# Application of Frequency-Domain Handling Qualities Criteria to the Longitudinal Landing Task

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## Abstract

A SIMULATION of the longitudinal handling qualities for the approach and landing task was performed on the USAF/AFWAL Total In-Flight Simulator. The basic configuration was a generic transport airplane with static instability. The control laws included proportional plus integral gain loops to produce pitch rate command/attitude hold systems that were evaluated with and without prefilters. Conventional response characteristics were obtained by using pitch rate and angle-of-attack feedback loops. The evaluation task was a conventional visual approach to a flared touchdown at a designated spot on the runway with a lateral offset. Previous analyses of this data base have shown that the use of pitch attitude characteristics alone do not adequately predict the observed results. This paper describes the development of a multiloop criterion based on pitch attitude and altitude in an effort to provide better correlation with the observed data. The focal point of this paper is the development of a technique to define the inner-loop pilot model such that the altitude performance characteristics can be defined by a single metric.

## Contents

An in-flight simulation of the longitudinal handling qualities for the approach and landing task was performed on the USAF/AFWAL Total In-Flight Simulator (TIFS). The experiment description and results are presented in Ref. 1. The basic aircraft configuration was a generic transport airplane with static instability. Seven aerodynamic configurations were obtained by varying the lift curve slope, static stability, and lift due to elevator characteristics. Eight variations of control laws were used with the seven aerodynamic models to produce 27 flight-control/airplane configurations for the study. The control laws included proportional plus integral gain loops to produce pitch rate command/attitude hold systems that were evaluated with and without prefilters. Conventional airplane response characteristics were obtained by using pitch rate and angle-of-attack feedback loops. The evaluation task was a conventional visual approach to a flared touchdown at a designated spot on the runway. A 300-ft lateral offset and a discrete vertical gust were used to increase pilot workload.

The general conclusions from Ref. 1 were that the existing criteria are generally based on pitch attitude response and that pitch attitude characteristics alone do not adequately discriminate between the good and bad configurations of this study. A time domain criterion was developed based on angle of attack and normal acceleration at the pilot station, and improved correlation was shown. A frequency domain criterion based on sink rate at the pilot station was also shown to be an improvement over the pitch attitude criteria. This paper describes the work that has been done to develop a multiloop criterion based on pitch attitude and altitude in an effort to provide better correlation with the observed data. The focal point of this paper is the development of a technique to define the inner-loop pilot model such that the altitude performance characteristics can be defined by a single metric.

### Pitch Attitude Neal-Smith Analysis

The Neal-Smith method is based upon a single-loop closure performed on pitch attitude using a pilot model that employs a lead/lag filter with a gain and time delay. The pilot model achieves a certain "standard of performance" which is defined by an assumed closed-loop bandwidth that must be chosen a priori. The bandwidth is defined by the 90° closed-loop phase requirement. At frequencies below the bandwidth, the steady-state tracking errors are minimized by limiting low-frequency droop to no more than −3 dB. The closed-loop resonant peak is also minimized to reduce oscillatory tendencies. These parameters then provide a measure of compensation with which the pilot closes the loop.

A bandwidth of 2.0 rad/s produced the most representative correlation between the predicted and actual pilot ratings in the analysis of Ref. 1. Although the Neal-Smith criterion is a function of both closed-loop resonance and pilot lead/lag, at this bandwidth, the configurations generally exhibited satisfactory levels of closed-loop resonance. As a result, the variations in the pilot ratings were primarily dependent upon the pilot lead compensation requirements, as shown in Fig. 1. In addition to the configurations from Ref. 1, selected configurations from Ref. 2 are also shown. All the individual evaluations are plotted rather than average pilot ratings. A significant amount of scatter is seen in the data for a wide range of pilot lead compensation. The overall indications from Fig. 1 are that pitch attitude characteristics by themselves are not sufficient to predict the handling qualities for the flared landing task.

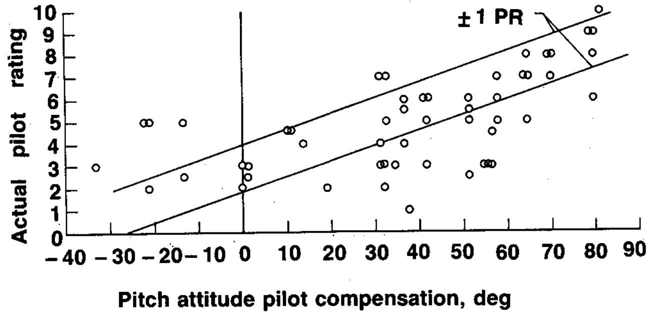


**Fig. 1 Pilot rating as a function of pitch attitude pilot compensation, pitch attitude bandwidth = 2.0 rad/s.**

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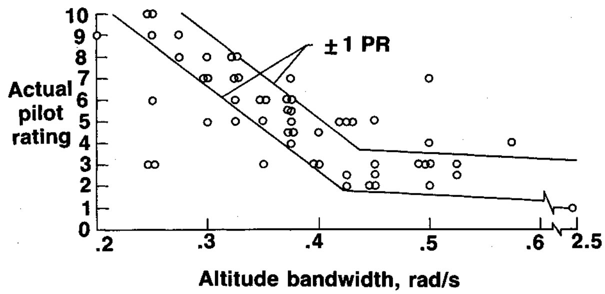


