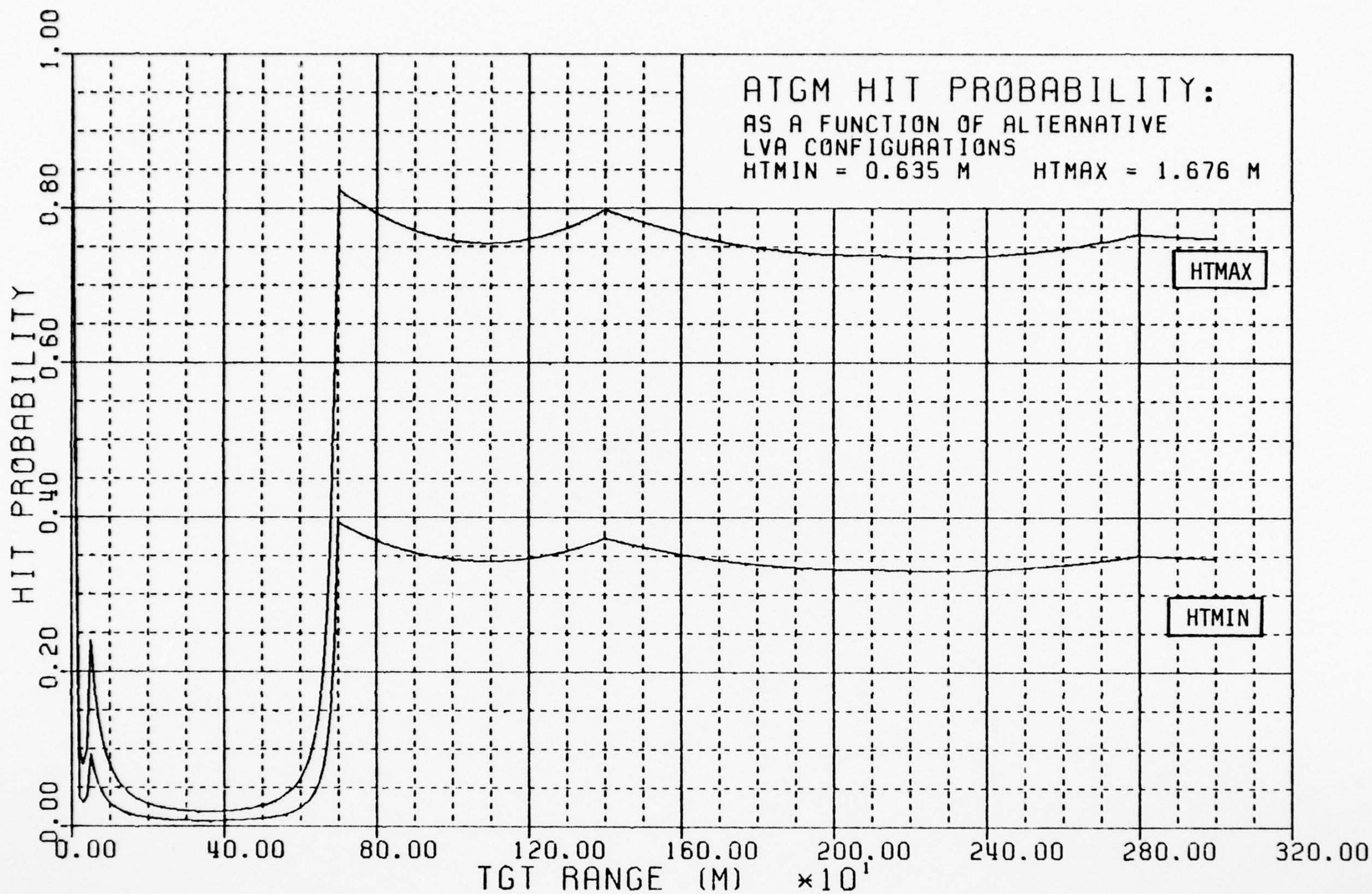


FIGURE (9): HEIGHT EFFECTS ON ATGM HIT PROBABILITY

SUPFAC = 1 — No incoming fires, i.e. the defensive unit casualty rate is zero.

SUPFAC = 2 — Maximum incoming fires i.e. the defensive unit casualty rate is comparable to that realized upon full allocation of the ATF fire support assets.

It was assumed that the aim-reload time (ARTM) would be increased by approximately 50% under the conditions represented by a SUPFAC of 2.0. Within the ROF submodel this is expressed by the linear relationship

$$ARTM_{SUP} = ARTM_{NONSUP} * (0.5 + \frac{SUPFAC}{2.0}) \quad .$$

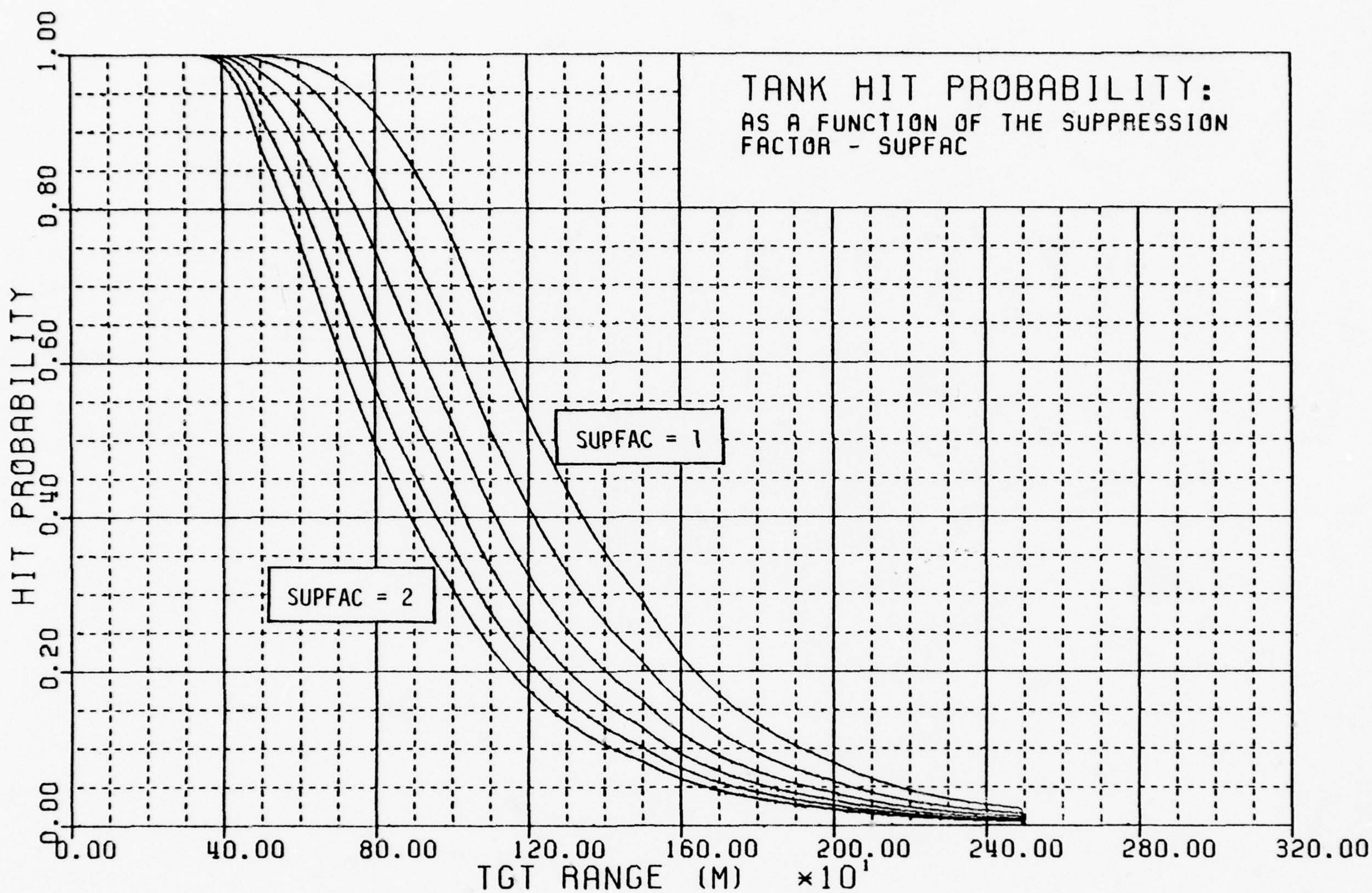
It is additionally assumed that up to a 100% increase in the error standard deviation could be expected under a maximum suppression environment, hence

$$ERROR\ SD_{SUP} = ERROR\ SD_{NONSUP} * SUPFAC \quad .$$

The consequences of this percentage increase in error standard deviation is illustrated for both defensive weapon systems in Figures 10 and 11.

4. Defensive Breakpoint

It is assumed that if during the course of the amphibious operation the defensive forces suffer a cumulative loss in excess of 70% of their initial force strength, the remaining shore defenses will withdraw, resulting in battle termination.



FIGURE(10): SUPPRESSION EFFECTS ON TANK HIT PROBABILITY

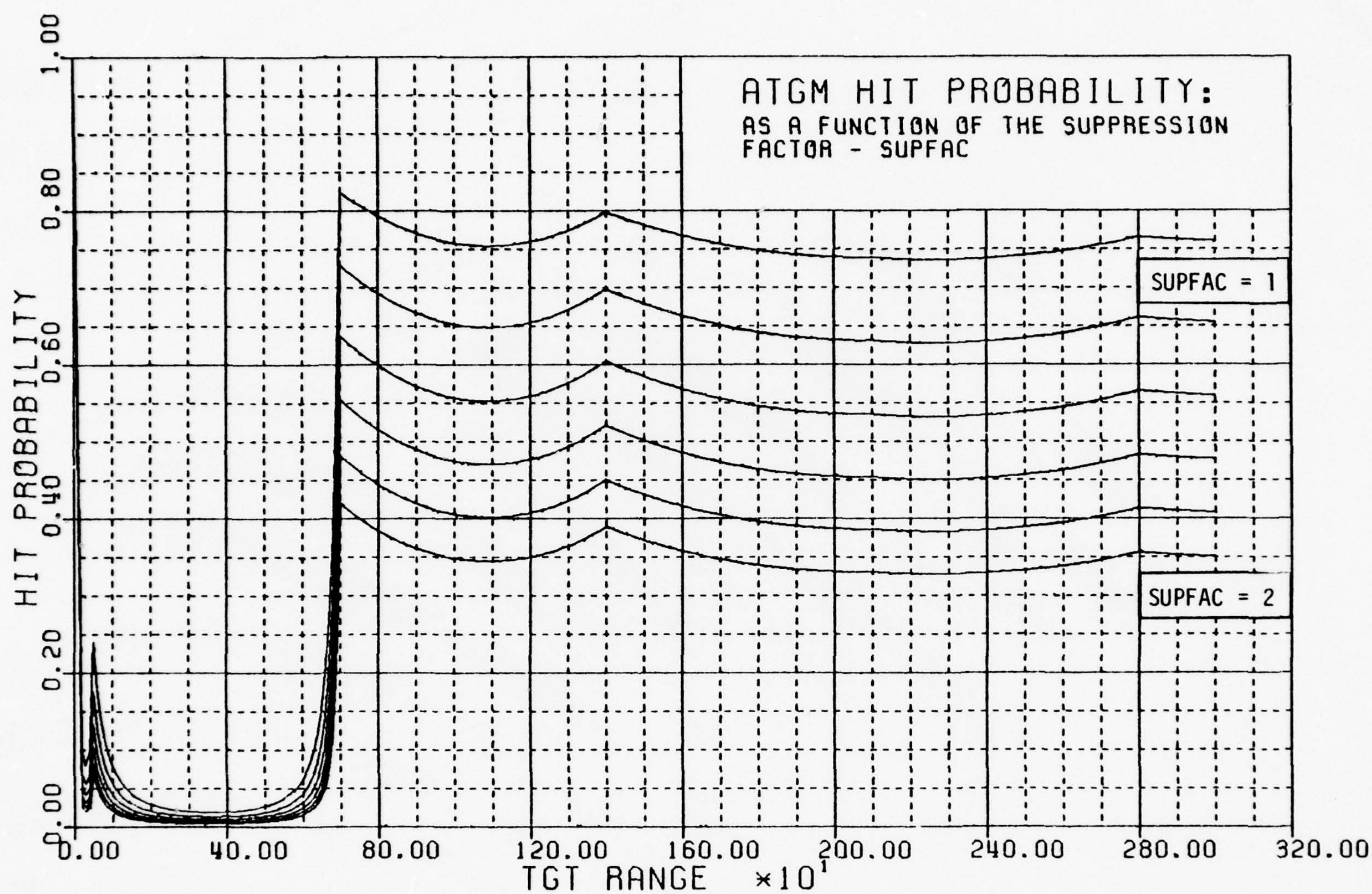


FIGURE (11): SUPPRESSION EFFECTS ON ATGM HIT PROBABILITY

D. LVA ASSAULT WAVE CONCEPTUALIZATION

The auxiliary model is programmed to handle up to five incoming waves of LVA. The initial composition of each of these waves is input by the user by means of the variable WVINT. There are no limitations as to the number of LVA in a wave.

1. Wave Posture

Model functions RNG,HT and SPD are called upon within the model logic to generate the range, height and speed respectively for each assault wave as time is incremented throughout the course of the amphibious operation. The input tactical employment parameters TBW and RD in conjunction with the physical design parameters SPDMAX, SPDMIN, HTMAX, HTMIN for the LVA being evaluated uniquely determines the exact range offshore and vehicle configuration (planing/displacement) for each of the five waves. This information is then implemented in the rate of fire and hit probability calculations.

2. Ground Forces Ashore

As each assault wave arrives at the beach, the total surviving strength of that wave is transferred to the state variable TLF (Total Landed Force). TLF represents a ground combat force equal to that transported by the number of LVA survivors having arrived ashore. Once established, TLF engages the two defensive units allocating its fires between the two defensive weapon categories in the same proportion as the number of surviving tanks and ATGM's, that is

$$TLF_{DT} = \frac{DT}{DT + DS} * TLF$$

$$TLF_{DS} = \frac{DS}{DT + DS} * TLF \quad .$$

The casualty rates applied against the DT and DS state survivor variables are determined by means of the Lanchester aimed-fire attrition rate coefficients $WBETA_{TLF-DT}$ and $WBETA_{TLF-DS}$ by the equations

$$\frac{dDT}{dt} = - WBETA_{TLF-DT} * TLF_{DT}$$

$$\frac{dDS}{dt} = - WBETA_{TLF-DS} * TLF_{DS} \quad .$$

The computation of these WBETA coefficients is not performed within the model utilizing the detailed rate of fire and P(HIT) arguments described previously. Since the defensive losses are significant but not a primal issue in the auxiliary model, a high level of complexity is not necessary nor desirable with respect to this particular aspect of the operation. By curve fitting these equations to casualty curves realized in a full-scale model calibration run, generalized input parameters are obtained for these two coefficients. Thus, the sophistication of the auxiliary model with respect to this potentially complex modelling situation is kept to a minimum.

E. ATF FIRE SUPPORT CONCEPTUALIZATION

The impact of the Amphibious Task Force's fire support assets contributes significantly to the combat effectiveness of the shore defense units; however, this is essentially a peripheral aspect of the auxiliary model's primary function and is capable of being modeled without resorting to an analysis of individual sorties. By characterizing each of the two defensive force units by a simple "located" or "not located" attribute, the attrition rates realized by these force units can be simplified substantially by the following approach.

1. "Not Located" Shore Defenses

At the commencement of the model it is assumed that the defensive units DT and DS are emplaced on shore at locations unknown to the ATF. The units are then initially engaged as "not located" targets by area fire for which the following Lanchester area fire equations are applicable

$$\frac{dDT}{dt} = -(ALPHA_{DT} * ATFFS) * DT$$

$$\frac{dDS}{dt} = -(ALPHA_{DS} * ATFFS) * DS$$

The terms in parentheses on the right hand side of these equations are to be considered a generalized input parameter. The combat effectiveness of the ATF fire support assets is also to be considered relatively constant during this segment of combat time and thus it is possible to synthesize these input factors by examining the attrition losses due to area fires realized in a previous full-scale model calibration run.

2. "Located" Shore Defenses

Once a particular defensive unit has initiated its engagement of incoming waves of LVA it is considered "located." At this point it is assumed that the ATF fire support organization will engage that defensive unit through the use of aimed fire. Again it is assumed that the loss rate will be in accordance with the Lanchester hypothesis for aimed fire, that is

$$\frac{dDT}{dt} = -BETA_{DT} * ATFFS$$

$$\frac{dDS}{dt} = -BETA_{DS} * ATFFS$$

It is noted that the right hand sides of both these equations are to be regarded again as synthesized factors to be calibrated from a previous high-resolution application.

F. AUXILIARY MODEL REMARKS

It is again emphasized that in the development of the auxiliary model the primary consideration addressed in the ship-to-shore movement of incoming waves of LVA was the attrition effects upon those waves due to the two direct-fire weapon assets ashore. The model attempts to simplify as much as possible the peripheral issues which supplement this direct-fire weapon vs. LVA interrelationship through the use of data generated by previous high-resolution modelling applications.

The next two chapters present two separate yet related applications of the auxiliary model. These applications will hopefully serve to illustrate the advantages of this proposed modelling strategy as introduced in the first chapter.

IV. MODEL APPLICATION: TACTICAL EMPLOYMENT CONSIDERATIONS

The auxiliary model has been used for two different types of problems. In this chapter we address the problem of how to best utilize the LVA in a tactical sense given that the physical performance characteristics have been relatively well defined. A second application will be presented in the next chapter which will attempt to identify those design parameters which contribute significantly toward mission performance.

A. INPUT PARAMETER GENERATION

In the evaluation of tactical employment alternatives, it is necessary to identify those input parameter sets which are of interest to the decision-maker.

1. Decision Criteria

The two decision variables previously discussed which describe the manner in which incoming waves of LVA are deployed are RD and TBW. In addressing the sequential transition of assault waves at RD meters offshore, a tradeoff exists: Is it better to move as quickly as possible toward shore projecting a large target profile, or alternatively, is it better to move at a slower rate of speed but as a much smaller target? The hit probability curves in Figures 8 and 9 highlight this tradeoff consideration. The time interval between the arrival of successive waves ashore (TBW), due to the difficulties in coordinating the debarking Marine ground units, must also be constrained to certain feasible bounds. It was decided to exercise the model over the following feasible values for each of these decision variables.

FEASIBLE EMPLOYMENT CRITERIA

RD: Distance offshore at which waves initiate transition.
TBW: The interarrival time between waves arriving at the beach.

RD (METERS)	TBW (SECS)
500	120
1000	180
1500	240
2000	
2500	
3000	

The model output was specifically designed to provide the user with sufficient information to develop insights into the operational dynamics. From these insights, it is possible to more readily evaluate the impact each of these 18 tactical employment alternatives has upon the survivability of a proposed LVA design.

2. Scenario Development

In comparing these alternative tactical schemes it was decided that this evaluation should be performed with regard to several combat environments reflecting the realm of possibilities against which this tactic could be implemented. The combat environment was varied with respect to the following categories:

* the composition of the shore defenses,
* the capabilities of the ATF fire support assets,
* the capabilities of the ground units ashore, and
* specific LVA prototype variants.

The entire auxiliary modelling methodology is structured in order to be capable of performing this detail of sensitivity analysis. By explicitly evaluating the decision criteria against the numerous feasible environments, it is possible to determine not only what is a "preferred" tactic against a single particular scenario but also to evaluate the relative stability of that tactic against a broad range of scenario variations.

a. Shore Defenses

Three variations in the initial strengths ofthe two defensive weapon categories were implemented in this analysis. The combinations were chosen so that it would be possible to determine if the preferred tactical alternative as defined by the variables TBW and RD was a function of the defensive force mix. The radically different effective engagement ranges of the tank and ATGM systems provide a means by which it can be determined if the preferred RD is dependent upon the engagement ranges of the beach defenses. The three force mixes (I, II and III) are defined below.

DEF. FORCE MIX	INITIAL STRENGTH OF STATE VAR.	
	DT	DS
I	3	1
II	2	2
III	1	3

In implementing these three force combinations it was desired to eliminate as much as possible the "scenario dependent result."

b. ATFFS/TLF Capabilities

The effects of the ATF's fire support on the shore defenses was aggregated, through the use of data reduction techniques, into several generalized input parameters. A similar methodology was used with respect to the effect of ground engagements between the Marine forces ashore and the two defensive units. In this application two levels of ATFFS/TLF capability were assumed which reflect both an optimistic and a pessimistic viewpoint as to the real effectiveness which would be realized in these facets of an amphibious operation. The coefficients for these two levels of effectiveness are specified in Table II.

c. LVA Prototypes/Wave Composition

Table III lists the design characteristics for two hypothetical LVA prototype vehicles. Similar specifications for the current LVTP-7 are also given. The essential difference between LVAX1 and LVAX2 is that the LVAX1 travels more quickly in the displacement mode while the LVAX2 design is significantly faster in the planing mode.

For all three vehicles it is assumed that the assault waves would be composed of the following numbers of craft per wave:

WAVE NUMBER	NUMBER OF CRAFT
1	12
2	12
3	11
4	10
	45 TOTAL

B. MODEL REPLICATIONS

In applying the auxiliary model to the evaluation of alternative (RD,TBW) combinations, the sensitivity analysis envisioned included the following numbers of feasible parameter sets within each of the four basic categories of model input:

CATEGORY	APPLICATION DESCRIP.	NO. SETS
System Attributes	LVA Prototypes	2
System Tactical Employment Concepts	(RD,TBW) Combinations	18
Anticipated Force Capabilities	ATFFS/TLF Levels of Effectiveness	2
Anticipated Enemy Threat	Def. Force Mix	3

This yields a total of 216 replications of the model. It can be seen that the total number of model runs increases rapidly during the course of a detailed sensitivity analysis, which may serve to be indicative of the difficulties encountered in utilizing only a high-resolution stochastic simulation in this type of analysis.

TABLE II. ATFFS/TLF COEFFICIENT LEVELS

GENERALIZED INPUT ATTRITION RATE COEFFICIENTS	ATFFS/TLF LEVEL OF EFFECTIVENESS OPTIMISTIC ICOEF = 1	PESSIMISTIC ICOEF = 2
TLF:		
$WBETA_{DT}$	0.0007	0.0005
$WBETA_{DS}$	0.0009	0.0006
ATFFS AREA FIRE:		
$ALPHA_{DT}$*ATFFS	0.00006	0.00006
$ALPHA_{DS}$*ATFFS	0.00008	0.00008
ATFFS AIMED FIRE:		
$BETA_{DT}$*ATFFS	0.0005	0.0002
$BETA_{DS}$*ATFFS	0.0007	0.0004

TABLE III: HYPOTHESIZED LVA PROTOTYPE SPECIFICATIONS

DESIGN SPEC.	LVAX1	LVAX2	LVTP-7
SPDMAX	12.0 M/SEC	16.0 M/SEC	3.57 M/SEC
SPDMIN	5.0	3.7	-
HTMAX	1.676 M	1.676 M	0.83 M
HTMIN	0.635	0.635	-
WID	3.353 M	3.353 M	3.25 M
TTS	10. SEC	30. SEC	-

The auxiliary model by design provides a flexibility to the user in its ability to process a large number of parametric combinations in a relatively efficient manner.

C. INITIAL MODEL RESULTS

The initial approach in evaluating the employment criteria problem was the generation of a single data point for each of these 216 possible input parameter sets. That single number was the MOE defined for the application: the total number of surviving LVA arriving ashore, designated by the variable TSURV. Appendix A contains a complete compilation of these survivor populations. This section shall analyze in detail those results pertaining to the defensive force mix initially comprised of the state variable combinations DT = 3 and DS = 1. The complete set of data indicated that the tank system appeared to dominate the attrition of incoming LVA. The (DT=3;DS=1) force mix therefore may be considered to represent a "worst case" situation with respect to the other scenarios.

Figures 12 through 14 illustrate certain trends with regard to the two tactical decision variables. Each plotting symbol represents a replication of the auxiliary model with the particular (RD,TBW) combination indicated. From these survivor plots the following observations have been made:

* The runs applied against defensive force mixes II and III tended to result in relatively stable tactical employment. The term stable indicates a tendency for the MOE to remain relatively constant over a broad range of independent parameters, i.e. RD and TBW. In these runs there did exist a tendency for the total number of LVA survivors (TSURV) to increase slightly as the slowdown distance was moved farther out from shore.

* The runs applied against defensive force mix I (Tank heavy) appeared to exhibit the most radical variations with respect to the two tactical employment criteria. This observation can be made with respect to both the LVAX1 and LVAX2 designs. The general trends against this mix include:

1. a relatively stable survivor outcome for RD transitions initiated from 2000 to 3000 meters offshore,

2. a general increase in TSURV as TBW is decreased from 240 seconds down to 120 seconds between successive waves arriving ashore,

3. both vehicles demonstrate a high degree of sensitivity to the RD parameter in the 500 to 1500 meter range (generally TSURV is significantly less at RD = 1000 than at RD greater than 1500),

4. LVAX2 tends to exhibit a substantial increase in survivability when RD is as close to shore as possible (RD=500M).

* Both LVA prototype designs indicate similar trends with regard to the tactical criteria, differences being in relative magnitudes of the results.

