

A METHOD FOR DETERMINING THE BALLISTIC
TRAJECTORY OF A PROJECTILE, AS WELL AS DEVICES
FOR CARRYING OUT THE METHOD

5 The invention concerns improvements in or relating to determining the ballistic trajectory of a projectile, as well as a device for carrying out the method.

10 It is known to provide means for the end-phase steering of artillery projectiles (see the article by Peter J. Geogre in "WEHRTECHNIK" 3/79, pages 19, 22, 24-27) which are fired in a caseless manner and without self-propulsion so that projectiles initially describe a purely ballistic trajectory which is afforded by the propellant-charge number (e.g. the launching speed) and the weapon
15 barrel elevation.

 This Application is divided from our Application No. 2134632A which discloses a method for the target homing of a projectile such as an artillery projectile which is self-controlling in its flight end
20 phase along a flat flight path, such as a range extending glide path at a small angle of inclination, from which a target search and target homing is effected, characterised in that after detection of the target object that is to be homed in on initially the flat flight path is still maintained, before upon further distance shortening with
25 regard to the target object a pitch-angle control for transition from the flat flight path into a steeper target approach path is effected; and further discloses a device for steering a projectile, such as an artillery projectile, which self-controls in a programme-controlled manner its flight end phase and which is equipped with a target search
30 mechanism, with regulating and control mechanisms and with control surfaces for the transition from a ballistic firing flight path into a flat range extending flight path and then for steering into a target approach path, for example for carrying out said method; characterised in that a navigation computer is connected subsequent to a store for
35 characteristic data of the ballistic firing flight path and for the transition, ensuing therefrom, into the flat flight path, the

navigation computer having a flight-path extrapolation computing mechanism to which also the target search mechanism is connected and which determines a pitch-angle change point in time for a pitch angle change for steering of the projectile control surfaces to give a steeper target approach path, the pitch-angle change point in time being delayed as compared with a target acquisition point in time and delivered into a flight-cycle time control circuit so that the flat flight path is maintained until the pitch angle change point in time is reached.

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It is known to in-put manually on the projectile that is to be fired (prior to introduction thereof into the weapon barrel) characteristic values regarding the barrel elevation and propellant-charge number, or to put-in directly the range, calculable from these parameters and the preset linearly-flat flight path, to the theoretical path end point. However, this is complicated and, particularly under combat conditions, is extremely fraught with error.

Therefore there arises a problem of ascertaining on board the missile, without the need for a manual data input regarding the firing factors, the ballistic trajectory or the actual initial flight path of the fired projectile.

In order to solve this problem, there is provided in accordance with the invention, a method of determining characteristic data of a ballistic firing flight path of a projectile, such as an artillery projectile which self-controls its flight end phase, characterised in that on board the projectile, during and after the firing thereof from a weapon barrel, the muzzle velocity and the timespan between firing and apogee passage of the projectile are measured, which, in relation to preset ballistic characteristic values of the projectile, represent a measure of the firing propellant-charge number and the firing elevation angle, and thus a determination the ballistic firing flight path of the projectile. There is further provided a device for the input of the characteristic values of a ballistic firing flight into the store of a navigation computer on board a projectile which is

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self-steering along a flat end-phase flight path, such as for carrying out the method of the invention, characterised in that provided on board the projectile is a time measuring circuit for measuring the timespan which elapses between the exit of two sensors, offset
5 relative to one another by a specific distance along the projectile, from the muzzle of a firing weapon barrel, and which circuit also measures the timespan to apogee, to provide information dependent upon these timespans, which information provides the ballistic firing characteristic values for the store.

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This solution stems from the realisation that the purely ballistic trajectory or flight path, can be determined not solely from the firing barrel elevation and propellant-charge number, i.e. from data specific to the gun, but can also be determined specifically from
15 the muzzle velocity and apogee instant, in other words from actual flight derived data. This flight derived data can be ascertained on board the projectile itself, from which data therefore the sought flight-path information can be made available on board the projectile, without having to in-put manually information specific to the gun.

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An embodiment of the invention is described, by way of example, with reference to the accompanying simplified diagrammatic drawings, wherein:-

FIGURE 1 shows the entire flight path of a projectile over the
25 path covered above ground;

FIGURE 2 shows, in a detail representation enlarged as compared with FIGURE 1, the flight end phase beginning with onset of the target search phase;

FIGURE 3 shows a block schematic diagram of essential functional
30 elements for control of the projectile during in the flight end phase represented with FIGURE 2; and

FIGURE 4 shows a block schematic diagram of a device of the invention for an on-board ascertainment of the ballistic firing flight path of the projectile for obtaining information for control of the
35 end-phase represented in with FIGURE 2.

