

Development of a Model Following Control Law for Inflight Simulation and Flight Controls Research

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Abstract

The U.S. Army and NASA are currently developing the Rotorcraft Aircrew Systems Concepts Airborne Laboratory (RASCAL) at the Ames Research Center. RASCAL, shown in Figure 1, is a UH-60, which is being modified in a phased development program to have a research fly-by-wire flight control system, and an advanced navigation research platform[1]. An important part of the flight controls and handling qualities research on RASCAL will be an FCS design for the aircraft to achieve high bandwidth control responses and disturbance rejection characteristics. Initially, body states will be used as feedbacks, but research into the use of rotor states will also be considered in later stages to maximize agility and maneuverability. In addition to supporting flight controls research, this FCS design will serve as the inflight simulation control law to support basic handling qualities, guidance, and displays research.

Research in high bandwidth controls laws is motivated by the desire to improve the handling qualities in aggressive maneuvering and in severely degraded weather conditions. Naturally, these advantages will also improve the quality of the model following, thereby improving the inflight simulation capabilities of the research vehicle. High bandwidth in the control laws provides tighter tracking allowing for higher response bandwidths which can meet handling qualities requirements for aggressive maneuvering. System sensitivity is also reduced preventing variations in the response from the vehicle due to changing flight conditions. In addition, improved gust rejection will result from this reduced sensitivity. The gust rejection coupled with a highly stable system will make more precise maneuvering and pointing possible in severely degraded weather conditions.

The difficulty in achieving higher bandwidths from the control laws in the feedback and in the responses arises from the complexity of the models that are needed to produce a satisfactory design. In this case, high quality models that include rotor dynamics in a physically meaningful context must be available. A non-physical accounting of the rotor, such as lumping the effect as a time delay, is not likely to produce the desired results[2]. High order simulation models based on first principals are satisfactory for the initial design phase in order to work out the control law design concept and get an initial set of gains. These models, however, have known deficiencies, which must be resolved in the final control law design. The error in the pitch-roll cross coupling is one notable deficiency[3] that even sophisticated rotorcraft models including complex wake aerodynamics have yet to capture successfully. This error must be accounted for to achieve the desired decoupling.

The approach to design the proposed inflight simulation control law is based on using a combination of simulation and identified models. The linear and nonlinear higher order models were used to develop an explicit model following control structure. This structure was developed to accommodate the design of control laws compliant to many of the quantitative requirements in ADS-33C. Furthermore, it also allows for control law research using rotor-state feedback and other design methodologies such as Quantitative Feedback and H-Infinity. Final gain selection will be based on higher order identified models, which include rotor degrees of freedom.

Identified models will be employed in order to ensure a high degree of modeling accuracy at various design points. The CIFER frequency domain identification procedure is used [4] to obtain minimally parameterized models. The models contain explicit rotor degrees of freedom. Models with simple flapping dynamics have been identified from flight test data without rotor measurements, and models with more complex dynamics are currently being identified from flight test data including rotor blade measurements.

The purpose of the paper will be three fold 1) to describe the proposed control law structure that is being developed for RASCAL 2) to describe the identification models being developed to allow calculation of the final set of control gains 3) to describe the integration of the identification models in the control law design process.

The paper will first present the proposed control law structure shown in Figure 2. The bare airframe response is dynamically decoupled using a few constant, first order, and second order transfer functions. Once decoupled, each axis is designed according to the structure shown in the figure for the roll axis. The inner crossover loop is structured to facilitate setting the crossover behavior of the design, thus, this block determines most of the performance of the feedback. This block is a modified form of the control law structure used in Refs. [5] and [6]. The outer hold loop is a lower gain feedback to give the system attitude hold. Once a tight attitude loop is established, roll shaping is applied to give the desired response.

A description of the design approach to pick the gains inside of the blocks in figure 2 will then be given followed by some representative results using linear and nonlinear high order simulation models. A typical example is shown in Figure 3, which shows the step response in pitch of a non linear UH-60 model using the control law configured as an attitude command system. Coplotted with the standard aircraft states are the command model states, which are being tracked by the control law.

