N87-22605

INVESTIGATION OF AIR TRANSPORTATION TECHNOLOGY AT MASSACHUSETTS INSTITUTE OF TECHNOLOGY, 1984

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SUMMARY OF RESEARCH

There have been three projects sponsored by the Joint University Program at MIT during 1984. Two projects are focussed on the potential application of Loran-C in flying nonprecision approaches to general-aviation runways, and the third project involves basic research on aircraft icing. Four faculty members were responsible for supervising student research in the program: Robert Simpson, Antonio Elias, R. J. Hansman and Walter Hollister.

Aircraft Approach Guidance Using Relative Loran-C Navigation

This project was aimed at a flight test demonstration of an approach guidance system based on the relative navigation concept of Professor Antonio Elias. It uses the difference in TD's from those of the touchdown point to simplify and speed navigation computer processing, and to take advantage of the short-term accuracy of less than 100 feet for Loran-C. The project led to three sub-project areas concerning methods of displaying guidance information to the pilot, investigation of dynamic response of the Loran-C receiver, and possible smoothing with rate gyro data, and the need to study the micro-distortion of the Loran-C field discovered in surface measurements over open terrain.

The system being constructed for flight testing by Norry Dogan is based on a Micrologic M3000 Loran-C receiver especially modified to output TD's, and TD's in digital form every 12 GRI, and whose tracking filter constants can be set by the experimenter. A flight test pallet has been constructed to carry the receiver, the memory storage system, power supply, auxiliary display, etc. Three different display devices have been constructed. The original display was an LED bar-graph display of cross track distance and velocity, and an LED numeric digital display of range and desired altitude. This system will now display these data to the experimenter from the flight test rack. For the pilot, a CRT cross-pointer display has been constructed, driven by software resident in an Apple II computer. This has the advantage of flexible formats and ease in programming software changes for the pilot's display. The third display was developed by another student, Lee Marzke, using a Sharp LM-24003G Graphics Display. This is an 128×240 pixel display, which uses liquid crystal technology, and is roughly 4×8 inches in size. A special, programmable controller using the MCG-8085 processor was built to accept data over an RS-232 line and convert it to a cross-pointer display, with TO-FROM, altitude, and airspeed. It was decided to use the CRT display for flight test and to retain this display for other applications in future research. Flight testing of the system was planned for early in 1985, at a few selected sites in the 9960 Loran-C chain.

In the course of constructing the system, ground surveys were conducted using the Loran-C receiver and Apple Computer. These discovered that there were unexplainable micro-distortions of the Loran-C signals over a grid of roughly 50 meters. The averaged position deviation from the grid was repeatable and of the order of 10 meters. This would appear as noise to the receiver if it exists above the Earth's surface in the approach path to the runway. This has triggered investigations of methods to survey the approach airspace using the flight test pallet mounted on a tethered balloon or kitoon. The size of these micro-distortions will affect the performance of the Loran-C guidance system in estimating cross track velocities and thus its dynamic response in displaying cross track deviations to the pilot. Further research is planned by Professor Antonio Elias to gather more data on these microdistortions.

Probabilistic Modelling of Loran-C Errors for Nonprecision Approaches

The goals of this project are to develop a mathematical model which will predict the probability that an approach flown to a runway with a particular Loran-C receiver will fall within a given standard (such as FAA AC90-45A). Flight tests will be used to validate the model performance. During 1984, the model was developed and programmed to handle both short-term update (5 minutes) and long-term update (6 weeks) cases. It accounts for runway heading, the chain and slaves used and their geometry and distance relative to the airport, the current SNR (signal-to-noise ratio), and the seasonal history of Loran-C deviations at nearby monitoring stations. Several models for predicting long-term drift have been examined. The model produces a bivariate normal error ellipse for the position of the aircraft on approach to the runway. The percentage of this ellipse which falls within any other geometric standard can be computed.

This research is being performed by John Einhorn, with supervision by Walter Hollister.

Aircraft Icing Research

This research is a continuation of work done originally by R. J. Hansman as a graduate student in the Joint University Program. Experimental work in 1984 has focussed on two main areas:

1) Measurement of droplet trajectories and droplet impingement/runback characteristics

2) Measurement of real-time ice accretion using ultrasonic pulse-echo techniques

DROPLET RESEARCH

In order to experimentally measure the trajectories of droplets, a controlled method for producing droplets of the known, repeatable initial conditions to be "injected" into the free-stream flow at any desired location has been successfully developed. The system utilizes a syringe reservoir connected to an extremely fine bore length of tubing, described in the next section.

The syringe reservoir supplies water to a 0.005 in. (ID) tube approximately 2 in. long. The tube is extended into the free-stream flow at a 30 degree angle. Droplets bead at the end of the tube until they are drawn off by the free-stream drag. In order to minimize the droplet size at which this occurs, the tube tip is coated with wax to increase the droplet/tube contact angle. Droplets can be produced at a rate of several per second using this technique, although the current trajectory measurement scheme does not require such a "stream" of droplets. The approach being taken to measure the droplet trajectories is to use a double strobe light pulse to illuminate the droplet at two points along its trajectory. Since the time between these points is fixed by the strobe pulse interval, the velocity of the droplet between the points can be obtained by measuring the distance travelled in this interval from a 35-mm photograph. By moving the injection point across the entire injection plane upstream of the body, the velocity field around the body can be completely mapped. One of the distinct advantages of the developed injection technique is that the initial droplet conditions can be accurately measured and thus used as inputs to existing trajectory codes to aid verification and/or development of trajectory codes for complex bodies such as glaze ice shapes. Since the droplet is pulled off the injector tip, the initial velocity of the droplet is zero; furthermore the initial co-ordinates of the droplet are also those of the injector tip. The initial size of the droplet is obtained from a triggered photograph taken immediately after the droplet release occurs.

