Approach Trajectory Guidance for Maximum Concealment

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Introduction

POTENTIALLY useful technique for maximum concealment in military tactical operations consists of using low-altitude terrain-following/terrain-avoidance procedures to approch a landing site followed by a transition to a landing-approach path. If the landing site is obscured from the aircraft by terrain, a pop-up maneuver is required to locate the runway visually, to correct navigational errors, and to establish a minimum period of stable final descent prior to landing. This maneuver requires that the aircraft climbs rapidly from its initial concealed altitude of 100 to 200 ft above ground level (AGL) to an altitude of about 500 ft AGL, and then begin transition to a final-approach path. The requirement to reduce aircraft exposure to visual or radar detection suggests that the pop-up maneuver must minimize flight time spent above the concealment altitude. If the pop-up maneuver is to be flown manually, an increased workload is placed on the pilots, more so when the aircraft is flown on the backside of the power-required curve for powered-lift short takeoff and landing (STOL) operation.

This paper examines the use of an energy-management concept (Ref. 1) with the potential to provide a near-optimum pop-up maneuver guidance system. The energy-management concept consists of a set of computer algorithms that plan flightpaths along three-dimensional, curved capture flightpaths, and prestored flightpaths using procedures designed to minimize fuel usage. The fuel conservative guidance (FCG) system algorithms plan horizontal capture flightpaths to minimize the distance to a pilot-selected waypoint on a prestored reference flightpath. The vertical and speed profiles along the capture flightpath and the prestored flightpath are planned using simplified aero- propulsion-performance models of the aircraft. These performance models can be used to obtain minimum exposure along the prestored flightpath.

Previous studies using the FCG system have concentrated primarily on saving fuel in basically conventional land- and ship-based operations.[1-3] This study explores the use of the FCG system to provide guidance in situations which are more mission-critical and airplane-performance oriented than were previous studies. Specifically, landing operations which feature a pop-up maneuver were investigated including entry approaches to a final descent to landing from any direction and heading relative to the runway. Computer generated data are used to determine guidance and configuration-change commands which guide the pilot through a difficult flight procedure or to provide those commands to a full-function autopilot.

System Description

The basic objective of the FCG system is to plan a flightpath from the current aircraft states, through some specified intermediate states, to desired terminal states. On command from the pilot, the system will then plan the flightpath in real time and provide inputs either to an automatic control system or to an electronic display to enable the pilot to fly the aircraft along the planned path.

The planning of a "flyable" flightpath implies compliance with certain constraints, such as limits on flightpath angles and rates, airspeed rates, normal and longitudinal acceleration, bank angle, angle of attack, and the flight envelope of the aircraft for a particular flight condition. Determining the aircraft constraints requires a fast-time solution of the aircraft's equations of motion. The algorithms used for this solution depend upon energy-rate methods and are described in Refs. 1 and 3.

The planned horizontal path consists of a fixed path defined by a set of prestored waypoints and a minimum-distance capture path from the aircraft's initial position and course, to the position and course at the capture waypoint on the fixed path. The capture path consists of either an initial turn, a straight segment with a final turn, or three consecutive turns.

The basis of the energy-rate method is that the aircraft energy is defined as the sum of the kinetic and potential energies

$$E = mgh + \tfrac{1}{2} m V_a^2 \tag{1}$$

After differentiation and appropriate substitutions related to aircraft flight, the normalized energy rate, $\dot{E}_n$, is

$$\dot{E}_n = \sin\gamma_a + \frac{\dot{V}_a}{g} \tag{2}$$

For convenience, $\dot{E}_n$ will be referred to as the energy rate and represents the total capability of the aircraft to change altitude and speed. Thus the algebraic sum of commanded values of γ_a and $\dot{V}_a/g$ must always be less than the maximum, and greater than the minimum, allowable energy rate. It also provides the means to apportion the available energy between altitude changes and speed changes. When a change in altitude or speed is called for, the system will attempt to make the change at the maximum or minimum values of sin γ_a or $\dot{V}_a/g$. If the aircraft is on a performance limit and is only capable of an energy rate, $\dot{E}_n$, which is less than the desired value, the available $\dot{E}_n$ is allocated between $\sin\gamma_a$ and $\dot{V}_a/g$.

