

Feb. 8, 1966

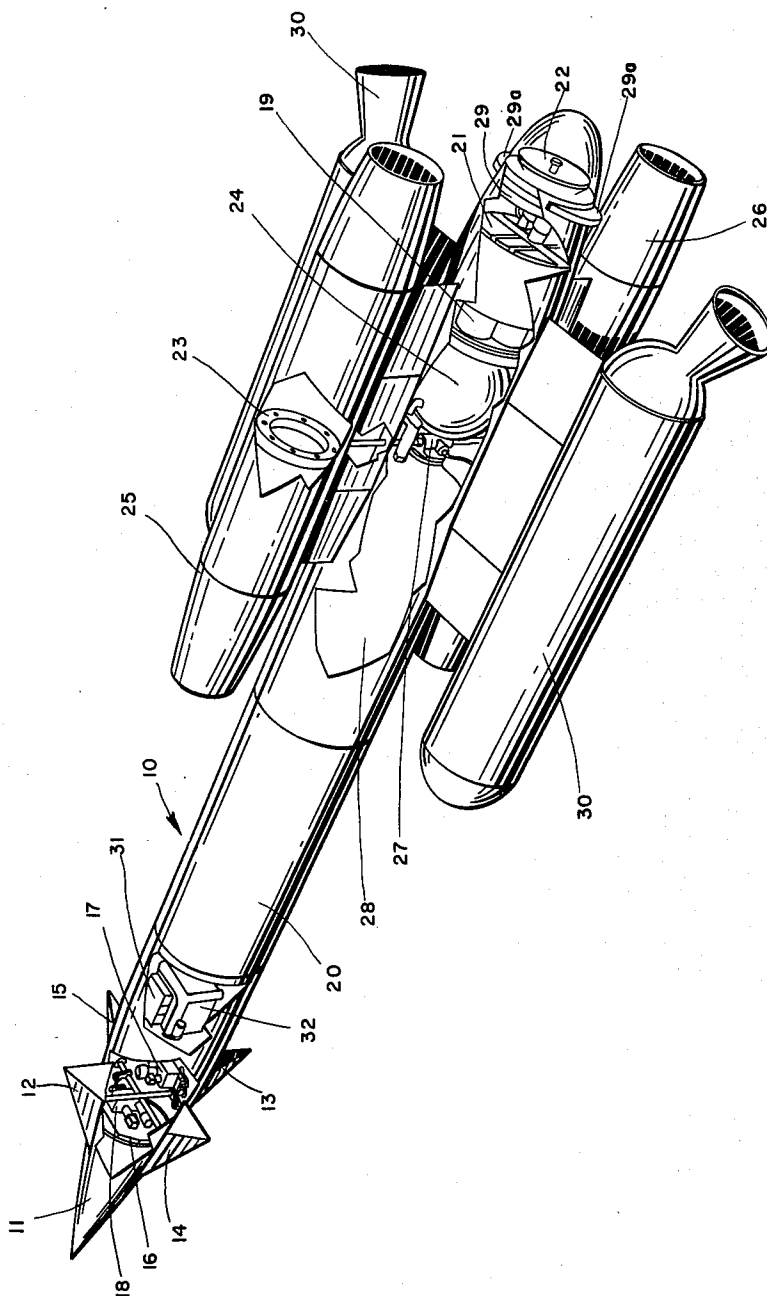
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3,233,848

