N73-10121

Preceding page blank

17. Analytic Evaluation of Display Requirements for Approach to Landing*

DAVID L. KLEINMAN AND SHELDON BARON

Bolt, Beranek and Newman Inc.

In recent years we have developed an integrated approach to the analysis of manned vehicles systems (refs. 1 through 4). We have blended human response constraints within an optimal control theoretic framework to represent the pilot's limitations as a decision and control element. The resulting pilot-vehicle-display model can be used to study information and display requirements and the effects on system performance and reliability of pilot-induced randomness, wind gusts, configurational changes, etc. In this paper, we give a brief description of our control theoretic systems model and demonstrate its use and validity by applying it to a piloted approach to landing situation.

The analysis procedure assumes that the vehicle dynamics (which may also include actuator and sensor dynamics) are represented by the linearized equations of motion

$$\dot{\underline{x}}(t) = \underline{A}\,\underline{x}(t) + \underline{B}\,\underline{u}(t) + \underline{w}(t). \qquad (1)$$

$\underline{x}(t)$ is a vector that describes the vehicle state; $\underline{u}(t)$ is the pilot-generated control input; $\underline{w}(t)$ represents external disturbances (turbulence, wind-gusts, up-drafts, etc.).

Several system outputs

$$\underline{y}(t) = \underline{C}(t)\underline{x}(t) \qquad (2)$$

may be of concern, and it is assumed that they are presented continuously to the pilot via some visual display or instrument panel. The observations of $\underline{y}(t)$ represent the information set upon which the pilot bases his control actions.

The methods for representing the human's limitations and the resulting optimally compensating elements are the unique and crucial features of our approach. Several pilot limitations that we represent explicitly in the model are

(1) The various internal time-delays associated with visual, central processing, and neuromotor pathways are represented by a lumped "equivalent" perceptual time-delay τ.

(2) Observation noise represents the combined effects of sensory and central-processing sources of pilot randomness, as well as display-related noise sources. This noise process is modeled by associating with each displayed output $y_i(t)$ a white observation noise $v_i(t)$ with power-density level V_i. Values for V_i depend on the nature (quality, type, and form) of the display panel, where the pilot 'is looking, etc.

(3) Visual and/or indifference thresholds that represent human nonlinear characteristics for small signals.

(4) A motor noise $\underline{v}_u$ is added to $\underline{u}(t)$ and represents the fact that a pilot cannot generate commanded control inputs perfectly. The sum of $\underline{v}_u(t)$ and $\underline{v}_y(t)$ represents inherent pilot "remnant," or randomness.

The pilot is assumed to adopt a control strategy that minimizes a weighted sum of averaged state and control variances (i.e., a quadratic cost functional conditioned on the displayed information and subject to his inherent constraints. With this assumption, the human's control characteristics are determined by the solution of an optimal linear regulator problem with time-delay and observation noise. Pilot equalization is modeled by the cascade combination of three elements: (1) a least-mean-squared predictor that compensates optimally for the inherent delay, (2) a Kalman filter that yields a best estimate of the system state from (noisy) observations of $\underline{y}(t)$,

* **Entire paper** to **appear in Proceedings of 1972 IFAC Congress.**

PRECEDING PAGE BLANK NOT FILMED

and **(3)** a set of optimal gains that operates on the best estimate of the state to produce the desired control response. The general expressions for these model elements, in the time-invariant case, are given in reference **4.** The extensions of the model to a time-varying approach to landing situation are covered in this paper.

The analysis procedure that we developed is used to investigate pictorial display requirements for the landing approach of a light aircraft. Input disturbances include vertical drafts and random gusts. Pilot variability is accounted for, leading to statistical performance predictions even in the absence of external random disturbances. The effects on system performance of several display modifications and different wind disturbances are predicted by the model and are compared with data obtained in an independent experimental study. The comparison affirms the validity of our system model and demonstrates its utility in manned-vehicle analysis and synthesis.

REFERENCES

1. **KLEINMAN,** D. **L.; AND BARON,** S.: Manned Vehicle System Analysis by Means of Modern Control Theory. Rept. No. 1967, Bolt, Bernak and Newman, Inc., June 1970.
2. **BARON,** S.; **AND KLEINMAN,** D. **L.:** The Human **as** an Optimal Controller and Information Processor. IEEE, Trans. on Man-Machine Systems, vol. MMS-10, no. **1,** Mar. 1969.
3. LEVISON, W. **H.; BARON,** S.; **AND KLEINMAN,** D. **L.:** A Model for Human Controller Remnant. IEEE, Trans. on Man-Machine Systems, vol. MMS-10, no. **4,** Dec. 1969.
4. **KLEINMAN,** D. **L.; BARON,** S.; **AND** LEVISON, W. H.: An Optimal Control Model of Human Response. Automatica, vol. 6, pts. I and II, **no. 3,** May 1970.