The paper will then discuss the system identification modeling approach and the model structures used in the identification. The identification of models including rotor states from flight data with and without rotating system measurements will be covered. A model structure including simple flapping dynamics which does not require rotor state measurements is shown in Figure 4. Models with more complex rotor dynamics are currently under development.

Identification results will be used to show the current known deficiencies in the simulation models. An example is shown in Figure 5, which is a comparison of frequency responses of the roll from pitch response of the open loop UH-60 from flight data, the identified model, and two different blade element simulation models. The two simulation models show significant errors in prediction the phase, which is expected to severely affect the response of the closed loop system. The process of integrating the identification models into the design process will then be discussed and results will be shown using the identification model in the control law structure.

References

1. Aiken, E., Jacobsen, R., Eshow, M., Hindson, W., and Doane, D., "Preliminary Design Features of the RASCAL - A NASA/Army Rotorcraft In-Flight Simulator," AIAA-92-4175, August, 1992.
2. Takahashi, M.D., "Rotor-State Feedback in the Design of Flight-Control Laws for a Hovering Helicopter," J. of the Amer. Hel. Soc., January 1994.

3. Fletcher, Jay W., "Identification of UH-60 Stability Derivative Models in Hover from Flight Test Data," 49th Annual Forum of the Amer. Hel. Soc., St. Louis, Missouri, May 19-21, 1993.
4. Tischler, M.B. and Cauffman, M.G., "Frequency Response Method for Rotorcraft System Identification: Flight Applications to BO 105 Coupled Rotor/Fuselage Dynamics," *Journal of the American Helicopter Society*, Vol. 37, No 3, PP 3-17, 1992.
5. Landis H. Kenneth, and Glusman, Steven I., "Development of ADOCS Controllers and Control Laws, Vols. 1-3," NASA CR 177339, or USAAVSCOM TR 84-A-7, March 1985.
6. Pausder, H.J., and Bouwer, G, Von Grunhagen, W., "A Highly Maneuverable Helicopter Inflight Simulator - Aspects of Realization," 14th European Rotorcraft Forum, Milano, Italy, 1988.

Figure 1 - The RASCAL UH-60 Helicopter

Figure 2 - Model following control law structure

Figure 3 - Closed loop, nonlinear, response to a longitudinal doublet

Figure 4 - 14 DOF identification model structure for the UH-60 in Hover

Figure 5 - Roll from pitch coupling from flight data, identification model, and simulation models



