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3 METHOD AND SYSTEM FOR DETERMINING THE
4 PROBABLE LOCATION OF A CONTACT

5
6 STATEMENT OF GOVERNMENT INTEREST

7 The invention described herein may be manufactured and used
8 by or for the Government of the United States of America for
9 governmental purposes without the payment of any royalties
10 thereon or therefor.

11 BACKGROUND OF THE INVENTION

12 (1) Field of the Invention

13 The present invention relates to a system and a method for
14 determining a weapon firing strategy for an evading target, which
15 system and method enable an operator to preset a single weapon
16 against an evading target through the utilization of a
17 man/machine interface which allows the operator to model target
18 evasion schemes.

19 (2) Description of the Prior Art

20 Various systems have been used to analyze the motion of a
21 target and to allow a weapon to be directed towards the target.
22 U.S. Patent No. 3,722,447, for example, illustrates an acoustic
23 homing system for a torpedo. U.S. Patent Nos. 3,883,070;
24 4,146,780; and 4,739,329 illustrate non-alerted/non-evading
25 targets and weapon placement systems. None of these systems

1 account for changes in target position as a result of target
2 evasion.

3 U.S. Patent Nos. 4,224,507; 4,796,187; 5,062,056; 5,267,329;
4 5,317,319; and 5,365,236 illustrate target selection and tracking
5 systems, and are incorporated by reference herein. The target
6 localization, tracking and classification information generated
7 by these systems may be used in the system and method of the
8 present invention.

9 Current systems preset the weapon on an intercept trajectory
10 which assumes the target will not be alerted to the attack. The
11 assumption is not realistic. There is minimal guidance given to
12 combat control system operators for presetting weapons to be
13 launched at evading targets. To increase weapon performance
14 against an evading target, it has been suggested to fire two
15 weapons on a lead/lag firing strategy based upon an intercept
16 solution.

17 SUMMARY OF THE INVENTION

18 Accordingly, it is an object of the present invention to
19 provide a more realistic method and system for determining the
20 firing point for a weapon when a target or contact is alerted to
21 the attack.

22 It is a further object of the present invention to provide a
23 method and system as above which enables an operator to preset a
24 single weapon against an evading target.

1 It is yet a further object of the present invention to
2 provide a method and system as above which provides for an
3 interactive mechanism for combining apriori knowledge of an
4 evading target with subjective operator knowledge.

5 The foregoing objects are attained by the method and the
6 system of the present invention.

7 In accordance with the present invention, a method for
8 determining a weapon firing strategy for an evading target
9 comprises the steps of sensing the motion of the target prior to
10 alertment, analyzing the motion of the target prior to alertment,
11 providing a weapon employment decision aid, determining an
12 evasion region for the target using the weapon employment
13 decision aid and the analyzed motion, visually displaying the
14 evasion region, inputting operator knowledge about the evading
15 target, and generating a representation of the probability of the
16 location of the evading target. The weapon employment decision
17 aid utilizes beta density functions to determine the evasion
18 region, displays target course and speed in the form of bar
19 graphs, and allows the operator to input information about target
20 evasion course and speed and uncertainty levels.

21 A system for determining a weapon firing strategy for an
22 evading target in accordance with the present invention comprises
23 means for sensing motion of the target prior to alertment, means
24 for analyzing the motion of the target prior to alertment, means
25 for determining an evasion region for the target using the
26 analyzed target motion, means for visually displaying the evasion

1 region, means for inputting operator knowledge about the target,
2 and means for generating a representation of the probability of
3 the location of the evading target.

4 Other details of the method and system of the present
5 invention, as well as other advantages and objects, are set forth
6 in the following detailed description and the accompanying
7 drawings.

8 BRIEF DESCRIPTION OF THE DRAWINGS

9 FIG. 1 is a schematic representation of a system in
10 accordance with the present invention;

11 FIG. 2 is a graph showing evasion speed density functions
12 for different shaping parameters;

13 FIG. 3 is a speed bar graph display generated and used by
14 the weapon employment decision aid of the present invention;

15 FIG. 4 is a course bar graph display generated and used by
16 the weapon employment decision aid;

17 FIG 5 illustrates a target probability location
18 representation generated by the weapon employment decision aid;

19 FIG. 6 illustrates a weapon employment decision aid display;

20 FIG. 7 illustrates a representation of a torpedo run preset
21 from instantaneous and realistic target motion models; and

22 FIGS 8A and 8B are graphical comparisons of presetting with
23 realistic and instantaneous motion models (MM).

1 DESCRIPTION OF THE PREFERRED EMBODIMENT(S)

2 The speed, maneuverability, and sophistication of today's
3 threat platforms make the problem of target localization and
4 tracking increasingly difficult. Moreover, once a target is
5 alerted and begins evasive maneuvers, current tracking techniques
6 have been shown to be inadequate. In locating an evading target,
7 the use of in-situ tactical information together with empirical
8 information can help to concentrate search efforts in regions
9 where the target is likely to be. The present invention relates
10 to an interactive mechanism for combining apriori knowledge of
11 the problem with subjective operator knowledge. The weapon
12 employment decision aid (WEDA) of the present invention accepts
13 heuristic information about an evading target's strategies and
14 transforms this information into data that can be used to specify
15 a target's evasion speed and course. The WEDA is preferably
16 formed from a computer which has been programmed to carry out the
17 functions set forth hereinbelow. The computer forming the WEDA
18 may comprise any suitable computer known in the art.