GUIDANCE SYSTEM WITH A FREE FALLING MASS

Filed Sept. 17, 1959

4 Sheets-Sheet 1



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FIG. 2

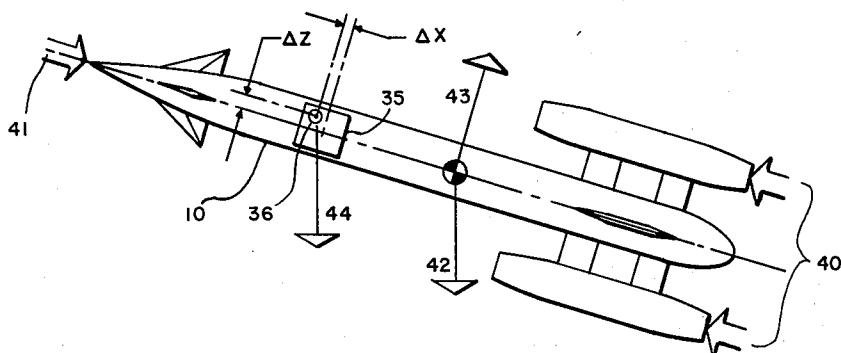


FIG. 3

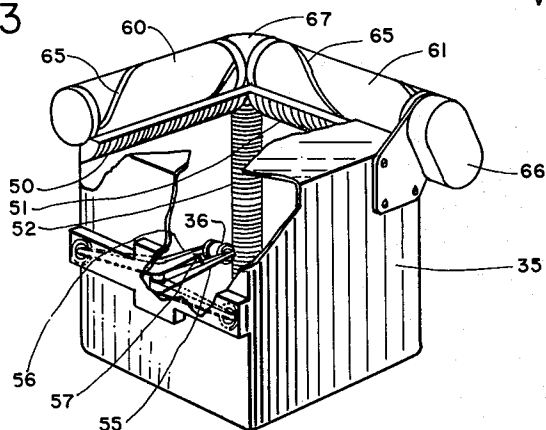
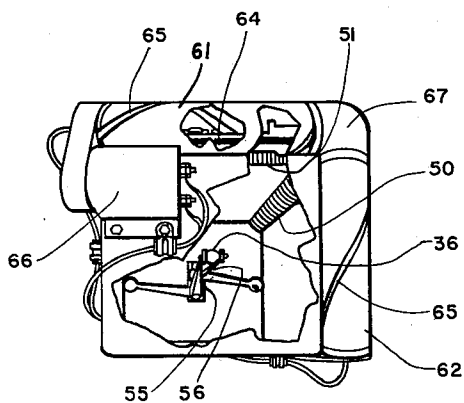


FIG. 4



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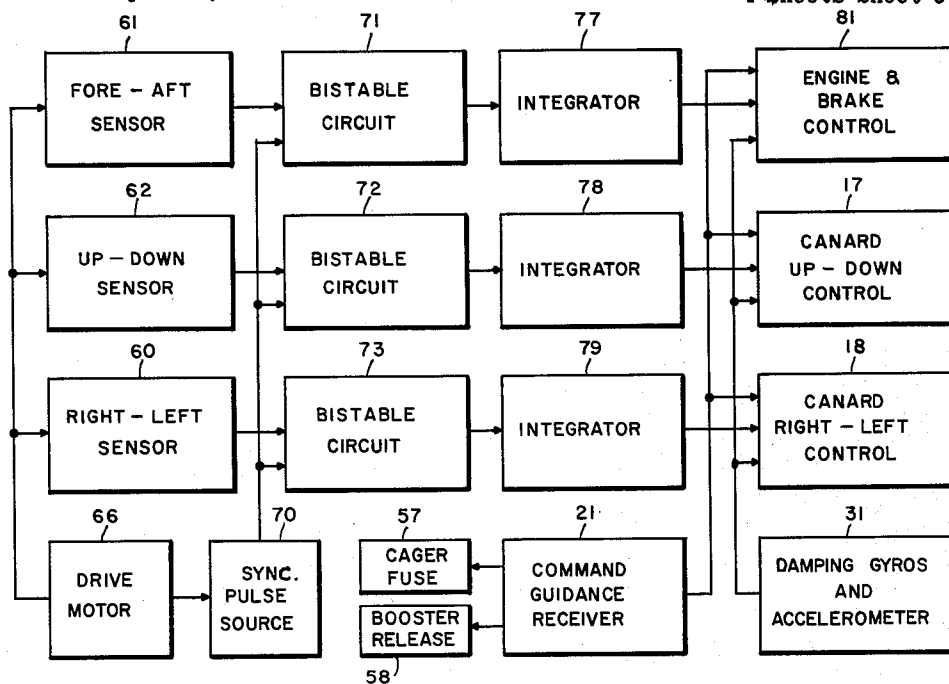


