Aug. 27, 1963 R. G. SHELLEY 3,102,262

LEAD COLLISION TRACK AND SCAN SYSTEM

Filed Feb. 1, 1957 2 Sheets-Sheet 1

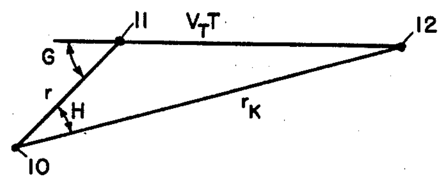

FIG. 1

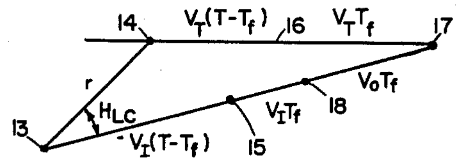

FIG. 2

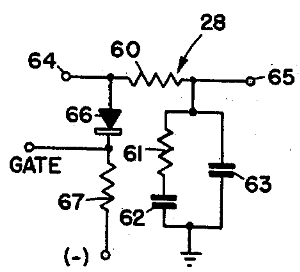

FIG. 6

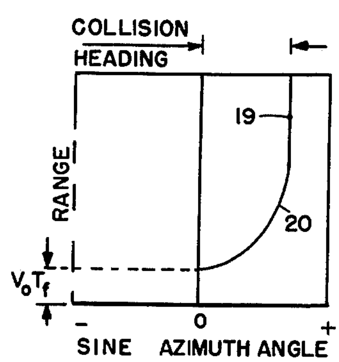

FIG. 3

INVENTOR.
RULON G. SHELLEY
BY Allan Rothenberg
ATTORNEY

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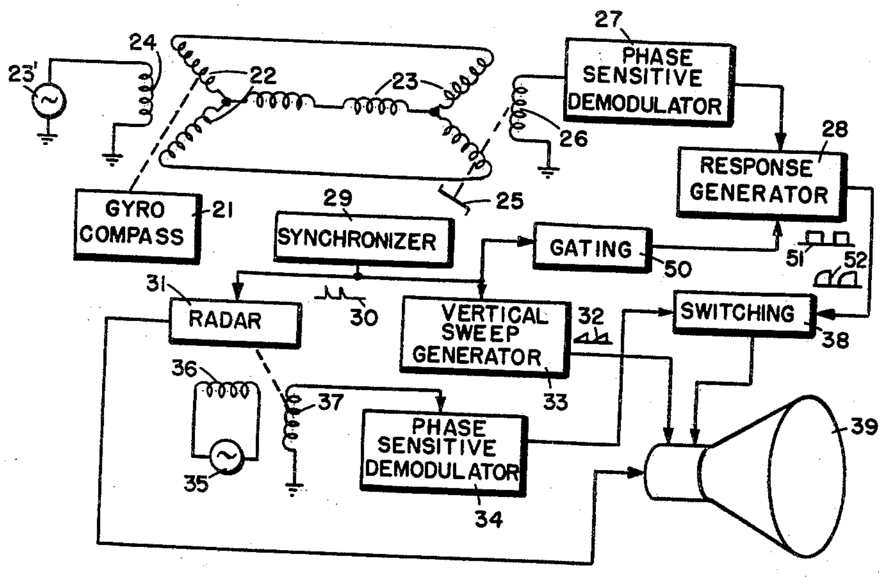

FIG. 4

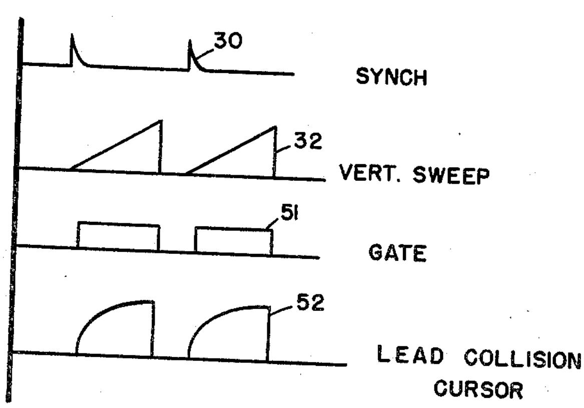

FIG. 5

INVENTOR.
RULON G. SHELLEY

BY Allan Rothenberg

ATTORNEY

United States Patent Office

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LEAD COLLISION TRACK AND SCAN SYSTEM

Rulon G. Shelley, Downey, Calif., assignor to North American Aviation, Inc.