19 FIG. 1 illustrates a combat control weapon targeting system
20 10. As shown therein, the system 10 has two major functions -
21 target motion analysis and weapon setting and control. Onboard
22 sensors 12 provide measurements related to target contacts, own
23 ship and the environment as well as intelligence data depicted in
24 the block 14. The sensors 12 may comprise any suitable sensors
25 known in the art such as acoustic sensors. The target motion
26 analysis block 16 comprises a computer or a portion of a computer

1 which has been programmed to analyze the information received by
2 the sensors 12. As shown in FIG. 1, the block 16 receives
3 information from the stored data block 14 as well as the sensors
4 12. The block 16 computes estimates of the contact state
5 (bearing, range, course and speed) in a known manner. For
6 example, the block 16 may comprise any of the target motion
7 analysis systems shown in U.S. Patent Nos. 4,224,507; 4,796,187;
8 5,062,056; 5,267,329; 5,317,319; and 5,365,236, which are hereby
9 incorporated by reference herein.

10 The output from the target motion analysis block 16 is fed
11 to the weapon employment decision aid 18 along with stored data
12 from the block 14. The weapon employment decision aid as
13 previously discussed is formed by a computer or a portion of a
14 computer programmed to carry out the functions described
15 hereinafter. The output from the WEDA 18, namely target mean
16 evasion course and target mean evasion speed, is supplied to a
17 weapon setting and control block 20 which communicates with the
18 weapon 22. The weapon setting and control block 20 may comprise
19 any suitable weapon setting and control means known in the art.

20 It is the purpose of the WEDA 18 to enable the operator to
21 preset a single weapon against an evading target through the
22 utilization of a man/machine interface which allows the operator
23 to model target evasion schemes. The first step in achieving a
24 solution to an evading target problem is for the WEDA to
25 determine the evasion region. Bounding regions for alerted and
26 evading targets have been defined as a function of time based on

1 known target information and characteristics. These regions are
2 pessimistic since they assume that the target travels at maximum
3 speed and turns with a constant minimum turning radius. A more
4 realistic definition of the evasion region can be achieved by
5 using appropriate probability density functions to model the
6 anticipated course and speed changes.

7 The bounding regions are generated under the assumption that
8 target location and direction prior to alertment are known.
9 After alertment, the target is assumed to be capable of traveling
10 in any direction from present course and at any speed up to
11 maximum. The maximum distance traveled by the target, defined as
12 a radial distance R , is a function of the post-alertment time.
13 Since target maneuvers are unrestricted, R is the radius of a
14 bounding circle that increases with time. This growing circle
15 defines the evasion region and bounds all possible target
16 locations after alertment.

17 In accordance with the present invention, beta density
18 functions have been developed to model the maneuvering target
19 position as a function of alertment time. In other words, the
20 beta density functions model both the evasion speed and course of
21 the alerted target. It has been found that this is the most
22 comprehensive model since both symmetrical and skewed positional
23 density functions can be generated. For this model, any maneuver
24 results in a position lying within the circular bounding region
25 and the final spectrum of positions distributed over the entire
26 evasion region.

1 The modeling of any type of evasion tactic is possible
 2 simply by choosing the appropriate shaping parameters in the
 3 density function. The density function for characterizing the
 4 evasion speed is of the form

$$f_s = \frac{S^{(a-1)}(S_m - S)^{(b-1)}}{S_m^{(a+b-1)}B(a,b)} \quad 0 \leq S \leq S_m, \quad (1)$$

5
 6 where S is the target speed, S_m is the maximum target speed, a
 7 and b are shaping parameters, and B(a,b) is the beta function.
 8 The density function for the evasion course is given by

$$f_\theta = \frac{(\theta + \pi + C_r)^{(c-1)}(\pi + C_r - \theta)^{(d-1)}}{(2\pi)^{(c+d-1)}B(c,d)}, \quad C_r - \pi \leq \theta \leq C_r + \pi \quad (2)$$

9 where θ is the course change, C_r is the target course before
 10 evasion, and c and d are shaping parameters. The resultant
 11 positional density function is written as

$$f(x,y) = \frac{\sqrt{X^2 + Y^2}^{(a-2)} \left[r_m - \sqrt{X^2 + Y^2} \right]^{(b-1)} \left[\tan^{-1}(X/Y) + \pi - C_r \right]^{(c-1)} \left[\pi + C_r - \tan^{-1}(X/Y) \right]^{(d-1)}}{r_m^{(a+b-1)} (2\pi)^{(c+d-1)} B(a,b) B(c,d)}, \quad (3)$$

12 where r_m is the maximum distance the contact can travel based on
 13 the evasion time t, or

$$r_m = S_m t. \quad (4)$$

15 These particular densities meet all of the requirements
 16 stated above. Each one is a one-dimensional, four-parameter
 17 function (minimum and maximum values for evasion speed (S_{min},

1 Smax) or course (Cmin, Cmax) and two shaping parameters for
2 evasion speed (a,b) or course (c,d)) and can assume widely
3 differing shapes for various values of the shaping parameters.
4 Figure 2 shows various evasion speed models for different shaping
5 parameters (a,b) for the beta density function. Each one of
6 these density functions represents a possible model of target
7 evasion speed. For example, when $a=b=1$, a uniform density
8 results, implying that all speeds between zero and Smax are
9 equally likely. The ramp density function ($a=2,b=1$) would weight
10 more heavily those evasion speeds near the maximum, while the
11 skewed model ($a=12,b=3$) weights speeds near the maximum in a
12 nonlinear fashion. The symmetrical model ($a=b=5$) would have a
13 mean evasion speed at $sm/2$. Similar models for evasion course
14 can be generated through the selection of the shaping parameters
15 c, and d. Thus, an infinite number of possible evasion
16 strategies can be modeled from the beta density functions.

