HARD/SOFT KILL EFFECTIVENESS IN A MULTI-SHIP ENVIRONMENT

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• with thanks to LT Cengiz Sengel, Turkish Navy & LT Douglas Otte, United States Navy

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--1.

At the October SWG/4 meeting I described an approach to modeling EW effectiveness, and I'll review that approach in a moment. As a result of the discussions that followed my presentation it was decided to investigate the feasibility of applying that approach to the types of Battle Group formations of interest to NATO, using a realistic data base. In particular, it was decided to approximate the Surface Action Group (SAG) type configuration used in recent NATO EW exercises.

This required that we take an existing, generic approach that seemed to have some appealing elements and determine what modeling assumptions were still appropriate for a 5 ship SAG consisting of specific ships having specific hard and soft kill assets. A data base was required to feed the modified modeling effort and we needed to determine what realistic data was readily available. Following a description of the general modeling approach for the benefit of those people not present at the October meeting, I'll return to these issues.

The original conceptual approach and computer model were developed with the help of Lt. Cengiz Sengel of the Turkish Navy who graduated this past September. The application to a 5 ship SAG is being pursued with the help of Lt. Douglas Otte of the US Navy as his Master's thesis in Operations Analysis. I'll begin by reviewing the general approach that we're taking.

Our original analysis focused on determining the effectiveness of expendable decoys deployed from ships. Along with Hard Kill assets these decoys defend against incoming missiles, e.g. anti-ship cruise missiles (ASCM's). However, the analysis could apply to any Electronic Warfare (EW) assets that might divert an incoming missile; such diversion possibly being onto a neighboring friendly ship.

When I speak of "**Effectiveness**" I mean an appropriate higher level measure of effectiveness (MOE) for the battle group (BG), not just maximizing single ship survivability. The emphasis is on cooperative planning, deployment and tactics; not each ship for itself; and the choice of MOE must reflect that.

Finally, by multi-ship environment I mean a battle group: on the order of 5 to 15 ships, possibly with 1 or 2 high value targets, carriers or battleships, near its center; or possibly up to 50 ships in an amphibious landing force.

The emphasis is on the "**nonlinearities**" of ship-missile-ship interactions, not just one ship N times, <u>plus</u> the spatial/geometric relations of the ships.

--2.

Originally, our objectives for the the study included trying to see "how serious is the EW/high-density problem?" An important aspect of that problem requires some method to evaluate the diversion of ASCM's, by decoys or some other EW assets, onto neighboring ships, i.e. "reverse seduction". To what extent does decoy effectiveness degrade with an increasing number, N, of ships in the Battle Group, or with an increase in the density of ships?

We also need to determine the appropriate Battle Group Measures of Effectiveness. Even if all ships had the same value (not, in fact, the case), it's likely that a myopic strategy of each ship trying to maximize its own probability of survival would not result in the best tactics from the point of view of a higher level MOE for the Battle Group, because of the interactions among the ships, for example reverse seduction. We anticipate a need for more **cooperative** tactics with respect to Electronic Warfare Assets, and for their optimum integration with Hard Kill Assets. To develop such tactics requires that we better understand the multi-ship interactions.

Hence, to investigate "how tacticians and decision makers should think about the problem", we developed a multi-ship ASCM attack model. Although it is a computer model, the emphasis was on physical, operational, and conceptual modeling of the situation, rather than computations. When the model is sufficiently validated, the ultimate goal is to use the model, and insights and intuition gained from its development, to compare alternative employment tactics, especially hard-kill/soft-kill (HK/SK) trade-offs.

-- sensitivity studies can help identify driving system parameters such as inter-ship distance, reaction rates, etc.

-- optimization studies and trade-off analyses for tactics will also be carried out.

--3.

The objective was NOT intended to calculate "the answer" i.e. to make specific optimum decisions.

We were not trying to maximize the realism of the model. We did not want a highly detailed simulation of specific EW and other relevant assets. Rather, we wanted to capture the essential features of generic EW assets in a multi-ship environment.

We did not want to assess individual weapons systems nor predict the outcome of an ASCM attack. We did not even try to develop a model to actually determine the optimum mix of decoys and hard kill assets.

What the modeling effort WAS intended to do was to be an aid to thinking about alternatives. "How to think about the nonlinear interactions among ships caused by ASCM's when EW is present".

I was thus, originally, seeking a transparent model, using back-of-the-envelope type of thinking. I wanted to maximize communication and facilitate discussion of the problem by increasing our "vocabulary" and thereby our ability to visualize the situation. To develop our intuition and understanding of how the Battle Group differs from the single ship case when EW is employed, and to understand the interactions between hard and soft kill assets, we must back up, to a sufficient distance from the Battle Group, so that we model it from a high enough level of aggregation that single ships are represented by just a few parameters, but so that we retain the spatial features of the Battle Group configuration, e.g. distances between them.

--4. Sometimes it helps in understanding a problem to look at extreme cases. One extreme is when there is just one ship present, i.e., N=1. In that case a truly successful diversion is as good as a hard kill. In some sense SK=HK in effectiveness if the soft kill <u>really</u> sends the missile off into the open ocean or causes it to splash. Here the MOE could reasonably be, simply survival probability of the single ship.

In the <u>opposite</u>, <u>high</u> density, limit where the number of ships, N, is a large number, the diversion from one ship is still sufficient if the missile splashes as a result. Presumably that is not always the case, however. Of course, it is also true that the decoys may buy time in which the hard kill assets may act. However, without a HK or a splash, the missile will <u>repeatedly</u> find new targets until it eventually hits a ship. (assuming of course, the missile reliability = 1, it does not run out of fuel, and it tries to lock onto the nearest ship within its beam width). Hence, in the absence of HK capabilities, SK may be much less effective.

These sorts of considerations lead me to ask:

1. Is the outer edge of the BG similar to the low density case? i.e. diversion of a missile may be onto the open ocean, implying decoys may be relatively more effective than they are near the center of the BG.