FIG. 5

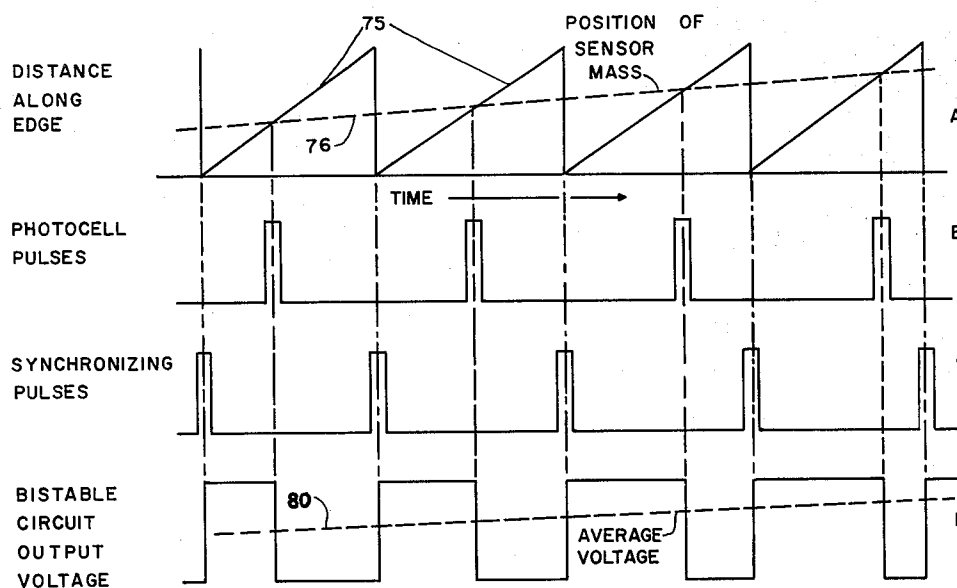


FIG. 6

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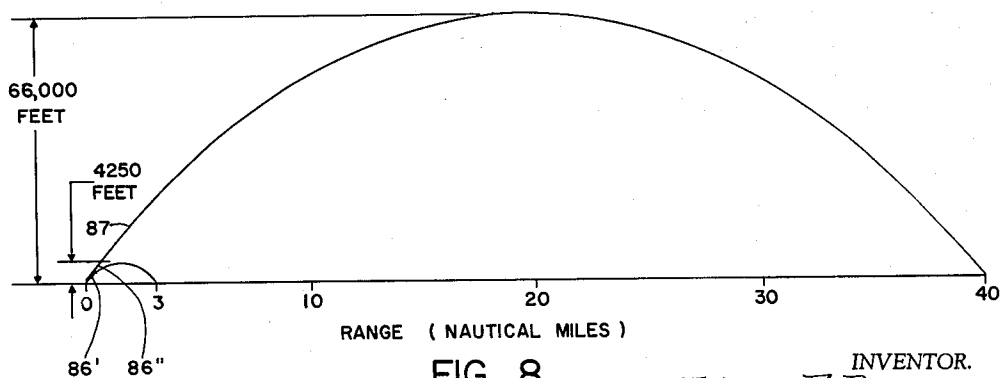
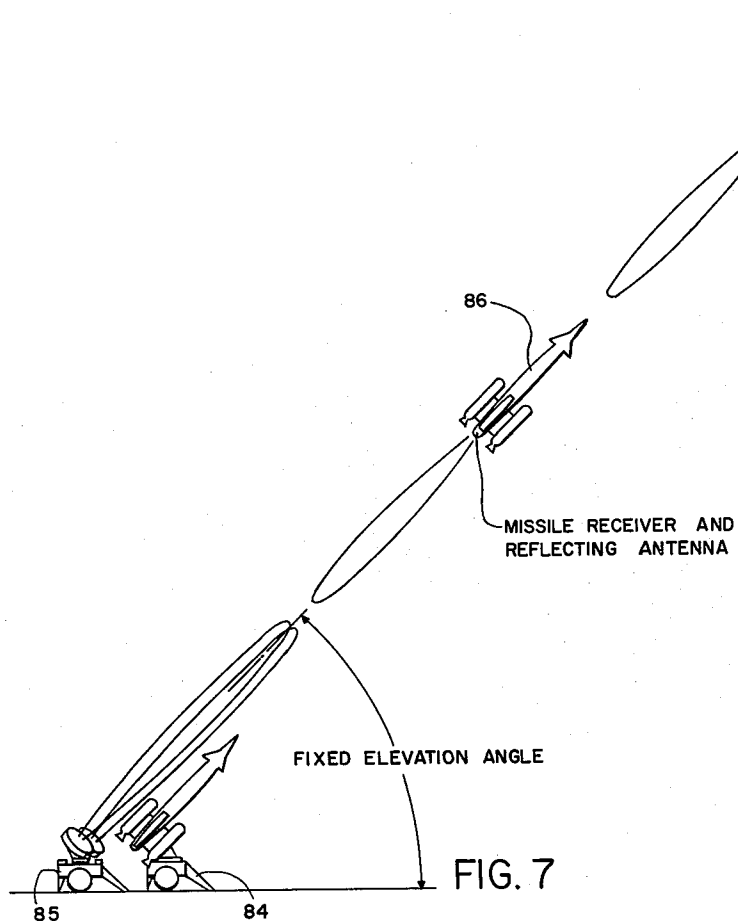
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GUIDANCE SYSTEM WITH A FREE FALLING MASS