17 The positional density function developed in the preceding
18 section contains valuable information about evading target
19 characteristics. But for this information to be of any use to an
20 operator, it must be presented in a manner that can be easily
21 understood. A major step in accomplishing this goal is to
22 represent the density functions as target containment regions;
23 that is, transform the three-dimensional information (x, y, and
24 associated probability) into two dimensions where the regions
25 describe the high probability areas. The method employed in the
26 WEDA converts the resultant two-dimensional positional density

1 function into a sectionalized probability map where the
2 probability of the target being in a certain location is
3 displayed as a color intensity. Darker intensities represent
4 higher probabilities of target location (see FIG. 5) This
5 technique is well suited to torpedoes since the problem is a
6 dynamic one; that is, as the torpedo is searching the region, the
7 target is evading, resulting in a time-varying probability
8 region. Because the probability map sectors are much smaller
9 than contour regions, an operator can preset a torpedo to run
10 through the highest probability sector. In addition, this method
11 generates the target containment region quickly, which is very
12 critical in a dynamic situation.

13 The generation of FIG. 5 involves a number of steps. First
14 a 100-percent containment circle about the current target
15 location is computed. This containment circle is based on the
16 target's maximum evasion speed S_m multiplied by the evasion time
17 t (equation (4)). Next, the containment circle is divided into
18 sectors, the number of which affects computation time and
19 solution resolution. The system may use 200 sectors -- 10 radial
20 divisions and 20 angular divisions. The probability for each
21 sector is approximated by

$$P_{s_i} = [I_{r_{u_i}}(a,b) - I_{r_{l_i}}(a,b)] [I_{\theta_{u_i}}(c,d) - I_{\theta_{l_i}}(c,d)], \quad (5)$$

1 where r_{ui} , r_{li} , θ_{ui} , θ_{li} are the radial and angular values of each
2 sector and $I_{rui}(a,b)$; $I_{rli}(a,b)$; $I_{\theta ui}(c,d)$; and $I_{\theta li}(c,d)$ are the
3 incomplete beta functions. All values of P_{si} are displayed in an
4 ordered fashion, the highest probability sector having the
5 darkest intensity and the lowest probability sector having the
6 lightest intensity. This procedure yields a display that allows
7 an operator to quickly identify the most likely evading target
8 location. Such a capability enables the operator to determine
9 the number of weapons required, as well as associated placement
10 coordinates, to effectively cover the target evasion region.

11 The WEDA 18 is designed to function in a user-friendly
12 manner. The operator uses menus and bar graphs to construct a
13 target evasion region while symbolically accounting for the
14 uncertainty contained within the problem. The main obstacle in
15 the design of the man-machine interface was the development of a
16 scheme that would closely adhere to the operator's concept of the
17 problem while allowing for the inclusion of varying degrees of
18 uncertainty in the target's evasion course and speed. This
19 uncertainty was found to be of a symbolic type that is usually
20 expressed verbally, ranging from "I'm very uncertain as to the
21 target's evasion course" to "I'm very certain the target will
22 evade at course 180° ." Such verbal comments indicated that
23 operators typically worked within a finite set of uncertainties.
24 A quantization of the uncertainty spectrum resulted in defining

1 five levels of uncertainty (viz., very uncertain, uncertain,
2 somewhat uncertain, certain, very certain).

3 After quantitizing the uncertainty levels, a method for
4 mapping the symbolic uncertainty into a probabilistic format that
5 could be computed numerically was developed. Various methods of
6 representing uncertainty were examined from the fields of
7 computer science and artificial intelligence. Analysis indicated
8 that the type of uncertainty mapping being sought was not
9 completely represented in any of the methods examined. Past
10 experience in human factors techniques subsequently led to a
11 graphic representation of the target evasion parameters and
12 associated uncertainties. A bar graph scheme was determined to
13 be a good mechanism for translating an operator's internal
14 concept of target evasion and associated uncertainties into
15 numerical statistical information.

16 The bar graph representation, depicted in Figures 3 and 4,
17 uses various symbols as markers to indicate evasion parameters of
18 the target. An X is used to indicate the operator's choice for
19 "most likely evasion value" in both course and speed.
20 Uncertainty in the most likely value is indicated by inserting
21 "padding" (asterisks) on each side of the value. The larger the
22 padding (i.e., the more asterisks), the greater the uncertainty;
23 an absence of padding indicated certainty. As the padding of
24 asterisks is entered, a symbolic description of the current level
25 of uncertainty is displayed to the operator in the window labeled
26 CONFIDENCE.

