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INVESTIGATION OF AIR TRANSPORTATION TECHNOLOGY AT PRINCETON UNIVERSITY, 1983

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SUMMARY OF RESEARCH

The Air Transportation Technology Program at Princeton University, a program emphasizing graduate and undergraduate student research, proceeded along four avenues during 1983:

- Voice Recognition Technology for Flight Control
- Guidance and Control Strategies for Penetration of Microbursts and Wind Shear
- Application of Artificial Intelligence in Flight Control Systems
- Computer-Aided Aircraft Design

Areas of investigation relate to guidance and control of commercial transports as well as general aviation aircraft. Interaction between the flight crew and automatic systems is a subject of principal concern.

Computerized voice recognition of pilot inputs could play a major role in future air transportation. This capability has particular significance for single-pilot instrument-flight operations, where one pilot is required to perform all the tasks normally assigned to two or three persons in a larger aircraft. The tasks that can be carried out using voice command are varied; as a generality, they can be characterized as the jobs that a captain might ask the co-pilot to do, e.g., tuning radios, maintaining contact with air traffic control, holding altitude, and performing system status checks. Graduate student Chien Huang conducted flight tests in which the DME radio of Princeton's Avionics Research Aircraft was tuned by voice {1}. Tuning was accomplished by sending digital signals from a microprocessor, which received inputs from the pilot via the microphone and voice recognition board. Initial developments were extended to include the statistical evaluation of the system when used with different vocabularies, operators, and background noise conditions.

Recently, it has become apparent that severe downdrafts and resulting high velocity outflows present a significant hazard to aircraft on takeoff and final approach. This condition is called a microburst, and while it often is associated with thunderstorm activity, it also can occur in the vicinity of dissipating convective clouds that produce no rainfall at ground level. Microburst encounter is a rare but extremely dangerous phenomenon that accounts for one or two air carrier accidents and numerous general aviation accidents each year (on average). Conditions are such that an aircraft's performance envelope may be inadequate for safe penetration unless optimal control strategies are known and applied. While a number of simulation studies have been directed at the problem, there are varied opinions in the flying community regarding the best piloting procedures, and optimal control strategies remain to be defined.

Graduate student Mark Psiaki has undertaken a study of guidance and control strategies for penetration of microbursts when encounter is unavoidable. It appears that the scale of meteorological activity that presents the greatest hazard for transport-type aircraft is quite different from that for general aviation aircraft. Nevertheless, preliminary investigation has revealed commonalities in control laws that reduce altitude response to microbursts {2}. Professor Stengel also contributed to the National Research Council report on the subject {3}.

Undetected system failures and/or inadequately defined recovery procedures have contributed to numerous air carrier incidents and accidents. The infamous DC-10 accident at Chicago's O'Hare Airport, in which loss of an engine pod, subsequent loss of subsystems, and asymmetric wing stall led to disaster, provides a prototype for the kind of tragedy that could be averted by intelligent flight control systems. (An intelligent control system is one that uses artificial intelligence concepts, e.g., an expert systems program, to improve performance and fault tolerance.) Although many methods of modern control theory are applicable, the scope of the problem is such that none of the existing theories provides a complete and practical solution to the problem. At the same time, heuristic logic may be applicable, but it has yet to be stated in satisfactory format.

As a first step in our investigation, graduate student Francois Dallery has completed an M.S.E. thesis on reconfigurable flight control systems {4}. In this work computer simulations verify the ability of relatively simple logic to detect and identify failures in flight control systems and in the airframe itself. Graduate student David Handelman is continuing this work with the design of a knowledge-based reconfigurable flight control system that will be implemented using parallel microprocessors.

Work was continued on the Princeton Aircraft Design System (PADS), a modular interactive graphics computer program for the design of aircraft. The objective is to facilitate the design of aircraft configurations ranging from general aviation and glider aircraft to supersonic transports and other high-performance aircraft. Two students produced reports on various aspects of the PADS computer program, which is implemented in the APL computer language using Princeton University's IBM 3081-based Interactive Computer Graphics Laboratory facilities {5,6}. Seniors John Schneider and Brian Holasek completed program modules for three-dimensional display of aircraft configurations and for the design of wing and tail components.

Additional documentation of prior work occurred during the year. A paper on the use of fiber optics in flight control systems appeared in the IEEE Transactions on Aerospace and Electronic Systems {7}, while a summary of work on flying qualities criteria for single-pilot instrument flight was presented at the SAE Business Aircraft Meeting and Exposition {8}.

The NASA grant supporting student research in air transportation technology has inestimable value in helping educate a new generation of engineers for the aerospace industry, and it is producing research results that are relevant to the continued excellence of aeronautical development in this country.

REFERENCES AND ANNOTATED BIBLIOGRAPHY

1. Stengel, R.F., and Huang, C.Y., "Flight Tests of Voice Recognition Technology", presented at a Meeting of the Voice Technology for Systems Application Subgroup of the Department of Defense Human Factors Engineering Technical Advisory Group, Fort Monmouth, Oct 1983.