   -- does this imply that ships near the edge of the BG should carry relatively more decoys and less HK assets than those near the center?

2. Is the center of the BG similar to the high density extreme? Decoys might be relatively less effective because diverted missiles may be more likely to find alternate targets before leaving the BG area. Does <u>this</u> imply that ships near the center of the BG should have relatively <u>more</u> <u>HK</u> assets and <u>less</u> decoys?

Of course, the presence of <u>high</u> <u>value</u> carriers or battleships near the center will have to be factored into these analyses.

Questions: Can we develop a model to answer these sorts of questions or at least to help us think about them?

Can such a model help determine a near optimal mix of HK/SK assets as a function of the number of ships (N), the ship density (rho), the distance of a ship from the center of the BG, etc.?

--5. To think about the problem, and to help us to <u>abstract</u> from the real situation the minimal, essential features of multi-ship interactions in defense against ASCM attack, consider an idealized battle group.

The battle group consists of N ships within a, possibly irregular, area A. There is a carrier or battleship near the center. The ship density is rho = N/A (ships per unit area). The ships could be somewhat randomly distributed in the area A. Rather than the ships being randomly placed independently of each other, it seems more reasonable to assume that they try to stay apart from each other, especially when in an alert status. For ease of modeling, as a first approximation suppose the ships form a lattice, as pictured here. We will relax this somewhat, later. From the figure you can see that each ship might be thought of as being within a square of area A/N. A side of the square is then SQRT (A/N). It is easy to see that this is also the distance between ships. Now, missiles may come from any direction, as indicated by the arrows. Consider one missile trajectory as it traverses the battle group (assuming it is successfully diverted and not shot down). If the potential path length within the battle group is the random variable, L, then the maximum number of possible encounters of that missile with ships is approximately L/SQRT (A/N).

--6. Actually, since the attack may come from any direction, it is reasonable to suppose that the battle group configuration will have circular symmetry. We now relax somewhat our requirement that the ships are located on the intersections of the vertical and horizontal lines. Assuming, without any loss of generality, that the attack comes from the left, we allow the ships to be randomly placed on the vertical lines. Hence, a missile may find no ships within its beam width during an encounter with a particular line.

We assume a missile's vertical offset from the middle of the battle group (i.e. its closest point of approach, CPA, to the center or CV) is uniformly distributed between 0 and r, the radius of the battle group. L, the path length through the battle group, will correspondingly vary between 2r (the diameter of the battle group) and 0. From our formula for the number of possible ship-missile encounters we see that n will vary between 1 (we do not consider missiles that miss the battle group completely) and 2r times the square-root of N/A. Using the area of a circle for A we see that n lies between 1 and 2*SQRT(N/PI).

Rounding off n to integer values, it is straight-forward to derive the probability distribution for the number of possible encounters a missile might have with ships. (and hence also the number of possible reverse seductions).

--7. This figure shows the probability distribution for N = 14 ships. The dotted line is the continuous probability density function for n before it is rounded off. The black circles show the corresponding probabilities for the integer valued random number of possible encounters.

For example, for a 14 ship battlegroup, there is approximately a 25% chance that a given missile will traverse the battle group at an offset yielding 3 possible encounters with ships.

Note that this probability distribution depends only on N. It only applies when the seeker locks onto the nearest ship.

A more realistic analysis including the missile range will yield a distribution depending on both N and A (the battle group area).

-- 8. Consider the sequence of events for a single missile encountering the battle group. This can be described with the use of a probability tree.

Depending on the missile offset from the middle of the BG, there will be a maximum number of possible encounters with ships (as we just discussed).

For instance, if the closest point of approach is such that there will be three possible encounters with ships, the system evolves along this branch of the probability tree. Each black ellipse represents a possible encounter with a ship (the details are presented on the next viewgraph)

As a result of each possible encounter, there are three possible outcomes:

1) The ship may be hit.
2) The missile may be destroyed ("hard kill")
or 3) The missile may be diverted or fail to encounter a ship at that " line of ships".

Truly successful diversion requires three diversions in a row, or 1 or 2 diversions followed by a hard kill.

Note:

> The detailed calculations may be different in each ellipse: there might be varying levels of HK and SK levels as a function of ship position within the battle group.

-- 9. Now, let us look at an expanded view of the solid ellipses at each node. Looking at the details, we see it as a sub-probability tree describing what may happen as the missile traverses a distance on the order of $\sqrt{A/N}$.

Let us follow just one path along this tree, as a missile "arrives at a line" of ships (i.e. traverses $\sqrt{A/N}$ distance) a ship may or may not fall within the missile seeker head's beamwidth.

If there is at least one ship within the beam width, the missile may be diverted successfully by distraction decoys.

If the missile is Not distracted, there may be a chance that a seduction decoy is effective.

If the seduction <u>fails</u>, perhaps the missile will be shot down by the HK assets.

If all these defenses fail, then we assume the ship is hit.

There is only one terminal node here where the ship is hit, six paths lead to "missile kill" and three paths lead to diversion.

There is a conditional probability for each segment of the tree which may depend on position in the battle group, number of missiles already handled, etc.

- We will follow <u>one</u> path on the next viewgraph.

-- <u>10.</u> Now, for the <u>simplest</u> model for some of these conditional probabilities, which is the one we have already developed a computer code for, let us look at the probability a ship is hit in <u>one</u> encounter. (This is the probability of just <u>one</u> of the paths in the sub-tree we just discussed).

- two alpha is the beam width of the missile seeker
- the distance traversed before encountering the next line of ships is $\sqrt{A/N}$
- the line density of ships is $\sqrt{N/A}$
- hence, a simple, approximate analysis yields $1-e^{-2\alpha}$ for the probability that at least one ship lies within the missile beam width. (a target is acquired)

Combining this with other simple models for probabilities of branching in the sub-tree, we obtain the probability a ship is hit in a given layer. It is the product of:

1) the probability a target is acquired
2) the probability the missile is not shot down
3) the probability distraction decoys fail

D = number of distraction decoys deployed per ship per missile.