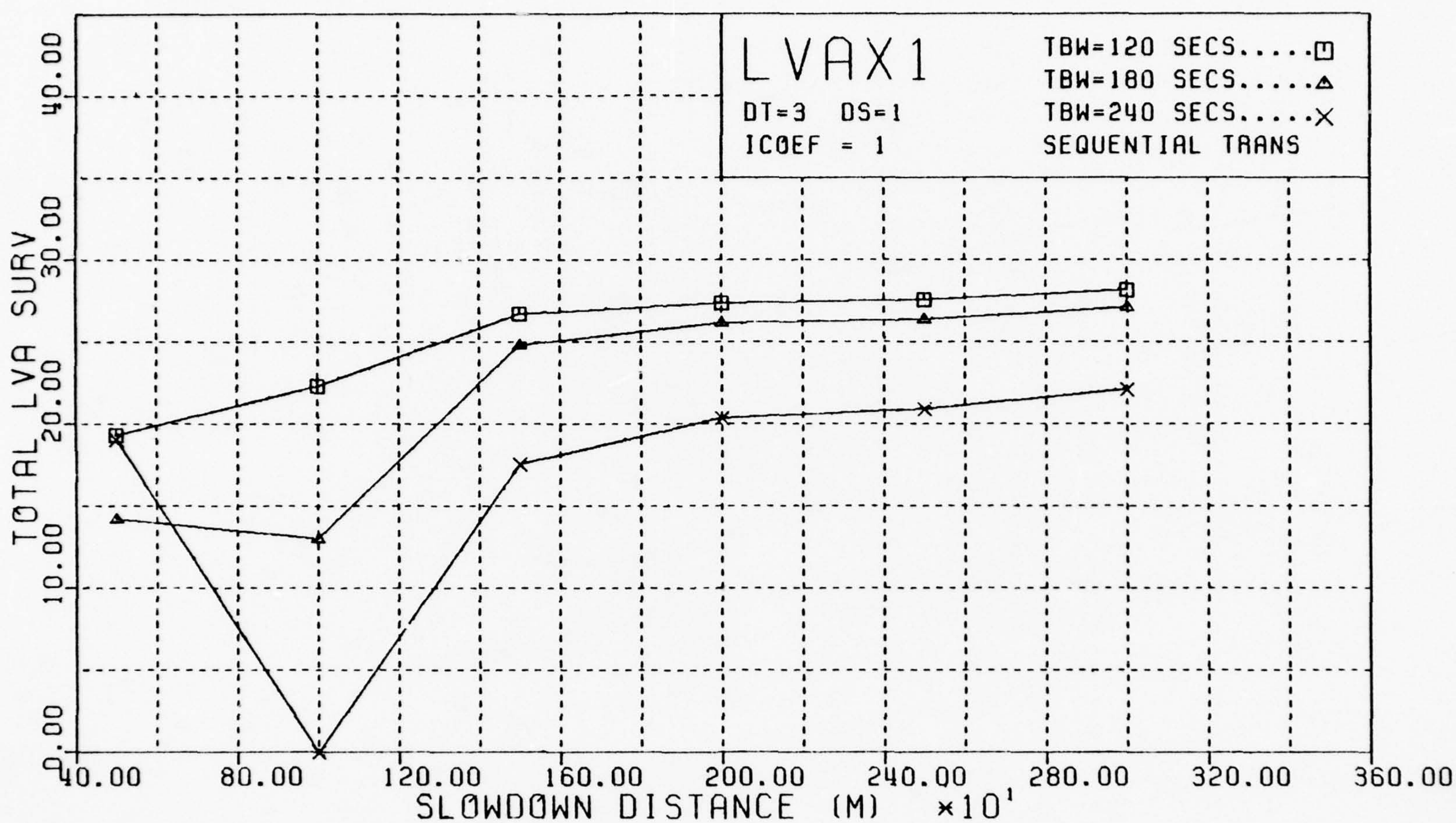


FIGURE (12): TACTICAL EMPLOYMENT EFFECTS ON LVA SURVIVOR OUTCOME

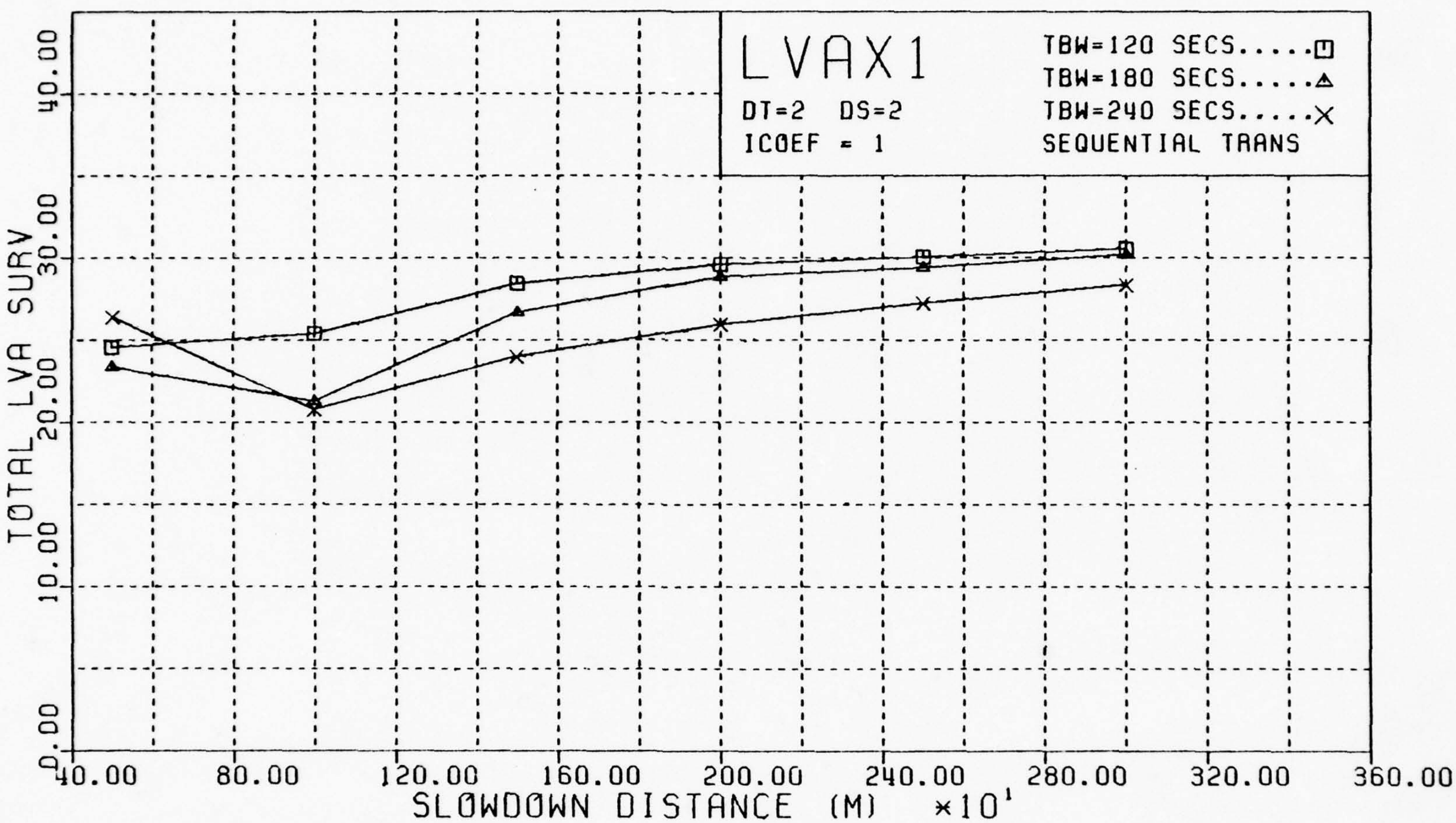


FIGURE (13): TACTICAL EMPLOYMENT EFFECTS ON LVA SURVIVOR OUTCOME

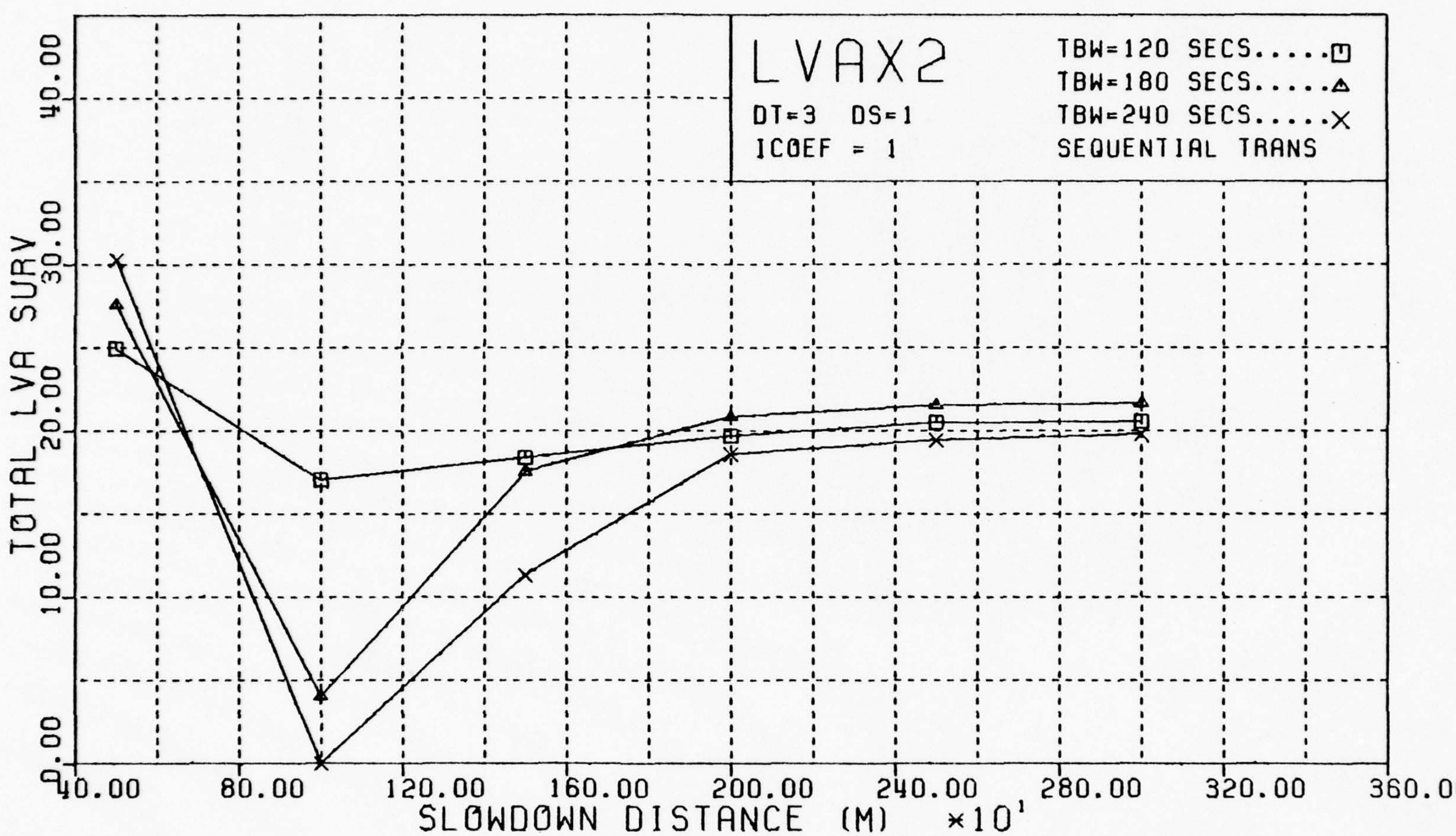


FIGURE (14): TACTICAL EMPLOYMENT EFFECTS ON LVA SURVIVOR OUTCOME

Figures 15 and 16 illustrate the results obtained by utilizing a lower level of effectiveness for the ATFFS/TLF units. In contrast with Figures 12 and 14 it may be seen that the same general pattern exists between the MOE and the (RD,TBW) combinations. The magnitude difference in the final model outcome reflects the differences in fire support capability between the two sets of data.

To provide a basis of comparison for the relative magnitudes of the final survivor outcomes, the auxiliary model was also executed with the performance characteristics of the LVTP-7. These results are listed in Table IV. It can be seen that both LVA prototype designs generated significant increases over the LVTP-7 in the desired MOE when employed with a "preferred" tactic. It should be noted however that when evaluated under certain tactical employment options, the LVA was not as effective as the current LVTP-7. It is with regard to this type of comparison that the ability to perform extensive sensitivity analysis with respect to the various input parameters is essential. If such variations in the input criteria are not readily performed, the analyst is required to assume what constitutes a "good" tactical employment of the proposed design. The serious implications of such a tactical assumption have been demonstrated by this example.

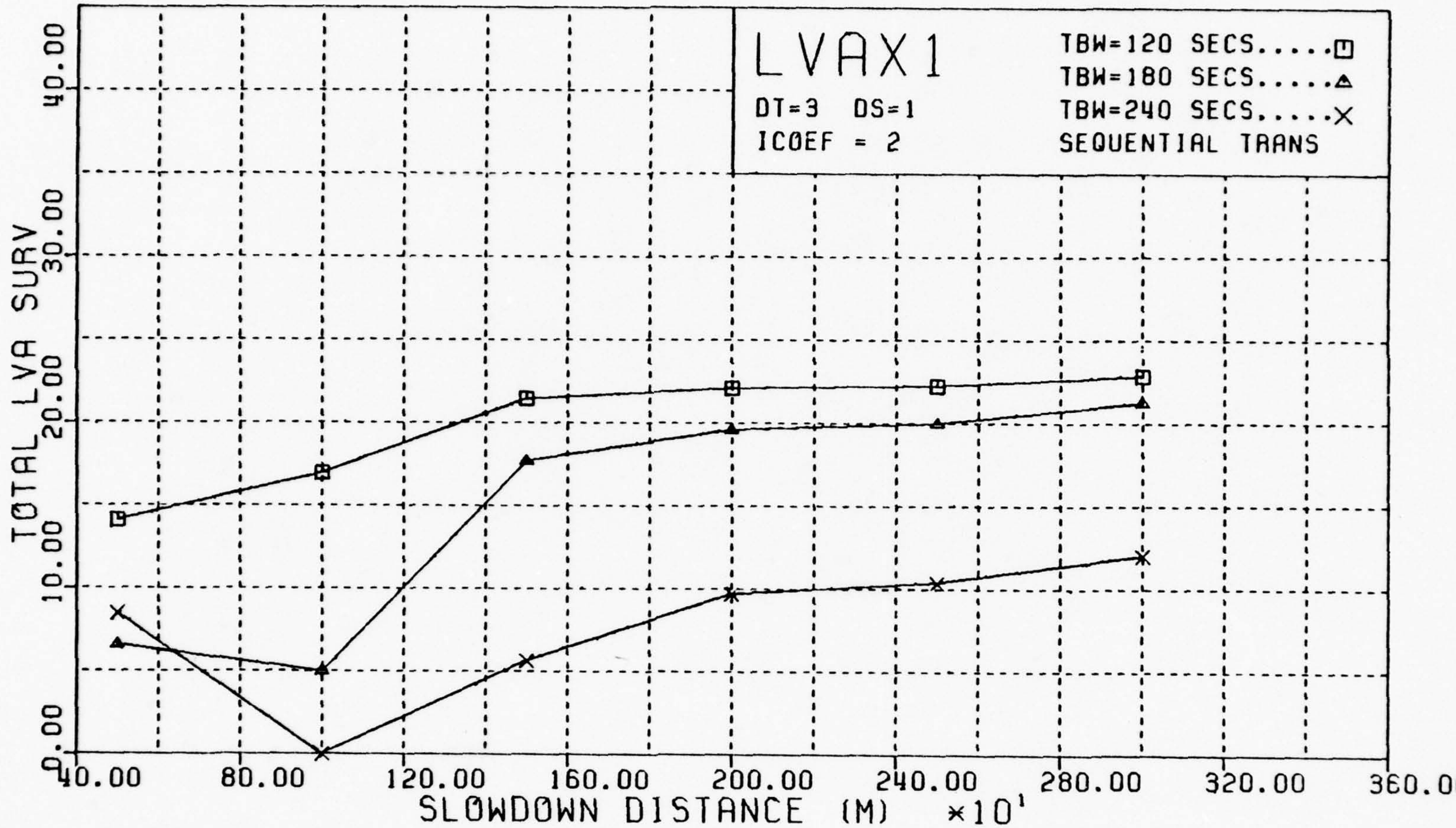


FIGURE (15): TACTICAL EMPLOYMENT EFFECTS ON LVA SURVIVOR OUTCOME

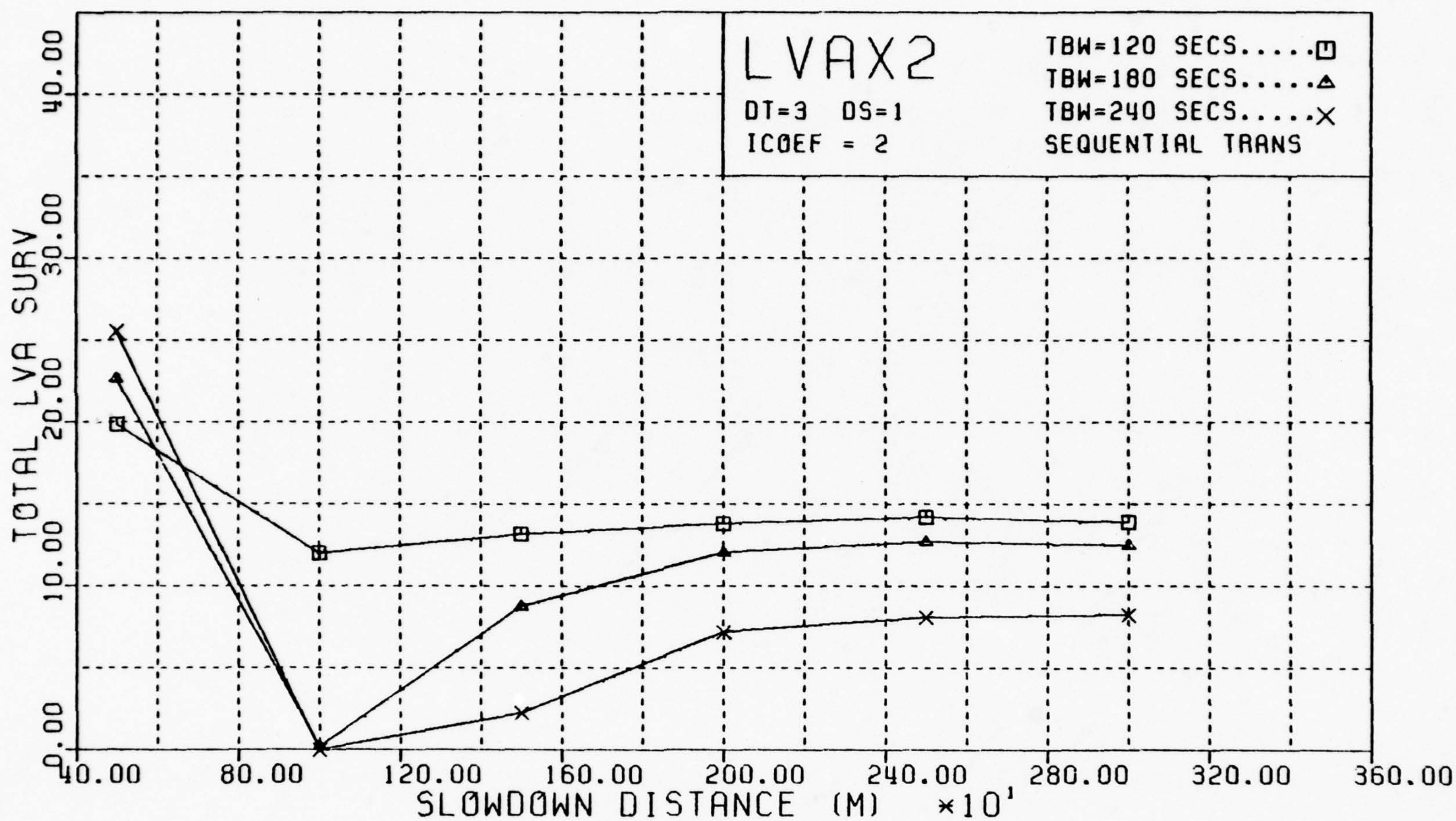


FIGURE (16): TACTICAL EMPLOYMENT EFFECTS ON LVA SURVIVOR OUTCOME

TABLE IV: AUXILIARY MODEL RESULTS - LVTP-7

CASE	ICOEF = 1	ICOEF = 2
DT = 3 DS = 1		
TBW = 120.	14.99	8.55
TBW = 180.	16.52	5.70
TBW = 240.	13.40	4.91
DT = 2 DS = 2		
TBW = 120.	21.55	15.52
TBW = 180.	21.39	13.15
TBW = 240.	19.47	11.21
DT = 1 DS = 3		
TBW = 120.	26.18	21.76
TBW = 180.	25.89	20.53
TBW = 240.	25.33	18.73

D. SEQUENTIAL WAVE TRANSITION - DETAILED ANALYSIS

The initial model runs implied certain trends which seemed somewhat counterintuitive and hence required further investigation. The model program contains an option which when implemented provides the user with a time breakdown of the state variable status and also the attrition rate being applied to each unit. Through the use of this model generated information, it was possible to formulate certain plausible explanations as to why the model behaved as it did. To perform the analysis, certain input parameter cases were defined which demonstrated widely variant initial results. The following cases represent a cross-section of the parameter sets investigated.

SEQUENTIAL TRANSITION: CASE DEFINITIONS

CASE	PROTOTYPE	ICOEF	DEF.MIX	RD	TBW	TSURV
A	LVAX1	1	I	3000.	120.	28.13
B	LVAX1	1	I	1000.	240.	0.
C	LVAX2	1	I	1500.	240.	11.33
D	LVAX2	1	I	500.	240.	30.31

The time breakdown data generated by the auxiliary model for these case studies is presented graphically in Figures 17 to 24.