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This invention relates to track and scan systems and more particularly to apparatus for providing the operator of an attacking vehicle such as an interceptor aircraft with means for obtaining a suitable approach course while simultaneously scanning in and about a target area.

Present lead pursuit systems provide a pursuit type approach course which ends upon the tail of the target or else are "g" limited (limited by the maneuverability of the aircraft) or beyond firing range. A tail chase is undesirable when attacking a target which carries tail armament. Further, the interceptor would be better able to say out of the target jet wash and the kill probably would be increased if, at the time of firing or at the time of initiation of a lead pursuit course, the interceptor could be positioned at a greater angle off the tail of the target.

The present invention provides the interceptor pilot with means for obtaining a straight line approach course that terminates tangent to a lead pursuit path, thus placing the interceptor in a more favorable position to complete the attack. Such an approach course is a lead collision course. In accordance with the invention, the interceptor pilot is provided with a display of the range and bearing of the target relative to the interceptor and its heading. There is generated a signal which is indicative of the lead collision angle, defined as the angle between the line of sight from the interceptor to the target and a line from the interceptor which lies along the lead collision path. This signal is utilized to provide a bearing cursor on the display which when superimposed upon the displayed target indicates the desired lead collision course. By suitable azimuth maneuver of the interceptor, the pilot will maintain coincidence of target and cursor to keep the interceptor on the lead collision course.

It is an object of this invention to improve the tracking of a moving target.

A further object of this invention is to track a moving target while simultaneously scanning an area in and about the target.

Another object of this invention is to obtain an improved approach course.

A further object is the provision of apparatus for enabling a pilot to maintain a lead collision approach course.

These and other objects of the invention will become apparent from the following description taken in connection with the accompanying drawings in which:

FIGS. 1 and 2 illustrate attack geometry;

FIG. 3 illustrates a typical display obtained with the apparatus of the present invention;

FIG. 4 comprises a schematic illustration of the electrical components of a preferred embodiment of the invention;

FIG. 5 is a timing chart of the wave forms which exist in the apparatus of FIG. 4; and

FIG. 6 illustrates the circuitry of one form of response generator.

For a brief discussion of attack geometry reference is made to FIGS. 1 and 2, wherein an interceptor aircraft located at point **10** is attacking a target located at point **11** and headed in the direction of the line **11—12**.

The symbols used in FIGS. 1 and 2 are defined as follows:

G represents the angle between target heading and the line of sight from interceptor to target.

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H represents the lead angle.

H_{LC} represents the lead collision angle.

V_T represents target velocity.

T represents the time interval between the time at which the approach course is computed and the time of the attack.

r_K represents the distance from the initial interceptor position to the point of attack.

r represents the range of the target.

V_I is the interceptor velocity.

V_0 is the velocity of the interceptor's missiles relative to the interceptor.

T_f is the flight time of the missiles.

From the general attack diagram of FIG. 1, the lead angle H may be defined as

$$\text{sine } H=\frac{V_T T}{r_K}\text{ sine } G \quad (1)$$

For a pure collision course

$$r_K=V_I T \quad (2)$$

and the collision lead angle H_C may be defined as

$$\text{sine } H_C=\frac{V_T}{V_I}\text{ sine } G \quad (3)$$

The lead collision geometry is illustrated in FIG. 2 and defines a course which will bring about collision of the interceptor's missiles with the target rather than collision between the interceptor itself with the target as in the pure collision course. With the interceptor and target initially at points **13** and **14** respectively, the interceptor will fire its rocket or other missiles when it is at point **15** at which time the target is at point **16**. The target then travels a distance of $V_T T_f$ to point **17** where it meets the fired missile. At the time of collision between target and missile, the interceptor is at point **18**. Since the missiles are fired along the interceptor heading, it will be seen that when the interceptor is at point **18**, the lead angle is zero since the interceptor is now headed directly at the target and the target range is $V_0 T_f$. Thus for the lead collision course

