NAVSEA
WARFARE CENTERS
NEWPORT

DEPARTMENT OF THE NAVY
NAVAL UNDERSEA WARFARE CENTER
DIVISION NEWPORT
OFFICE OF COUNSEL
PHONE: 401 832-3653
FAX: 401 832-4432
DSN: 432-3653

Attorney Docket No. 84901
Date: 29 June 2009

The below identified patent application is available for licensing. Requests for information should be addressed to:

TECHNOLOGY PARTNERSHIP ENTERPRISE OFFICE
NAVAL UNDERSEA WARFARE CENTER
1176 HOWELL ST.
CODE 07TP, BLDG. 990
NEWPORT, RI 02841

Serial Number	12/383,433
Filing Date	13 March 2009
Inventor	Robert Kuklinski

Address any questions concerning this matter to the Office of Technology Transfer at (401) 832-1511.

DISTRIBUTION STATEMENT
Approved for Public Release
Distribution is unlimited

Attorney Docket No. 84901

UNDERWATER ACOUSTIC TRACER SYSTEM

STATEMENT OF GOVERNMENT INTEREST

[0001] The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

[0002] Not applicable.

BACKGROUND OF THE INVENTION

(1) Field of the Invention

[0003] The present invention relates to underwater targeting and tracing systems and more specifically to systems and methods for controlling and utilizing supercavitating projectile dynamics to produce a distinctive radiated noise signal.

(2) Description of the Prior Art

[0004] There exists a need for accurate localization of underwater targets for a variety of underwater systems. The basic means of identification of an underwater object or target usually relies on the transmission of an acoustic signal from a fixed location and processing of a return echo at that same location. As in the case of an in-air tracer bullet, when launching a plurality of high velocity underwater projectiles against a target, it would be desirable to trace the path of a number of such projectiles so as to localize the proximity of the projectile stream on the intended target.

[0005] The art for tracing underwater high speed objects previously has been limited to measuring the speed of relatively small metallic objects which travel relatively closely to a magnetic pickup. For larger, high speed, underwater projectiles, supercavitating underwater vehicles have been proposed for use. The conditions for supercavitation are known in the art. Supercavitation allows for higher speeds to be sustainable by reducing skin friction drag to a great extent at such higher speeds.

[0006] Proposed means for tracking larger underwater high speed objects, such as a supercavitating vehicle, rely on a number of hoops aligned on a range in the anticipated path of the high speed projectile. The hoops are sufficiently large relative to the size of the projectile and anticipated path. Each hoop contains a number of independent hydrophones. The signals from the hydrophones may be analyzed to accurately determine position and track of an underwater projectile along the plane of each hoop. The system may be used as a fixed range or as a mobile range in a remote location. However, since the hoops must be placed in the anticipated path of the projectile, such means do not aid in localizing the proximity of a projectile stream on an intended target.

[0007] Systems and methods are needed that can produce radiated acoustic signals from the projectile in the near vicinity of the targeted object. In order to properly distinguish the radiated acoustic signals from the projectile so as to accurately track its path, the signals can be designed to be either greater in amplitude or easier to characterize than would a transmitted signal from the receiver or target location.

[0008] By providing a distinguishable acoustic signal, the systems and methods can provide better resolution of underwater vehicle position and improved tracking of an underwater object. The ability to more effectively target underwater objects moving at high speed may be enhanced through better resolution of underwater objects and tracks in poor acoustic environments.

[0009] The distinguishable acoustic signal of the systems and methods herein can lead to decreased signal processing requirements to achieve a desired target resolution and a better ability to resolve multiple targets. Accordingly, the systems and methods may be particular effective in conjunction with projectile-based terminal defense systems, mine clearance systems, stand alone gun systems for augmenting existing targeting systems, and the like.

SUMMARY OF THE INVENTION

[0010] It is therefore a general purpose and primary object of the present invention to provide systems and methods for controlling the cavity dynamics of a supercavitating underwater projectile to produce a distinctive radiated noise signal. The distinctive noise signal may then be used in conjunction with an underwater targeting system to help identify, localize and track targets.

[0011] The object of the present invention is attained by modifying a supercavitating projectile to provide a well-defined, prescribed disruption of its surrounding cavity. The disruptions, in turn, can produce well characterized acoustic signals that contain unique features that interact with the acoustic environment and aid in the identification of underwater objects.

[0012] In operation, a supercavitating projectile can be fired toward a target from a firing platform. The projectile can include rippling means that cause one or more ripples to form on the cavity boundary so as to provide well-defined disturbances of the cavity boundary. As the projectile advects through the water, the ripples move aft of the supercavitating projectile at the speed of advance. As the ripples move into the wake, the ripples detach to form a pattern of vapor bubbles in the wake that are distinct in both size and regularity from the typical vapor bubbles formed as the cavity collapses behind the advecting projectile. This distinction in the pattern of vapor bubbles results in a distinct acoustic signature.

[0013] Sensors can record the track of the projectile along its path based on the distinct acoustic signature. Combining this information with the acoustic echo from the target, the relative distance of the projectile to the target can be determined using methods known in the art. The aiming of the supercavitating projectiles towards the target can be adjusted to reduce the relative distance. As in the case of using tracer bullets in air to lock onto a target, multiple projectile trajectories can be used to increase the ability to resolve the target.

[0014] The rippling means may be varied to produce differing patterns of ripples and hence vapor bubbles. Thus, a variety of distinct sound fields may be created. The rippling means may be in the form of a mechanical actuator that can be extended from the projectile to contact the cavity boundary and cause a ripple to be created. Depending on the extent to which the actuator contacts the cavity boundary and the shape of the actuator, various sizes of ripples and hence vapor bubbles can be formed. Additionally, the actuator can contact the cavity boundary in a specified sequence to produce a corresponding specified pattern of vapor bubbles.