1 A mapping algorithm from graphic to statistical
2 representation was developed. The algorithm uses the mean value,
3 standard deviation, and mode of course and speed bar graphs to
4 develop beta density functions containing the same statistics.
5 The first step in conversion requires determination of the mode
6 of the bar graph. This is a straightforward process in which the
7 most likely value represented by X is equated directly to the
8 mode of a beta density function. The mean of the bar graph is
9 computed by an averaging technique, wherein all values indicated
10 by asterisks are summed and then divided by the total number of
11 asterisks. The standard deviation (STDV) of the bar graph is
12 finally computed by taking each value indicated by asterisks,
13 subtracting the mean from it, squaring it, summing all of them,
14 dividing by the total number of asterisks, and finally taking the
15 square root (SQRT).

16 When the uncertainty is nonsymmetric, the padding of
17 asterisks is unequal about X (see FIGS. 3 and 4). In this case,
18 the resulting density function is skewed, indicating a higher
19 probability of values on the skewed side.

20 The mode and standard deviation are subsequently used to
21 compute the shaping parameters (a, b, c, d) by employing
22 equations (6) and (7) for speed density and equations (8) and (9)
23 for course density are written below. This results in the
24 solution of a cubic equation in determining the shaping
25 parameters, and yields the target speed and course density
26 functions for this specific evasion tactic.

$$\text{mode}_s = [(a-1)S_m]/(a+b-2), \quad (6)$$

$$\sigma_s = (\sqrt{ab} S_m)/[(a+b)\sqrt{a+b+1}], \quad (7)$$

$$\text{mode}_\theta = \{(c-d)\pi\}/(c+d-2) + C_T, \quad (8)$$

$$\sigma_\theta = (2\pi\sqrt{cd})/[(c+d)\sqrt{c+d+1}]. \quad (9)$$

1 The principal advantage to the WEDA 18 is that it allows the
 2 operator to enter heuristic knowledge about target evasion course
 3 and speed and that it is designed to function in a user-friendly
 4 manner. The operator uses menus and bar graphs to construct a
 5 target evasion region while symbolically accounting for the
 6 uncertainty contained in the problem. The operator may input the
 7 evasion course and speed into the WEDA using any suitable means
 8 known in the art such as pull-down menus and a keyboard.

9 The following is an example of the use of the WEDA 18.

10 This example involves a single target on an initial course
 11 of 180° with a current speed of 9 knots. The target is assumed
 12 to be alerted when the torpedo enables at a range of 3000 meters
 13 from the target. The operator can now construct the target
 14 evasion model through interaction with the WEDA. The speed bar
 15 graph is used to enter the evasion speed and associated
 16 uncertainty. In this case, the operator estimated that the
 17 target will evade at 25 knots (see FIG. 3), with a skewed
 18 uncertainty indicating higher probabilities of fast evasion

1 speed. The tactical description yields a skewed speed density
2 function with shaping parameters of $a = 8$, $b = 6$. The density
3 function generated with these shaping parameters has
4 approximately 55 percent of its area located between 20 and 28
5 knots, indicating that this is a good representation of the
6 evasion speed entered. The operator now uses the course bar graph
7 to enter the evasion course and associated uncertainty. Here,
8 the operator estimates that the target will evade on a course of
9 0° (see FIG. 4), with more probability that the target will turn
10 left rather than right to evade. The resulting skewed course
11 density function has shaping parameters of $c = 4$, $d = 5$ and again
12 closely represents the evasion course entered.

13 The aforementioned combination of the course and speed
14 density functions results in most probable target positions being
15 located in a sector centered at bearings 300° and a range of 1100
16 meters beyond current target location. This information is
17 displayed on the WEDA's sectionalized probability map (see Figure
18 6). The darker areas indicated higher probabilities of target
19 location.

20 It has been found that two special cases exist when using
21 the WEDA. The first is when the operator is very uncertain about
22 target evasion course and speed. In this case, both beta density
23 functions begin to approximate uniform densities, exponentially
24 tapering off in the radial direction to zero at the boundary of
25 the 100-percent containment circle. The second special case

1 occurs when the mode of the evasion speed is set equal to the
2 maximum evasion speed and the evasion course is very uncertain.
3 In this case, the speed beta density function approximates a ramp
4 function and the course density function approximates a uniform
5 distribution inside the 100 percent containment circle.

6 It has been found that when the WEDA is employed on a
7 submarine, the accuracy of the weapon firing point is contingent
8 upon the fidelity of the submarine motion models which generate
9 the target location region. These regions are a function of
10 submarine classification (i.e. diesel, SSN, SSBN, etc.) as well
11 as the initial submarine velocity before evasion. The regions
12 that are generated in WEDA employ a simple motion model that only
13 characterize submarine classification by using the maximum speed.
14 The end result is circular regions which only vary in size from
15 submarine to submarine by the radius. Thus, a more sophisticated
16 motion model may be incorporated into WEDA which models the
17 acceleration of the submarine for both speed and course changes.
18 This motion model employs target characteristics such as turn
19 rate, turning radius and acceleration for various submarine
20 classes in the computation of the mean evasion course and speed.
21 The firing point for this region would also be different from
22 that shown in FIG. 5. FIG. 7 shows two sets of weapon presets
23 one using the instantaneous motion model and the other using the
24 realistic motion model. As can be seen, there is a significant
25 difference in the torpedo run.