Q = Quality factor or effectiveness of a distraction decoy (OC RCS)

and 4) the probability the seduction decoys fail where,

B = probability of break lock by seduction decoy during homing phase

MS = number of seduction decoys

11. The sensitivity diagrams are not of much significance yet because

1) we used made up numbers for decoy and HK parameters

2) we used the simplest possible models for each sub-tree calculation to develop the overall architecture of the model.

3) we did not have full access to realistic exercise scenarios or data.

I now have a U.S. Navy officer working on extending the model as part of his master's thesis in operations analysis.

We will model some aspects analytically as before, but will consider Monte Carlo simulation for other aspects where needed to enable us to include more realistic scenarios and models of EW or Close In Weapons Systems (CIWS), as needed.

12.

We have endeavored to apply our concepts to a more realistic situation using real, and to some extent validated, numbers for hard and soft kill asset performance. In particular, we wanted to choose a specific multi-ship formation to model, so we are using as our baseline a 5 ship Surface Action Group formation used in a recent NATO Sea Trial. This serves to define specific hard kill assets available for defense, such as NATO Sea Sparrow missiles, medium and extended range SAM's, 76mm and 5"54 gun systems as well as close in weapon systems (CIWS), the latter available on each ship. In addition, the ships all have mk36 decoy launching systems for chaff deployment.

Eventually we want the model to deal with both sea skimming missiles, for which reverse seduction might be an important consideration, as well as high dive angle missiles, for which reverse seduction is unlikely. Similarly, warheads targeting on either near or far ships within a certain range are possible. Again, to be definite, we have made a specific assumption, initially, that we will deal with high dive angle missiles targeting on the closest ship.

A decision was made not to try to model this formation exactly, to the extent of devising a detailed simulation model that flys individual missiles through the physical formation. Such models are already available, although they often don't integrate EW completely with Hard Kill factors. We felt that it was useful to retain the same general concepts and level of abstraction that I've just described, so that the model, and the "lessons learned" would be more generally useful in developing a "conventional wisdom" about hard-kill/soft-kill interactions. Hence, what we are doing is to use this specific formation to determine distances, missile ranges and overlapping coverages, assets of targeted and non-targeted ships, etc. to input into our more generic, abstract model. The computer code we are now in the process of developing is driven both by the demands of a realistic scenario and data base, as well as the demands of our conceptual model.

13.

This summarizes some of our initial assumptions. We assume that the threat originates from a single direction, although this is clearly something we'd like to modify later. We will first deal with active missiles rather than anti-radiation missiles. There is no blue air defense available for this attack. The threat sector is assumed known, and the incoming missiles are detected and identified at 50 NM.

14.

Because our model is now driven by specifications for the particular SAG we just showed, one of the first tasks has been to identify sources for the data base, consistent with our evolving model. What is required needs to match what is available. This puts some constraints on how we define performance parameters in our model.

This table shows some of the sources of data we are using in formulating our data base.

Finally, let me just reiterate that this work-in-progress is directed towards an appropriate systems and operations analysis of hard kill and soft kill effectiveness when more than one ship is present, rather than a detailed engineering-level analysis. The hope is that by our choice of modeling strategy we will capture important aspects of the interactions of hard/soft kill assets even though (or even <u>because</u>) we neglect many of the details of this complex system.

OBJECTIVES OF THE STUDY

- EVALUATE ASCM DIVERSION ONTO NEIGHBORING SHIPS

  -- DOES DECOY EFFECTIVENESS DEGRADE WITH N?

  -- DETERMINE APPROPRIATE BG MOEs

  -- DEVELOP MULTI-SHIP ASCM ATTACK MODEL

  -- COMPARE EMPLOYMENT TACTICS, HK/SK TRADE-OFFS

OBJECTIVES OF THE STUDY (continued)

- **NOT** INTENDED TO
  - -- ASSESS INDIVIDUAL WEAPONS SYSTEMS
  - -- PREDICT OUTCOME OF AN ASCM ATTACK
  - -- DETERMINE OPTIMUM MIX OF DECOYS, HK ASSETS ...
- **IS** INTENDED TO
  - -- DEVELOP INTUITION, UNDERSTANDING OF HOW BG DIFFERS FROM SINGLE SHIP CASE

