Nonlinear Simulation of Flight Along Wind Compensating Curved Glidepaths

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Abstract

A technique for defining curved glidepath geometries that compensate for some of the undesirable effects of low altitude winds is described. This technique uses an a priori estimate of the wind conditions present at the time of the landing approach to define a suitable glidepath geometry. The results of closed-loop, six degree-of-freedom simulation of a two-engined STOL transport conducting landing approaches on such curved approaches are summarized, and a number of recommendations for future work are made.

Contents

Developments in microwave landing system technology have given rise to the possibility of defining curved precision approach trajectories. Since the early 1970's a considerable amount of work has been carried out on curved approach trajectories defined in the horizontal plane.

This new landing aid technology has also made possible curved approaches in the vertical plane (Fig. 1). The literature has occasionally made reference to such trajectories (e.g., the "ideal descending route" of Ling[1]). These might be used for constant rate of descent procedures for portions of the approach and a steep initial approach gradually transitioning to a shallow approach for the last segment prior to landing.

This paper briefly summarizes the key results of an evaluation of a particular subset of such vertical plane modified approach geometries. [For brevity, such approach trajectories will be referred to as curved glidepath geometries (CGG).] This subset is based on an estimate of the wind conditions present at the time of the approach through an algorithm that compensates for some of the undesirable effects of wind on aircraft, and potentially reduces pilot workload.

Preliminary study of the problem from this viewpoint was undertaken by Hindson and Gould[2] in 1974. Their results suggested that CGG may be desirable in the presence of wind gradients in order to alleviate pilot workload, particularly for V/STOL aircraft. This was followed by flight test evaluations in the National Aeronautical Establishment airborne simulator in 1975—76, with encouraging results.[3]

Method

The source of Hindson and Gould's proposal was the observation that vertical wind gradients of the horizontal

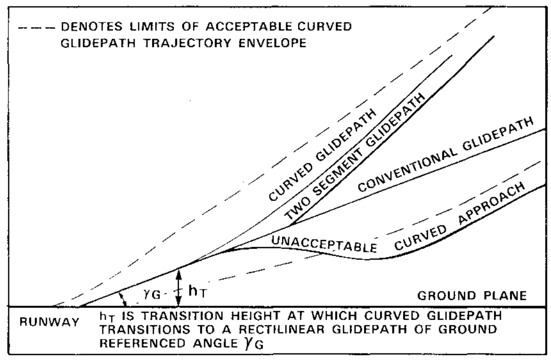

Fig. 1 Curved glidepath concept.

wind forces the pilot to continuously adjust rate of descent on the landing approach. For a constant airspeed approach, this implies continuously changing the throttle settings. If there is some a priori knowledge of the wind profile (as might be provided by remote sensing systems currently under development[4]), then it may be possible to determine a flight trajectory that will permit the pilot to fly an almost constant rate of descent approach in tracking this trajectory. For a given airspeed, such approaches are nearly constant attitude and constant throttle and consequently the need for pilot control inputs is minimized. Depending on the wind profile, this trajectory may be markedly curved in ground-referenced coordinates.

Broadly speaking, any approach trajectory determined to alleviate the undesirable effects of variable winds is encompassed by a dynamic state trajectory of the aircraft, which falls within an acceptable approach state envelope and a desired decision height state window (Fig. 1). Practical limitations for implementing such general curved reference trajectories arise from a number of factors. The most important of these are: 1) the accuracy to which the wind conditions are known at the time of aircraft passage; 2) the availability of landing aids with which general curved spatial trajectories may be defined; 3) the accuracy to which the aircraft dynamics and aerodynamics are known; and 4) the onboard aircraft computing power with which to compute the general approach reference state trajectory.

The first two factors are no longer limiting technological barriers with the recent progress in the development of real-time wind sensing systems and with the advent of microwave landing systems, as has already been indicated. The last two factors are unfortunately more difficult to overcome.

The general approach may be simplified considerably, however, if the aircraft groundspeed vector is assumed to be well-approximated by the vector sum of an airspeed vector V_c of specified magnitude and the estimated wind vector W_c. The

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resulting aircraft groundspeed vector is thus

$$V_{E_c} = V_c + W_c \tag{1}$$

In Ref. 5 it is shown that Eq. (1) leads to a spatial trajectory which approximates the actual trajectory. In particular, the two will be the same if 1) the true airspeed vector V is identical to V_c, 2) the dynamic effects of the variable winds are negligible, and 3) the estimated wind velocity W_c corresponds to the actual wind velocity vector encountered throughout the landing approach. Conditions 1 and 3 follow immediately from Eq. (1). Condition 2 is a consequence of the requirement that the magnitude of V_c be constant.