REAL-TIME ICE ACCRETION MEASUREMENT

Experiments to measure ice growth on a cylinder have been conducted in the Icing Research Tunnel (IRT) at the NASA Lewis facility in Cleveland, Ohio. A 4 in. (OD) cylinder approximately 12 in. long was suspended vertically from the roof of the IRT and exposed to a variety of icing conditions[1] at the velocities from 110 mph to 230 mph. The cylinder was instrumented with 4 ultrasonic transducers to measure the real-time ice accretion using the pulse-echo technique. The transducers were all of the longitudinal wave type, three being 0.5 in. diameter transducers and a 0.25 in. diameter delay-line transducer. The transducers are mounted flush with the cylinder surface and are thus "non-intrusive." For the series of tests performed at NASA Lewis three of the transducers were mounted on the cylinder stagnation line and the remaining (0.5 in.) transducer was mounted 25 degrees off-axis to allow simultaneous measurement of horn growth rates and the growth rate on the stagnation line. Data were collected by video-taping the oscilloscope output from the transducers and pulser/receivers. Although data reduction from the entire series of tests is still under way (over three hours of real-time ice accretion data were recorded in 38 tests in the IRT), initial results have shown the following:

1) The ultrasonic pulse-echo system is capable of measuring ice thickness in real time over a wide range of icing conditions. Ice thickness data were successfully recorded for all the tests conducted, although ice formations at warmer temperatures (+27°F) sometimes resulted in a cavity forming over the transducer at some point in the ice growth, after which the transducer can no longer measure further ice accretion (due to the reflection of the pulse signal from the air cavity). At the colder temperatures (+10°F to -10°F) the pulse-echo system performed extremely well, producing a discrete, large amplitude echo at the moving ice/air interface.

2) The optimum transducer frequency appears to be 5 MHz, although even higher frequencies have yet to be evaluated. The optimum transducer size for ice accretion measurement is driven by two conflicting requirements. A small diameter transducer is relatively insensitive to the irregular ice/air surfaces that are characteristic of ice accretion at warm temperature, and hence produces a "narrower" interface echo than a larger diameter transducer would under similar condition.[2] However under the same warm (glaze) icing conditions, air cavities and inclusions were observed which

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[1] A temperature range of 37 degrees Fahrenheit was covered, with runs from -10 degrees Fahrenheit to +27 degrees Fahrenheit. Liquid water contents were varied from 0.6 g/m^3 to 2.4 g/m^3. Droplet diameter was also varied from 12 micrometers to 20 micrometers.

[2] The ice thickness resolution achievable is fundamentally limited by the ice thickness variation across the ultrasonic field produced by the transducer, and hence by the diameter of the transducer (since the ultrasonic field is a collimated beam of the same diameter as the transducer).

threaten to "blind" a small diameter transducer to further ice accretion and thus dictate either a transducer large enough to see around these cavities or else several smaller transducers operating in parallel.

3) In addition to providing information on the thickness and surface variation of the accreted ice formation, the ultrasonic system also clearly shows the presence of liquid water on top of the ice layer, and it is hoped that further measurements on the data recorded will allow the thickness of this layer to be determined. At the colder temperatures no such water layer was observed, from which it can be concluded that the droplets are indeed freezing "on impact," as in the classical rime ice model.

FURTHER WORK

Droplet Studies

Having developed and tested the droplet injection technique, work is now under way on the development of a laser triggered multiple strobe setup. By breaking a laser beam aimed across its path, the droplet triggers a multiple strobe arrangement that allows the desired point velocity measurement to be photographically recorded as described earlier. In addition the laser trigger will also be used to study droplet impingement on bodies and runback characteristics. This can be accomplished by aiming the laser beam on the desired impingement point to be studied, and triggering from the droplet's occlusion of the reflected beam signal.

Ultrasonic Pulse-Echo Developments

Following the successful series of tests at NASA Lewis, work was conducted to allow flight testing of the ultrasonic system aboard the NASA Lewis icing research Twin Otter aircraft. Signal processing algorithms to track the ice/air interface echo under all icing conditions are being studied with a view to building a real-time data acquisition system providing ice thickness and ice accretion rate output. Existing, commercially available pulse-echo thickness readers will also be investigated for this prupose. Data reduction from the IRT tests will continue and were presented at the 23rd Aerospace Conference (Hansman R. J., and Kirby M. S., "Measurement of Ice Accretion Using Ultrasonic Pulse-Echo Techniques," AIAA 85-0471). The real-time ice accretion data taken will also be compared with existing computer model predictions for "identical" icing conditions on a cylinder. Additional theoretical modelling of the ultrasonic wave propagation in different ice types will also be undertaken and analytic models developed for wave propagation and reflection characteristics. Further refinement of the speed of sound in ice will be made from the results of the Lewis tests. It is hoped that fundamental information on the elastic properties of different ice types may be obtained from this velocity data.

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