[0015] Supercavitating projectiles with flammable cores, which are ignited upon launch, are known in the art. Combustion of the core causes a flame front to move from the aft end toward the cavitator, or forward end, of the projectile. For such projectiles, a number of small bores can extend through the outer casing of the projectile and penetrate into the core. As the flame front reaches each bore, a pressure disturbance is created, which causes a ripple to form. As in the case of a mechanical actuator, ripples from the pressure disturbance result in vapor bubbles forming and a distinct sound field can be created. The number, size and spacing of the bores are chosen to produce ripples of varying size and frequency. The rate of flame front propagation can determine the rate of ripple formation and, as such, additional distinguishing characteristics of the acoustic signal can be produced.

[0016] In one embodiment, an underwater targeting system comprises a supercavitating projectile launched towards a target that includes a rippling means for providing the projectile with a distinct acoustic signature. An acoustic sensor receives first acoustic signals based on the distinct acoustic signature. The acoustic sensor also receives second acoustic signals based on an echo of the distinct acoustic signature from the target when the projectile approaches the target. An acoustic processor resolves the trajectory of the projectile based on the first acoustic signals and resolves the relative distance between the projectile and the target based on the first and second acoustic signals.

[0017] In one variation, the acoustic processor is attuned to the distinct acoustic signature so as to preferentially resolve the trajectory and relative distance. The acoustic sensor may also or separately be attuned to the distinct acoustic signature so as to preferentially receive the first and second signals.

[0018] In another variation, the rippling means forms one or more disturbances at a cavity boundary of the supercavitating projectile. The disturbances separate from the cavity boundary to form vapor bubbles in the wake of the projectile. The collapse of the vapor bubbles results in the distinct acoustic signature of the projectile.

[0019] The rippling means can be programmed to form a predetermined series of disturbances, with the disturbances having a specified timing, shape and/or size.

[0020] The rippling means can include an actuator and a controller. The controller can direct the movement of the actuator so as to disturb the flow within a cavity surrounding the projectile. The disturbed flow results in the formation of the disturbances. In one variation, the controller extends the actuator into the flow. In another variation, the movement of the actuator pivots a control surface of the projectile into the flow. In yet another variation, the movement of the actuator opens a port one the projectile to the flow.

[0021] In a further variation, the rippling means includes a flammable core within the projectile and one or more bores in the projectile, which expose the core to the cavity surrounding the projectile. The passage of the flame front of the flammable core by a bore disturbs the flow within the cavity, which results in the formation of a disturbance at the cavity boundary. The size of the bores, the location of the bores and/or the flame rate of the flammable core can be varied to form a predetermined series of disturbances.

[0022] In one embodiment, a supercavitating projectile comprises an actuator and a controller, which directs the movement of the actuator to disturb a flow within a cavity surrounding the supercavitating projectile. The disturbed flow forms one or more disturbances at a cavity boundary of the projectile. These disturbances separate from the cavity boundary to form vapor bubbles in the wake of the supercavitating projectile. The collapse of the vapor bubbles results in a distinct acoustic signature.

[0023] In one variation, the controller extends the actuator into the flow. In another variation, the movement of the actuator pivots a control surface of the projectile into the flow. In yet another variation, the movement of the actuator opens a port on the projectile to the flow.

[0024] In one embodiment, a supercavitating projectile comprises a flammable core and one or more bores in said projectile. The bores expose the core to a cavity surrounding the projectile. Passage of the flame front of the flammable core by a bore disturbs a flow within the cavity and the disturbed flow forms one or more disturbances at the cavity boundary of the projectile. The disturbances separate from the cavity boundary to form vapor bubbles in the wake of the projectile. Collapse of the vapor bubbles results in a distinct acoustic signal.

[0025] In one variation, a size of the bores, a location of the bores and/or a flame rate of the flammable core can be varied to form a predetermined series of disturbances.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] A more complete understanding of the invention and many of the attendant advantages thereto will be readily appreciated as the same becomes better understood by reference to the following detailed description when considered in conjunction with the accompanying drawings wherein:

[0027] FIG. 1 illustrates a side view of an underwater projectile advecting through a medium;

[0028] FIGS. 2A-2C illustrate the formation of ripples at the cavity boundary of the supercavitating projectile and its progression along the cavity;

[0029] FIGS. 3A and 3B illustrate the formation of ripples and vapor bubbles;

[0030] FIG. 4 illustrates a targeting, tracking system;

[0031] FIGS. 5A-5C illustrate actuator rippling means; and

[0032] FIG. 6 illustrates a pressure disturbance rippling means.

DETAILED DESCRIPTION OF THE INVENTION

[0033] Referring now to **FIG. 1**, there is shown a side view of underwater projectile **10** advecting through a fluid medium **11** in the direction indicated by arrow **A**. For ease of reference, but not limitation, medium **11** may be described herein as water. As is known in the art, water **11** is accelerated over a cavitator **12** attached to a nose portion **10a** of vehicle **10**. The downstream pressure drops below the vapor pressure of water **11** after passing cavitator **12**, resulting in the formation of cavity **13**, through which projectile **10** traverses.

[0034] Cavity **13** terminates in a cavity closure region **13a**. Cavity closure region **13a** is usually well defined spatially but is not steady. Quasi-steady rupture of cavity closure region

13a produces a trail of vaporous bubbles **14** behind closure region **13a**. Bubbles **14** ultimately collapse and produce a large amplitude radiated acoustic signal.