$$r_K=V_I T+V_0 T_f \quad (4)$$

and the lead collision angle H_{LC} is defined as

$$\text{sine } H_{LC}=\frac{V_T T}{V_I T+V_0 T_f}\text{ sine } G \quad (5)$$

$$=\frac{V_T}{V_I}\frac{1}{1+\frac{V_0 T_f}{V_I T}}\text{ sine } G \quad (6)$$

For a long initial range $V_I T$, the lead collision angle H_{LC} and the collision angle H_C are substantially equal,

$$\text{sine } H_{LC}=\text{sine } H_C=\frac{V_T}{V_I}\text{ sine } G \quad (7)$$

It can be shown that the equation relating the lead collision angle to the collision angle is

$$\text{sine } (H_C-H_{LC})=\frac{V_0 T_f}{r_k}\text{ sine } H_C \quad (8)$$

For a collision course, it is known that the rate of rotation in inertial space of the line of sight from the interceptor to the target is zero. Since the approach problem is mainly one of azimuth only and along the earth's surface a suitable criterion for a collision approach course is a constant azimuth angle between the line of sight from the interceptor to the target and the line from the interceptor in a fixed spatial direction such as magnetic north. Thus a collision course cursor may be displayed on a B type radar presentation for example, by initially superimposing a bearing cursor upon the displayed target and causing such cursor to move relative to the interceptor heading in accordance with the relative rotation of the interceptor heading and magnetic north. However, since the collision approach course does not put the attacking airplane near a firing position, it is more desirable to provide a cursor which indicates a lead collision course to enable the interceptor to fly a straight line course that terminates tangent to a lead pursuit path in a position to complete the attack. The characteristics of such a lead collision course are that at long ranges the rate of rotation in inertial space of the line of sight from the interceptor to the target approaches zero, i.e., the lead collision and collision paths are essentially the same at long range as indicated by Equation 7. As range decreases, the rate of rotation of the line of sight to the target increases for the lead collision course thus decreasing the lead angle which, as pointed out above, becomes zero at the nominal relative firing distance, V_0T_f.

In accordance with the invention, there is generated a reference signal continuously indicative of the heading of the interceptor relative to a fixed spatial direction and a bias signal is added to this reference signal to produce a collision course signal. The collision course signal H_C is fed to a response generator which substantially computes the lead collision angle H_{LC} in accordance with Equation 8. The output of this response generator is plotted against range from the interceptor to provide the lead collision cursor. The display thus provided will appear as indicated in FIG. 3 and comprises the target trace **19** and the lead collision cursor **20** together with such other targets that may be within the scanning field of the radar.

Referring now to FIG. 4, a gyro compass **21** may include a suitable position indicating synchro which provides a shaft rotation output proportional to the angle between interceptor heading and a fixed spatial direction such as magnetic north. This angle may be the aircraft azimuth heading. This shaft rotation output is applied to rotor coils **22** which are energized at some suitable frequency such as for example, 400 cycles per second, by source **23'** and stator coil **24**. A bias angle may be added to the gyro compass derived angle by a manual control **25** connected to rotate rotor coil **26** which is energized from rotor **22** through stator coils **23**. The signal thus induced in rotor **26** alternates at the frequency of source **23'** and has a magnitude directly proportional to the sine of the difference or algebraic sum of the gyro compass derived angle and the manually derived bias angle. This signal is fed to a phase sensitive demodulator **27** which produces a direct current output of a polarity and magnitude in accordance with the phase and magnitude of the signal in rotor **26**. Thus the output of the phase sensitive demodulator is proportional to sine H_C, the collision lead angle. The signal sine H_C is fed to response generator **28** more particularly described hereinafter which substantially computes the lead collision angle sine H_{LC}.