1 Table 1 shows the different weapon presets (gyro angle, run
 2 distance and run time) for the improved version for the same two
 3 different submarine types in Table 1. Parameters for each
 4 submarine are selected as a function of classification which
 5 results in regions that are very accurate for that contact.

SUBMARINE TYPE	EVASION COURSE	EVASION SPEED	TOTAL WEAPON RUN	WEAPON COURSE
SSN	45 DEG	20 YDS/SEC	3985 YDS	37.3 DEG
SSBN	45 DEG	12 YDS/SEC	3786 YDS	37.1 DEG

6 Table 1 WEDA presets using the realistic motion model

7 Since these parameters are inputs to the weapon order
 8 generation (WOG) algorithm, the resulting presets are also
 9 different. The value added in using the WEDA algorithm presented
 10 in this patent application can be demonstrated employing a Monte
 11 Carlo simulation. Four targeting solutions were evaluated using
 12 this simulation and the results are shown in Table 2.

	SSN/WEDA REALISTIC MM	SSN/WEDA INSTAN MM	SSBN/WEDA REALISTIC MM	SSBN/WEDA INSTAN MM
PROBABILITY OF ACQUISITION	80	70	95	87

Table 2 Probability of Acquisition for different weapon presets

13 Table 2 shows the importance of using the more realistic
 14 target kinematics model in the determination of the firing
 15 solution. There is at least a 10% increase in torpedo
 16 acquisition using the evasion parameters from the realistic MM
 17 over the instantaneous MM. Figures 8A and 8B further support
 18 this by comparing probability of acquisition for a torpedo preset
 19 with the two motion models.

1 Summarizing, this added feature results in improved firing
2 points for advanced weapons. The real time performance of WEDA
3 has not been diminished and overall weapon performance has
4 improved by it.

5 It is apparent that there has been provided in accordance
6 with the present invention a method and a system for determining
7 the probable location of a contact which fully satisfies the
8 means, objects and advantages set forth hereinbefore. While the
9 present invention has been described in combination with specific
10 embodiments thereof, it is evident that many alternatives,
11 modifications, and variations will be apparent to those skilled
12 in the art in light of the foregoing description. Accordingly,
13 it is intended to embrace all such alternatives, modifications,
14 and variations,

15

2

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METHOD AND SYSTEM FOR DETERMINING THE

4

PROBABLE LOCATION OF A CONTACT

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6

ABSTRACT OF THE DISCLOSURE

7 The present invention relates to a method and a system for
8 determining a weapon firing strategy for an evading target. The
9 method of the present invention comprises the steps of sensing
10 the motion of the target, analyzing the motion of the target,
11 providing a weapon employment decision aid, determining the
12 evasion region for the target using the weapon employment
13 decision aid and the analyzed motion, visually displaying the
14 evasion region, feeding operator knowledge about the evading
15 target, and generating a representation of the probability of the
16 location of the evading target. The weapon employment decision
17 aid utilizes beta density functions to determine the evasion
18 region. The weapon employment decision aid displays target
19 course and speed in the form of bar graphs and allows the
20 operator to input information about target evasion course and
21 speed and uncertainty levels.

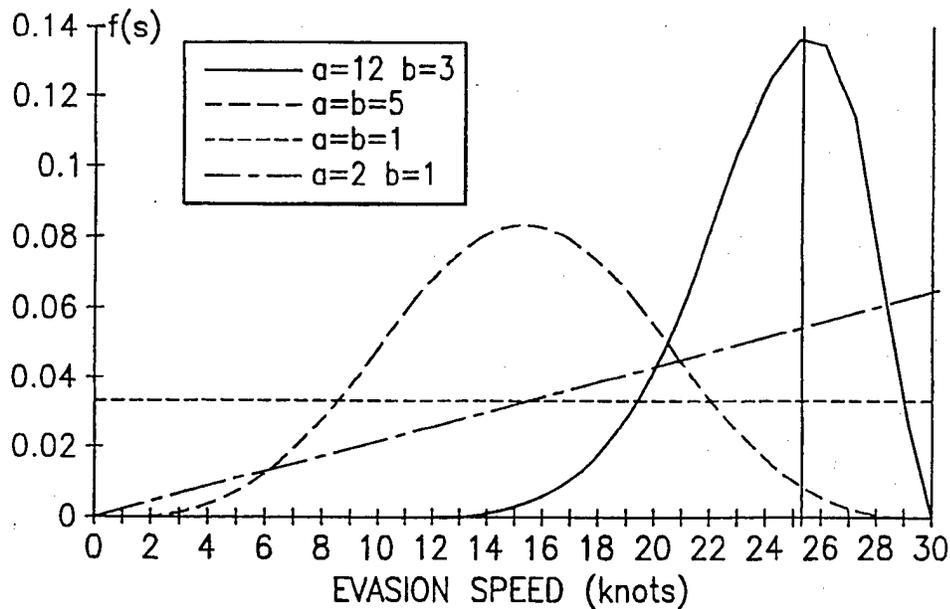
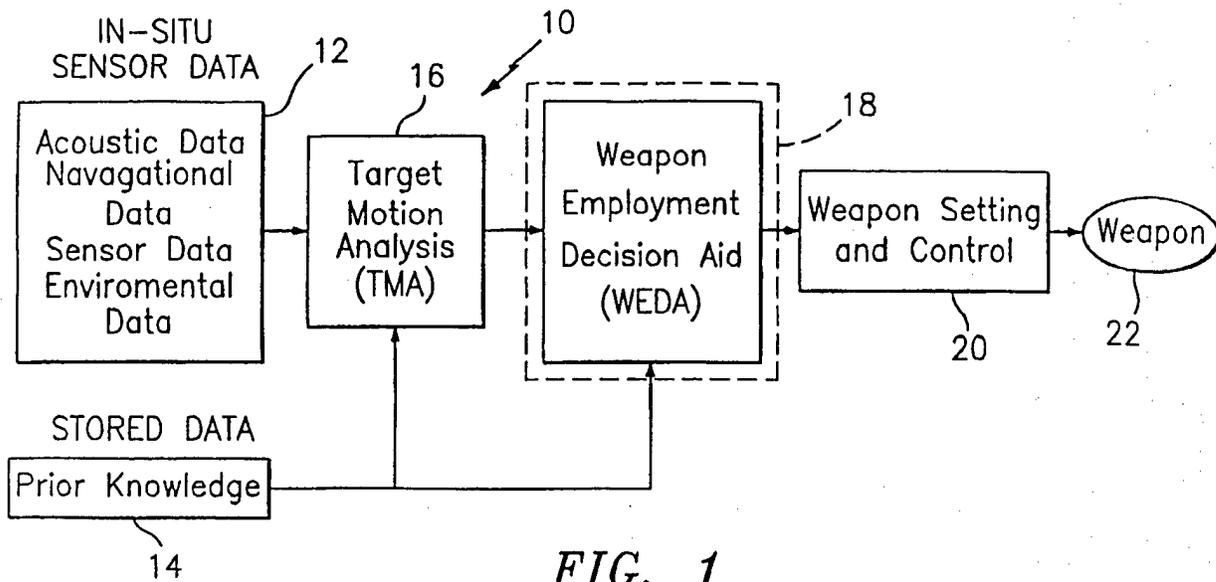


