Closed-Loop Hybrid Flight Management Systems

George Meyer
NASA Ames Research Center
Moffett Field CA

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Extended Abstract

The objective of our research is to develop a methodology for the modeling, design, and verification of flight management systems for the next generation of airspace operations. The overall point of view taken is shown schematically by the block diagram in figure 1 with the following major sub-blocks.

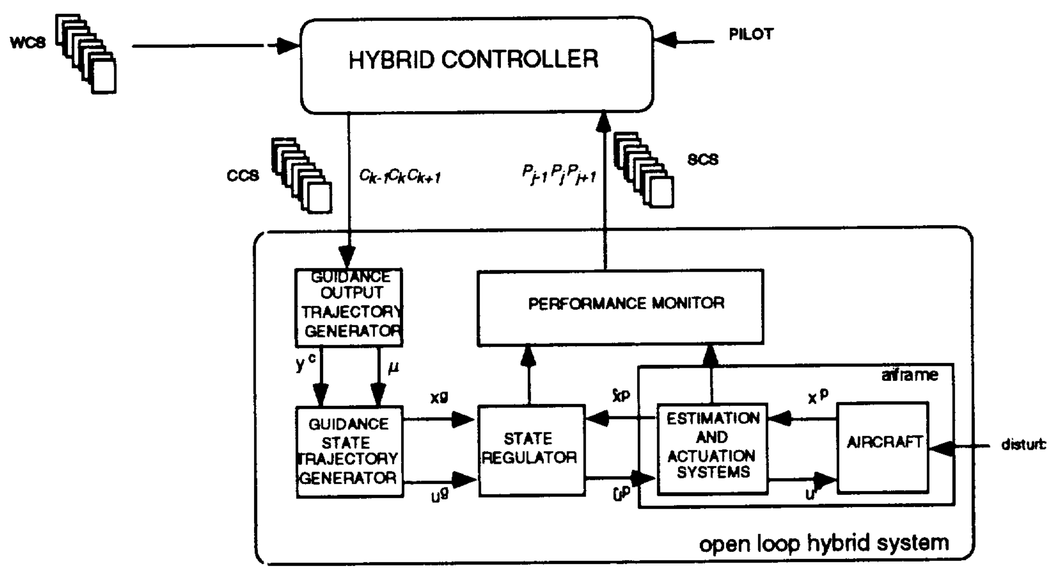

Figure 1: Closed loop hybrid flight control model.

- The **airframe** includes the aerodynamics, propulsion, and atmospheric disturbances, as well as, the actuation and sensing systems and the associated algorithms. This is considered as a continuous subsystem, which is represented by means of continuous differential and sampled data difference equations and transfer functions in the standard manner.

- The multi-axis **regulator** which transforms the estimated state error x^e into corrective perturbations u^e to the open-loop (guidance) control signals. That is, the regulator together with the airframe constitute a multi-axis state servo whose input is the desired evolution of the airframe state and the corresponding control (x^g, u^g) supplied by the guidance system. It is assumed that the regulator has been made robust within its operating range Υ by means of the standard design techniques. It is further assumed that the regulator, being a local device, must not be allowed to wander outside Υ. That is accomplished in our approach by means of perturbations in guidance, which is the central topic of the present paper.

- The **guidance state trajectory generator** transforms the desired evolution of the output $y^c = h_\mu(x^g)$ into the complete guidance state and control (x^g, u^g) which serves as the input to the regulator [1], [2] and [3]. In general, there may be may ways to do that. The possibilities are distinguished by means of the discrete multi-dimensional **operation mode** whose coordinates include the output mode μ_y, which selects the output map h such as Cartesian coordinates, path coordinates, etc; the control mode μ_u which selects a partition of control axes into active controls and parameters, where the parameters may chosen to keep the active control within their range of operation; the coordinate mode μ_α, which selects the aircraft attitude representation, such as runway axes, stability axes, etc; and optimization mode μ_J, which selects the smoothness of the maneuver, such as slow easy recovery with good ride quality or bang-bang emergency recovery.

- The **guidance output trajectory generator** transforms an asynchronous, time-tagged sequence of **control cards** into a continuous (e.g. polynomial) multi-dimensional segment linking the **control points**. The control cards define the boundary conditions for each segment of a standard maneuver as well as the operation mode for the segment. The guidance output trajectory generator is the "D to A" interface from the hybrid controller to the largely analog system below.

- The **performance monitor** is the "A to D" interface from the analog system below to the hybrid controller above. The output is an asynchronous sequence of status cards describing off nominal behavior of the regulator and the airframe.

The resulting system is considered as an open-loop hybrid system. Its input is the sequence of control cards; its output is the sequence of status cards. Its environment consists of the Air Traffic Control which is represented by a sequence of waypoint control cards which specifies the large-scale characteristics of the aircraft trajectory; there is the human crew interacting with the system at several levels; there is the atmosphere affecting the airframe as well as flight planning, including way point selection; and there are other aircraft potentially requiring collision avoidance maneuvers. The loop is closed on this environment by means of the **hybrid controller**. The resulting system is then the closed-loop hybrid flight management system. The hybrid controller is modeled as in [4] with R^n fibers on the discrete states of an automaton. The evolution on the fibers bounded-rate.

The paper focuses on the specific problem of generating recovery maneuvers after atmospheric disturbances which if ignored would drive the regulator out of its permissible region of operation Υ. The problem is analogous to the system with several water tanks which are to be kept from either underflowing or overflowing.

References

[1] S. Devasia, D. Chen, and B. Paden: Nonlinear inversion-based output tracking, IEEE Transactions on Automatic Control, **43**, 930-942, 1996.

[2] Meyer, G.; Hunt, L. R.; Su, R.: Nonlinear System Guidance in the Presence of Transmission Zero Dynamics, NASA Technical Memo 4661, Jan. 1995.

[3] G. Meyer and G. A. Smith, "Dynamic Forms Part II: Application to Aircraft Guidance," NASA Technical Paper in preparation.

[4] M. Heymann, F. Lin, and G. Meyer, "Control Synthesis for a Class of Hybrid Systems Subject to Configuration - Based Safety Constraints," NASA Technical Paper in preparation.