[0035] The characteristics of radiated signals from collapsing bubbles are known in the art. However, the acoustic signature of projectile **10** does not lend itself to tracking since the formation of bubbles **14**, as illustrated in **FIG. 1**, is chaotic. To provide a more well-defined and distinguishable acoustic signature, projectile **10** includes rippling means **16**, shown schematically in **FIG. 1**, which forms disturbance **18** in boundary **13b** of cavity **13**. The operation of rippling means **16** and its formation of a disturbance in boundary cavity **13b** will be discussed in further detail with respect to **FIGS. 5** and **6**. For illustrative purposes and not for limitation, the formation of disturbance **18** in **FIG. 1** is taken as time t_0.

[0036] **FIG. 2A**, **FIG. 2B** and **FIG. 2C** illustrate projectile **10** at subsequent times t_1, t_2 and t_3, respectively. In **FIG. 2A**, disturbance **18** is shown at a position further towards aft end **10b** of projectile **10** as a result of projectile **10** advecting through medium **11** for time $t_1 - t_0$. Additionally, **FIG. 2A** illustrates rippling means **16** forming disturbance **18a**.

[0037] In **FIG. 2B**, disturbances **18** and **18a** are shown at positions still further towards aft end **10b** of projectile **10** as a result of projectile **10** advecting through medium **11** for time

$t_2 - t_1$. Additionally, **FIG. 2B** illustrates rippling means **16** forming disturbance **18b**.

[0038] Correspondingly at time t_3, **FIG. 2C** illustrates disturbances **18**, **18a** and **18b** at positions still further towards aft end **10b** of projectile **10** and the formation of disturbance **18c** by rippling means **16**. **FIGS. 2A-2C** further illustrate the continuing chaotic formation of bubbles **14** as projectile **10** advects through medium **11**.

[0039] As can be seen in **FIGS. 2A-2C**, rippling means **16** forms a series of disturbances (**18-18c**) at boundary **13b**. The operation of rippling means **16** can be such that the disturbances (generally referred to herein as **18**) formed by rippling means **16** are regularly shaped and spaced at boundary **13b**. The advection or movement of projectile **10** through medium **11** results in such consistent disturbances **18** progressing towards cavity closure region **13a**.

[0040] Referring to **FIG. 3A**, there is shown projectile **10** at a time t_z subsequent to time t_3 of **FIG. 2C**. Rippling means **16** has formed additional disturbances **18u-18y** at boundary **13b** in the manner shown in **FIGS. 2A-2C**. Disturbances **18u-18y** can be formed periodically or in a time encoded manner. **FIG. 3A** illustrates disturbance **18u** at cavity closure region **13a**, such that disturbance **18u** is in the process of separating from cavity boundary **13b** and forming disturbance bubble **20**. Additionally,

FIG. 3A illustrates a trail or pattern of disturbance bubbles **22** having been formed by disturbances separated from boundary **13b** previous to time t_z. As a result of the regularity, or uniformity of disturbances **18**, the pattern of disturbance bubbles **22** is distinct from that of typical vapor bubbles **14**. This difference in size and regularity of formation result in a distinct acoustic signature for the pattern of disturbance bubbles **22**.

[0041] Referring also to **FIG. 3B**, there is shown projectile **10** of **FIG. 3A**, wherein rippling means **16** is operated to form additional disturbances **18z**. For ease of illustration, but not limitation, disturbances **18z** are shown formed on cavity boundary **13b**, opposite from disturbances **18u-18y**. Disturbances **18z** have a distinct size and shape from that of disturbances **18u-18y**, resulting in a pattern of disturbance bubbles **22z** distinct from that of the pattern of disturbance bubbles **22** and further distinct from that of typical vapor bubbles **14**. For clarity, but not limitation, vapor bubbles **14** are not shown in **FIG. 3B**.

[0042] Thus, projectile **10** can produce a variety of distinct bubble patterns, depending on the operation of rippling means **16**. Those of skill in the art can readily determine the acoustic signatures resulting from such distinct bubble patterns. Accordingly, acoustic sensors can be sensitized to the particular characteristics of the distinctive acoustic signature of the projectile. Similarly, acoustic processors can be optimized for resolving the distinctive acoustic signature amongst other acoustic input. Thus, the path of the projectile can be preferentially tracked to assist in targeting projectiles.

[0043] Referring to **FIG. 4**, there is shown a schematic representation of targeting system **100**. For aid in targeting, system **100** utilizes projectile **102**, which has a distinct acoustic signature produced by a rippling means, as described with relation to **FIGS. 1**, **2A-2C** and **3A-3B**. Projectile **102** is fired from gun **104** of platform **106**. Gun **104** is aimed along a trajectory, indicated by dashed line **108**, which is estimated to intercept target **110**. Sensor **112** records the track of projectile **102** along trajectory **108**. As described previously herein, sensor **112** can be sensitized to the acoustic characteristics of projectile **102**, so as to preferentially track the distinct acoustic signal **114** of projectile **102** amidst other acoustic energy within medium **11**.

[0044] As illustrated in **FIG. 4**, projectile **102** does not intercept target **110**. However, projectile **102** does approach target **110** such that sensor **112** receives an additional echo (schematically illustrated as arcs **114a**) of the distinct acoustic signal of projectile **102** along path **116**. As is known in the art, such an echo, combined with the acoustic track of projectile **102**, contains information about the relative distance of projectile **102** to target **110**. Processors **118**, optimized for the distinct acoustic signature of projectile **102**, can resolve the path of projectile **102** and hence the relative distance between projectile **102** and target **110** at closest approach. In turn, the relative distance information can be used for targeting a next set of projectiles, in a manner similar to the use of tracer bullets in resolving a target on land.