The radar system itself is substantially conventional and comprises synchronizer **29** which produces the synch pulses **30** which control the repetition rate of the pulses transmitted by the radar **31** and of the vertical sweep voltage **32** produced by the vertical sweep generator **33**. A horizontal deflection voltage proportional to the sine of the bearing of the radar antenna relative to the aircraft heading is obtained from a phase sensitive demodulator **34** which is energized from alternating current source **35** and stator coil **36** through rotor coil **37** which is physically positioned by an angular position signal derived from the radar **31**. The position signal from the radar is directly proportional to the antenna bearing angle. This direct current signal from demodulator **34**, proportional to the sine of the antenna bearing, is fed through the switching or time-sharing circuit **38** to the horizontal deflection controls of display device or cathode ray tube **39** together with the vertical sweep voltage **32** which is fed to the vertical deflection controls of the display device. Thus the cathode ray of the tube **39** is caused to move over the display area or screen of the tube is accordance with the angular antenna position and a predetermined time base indicative of range. Echoes of pulses transmitted by the radar and reflected from a target are received by the radar and fed to the intensity controls of the cathode ray tube whereby there is produced a B scan display indicating target range in accordance with the vertical deflection of the display point **19** (FIG. 3). The display also indicates the sine of the target azimuth angle relative to the interceptor heading as indicated by the horizontal deflection of the display point **19**. Thus with the switching device or circuit **38** in position to feed the antenna bearing signal to the tube **39**, the apparatus will provide for the scanning of the area within an angle such as, for example, 60° to either side of the aircraft heading. With the switching circuit **38** disposed to couple the output of the response generator **38** to the horizontal deflection control of tube **39**, the vertical sweep signal is fed, as above, to the vertical deflection controls and the cathode ray of the tube is horizontally displaced in accordance with magnitude of the sine of the lead collision angle. Thus the lead collision angle is plotted on the screen as a function of range from the interceptor to produce the lead collision cursor **20**. Gating circuit **50**, timed from synchronizer **29**, generates a gating signal **51** which is delayed from the start of the vertical sweep by a predetermined time which may be proportional to V_0T_f range as indicated in FIG. 5. The switching circuit **38** effects the time sharing of the lead collision cursor with the antenna bearing signal whereby there is simultaneously (due to screen persistence) displayed results of the antenna search of the target area and the azimuth cursor which enables the pilot to maintain the lead collision approach course as will presently be described.

It will be readily appreciated that the invention could be implemented by means of a multiple gun oscilloscope thus eliminating the need for switching circuit **38**. With such a multiple gun arrangement the cursor and vertical sweep might be put on one gun while the target and search information would be on another.

Assume the pilot has acquired a target on the B scope display during normal scanning operation at or near maximum range. The cursor **20** is now appearing on the screen or at this time a suitable switch may be operated to cause the azimuth cursor to be timed-shared with the search display. Manual control **25** is then actuated by the pilot to generate the bias signal indicative of the angle between a spatial reference line (the magnetic north detected by the gyro compass) and a line between the target and the interceptor. This is actually effected by turning the knob **25** until the crustor **20** is shifted horizontally to be positioned directly over the target. It is then necessary for the pilot to maneuver and fly the interceptor so as to keep the target azimuth rate or drift relative to the collision trace zero. In effect the pilot has established the collision angle H_C which at this long range is substantially equal to the lead collision angle H_{LC}. The pilot maneuvers the aircraft so as to maintain the target superimposed upon the azimuth cursor. If the pilot has established the proper course, the target will continue to move down the lead collision trace and this maneuver is continued until the display indicates to the pilot that a suitable firing range has been reached or that a range suitable for initiating a lead pursuit path has been reached. If the target appears to drift with respect to the trace, a change in heading of the aircraft is required until the drift is again zero. The hand control **25** would then be adjusted slightly to again superimpose the cursor on the target if lateral displacement had occurred. This procedure will result in a proper lead collision approach course to the firing range. It will be seen, therefore, that the juxtaposition or superposition of the lead collision cursor on the target by the display device in effect compares the target bearing with the lead collision angle at substantially all target ranges.