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4 Sheets-Sheet 4



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GUIDANCE SYSTEM WITH A FREE
FALLING MASS

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5 Claims. (Cl. 244-14)

This invention relates generally to guided missile systems and more particularly to a system for guiding an airborne missile which is contained within the missile itself.

Missiles have been developed for delivering a war head which is guided so that the war head reaches a desired point. It has been proposed to direct missiles over ballistic trajectories by providing the initial movement with the desired accuracy such that the missile will reach a calculated point. However when missiles travel through the atmosphere the disturbing effects of the atmosphere may cause the missile to vary from the path which would normally be provided by the initial velocity. Accordingly missiles which travel over relatively short ranges, and which therefore travel through the atmosphere, are subject to being diverted by atmospheric disturbances which greatly reduce the accuracy and make the missile unsuitable for the desired use.

Although missiles have been provided wherein the flight is controlled throughout its course by radio, due to the use of electromagnetic counter measures (jamming), such systems may be interfered with and rendered inaccurate. Self-contained inertial guidance systems which have been available to provide guidance all the way to the target have been extremely complex and quite expensive. This has rendered such guidance systems impractical for many applications.

It is therefore an object of the present invention to provide a simple and improved inertial guidance system for missiles.

Another object is to provide a method of guiding a missile so that the missile will follow its true vacuum trajectory and the effect of disturbances produced by the atmosphere are removed.

A further object of the invention is to provide a guidance system for missiles wherein a simple self-contained control system provides complete control of the missile so that it follows a true vacuum trajectory.

A feature of the invention is the provision of an inertial guidance system including a mass which is shielded from atmospheric forces so that it follows the true vacuum ballistic trajectory, and sensors controlled by the mass to guide the missile so that it follows the same path as the mass.

Another feature of the invention is the provision of a method for guiding a missile wherein a mass is shielded within the airframe of the missile and the missile is started on its desired trajectory, with the mass then being freed and any change in position of the missile with respect to the mass being detected, and the course and speed of the missile being altered to eliminate such changes in the relative position of the missile and the reference mass.

A further feature of the invention is the provision of a missile which is initially guided by a radio command system into a desired trajectory, with the missile having aerodynamic control and thrust control for holding the missile on course under control of damping gyros and accelerometers, wherein a reference mass in the missile is freed when the radio command is released and its position is sensed to further operate the aerodynamic and thrust controls of the missile so that the missile follows the same trajectory as the mass, and any changes in path

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resulting from atmospheric disturbances are counteracted.