FIG. 2

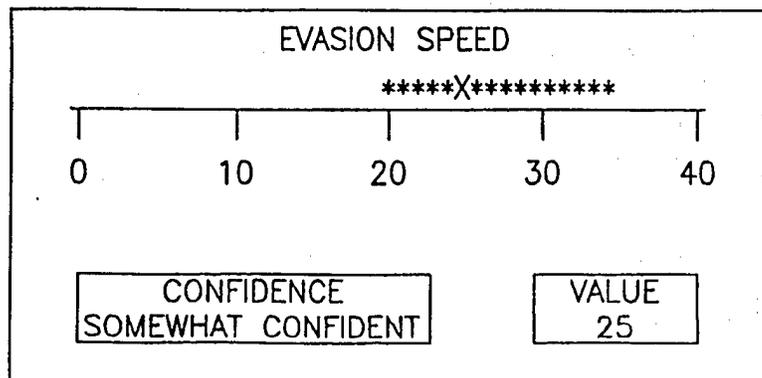


FIG. 3

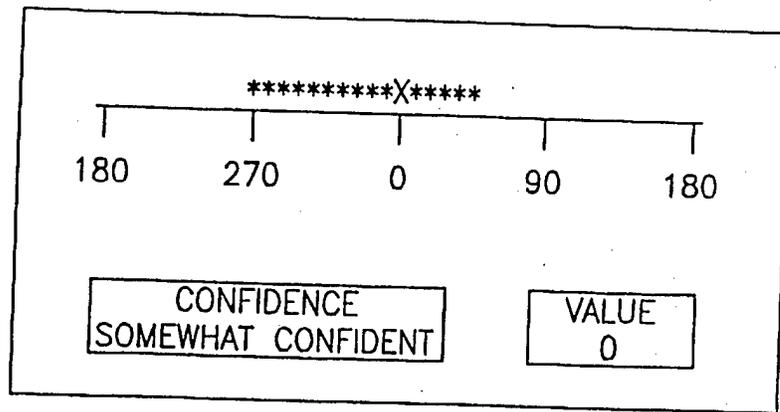
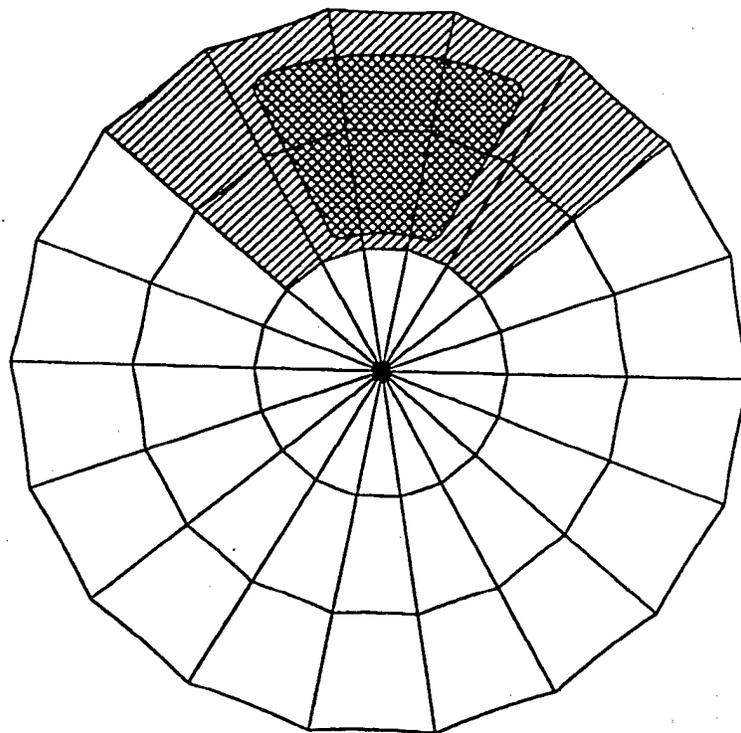


