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CLOSED-LOOP, PILOT/VEHICLE ANALYSIS OF THE APPROACH AND LANDING TASK

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Extended Abstract

Recently, Bacon and Schmidt[1] presented an integrated optimal-control, frequency-domain approach for pilot/vehicle analysis of the precision attitude control task. When applied to the flight test results of Neal and Smith[2], the optimal control approach was shown, not only to agree extremely well with the original technique developed by Neal and Smith, but also to yield additional information on the achieveable closed-loop bandwidth in the task. This task was essentially modeled as a single-input, single-output, closed-loop task.

In the case of approach and landing, however, it is universally accepted that the pilot uses more than one vehicle response, or output, to close his control loops. Therefore, to model this task, a multi-loop analysis technique is required. The analysis problem has been in obtaining reasonable analytic estimates of the describing functions representing the pilot's loop compensation. Once these pilot describing functions are obtained, appropriate performance and workload metrics must then be developed for the landing task.

The optimal control approach[1,3] provides a powerful technique for obtaining the necessary describing functions, once the appropriate task objective is defined in terms of a quadratic objective function. In this discussion, we will present such an approach through the use of a simple,

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reasonable objective function and model-based metrics to evaluate loop performance and pilot workload. We will also present the results of an analysis of the LAHOS (Landing and Approach of Higher Order Systems) study performed by R.E. Smith[4].

In flare or near touchdown, precision flight-path control is required. Assuming a "frontside" landing technique is used, the pilot can control flight path or sink rate through elevator commands. Including inner pitch-attitude and flight-path-angle feedback loops, this situation leads to a block diagram of the approach and landing task shown in Figure (1). A reasonable task objective function would then reflect the pilot's desire to minimize flight-path error, γ_{error}, by using pitch-attitude, flight-path, and flight-path-error information in the following form,

$$J_p(u_p) = E\{\lim_{T\to\infty} \frac{1}{T}\int_0^T (q\gamma_{error}^2 + g\dot{u}_p^2)dt\} \tag{1}$$

where u_p is the pilot's stick force input.

The pilot describing functions, $P_{(\cdot)}$, shown in the closed-loop structure of Figure (1) can then be obtained using the optimal-control approach. These describing functions represent those required to achieve the best loop performance, subject to the task definition and inherent pilot limitations modeled. Once determined, they can also be manipulated using block diagram algebra to obtain, for example, an equivalent unity feedback single-loop structure shown in Figure (2).

Neal and Smith, as well as Bacon and Schmidt, described the pilot/vehicle handling-quality criteria problem as a trade-off between the pilot workload required to achieve acceptable task performance and a subsequent measure of the pilot/vehicle closed-loop performance. The most important aspect of closed-loop performance, furthermore, is stability and robustness (or insensitivity to small changes in pilot compensation). These loop characteristics are clearly reflected in the open-loop, γ/γ_{error}, frequency response. In fact, for good closed-loop stabilty properties, the desirable "shape" of this frequency response in the crossover region is well known (i.e. constant -20 dB/decade slope). Any deviation from the desirable frequency response is defined herein as a reduction in *loop quality.*

A model-based measure of the "loop quality" has been developed and is entitled the "open loop peak", obtainable from the open-loop frequency response plots after the pilot/vehicle system has been modeled. Also a model-