[0045] Referring now to **FIGS. 5A-5C** and **FIG. 6**, the operation of various rippling means is schematically represented and described. **FIG. 5A** illustrates a schematic cross-section of a nose portion **200a** of projectile **200**. To form disturbance **202** on cavity boundary **204**, actuator **206** extends from nose portion **200a** into cavity **208** towards cavity boundary **204**. In so doing, actuator **206** disturbs the flow within cavity **208**. In turn, the disturbed flow creates disturbance **202** on cavity boundary **204**.

[0046] Control mechanism **210** can be linked to actuator **206** and can control the timing and/or the extent of actuator **206** into cavity **208**. Power supply **212** provides power for the operation of control mechanism **210** and actuator **206**. The dynamics of cavity boundary **204** are well known and understood in the art. Thus, the shape and timing of disturbance **202** can be controlled. Further, control mechanism **210** can be preprogrammed to provide the well-defined series of disturbances **18**, as illustrated in **FIGS. 2A-2C** and **FIGS. 3A** and **3B**.

[0047] The shape and operation of actuator **206** can take many forms. **FIG. 5B** illustrates actuator **206a** pivoting control surface **214** into cavity **208** to form disturbance **202a**. **FIG. 5C** illustrates actuator **206b** opening port **216** in projectile **200**, in the direction of arrow **216a**, so as to form disturbance **202b**. Based on the particular acoustic signature required, one or more of actuators **206**, **206a**, **206b**, may be used.

[0048] The use of flammable cores in underwater supercavitating projectiles is known in the art. Such projectiles can be modified to produce distinct acoustic signatures. **FIG. 6** illustrates a schematic cross-section of a nose portion **300a** of modified projectile **300** having flammable core **302**. Core **302** is penetrated by one or more bores **304**. Upon launch of projectile **300**, flammable core **302** is ignited. Combustion of core **302** results in flame front **306** advancing toward nose portion **300a** of projectile **300**, as indicated by arrow **306a**. As flame front **306** reaches bore **304**, the flow within cavity **308** is disturbed. (A portion of bore **304** is shown dotted to illustrate the passage of flame front **306**.) In turn, the disturbed flow creates disturbance **310** on cavity boundary **312**.

[0049] The number and size of bores **304** can be chosen to produce disturbances **310** of varying size and frequency. Additionally, the rate of propagation of flame front **306** can depend on the composition of flammable core **302**. Accordingly, the rate of formation of disturbances **310** can vary depending on the composition of core **302**. Thus, a desired acoustic signature can be generated depending on the size and location of bores **304** and/or the composition of core **302**.

[0050] What have thus been described are systems and methods for providing well-defined, prescribed disruptions to the cavity boundary of a supercavitating projectile as it advects through a medium. The disruptions, in turn, lead to the formation of a distinct pattern of vapor bubbles, which burst as they trail behind the advecting projectile. This produces well characterized acoustic signals that contain unique features that interact with the acoustic environment and aid in the targeting of underwater objects.

[0051] To produce the disruptions to the cavity boundary, the projectile includes one or more rippling means, which disturb the flow within the cavity. The disturbed flow results in the disruptions of the cavity boundary. The rippling means can include mechanical actuators under preprogrammed control. The actuators can disturb the flow within the cavity by being extended into the cavity, by pivoting a control surface to interact with the flow, or by opening a port within the projectile. In a projectile having a flammable core, the core can be penetrated by one or more bores. Once the core is ignited, the passing of the flame front by such a bore results in the disturbance to the flow within the cavity.

[0052] In use, such a modified projectile is launched towards a target. Based on its distinct acoustic signature, acoustic sensors and processors can be attuned to better track and resolve the path of the projectile. When the projectile approaches the target, the echo of the projectile's acoustic signature from the target can also be tracked and resolved by the attuned sensors and processors. Combined with the projectile tracking information, the echo information is processed to determine a relative distance between the projectile and the target. This information can then be used for aiming additional projectiles at the target.

[0053] The systems and methods described herein provide for an enhanced ability to determine the near instantaneous track of an underwater object and to more accurately determine the instantaneous position of an underwater object. This is accomplished by providing means to control the spectrum and the amplitude of the radiated noise from a projectile.

[0054] Obviously many modifications and variations of the present invention may become apparent in light of the above teachings. As described previously, the shape of the actuator may be varied to suit the desired acoustic signature, or the extent to which the actuator interacts with the cavity flow may be varied. The location and size of the bores, as well as the composition of the flammable core can be varied to suit. Further, one or more of the actuators and the flammable core may be used in combination.

[0055] Additionally, it is known in the art that a tumbling projectile produces a robust, distinctive acoustic signature. The actuator or the final bore may be used to tumble the projectile at a fixed time or point in its trajectory to provide an especially strong acoustic signal for processing.

[0056] As another example, it is known in the art to have the projectile introduce gas into the cavity so as to maintain the closure region of the cavity further from the projectile. Such a projectile may be fitted with one or more ports for releasing compressed gas into the flow so as to form disturbances along the cavity boundary.

[0057] It will be understood that many additional changes in details, materials, steps, and arrangements of parts which have been described herein and illustrated in order to explain the nature of the invention, may be made by those skilled in the art within the principle and scope of the invention as expressed in the appended claims.

