Analysis of Aircraft Control Performance using a Fuzzy rule base representation of the Cooper-Harper Aircraft Handling Quality Rating

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The Cooper-Harper rating of Aircraft Handling Qualities has been adopted as a standard for measuring the performance of aircraft since it was introduced in 1966. Aircraft performance, ability to control the aircraft, and the degree of pilot compensation needed are three major key factors used in deciding the aircraft handling qualities in the Cooper-Harper rating. We formulate the Cooper-Harper rating scheme as a fuzzy rule-based system and use it to analyze the effectiveness of the aircraft controller. The automatic estimate of the system-level handling quality provides valuable up-to-date information for diagnostics and vehicle health management.

Analyzing the performance of a controller requires a set of concise design requirements and performance criteria. In the case of control systems for a piloted aircraft, generally applicable quantitative design criteria are difficult to obtain. The reason for this is that the ultimate evaluation of a human-operated control system is necessarily subjective and, with aircraft, the pilot evaluates the aircraft in different ways depending on the type of the aircraft and the phase of flight. In most aerospace applications (e.g., for flight control systems), performance assessment is carried out in terms of *handling qualities*. Handling qualities may be defined as those dynamic and static properties of a vehicle that permit the pilot to fully exploit its performance in a variety of missions and roles. Traditionally, handling quality is measured using the Cooper-Harper rating and done subjectively by the human pilot. In this work, we have formulated the rules of the Cooper-Harper rating scheme as fuzzy rules with performance, control, and compensation as the antecedents, and pilot rating as the consequent. Appropriate direct measurements on the controller are related to the fuzzy Cooper-Harper rating system: a stability measurement like the rate of change of the cost function can be used as an indicator if the aircraft is under control; the tracking error is a good measurement for performance needed in the rating scheme. Finally, the change of the control amount or the output of a confidence tool, which has been developed by the authors, can be used as an indication of pilot compensation. We use a number of known aircraft flight scenarios with known pilot ratings to calibrate our fuzzy membership functions. These include normal flight conditions and situations in which partial or complete failure of tail, aileron, engine, or throttle occurs.

After calibration with known scenarios, the system will be able to offer Cooper-Harper rating under various situations in the application stage. This generalization capability of fuzzy logic allows the system to respond to novel scenarios. To demonstrate the effectiveness of our methodology, we integrated our proposed Cooper-Harper rating scheme with a Grumman Aerospace F-14 longitudinal motion control system. With a square-wave pilot input that alternate between the extremes, our fuzzy system is able to rate the aircraft handling control qualities. The fuzzy rule-based system shows the appropriate rating, 1 to 10, based on the current aircraft state and control measurements. The rating profile also shows related changes as pilot input changes. This justifies the effectiveness of our proposed scheme.

In conclusion, our proposed Cooper-Harper rating scheme in fuzzy rule-based form can be an effective tool for diagnostic and health-management purposes. In contrast to using a low level measurement (like the tracking error), the system-level metric of handling quality provides a concise, yet high-level metric. Thus, systems modeling within a health management system, for example, can be simplified substantially and conveyed to review and safety boards more easily, as this metric is well known and easy to understand.