Figure 1. The RASCAL UH-60 Helicopter

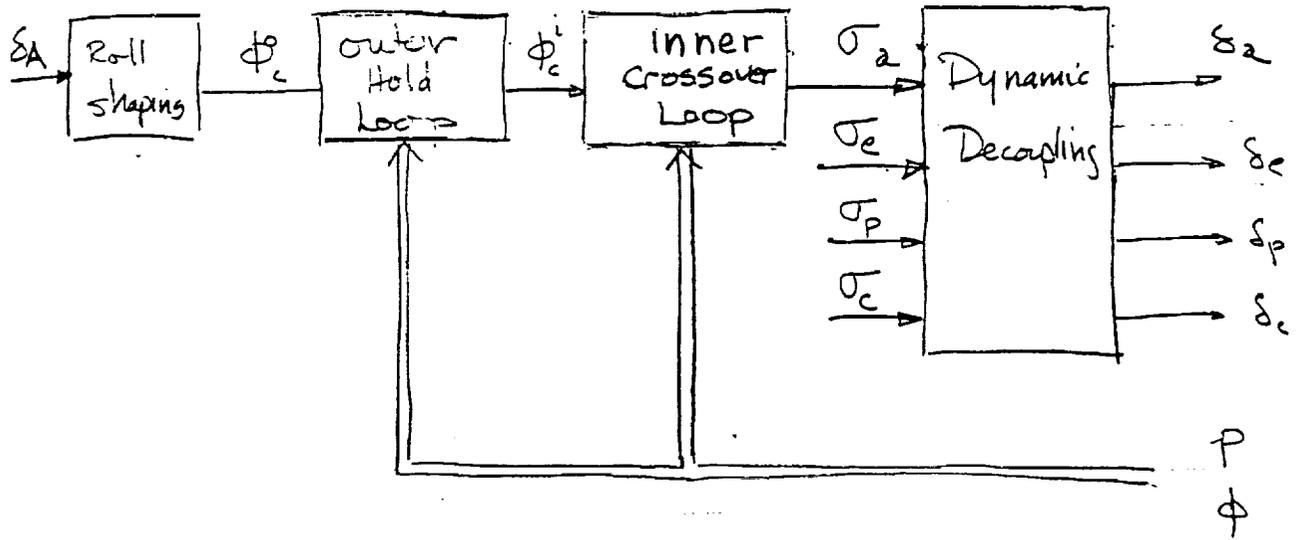


Figure 2 - Model following control law structure

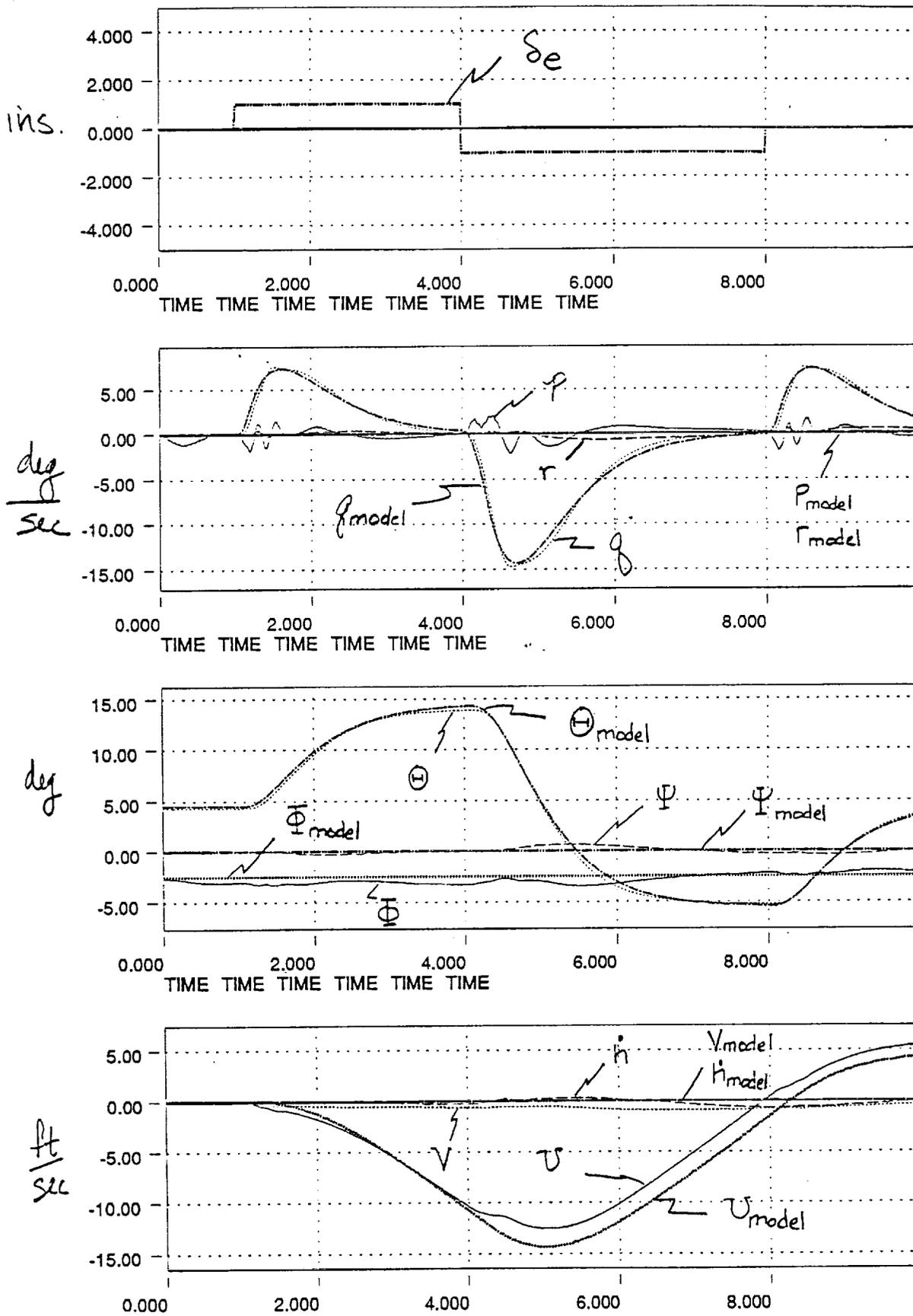