FIG. 4



PROB OF TARGET LOCATION



0 (LOW)

1 (HIGH)

FIG. 5

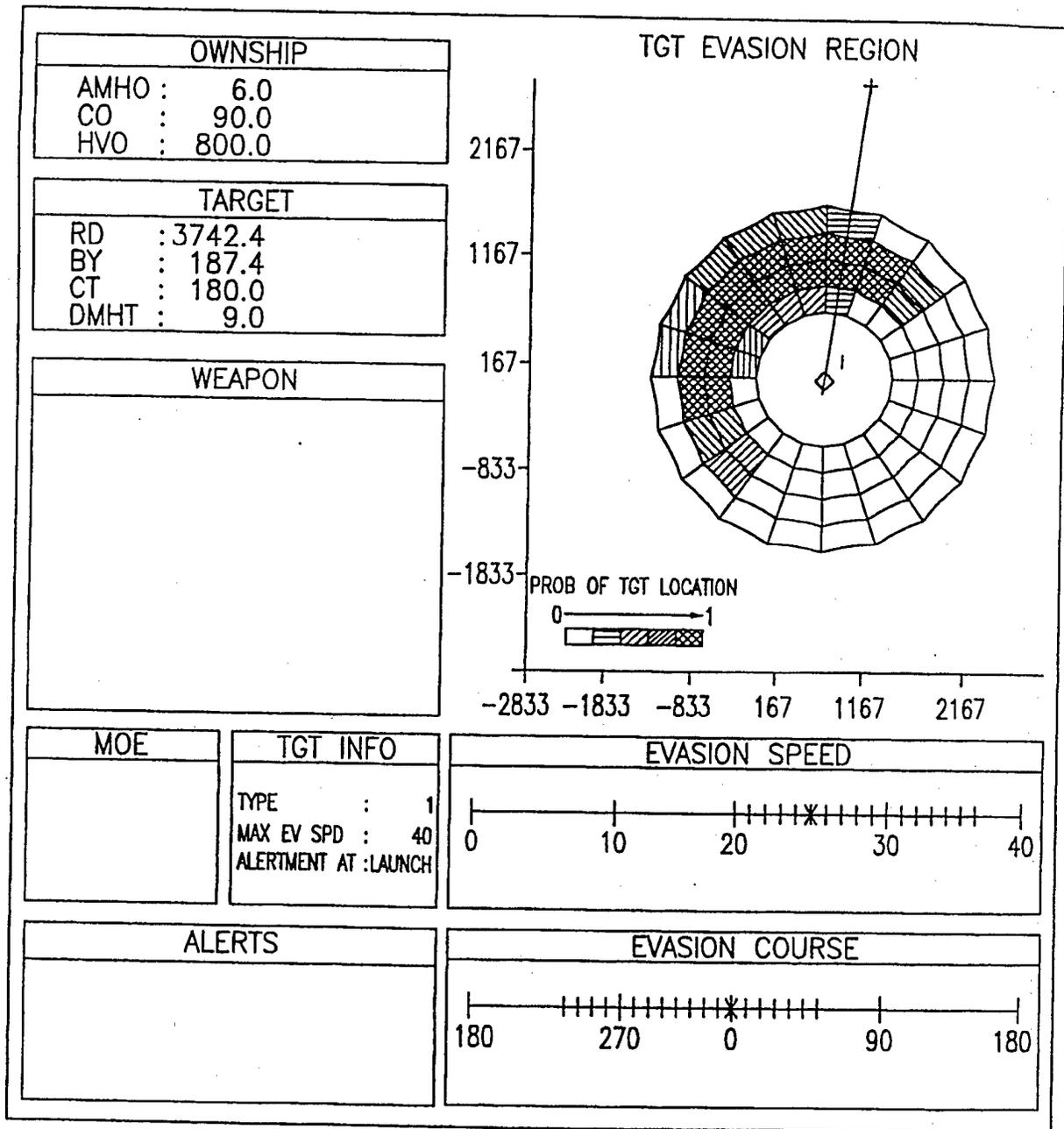


FIG. 6