After the desired flightpath angle and airspeed rate are determined for a flightpath segment, the next step is to determine whether the desired $\dot{E}_n$ can be achieved at the current flight conditions, and if so, to determine the corresponding required control settings for flaps, angle of attack, and thrust. Sets of tabular data referred to as "energy-rate tables," which are aircraft-specific, have been generated for this purpose. For this study, a powered-lift STOL transport aircraft is represented by data for the Quiet Short-Haul Research Airplane (QSRA).

A complete system description is contained in Ref. 3.

The Pop-up Maneuver

A typical approach flightpath with a pop-up maneuver is illustrated in Figs. 1 and 2. The aircraft starts the approach at some location A and is assumed to be at an initial altitude of 100 to 200 ft AGL and at near-cruise airspeed (i.e., a terrain-following-type flightpath). The objective is to climb in order to capture a −4.5 deg glidepath at approximately one minute before touchdown. This procedure allows the pilot an opportunity to acquire the runway visually, correct navigation errors, and establish a stabilized approach to touchdown.

In order to reduce the probability of detection, a primary requirement is to minimize the time spent above the initial approach entry altitude. The preferred method of performing this pop-up maneuver is to use the energy-management procedures described earlier to trade airspeed for altitude during the climb from point B so as to arrive at point C at 500 ft altitude with an airspeed of 65 knots. By setting the operational constraints placed on airspeed rate and flightpath angle to their respective minimum and maximum allowable values,

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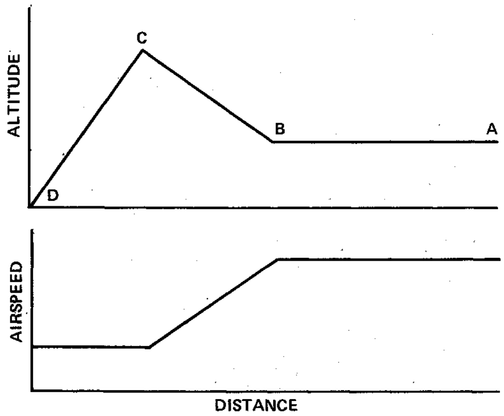

Fig. 1 Pop-up maneuver vertical-speed profile.

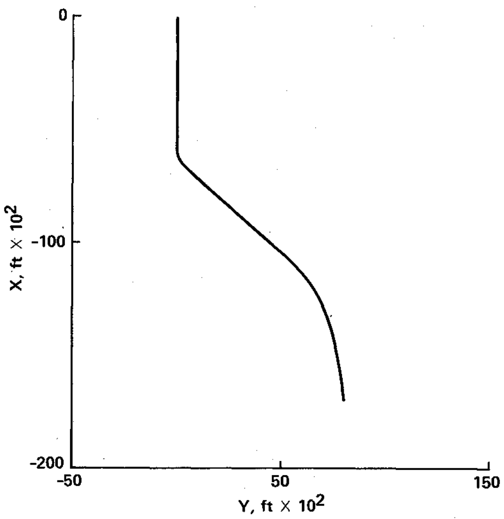

Fig. 2 Turning approach horizontal profile.