The projectile 21 sketched in FIGURE 1 represents a caseless artillery shell which is equipped with control circuits and control means for an end-phase steering and with a built-in target search mechanism for increasing the accuracy of fire.

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The projectile 21 is fired from a weapon barrel 22. A purely ballistic firing flight path 23 and therewith the orientation of the projectile 21 relative to the horizontal results from the elevation w_1 of the weapon barrel 22 at the firing point z_1 , taking into account
10 factors such as the flow geometry of the projectile 21 and the control fins being swung out, as shown, immediately after the firing; and from the firing or muzzle velocity v_1 of the projectile 21. The latter in turn is determined by the number $\#$ (in other words the quantity) of the firing propellant charges which are arranged and
15 ignited, for the initial acceleration of the projectile 21, behind the projectile in the weapon barrel 22. For a purely ballistic flight path 23 there would thus emerge a ballistic point of impact z_3 .

To achieve a greater combat range, the projectile 21 is steered
20 into a non-ballistic range extending linearly-flat flight path 25. For this, after flying through the apogee 26 of the height h_2 above the location z_2 , flight stabilisation and control measures are initiated in a programme-controlled manner by means of the control surfaces 24, and lift wings 27 (see FIGURE 2) are run out (deployed).
25 From the stored advance data for the automatic control along the flat flight path 25 and the firing derived ballistic flight data there would result an advanced point of impact z_{11} of the projectile 21 in a correspondingly further remote target zone.

30 The projectile is steered out of the ballistic flight path 23 so that the inclination w_{25} (FIGURE 2) of the approximately linear flight path 25 amounts typically to 20° relative to the horizontal. From this, in the advanced target point of impact z_{11} an impact path angle w_{11} of the order of magnitude of also 20° would result, which would
35 however represent an unfavourable attack effective angle with respect to the combat charge in the projectile 21. Therefore there is

10 effected an approach the target object 28 to be combatted in the
actual target point z8 with a target approach path 29, made steeper
relative to the flat flight path 25, at an actual target path angle w8
which is at least twice as large as the impact path angle w11 in the
5 case of the uninfluenced flat flight path 25, and preferably lies in
the order of magnitude of 45° , whereby to greatly improve the
effectiveness of the combat charge in the projectile 21 upon the
target object 28 to be attacked.

10 The so-called flight end-phase begins with the falling below of a
pre-programmed target search height h4, which is preset in accordance
with the target search and target tracking mechanism 30 incorporated
into the projectile 21 and in the case of a millimetre-wave radar
target search mechanism 30 the height is for example of the order of
15 650 m to 700 m, whereupon the target search mechanism 30 (FIGURE 3) is
switched on. Because constructional reasons restrict the angle of
pitch relative to the flight angle of the projectile 21, and because
of the, somewhat steeper, inclination of the flat flight path 25
downwards, there results a target-acquisition limiting angle w6 of,
20 for example, 35° (FIGURE 2); which is why from the position of the
search start location z4 only target objects 28 can be acquired which
lie beyond the nearest acquisition point z6. Potential target objects
beyond the advanced point of impact z11 of the flat flight path 25
cannot as a rule be attacked from this, because that would require a
25 reversal of direction (decrease in inclination) of the flight path
angle w25, which would as a rule be impermissible because it would
apply high accelerative forces to the projectile which could affect
the mechanical stability of the projectile 21 and the mechanisms
incorporated therein.

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If the intended target object 28 were to be attacked directly,
upon being acquired by the target search mechanism 30, by target
tracking homing of the projectile, a target tracking path 31 would
occur which would indeed deviate downwards from the flat flight path
35 25, but would still yield a too small and therefore unfavourable
impact path angle w31 for effective attack.

In the present embodiment, provision is made to control the projectile 21, even after acquisition of the intended target object 28, in such a way that, whilst its yaw direction is immediately changed at the target acquisition point z5 towards the direction of the target object 28, the projectile continues to follow the actual flat flight path 25 so that its inclination is maintained.