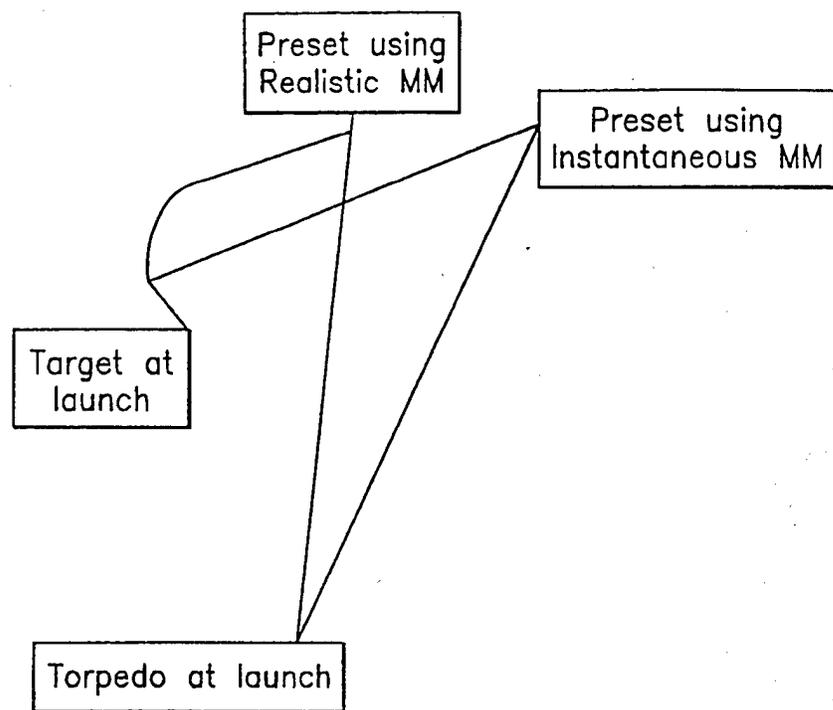


FIG. 7

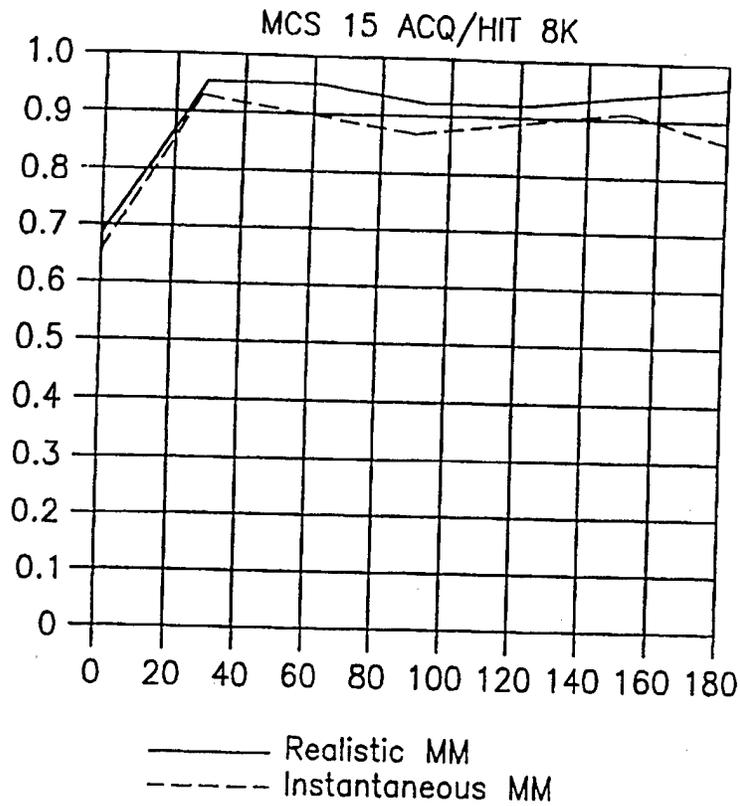


FIG. 8A

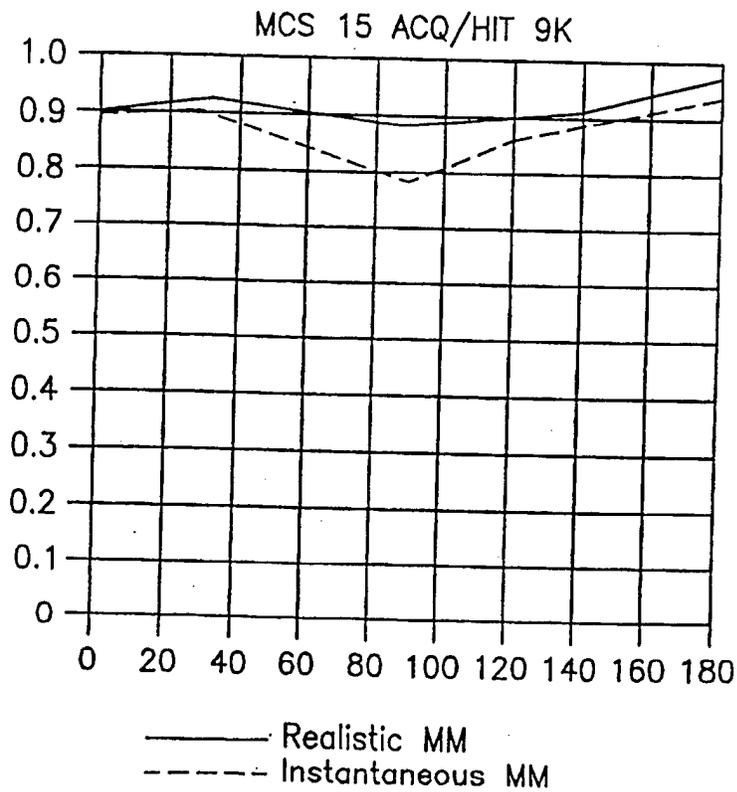


FIG. 8B