In order to investigate the suitability of the proposed method under the assumptions made, a six degree-of-freedom, nonlinear, rigid-body, body-axes dynamic model was developed and simulation runs were carried out on an IBM 3033 computer at the University of Toronto. Wind effects were modeled as the three components of the wind vector acting at the center-of-mass of the aircraft. The aerodynamic model was a nonlinear quasisteady model in lookup table form with thrust coefficient C_T and fuselage reference line angle-of-attack α_f as interpolation variables. The approach autopilots were modeled as optimal controllers synthesized using the linear, infinite terminal time quadratic techniques described in detail in Ref. 5.

Over 200 cases were run for a number of curved and conventional glidepath geometries and wind models spanning a broad cross section of possible approach scenarios. As well as the usual time histories of the aircraft response, root-mean-square (rms) values were computed for the important aircraft response and control variables, as well as for the wind inputs. The latter were used as objective measures of controller performance and wind variability.

The example aircraft was a twin-engined, light STOL transport of 4500 kg (11,000 lb) gross weight.

A number of wind models were used in the study. These included both typical power law profiles representative of atmospheric boundary layer conditions, power law profiles with wind jets of various intensities superimposed, and a model representative of the highly variable wind conditions present at the time of the well-documented JFK accident.[6]

Results

Figure 2 gives the flight paths for the STOL transport tracking, respectively, a conventional 7 deg glidepath and a curved glidepath defined using the proposed method based on the JFK wind profile (see the insert in Fig. 2). The vertical wind profile has two regions with strong downdraft activity. These cause the aircraft to deviate significantly below the glidepath at two points along the approach.

The rms values of the important response variables were found to be generally larger on the curved approach than for the conventional case. However, for glidepath tracking, the curved approach shows a small improvement in performance over the conventional approach. Also in favor of the curved glidepath, for this example, is that for a large part of the approach it is significantly above the conventional glidepath and thus the downdraft does not take the aircraft to as low an altitude as for the conventional approach. This particular advantage disappears below 100 m of altitude where the curved and conventional glidepaths are nearly identical.

Conclusions and Recommendations for Future Work

The simulations conducted, only an example of which has been presented here, have demonstrated a number of advantages and limitations of curved glidepath geometries defined with the kinematic method. In general, the comparison with conventional approaches has not proven to be as favorable as purely kinematic considerations would suggest.

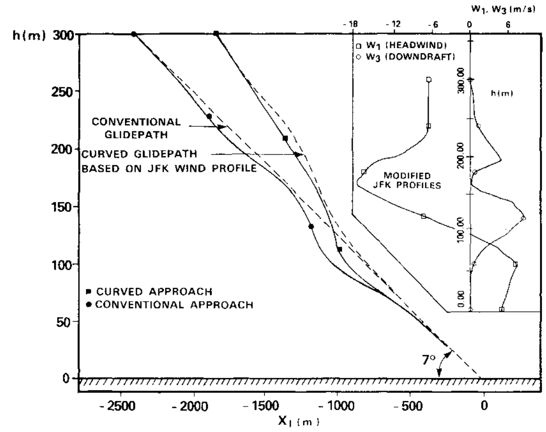

Fig. 2 Flight path in the presence of the JFK profiles.

The main conclusions that were drawn from this study are as follows:

1) For the most common decreasing headwind with decreasing altitude cases, the dynamic effects of the variable winds encountered tend to be greater on curved approaches due to the greater rates of descent.

2) There are wind conditions where curved approaches have some advantages over conventional approaches. These are decreasing headwind cases where the wind shear is nearly constant throughout the approach; increasing headwind or decreasing tailwind with decreasing altitude cases; and decreasing headwind cases where there is downdraft activity.

3) Curved approaches based on highly variable headwind profiles showed no particular advantage over the corresponding conventional approaches in terms of controller performance.

The recommendations for future work are as follows:

1) From the point of view of reducing airspeed and glidepath deviations, improvement in performance could be obtained for the usual decreasing headwind cases by specifying the curved glidepath geometry in a way which results in rates of descent that are identical to initial rates of descent on conventional approaches.

2) From the point of view of reducing control activity for kinematically defined curved glidepath approaches, a fixed throttle technique could be employed in mild wind shears. In this way, the longitudinal control task is reduced to one of maintaining the nearly constant attitude that would be required to track the glidepath. Throttle settings would change only when airspeed deviations become too large to be compatible with flight safety.

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