Attorney Docket No. 84901

UNDERWATER ACOUSTIC TRACER SYSTEM

ABSTRACT OF THE DISCLOSURE

An underwater supercavitating projectile includes means to form ripples on its surrounding cavity so as to provide well-defined disturbances of the cavity boundary. As the ripples move aft of the supercavitating projectile and into the wake behind the advancing projectile, the ripples detach to form a pattern of vapor bubbles in the wake that are distinct in both size and regularity from the typical vapor bubbles formed as the cavity collapses behind the advecting projectile. Sensors record the track of the projectile along its path based on the distinct acoustic signature of the vapor bubbles. Combined with the acoustic echo from a target, the relative distance of the projectile to the target can be determined using methods known in the art. Multiple projectile trajectories are used to increase the ability to resolve the target by adjusting the aiming of the projectiles to reduce the relative distance.

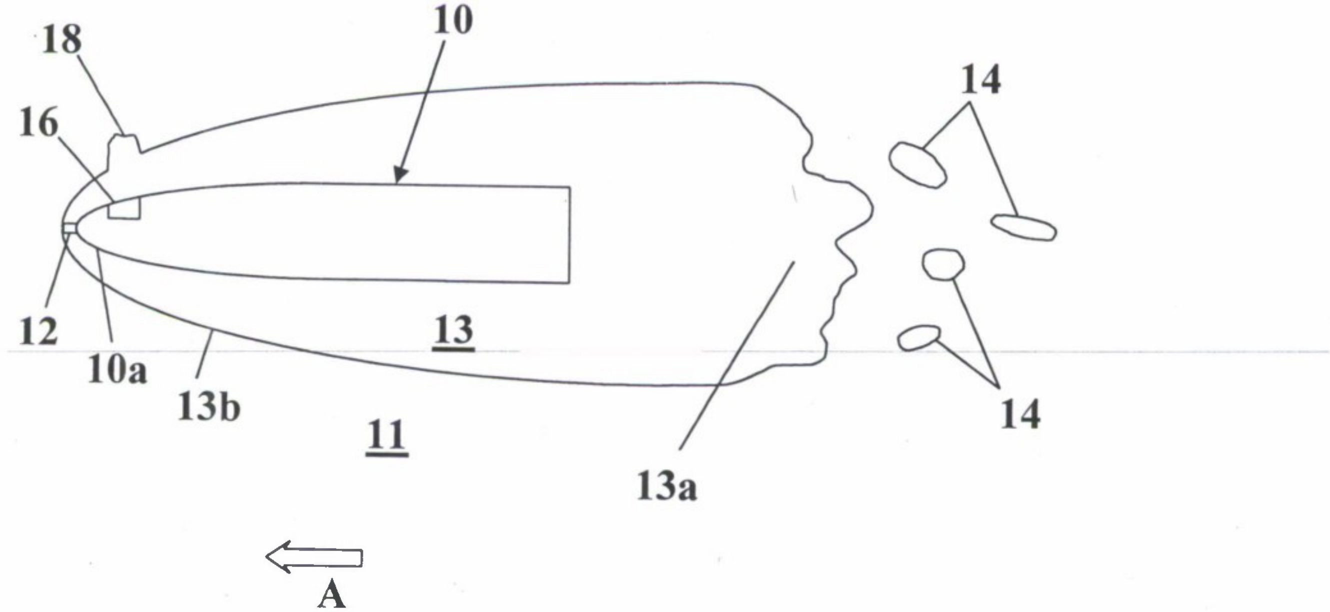

FIG. 1

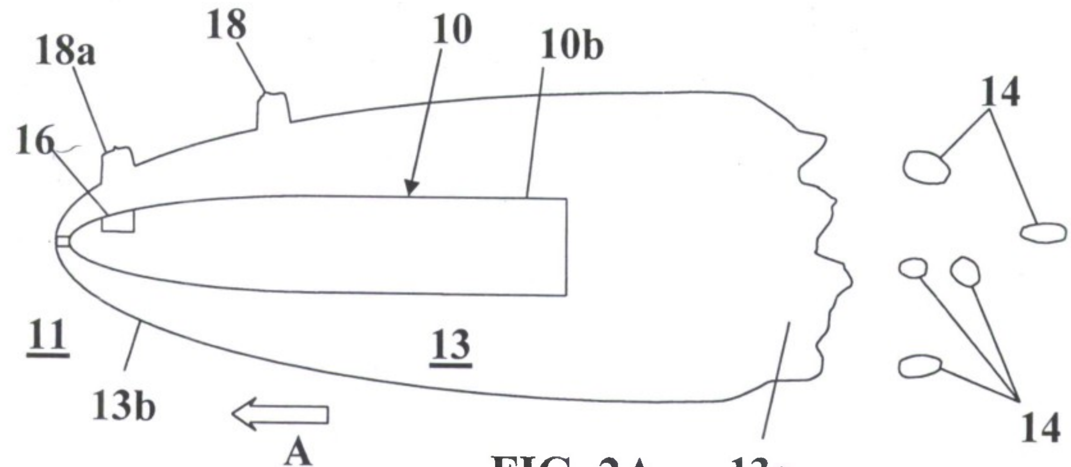

FIG. 2A

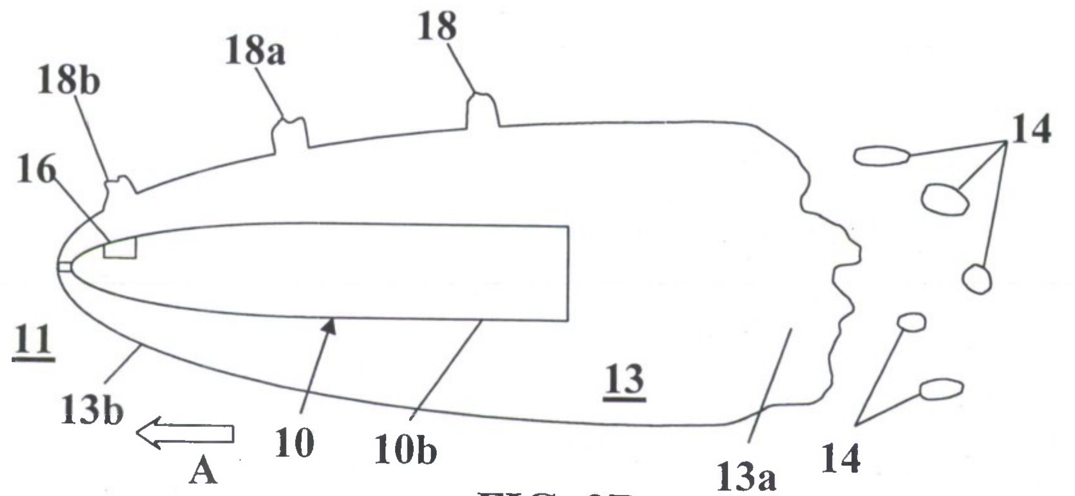

FIG. 2B

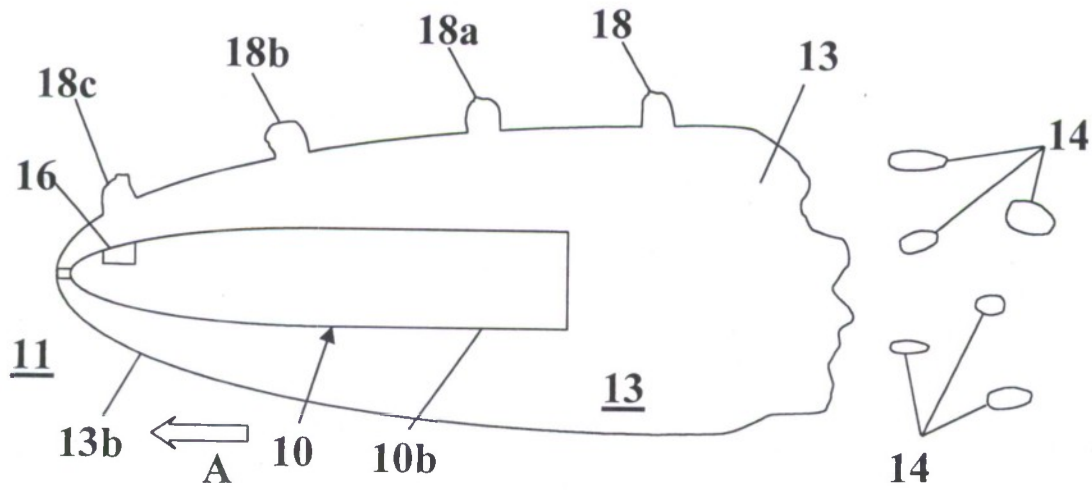

FIG. 2C

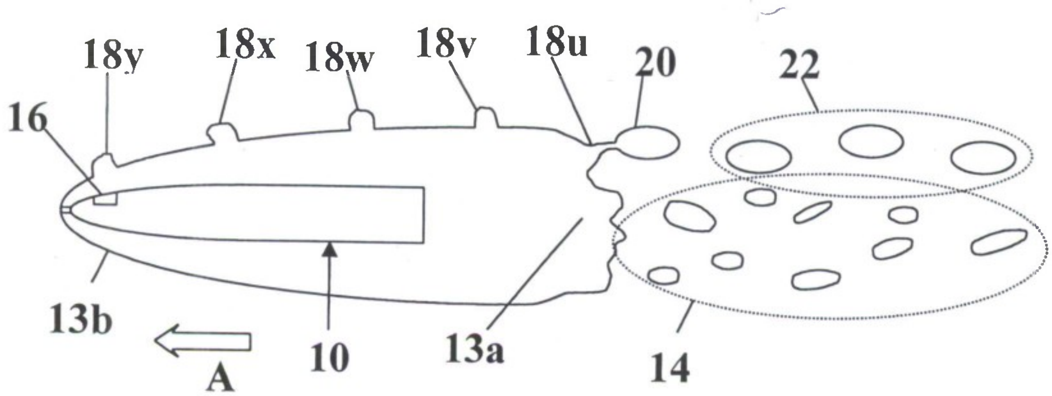
18y
18x
18w
18v
18u
20
22
16
13b
A
10
13a
14

FIG. 3A

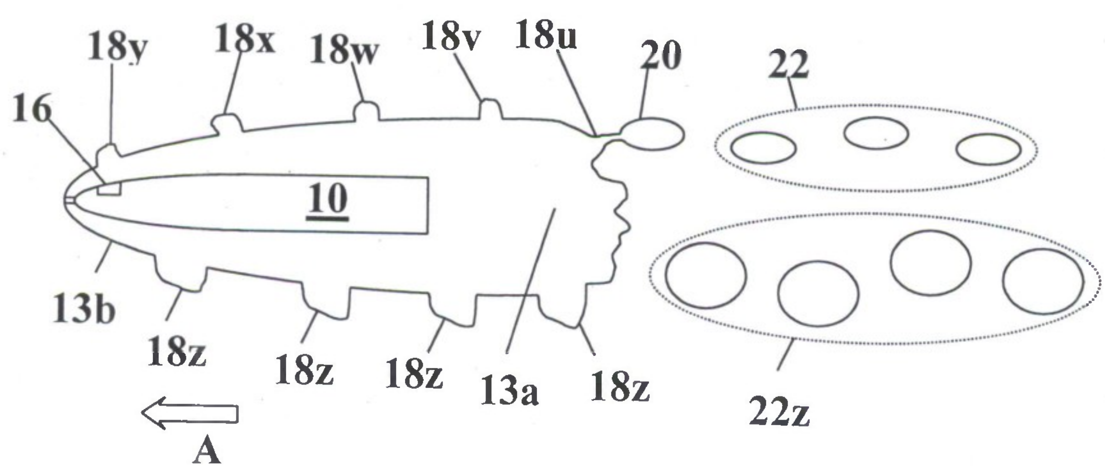
18y
18x
18w
18v
18u
20
22
16
10
13b
18z
18z
18z
13a
18z
22z
A