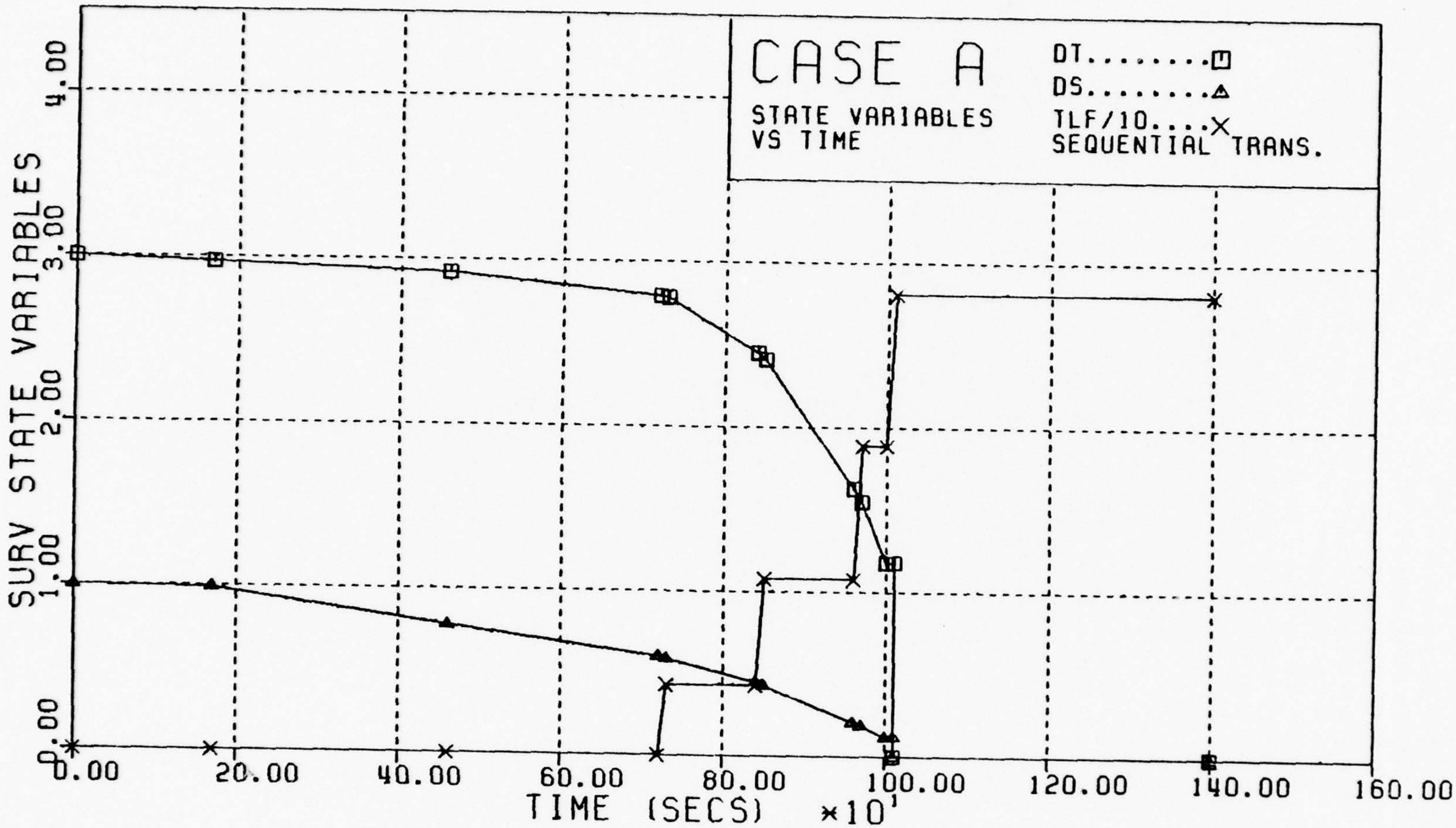


FIGURE (17): TIME BREAKDOWN OF UNIT STRENGTHS

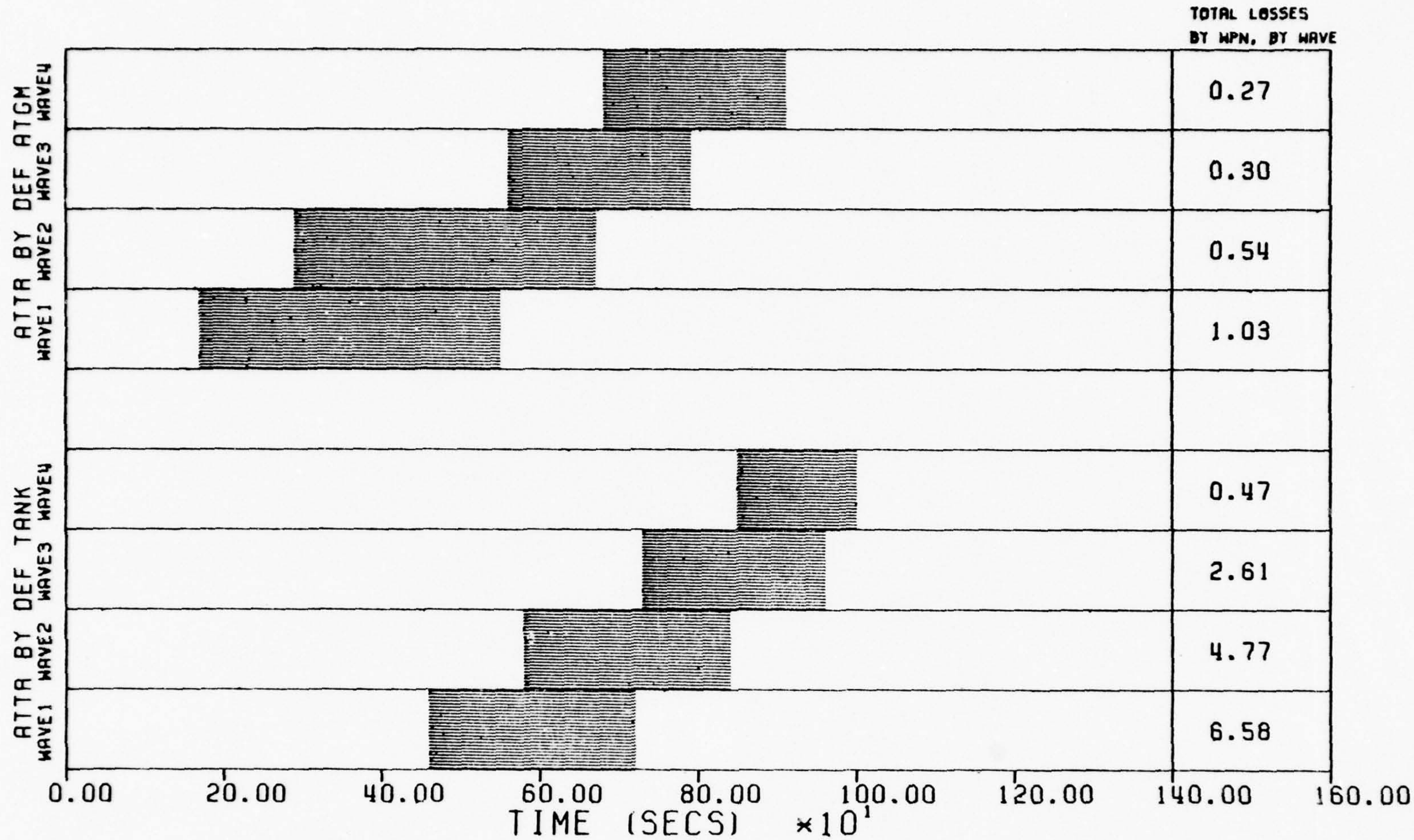


FIGURE (18): TIME BREAKDOWN OF LVA ATTRITION BY WAVE AND DEFENSIVE WEAPON TYPE - CASE A SEQUENTIAL TRANSITION

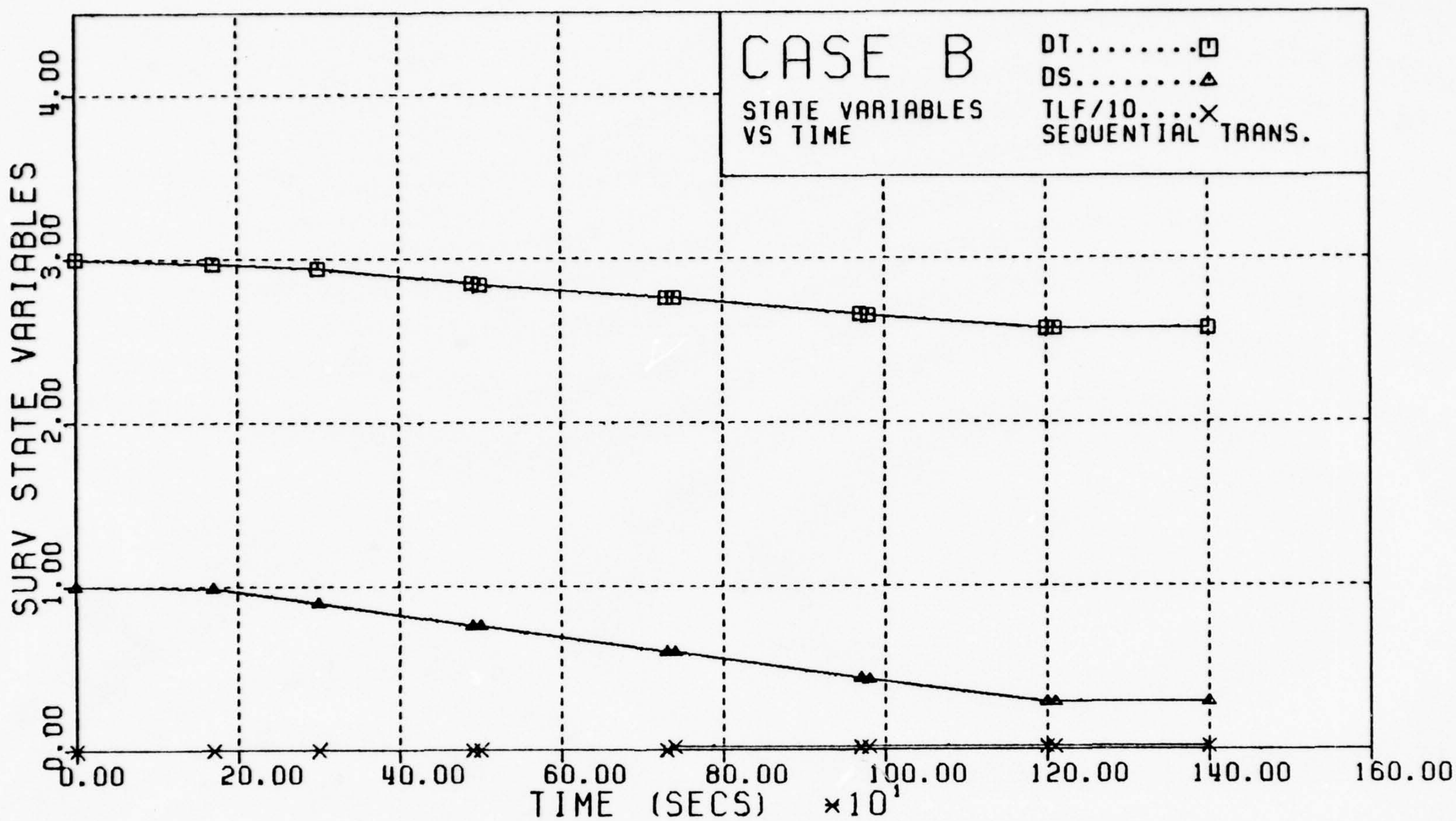


FIGURE (19): TIME BREAKDOWN OF UNIT STRENGTHS

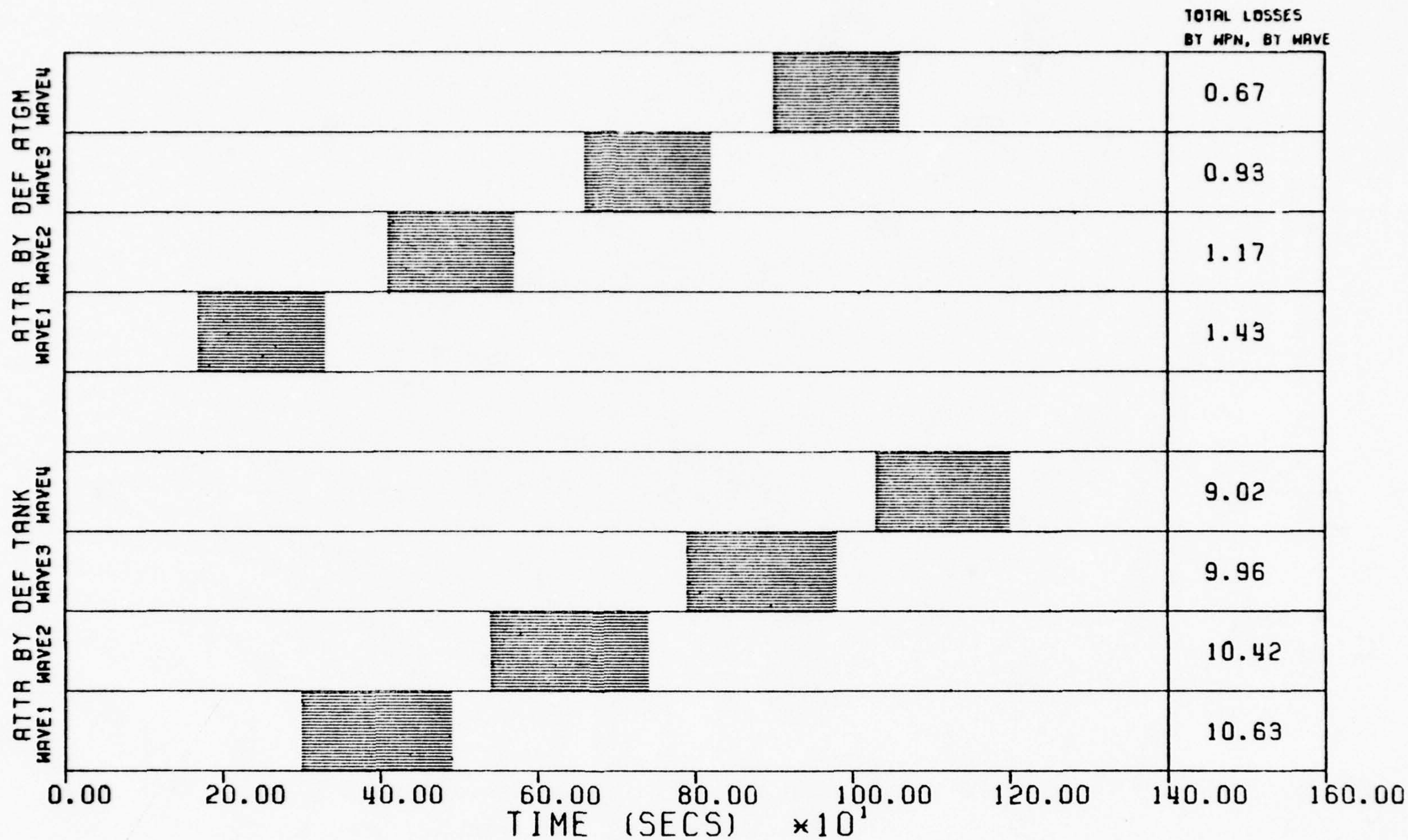


FIGURE (20): TIME BREAKDOWN OF LVA ATTRITION BY WAVE AND DEFENSIVE WEAPON TYPE - CASE B SEQUENTIAL TRANSITION

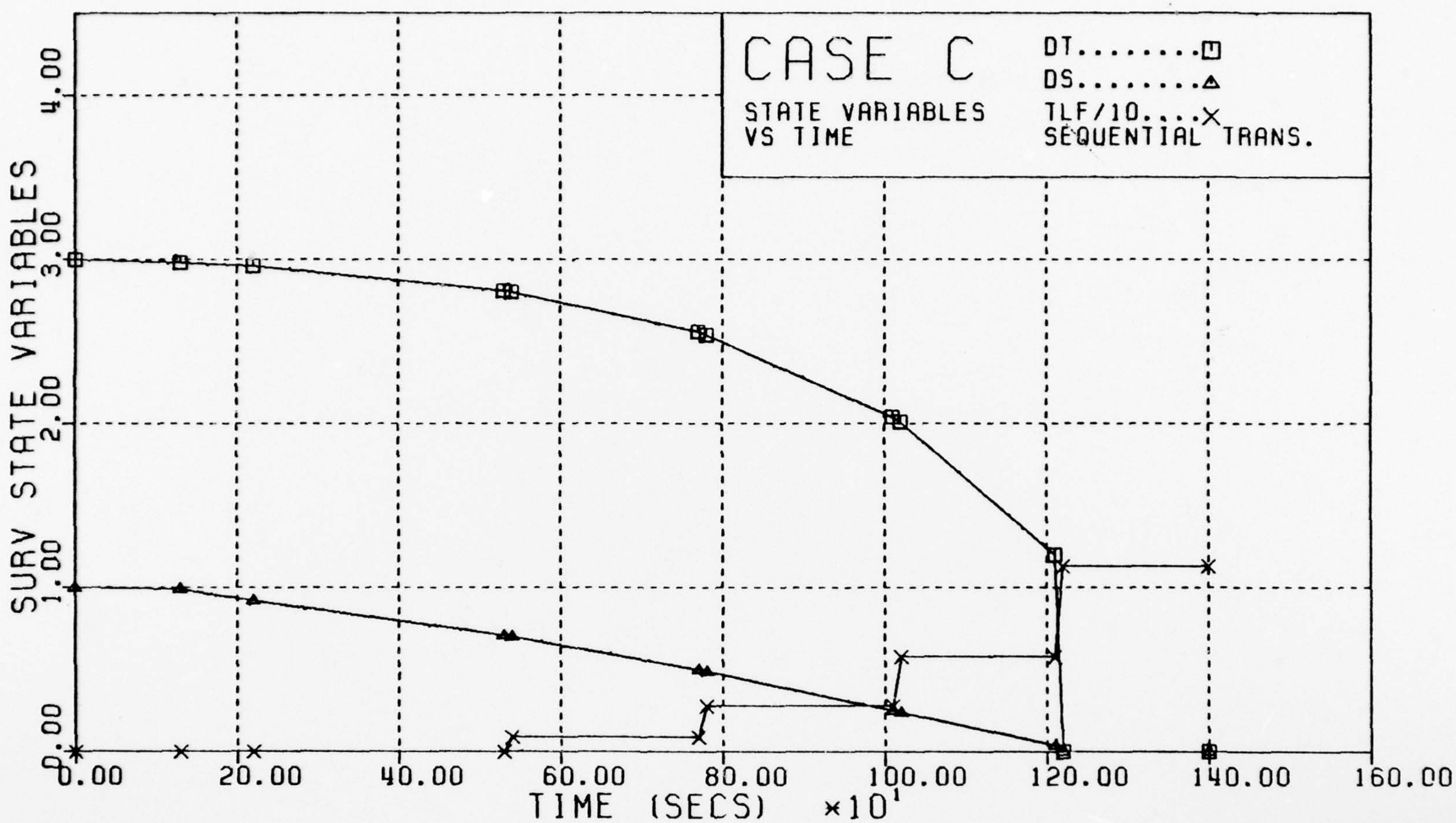


FIGURE (21): TIME BREAKDOWN OF UNIT STRENGTHS

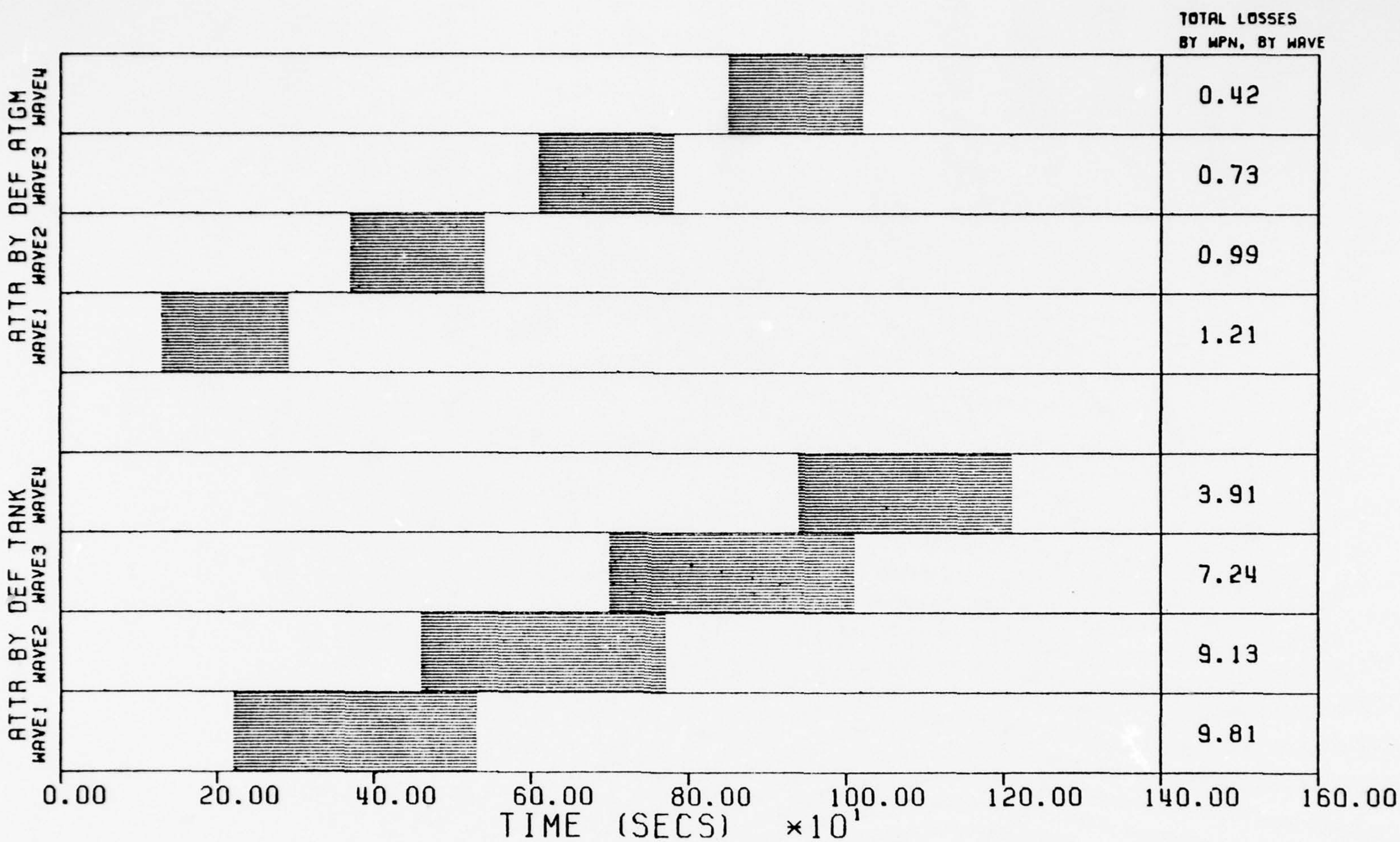


FIGURE (22): TIME BREAKDOWN OF LVA ATTRITION BY WAVE AND DEFENSIVE WEAPON TYPE - CASE C SEQUENTIAL TRANSITION

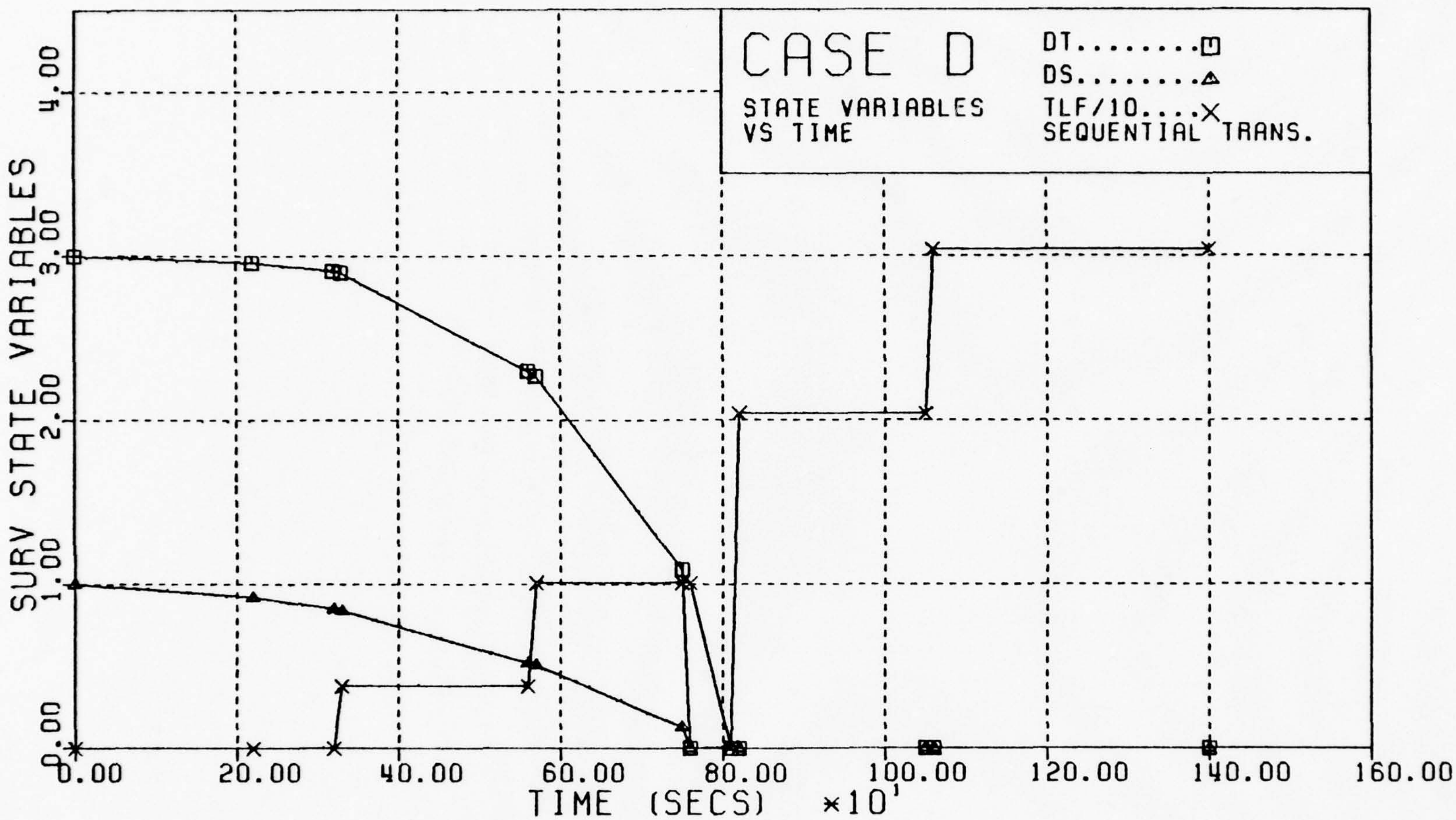


FIGURE (23): TIME BREAKDOWN OF UNIT STRENGTHS

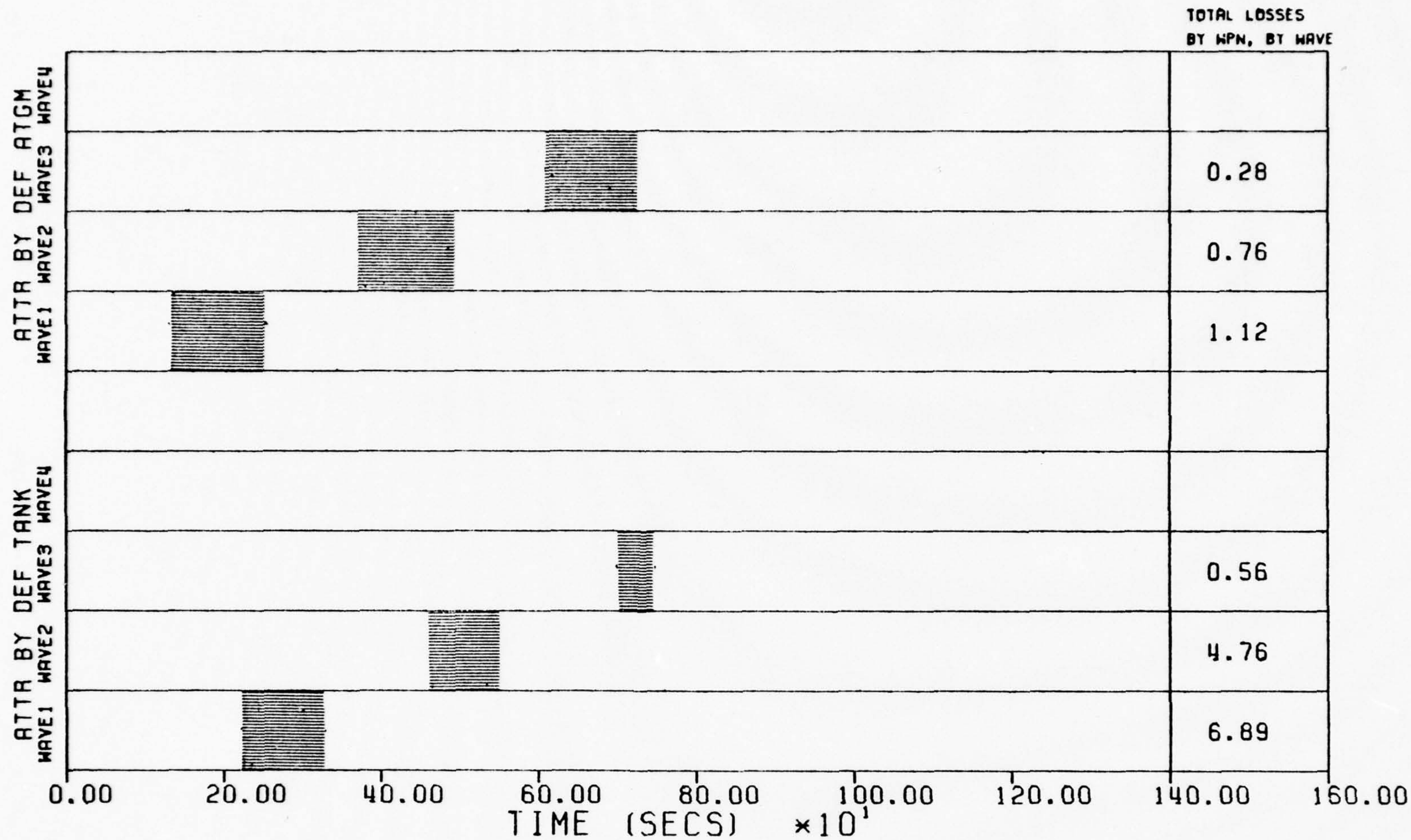


FIGURE (24): TIME BREAKDOWN OF LVA ATTRITION BY WAVE AND DEFENSIVE WEAPON TYPE - CASE D SEQUENTIAL TRANSITION

Certain significant factors which influence the final model outcome were determined in the analysis of these time breakdowns. The following general trends exist:

* A rapid initial buildup of TLF results in a steep decline in the strength of the defensive units. This rapid buildup is precipitated by a relatively high percentage of survivors in the first LVA assault wave ashore.

* The cases which resulted in low final survivor outcomes were characterized by high attrition losses in the first LVA assault wave. The results indicated that the survivor rate in the first wave was the crucial factor in total survivor results.

* The degree of attrition loss to an incoming wave is dependent upon two factors:

    1. time within a defensive weapon engagement window, and

    2. the existance of multiple waves within an engagement window forcing a splitting of fires between the waves.

In comparing LVAX1 CASE A (yielding a high TSURV) to CASE B (yielding a low TSURV) several possible explanations were formulated as to the underlying reason for the differences in final outcome. The high losses suffered in CASE B seem to be characterized by disjoint firing brackets, these brackets being the shaded areas in Figure 20. Each wave is initially engaged immediately upon entering the engagement window and receives the full impact of that defensive capability until it leaves the window, i.e. there is no allocation of fire between multiple waves. Alternatively, in CASE A the firing brackets overlap to such an extent that both defensive units are constantly splitting their fire between two waves. Waves 3 and 4, in this case due to their physical relationship with the first two waves, are well into the engagement windows before receiving any fire at all. This can be seen by observing in Figure 18 the short engagement times the last two waves are exposed to in comparison with the first two waves. The high proportion of engagement overlap is also evident. In effect, CASE A exemplifies the capability of the incoming assault waves to saturate the shore defenses. It therefore becomes the objective of tactical employment to capitalize on this saturation phenomenon.

The high planing speeds of the LVAX2 design provides another option to be considered in the minimizing of LVA losses. Figure 24 for CASE D demonstrates the case where the high speed of the vehicle through the engagement window more than compensates for the detrimental effects of disjoint firing brackets. Although in this case there is no allocation of fires between multiple waves, the time under fire per wave is extremely short resulting in low attrition losses.

The results of the detailed time breakdowns for these four cases has provided several cues as to what distinguishes a preferred tactical employment scheme. The two criteria which must be considered in implementing a sequential wave transition plan are:

* Saturate the defensive capabilities by forming the assault waves such that multiple waves will occupy the engagement windows concurrently.

* Employ the LVA such that it traverses the engagement area in a minimum amount of time, i.e. minimize time under fire.

Upon examining these two factors, it was discovered that an employment pattern did exist which might both minimize the time under fire and require a splitting of the defensive fires. I have termed this tactic simultaneous wave transition.

E. SIMULTANEOUS WAVE TRANSITION

In an attempt to minimize the losses incurred by the assault waves of LVA in an amphibious operation, the following tactical scheme is proposed.

SIMULTANEOUS TRANSITION: Waves of assault craft are formed in the maneuver area at a specified intra-wave distance. When the first wave reaches the RD coordination line, all waves of LVA initiate their transition from the planing mode to the displacement mode simultaneously. Figure 25 illustrates this concept.

In order to maintain the interarrival time between waves reaching the beach at TBW, the waves are preset prior to the onset of this model at the distance TBW * SPDMIN apart. The assault waves maintain this distance both before and after transition.

The original results obtained for this developed tactic were based on the four case studies used in the previous time breakdown analysis. The final model outcomes were encouraging.

SIMULTANEOUS WAVE TRANSITION: CASE STUDY RESULTS

CASE	PROTOTYPE	ICOEF	DEF.MIX	RD	TBW	$TSURV_{SEQ}$	$TSURV_{SIMUL}$
A	LVAX1	1	I	3000.	120.	28.13	28.14
B	LVAX1	1	I	1000.	240.	0.	23.74
C	LVAX2	1	I	1500.	240.	11.33	19.89
D	LVAX2	1	I	500.	240.	30.31	30.17

While CASES A and D resulted in essentially the same LVA survivor populations, there was a significant increase in the survivability of the LVA in CASES B and C when employed in the simultaneous mode. Again, for the purposes of developing an explanation into why these results occurred, time breakdown data was generated. Figures 26 and 27 provide the same graphical representation of the timed data as used in the sequential transition version of case study B. Several observations can be made:

* There is a significant increase in the number of surviving LVA in the first assault wave arriving ashore. This first wave's arrival ashore initiates the rapid decline in defensive force strength for the tank and ATGM units.

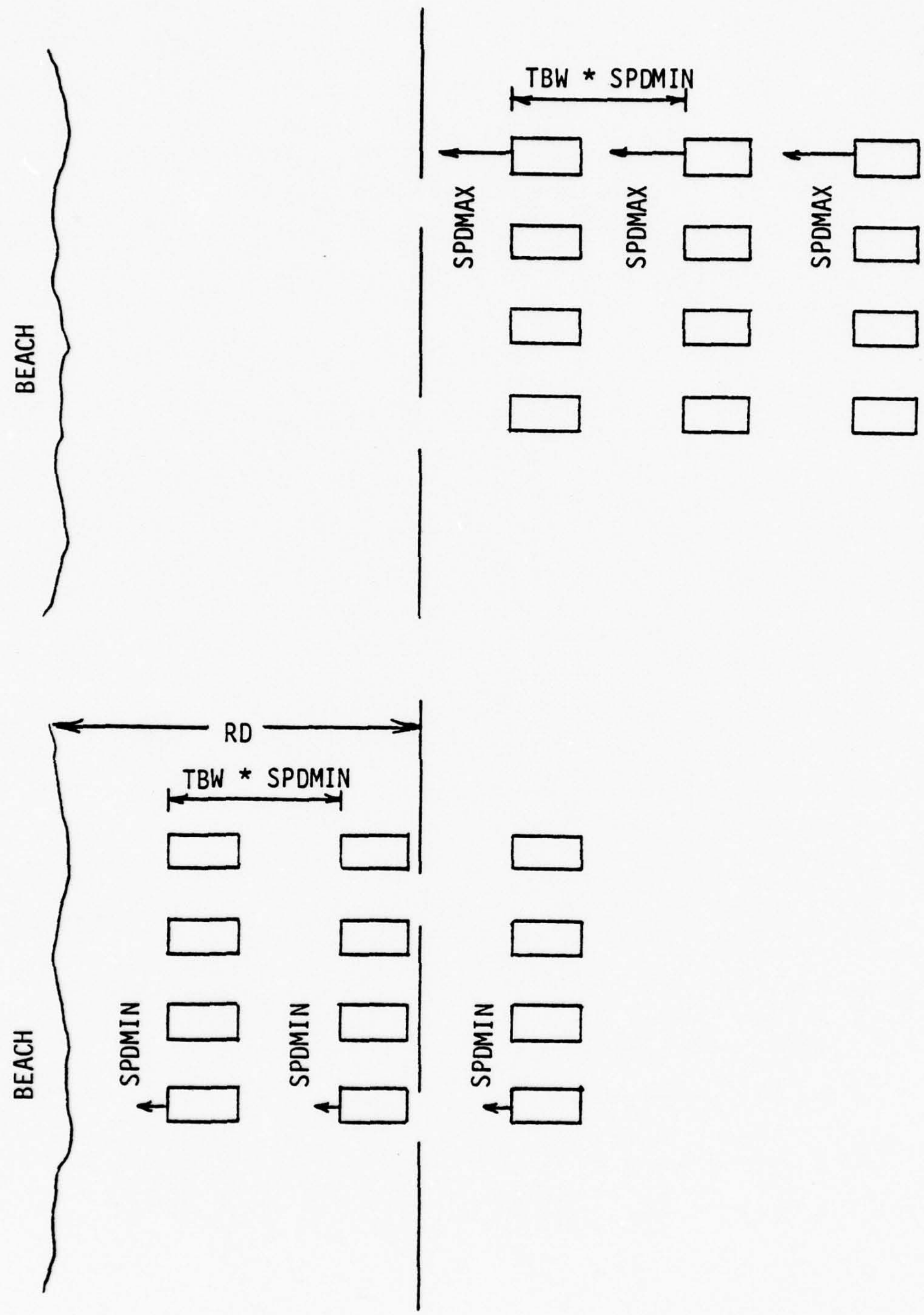


FIGURE (25): TACTICAL EMPLOYMENT PARAMETERS - SIMULTANEOUS TRANSITION

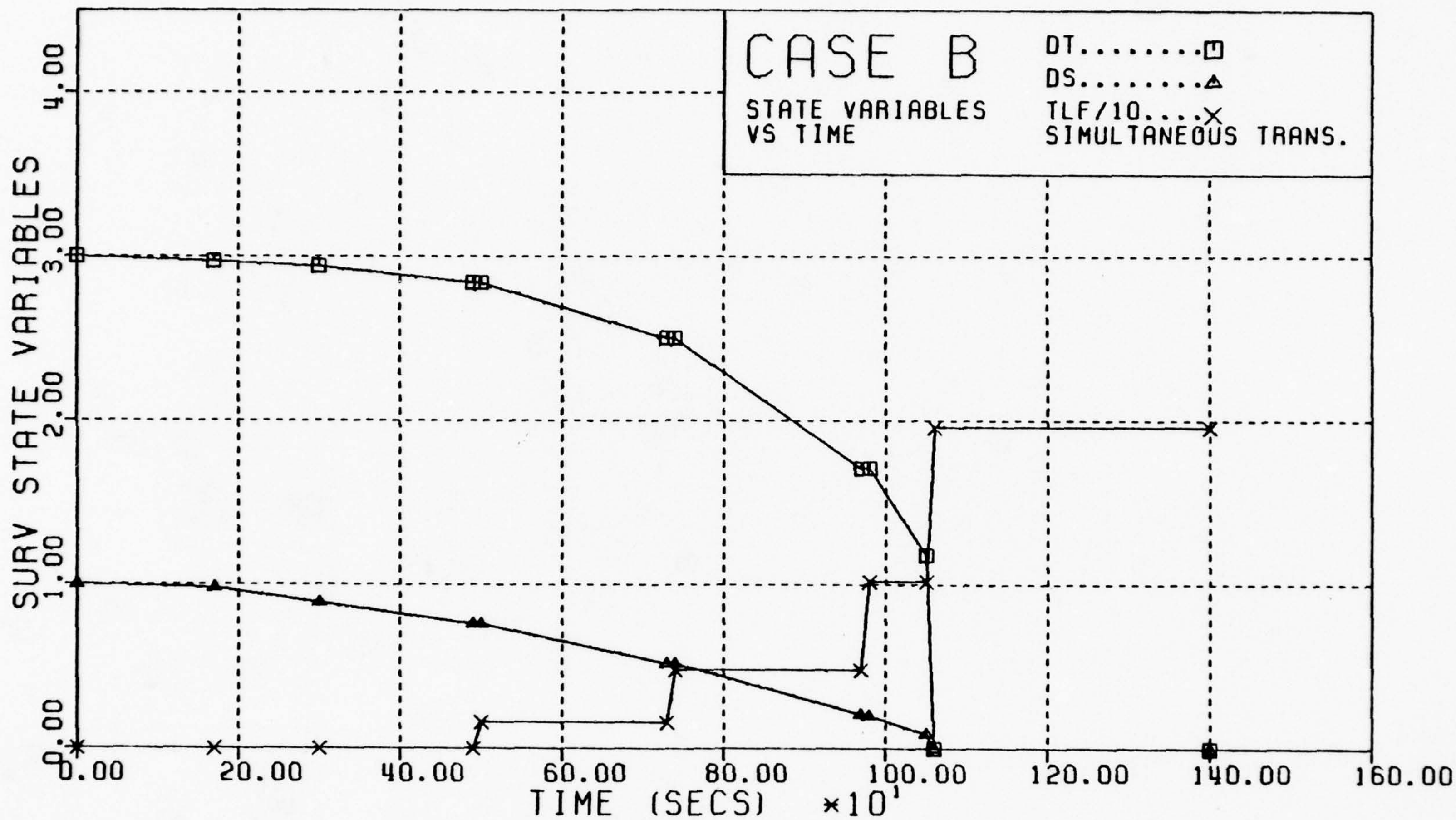


FIGURE (26): TIME BREAKDOWN OF UNIT STRENGTHS

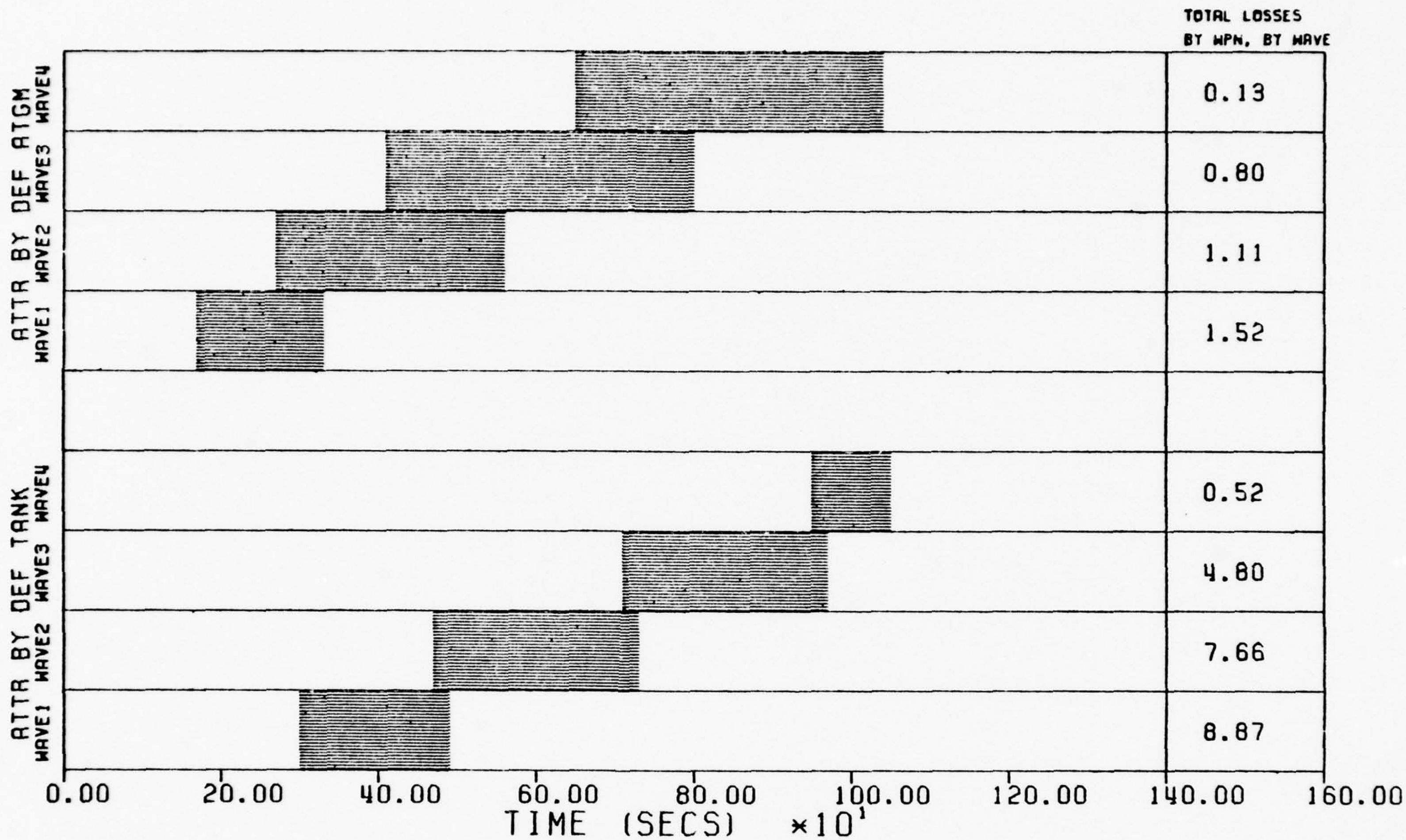


FIGURE (27): TIME BREAKDOWN OF LVA ATTRITION BY WAVE AND DEFENSIVE WEAPON TYPE - CASE B SIMULTANEOUS TRANSITION

* The first assault wave is exposed to hostile fire for a relatively short period of time. This, augmented by the fact that the second wave enters the defensive weapon's engagement range prior to the first wave departing it, accomplishes for the critical first wave the desired criteria of:

    1. minimizing exposure time, and

    2. saturating the engagement windows with multiple waves.

* The spacial relationships involved require the second through fourth assault waves to be exposed to defensive fires for longer periods of time than the first wave is. This effect is compensated for by the weakened posture of the defensive units precipitated by the increase in TLF capability.

The time breakdown data emphasizes the intuitive notion that the initial landing wave is critical to mission accomplishment. If a significant number of LVA in that first assault wave survive, the combat strength they contain can be immediately allocated to the defensive units. This reduction in defensive capability substantially diminishes the attrition of incoming LVA.

Appendix A contains the TSURV results for the 216 original input parameter sets utilizing a simultaneous transition employment scheme. Figures 28 and 29 provide a representative sampling of this data base. It is noted that the survivor results tend to exhibit greater stability over the 18 (RD.TBW) combinations, that is, there does not exist a wide variance in survivor outcome as the slowdown distance RD is moved toward shore as was evident in the sequential runs. From a practical viewpoint this provides a greater measure of tactical flexibility. Several additional trends were dictated by the data generated for the simultaneous mode.

* The data indicates a tendency for the number of survivors of the LVAX2 design to increase as the RD coordination line is brought closer to shore. This trend is not as prevalent for the LVAX1 prototype.

