Sight Line Autopilot: A New Concept in Air Weapons

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Theme

ALTHOUGH the accuracy of the sidefiring aircraft (represented by the AC-130s) is excellent relative to other weapon systems, a detailed error analysis reveals that the pilot is by far the dominant source of remaining error. It was concluded that the accuracy of his pointing the aircraft could be dramatically improved if the sight line were aimed automatically. The sight line autopilot (SLAP) is designed to meet this need. The design accounts for the linearized motions of the sight line as seen in the pilot's reference frame and adjoins these to the aircraft attitude states and two oscillating wind states.

Using optimal regulator theory, the control gains are generated. Using these gains, extensive simulations were run to validate the controller. Included were winds and sensor noise. The results show that the concept of a SLAP will significantly improve the capability of the sidefiring weapons system.

Contents

The development of the gunship concept for air warfare has progressed steadily since the early operations of the AC-47 "Dragonships" through the initiation of the AC-130 model aircraft into the program. The degree of sophistication has also increased from an area coverage device, which required little accuracy, to a designated target device, requiring a high degree of accuracy. The accuracy requirement demanded of further investigation of error sources in the weapon system.

The Department of Astronautics and Computer Science at the U.S. Air Force Academy has been steadily supplying assistance to the Gunship Office and conducted the principal investigation of error sources. Early in the research it was determined that the pilot was a major error source. This was not entirely his fault. The AC-130 has lightly damped dutchroll characteristics which make it very difficult to fly attitude to fractions of a degree. Vastly complicating the picture is the fact that the attack geometry is a steady turn with the guns mounted out the side. Thus, lateral and longitudinal motions are not separable. Furthermore, the required attack mode is to fly at nearly constant altitude and air speed on any given firing run.

The New Autopilot

The requirements to maintain the necessary flight condition to achieve acceptable accuracy are so severe that it became quickly apparent that the pilot would greatly benefit from a specialized new autopilot. The autopilot would hold the weapons on target, even in the face of winds, using errors detected by the fire control system. The important thing is to be able to fire and hit the target—not to fly a circular pattern. Thus, with this autopilot, the target should always lie along the "hot line". A problem overview can be obtained from Fig. 1. It can be seen that this is a classic regulator problem. The principle complication is that this is at least a twelve state, three input system. Because of the turning condition it is not possible to separate the modes, and the wind is a very significant factor.

This problem was attacked and solved using optimal control theory. The optimal design has been verified by extensive simulations including the effect of noise, outside unknown constant error sources, and limiters on the control surface motion.

The Dynamical Model

The dynamic model equations for the gunship problem can be considered in two parts. These two parts correspond to 1) the motion of the aircraft with respect to a given air mass, and 2) the motion of a point on the ground with respect to an observer on the aircraft. The development of the linearized velocity and attitude equations of motion of an aircraft about a nominal flight condition are very well known; for a complete derivation see Ref. 1.

The equations for the second part were specifically derived for this problem as motion of the sight-line about the nominal position, in the aircraft coordinate frame. These equations are presented in Ref. 3.

The seven aircraft states,§ the three position states, and the two wind states form the dynamic plant for the problem. The control elements chosen are the aircraft control surfaces, rudder, aileron, and elevator. Conspicuously left out here is a throttle control; however, the throttle is used to independently maintain constant airspeed. The system we have defined is therefore of twelve coupled states with three independent inputs.

The Control Problem

The gunship, during its attack maneuver, attempts to maintain the target in a very nearly fixed position in the aircraft coordinate frame. This position is on the left beam and below the wing line. Thus, the aircraft flies a modified pylon turn about the target. For this reason it was natural to select an aircraft oriented coordinate frame in order to define the translational position of the aircraft. In other words, the autopilot will attempt to position the target out the left wing and down, using the coordinates Elevation E, and Azimuth A which were defined in Fig. 1. In addition, altitude is to be held near nominal.

The problem being addressed is that of a linear regulator. The solution for quadratic penalties using optimal control theory is well known.[2]

The selection of the penalties on control was initially made on the basis of the Bryson rule (Ref. 2, p. 149). That is, weights on A, E and h which were inversely proportional to

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Index categories: Aircraft Handling, Stability and Control; Aircraft Performance; Navigation, Control and Guidance Theory.