It can be shown that the lead collision trace indicated by Equation 8, the variation of the lead collision angle with collision angle, can be substantially matched by an exponential of the following form

$$\text{sine } H_{LC}=1-K_1e^{-\alpha t}-K_2e^{-\beta t} \quad (9)$$

where

$$t=\frac{r}{V_0T_f}-1 \qquad \alpha=.15$$

$$K_1=.217 \qquad \beta=1.5$$

$$K_2=.783$$

This exponential curve may be substantially duplicated by the response to a step input in sine H_C, delayed $2.031\times10^{-9}\ V_0T_f$ seconds, of a network which has the transfer function of

$$\frac{\text{sine } H_{LC}}{\text{sine } H_C}=\frac{T_1S+1}{(T_2S+1)(T_3S+1)} \quad (10)$$

where T_1, T_2, and T_3 are predetermined values given in real time as indicated below and S represents the complex operator indicating the operation of differentiation. However, the actual values required will be determined by the vertical sweep rate used on the display tube.

A network having the transfer function defined in Equation 10 is indicated in FIG. 6 and comprises a resistor **60** having one end thereof coupled to ground through a pair of parallel paths comprising resistor **61**, capacitor **62** and capacitor **63**. The input to the circuit from the phase sensitive demodulator **27** (FIG. 4) is at terminal **64** while the output thereof is derived at terminal **65** which comprises the junction of elements **60**, **61** and **63**. The gating signal **51** may be fed to the junction between the cathode of diode **66**, which has its anode connected to terminal **64**, and resistor **67** which is connected to a suitable source of negative potential. Thus in the absence of the gating signal, the diode clamps terminal **64** to a relatively low potential which may be ground while the positive gating signal will cut off the diode and allow the collision signal H_C to be fed to the response generator **28**.

Exemplary component values of the circuit of FIG. 6 which will provide an output H_{LC} closely approximating the value thereof given in Equation 8 are as follows: For an assumed value of V_0T_f equal to 5,000 feet.

Resistor **60**=200.6 ohms
Resistor **61**=1,000 ohms
Capacitor **62**=.055 microfarad
Capacitor **63**=.0415 microfarad

These values define the constants T_1, T_2 and T_3 of Equation 10 and the latter becomes

$$\frac{\text{sine } H_{LC}}{\text{sine } H_C}=\frac{(11.013V_0T_f\times10^{-9})S+1}{[(13.53V_0T_f\times10^{-9})S+1][(1.35V_0T_f\times10^{-9})S+1]} \quad (11)$$

It is to be understood that the invention is not to be limited to the specific circuitry or values thereof which have been disclosed since the desired response, H_{LC} or sine H_{LC}, may readily be obtained by other circuits or components of other values as will readily be apparent to those skilled in the art.

Although the invention has been described and illustrated in detail, it is to be clearly understood that the same is by way of illustration and example only and is not to be taken by way of limitation, the spirit and scope of this invention being limited only by the terms of the appended claims.

I claim:

1. Tracking apparatus comprising means for deriving the range of a moving target relative to an attacking aircraft and the target bearing, means for deriving the lead collision angle of said aircraft relative to said

target as a function of target range, and means for presenting said angle for comparison with said bearing at varying ranges.

2. A tracking system comprising means for obtaining the range and bearing of a moving target with respect to an approaching vehicle and its heading, means for generating a signal representative of collision angle of said vehicle relative to said target, response means coupled with said generating means for providing a course signal representative of lead collision angle of said vehicle, and means for presenting said course signal for comparison with said range and bearing.

3. A tracking system comprising means for obtaining the range and bearing of a moving target with respect to an approaching vehicle and its heading, means for generating a signal representative of collision angle of said vehicle relative to said target, response generator means responsive to said signal for providing a recurring and delayed step function of said signal, said step function comprising a lead collision course signal having a substantially exponential rise, and means for presenting said lead collision course signal for comparison with said range and bearing.

4. A track and search system comprising a display device having a display area and means for producing a display point on said area, first deflection means including a sweep generator for controlling the position of said display point in a first direction on said area, radar means for generating range and bearing signals, means responsive to said range signal for intensity modulating said display point, second deflection means for controlling the position of said display point in a second direction on said area, means for generating a collision signal indicative of the angle between the heading of an attacking aircraft and a spatial reference line, means for generating a lead collision course signal as a function of said collision signal, and means for alternatively feeding said bearing signal and said lead collision course signal to said second deflection means.