Still another feature of the invention is the provision of a guided missile including drag brakes for controlling the missile velocity, with the brakes having a normal mean position and being moved to either increase or decrease the braking effect, and the missile having driving means controlled by the position of the brakes to drive the missile so that the brakes may return to the mean position. Alternatively, the driving means and brakes may be simultaneously controlled, or adequate control may be provided in certain applications by adjustment of only the brakes or the driving means.

The invention is illustrated in the accompanying drawings wherein:

FIG. 1 illustrates a missile in accordance with the invention;

FIG. 2 is a schematic drawing showing the guidance concept of the invention;

FIGS. 3 and 4 show the device for sensing the position of the reference mass;

FIG. 5 is a block diagram illustrating the control provided by the sensing device;

FIG. 6 includes curves which illustrate the operation of the guidance control system;

FIG. 7 illustrates the initial guidance of the missile by the system of the invention; and

FIG. 8 illustrates the overall guidance of the system.

In practicing the invention there is provided a self propelled elongated missile for operation over intermediate ranges. The missile includes a nose with aerodynamic control means such as canard control surfaces and actuating means therefor. Thrust control is provided by engines mounted adjacent the rear end of the missile and drag brakes. The engines may be of the ram jet type, with rocket type boosters being provided for the initial acceleration. A war head may be carried at an intermediate section of the missile. A radio receiver is provided at the rear of the rocket for command control of the initial movement thereof. Damping gyros and accelerometers are provided for operating the engine and brakes, and also the canard control surfaces to hold the rocket on its desired course. The main lifting surfaces are located at the rear end of the missile body in a cruciform arrangement.

For providing more precise control to return the missile to course when its trajectory is disturbed by atmospheric conditions, a guidance system is provided which includes a reference mass and means for sensing the position thereof. The reference mass is caged during the initial movement of the rocket while it is under radio control. When the rocket reaches a predetermined velocity the mass is freed and the radio control is discontinued. Sensing devices operate when the missile moves with respect to the mass to guide the missile and hold the same at a predetermined position with respect to the mass. The sensing system includes a sensing device responsive to the longitudinal position to control the engine and brakes, and devices responsive to the right-left and up-down positions to control the right-left and up-down canard control surfaces in the nose of the missile. The missile is therefore adjusted for position in every direction to hold the same in the desired position with respect to the reference mass.

Referring now to the drawings, in FIG. 1 there is shown an airframe, indicated generally at 10, and having a nose 11. Extending from the nose are right-left canard control surfaces 12 and 13, and up-down canard control surfaces 14 and 15. An auto pilot system 16 is provided in the nose including an actuator 17 for the right-left control surfaces 12 and 13 and an actuator 18 for the up-down control surfaces 14 and 15. Back of the nose

11 is a space 20 which may contain the war head. At the rear of the missile is a command radio receiver 21 with an antenna 22.

Ram jet engines 25 and 26 are provided on the tips of one set of the cruciform lifting surfaces at the rear of the missile, with a fuel control valve 27 controlling the flow of fuel to burner rings 23 in the engines. Fuel from the tank 28 is applied through a fuel pressure system 24 to the control valve 27. Drag brakes 29 are also provided having symmetrically positioned adjustable portions extending from the airframe at the rear to further control the movement of the missile. Booster rockets 30 may be provided for generating the desired momentum to establish the initial velocity of the missile. These may be dropped at a predetermined time by a release mechanism 58 (FIG. 5) under control of the command receiver. In the forward part of the missile damping gyros and accelerometers 31 may be provided which will aid in controlling the fuel supply to the engines, the brakes, and the canard control surfaces to hold the missile on its desired course. For more precise control of the missile, a guidance system in accordance with the invention is provided which is indicated generally at 32. Electrical power to operate the missile is derived from a turbine-driven hot-gas electrical generator 19.

The basic guidance system of the invention is illustrated in FIG. 2, which is a schematic diagram showing the rocket as shown more specifically in FIG. 1. Within the airframe 10 there is provided a closed chamber 35. A reference mass 36 is contained in the chamber and is initially held or caged in a central position therein. The missile is started on its course under the control of the command radio system, and after the desired initial velocity is reached the mass 36 is freed and the radio control is discontinued. The missile movement in flight depends upon the thrust of the engine, the missile aerodynamics, the force of gravity and the drag of the atmosphere together with the effect of atmospheric disturbances. The thrust is illustrated by the arrows 40 and the drag by the arrow 41. The force of gravity is illustrated by the arrow 42 and the effect of atmospheric disturbance is indicated by the arrow 43. The reference mass 36 however is influenced only by its initial velocity and the force of gravity which is indicated by the arrow 44.