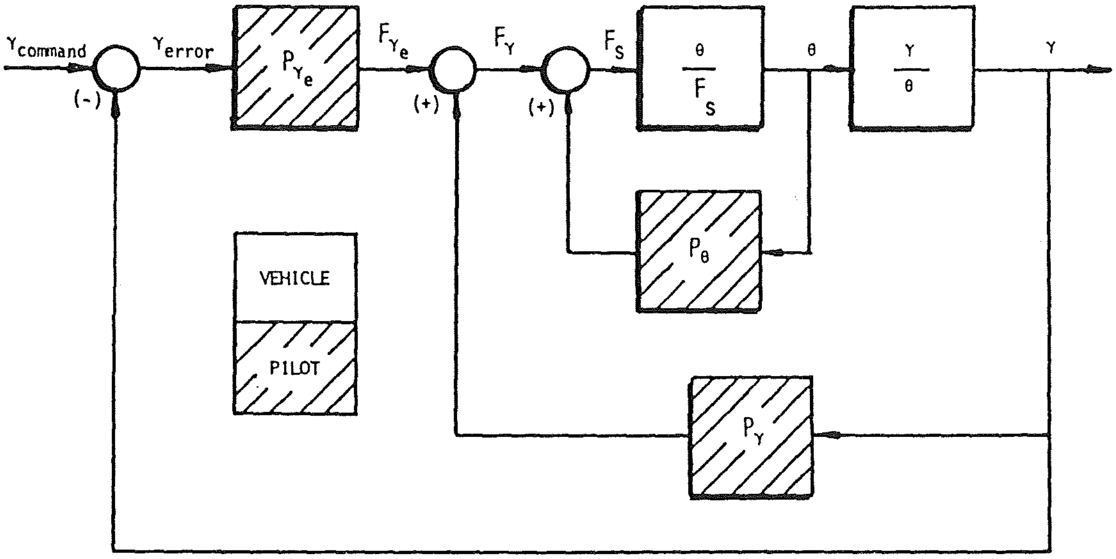

Figure 1 The Multi-Loop Flight Path Tracking Task

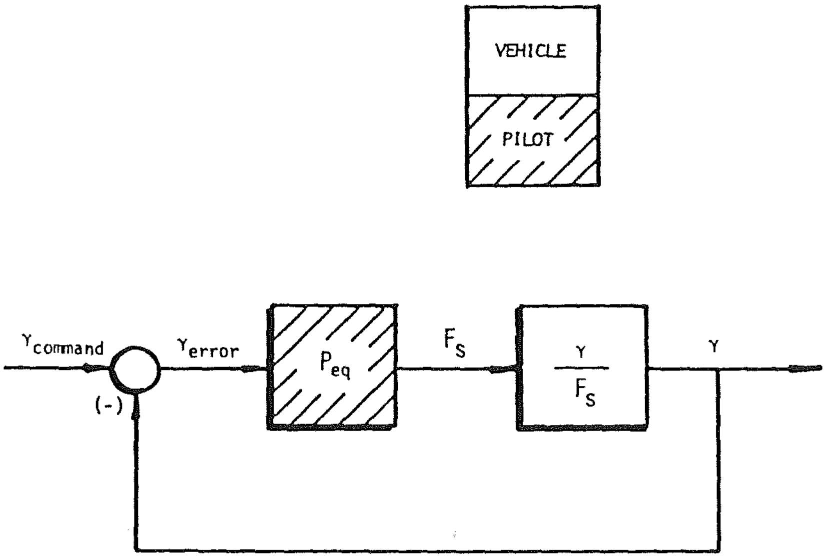

Figure 2 Flight Path Tracking with
Equivalent Pilot Function

based metric has been identified that reflects the pilot workload necessary to achieve closed-loop stability. This workload metric is expressed in terms of a pilot phase compensation angle.

When thirty-two of the aircraft configurations flight tested in the LAHOS study were modeled and analyzed, the results are as shown in Figure (3). Recalling that the " open-loop peak" is a measure of stability robustness, and the "pilot compensation" is a measure of workload, we see a characteristic grouping of the results not unlike that presented in References [1] and [2]. However, in these references, the task modeled was precision attitude control, and two different (though similar) model-based metrics were used in the related plots.

It is also noted from Figure (3), that those configurations rated best (Cooper-Harper Level 1) in the *approach and landling task* were appropriately grouped together, in terms of "performance" and "workload". Those rated worse were the result of excessive pilot phase lead or lag conpensation required or a reduction in "loop quality". Other results concerning loop characteristics such as achieveable loop bandwidths, pilot comments, and pilot behavior can be found in Reference [5].