CONSIDER THE EXTREME CASES

- ONE SHIP (N = 1): SUCCESSFUL DIVERSION AS GOOD AS HK

  MOE IS PROBABILITY SHIP SURVIVES

- HIGH DENSITY LIMIT (N LARGE): DIVERSION FROM ONE SHIP OK IF

  MISSILE SPLASHES

  DECOYS ALSO USEFUL IN ALLOWING

  HK ASSETS TIME TO ACT

  w/o HK OR SPLASH MISSILE WILL

  EVENTUALLY HIT A SHIP

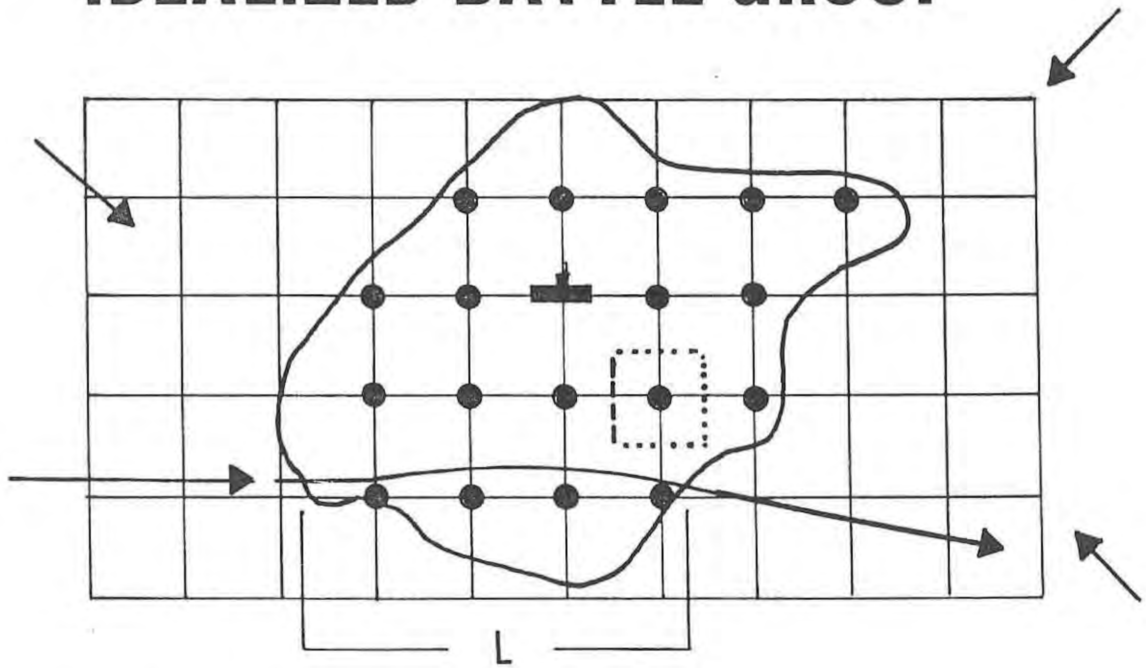
- IS OUTER EDGE OF BG SIMILAR TO LOW DENSITY CASE?

  --MORE DECOYS, LESS HK?

  CENTER OF BG SIMILAR TO HIGH DENSITY CASE?

  --MORE HK, LESS DECOYS?

IDEALIZED BATTLE GROUP



- NUMBER OF SHIPS, **N** = 19

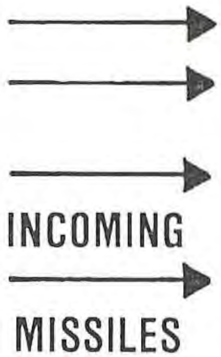
  BG AREA = A

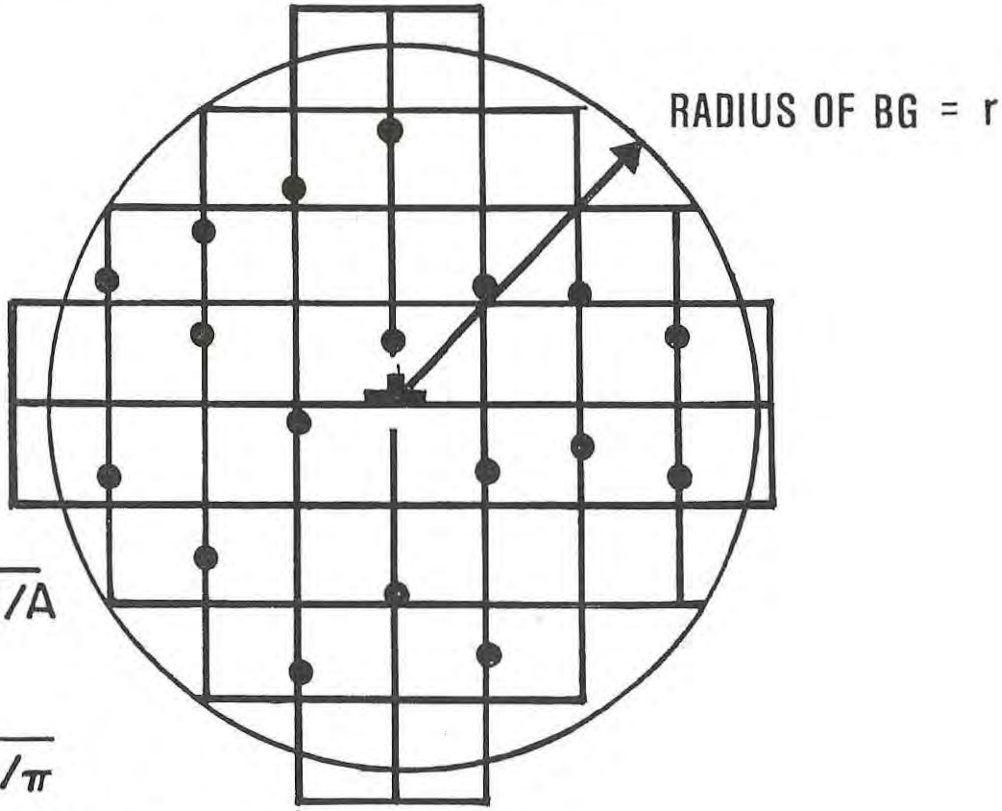
  SHIP DENSITY, ρ = N/A

- APPROXIMATE DISTANCE BETWEEN SHIPS = $\sqrt{A/N}$

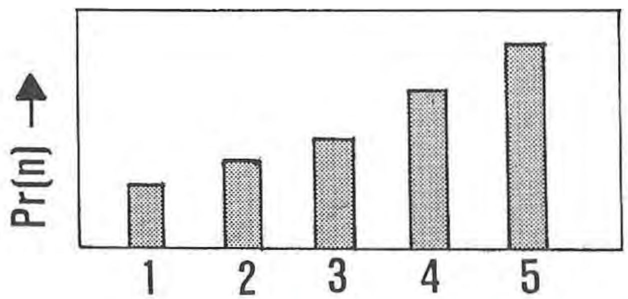
  NUMBER OF ENCOUNTERS WITH SHIPS/MISSILES, **n** = $\frac{L}{\sqrt{A/N}}$