The mass 36 obtains its initial velocity as it is held within the missile when the missile starts on its course. However when the mass is freed, because it is shielded from atmospheric forces, it is subject only to its initial velocity and the force of gravity. Accordingly the movement of the mass can be very accurately controlled by control of its initial velocity, since the force of gravity remains essentially constant. Therefore, the missile can be accurately held on course by controlling the movement of the missile so that it follows the movement of the reference mass.

When the reference mass moves ahead of the center position as shown by the increment ΔX shown in FIG. 2, it is necessary to increase the thrust of the engine, or reduce the drag of the brakes, so that the missile will accelerate faster than the mass and the initial relative position of the missile and mass are re-established within small tolerances. Likewise when the missile is below the mass as shown by the increment ΔZ , the missile must be caused to rise so that the normal relative position of the missile to the mass is again provided.

Reference is now made to FIGS. 3 and 4 which illustrate a sensor for the reference mass which may be utilized in the system of the invention. In these figures the reference mass 36 may be a self-luminous ball such as a transparent hollow sphere having its inner surface coated with a phosphorous layer and filled with a radio active material. The radiation from the radio active material excites the phosphorous coating causing the ball to emit light radiation isotropically. The cavity 35 is a cubic box each side of which may be of the order of 10 to 20

times the diameter of the ball 36. Along three orthogonal edges of the box 35 are light baffle plates 50, 51 and 52. The baffle plates are perpendicular to the edges along which they are placed so that light from the ball is isolated to small regions along the three edges to define the position of the reference mass with respect to the box.

During the radio controlled movement of the missile the ball 36 is caged or held between arms 55 and 56. These arms are spring biased to open positions, shown in dotted lines, and are held together to retain the ball 36 therebetween by a fuse link 57. The fuse link 57 may be destroyed by applying a pulse of current therethrough under control of the command receiver so that the arms 55 and 56 swing back to free the ball 36. The ball is held by the arms in a central position within the box 35 so that when it is released it is in the desired initial position.

For sensing the position of the ball 36 an optical scanning system is used including three scanning devices 60, 61 and 62 individually associated with the light baffle plates 50, 51 and 52. Each of the sensors includes an opaque cylindrical tube having a transparent spiral slot 65 therein. Inside each tube and directly opposite the baffle plate is a photo-sensitive strip 64 such as a selenium photovoltaic cell. As the scanner rotates the spiral slit 65 exposes a different portion of the strip 64 to the baffle plates. When the portion of the photo-sensitive strip adjacent the region of the baffle plate which is illuminated is exposed by the slot, a pulse of voltage will be produced by the photo-sensitive element. The relation of this pulse to the time when the ends of the strip are exposed will indicate the position of the sphere along one edge of the box. The cylindrical tubes of the three sensors 60, 61 and 62 may be rotated by a single motor 66, with the three tubes being interconnected by gearing 67. The positions of the ball along the three orthogonal edges is therefore simultaneously sensed.

The operation of the sensor and the provision of control voltage thereby is illustrated in FIGS. 5 and 6. FIG. 5 is a block diagram showing the sensors 60, 61 and 62 operated by the drive motor 66. A source of a synchronizing pulse is required and this may be provided by a pickup coil within one of the cylindrical tubes and a mass on the tube which passes the coil at the time the slot exposes one end of the photosensitive strip. This is represented in FIG. 5 by the box 70. Pulses from the source 70 will therefore indicate when the first ends of photo-sensitive strips are exposed to set up the initial time from which the time of the pulses produced by the sensors may be measured.