FIG. 3B

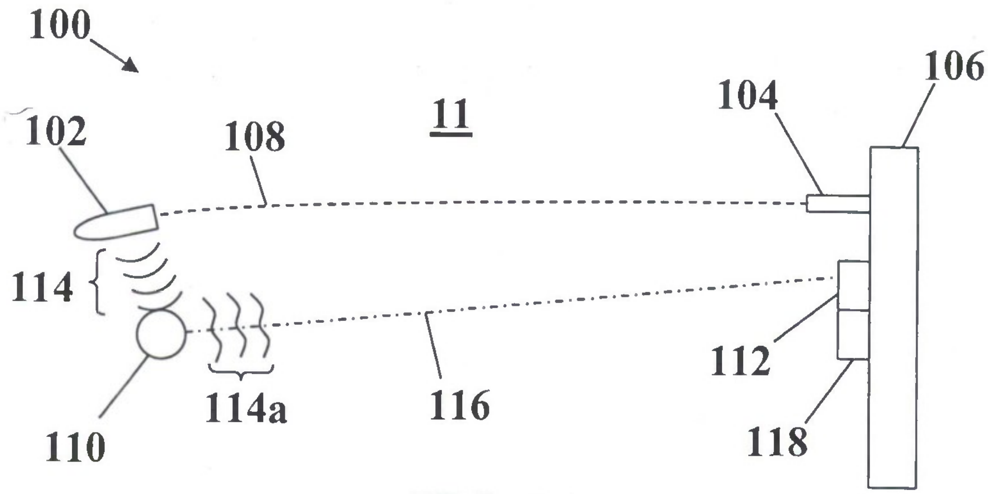
100
102
108
11
104
106
114
110
114a
116
112
118