ATTACK ORIGINATES FROM RANDOM BEARING

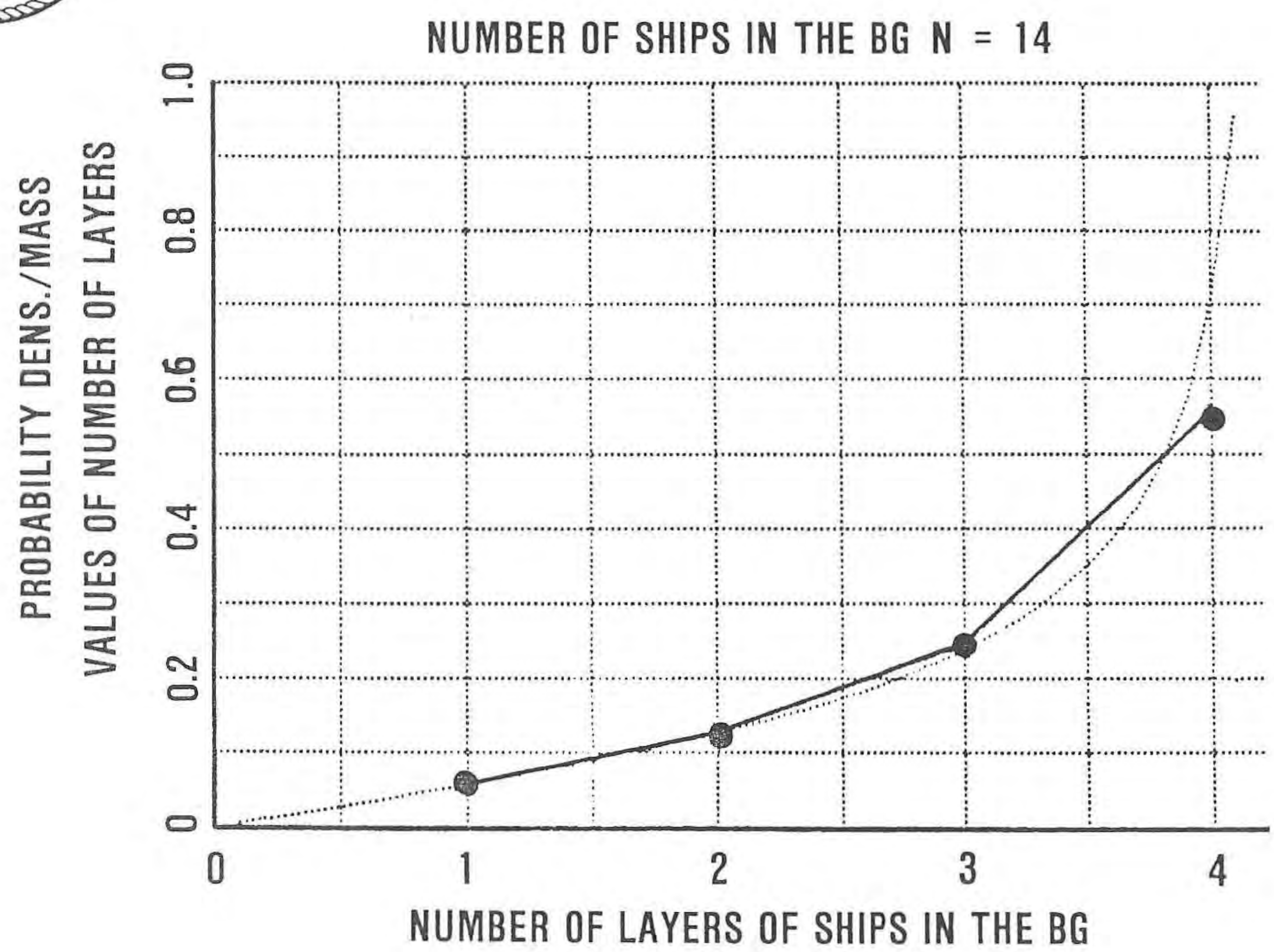




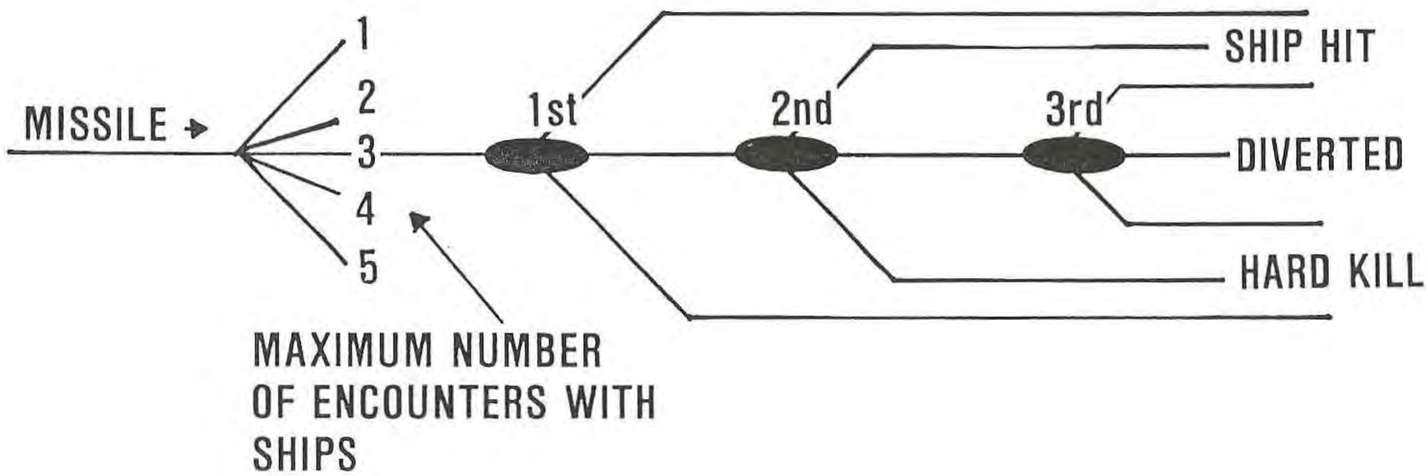
- $1 \leq n \leq 2r\sqrt{N/A}$
  $A = \pi r^2$
  $1 \leq n \leq 2\sqrt{N/\pi}$
- LET MISSILE CPA BE U(0, r)
  n = RANDOM VARIABLE
  ROUND(n) = NUMBER OF SHIPS ENCOUNTERED PER MISSILE