References

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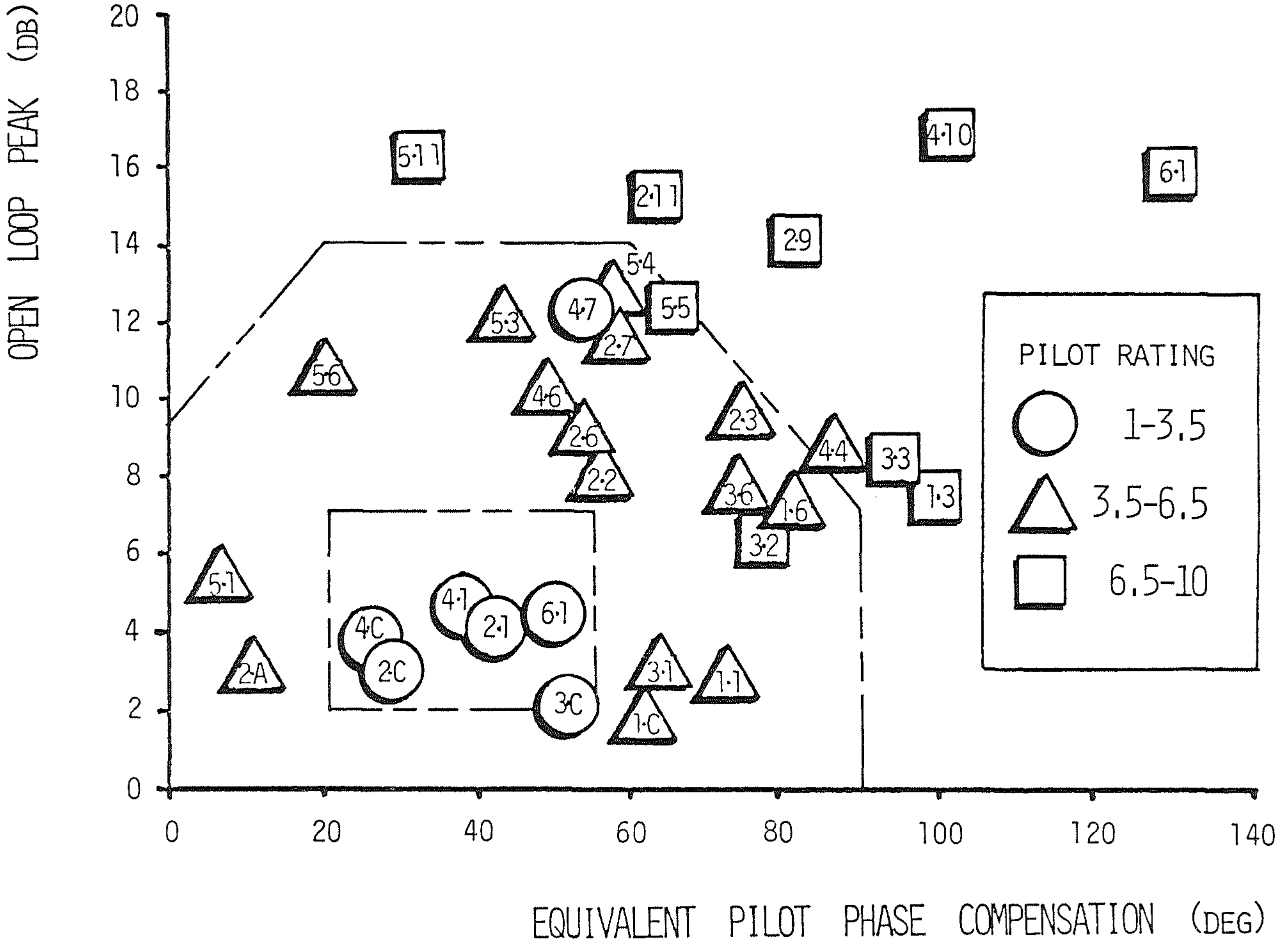

Figure 3 OCM Results for the Flight Path Tracking Task