The same pulse from the source 70 is applied to three bistable circuits 71, 72 and 73 to hold these circuits in one state to produce an output voltage. The sensors 60, 61 and 62 are individually coupled to the bistable circuit 73, 71 and 72 respectively. When a pulse from a sensor is applied to a bistable circuit, the circuit is changed to its second state to cut off the output voltage.

This operation is illustrated by FIG. 6 wherein the upper section A represents the scanning of any one of the sensors, with the slanted solid lines 75 showing the individual scans. The dotted line 76 indicates the position of the reference mass, and the figure illustrates movement of the mass as the point where the mass is exposed by the scan differs in the successive scans. Section B of FIG. 6 shows the pulses produced by the photo-sensitive strip, and these are produced when the scan exposes the light from the mass to the photo-sensitive elements, which occur when the scans 75 cross the dotted line 76 (Section A). Section C shows the synchronizing pulses produced by the source 70 which occur at the initiation of the scan and have a constant repetition rate.

Section D of FIG. 6 shows the output produced by each bistable circuit in response to the synchronizing

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pulses and the pulses from the sensors. It will be obvious that the duration of the pulse increases as the mass moves as shown by the four scans illustrated. The second scan shows the mass at the normal or central position and the pulse has a duty cycle of one-half. In the first scan the pulse is shorter and in the third and fourth scans the pulse is longer.

As shown in the block diagram of FIG. 5 the pulses produced by the bistable circuits 71, 72 and 73 are applied to integrators 77, 78 and 79 respectively. Each of these produces a direct current control voltage which is a measure of the duration of the pulses. The output of the integrator is illustrated by the dotted line 80 of section D of FIG. 6, with the average voltage increasing with the pulse width. This direct current control voltage may be used to control a servo system to position an element which controls the missile so that the voltage is held at an average value. This is shown in FIG. 5 wherein the output of integrator 77, which is a control voltage from the fore-aft sensor 61 controls the engine and brake of the missile designated 81. Actually this will control the engines 25 and/or the brake 29 as required to increase or decrease the velocity of the missile.

As shown in FIG. 1 the drag brakes 29 may have portions 29a positioned symmetrically and extending outwardly from the airframe to produce drag. The extending portions may have a normal or means position and may then be withdrawn to reduce the braking effect or further extended to increase the brake effect. The engines may be controlled from the position of the brakes to provide the required thrust so that the brakes can return to the normal or mean position. The brakes may have sufficient range to provide the required control in a particular application so that control of the engines is not necessary. Alternatively, the engines may be controlled with the brakes, or may provide the full control of the missile velocity. Control by the drag brakes has the advantage of very rapid response.

The output of the integrator 78 is a control signal from the up-down sensor 62 and this controls the up-down canard actuator 17 which controls the surfaces 14 and 15. Similarly the output of integrator 79 is applied to the actuator 18 for the right-left canard control surfaces 12 and 13.

FIG. 5 also shows the coupling of the command guidance receiver 21 to the engine and brake controls and the canard surface controls for guiding the missile and providing the initial velocity thereof under radio control. This figure further shows the coupling of the damping gyros and accelerometers 31 to the engine and brake controls and to the canard controls. The command receiver 21 may also control the booster release 58 and caging fuse 57 to free the reference mass when it is desired that the guidance system take over control of the missile.

FIG. 7 shows the launching of a missile in accordance with the invention. A launcher 84 is provided which may direct the missile at an angle of the order of 45°. A ground radar 85 tracks the missile during the radio control portion of its travel, and may be of the type having a wide angle beam for missile capture and a narrow angle beam for missile control. The initial travel is produced by operation of the booster rockets which may fire for a period of time of from one to three seconds depending upon the range desired. This moves the missile to the point 86 and during this time radio control is transmitted to the missile to correct its direction error. When the missile reaches the point 86 the ram jet engines are ignited and the booster rockets are released. For the next period of movement, the missile velocity is determined by Doppler radar and is controlled by control of the ram jet engines and the brakes so that the missile travels at the desired velocity. The direction of travel is still under the control of the command radio system.