   A commercially available voice-recognition module was used to tune a DME navigation system in flight tests of Princeton University's Avionics Research Aircraft (ARA). The ARA is a fly-by-wire aircraft that is equipped with a digital flight control and data acquisition system; microprocessor-based systems installed in the aircraft facilitated integration of the voice-recognition unit, and initial tests proceeded at a rapid pace. Experimental error rates were no greater than those associated with manual inputs, and subsequent laboratory tests have indicated areas for further improvement.

2. Psiaki, M.L., and Stengel, R.F., "Analysis of Aircraft Control Strategies for Microburst Encounter", AIAA Paper No. 84-238, Aerospace Sciences Meeting, Reno, Jan 1984.

   Penetration of a microburst during takeoff or approach is an extreme hazard to aviation, but analysis has indicated that risks could be reduced by improved control strategies. Attenuation of flight path response to microburst inputs by elevator and throttle control was studied for a jet transport and a general aviation aircraft using longitudinal equations of motion, root locus analysis, Bode plots of altitude response to wind inputs, and nonlinear numerical simulation. Energy management relative to the air mass, a pitch-up response to decreasing airspeed, increased phugoid-mode damping, and decreased phugoid natural frequency were shown to improve microburst penetration characteristics. Aircraft stall and throttle saturation were found to be limiting factors in an aircraft's ability to maintain flight path during a microburst encounter.

3. Townsend, J., ed., Low-Altitude Wind Shear and Its Hazard to Aviation, National Research Council Committee Report, National Academy Press, Washington, 1983.

   The committee reviewed the state of knowledge about low-altitude wind shear, studied the hazards of low-altitude wind variability, and recommended actions to reduce the hazards of wind-shear encounters. A principal finding was that low-altitude wind variability presents an infrequent but highly significant hazard to aircraft during takeoff and landing; when

significant wind shears are known to be present, pilots should avoid flight into the area. In the near term, risks can be reduced by improving and automating the Low-Level Wind Shear Alert System (LLWSAS) and by installing the system at more airports. Education and training of pilots about wind-shear hazards are inadequate and should be improved. Better information is required concerning the response to wind shear of aircraft of various categories and sizes, taking account of the effects of piloting techniques and guidance and control systems. Utilization of ground-based Doppler weather radar would enhance detection of wind shear in the terminal area. Research should be conducted on the meteorological phenomenon, on the effects of heavy rain on aircraft aerodynamics, and on airborne wind-shear detection systems.

4. Dallery, F., "Failure Detection and Identification for a Reconfigurable Flight Control System", M.S.E. Thesis, Princeton University Report No. MAE-1639T, Nov 1983.

This thesis presents a fault-tolerant control system architecture that uses analytical and parallel redundancy to achieve failure detection, identification, and system reconfiguration. The proposed system has been developed and tested through extensive numerical simulations. The procedure is applied to a mathematical model of a transonic executive jet aircraft. The control system is found to provide excellent stability for standard aircraft sensors of comparable noise levels, and performance is found to be sensitive to control sampling interval.

5. Schneider, J., "PADS Multi-View Display Package", Princeton University Senior Independent Work Project Report, Jan 1983.

This multi-view display package uses a node-link data base to list, store, and retrieve designs. It displays three-view and oblique-view representations of an object described as an assemblage of polygons. Graphic examples for a simple aircraft configuration are shown.

6. Holasek, B.C., "Princeton Aircraft Design System (PADS): Wing and Tail Design Component", Princeton University Senior Independent Work Project Report, Jan 1983.

Detailed design of a three-dimensional wing or tail section can be accomplished using this program module. The wing geometry is specified by its planform and airfoil sections, allowing variations in sweep, aspect ratio, taper ratio, twist, dihedral, root chord, and tip chord. NACA 4-digit and 5-digit airfoils are stored in the program, and the user can specify arbitrary airfoil sections by direct entry.

7. K.A. Farry and R.F. Stengel, "Distributed Processing and Fiber Optic Communications in Air Data Measurement", IEEE Transactions on Aerospace and Electronic Systems, Vol. AES-19, No. 3, May 1983, pp. 467 - 473.

This paper describes the application of distributed processing, fiber optics, and hardware redundancy to collecting air data. Microprocessor-controlled instrumentation packages in each wingtip of Princeton's Variable-Response Research Aircraft (VRA) collect angle-of-attack and sideslip-angle data in digital form. After scaling, filtering, and calibrating the data, the wingtip processors send the data to the central processor, located in the VRA's fuselage, via fiber-optic links. The system design is presented, and results of a preliminary flight test are discussed. During this flight, over 2000 data transmissions occurred without error. The technology shows considerable promise for enhancing the reliability and performance of future flight control systems.

8. Bar-Gill, A., and Stengel, R.F., "Longitudinal Flying Qualities Criteria for Single-Pilot Instrument Flight Operations", SAE Paper No. 830761 for Business Aircraft Meeting & Exposition, Wichita, Apr 1983.

Experiments to determine the flying qualities of more than a dozen dynamic configurations have been conducted using the variable-stability Avionics Research Aircraft. Particular attention was paid to variations in long-period longitudinal characteristics and their effects on the performance of simulated IFR flights from takeoff through landing. Over the range of values tested, lift slope had the greatest effect on pilot opinion, workload, and tracking error. Bounds for satisfactory flying qualities were found for three parameters: phugoid mode damping, stick force gradient (with respect to trim airspeed), and pitch/airspeed gradient.