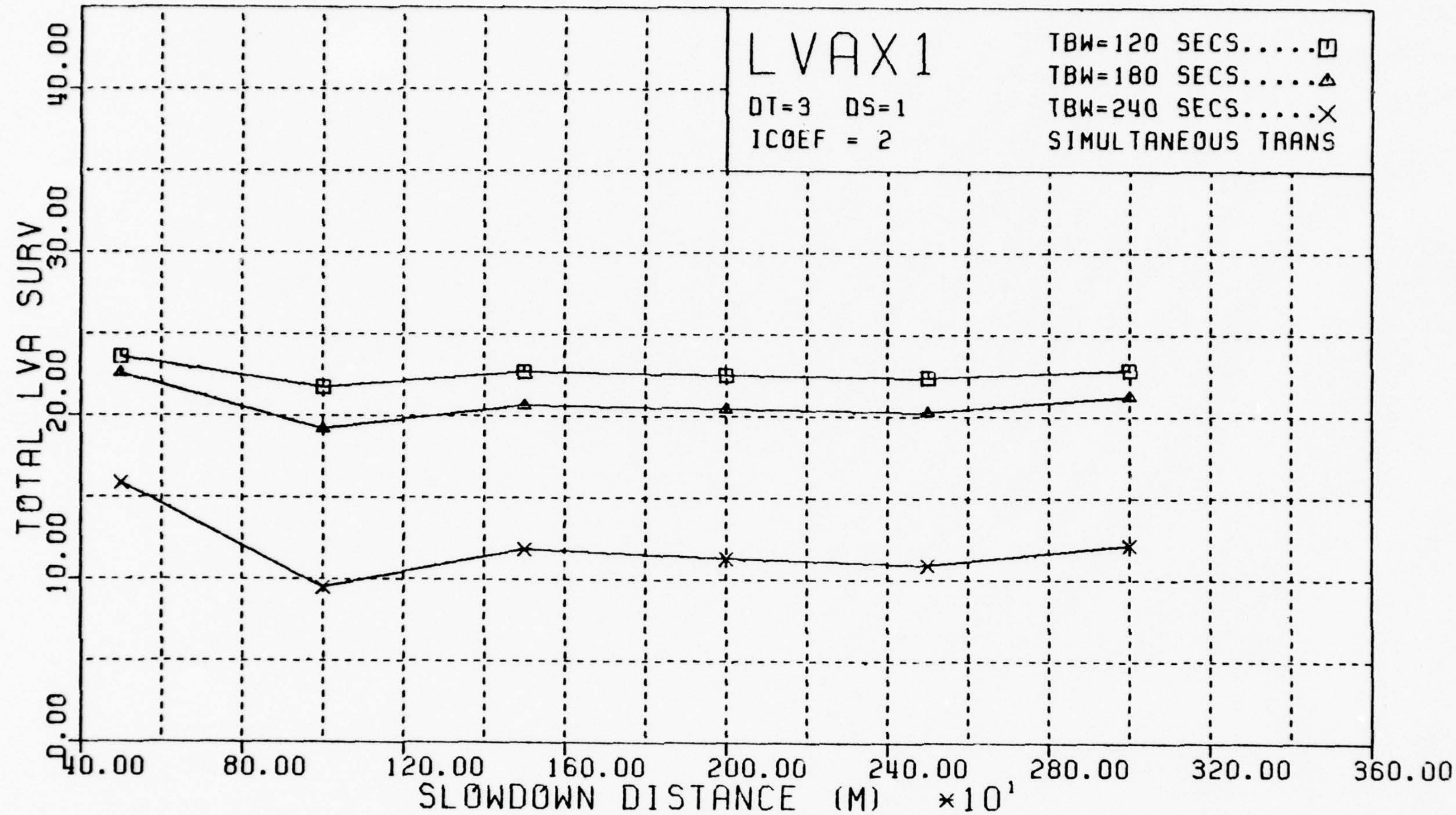


FIGURE (28): TACTICAL EMPLOYMENT EFFECTS ON LVA SURVIVOR OUTCOME

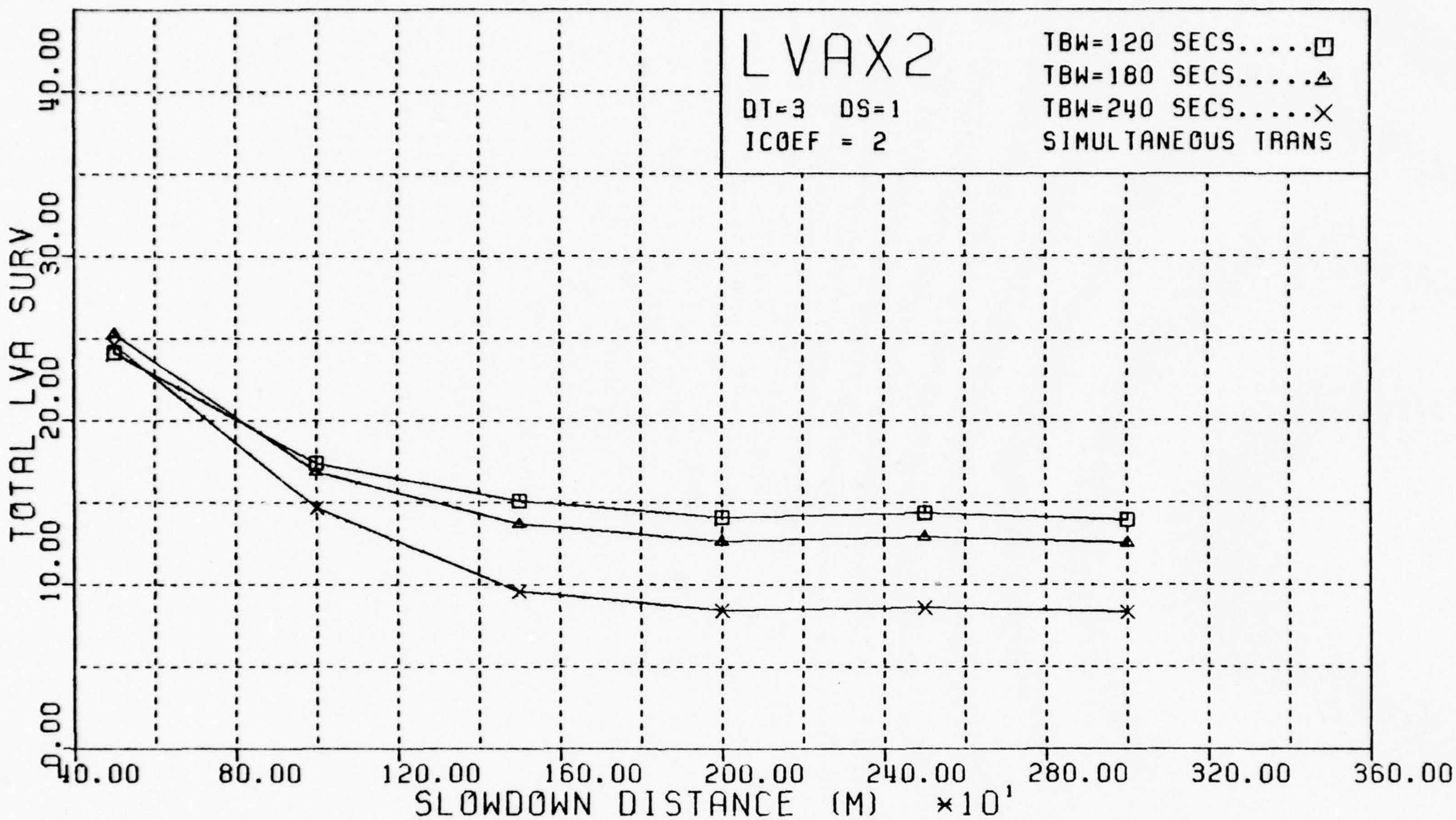


FIGURE (29): TACTICAL EMPLOYMENT EFFECTS ON LVA SURVIVOR OUTCOME

* The LVAX1 design demonstrated a decrease in survivability when employed with a large TBW parameter. This is due to the slower speed of this design. At shorter interarrival times between waves at the beach there exists considerably more firing bracket overlap than when this interarrival time is increased to 240 seconds. This is due to the fact that the intrawave distance is also increased to 240.*SPDMIN, causing a significant decrease in the total time spent with multiple waves within the engagement windows.

F. HYPOTHESIS FORMULATION

In order to investigate the large number of feasible combat environments in which the LVA might be employed, 435 replications of the auxiliary model were performed in this application. From the model results several insights into the dynamics involved in an amphibious operation were developed. Specific hypotheses were formulated which should be tested by utilizing a high-resolution combat simulation. These hypotheses include:

* Two primary employment schemes exist with respect to the deployment of assault waves of LVA in the waterborne phase of an amphibious operation:

  1. Sequential Wave Transition

  2. Simultaneous Wave Transition

* The use of simultaneous wave transition provides a greater stability in the resultant number of LVA survivors over a broad range of (RD,TBW) combinations than does the sequential scheme.

* In the simultaneous transition tactic, TSURV tends to <u>increase</u> as:

  1. RD is decreased to 500 meters, and as

  2. TBW is decreased to 120 seconds.

* With regard to the survivor criteria, the simultaneous transition tactic generally results in better performance than the sequential transition tactic, for any particular set of RD, TBW parameters.

V. MODEL APPLICATION: DESIGN SPECIFICATION CONSIDERATIONS

In the examination of the various tactical employment options it was discovered that if the speed of an LVA in the planing mode was substantially higher than the minimum requirement of 25 MPH, a single wave was capable of traversing both defensive weapon engagement windows quickly enough to sustain significantly less attrition than when using the same tactic with a slower vehicle. This is an example of the situation the designer is faced with when attempting to specify the various physical performance characteristics of a new system such as the LVA. Is the increase in production costs justified by a commensurate increase in the ability of the system to accomplish its intended mission?

Another similar sort of problem has been stated previously. Is it best to traverse the engagement area quickly presenting a large target profile or alternatively, is it best to cross the engagement area more slowly but in the process expose a much smaller target area? This question also directly relates to certain design parameter tradeoffs which must be made by the system designer.

This section describes an application of the LVA auxiliary model to the evaluation of selected physical performance characteristics. It is assumed that theLVA at the time of this application is still in the conceptual stages of its development.

A. TIME UNDER FIRE/TARGET PROFILE TRADEOFFS

The strategy used with regard to this design question was substantially different than that utilized in the tactical employment application.

In order to develop an intuitive base for the dynamics of the problem, the scope of the modelling effort was initially reduced to investigating the relationship that existed between the height and speed characteristics of an LVA to that vehicle's vulnerability to direct-fire while traversing an engagement window. This was accomplished for each of the defensive weapon systems.

The auxiliary model was initially executed with a single wave comprised of essentially an infinite number of LVA. For the purposes of these initial runs, the height and speed of the incoming wave was considered fixed, that is, there was no transition from a planing to a displacement mode. The initial defensive force units were set at DT = 5.0 and DS = 5.0 at the start of each run. For each set of design specifications the total number of incoming LVA attrited by the tank and by the ATGM defensive units was recorded. The intent of this approach was to determine the total number of target vehicles the defensive units were capable of destroying as a single wave of LVA traversed each of the engagement windows. This number of attrited LVA's was then considered an indication of the LVA's vulnerability to that category of direct-fire weapon. The objective then from the standpoint of LVA design was to identify that combination of feasible height and speed characteristics which minimized this vulnerability. These results are contained in Tables V and VI. It is noted that certain (HT,SPD) combinations were assumed to be infeasible due to engineering constraints. For example, it is physically impossible to achieve a high water speed while the landing craft is submerged such that only less than a meter is exposed above the waterline. Several rather intuitive observations may be made with respect to these initial attrition results:

TABLE V: VULNERABILITY ASPECTS OF LVA HEIGHT AND SPEED AGAINST THE DEFENSIVE TANK

		HEIGHT (METERS)						
		0.6	0.7	0.8	0.9	1.5	1.7	1.9
DISP MODE	3.5	25.26	27.25	28.99	30.53			
	4.0	22.83	24.58	26.11	27.46			
SPD (M / SEC)							NOT FEASIBLE	
	4.5	20.03	21.60	22.98	24.20			
	5.0	19.25	20.68	21.94	23.04			
PLAN MODE	10.0					14.53	14.98	15.33
	12.0					12.26	12.60	12.87
SPD (M/ SEC)	14.0		NOT FEASIBLE			10.07	11.03	11.29
	16.0					8.64	8.92	9.15
	18.0					8.07	8.32	8.50

Note: Table entries represent the total number of LVA, employed in a single incoming wave at the height and speed characteristics indicated, that a defensive TANK unit of initial strength of 5.0 is capable of attriting. ($TATTR_{DT}$)

TABLE VI: VULNERABILITY ASPECTS OF LVA HEIGHT AND SPEED AGAINST THE DEFENSIVE ATGM

		HEIGHT (METERS)						
		0.6	0.7	0.8	0.9	1.5	1.7	1.9
DISP MODE:	3.5	9.75	11.27	12.74	14.16			
	4.0	8.84	10.21	11.55	12.84			
SPD (M/SEC)							NOT FEASIBLE	
	4.5	7.69	8.88	10.05	11.16			
	5.0	7.24	8.37	9.46	10.50			
PLAN MODE:	10.0					8.50	9.25	9.98
	12.0					6.94	7.55	8.08
SPD(M/SEC)	14.0		NOT FEASIBLE			5.75	6.26	6.69
	16.0					5.39	5.87	6.28
	18.0					4.60	5.01	5.35

Note: Table entries represent the total number of LVA, employed in a single incoming wave at the height and speed characteristics indicated, that a defensive ATGM unit of initial strength of 5.0 is capable of attriting. ($TATTR_{DS}$)

* The total number of LVA that were attrited by the defensive tank unit ($TATTR_{DT}$) and also by the ATGM unit ($TATTR_{DS}$) decreased for any given height as the speed of the LVA increased reflecting the reduction in time under fire.

* Both $TATTR_{DT}$ and $TATTR_{DS}$ increase for any given speed of the LVA as the height of the LVA is increased, reflecting the increase in the hit probability attained due to the larger target profile.

* Although in these runs the two defensive force units were identical in initial strength, the defensive tank unit was capable of attriting significantly more LVA than was the ATGM unit.

Attrition matrices similar to those contained in Tables V and VI provide valuable tradeoff information to the designer in his choice of appropriate (HT,SPD) specifications for each of the two operating modes. For example, in the displacement mode the following designs would exhibit roughly comparable vulnerabilities to the direct-fire weapon systems modeled.

DESIGN	HEIGHT	SPEED	$TATTR_{DT}$	$TATTR_{DS}$
A	0.6 M	4.0 M/SEC	22.83	8.84
B	0.8	4.5	22.98	10.05
C	0.9	5.0	23.04	10.50

This information then provides a flexibility in the selection of the final design specifications. Assuming a maximum allowable threshold for the expected total number of LVA attrited, comparable designs might be evaluated with respect to a second criteria such as cost.

It is noted that the magnitudes generated for $TATTR_{DT}$ and $TATTR_{DS}$ in this preliminary approach reflect an abstract situation with regard to what might be considered a realistic employment scheme for LVA in the ship-to-shore movement. The value of the TATTR results is that they provide a convenient measure from which gross design comparisons may be made. If a greater number of LVA of a particular (HT,SPD) combination are attrited than with an alternative design, one can conclude that the first design tends to be more vulnerable to the effects of the two direct-fire defensive systems.

B. SURVIVOR MATRIX GENERATION

The auxiliary model provided an analytic tool by which performance trends between alternative system design parameters were established. A fundamental fallacy in the single wave preliminary approach was the fact that the interactions between the LVA design parameters and the actual tactical employment procedures were essentially ignored. This section presents an extension to the preliminary approach which incorporates these tactical interactions in the evaluation of the various design specifications.

1. Feasible Design Combinations

It was assumed that due to imposed engineering constraints certain specification limits had been placed on the four design variables to be evaluated. Within these bounds several values were chosen for each variable as listed below.

FEASIBLE LVA DESIGN PARAMETERS

	DESIGN VARIABLE	FEASIBLE VALUES					
DISP MODE:							
	HTMIN	0.6	0.7	0.8	0.9		meters
	SPDMIN	3.5	4.0	4.5	5.0		meters/sec
PLAN MODE							
	HTMAX	1.5	1.7	1.9			meters
	SPDMAX	10.	12.	14.	16.	18.	meters/sec

These values yielded a total of 16 displacement designs and 15 planing designs. It was further assumed that it was possible to combine any of the displacement designs with any of the planing designs to generate a feasible description for an LVA prototype. There existed a total of 240 such possibilities.

2. Scenario Development

It was decided to exercise each of the feasible LVA designs with the following tactical variations:

* TACTIC A: Simultaneous Transition, RD = 3000. TBW = 180.
* TACTIC B: Simultaneous Transition, RD = 500. TBW = 240.

The scenario against which the designs were to be evaluated was for the purposes of this example restricted to the following input parameter set.

* DT = 3.0 DS = 1.0 ICOEF = 1 .

3. Model Results

Appendix B contains the resultant survivor matrices. The measure of effectiveness by which the LVA designs were compared was the total number of LVA survivors arriving ashore (given an initial wave population of 45):TSURV. In interpreting the model results the objective was to identify significant trends which relate the four decision variables to the stated MOE. Figures 30 and 31 illustrate the significant factors with respect to the two tactical employment options used in the example. The shaded bands in these figures represent the range of the results realized for the two factors noted. Several trends are suggested by these factors:

* As might be expected, in using a tactic that has the LVA slow down at 3000 meters offshore, the height and speed characteristics in the displacement mode (HTMIN,SPDMIN) are the critical design features influencing the survivor results. Similar trends to those found in the preliminary single wave modelling effort were again seen here.

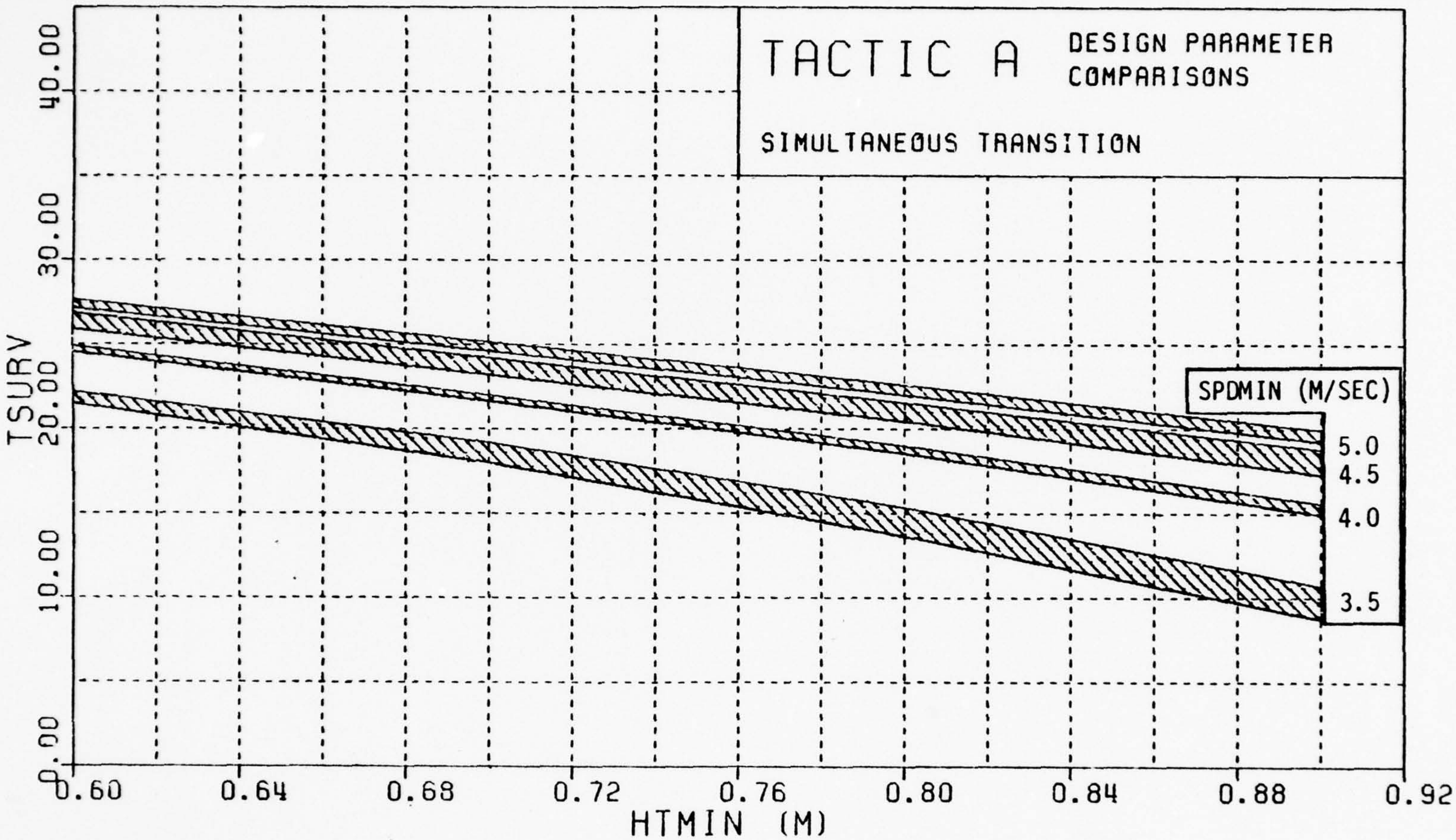


FIGURE (30): TOTAL LVA SURVIVORS VERSUS DESIGN PARAMETERS

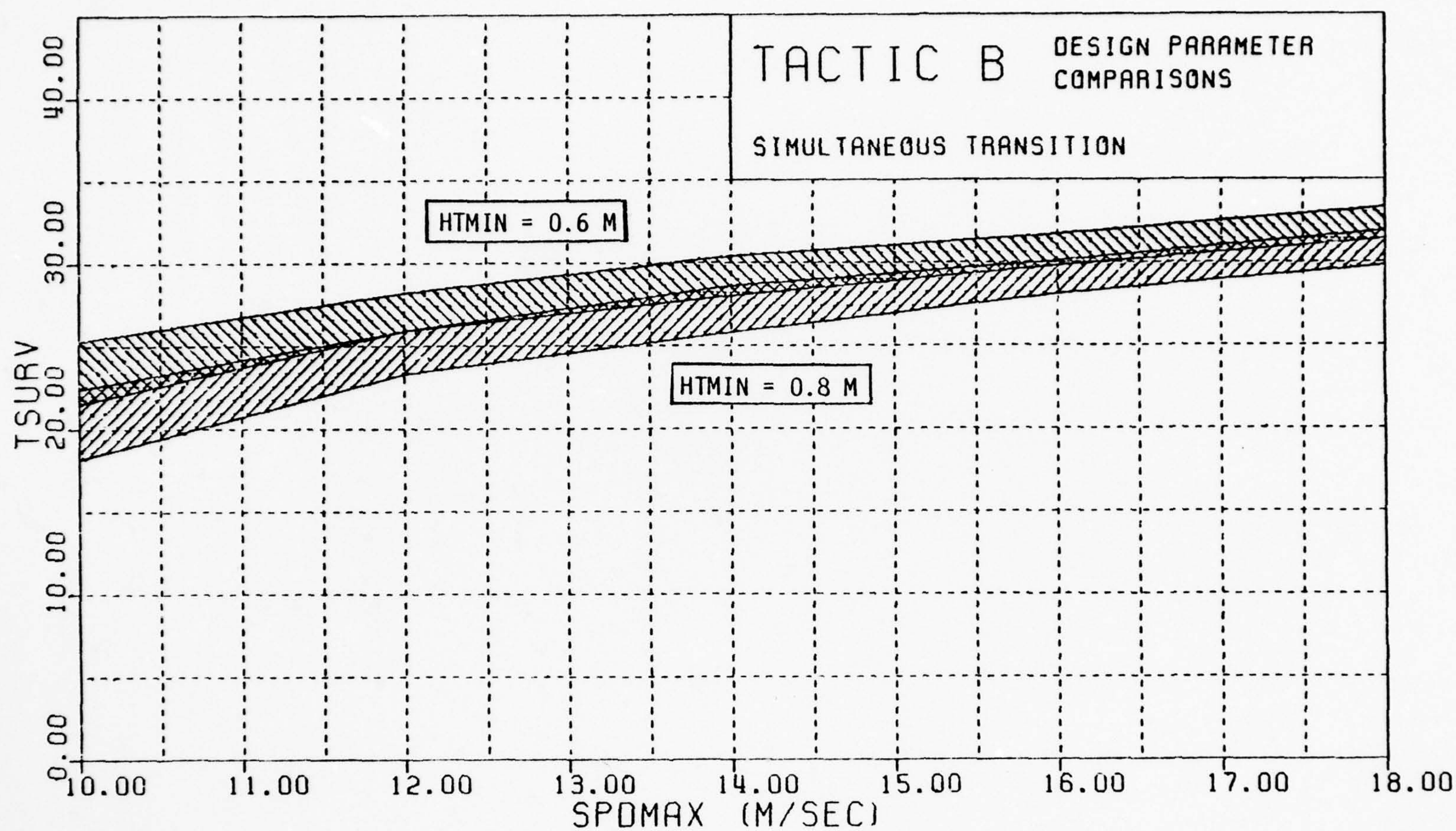


FIGURE (31): TOTAL LVA SURVIVORS VERSUS DESIGN PARAMETERS

* In using TACTIC B somewhat different explanatory design parameters were discovered. Of the four decision variables, the speed in the planing mode (SPDMAX) and the height in the displacement mode (HTMIN) provided the major contributions to the final survivor outcome. The effects of these variables on TSURV also followed the same trends as exhibited by the preliminary model with respect to the impact of time under fire and the resultant target profile. Specifically,

  1. TSURV increases as SPDMAX increases for any given HTMIN, and also

  2. TSURV decreases as HTMIN increases for any given SPDMAX.

The primary advantage of this second approach to the design tradeoff problem is that the synergistic effect of the LVA speed characteristics on both time under fire and the intra-wave distance is explicitly modeled into the final outcome. The importance of the intra-wave distance to the splitting of defensive fires between multiple waves has been seen to be a factor which cannot be ignored.

C. HYPOTHESIS FORMULATION

By examining numerous replications of the auxiliary model, certain insights were formed which were formalized into several specific hypotheses. These generalizations include:

* In the design of an LVA which is to be employed such that the waves of incoming craft will simultaneously transition from the planing mode to the displacement at a relatively close distance from the shore, i.e. 500 meters, the primary design specifications which determine the total survivors ashore are SPDMAX and HTMIN. The relationship illustrated in Figure 31 indicates the general tendencies.

* In implementing a tactic that initiates the simultaneous transition of incoming waves relatively far from the beach, the primary design specifications which determine the total survivors reaching shore are SPDMIN and HTMIN. The relationship illustrated in Figure 30 provides an example of the general tendencies to be expected.

It must be recognized that the purpose of this model application was to provide certain insights into the behavior of the system. The objective of the auxiliary model methodology is the identification of certain patterns. A subsequent testing of these hypotheses would be accomplished by utilizing a high-resolution combat simulation followed by actual field testing. The potential of this type of modelling effort rests in its ability to easily provide a crude functional relationship between the design variables and the performance measure. The synthesis of this approach with a design-to-cost methodology warrants further investigation.

VI. SUMMARY

In the development of a proposed system which implements a state-of-the-art advancement in its conceptual basis, there exists dual facets to the conceptual problem which must be addressed simultaneously. It is necessary to

* establish specification limits for the primary physical performance characteristics, and

* formalize the proposed concept of employment.

These two aspects of the developmental process are normally highly correlated. In the analysis of a proposed employment concept, it is necessary to make certain assumptions with respect to the physical capabilities of the new system, and alternatively, the determination of significant design requirements is highly dependent on the assumed method of system use.

A fundamental difficulty encountered in addressing this dual problem is the tendency to generate numerous combinations of "interesting" feasible input cases requiring evaluation and then in the process of this evaluation utilize a costly, highly sophisticated, "off-the-shelf" combat simulation model. Such a detailed investigation of each of the feasible input cases requires substantially more time and resources than are normally available for this type of analysis. In an attempt to institute a measure of modelling efficiency into this process, this thesis has proposed an analytic procedure which attempts to identify a smaller representative subset of the entire feasible input region for subsequent application to a full scale model. This is accomplished by the development of a simplified model, specifically tailored to addressing a particular aspect of the combat environment, which then provides the vehicle by which the analyst may gain insights into the underlying variable interrelationships. In order to provide an illustration of this auxiliary modelling approach, the methodology was applied to selected facets of the dual problem as it relates to the development of a high speed amphibious vehicle, the LVA.