A delayed point in time t_7 , for a change of angle of pitch for the derivation from the flat flight path 25, is ascertained in accordance with the proximity to the target object 28, taking into account the theoretical end flight time as far as the linearly advanced point of impact z11 of the flat flight path 25 and the target approach path 29 striven for, on board the projectile 21 as a delay or residual flight timespan t_5 to t_7 . At the point in time t_7 then initially the target tracking and the regulation for the previous maintenance of the projectile path inclination w25 are transiently interrupted and a non-controlled change to a steeper angle of pitch undertaken; whereupon the flight attitude regulation is again put into operation in accordance with this more steeply preset path impact angle w8, in conjunction with target tracking, switched on again, by means of the target search mechanism 30.

For these flight phases, shown in FIGURE 2 as height/path diagrams, for attacking the target object 28 at an optimum target-path impact angle w8, provided on board the projectile 21 is a time control circuit 32 (FIGURE 3). [In FIGURES 3 and 4 lines are denoted by the reference characters accorded to the specific information referred to hereinafter, for the sake of brevity.] The circuit 32 determines the function of the time t and thus, from the known data of the ballistic and the flat flight paths 23 to 25, the point in time t_4 , so that, as the limiting height h_4 for the commencement of the target search is fallen below, the target search mechanism 30 is thus put into operation. Upon target acquisition at the point in time t_5 , the target search mechanism 30 provides follow-up control information regarding the horizontal target displacement 33 and the vertical target displacement 34, in each case related to the instantaneous

spatial orientation of the projectile 21 in its situation relative to the flat flight path 25. The horizontal target displacement information 33 serves immediately as control information for a yaw target follow-up regulator 35. A simple flight-path extrapolation
 5 calculating mechanism 36, determines the point-in-time t_7 for the initiation of the pitch manoeuvre from the flat flight path 25, which manoeuvre, as mentioned, is intended to be left for the transition into the steeper target approach path 29.

10 After receipt of the point-in-time information t_7 from the mechanism 36, the time control circuit 32 supplies, upon occurrence of the point in time t_7 , to pitch regulation mechanism 37 an item of information to cause the pitch control system to be initially interrupted for the change into the steeper target approach path 29,
 15 and, after renewed achievement of a stable flight state, to put the regulation mechanism 37 into operation again, but now taking into account the new path-direction desired value w_8 and the follow-up control by the target search mechanism 30 which is likewise interrupted or switched off and on again. By appropriate control of
 20 the adjusting members for the control surfaces 24 from the yaw target follow-up regulator 35 and the pitch regulation mechanism 37 there is effected an end-phase steering in accordance with the target approach path 29 up to impact at the target point z_8 .

25 For the characteristic values of the actual data regarding the initially ballistic flight path 23 and the following flat flight path 25, for determining the point in time t_7 of the pitch angle change, as well as for the determining, derived from the path data, of the point in time t_4 for the beginning of the flight end-phase target search, a
 30 store 38 is provided. Into this there are in-put prior to the firing point in time t_1 (FIGURE 1) - or immediately afterwards and at any rate prior to the transition into the flat flight path 25 after reaching of the apogee point in time t_2 - the firing data which determine the ballistic flight path 23 of the projectile 21 and which
 35 correspond to the elevation angle w_1 and the muzzle velocity v_1 of the projectile 21. Together with projectile-typical characteristic values

preset in the store 38 there can thus be determined by a navigation computer 54 the height/time flight path picture (as is shown in FIGURE 1 and FIGURE 2 (taking into account the time coordinates t over the location z), after which the described search and control procedures
5 can be triggered by the time control circuit 32.

The actual elevation and velocity data w_1 , v_1 , or the range z_1 to z_{11} calculable therefrom, are set customarily by means of externally accessible adjusting elements on the projectile 21, that is to be
10 fired, prior to loading thereof into the weapon barrel 22 in accordance with the inclination w_1 thereof and in accordance with the propellant charges that are to be supplied. This handling is, however, very prone to non-reproducible false settings or inputs, particularly under combat factors.

15 In this embodiment of the invention, provision is made for determining this initial data, decisive for the flight paths 23 to 25, and thus for the time course of the control interventions from the time control circuit 32, without the need for a manual setting,
20 immediately after the firing of the projectile 21, on board the projectile 21 and for feeding the data into the store 38.

In the projectile walling 40 are two exit sensors 41, 42 which respond to the leaving of the weapon barrel 22 through the muzzle
25 thereof, to ascertain the muzzle or exit velocity v_1 . The sensors 41, 42 are offset mutually by a specific extent 39 in the direction of the velocity vector and thus in the longitudinal direction of the projectile 21. The sensors 41, 42 may be opto-electronic pick-ups which respond to the jump in the ambient brightness upon exit from the
30 weapon barrel 22, or preferably simply coil arrangements which supply exit signals t_{41} , t_{42} as a result of the field change at the weapon barrel muzzle.

