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Research Directions and Goals:

1) Intelligent Aerospace Vehicles and Systems
2) Low Cost Flight Testing
3) Handbooks and Specifications
4) Aircraft Conceptual Design
5) Nonlinear Control of Unstable Systems
6) Performance Based Model Reduction

Intelligent Aerospace Vehicles and Systems: Intelligent aerospace vehicles and systems represent a major area of multidisciplinary, systems oriented research and development. For example, one of the key research topics to enable Uninhabited Air Vehicles (UAVs) as viable systems is the development of reliable autonomous control technologies. My research is focused on the development of cutting-edge embedded control technologies to enable the realization of autonomous vehicles capable of conducting safe operations in conjunction with other vehicles, including formation flight. This is required to achieve a high level of mission effectiveness and to accommodate real-world operational issues. The core thrust of my research is on developing the framework for a real-time vehicle management system to obtain self-awareness, external awareness, and perform intelligent decision-making based on that awareness. This research has a major tie into aerospace system applications, including formation flight, collision avoidance, deep space probes, autonomous robots, and UAVs. The use of UAV helicopters, including the Yamaha R-Max and Raptor 50 and 90 helicopters, at the Lawrence Airport Flight Research Facility is to develop and verify these autonomous control technologies, to identify and verify dynamic vehicle models, and to train students in rigorous flight test procedures. Autonomous operations of the Yamaha R-Max have been conducted since October 2006.

Internal awareness for a system such as a UAV allows pertinent information about the vehicle's internal state (i.e., subsystem status, mission resources, et cetera) to be obtained and processed by the vehicle management system. The desire is to improve UAV reliability and mission effectiveness to the order of piloted aircraft. This includes the development of innovative prognostics and diagnostics methods. The UAV must adapt its mission plan and goals based on priorities to maximize its effectiveness and reliability.

External awareness for a system such as a UAV entails gathering and fusing data about the outside world. For a UAV, the autonomous air vehicle must have the sensing and processing resources to identify and track other air traffic, weather hazards, and terrain. It must be capable of receiving and processing air-traffic control (ATC) commands to operate in a safe manner in controlled airspace with other UAVs as well as piloted aircraft. It must also be capable of conducting safe terminal operations, making go-around or takeoff abort decisions where necessary. This entails the innovative use of current communications technologies, as well as the development and implementation of new communications methods within the constraints of the existing ATC system.

The UAV must be able to take internal and external state information and make intelligent decisions to fly in formation, act in concert, and see and avoid other traffic while maximizing its effectiveness within the global measure of total mission effectiveness. It must be able to interpret and respond to ATC commands or to multi-mission UAV coordination, while ensuring that such commands don't create a safety hazard or preclude mission completion. The vehicle must be able to adjust its mission plan, always seeking to complete as many of the intended mission goals as possible, while minimizing the probability of flight envelope exceedance and a flight mishap.

Low Cost Flight Testing: I have been working with Wayne Olson, Jay Ferrell, and other retired engineers from NASA Dryden and the Air Force Flight Test Center on low cost methods for flight testing. These techniques and methods have direct application to both the development of experimental general aviation aircraft and to Uninhabited Air Vehicle (UAV) flight testing. They use inertial and GPS sensors with minimal modifications to the vehicle. Estimation techniques are used to correct for winds and derive air data parameters. A paper on a portion of this work covering flight testing conducted this winter was presented at the August 2003 AIAA Modeling and Simulation Technologies Conference.

Current flight test work is centered at Lawrence Airport on helicopter UAVs. Progress and results of this flight test work will periodically be posted on this web site. We are beginning flight test of the ARF Mars Flyer low altitude technology demonstrator. We are approximately 75 percent through the completion of the CryoHawk stability and control demonstrator of the twin engine Polar Flyer (Tier B) Concept. Opportunities for research and study in this area will also be posted as they become available.

Aerospace Handbooks and Specifications: Multiple grant award have been received in this area of research. When approved for release, more information on this new grant will be made available on this web site.

Aircraft Conceptual Design: I transitioned this teaching and research area from Jan Roskam, Deane E. Ackers distinguished professor of aerospace engineering at the University of Kansas and world-renowned aircraft designer, who retired from KU. With Robert Loschke, retired Technical Fellow from the Lockheed Martin Skunk Works in Palmdale, California, I received the best paper award at the August 2003 AIAA Modeling and Simulation Technologies Conference. This was for the aircraft conceptual design paper "To Tail or Two Tails? - The Effective Design and Modeling of Yaw Control Devices." It was presented at the August 2002 AIAA Modeling and Simulation Technologies Conference.

Nonlinear Control of Unstable Systems: An Uninhabited Air Vehicle's (UAV's) dynamics change throughout the flight envelope in a nonlinear manner. Flight control surfaces and their actuators exhibit nonlinear behaviors, such as deadzones, rate and deflection limits. These nonlinear plant variations are accommodated by adjusting the flight control system in a nonlinear manner, often with a gain schedule. This gain schedule is frequently generated in a relatively ad-hoc manner, for example by examining the change in the stability derivatives with dynamic pressure. I have spent many years applying advanced mathematical theory such as H-Infinity control to design projects, and have used describing functions and dynamic inversion to generate the adaptive controller in a rigorous manner. I combined these methodologies into a three step system design process. These steps are: 1) modeling (using the describing function approach), 2) synthesis (using the H-Infinity loop-shifting technique), and 3) robustness analysis (using the labeling technique of simplicial algorithms). This method accommodates both discrete nonlinearities and instabilities, which other nonlinear control methods cannot. I have shown for at least a class of problems that H-Infinity optimization naturally generates an adaptive controller that cancels the nonlinearity in a manner analogous to a dynamic inversion controller. This method has been demonstrated using Matlab/Mathematica numerical analysis, FORTRAN simulation, and an analog circuit implementation of an unstable plant with an adaptive controller. This work has been documented in several technical papers and a book on this subject is nearing publication. When published, detailed information on this book will be available through this web site.

Performance Based Model Reduction: I have spent several years researching model reduction methods. We have been actively generating models of the Raptor 50, the R-Max and other UAVs. I generated a gradient curve fitting methodology that allowed for the simultaneous fitting of equivalent system models to several related frequency responses. One major research effort I accomplished in the field of state space model reduction concerned finite bandwidth balancing. This method, which I developed with Dr. Edmond Jonckheere of the University of Southern California, allows for balancing over a disk shaped region (versus the entire right half plane). It is analytically more robust than standard balancing and generates a model whose accuracy is ensured over the frequency domain of interest. It also eliminates some of the difficulties encountered in guaranteeing error bounds that arise in the infinitely sized domain used in standard balancing. All the primary methods for generating reduced order models preserve stability properties at the expense of dynamic system performance. For example, to achieve acceptable controller performance I found that feedforward and feedback portions of the controller would need to be reduced separately. The feedforward portion of the controller was designed to achieve performance specifications, while the feedback portion was designed to achieve the desired level of stability. I would work to develop model reduction methods that would allow a tradeoff between performance, robustness, and model size.