In formalizing the LVA concept, certain simplifications were instituted in order that such a simplified model might be developed. Having assumed that the survivability characteristic of the LVA was the fundamental criteria by which various proposals might be compared, it was necessary to structure the model to address that particular aspect of the amphibious combat environment. It was assumed that the defensive direct-fire weapon systems played the predominant role in the attrition of incoming waves of LVA. The auxiliary model was therefore specifically designed to provide a high level of detail with respect to the interrelationships each of the decision variables made with regard to the attrition effects attributable to the two defensive direct-fire assets, tank and ATGM. Peripheral issues related to the primary focus of the modelling effort were simplified by the use of generalized input parameters which in an actual application would be generated by data reduction techniques from previous high-resolution modelling applications.

Two specific applications have been discussed which demonstrated various modelling approaches with regard to the dual aspects of this system developmental process. In both examples, the auxiliary model was utilized to evaluate a large number of alternative decision variable combinations. The relative simplicity of the model made it economically feasible to perform extensive sensitivity analysis and in so doing establish the stability of the resultant trends to various input fluctuations.

A. LVA CONCEPT OF EMPLOYMENT

As originally envisioned this application of the LVA attrition model was to encompass approximately 216 input cases reflecting various feasible combinations of the two decision variables, RD and TBW. RD is the distance offshore at which the incoming waves of LVA initiate the transition from a planing mode to a displacement mode. TBW is the time between the arrival of incoming waves at the beach. A sequential wave transition process was to be used by the incoming waves. A detailed sensitivity analysis was performed which encompassed varying combinations of two hypothetical LVA designs, three defensive force mixes and two generalized levels of effectiveness for the fire support capabilities of the Amphibious Task Force. The intent in addressing this large number of cases was to establish whether a tactical employment procedure resulted in consistent performance, or whether there existed certain dependencies on the various feasible scenario assumptions.

The auxiliary model, although relatively unsophisticated in nature, has demonstrated by means of this example that a simple modeling approach is capable of providing not only gross trends with respect to the decision parameters involved in a problem, but also is capable of generating sufficient information regarding the combat dynamics of the process to cue the development of additional alternatives. The state variable and attrition rate time breakdowns aggregated the complexities incorporated in the ship-to-shore movement in order that the following rather intuitive observations might be made.

* The survivor rate for the first assault wave is a dominant factor in determining the final LVA survivor outcome.

* The magnitude of attrition imposed upon an incoming wave is determined by the

  1. Time under fire, i.e. the time required to traverse the defensive weapon engagement window, and

  2. The existance of multiple waves within an engagement window "forcing" the defensive unit to split his fire between the multiple waves.

In the analysis of the model results pertaining to sequential wave transition, various insights were gained into the general behavior of the system. These insights highlighted certain aspects of the dynamics which prompted the definition of an up-to-that-point unrealized alternative tactical option: SIMULTANEOUS WAVE TRANSITION. From the extensive application of the simple auxiliary model to this problem, several tentative hypotheses were formed.

* The simultaneous wave transition tactic generally results in a larger number of surviving LVA reaching the shore than when using the sequential wave transition tactic. This generalization appears to hold for any set of (RD, TBW) tactical employment parameters.

* In using simultaneous wave transition, TSURV tends to increase as:

  1. the transition is initiated closer to shore, and
  2. as the time between the arrival of successive waves is decreased.

B. LVA DESIGN APPLICATION

A second example of the use of a simplified auxiliary model has been presented with regard to the evaluation of certain design specifications for the LVA. The model was initially implemented to derive the interrelationships of the height and speed of an LVA traversing a direct-fire weapon engagement window with the vulnerability of that vehicle to the attrition effects of the tank and ATGM weapon systems. This elementary approach identified tradeoff guidance in the comparison of various (HT,SPD) combinations. Attrition matrices for both the tank and the ATGM weapon systems were created which provided specific vulnerability measures for each of the input design cases. From this information it was possible to address the question: "What are the consequences of traversing an engagement window quickly while presenting a large target profile in comparison with traversing the same window more slowly as a smaller target?" This size-speed tradeoff served as the basic issue underlying the remainder of the design application.

In order to capture the synergistic effect of the LVA speed characteristic with the actual tactical criteria involved in the employment of waves of LVA, a total of 480 replications of the model were made. These runs represent the evaluation of 240 feasible LVA designs each utilized in two tactical employment options. The results of this analysis established the significance each of the four design features addressed makes with respect to the survivability of the craft. The following hypotheses describe these results.

* In the design of a planing hull vehicle which is to be employed utilizing a simultaneous wave transition initiated close to the surfline, the dominant design features are the speed of the craft in the planing mode and the height of the craft in the displacement mode. Over the broad feasible ranges investigated, SPDMIN and HTMAX are essentially secondary considerations.

* In the design of a planing hull vehicle which is to be employed utilizing a simultaneous wave transition initiated outside the maximum effective ranges for the direct-fire defensive weapons, HTMIN and SPDMIN are the dominant factors influencing the vehicle's survivability.

C. CONCLUSION

It must be emphasized that the purpose of a simplified auxiliary model as proposed within this thesis is to provide preliminary insights into the specific problem being modeled. The simple model is to be used as a tool in conjunction with a high-resolution simulation model, not as a replacement for such a detailed model. The primary intent for developing the simple model is encompassed by the fact that full scale simulation results are essentially driven by input data. The benefit of preliminary auxiliary modelling is in the assistance it provides the analyst in defining a relatively small subset of the entire realm of possible input cases. This case subset may then be thoroughly investigated using the highly detailed and usually costly full-scale simulation. This methodology is illustrated in Figure 32.

It has been the intent of this thesis to use the LVA design and employment problem as an illustration of this proposed modelling strategy. In the process of developing this example, several intuitive insights into the survivability aspects of the LVA have been highlighted. The tentative hypotheses which have been formulated with regard to the LVA concept hopefully provide a basis from which subsequent modeling efforts may be initiated.

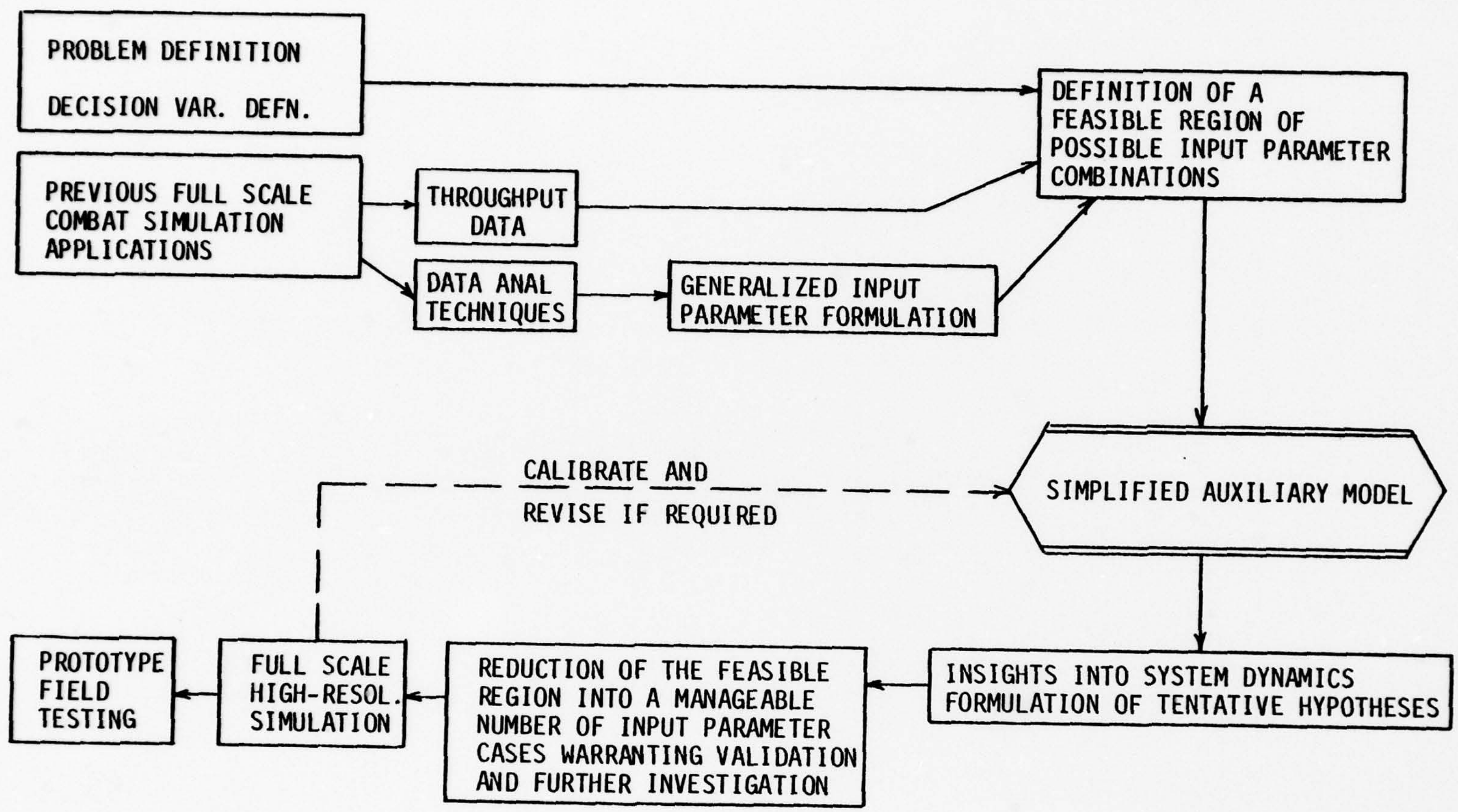


FIGURE (32): AUXILIARY MODELING METHODOLOGY SUMMARY

APPENDIX A: TACTICAL EMPLOYMENT APPLICATION RESULTS
LVA AUXILLIARY MODEL

LVAX1 SEQUENTIAL WAVE TRANSITION DT = 3 DS = 1
ICOEF = 1

	RD:	500.	1000.	1500.	2000.	2500.	3000.
TBW:	120.	19.32	22.29	26.68	27.33	27.55	28.13
	180.	14.22	13.02	24.78	26.15	26.35	27.09
	240.	19.03	0.00	17.55	20.36	20.88	22.09

LVAX1 SEQUENTIAL WAVE TRANSITION DT = 2 DS = 2
ICOEF = 1

	RD:	500.	1000.	1500.	2000.	2500.	3000.
TBW:	120.	24.56	25.39	28.44	29.59	30.06	30.54
	180.	23.34	21.30	26.69	28.84	29.39	30.19
	240.	26.42	20.82	24.00	25.94	27.24	28.33

LVAX1 SEQUENTIAL WAVE TRANSITION DT = 1 DS = 3
ICOEF = 1

	RD:	500.	1000.	1500.	2000.	2500.	3000.
TBW:	120.	28.43	27.89	29.83	31.45	32.20	32.80
	180.	27.75	26.29	28.75	31.02	31.73	32.69
	240.	30.79	28.22	28.63	29.65	30.99	32.00

LVAX1 SEQUENTIAL WAVE TRANSITION DT = 3 DS = 1
ICOEF = 2

TBW \ RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	14.12	16.93	21.45	22.12	22.24	22.85
180.	6.61	5.00	17.71	19.61	19.98	21.26
240.	8.49	0.00	5.63	9.72	10.38	12.07

LVAX1 SEQUENTIAL WAVE TRANSITION DT = 2 DS = 2
ICOEF = 2

TBW \ RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	19.73	20.78	24.31	25.54	26.05	26.64
180.	16.42	14.10	21.76	24.41	24.93	25.84
240.	20.44	11.47	16.63	19.38	20.99	22.26

LVAX1 SEQUENTIAL WAVE TRANSITION DT = 1 DS = 3
ICOEF = 2

TBW \ RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	24.62	24.37	26.83	28.67	29.43	30.09
180.	22.83	21.35	24.66	27.52	28.29	29.35
240.	26.12	22.28	23.11	24.74	26.59	27.88

APPENDIX A: TACTICAL EMPLOYMENT APPLICATION RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

LVAX2 SEQUENTIAL WAVE TRANSITION DT = 3 DS = 1
ICOEF = 1

TBW \ RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	24.97	17.03	18.41	19.69	20.49	20.56
180.	27.59	4.06	17.56	20.86	21.56	21.67
240.	30.31	0.00	11.33	18.60	19.43	19.78

LVAX2 SEQUENTIAL WAVE TRANSITION DT = 2 DS = 2
ICOEF = 1

TBW \ RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	28.59	22.98	24.12	25.52	25.76	25.54
180.	31.19	19.57	22.51	25.15	25.76	25.70
240.	33.24	17.94	21.42	23.66	24.64	24.96

LVAX2 SEQUENTIAL WAVE TRANSITION DT = 1 DS = 3
ICOEF = 1

TBW \ RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	30.39	26.90	27.61	29.34	29.40	29.07
180.	32.93	27.42	26.49	28.87	29.23	29.13
240.	34.86	28.45	28.13	27.82	28.59	28.77

APPENDIX A: TACTICAL EMPLOYMENT APPLICATION RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

LVAX2 SEQUENTIAL WAVE TRANSITION DT = 3 DS = 1
ICOEF = 2

TBW:	RD: 500.	1000.	1500.	2000.	2500.	3000.
120.	19.85	11.98	13.15	13.81	14.22	13.92
180.	22.65	0.22	8.75	12.03	12.71	12.49
240.	25.57	0.00	2.26	7.20	8.12	8.25

LVAX2 SEQUENTIAL WAVE TRANSITION DT = 2 DS = 2
ICOEF = 2

TBW:	RD: 500.	1000.	1500.	2000.	2500.	3000.
120.	24.19	18.24	19.19	20.44	20.59	20.16
180.	27.49	12.01	15.65	19.21	19.91	19.56
240.	29.36	7.58	12.73	16.16	17.48	17.65

LVAX2 SEQUENTIAL WAVE TRANSITION DT = 1 DS = 3
ICOEF = 2

TBW:	RD: 500.	1000.	1500.	2000.	2500.	3000.
120.	26.85	23.20	24.03	25.84	25.81	25.30
180.	29.40	22.70	21.95	24.76	25.14	24.84
240.	31.72	22.47	22.63	22.52	23.54	23.63

APPENDIX A: TACTICAL EMPLOYMENT APPLICATION RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

LVAX1 SIMULTANEOUS WAVE TRANSITION DT = 3 DS = 1
ICOEF = 1

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	28.23	26.73	27.69	27.67	27.63	28.14
180.	27.48	25.58	26.63	26.57	26.55	27.11
240.	23.74	19.61	21.50	21.33	21.20	22.12

LVAX1 SIMULTANEOUS WAVE TRANSITION DT = 2 DS = 2
ICOEF = 1

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	30.55	29.68	30.28	30.26	30.23	30.56
180.	30.27	29.02	29.84	29.84	29.82	30.26
240.	28.89	26.78	27.93	27.86	27.86	28.38

LVAX1 SIMULTANEOUS WAVE TRANSITION DT = 1 DS = 3
ICOEF = 1

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	33.18	32.84	33.22	33.22	33.20	33.40
180.	33.12	32.66	33.06	33.06	33.04	33.24
240.	32.56	31.94	32.41	32.39	32.37	32.57

LVAX1 SIMULTANEOUS WAVE TRANSITION DT = 3 DS = 1
ICOEF = 2

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	23.58	21.73	22.68	22.48	22.34	22.86
180.	22.59	19.18	20.67	20.44	20.26	21.27
240.	15.92	9.48	11.84	11.32	10.89	12.13

LVAX1 SIMULTANEOUS WAVE TRANSITION DT = 2 DS = 2
ICOEF = 2

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	27.06	25.87	26.50	26.36	26.32	26.66
180.	26.55	25.04	25.75	25.60	25.48	25.86
240.	23.77	21.13	22.19	21.97	21.79	22.33

LVAX1 SIMULTANEOUS WAVE TRANSITION DT = 1 DS = 3
ICOEF = 2

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	31.11	30.58	30.89	30.79	30.71	30.86
180.	30.42	29.75	30.08	29.99	29.91	30.06
240.	29.31	28.26	28.71	28.56	28.52	28.73

LVAX2 SIMULTANEOUS WAVE TRANSITION DT = 3 DS = 1
ICOEF = 1

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	29.15	22.76	20.64	20.07	20.61	20.60
180.	29.95	24.07	21.86	21.33	21.76	21.71
240.	30.17	22.86	19.89	19.46	19.75	19.84

LVAX2 SIMULTANEOUS WAVE TRANSITION DT = 2 DS = 2
ICOEF = 1

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	31.68	27.97	26.73	26.07	25.93	25.62
180.	32.28	28.54	26.93	26.26	26.17	25.85
240.	32.21	28.22	26.24	25.61	25.44	25.08

LVAX2 SIMULTANEOUS WAVE TRANSITION DT = 1 DS = 3
ICOEF = 1

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	34.58	32.57	31.68	30.97	30.48	29.94
180.	34.77	32.86	31.86	31.16	30.66	30.08
240.	34.67	32.65	31.55	30.85	30.31	29.71

LVAX2 SIMULTANEOUS WAVE TRANSITION DT = 3 DS = 1
ICOEF = 2

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	24.16	17.42	15.10	14.11	14.33	13.96
180.	25.31	16.88	13.71	12.63	12.91	12.55
240.	24.64	14.69	9.58	8.45	8.58	8.33

LVAX2 SIMULTANEOUS WAVE TRANSITION DT = 2 DS = 2
ICOEF = 2

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	28.37	23.82	22.06	21.06	20.82	20.24
180.	28.64	24.34	21.94	20.69	21.41	19.74
240.	27.95	23.06	20.20	18.98	18.54	17.86

LVAX2 SIMULTANEOUS WAVE TRANSITION DT = 1 DS = 3
ICOEF = 2

RD:	500.	1000.	1500.	2000.	2500.	3000.
120.	32.63	30.22	28.92	27.86	27.25	26.44
180.	32.29	30.01	28.59	27.52	26.88	26.06
240.	32.09	29.44	27.68	26.50	25.74	24.87

APPENDIX B: ENGR. DESIGN CRITERIA TRADEOFF RESULTS
LVA AUXILLIARY MODEL

TACTIC A: RC = 3000. DT = 3. DS = 1.
TBW = 180. ICOEF = 1

DATA VALUE REPRESENTS THE TOTAL NUMBER OF LVA SURVIVORS REACHING SHORE AS A FUNCTION OF THE INDICATED DESIGN PARAMETERS

SPDMAX:	SPDMIN:	HTMAX: / HTMIN:	1.50 / 0.60	1.50 / 0.70	1.50 / 0.80	1.50 / 0.90
10.00	3.50	*	21.98	18.54	14.41	9.52
10.00	4.00	*	24.65	21.76	18.77	15.32
10.00	4.50	*	25.98	23.29	20.53	17.49
10.00	5.00	*	27.20	24.64	22.04	19.30
12.00	3.50	*	22.58	19.20	15.34	10.71
12.00	4.00	*	24.88	22.00	19.02	15.61
12.00	4.50	*	25.94	23.24	20.46	17.33
12.00	5.00	*	27.27	24.72	22.12	19.38
14.00	3.50	*	22.13	18.67	14.54	9.64
14.00	4.00	*	24.60	21.67	18.64	15.00
14.00	4.50	*	26.84	24.22	21.57	18.79
14.00	5.00	*	27.24	24.66	22.08	19.34
16.00	3.50	*	21.61	18.02	13.68	8.82
16.00	4.00	*	24.65	21.75	18.65	15.10
16.00	4.50	*	26.07	23.38	20.62	17.58
16.00	5.00	*	27.61	25.14	22.60	19.94
18.00	3.50	*	22.19	18.67	14.61	9.69
18.00	4.00	*	24.59	21.71	18.64	15.11
18.00	4.50	*	26.49	23.84	21.16	18.24
18.00	5.00	*	27.63	25.15	22.62	19.96

APPENDIX B: ENGR. DESIGN CRITERIA TRADEOFF RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

TACTIC A: RD = 3000. DT = 3. DS = 1.
TBW = 180. ICOEF = 1

DATA VALUE REPRESENTS THE TOTAL NUMBER OF
LVA SURVIVORS REACHING SHORE AS A FUNCTION
OF THE INDICATED DESIGN PARAMETERS

SPDMAX:	SPDMIN:	HTMAX: 1.70 HTMIN: 0.60	HTMAX: 1.70 HTMIN: 0.70	HTMAX: 1.70 HTMIN: 0.80	HTMAX: 1.70 HTMIN: 0.90
10.00	3.50	21.96	18.46	14.39	9.49
10.00	4.00	24.63	21.74	18.75	15.30
10.00	4.50	25.96	23.27	20.51	17.47
10.00	5.00	27.18	24.62	22.02	19.28
12.00	3.50	22.56	19.19	15.32	10.70
12.00	4.00	24.87	21.98	19.01	15.59
12.00	4.50	25.92	23.22	20.45	17.31
12.00	5.00	27.25	24.70	22.10	19.36
14.00	3.50	22.11	18.65	14.52	9.62
14.00	4.00	24.58	21.66	18.62	14.98
14.00	4.50	26.82	24.20	21.55	18.77
14.00	5.00	27.22	24.64	22.06	19.25
16.00	3.50	21.59	18.00	13.65	8.79
16.00	4.00	24.63	21.73	18.63	14.96
16.00	4.50	26.05	23.36	20.59	17.56
16.00	5.00	27.58	25.10	22.57	19.91
18.00	3.50	22.17	18.66	14.59	9.67
18.00	4.00	24.58	21.69	18.62	15.09
18.00	4.50	26.48	23.82	21.15	18.22
18.00	5.00	27.61	25.13	22.60	19.94

APPENDIX B: ENGR. DESIGN CRITERIA TRADEOFF RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

TACTIC A: RD = 3000. CT = 3. DS = 1.
TBW = 180. ICOEF = 1

DATA VALUE REPRESENTS THE TOTAL NUMBER OF
LVA SURVIVORS REACHING SHORE AS A FUNCTION
OF THE INDICATED DESIGN PARAMETERS

	HTMAX:	1.90	1.90	1.90	1.90
	HTMIN:	0.60	0.70	0.80	0.90
SPDMAX:	SPDMIN:				
10.00	3.50	21.95	18.44	14.37	9.47
10.00	4.00	24.61	21.72	18.74	15.28
10.00	4.50	25.94	23.25	20.49	17.45
10.00	5.00	27.16	24.61	22.00	19.26
12.00	3.50	22.55	19.17	15.30	10.68
12.00	4.00	24.85	21.97	18.99	15.57
12.00	4.50	25.91	23.21	20.43	17.29
12.00	5.00	27.24	24.68	22.08	19.34
14.00	3.50	22.09	18.64	14.51	9.59
14.00	4.00	24.56	21.64	18.54	14.96
14.00	4.50	26.81	24.18	21.53	18.75
14.00	5.00	27.20	24.63	22.04	19.23
16.00	3.50	21.58	17.98	13.63	8.77
16.00	4.00	24.61	21.71	18.61	14.94
16.00	4.50	26.03	23.34	20.57	17.53
16.00	5.00	27.57	25.08	22.55	19.89
18.00	3.50	22.16	18.64	14.57	9.65
18.00	4.00	24.56	21.64	18.60	15.07
18.00	4.50	26.46	23.80	21.13	18.20
18.00	5.00	27.60	25.11	22.58	19.92

APPENDIX B: ENGR. DESIGN CRITERIA TRADEOFF RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

TACTIC B: RD = 500. DT = 3. DS = 1.
TBW = 240. ICOEF = 1

DATA VALUE REPRESENTS THE TOTAL NUMBER OF
LVA SURVIVORS REACHING SHORE AS A FUNCTION
OF THE INDICATED DESIGN PARAMETERS

	HTMAX:		1.50	1.50	1.50	1.50
	HTMIN:		0.60	0.70	0.80	0.90
SPDMAX:	SPDMIN:					
10.00	3.50	*	24.66	23.16	21.82	20.69
10.00	4.00	*	24.29	22.83	21.56	20.36
10.00	4.50	*	25.28	23.72	22.47	21.28
10.00	5.00	*	23.28	21.78	20.36	18.96
12.00	3.50	*	27.41	26.20	25.11	24.02
12.00	4.00	*	28.20	27.04	25.97	24.88
12.00	4.50	*	28.15	26.93	25.74	24.58
12.00	5.00	*	27.95	26.55	25.22	24.06
14.00	3.50	*	29.07	28.07	27.12	26.21
14.00	4.00	*	29.84	28.90	27.98	27.09
14.00	4.50	*	30.03	29.00	28.05	27.12
14.00	5.00	*	30.46	29.50	28.59	27.72
16.00	3.50	*	30.79	29.93	29.10	28.37
16.00	4.00	*	31.70	30.87	30.12	29.36
16.00	4.50	*	31.54	30.71	29.90	29.12
16.00	5.00	*	31.52	30.69	29.90	29.14
18.00	3.50	*	32.21	31.43	30.69	30.04
18.00	4.00	*	32.33	31.55	30.80	30.13
18.00	4.50	*	33.28	32.60	31.92	31.26
18.00	5.00	*	32.93	32.21	31.52	30.87