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§ Heading angle and air speed are not needed for this problem.

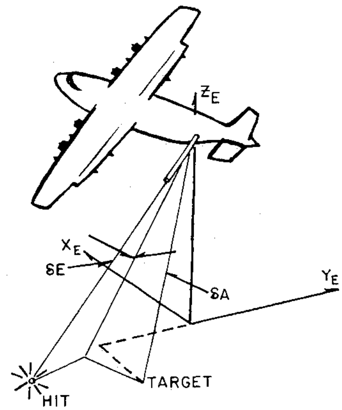

Fig. 1 Problem geometry where δ_E = elevation angle between sight and target line; δ_A = azimuth angle between sight line and target line; and $X_e - Y_e$ plane is Earth.

the acceptable maxima; and weights on control which are inverse to the desired control deflections. The resulting system tended to respond so quickly that rigid body assumptions were suspect. To solve this, weights were added to the body angular rates until the digital simulation demonstrated reasonable behavior for the assumed range of initial conditions.

Results

In order to verify the theoretical solution a number of rather complete simulations were run. Included were the effects of representative sensor noise, hydraulic servo lag, ($\tau = 0.1$ sec), winds (40 fps) and off-nominal initial conditions (δ altitude = 100 ft, $\delta A = 3°$, $\delta E = 3°$). The results of a typical run are shown in Fig. 2. The path flown by the aircraft is roughly ellipsoidal, with the added difficulty of the measurement errors.

The control gains are capable of maintaining target contact throughout the two-orbit period. The accuracy is slightly impaired by the external errors; however, the number of firing opportunities increases tremendously over the case when SLAP is not used. The altitude error is roughly 25 ft which has a negligible effect on fire control accuracy.

The control curves (Fig. 2b) reflect the increased difficulty of the firing problem. The control deflections are within the

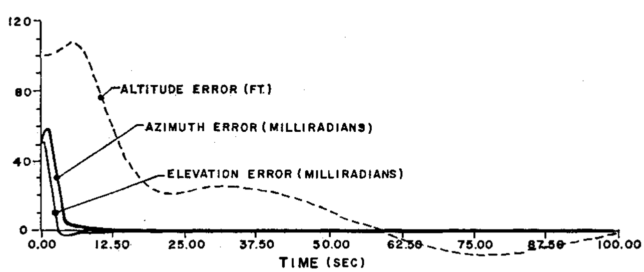

Fig. 2a Controlled variables.

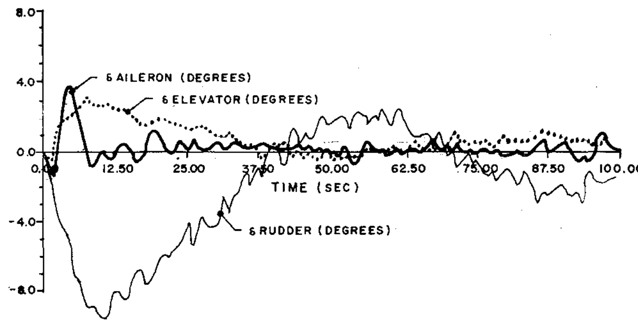

Fig. 2b Control surfaces.

operating limits, although the effect of measurement noise may be seen. The servo lags in the control surfaces have to a large extent filtered the higher frequency errors.

Hardware

The sight line autopilot is part of a funded Air Force development program. A contract has been let to Minneapolis Honeywell to determine the exact details based on the studies performed at USAFA. It is clear that all state variables should be instrumented. To accomodate different gain values for different flying configurations a digital computer is very desirable, and will be a part of the test aircraft configuration. [The SLAP will parallel existing flight hardware and consequently offer a redundant control method in the event of battle damage.] For flight test, an ensemble of autopilot gains will be designed, ranging from tight (small penalties on control) to very loose (large penalties on control). To change "gains" in flight it will only be necessary to alter the starting index value in memory.

Conclusions

The results clearly show that the addition of the sight line autopilot will greatly enhance the accuracy of the gunship operation. The results do not show the increase in pilot potential due to relieving him of fighting natural aircraft dynamics for extended periods. The resulting controller will be able to theoretically control the side firing aircraft sight line to an accuracy of better than one mil. This development should significantly advance the capability of weapons systems of this type.

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