PROBABILITY MASS FUNCTION



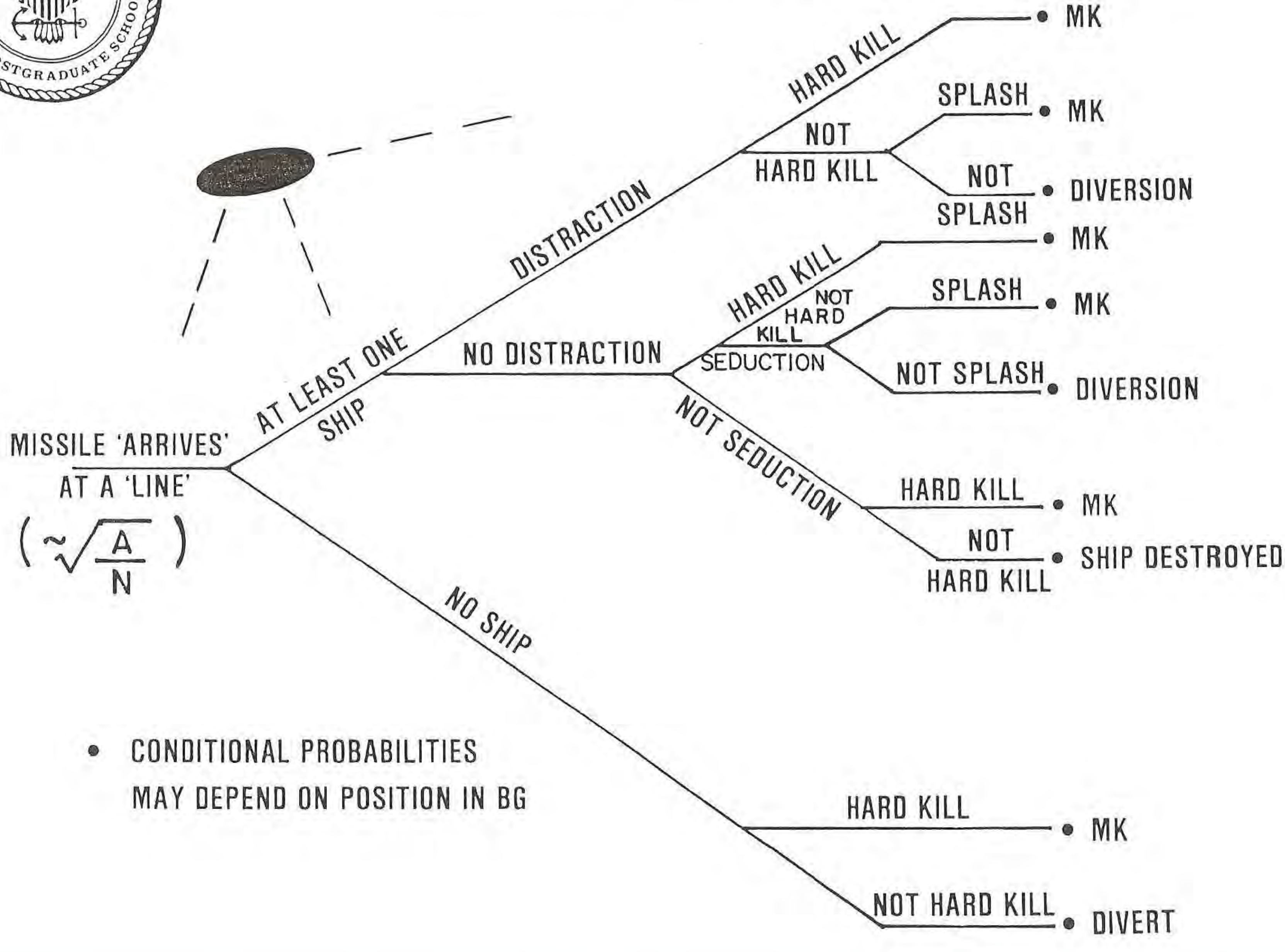
MODEL LOGIC:
PROBABILITY TREE OUTLINE



- ANALYTIC MODEL -- NOT A MONTE CARLO SIMULATION
- RAPID CALCULATIONS FOR: SENSITIVITY STUDIES

  OPTIMIZATION (s.t. CONSTRAINTS OF COST, CAPACITY)

SUB-TREE: MISSILE TRAVERSES $\sqrt{A/N}$



- CONDITIONAL PROBABILITIES MAY DEPEND ON POSITION IN BG

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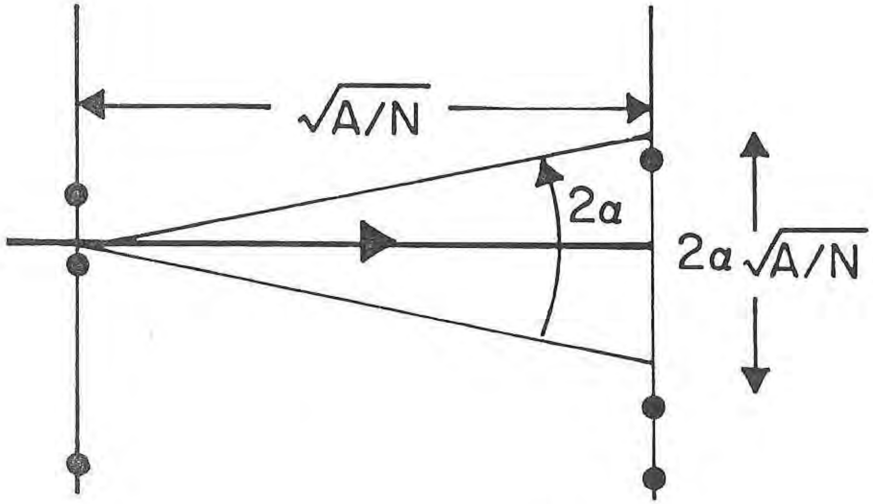
AN EXAMPLE CALCULATION