5. A track and scan system comprising radar means for producing a display of the range and bearing of a moving target relative to an attacking aircraft and the heading thereof, means for generating a reference signal continuously indicative of the heading of said aircraft relative to a fixed spatial line, means for generating a bias signal indicative of the angle between said spatial line and a line between said target and aircraft at relatively long target range, means for combining said reference and bias signals to produce a collision course signal indicative of the collision angle between the heading of said aircraft and a spatial reference direction, means for generating a lead collision course signal as a function of said collision course signal and decreasing with decreasing range, and means responsive to said lead collision course signal for producing an azimuth cursor on said display.

6. A tracking system for indicating a lead collision approach course of an attacking aircraft comprising gyro compass means for generating a signal proportional to the azimuth heading of said aircraft relative to a spatial direction, means for generating a bias signal proportional to the angle between said spatial direction and the line of sight from said aircraft to a target at relatively long target range, means for generating a collision course signal proportional to the sine of the algebraic sum of said angle and said azimuth heading, a lead collision circuit having a transfer function defined by

$$\frac{T_1S+1}{(T_2S+1)(T_3S+1)}$$

where T_1, T_2 and T_3 are predetermined values, means for repetitively feeding said collision course signal to said circuit, and means for indicating the output of said circuit as a function of range from said aircraft.

7. The system of claim 6 including means for superposing on said indication of the output of said circuit an

indication of the range and sine of the bearing of said target relative to said aircraft and its azimuth heading respectively.

8. Tracking apparatus comprising spatial reference means for generating a signal which is a predetermined function of the collision angle H_C between the heading of an attacking aircraft and the line of sight between said aircraft and a target, course means responsive to said reference means for generating a course signal which is a predetermined function of a lead collision angle H_{LC} substantially defined by

$$\text{sine } (H_C - H_{LC}) = \frac{V_0 T_f}{r} \text{ sine } H_C$$

where V_0T_f is a predetermined distance and r is the range of said target from said aircraft, and means responsive to said course means for plotting said angle H_{LC} as a function of said range r.

9. A track and search system comprising a display device having a display area and means for producing a display point on said area, first deflection means including a sweep generator for controlling the position of said display point in a first direction on said area, radar means for generating range and bearing signals, means responsive to said range signal for intensity modulating said display point, second deflection means for controlling the position of said display point in a second direction on said area, means for generating a collision signal indicative of the angle between the heading of an attacking aircraft and a spatial reference line, circuit means responsive to said collision signal generating means for computing a course signal indicative of the lead collision angle between the heading of said aircraft and a line therefrom to a target, and means for alternatively feeding said bearing signal and said course signal to said second deflection means.

10. A track and scan system comprising radar means for producing a B scan display of the range and bearing of a moving target relative to an attacking aircraft and the heading thereof, means for generating a reference signal continuously indicative of the heading of said aircraft relative to a fixed spatial line, means for generating a bias signal indicative of the angle between said spatial line and a line between said target and aircraft at relatively long target range, means for combining said reference and bias signals to produce a course signal indicative of the collision angle between the heading of said aircraft and a spatial reference direction, computer means responsive to said combining means for generating a signal substantially proportional to the lead collision angle between said aircraft heading and a line from said aircraft to said target, and means responsive to said computer means for producing an azimuth cursor on said display.

11. A track and scan system comprising radar means for generating range and bearing signals indicative of range and bearing of a moving target relative to an attacking aircraft and its heading respectively, a gyro compass having a shaft output proportional to the azimuth heading of said aircraft, a rotor coil connected to be driven by said shaft output, means for energizing said rotor coil, a second rotor coil, means for manually driving said second coil, means for energizing said second coil from said first rotor coil, a lead collision angle computer, a gating circuit synchronized from said radar means, means responsive to said gating means for repetitively feeding the output of said second coil to said computer, said radar means including means for displaying said range and bearing signals, and means synchronized from said radar means for plotting the output of said computer on said display means as a function of range from said aircraft.

12. The system of claim 11 wherein said lead collision angle computer comprises a first resistor, one end of said resistor comprising an input terminal to said computer, a series connected capacitor and resistor connected between the other end of said first resistor and a fixed potential level, and a second capacitor connected across said series connected capacitor and resistor, said other end of said first resistor comprising an output terminal of said computer.

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