Figure 3 - Closed loop, nonlinear, response to a longitudinal doublet

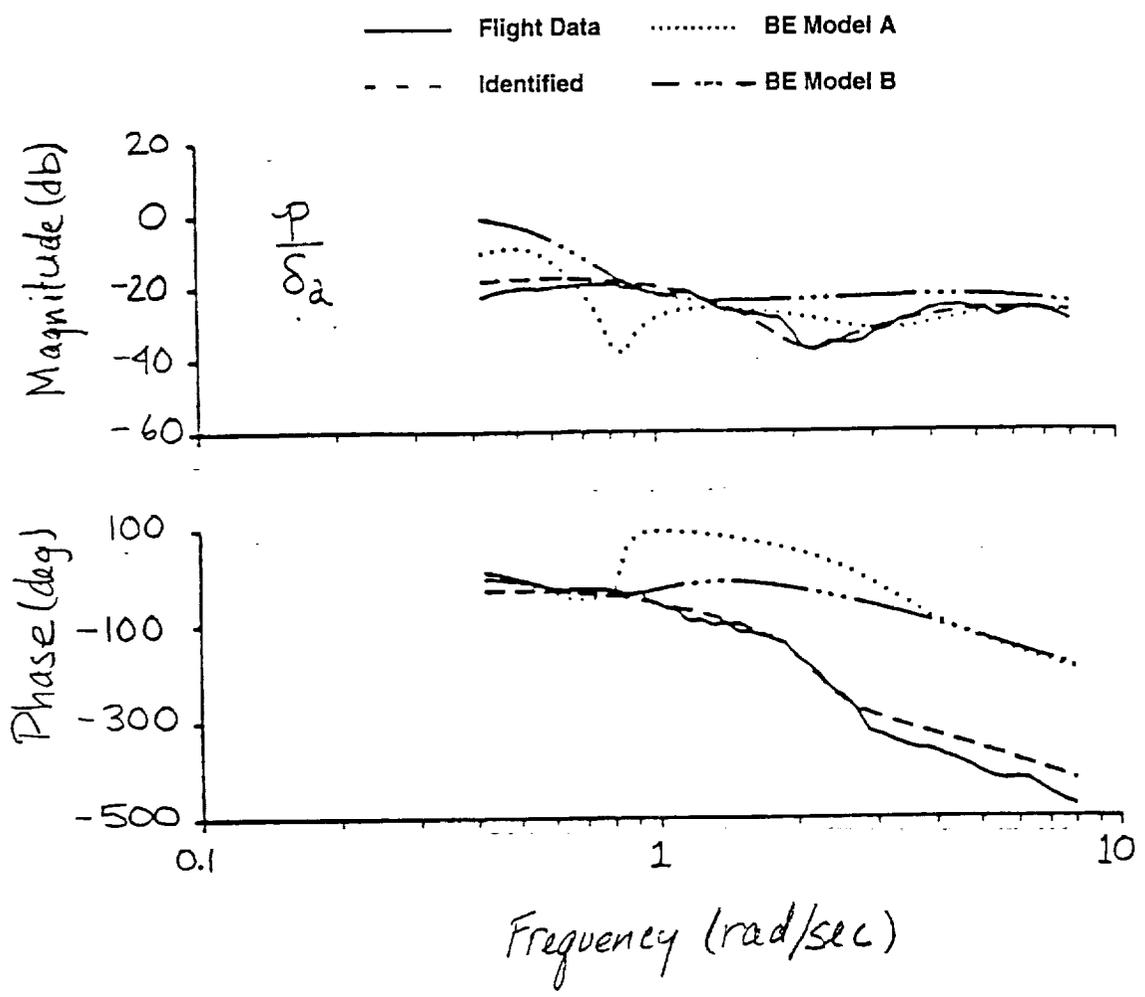


Figure 5 - Roll from pitch coupling from flight data, identification model, and simulation models