**Fig. 2 Pilot rating as a function of altitude bandwidth (25-deg lead compensation in inner loop).**

## Altitude Criterion with Attitude Inner-Loop Closure

In an effort to obtain a criterion that would better encompass the range of characteristics found in this data base, the closed-loop performance was examined using a series, multiloop control. This analysis technique assumed that the pilot controls an altitude outer loop through a pitch attitude inner loop to provide satisfactory longitudinal control. The pitch attitude loop was closed using the classical Neal-Smith approach with the inner-loop pilot model consisting of a lead/lag filter with a gain and time delay. The altitude outer-loop pilot model was assumed to be a pure gain. The altitude loop was closed to determine the bandwidth available for altitude control. The altitude bandwidth was defined as the frequency at which a satisfactory level of closed-loop resonance (2–4 dB) at −90 deg of closed-loop phase was achieved.

An example of this multiloop technique is found in Ref. 2. The method in Ref. 2 specified the inner loop as a result of the Neal-Smith attitude closure at a given bandwidth. This same technique was applied to the data base of this study with the inner-loop attitude bandwidth chosen at 2.0 rad/s for all the configurations. Overall, there was a slight improvement over the previous single-loop attitude closure technique, but the correlation was still poor.

## Fixed Inner-Loop Lead Compensation

A disadvantage of using an inner-loop attitude compensation that is based upon a fixed bandwidth is that the resulting outer-loop altitude bandwidth cannot be used as a single metric since there are varying degrees of pilot compensation required by the inner loop. The technique employed in this paper to alleviate this difficulty was to specify the same inner-loop compensation for each configuration and then examine the resulting outer-loop altitude bandwidth. This technique then provides a measure of the altitude performance achievable with the same amount of pilot compensation. For most of the configurations of this study, pilot lead compensation was required to improve the pitch attitude control (Fig. 1). As a result, it was assumed that the pilot could be modeled with an inner-loop lead and that the amount of lead would be consistent with level I handling qualities. From Fig. 1, it can be seen that 25 deg of lead can be used within the level I pilot rating constraint, and this value was selected for use in the inner-loop compensation. This amount of lead is also consistent with the original Neal-Smith boundaries of Ref. 3 in which 25 deg of lead is in the middle of the level I region for low resonance. The inner-loop pilot model was then determined from the classical Neal-Smith solution that provided 25 deg of lead compensation, which resulted in a different pitch-attitude bandwidth for each configuration. Following the closure of the inner loop, the altitude loop was closed and the altitude bandwidth was determined.

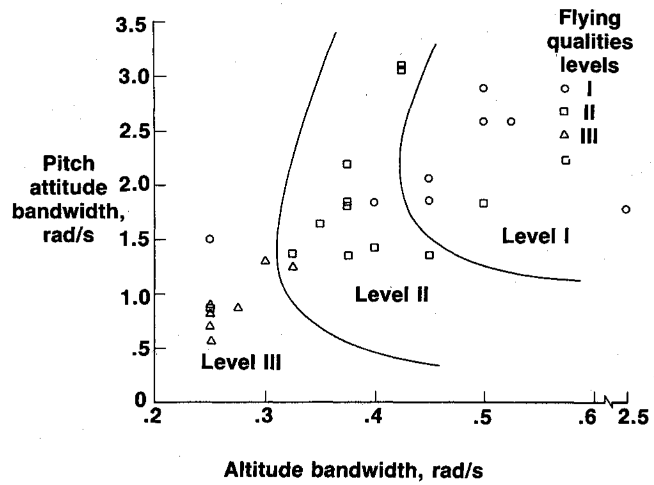


**Fig. 3 Pitch attitude bandwidth as a function of altitude bandwidth (results from Fig. 2).**

Figure 2 illustrates the relationship between the altitude bandwidth using this technique and the actual pilot ratings for the data used in Fig. 1. The correlation is significantly better than the pilot rating correlations found with either the single-loop pitch attitude or the multiloop analysis with the fixed inner-loop bandwidth. The overall trend in Fig. 2 shows that a minimum attitude bandwidth of 0.4 rad/s appears to be necessary for level I pilot performance. The relationship between the inner-loop pitch attitude bandwidth and the outer-loop altitude bandwidth from Fig. 2 is worth noting, as shown in Fig. 3. In general, it appears that good altitude bandwidth requires good inner-loop pitch attitude bandwidth, which is to be expected. However, good pitch attitude bandwidth is not in itself sufficient to define the landing handling qualities. By including the altitude control bandwidth as a metric, a much better correlation was seen with the observed data.

## References

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