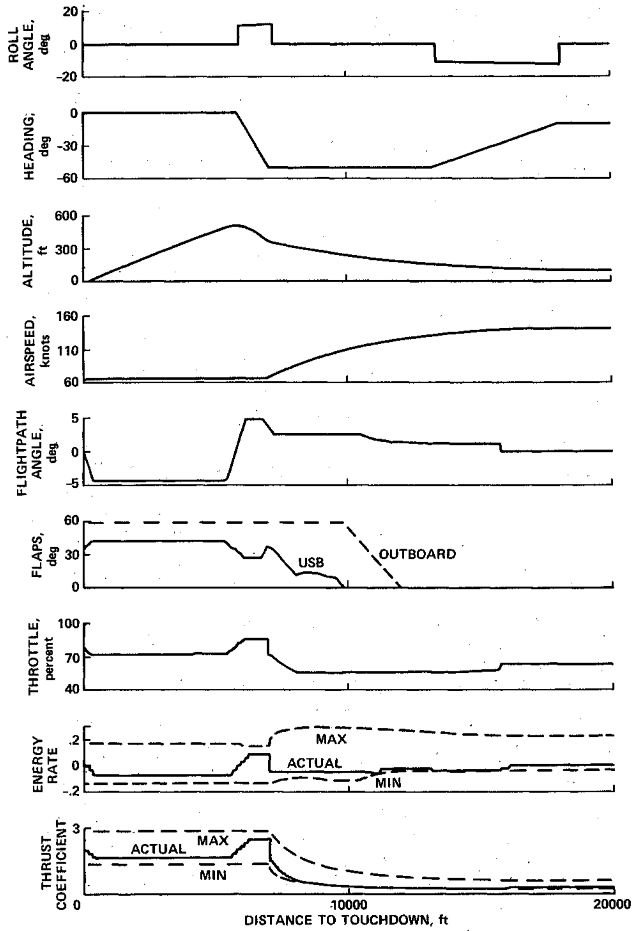

Fig. 3 Turning pop-up approach.

the FCG system can plan a flight segment whereby deceleration and the climb coincide so that the final-descent airspeed and the maximum altitude will be reached at the same time. For a powered-lift airplane like the QSRA, a configuration change from cruise mode to powered-lift mode is made at the appropriate speed during the climb segment. To compensate for the loss of energy owing to the decreased airspeed ($\dot{V}_a/g$), the flightpath angle ($\sin\gamma$) must be increased in accordance with the energy-rate equation. This is done by extending the upper surface blowing (USB) flaps and advancing the throttles as defined in the energy-rate tables. When the aircraft reaches point C, its state must have transitioned from a climb to a stabilized final descent to point D. For these tests, point D is defined as being at the touchdown point on the runway. Operationally, point D would be set at some altitude above the runway where a mode change would initiate automatic or display landing guidance. At this time, the pilot would correct the navigation errors and the descent flightpath.

Results

Results of computer simulation runs are shown in Fig. 3. Pertinent aircraft state and the energy-rate parameters are plotted vs distance to touchdown. The radii of the first and second turns are computed in order to provide a maximum roll angle of 20 deg for a ground speed which is equal to the sum of the current airspeed of the airplane and the wind speed. In this case, the maximum roll angle is about − 12 deg (Fig. 3), based on an initial airspeed of 140 knots and a 10-knot headwind. During the early part of the first turn (at 17,000 ft to go until touchdown) the pop-up is started, the airspeed deceleration begins, and the flightpath angle changes from 0 to 1.5 deg. The airspeed must stabilize at the desired 65 knots approach speed as specified for the capture waypoint before the final turn can begin so that the radius of the final turn can be minimized. The final turn ends at the capture waypoint, causing the speed decrease to end before the peak altitude is reached. As the airspeed decreases, the flightpath angle increases, and engine power increases, and the USB flaps extend to provide a sufficient lift margin from stall. When this occurs, the energy rate and thrust coefficient deviate temporarily from values near their minimums to near-maximums. Both return to values nearer minimum after the peak altitude is passed. The descent portion of the approach is representative of this class of aircraft.

Conclusions

This study has demonstrated that guidance commands for the pop-up maneuver can be generated using energy-rate concepts. Data presented show that the Quiet Short-Haul Research Airplane as modeled in the aircraft-specific energy-rate tables could fly the flightpaths shown. The example horizontal, vertical, and speed profile has shown the fuel conservative guidance system's ability to minimize pop-up flight time and carefully coordinate the airplane's controls for this performance-oriented flight-guidance requirement.

References

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