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When the missile reaches the point 87 the reference mass is freed and the remainder of the flight is controlled by the guidance system. Radio control is terminated at this time and the missile is held on its desired trajectory by the damping gyros and accelerometers, with the precise position being maintained through operation of the sensors which track the reference mass. FIG. 8 illustrates the use of the guidance system for controlling a missile used at various ranges from three to forty miles. These limits are merely representative and systems in accordance with the invention can be used for other ranges. As previously stated, the original movement by the booster rockets may have a time duration of from one to three seconds depending upon the overall range. In FIG. 8, point 86' represents the end of the boost period for a minimum range and point 86'' represents the end of the period for a maximum range. The next period during which the missile is driven by the ram jet engines under control of the radio control system is illustrated in FIG. 8 for maximum range as ending at the point 87, as in FIG. 7. The remainder of the flight is under control of the guidance system with the reference mass being uncaged at the point 87. The full trajectory of the missile is shown in FIG. 8.

Although the guidance system has been disclosed for use with a ground to ground surface missile, it will be apparent that the guidance system could be used in missiles operated in other manners. For example, the guidance system could be used in a missile launched from an aircraft, with the initial velocity being imparted by the aircraft. The guidance system would then take over the cause the missile to follow its desired trajectory after it is freed from the craft. The reference mass and sensing devices can control the flight of the missile so that it follows an undisturbed path in the presence of atmospheric disturbances when launched from an aircraft or other vehicle in the same manner as initially launched by use of booster rockets.

The sensing device used in the guidance system may be of various types other than the optical device disclosed. For example the mass may be conducting and its position sensed in an electrostatic system. Alternatively a magnetic mass may be used, the position of which can be detected by magnetic pickup coils. It may be desired to evacuate the chamber 35 containing the mass so that there is no friction on the mass. However this will generally not be necessary as the movement of the mass in the chamber will be slow.

The use of canard control surfaces for aerodynamic control, and ram jet engines and drag brakes for thrust control are merely representative of known apparatus which can be used. The use of ram jet engines is advantageous as the cost is less than for other solid fuel engines which are required in certain missiles.

I claim:

1. In a guidance system for a missile adapted to be slaved to a free falling reference mass having a ballistic trajectory, said mass being released in a closed cavity within said missile as a predetermined velocity is achieved by the missile, an optical scanning system for sensing the relative position of said mass in said cavity, including means for rendering said mass luminous, first, second and third light sensing means positioned along three orthogonal axes of said cavity, first, second and third series of baffle plates positioned between said light sensing means and said luminated reference mass, said baffle plates extending normal to said axes and disposed to allow exposure of discrete portions of said light sensing means to said luminated reference mass as same is displaced along each said axis, and scanner means to sequentially cause said discrete portions of said light sensing means to be exposed to said luminated reference mass to thereby obtain information as to the position of said mass along said three orthogonal axes.

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2. The optical scanning system of claim 1 wherein said scanner means includes an opaque cylindrical tube having a transparent spiral slot therein surrounding each said light sensing means, and means to simultaneously rotate said cylindrical tubes to thereby allow periodic scanning of the position of said mass along said three orthogonal axes.

3. The optical scanning system of claim 2 wherein means are provided on at least one said cylindrical tube to provide a synchronizing signal for each cycle of said scanner means.

4. In a guidance system for a missile adapted to be slaved to a free falling reference mass having a ballistic trajectory, said mass being released in a closed cavity within said missile as a predetermined velocity is achieved by said missile, the control system including in combination, means for rendering said mass luminous, an optical scanning system providing first, second and third output signals indicative of the relative position of said luminated mass in said cavity along three orthogonal axes, first, second and third bistable circuits each having first and second inputs and an output, circuit means coupled to said first input for initially maintaining said bistable circuits in a first state, means coupling said output signals of said first, second and third scanning means to said second input of separate ones of said first,

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second and third bistable circuits to change the state thereof in response to the position of said luminated reference mass along said three orthogonal axes, and an integrating network coupled to said output of each said bistable circuit means, thereby providing three time average signals indicative of the position of said luminated reference mass along said three orthogonal axes.

5. The control system of claim 4 wherein said circuit means for initially maintaining said bistable circuits in a first state provides synchronization for successive scanning cycles of said optical scanning system.

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