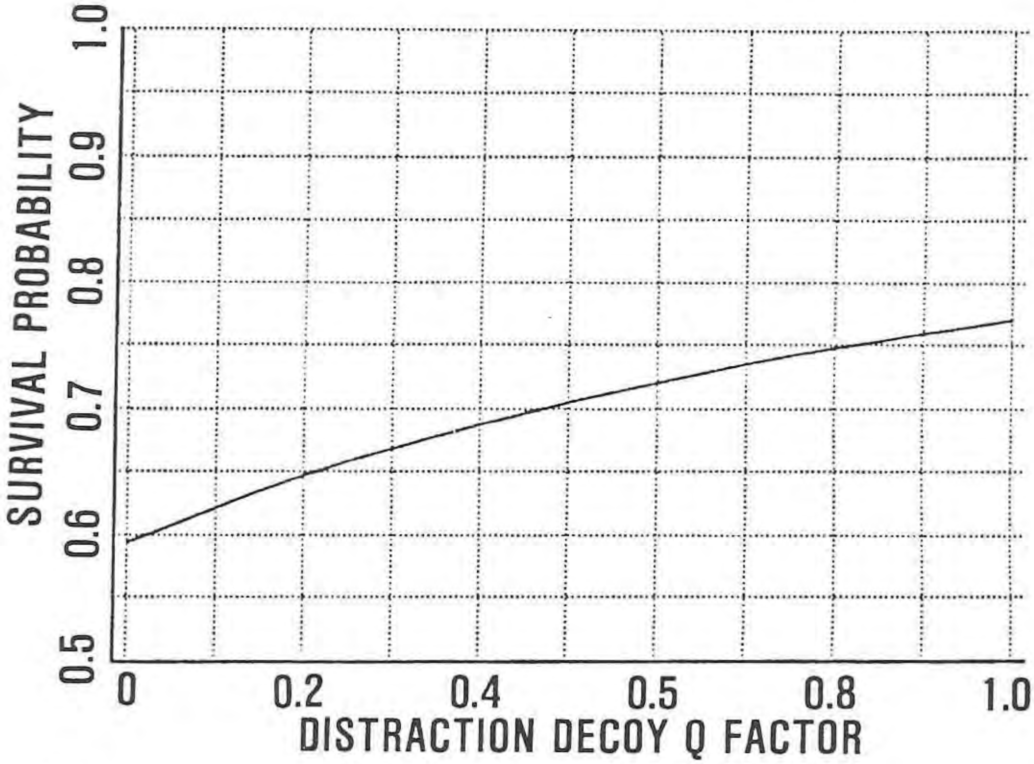


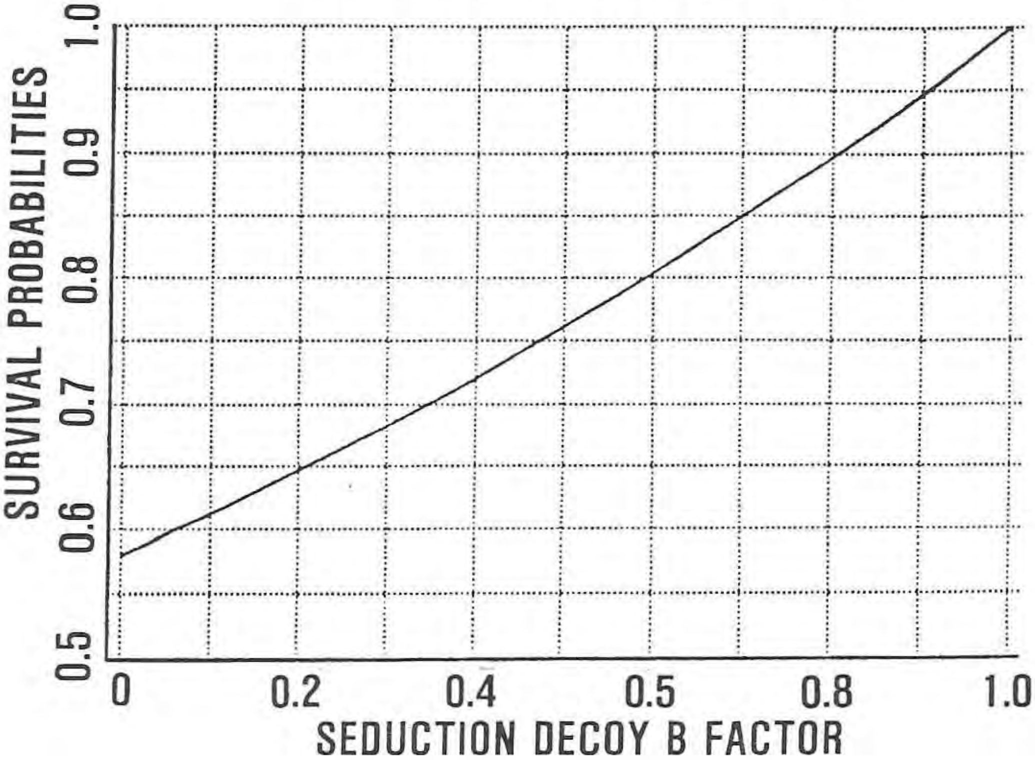
$$\rho_{line} = \sqrt{N/A}$$

- P_r [0 ships in missile beam-width] $\propto \exp\{-2\alpha\}$

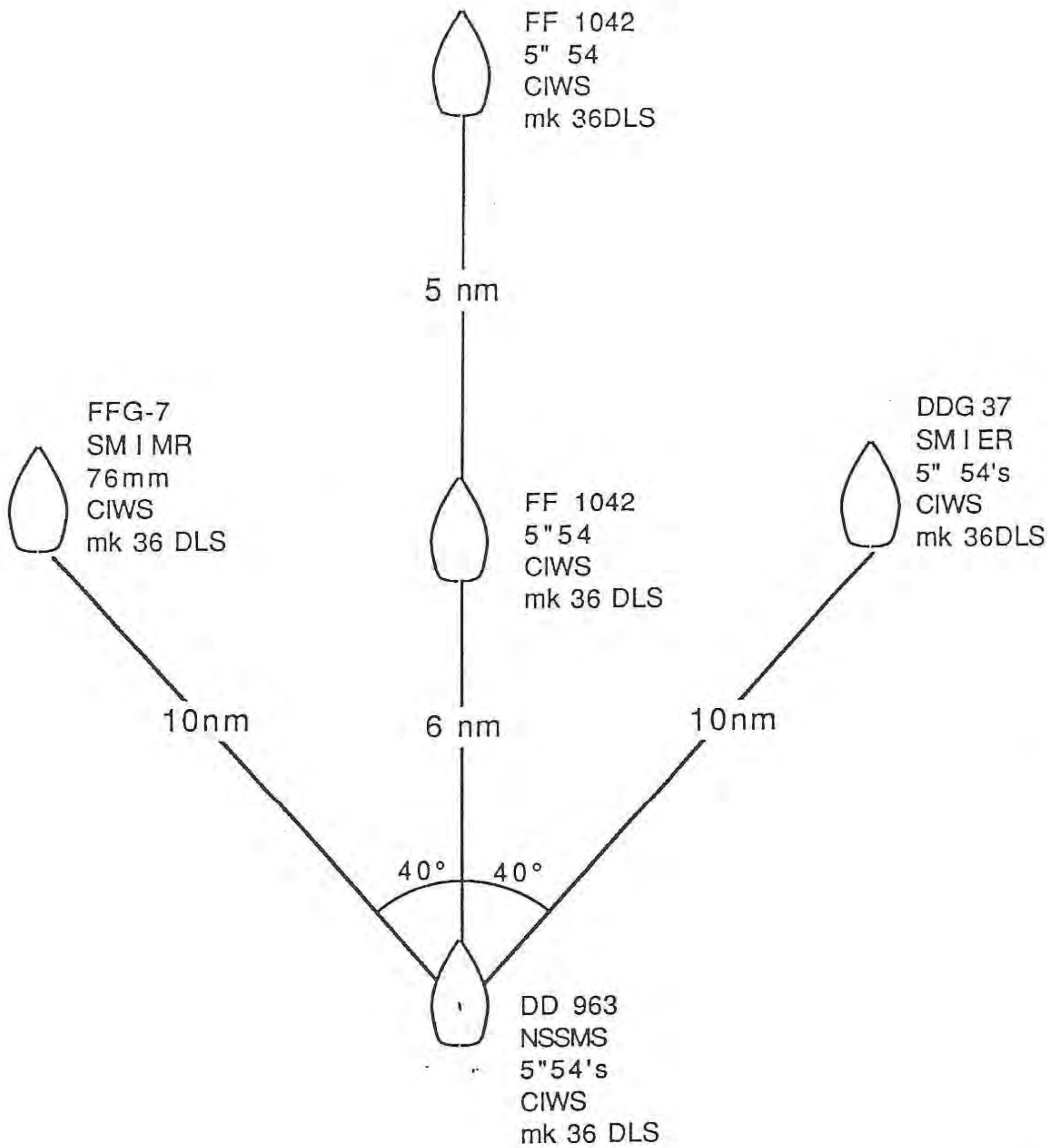
- P_r [missile hits ship/layer] $\propto (1-\exp\{-2\alpha\})(1-P_{hk})\frac{1}{1+QD}(1-B)^{m_s}$

SURVIVABILITY OF THE BG vs DECOY EFFECTIVENESS





NATO EW TRIALS: FORMATION



ASSUMPTIONS BEING MADE

- ATTACK IS SINGLE AXIS AIR ATTACK
- ALL MISSILES ARE ACTIVE MISSILES
  - NO SOFTKILL VS. ARM
- NO BLUE AIR ASSETS
- ALL MISSILES LAUNCHED OUTSIDE BLUE MISSILE RANGE
- ONLY CONCERNED WITH TERMINAL 50 NM OF FORMATION MISSILE TRACKS IDENTIFIED at 50 NM
- CONDITIONS HOT, THREAT SECTOR IS KNOWN