APPENDIX B: ENGR. DESIGN CRITERIA TRADEOFF RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

TACTIC B: RC = 500. DT = 3. DS = 1.
TBW = 240. ICOEF = 1

DATA VALUE REPRESENTS THE TOTAL NUMBER OF
LVA SURVIVORS REACHING SHORE AS A FUNCTION
OF THE INDICATED DESIGN PARAMETERS

SPDMAX:	SPDMIN:	HTMAX: 1.70 HTMIN: 0.60	HTMAX: 1.70 HTMIN: 0.70	HTMAX: 1.70 HTMIN: 0.80	HTMAX: 1.70 HTMIN: 0.90
10.00	3.50	23.56	22.12	20.87	19.69
10.00	4.00	23.33	21.92	20.59	19.34
10.00	4.50	24.23	22.81	21.47	20.21
10.00	5.00	22.31	20.72	19.16	17.62
12.00	3.50	26.68	25.41	24.20	23.07
12.00	4.00	27.43	26.26	25.07	23.93
12.00	4.50	27.34	26.04	24.78	23.57
12.00	5.00	26.89	25.53	24.13	22.87
14.00	3.50	28.46	27.42	26.42	25.48
14.00	4.00	29.27	28.26	27.30	26.30
14.00	4.50	29.41	28.32	27.30	26.20
14.00	5.00	29.85	28.82	27.86	26.83
16.00	3.50	30.32	29.42	28.57	27.76
16.00	4.00	31.23	30.36	29.54	28.73
16.00	4.50	31.03	30.15	29.30	28.48
16.00	5.00	31.00	30.13	29.30	28.48
18.00	3.50	31.78	30.98	30.23	29.56
18.00	4.00	31.90	31.10	30.32	29.57
18.00	4.50	32.88	32.14	31.47	30.78
18.00	5.00	32.49	31.74	31.07	30.39

APPENDIX B: ENGR. DESIGN CRITERIA TRADEOFF RESULTS
(CONTINUED) LVA AUXILLIARY MODEL

TACTIC B: RD = 500. DT = 3. DS = 1.
TBW = 240. ICOEF = 1

DATA VALUE REPRESENTS THE TOTAL NUMBER OF LVA SURVIVORS REACHING SHORE AS A FUNCTION OF THE INDICATED DESIGN PARAMETERS

SPDMAX:	SPDMIN:	HTMAX: / HTMIN:	1.90 / 0.60	1.90 / 0.70	1.90 / 0.80	1.90 / 0.90
10.00	3.50	*	22.79	21.37	20.09	18.87
10.00	4.00	*	22.64	21.18	19.78	18.47
10.00	4.50	*	23.52	22.05	20.66	19.31
10.00	5.00	*	21.50	19.80	18.13	16.37
12.00	3.50	*	25.96	24.64	23.47	22.31
12.00	4.00	*	26.80	25.51	24.26	23.09
12.00	4.50	*	26.68	25.33	23.94	22.69
12.00	5.00	*	26.17	24.65	23.34	22.16
14.00	3.50	*	27.98	26.84	25.81	24.83
14.00	4.00	*	28.79	27.71	26.70	25.66
14.00	4.50	*	28.87	27.70	26.62	25.55
14.00	5.00	*	29.31	28.22	27.10	26.08
16.00	3.50	*	29.88	28.95	28.07	27.29
16.00	4.00	*	30.82	29.94	29.08	28.25
16.00	4.50	*	30.63	29.72	28.77	27.91
16.00	5.00	*	30.60	29.69	28.76	27.90
18.00	3.50	*	31.42	30.61	29.83	29.10
18.00	4.00	*	31.54	30.71	29.91	29.14
18.00	4.50	*	32.53	31.77	31.09	30.39
18.00	5.00	*	32.14	31.37	30.63	29.97

APPENDIX C: GENERALIZED FLOWCHART FOR LVA AUXILIARY MODEL

State Variable Definitions:

DT - Unit Strength Defensive Tanks

DS - Unit Strength Defensive ATGM

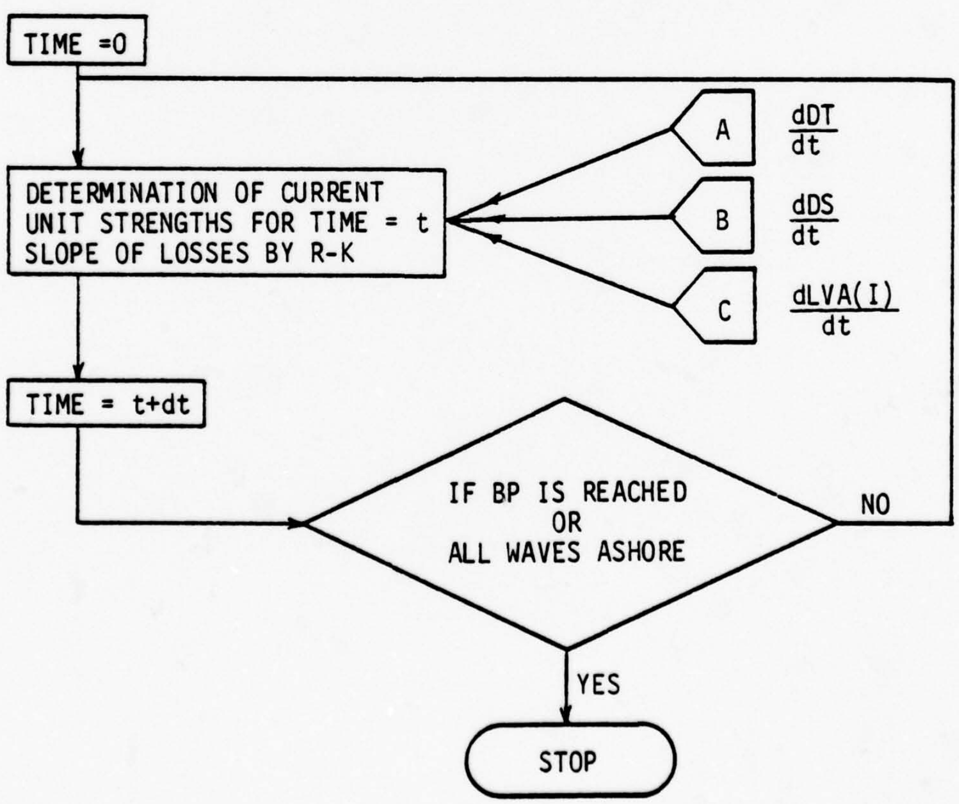
LVA(I) - Unit Strength Wave(I) of the Incoming LVA (I=1,2,3,4,5)

TLF - Unit Strength of Landed Waves of LVA

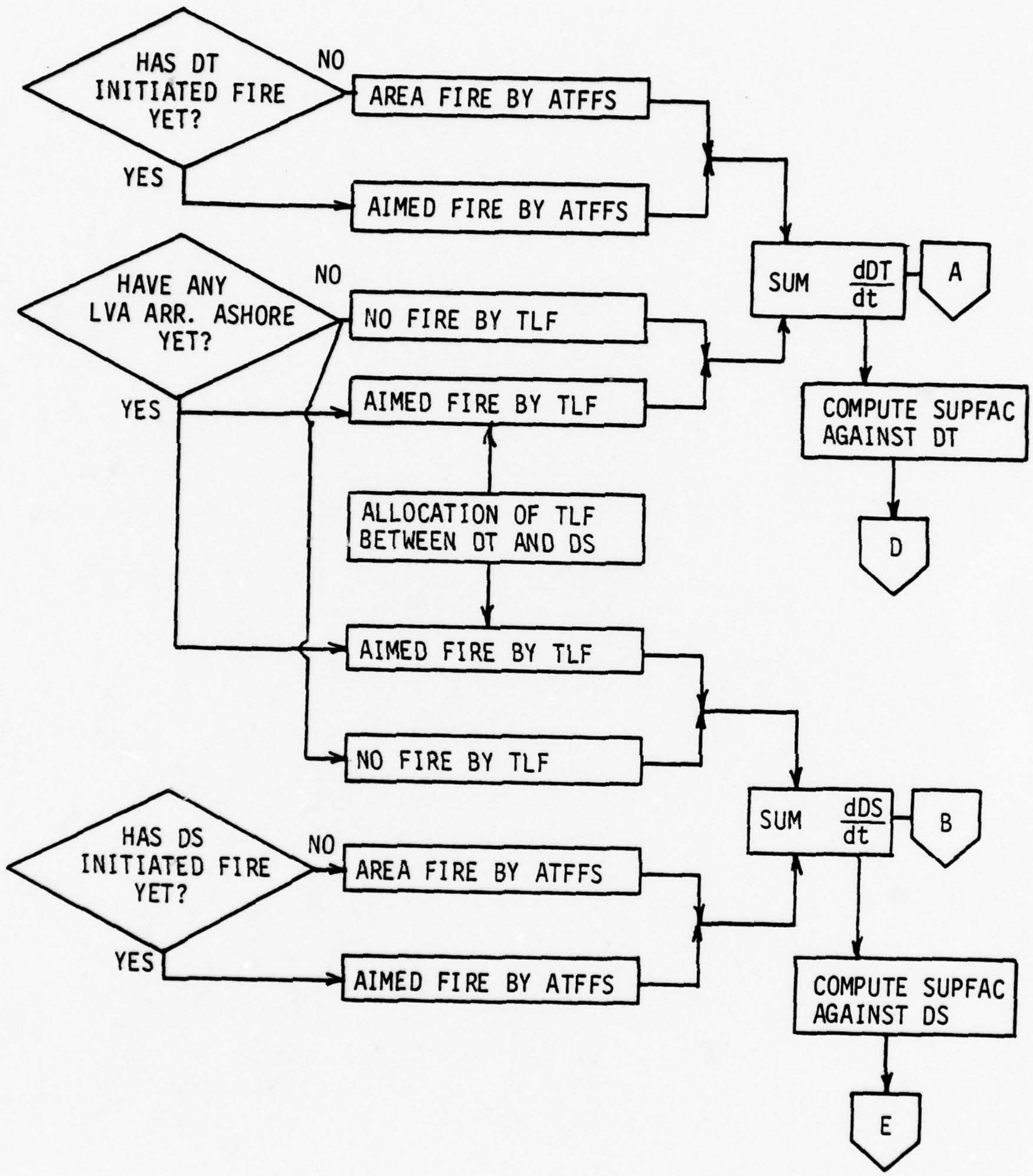
ATFFS - Unit Strength of ATF Fire Support assets

MAIN MODULE

Main Module utilizes a Runge-Kutta Numerical Integration Technique to aggregate the effects of all attrition processes.