FIG. 4

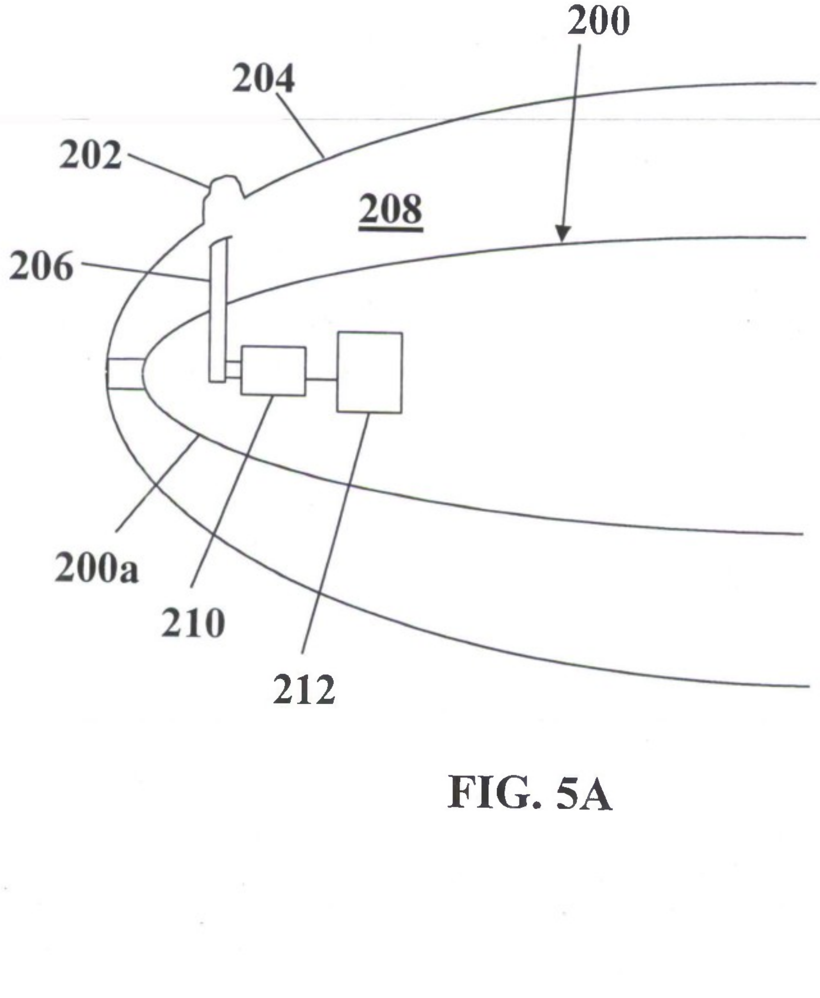
200
204
202
208
206
200a
210
212

FIG. 5A

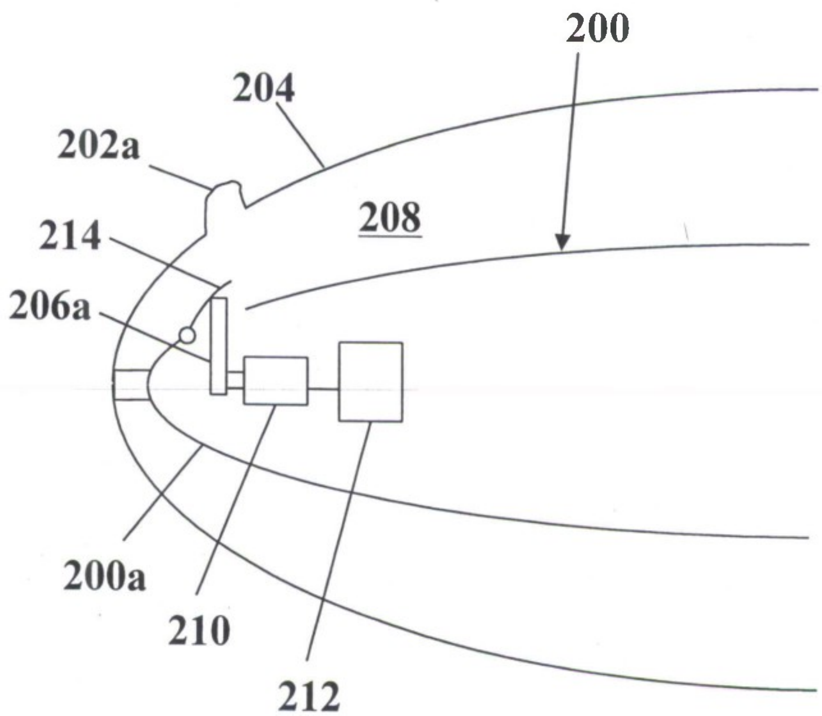

FIG. 5B

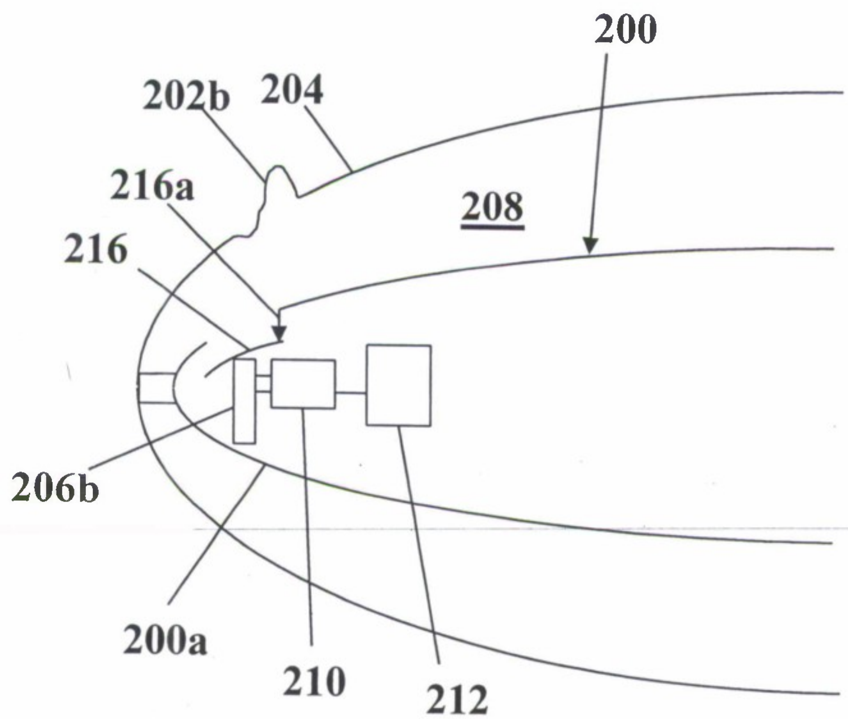

FIG. 5C

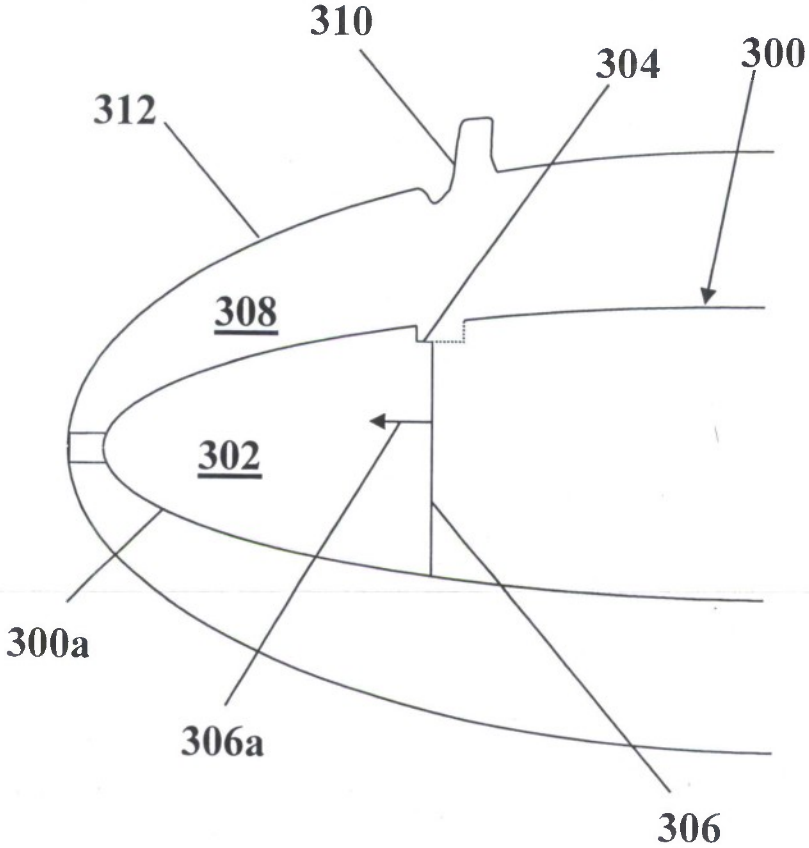

FIG. 6