Upon or in consequence of firing of the projectile 21 in the
35 weapon barrel 22, a power source 44 is activated, for example by control from an acceleration sensor 45. The power source 44 can, for

example, be an activatable battery, the electrochemical components of which are now brought into action with one another, or be a thermoelectrical or pizelectrical generator which, by reason of the temperature difference behind and in front of the rearward end of the projectile 21 or respectively the initial acceleration thereof, supplies electrical power into the signal processing circuit (in accordance with FIGURE 3 and FIGURE 4). What is crucial is the fact that upon exit from the weapon barrel 22 in any event already the electrical power is available to meet the needs a time measuring circuit 43 (for example a counting circuit for equidistant or regular timing impulses) in order to ascertain the timespan t_{41} to t_{42} . Since the installation distance 39 is preset constructively, in other words is known, it is sufficient, for the ascertainment of the firing velocity v_1 from that timespan t_{41} to t_{42} , to provide, instead of a computer, a table- or reference correlation or decoding store 47. Connected subsequent to this there could be an appropriate translation matrix 48 by means of which the velocity information would be expressed as propellant-charge number $\#$, as is more customary, in the case of artillery, than the numerical value regarding the firing velocity v_1 of the projectile 21.

A time-dependent or path-dependent determination of the ballistic flight path 23, can be made from the necessary knowledge of the muzzle velocity v_1 together with knowledge of the firing elevation w_1 ; and the latter would indeed be determinable by measuring techniques from the actual factors pertaining upon the firing of the gun, but this information is needed on board the fired projectile 21 in order, as described in connection with FIGURE 3, to determine the end point 11 and to derive therefrom the point in time for the control procedures for a delayed and thereby steeper target approach path 29. It is proposed herein to make a determination of the purely ballistic flight path 23 from the muzzle velocity v_1 of the projectile 21 in combination with the point in time t_2 of the passage thereof through the apogee 26, by means of an apogee detector 49 provided on board the projectile 21. The apogee detector may comprise a pressure sensor 50 which supplies a signal regarding the derivative trend in pressure with respect to time during the first time period derived from the

flight path height h ; or/and of an acceleration sensor 51 which supplies, as output signal, directly an item of acceleration information or else the second temporal derivation of the height course of the ballistic flight path 23. Connected subsequent to these 5 sensors 50 or/and 51 is at least one zero indicator 52 which supplies a signal (t_2) to the time measuring circuit 43 when the ballistic flight path 23 (FIGURE 1) passes in the apogee 26 through its height maximum over the time t or respectively over the path z .

10 The timespan t_1 (respectively with sufficient accuracy t_{41} or t_{42}) to t_2 thus represents the second necessary characteristic value for determining the theoretical course of the purely ballistic flight path 23. Together with the already ascertained velocity information in corresponding the actual propellant-charge number $\#$, thus by way 15 of a further reference table or decoding matrix 53 on board the projectile 21 the associated value of the firing elevation w_1 can be ascertained, or the matrix input information can be evaluated directly for the path determination.

20 These items of information (v_1 , t_2) (which correspond to the decisive characteristic data (w_1 , $\#$) for the describing of the ballistic flight path 23) are, as explained in connection with FIGURE 3, stored immediately in the store 38, in order to determine therefrom, by way of a navigation computer 54, the theoretical impact 25 point-in-time or instant t_{11} of the projectile 21 in the advanced path end point z_{11} . From this impact instant t_{11} , occurring only upon absence of the target acquisition, then by means of the calculating mechanism 36, on board the projectile 21, as explained in connection with FIGURE 2 and FIGURE 3, it is extrapolated what delay timespan t_5 30 to t_7 after target acquisition (t_5 over z_5) up to the delayed pitch angle change is to be preset in order then to initiate the target approach path 29 (which provides the considerably improved steeper impact path angle w_8) from the control circuit 32.