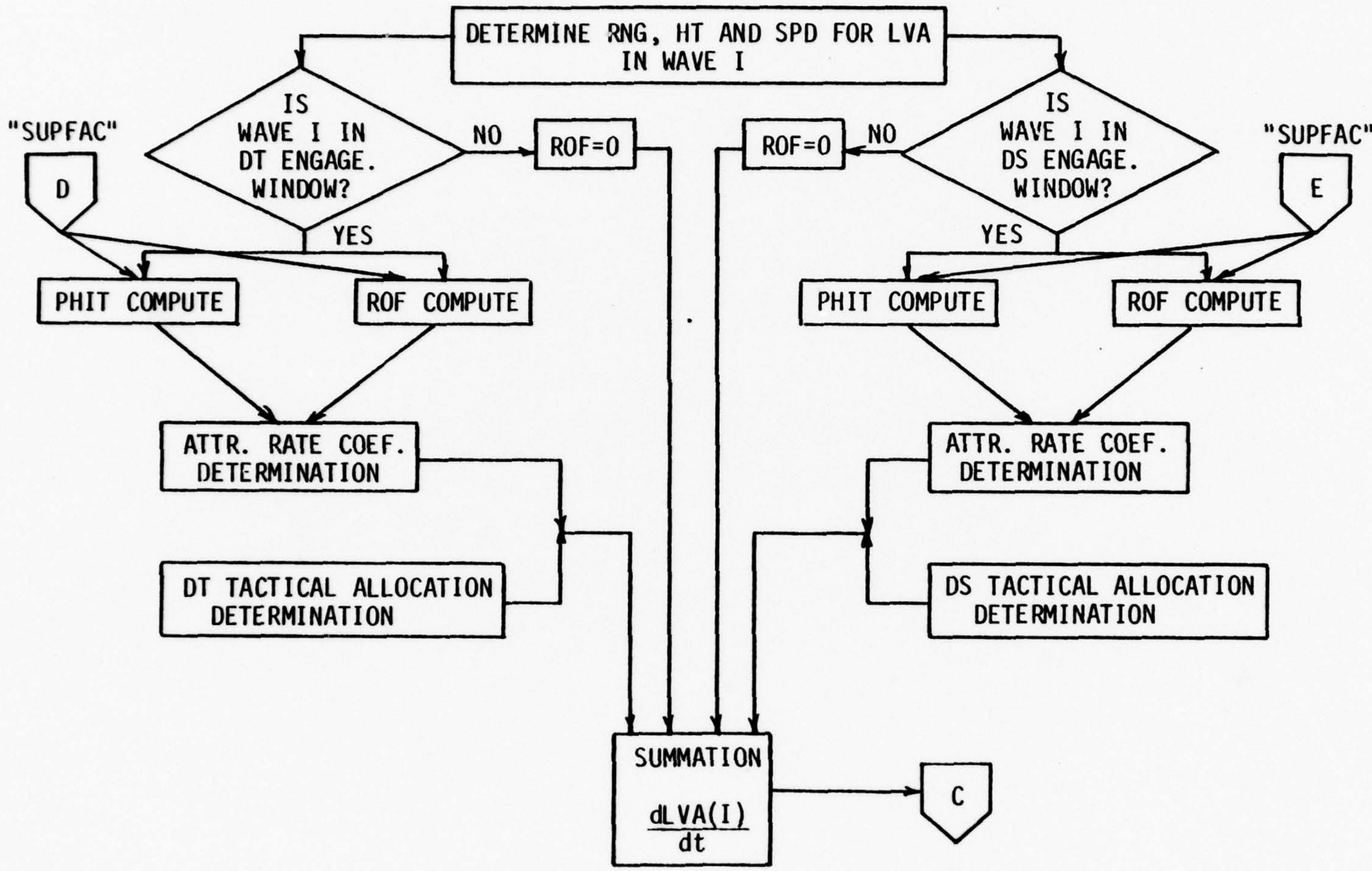


ATTRITION COEF. AGAINST SHORE DEFENSES MODULE



DIRECT FIRE DT/DS AGAINST INCOMING LVA MODULE

FOR EACH INCOMING WAVE I:



```
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,WVINT(5),WIC,
     1TBW,DINIT(2)
      COMMON /ENGF/ SPDMAX,SPDMIN,HTMAX,HTMIN,TTS,TA,TB,TF
      CALL DATAIN
      CALL CUTPUT
      DO 5000 IRD=500,3000,500
      DO 4000 ITBW=120,240,60
      RD=1.0*IRD
      TBW=1.0*ITBW
      TINIT=0.0
C*
C*****  COMPUTATION OF FIRST WAVE TIME PARAMETERS
C*             TA - TIME FIRST WAVE INITIATES TRANSITION
C*             TB - TIME FIRST WAVE COMPLETES TRANSITION
C*****         TF - TIME FIRST WAVE REACHES THE BEACH
C*
      TA=(5000.0-RD)/SPDMAX
      TB=TA+TTS
      TF=TB+(RD-(0.5*(SPDMAX-SPDMIN)*TTS)-150.0)/SPDMIN
      DEL=10.
      WRITE(6,55) RD,TBW
   55 FORMAT(///,' ITERATION INITIATED...RD= ',F10.3,'  TBW=
     1 ',F10.3)
      CALL RKINT(DEL,TINIT,N)
 4000 CONTINUE
 5000 CONTINUE
      STOP
      END
```

```
      SUBROUTINE RKINT(H,TI,N)
C*
C*****  SUBROUTINE RKINT PROVIDES THE INTERFACE BETWEEN
C*      THE RUNGE-KUTTA NUMERICAL INTEGRATION ROUTINE
C*      RKLDEQ AND THE SUBROUTINE ATTR WHICH DETERMINES EACH
C*      UNIT'S STATUS AS TIME PROGRESSES THROUGH THE
C*****  AMPHIBIOUS OPERATION
C*
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,WVINT(5),WID,
     1TBW,DINIT(2)
      COMMON /IOUT/ISURV,IATTR
      DIMENSION CSURV(5),CDSURV(2),TA(5),SA(5),DA(2),
     1RKSURV(7),RKATTR(7),TATTR(200,12),TIME(200)
C*
C*****  VARIABLE DEFINITIONS
C*
C*      IMAX - MAXIMUM ALLOWABLE NUMBER OF TIME INTERVALS
C*
C*      ITE - A SWITCH VARIABLE SET TO 1 WHEN THE DEF. TANK
C*            UNIT INITIATES ITS FIRE
C*
C*      ISE - A SWITCH VARIABLE SET TO 1 WHEN THE DEF. ATGM
C*            UNIT INITIATES ITS FIRE
C*
C*      T - CURRENT TIME
C*
C*      IT - CURRENT TIME PERIOD
C*
C*      IL(I) - A SWITCH VARIABLE WHOSE ELEMENT I IS SET TO
C*              1 WHEN WAVE I ARRIVES AT THE BEACH
C*
```

```
C*        TSURV - TOTAL NUMBER OF SURVIVING LVA AT THE
C*                CURRENT TIME
C*
C*
C*
C*****    STATE VARIABLE DEFINITIONS
C*
C*        CSURV(I) - CURRENT STRENGTH OF ASSAULT WAVE I
C*
C*        CDSURV(I) - CURRENT STRENGTH OF DEFENSIVE FORCE I
C*                            I=1      TANK
C*                            I=2      ATGM
C*
C*        RKSURV(I) - CONCATENATION OF CSURV AND CDSURV
C*
C*        DINIT(I) - INITIAL STRENGTH OF DEF. FORCE I
C*
C*****    WVINT(I) - INITIAL STRENGTH OF WAVE I
C*
      IF(ISURV.EQ.1) WRITE(6,5)
    5 FORMAT('1SURV MATRIX',//,4X,'T',T13,'CSURV1',T23,
     1'CSURV2',T33,'CSURV3',T43,'CSURV4',T53,'CSURV5',
     2T63,'TSURV',T70,'**',T75,'DT',T85,'DS',//)
      IMAX=199
      ITE=0
      ISE=0
      TSURV=0.
      TIME(1)=0.
      T=TI
      DO 10 I=1,5
      CSURV(I)=WVINT(I)
      TSURV=TSURV+CSURV(I)
      IL(I)=0
   10 CONTINUE
      DO 15 I=1,2
      CDSURV(I)=DINIT(I)
   15 CONTINUE
      DO 20 J=1,12
   20 TATTR(1,J)=0.
      IT=1
      DO 25 I=1,5
   25 RKSURV(I)=CSURV(I)
      RKSURV(6)=CDSURV(1)
      RKSURV(7)=CDSURV(2)
      DO 30 I=1,7
   30 RKATTR(I)=0.
      NT=0
 1000 CALL ATTR(T,CSURV,CDSURV,TA,SA,DA)
C*
C*****    VARIABLE DEFINITIONS
C*
C*        TA(I) - ATTRITION RATE FOR WAVE I DUE TO TANKS
C*
C*        SA(I) - ATTRITION RATE FOR WAVE I DUE TO ATGM
C*
C*        DA(I) - ATTRITION RATE FOR DEF. UNIT I DUE
C*****                TO THE EFFECTS OF ATFFS/TLF
C*
C*
C*****    RKATTR(I) IS A VECTOR CONTAINING THE CURRENT
C*        ATTRITION LOSS RATES TO BE APPLIED WITHIN THE
C*        RUNGE-KUTTA ROUTINE TO THE STATE VARIABLES.
C*                I=1,5       LVA WAVES 1-5
C*                I=6         DT
C*****            I=7         DS
      IF(IL(1).EQ.99) GO TO 1200
      DO 40 I=1,5
      RKSURV(I)=CSURV(I)
   40 RKATTR(I)=(TA(I)+SA(I))*(-1.0)
```

```
      DO 45 I=1,2
      RKSURV(I+5)=CDSURV(I)
   45 RKATTR(I+5)=-1.0*DA(I)
      S=RKLDEQ(7,RKSURV,RKATTR,T,H,NT)
      DO 50 I=1,5
      CSURV(I)=RKSURV(I)
   50 CONTINUE
      DO 55 I=1,2
      CDSURV(I)=RKSURV(I+5)
   55 CONTINUE
      IF(S-1.) 1100,1000,1200
 1100 WRITE(6,60)
   60 FORMAT(' ERROR....S.NE.1.OR.2')
      STOP
 1200 CONTINUE
      IT=IT+1
      TSURV=0.
      DO 65 L=1,5
   65 TSURV=TSURV+CSURV(L)
      IF(TSURV.LE.0.) TSURV=0.
      TIME(IT)=T
C*
C*****   ISURV IS A PRINT OPTION VARIABLE,
C*       WHEN ISURV IS EQUAL TO 1 THE MODEL WILL
C*       PRINT OUT THE SURVIVOR POPULATIONS FOR
C*****   EACH UNIT AT EACH TIME INTERVAL.
C*
      IF(ISURV.EQ.0)GO TO 75
      WRITE(6,70) T,CSURV,TSURV,CDSURV
   70 FORMAT(9F10.2)
   75 CONTINUE
C*
C*****   TATTR STORES THE RESULTANT ATTRITION RATES
C*       IMPOSED ON EACH UNIT FOR EACH TIME PERIOD.
C*       THE MODEL WILL PRINT OUT THIS MATRIX AT THE
C*       CONCLUSION OF THE RUN IF THE PRINT OPTION
C*****   VARIABLE IATTR IS SET EQUAL TO 1
C*
      DO 80 J=1,5
      TATTR(IT,J)=TA(J)
   80 TATTR(IT,J+5)=SA(J)
      DO 85 J=1,2
   85 TATTR(IT,J+10)=DA(J)
C*
C*****   DETERMINE R:  THE FIRING RANGE TO THE LAST (FIFTH)
C*****   INCOMING ASSAULT WAVE
C*
C*
      R=RNG(T-4.*TBW)
C*
C*****   THE MODEL IS TERMINATED IF:
C*             1.  THE FIRING RANGE TO THE LAST ASSAULT WAVE
C*                 IS LESS THAN 75 METERS
C*             2.  THE DEFENSIVE BREAKPOINT HAS BEEN REACHED
C*             3.  THE MAXIMUM NUMBER OF ITERATIONS HAS BEEN
C*****             EXCEEDED
C*
      IF(R.LT.75.) GO TO 2000
      IF(IT.GT.IMAX) GO TO 2000
      IF(IL(1).EQ.99) GO TO 2000
      GO TO 1000
 2000 N=IT
      WRITE(6,90) TSURV
   90 FORMAT(' FINAL LVA SURVIVORS ASHORE = ',F10.3)
      IF(IATTR.EQ.0) RETURN
      WRITE(6,91)
   91 FORMAT('1ATTR MATRIX',//,T4,'TA1',T14,'TA2',T24,
     1'TA3',T34,'TA4',T44,'TA5',T54,'SA1',T64,'SA2',T74,
     2'SA3',T84,'SA4',T94,'SA5',T104,'DA1',T114,'DA2',//)
```

```
      DO 100 IIT=1,IT
      WRITE(6,110) (TATTR(IIT,K),K=1,12)
  100 CONTINUE
  110 FORMAT(1X,12F10.2)
      RETURN
      END



      FUNCTION RKLDEQ(N,Y,F,X,H,NT)
      DIMENSION Y(1),F(1),Q(25)
      N1=NT+1
      GO TO (1,2,3,4),NT
    1 H1=H
      H2=H1*0.5
      H3=H1*2.0
      H6=H1/6.0
      DO 11 J=1,N
   11 Q(J)=0.
      A=0.5
      X=X+H2
      GO TO 5
    2 A=0.2928932
      GO TO 5
    3 A=1.707106
      X=X+H2
      GO TO 5
    4 DO 41 I=1,N
   41 Y(I)=Y(I)+H6*F(I)-Q(I)/3.0
      NT=0
      RKLDEQ=2.
      GO TO 6
    5 DO 51 L=1,N
      Y(L)=Y(L)+A*(H*F(L)-Q(L))
   51 Q(L)=H3*A*F(L)+(1.0-3.0*A)*Q(L)
      RKLDEQ=1.0
    6 RETURN
      END



      SUBROUTINE ATTR(T,CSURV,DSURV,TA,SA,DA)
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,Q(5),WID,
     1TBW,DINIT(2)
      COMMON /DEF/TENGMX,SENGMX,SENGMN,TARTM,SARTM,TVEL,
     1SVEL,DEFWTS(2)
      INTEGER TENG(2),SENG(2)
      DIMENSION CSURV(5),TA(5),SA(5),TRNG(2),TWTS(2)
     1,SRNG(2), DSURV(2),SWTS(2),DA(2)
C*
C*****     GIVEN THE CURRENT TIME AND STATE VARIABLE STRENGTHS,
C*         SUBROUTINE ATTR DETERMINES THE FOLLOWING:
C*
C*                   TA(I) - CURRENT ATTRITION LOSS RATE FOR
C*                           WAVE I DUE TO TANK FIRE
C*
C*                   SA(I) - CURRENT ATTRITION LOSS RATE FOR
C*                           WAVE I DUE TO ATGM FIRE
C*
C*                   DA(I) - CURRENT ATTRITION LOSS RATE FOR
C*                           DEF. FORCE I DUE TO ATFFS/TLF
C*                           EFFECTS
C*
C*                   IL(I) - WHEN EQUAL TO 99 INDICATES THE
C*                           DEFENSIVE BREAKPOINT HAS BEEN REACHED
```

```
C*        SUBROUTINE ATTR ALSO UPDATES THE STATUS OF EACH
C*        UNIT WITH RESPECT TO THE PROGRESS OF THE
C*        SHIP TO SHORE MOVEMENT AND IMPLEMENTS THIS
C*****    INFORMATION INTO THE ATTRITION LOSS RATE COMPUTATION
C*
      DO 10 I=1,5
      TA(I)=0.
      SA(I)=0.
   10 CONTINUE
C*
C*****    VARIABLE DEFINITIONS
C*
C*        DT1 - THAT PORTION OF THE DT UNIT ASSIGNED TO
C*              ENGAGING THE CLOSER OF TWO MULTIPLE WAVES
C*              IN THE TANK ENGAGEMENT WINDOW
C*
C*        DT2 - THAT PORTION OF THE DT UNIT ASSIGNED TO
C*              ENGAGING THE FARTHER OF TWO MULTIPLE WAVES
C*              IN THE TANK ENGAGEMENT WINDOW
C*
C*        DS1 - THAT PORTION OF THE DS UNIT ASSIGNED TO
C*              ENGAGING THE CLOSER OF TWO MULTIPLE WAVES
C*              IN THE ATGM ENGAGEMENT WINDOW
C*
C*        DS2 - THAT PORTION OF THE DS UNIT ASSIGNED TO
C*              ENGAGING THE FARTHER OF TWO MULTIPLE WAVES
C*****         IN THE ATGM ENGAGEMENT WINDOW
C*
      DS1=0.
      DS2=0.
      DT1=0.
      DT2=0.
      FAC=1.0
C*
C*****    DETERMINE IF DEF. BREAKPOINT HAS BEEN REACHED
C*
      IF((DSURV(1)+DSURV(2)).LT.0.3*(DINIT(1)+DINIT(2)))
     1 GO TO 20
C*
C*****    DETERMINE ATTRITION RATE ON DEFENSIVE FORCES BY
C*****    ATFFS BASED UPON AREA OR AIMED FIRE STATUS
C*
      DA(1)=B(1)
      DA(2)=B(2)
      IF(ITE.EQ.0) DA(1)=A(1)*DSURV(1)
      IF(ISE.EQ.0) DA(2)=A(2)*DSURV(2)
      GO TO 30
   20 DSURV(1)=0.
      DSURV(2)=0.
      DA(1)=0.
      DA(2)=0.
      IL(1)=99
      WRITE(6,25) T
   25 FORMAT(' BREAKPOINT REACHED AT TIME = ',F9.3)
      RETURN
C*
C*****    SUBROUTINE DTGTS DETERMINES THE FIRING STATUS FOR
C*****    THE TWO DEFENSIVE UNITS.
C*
   30 CALL DTGTS(T,TENG,TRNG,TWTS,SENG,SRNG,SWTS,DSURV)
C*
C*****    VARIABLE DEFINITIONS
C*
C*        TENG(1) - THE WAVE NUMBER OF THE CLOSER OF TWO
C*                  WAVES IN THE TANK ENGAGEMENT WINDOW
C*
C*        TRNG(1) - THE FIRING RANGE TO WAVE TENG(1)
C*
C*        TWTS(1) - THE PROPORTION OF THE TOTAL DT STRENGTH
C*                  TO BE ALLOCATED TO ENGAGING TENG(1)
```

```
C*        TENG(2) - THE WAVE NUMBER OF THE FARTHER OF TWO
C*                  WAVES IN THE TANK ENGAGEMENT WINDOW
C*
C*        TRNG(2) - SIMILAR INTERPRETATION AS TRNG(1)
C*        TWTS(2) - SIMILAR INTERPRETATION AS TWTS(1)
C*
C*        SENG(1) - THE WAVE NUMBER OF THE CLOSER OF TWO
C*                  WAVES IN THE ATGM ENGAGEMENT WINDOW
C*
C*        SRNG(1) - FIRING RANGE TO WAVE SENG(1)
C*
C*        SWTS(1) - THE PROPORTION OF THE TOTAL DS STRENGTH
C*                  TO BE ALLOCATED TO ENGAGING SENG(1)
C*
C*        SENG(2) - THE WAVE NUMBER OF THE FARTHER OF TWO
C*                  WAVES IN THE ATGM ENGAGEMENT WINDOW
C*
C*        SRNG(2) - SIMILAR INTERPRETATION AS SRNG(1)
C*****    SWTS(2) - SIMILAR INTERPRETATION AS SWTS(1)
C*
C*
C*
C*****    DETERMINE THE CUMULATIVE NUMBER OF SURVIVING LVA'S
C*****    THAT HAVE REACHED THE BEACH  - TLF
C*
      TLF=0.
      DO 40 J=1,5
      IF(IL(J).EQ.1) TLF=TLF+CSURV(J)
   40 CONTINUE
C*
C*****    ALLOCATE THE FORCE STRENGTH OF TLF BETWEEN THE TWO
C*****    DEFENSIVE FORCE UNITS
C*
      DSUM=DSURV(1)+DSURV(2)
      TLF1=(DSURV(1)/DSUM)*TLF
      TLF2=(DSURV(2)/DSUM)*TLF
C*
C*****    ADD TO DA1 AND DA2 THE ATTRITION LOSS RATE DUE
C*****    TO THE EFFECTS OF TLF1 AND TLF2
C*
      DA(1)=DA(1)+TLF1*WB(1)
      DA(2)=DA(2)+TLF2*WB(2)
      IF(DSURV(1).LE.0.0)DA(1)=0.
      IF(DSURV(2).LE.0.0)DA(2)=0.0
C*
C*****    DETERMINE IF THERE EXISTS AN INCOMING WAVE IN THE
C*****    TANK ENGAGEMENT WINDOW I.E. TENG(1).NE.0
C*
      IF(TENG(1).EQ.0) GO TO 100
      ITE=1
C*
C*****    DETERMINE THE TIME SINCE WAVE TENG(1) CROSSED THE
C*****    5000. METER OFFSHORE MARK - T1
C*
      T1=T-TBW*(TENG(1)-1)
      DT1=TWTS(1)*DSURV(1)
      FAC=1.
C*
C*****    DETERMINE THE SUPPRESSION EFFECT TO BE IMPOSED
C*        ON THE DT UNIT BASED ON THE ATTRITION LOSS RATE
C*****    CURRENTLY IN EFFECT
C*
      SUPFAC=1.0+FAC*(DA(1)/0.01)
C*
C*****    VARIABLE DEFINITIONS
C*
C*        DT1ROF - RATE OF FIRE UTILIZED BY DT1 AGAINST
C*                 WAVE TENG(1)
C*
C*        DT1PH -  HIT PROBABILITY OF ROUNDS FIRED BY DT1
C*****             AGAINST WAVE TENG(1)
C*
```

```
      CALL RATE(TRNG(1),SPD(T1),1,SUPFAC,DT1ROF)
      CALL PHIT(TRNG(1),WID,HT(T1),1,SUPFAC,DT1PH)
C*
C*****   DETERMINE THE ATTRITION LOSS RATE FOR
C*****   WAVE TENG(1) DUE TO DT1 FIRES
C*
      TA(TENG(1))=DT1PH*DT1ROF*DT1
C*
C*****   DETERMINE IF THERE IS A SECOND INCOMING WAVE THAT
C*       IS IN THE TANK ENGAGEMENT WINDOW, IF THERE IS THE
C*       ATTRITION RATE COMPUTATIONS ARE SIMILAR IN FORM
C*****   TO THOSE PREVIOUSLY PERFORMED FOR THE CLOSER WAVE
C*
      IF (TENG(2).EQ.0) GO TO 100
      T2=T-TBW*(TENG(2)-1)
      DT2=TWTS(2)*DSURV(1)
      CALL RATE(TRNG(2),SPD(T2),1,SUPFAC,DT2ROF)
      CALL PHIT(TRNG(2),WID,HT(T2),1,SUPFAC,DT2PH)
      TA(TENG(2))=DT2PH*DT2ROF*DT2
C*
C*****   DETERMINE IF THERE EXISTS AN INCOMING WAVE IN THE
C*       ATGM ENGAGEMENT WINDOW, IF THERE IS, DETERMINE THE
C*       ATTRITION EFFECTS AGAINST THAT WAVE DUE TO ATGM
C*       THE ATTRTION RATE COMPUTATIONS ARE SIMILAR IN FORM
C*****   TO THOSE FOR THE EFFECTS DUE THE TANK FIRE.
C*
  100 IF (SENG(1).EQ.0) GO TO 200
      ISE=1
      S1=T-TBW*(SENG(1)-1)
      DS1=SWTS(1)*DSURV(2)
      SUPFAC=1.0+FAC*(DA(2)/0.01)
      CALL RATE(SRNG(1),SPD(S1),2,SUPFAC,DS1ROF)
      CALL PHIT( SRNG(1),WID,HT(S1),2,SUPFAC,DS1PH)
      SA(SENG(1))=DS1PH*DS1ROF*DS1
      IF(SENG(2).EQ.0) GO TO 200
      S2=T-TBW*(SENG(2)-1)
      DS2=SWTS(2)*DSURV(2)
      CALL RATE(SRNG(2),SPD(S2),2,SUPFAC,DS2ROF)
      CALL PHIT(SRNG(2),WID,HT(S2),2,SUPFAC,DS2PH)
      SA(SENG(2))=DS2PH*DS2ROF*DS2
  200 RETURN
      END
```

```
      SUBROUTINE DTGTS(T,TENG,TRNG,TWTS,
     1SENG,SRNG,SWTS,CSURV)
C*
C*****   GIVEN THE CURRENT TIME AND LVA WAVE SURVIVOR
C*       POPULATIONS, SUBROUTINE DTGTS DETERMINES THE
C*       WAVE NUMBERS THAT ARE TO BE ENGAGED BY THE
C*       DT AND DS DEFENSIVE UNITS BASED ON THE ENGAGEMENT
C*****   WINDOW CRITERIA
C*
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,Q(5),WID,
     1TBW,DINIT(2)
      COMMON /DEF/TENGMX,SENGMX,SENGMN,TARTM,SARTM,TVEL,
     1SVEL,DEFWTS(2)
      INTEGER TENG(2),SENG(2)
      DIMENSION TRNG(2),SRNG(2),TWTS(2),SWTS(2),CSURV(5)
      DO 10 I=1,2
      TENG(I)=0
      TWTS(I)=0.
      TRNG(I)=0.
      SRNG(I)=0.
      SENG(I)=0
      SWTS(I)=0.
   10 CONTINUE
      JT=0
      JS=0
      TSUM=0.
      SSUM=0.
      DO 100 I=1,5
      WVRNG=RNG(T-TBW*(I-1))
      IF(WVRNG.LT.75.) IL(I)=1
C*
C*****   IF THE FIRING RANGE TO A WAVE IS LESS THAN 75
C*       METERS, THE WAVE IS CONSIDERED TO HAVE REACHED A
C*       COVERED AND CONCEALED POSITION ON THE BEACH
C*
      IF((WVRNG.GT.TENGMX).OR.(CSURV(I).LT.0.05).OR.
     1(WVRNG.LT.75.) .OR.(JT.GE.2)) GO TO 50
      JT=JT+1
      TENG(JT)=I
      TWTS(JT)=DEFWTS(JT)*CSURV(I)
      TSUM=TSUM+TWTS(JT)
      TRNG(JT)=WVRNG
   50 IF((WVRNG.GT.SENGMX).OR.(CSURV(I).LT.0.05).OR.
     1(WVRNG.LT.SENGMN) .OR.(JS.GE.2)) GO TO 100
      JS=JS+1
      SENG(JS)=I
      SRNG(JS)=WVRNG
      SWTS(JS)=DEFWTS(JS)*CSURV(I)
      SSUM=SSUM+SWTS(JS)
  100 CONTINUE
      IF(TENG(1).EQ.0) GO TO 500
      DO 200 I=1,2
      TWTS(I)=TWTS(I)/TSUM
  200 CONTINUE
  500 IF(SENG(1).EQ.0) RETURN
      DO 600 I=1,2
      SWTS(I)=SWTS(I)/SSUM
  600 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE DATAIN
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,WVINT(5),WID,
     1TBW,DINIT(2)
      COMMON /ENGR/ SPDMAX,SPDMIN,HTMAX,HTMIN,TTS,TA,TB,TF
      COMMON /DISPER/TSIGV(6,2),TSIGH(6,2),TMEANH(6,2),
     1SSIGV(7,2), SSIGH(7,2)
      COMMON /DEF/TENGMX,SENGMX,SENGMN,TARTM,SARTM,TVEL,
     1SVEL,DEFWTS(2)
      COMMON /IOUT/ISURV,IATTR
      READ(1,50) ISURV,IATTR
      READ(1,100) SPDMAX,SPDMIN,HTMAX,HTMIN,WID
      READ(1,100) TTS
      READ(1,100) TENGMX,SENGMX,SENGMN
      READ(1,100) TARTM,SARTM,TVEL,SVEL
      READ(1,100) ((TSIGV(I,J),I=1,6),J=1,2)
      READ(1,100) ((TSIGH(I,J),I=1,6),J=1,2)
      READ(1,100) ((TMEANH(I,J),I=1,6),J=1,2)
      READ(1,100) ((SSIGV(I,J),I=1,7),J=1,2)
      READ(1,100) ((SSIGH(I,J),I=1,7),J=1,2)
      READ(1,100) (DEFWTS(I),I=1,2)
      READ(1,100) (WVINT(I),I=1,5)
      READ(1,100) (DINIT(I),I=1,2)
      READ(1,101) (A(I),I=1,2)
      READ(1,101) (B(I),I=1,2)
      READ(1,101) (WB(I),I=1,2)
   50 FORMAT(2I5)
  100 FORMAT (7F10.3)
  101 FORMAT(2F10.5)
      RETURN
      END
```

```
      SUBROUTINE OUTPUT
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,WVINT(5),WID,
     1TBW,DINIT(2)
      COMMON /DISPER/ TSIGV(6,2),TSIGH(6,2),TMEANH(6,2),
     1SSIGV(7,2), SSIGH(7,2)
      COMMON /ENGR/ SPDMAX,SPDMIN,HTMAX,HTMIN,TTS,TA,TB,TF
      COMMON /DEF/TENGMX,SENGMX,SENGMN,TARTM,SARTM,TVEL,
     1SVEL,DEFWTS(2)
C*
C*****   INPUT SUMMARY PRINTOUT
C*
      WRITE(6,20)
   20 FORMAT('1*****INPUT SUMMARY*****',
     1'***SEQUENTIAL WAVE TRANSITION',/)
      WRITE(6,22) (WVINT(I),I=1,5),(DINIT(I),I=1,2)
   22 FORMAT(//,' INITIAL FORCE STRENGTHS:',/,'LVA
     1(WAVES 1-5) = ', 5F8.2,/,' DT = ',F8.2,
     2/,' DS = ',F8.2)
      WRITE(6,25) SPDMAX,SPDMIN,HTMAX,HTMIN,WID
   25 FORMAT(//,' ENGR SPECS.',/,' SPDMAX = ',F6.3,' SPDMIN
     1 = ',F6.3,/, 'HTMAX = ',F6.3,'    HTMIN = ',F6.3,/,
     1 ' WID  =  ',F6.3)
      WRITE(6,630) TENGMX,SENGMX,SENGMN
  630 FORMAT(//,' DEFENSIVE TACTICAL PARAMETERS',/,
     1'TANK MAX. ENGAGEMENT RANGE = ',F10.2,/,'ATGM MAX
     2ENGAGEMENT RANGE = ', F10.2, ' ATGM MIN ENGAGEMENT
     3RANGE = ',F10.2)
      WRITE(6,31) TARTM,SARTM,TVEL,SVEL
   31 FORMAT(' TANK AIM-RELOAD TIME = ',F10.2,/,
     1'ATGM AIM-RELOAD TIME = ',F10.2,/,' TANK PROJECTILE
     3VELOCITY = ',F10.2,/,' ATGM PROJECTILE VELOCITY = ',
     4F10.2)
      WRITE(6,50) DEFWTS(1),DEFWTS(2)
   50 FORMAT(//,' DEFENSIVE TACTICAL ALLOCATION WEIGHTS:',
     1/,'  WAVE 1 = ',F5.2,'    WAVE 2 = ',F5.2)
      WRITE(6,100) A(1),B(1),A(2),B(2),WB(1),WB(2)
  100 FORMAT(//,' DEFENSIVE FORCE ATTRITION COEFFICIENTS:',
     1 /,16X,'    ALPHA*A        ','        BETA*A',/,
     2 '    DT',6X,2F15.5,/,3X,'DS',6X,2F15.5,/,
     2 ' WBETA(1)= ',F10.5,'      WBETA(2)= ',F10.5,/,
     3 '   BREAKPOINT ASSUMPTION: 0.3*(TOTAL DEF FORCE)')
C*
C*****   DISPERSION DATA PRINTOUT
C*
      IDISP=0
      IF (IDISP.EQ.0) RETURN
      WRITE(6,601)
  601 FORMAT('1DISPERSION DATA',/,'    RANGE    STD DEV ERR.',
     1/,' TSIGV')
      WRITE(6,600)      ((TSIGV(I,J),J=1,2),I=1,6)
      WRITE(6,602)
  602 FORMAT('0TSIGH')
      WRITE(6,600)       ((TSIGH(I,J),J=1,2),I=1,6)
      WRITE(6,603)
  603 FORMAT('0TMEANH')
      WRITE(6,600)      ((TMEANH(I,J),J=1,2),I=1,6)
      WRITE(6,604)
  604 FORMAT('0SSIGV')
      WRITE(6,600) ((SSIGV(I,J),J=1,2),I=1,7)
      WRITE(6,605)
  605 FORMAT('0SSIGH')
      WRITE(6,600) ((SSIGH(I,J),J=1,2),I=1,7)
  600 FORMAT(1X,2F10.3)
  650 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE PHIT(RANGE,W,H,IWPN,SUPFAC,PRHIT)
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,Q(5),WID,
     1TBW,DINIT(2)
      COMMON /DISPER/TSIGV(6,2),TSIGH(6,2),TMEANH(6,2),
     1SSIGV(7,2), SSIGH(7,2)
C*
C*****   IWPN CODE:  TANK = 1    ATGM = 2
C*
C*
C*****   VARIABLE DEFINITIONS
C*
C*       TSIGH - THE STD DEV ERROR IN THE HORIZONTAL FOR TANK
C*
C*       TSIGV - THE STD DEV ERROR IN THE VERTICAL FOR TANK
C*
C*       TMEANH - THE BIAS ERROR IN THE HORIZONTAL FOR TANK
C*
C*       TMEANV - THE BIAS ERROR IN THE VERTICAL FOR TANK
C*
C*****   SSIGV/SSIGH - SIMILAR INTERPRETATIONS FOR THE ATGM
C*
      PI=ARCOS(-1.0)
      IF(RANGE.LT.25.) STOP
      IF(IWPN.EQ.1) GO TO 50
C*
C*****   ATGM FIRING DATA COMPUTATIONS
C*
      WMEANH=0.0
      WMEANV=0.0
      CALL INTRP(SSIGV,RANGE,WSIGV,7)
      CALL INTRP(SSIGH,RANGE,WSIGH,7)
      GO TO 100
C*
C*****   TANK FIRING DATA COMPUTATIONS
C*
   50 WMEANV=0.0
      CALL INTRP(TMEANH,RANGE,WMEANH,6)
      CALL INTRP(TSIGV,RANGE,WSIGV,6)
      CALL INTRP(TSIGH,RANGE,WSIGH,6)
C*
C*****   CONVERSION TO MILS
C*
  100 Z=ARSIN(H/RANGE)
      WSIGV=SUPFAC*WSIGV
      WSIGH=SUPFAC*WSIGH
      TGTH=(Z*6400.0)/(2.0*PI)
      TGTW=(ARSIN(W/RANGE))*(6400.0/(2.0*PI))
C*
C*****   INSTITUTE NORMALITY ASSUMPTIONS TO COMPUTE HOR
C*****   AND VER HIT PROBABILITIES
C*
      C=-1.0*SQRT(1./2.)
      HOR1=((TGTW/2.)-WMEANH)/WSIGH
      HOR2=(((-1.0*TGTW)/2.0)-WMEANH)/WSIGH
      PHITX=1.0
      IF(ABS(HOR1).GT.8.) GO TO 810
      PHITX=0.5*(ERFC(C*HOR1)-ERFC(C*HOR2))
  810 VER1=((TGTH/2.)-WMEANV)/WSIGV
      VER2=(((-1.0*TGTH)/2.)-WMEANV)/WSIGV
      PHITY=1.0
      IF(ABS(VER1).GT.8.) GO TO 820
      PHITY=0.5*(ERFC(C*VER1)-ERFC(C*VER2))
  820 PRHIT=PHITX*PHITY
      RETURN
      END
```

```
      SUBROUTINE INTRP(X,ARG,VAL,N)
      DIMENSION X(N,2)
      IF(ARG.LT.X(1,1))     GO TO 500
      DO 50 I=1,N
      IF(ARG.GT.X(I+1,1)) GO TO 50
      DIFF=X(I+1,1)-X(I,1)
      DELTA=ARG-X(I,1)
      VAL=X(I,2)+(DELTA/DIFF) *(X(I+1,2)-X(I,2))
      RETURN
   50 CONTINUE
      IF(ARG.GT.X(N,1)) GO TO 600
      VAL=X(N,2)
      RETURN
  600 WRITE(6,601)
  601 FORMAT(' ERROR IN INTRP ARG.GT.X(N,2)')
      STOP
  500 WRITE(6,501)
  501 FORMAT(' ERROR IN INTRP ARG.LT.X(1,1)')
      STOP
      END
```

```
      SUBROUTINE RATE(RANGE,SPEED,IWPN,SUPFAC,ROF)
      COMMON /DEF/TENGMX,SENGMX,SENGMN,TARTM,SARTM,TVEL,SVEL
      ROF=0.0
      IF(RANGE.LT.25.) RETURN
      IF(IWPN.EQ.2) GO TO 500
      IF(RANGE.GT.TENGMX) RETURN
      TRTM=TARTM*(0.5+SUPFAC/2.0)
      DT=TRTM+RANGE/(TVEL+SPEED)
      ROF=1.0/DT
      RETURN
  500 IF(RANGE.GT.SENGMX)RETURN
      IF(RANGE.LT.SENGMN)RETURN
      SRTM=SARTM*(0.5+SUPFAC/2.0)
      DT=SRTM+RANGE/(SVEL+SPEED)
      ROF=1.0/DT
      RETURN
      END
```

```
C*
C*****   IN THE FUNCTIONS HT, SPD AND RNG THE ARGUMENT T
C*       IS THE TIME SINCE THE WAVE BEING ADDRESSED
C*****   CROSSED THE 5000 METER OFFSHORE MARK
C*
```

```
      FUNCTION SPD(T)
      COMMON /ENGR/ SPDMAX,SPDMIN,HTMAX,HTMIN,TTS,TA,TB,TF
      IF(T.GT.TA) GO TO 50
      SPD=SPDMAX
      RETURN
   50 IF(T.GT.TB) GO TO 100
      SPD=SPDMIN+((TB-T)/TTS)*(SPDMAX-SPDMIN)
      RETURN
  100 SPD=SPDMIN
      RETURN
      END
```

```
      FUNCTION HT(T)
      COMMON /ENGR/ SPDMAX,SPDMIN,HTMAX,HTMIN,TTS,TA,TB,TF
      IF(T.GT.TA) GO TO 50
      HT=HTMAX
      RETURN
 50   IF(T.GT.TB) GO TO 100
      HT=HTMIN+((TB-T)/TTS)*(HTMAX-HTMIN)
      RETURN
100   HT=HTMIN
      RETURN
      END
```

```
      FUNCTION RNG(T)
      COMMON IL(5),WB(2),A(2),B(2),ITE,ISE,RD,Q(5),WID,
     1TBW,DINIT(2)
      COMMON /ENGR/ SPDMAX,SPDMIN,HTMAX,HTMIN,TTS,TA,TB,TF
      IF(T.GT.TA) GO TO 50
      RNG=5000.0-(SPDMAX*T)
      RETURN
 50   IF(T.GT.TB) GO TO 100
      RNG=RD-0.5*(T-TA)*(SPDMAX+SPD(T))
      RETURN
100   RNG=RD-(((TB-TA)/2.0)*(SPDMIN+SPDMAX))-((T-TB)*SPDMIN)
      IF(RNG.LT.75. ) RNG=0.0
      RETURN
```

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