  - TARGETS WITHIN THREAT CORRIDOR CONSIDERED HOSTILE

JUSTIFICATION

1. NATO EW TRIALS FORMATION
2. SHIPS APROXIMATE SIZES, CAPABILITIES OF TRIALS

REQUIRED DATA BASE

SYSTEM	SOURCE
SM-1 MR/ER INTERCEPT ENVELOPE VS. PARTICULAR MISSILES BY PARTICULAR SHIP	NWP-65 SERIES
NSSMS (DD 963) INTERCEPT ENVELOPE VS. PARTICULAR MISSILE	NWP-65 SERIES
5"-54 VS. PARTICULAR MISSILE (EFFECTIVENESS)	JMEMS
76mm VS. PARTICULAR MISSILE (EFFECTIVENESS)	JMEMS
CIWS VS. PARTICULAR MISSILE (EFFECTIVENESS)	JMEMS
ALL GUN ENVELOPES AND COVERAGE CUTOUTS FOR EACH CLASS 0F SHIP	NWP-65 SERIES
CHAFF EMPLOYMENT/TACTICS	TACMEMO XZ0050-1-87
CHAFF EFFECTIVENESS	TACMEMO XZ0050-1-87
ASM PROFILE/RANGE/RELIABILITY	DIS PUBS ON INDIVIDUAL MISSILE SYSTEMS
SLQ-32 COORDINATED TACTICS	TACMEMO XZ0050-1-87