35 These point-in-time ascertainments and flight path transitions are ensurable, with comparatively slight cost, in an exceedingly exact

and reproducible manner on board the projectile 21, as an apogee detector 49 (FIGURE 4) is present on board the projectile 21 for the combination of the flight paths 23 and 25. This is because the apogee 26 of the ballistic firing flight path (which the projectile ~~reaches~~ only after the apogee) extends transiently horizontally; and because the flight attitude of the projectile 21 upon passage through the apogee 26 is practically horizontal or in any event divergent only by a slight (and in this respect preset, or known) flight angle-of-incidence relative to the horizontal. Therefore, the apogee instant 10 t_2 , the instantaneous orientation of the projectile 21 in space can be accepted as a horizontal reference position for the function of the pitch regulation mechanism 37 (for control of the projectile along the paths 25 and 29), for example by resetting or zeroing a gyroscopically-stabilised position reference system and of a pitch 15 speed integrator, as taken into account symbolically in FIGURE 3 by a pitch-position reference transmitter 55. The end-phase steering control, crucial for the accuracy of fire, along the flat path 25 is thus effected in an exceedingly precise manner, because previously, namely immediately prior to leaving the ballistic firing path 23, the 20 pitch reference value, crucial for the path angle $w_{25/11}$, has been obtained from the actual flight factors of the projectile 21 itself.

The invention generally provides methods and means to produce a more favourably effective target approach path 29 and for removing the 25 need for error-prone firing-date inputs into the driveless projectile 21 that is to be fired from a weapon barrel 22 and which changes in a self-controlled manner from a ballistic firing flight path with linking flat flight path 25 into an end-phase flight path from which a located target object 28 is homed in on. For this, a change point in 30 time t_7 for a pitch angle change out of the flat end-phase flight path 25 is delayed relative to the target acquisition point in time t_6 , whilst the projectile 21 is still moving in accordance with the preset flat flight path 25, so that only upon the change point in time is the projectile turned to the more steeply extending target approach path 35 29. To determine the optimised change point in time t_7 in relation to the approach to the located target object 28, a theoretical impact

point in time z_{11} of the flat flight path 25, taking into account the ballistic firing flight path 23, is computed on board the projectile 21; for this the actual ballistic firing flight path 23 is ascertained from the timespans $t_{41} \dots t_{42}$, from the exit velocity v_1 of the projectile 21 from the weapon barrel 22 and from the time $t_1/t_{41} \dots t/2$ up to passage through the apogee 26 which are measured on board the projectile. Additionally, by measuring the apogee, the build-up of a positional reference for the path control is made possible.

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CLAIMS

1. A method of determining characteristic data of a ballistic firing flight path of a projectile, such as of an artillery projectile which self-controls its flight end phase, characterised in that on board the projectile during and after the firing thereof from a weapon barrel the muzzle velocity and the timespan between firing and apogee passage of the projectile are measured, which, in relation to preset ballistic characteristic values of the projectile represent a measure of the firing propellant-charge number and the firing elevation angle, and thus a determination of the ballistic firing flight path of the projectile.
2. A method as claimed in Claim 1 characterised in that to determine the launching velocity of the projectile a timespan is measured between the instants at which two points, at a specific distance from one another along the projectile, emerge from the barrel as the projectile leaves the weapon barrel.
3. A method as claimed in Claim 1 or 2, characterised in that, to obtain information regarding the ballistic flight path, on board the projectile upon or after launching thereof an evaluation of acceleration measuring signals is undertaken.
4. A device, for providing characteristic values of a ballistic launching flight path for a store of a navigation computer on board a projectile which is self-steering along a flat end-phase flight path, characterised in that the device is provided, on board the projectile, with a time measuring circuit for measuring a timespan which elapses between the emergence of two sensors, mutually offset by a defined distance along the projectile, from the muzzle of a launching weapon barrel, which circuit also measures the timespan to apogee, to provide information dependent upon these timespans which information provides the ballistic launching path characteristic values.
5. A device as claimed in Claim 4, characterised in that to the





device is arranged to receive an input from an acceleration sensor of the projectile.

6. A device as claimed in Claim 4 or 5, characterised in that a pitch-position reference transmitter is provided, which upon apogee passage provides an item of horizontal reference information for a pitch regulating mechanism.

7. A projectile incorporating a control system which is constructed or arranged to perform the method claimed in any one of Claims 1 to 3.

8. A projectile incorporating a device as claimed in Claim 4, 5 or 6.

9. A projectile comprising means to detect or ascertain measurements of the velocity of the projectile at the moment of discharge of the projectile from a weapon barrel and the timespan from discharge to the moment at which the projectile reaches apogee; means to store information relating to the ballistic or aerodynamic characteristics of the projectile; and means to derive from said measurements and information a determination of the flight of the projectile to apogee.

10. A device or a projectile incorporating a device arranged, substantially as hereinbefore described with reference to FIGURE 1 or FIGURE 4, of the accompanying drawings, to ascertain characteristic values of a ballistic flight path of a or the projectile from firing to apogee.

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