Current Status of Visibility Sensors for Aviation

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INTRODUCTION

The visibility sensor that is currently used in the United States is, of course, the Transmissometer. It is normally installed on a 250-foot base line and will measure runway visual range (RVR) between 600 and 6,000 feet. There is a need to increase the range of those measurements to both lower and higher visibility for various purposes. In order to extend the RVR coverage to include Category IIIb, the range needs to be extended down to 100 feet RVR. This extension can be done with the current transmissometer by simply adding a second shorter base line (40 feet). Current transmissometer technology provides only a factor of ten dynamic range with a single base line. A second limitation of current transmissometers is that they are expensive to buy, install and maintain. A less costly instrument would be desirable.

The FAA is preparing to install automated weather observing systems (AWOS) at many locations in the United States, particularly smaller airports that have no observations at present. These systems require visibilities up to approximately five (5) miles. They don't need to measure low RVR (only down to 1/4 mile). In order to use a transmissometer for this type of measurement, the base line must be about 1,000 feet; where alignment becomes very difficult to maintain. Practical AWOS systems require high reliability, low maintenance and low cost. Consequently, a transmissometer is not the ideal instrument to be used for AWOS systems. Fortunately, over the last ten years, new technologies have been developed for measuring visibility. Improved transmissometers, forward-scatter meters and back-scatter meters have become available.

A current practical issue for visibility sensors is how to specify one that is good enough to meet the needs of aviation. No concensus has been reached concerning visibility sensor acceptance criteria. The first question is what performance is required; how accurately must the sensor measure? Visibility sensors do not actually measure the visibility directly; in fact, they measure the extinction coefficient which is then converted by standard equations into visibility. The purpose of measuring the visibility is to predict what the pilot will see a considerable distance away from the sensor location. Because the atmosphere introduces considerable variation in the measurement, the basic sensor accuracy needed is difficult to define. The second question for high visibilities is what to use as the standard reference sensor. For the visibilities currently being measured, the transmissometer is certainly a reasonable reference; but, for higher visibilities, it is not an easy reference to use. Several other options have been examined. A third question pertains to the competitive procurement of visibility sensors, which is mandated at present. What acceptance test procedures should be used to insure satisfactory sensor performance?

VISIBILITY SENSOR TECHNOLOGY

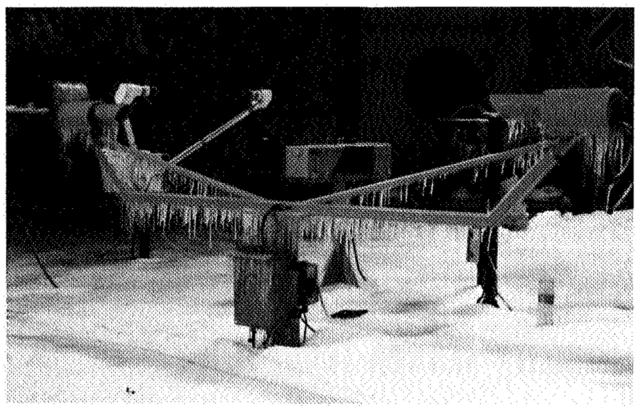
Three technologies are available for measuring visibility. The first is the conventional transmissometer; the second is the back-scatter meter; and the third is the forward-scatter meter.

The transmissometer has a primary virtue in that what it measure correlates most closely with what the human eye will see. The conventional transmissometer used in the United States suffers from a number of other problems, however. It is very sensitive to alignment and the window contamination. It must have a very narrow field of view in order to avoid systematic errors. It is also sensitive to background light because it uses a DC light level; and the windows must be cleaned often.

Recently we carried out some visibility sensor tests in the large climatic chamber at Eglin Air Force Base. The primary purpose of the tests was to evaluate sensor performance in dense Category IIIb fogs which are rare in nature. Of particular interest was the response of the current operational transmissometer, the Tasker RVR 500, on a 40-foot baseline. A variety of other transmissometers and forward-scatter meters were also tested.

The Europeans have developed a number of transmissometer systems that have a more advanced technology than what is used in the United States. One of these units is the Skopograph made by Impulsphysik in Germany. The projector uses a pulsed xenon flash lamp. Using the pulsed flash lamp eliminates background light problems. Otherwise, the Skopograph performance and costs are similar to the Tasker RVR 500. The Marconi MET-1 Transmissometer from England uses a very short baseline. Becasue the baseline is folded, the complete unit is slightly longer than three (3) meters and is installed on a single pedestal. The MET-1 includes precision light measurements and automatic calibrations in order to make a much more accurate measurement than in conventional transmissometers. As a result, a single MET-1 unit gives the same coverage achieved with a full dual-baseline system. Both the Skopograph and the MET-1 are used operationally in Europe.

A back-scatter meter called the Videograph is being used by the National Weather Service and the Coast Guard. It is also made by Impulsephysik in Germany. It is installed at a single

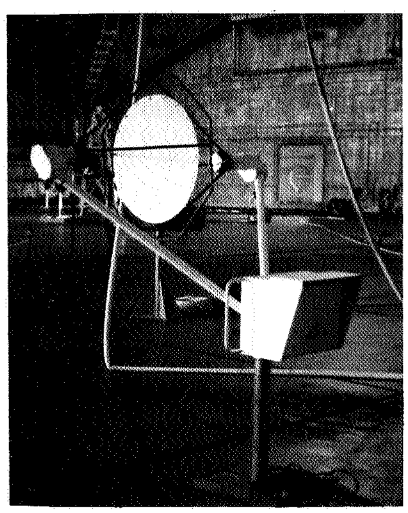


The Marconi MET-1 Transmissometer

point and transmits a narrow beam from a xenon flashlamp. A narrow receiver beam crosses the transmitted beam some distance away from the unit and looks for the back-scattered light. It averages over a reasonably large volume. The Videograph has developed into a good instrument in that it is stable and reliable. However, it has some calibration problems. The response to snow is much too large and cannot be corrected without a present-weather sensor. The response to haze is also too large, but it can probably be corrected with a realtive humidity measurement.

A forward-scatter meter (FSM) looks at forward-scattered light rather than back-scattered light. The forward-scattered light has been shown to give a better correlation with the extinction coefficient for fog and snow than what is achieved with back-scattered light. Consequently, a FSM has a fundamental advantage over the back-scatter meter. On the other hand, at the present time, no forward-scatter meter has proven to be a reliable, stable instrument. All the existing units are eithre too new to have an established performance record or have well-known maintenance problems.

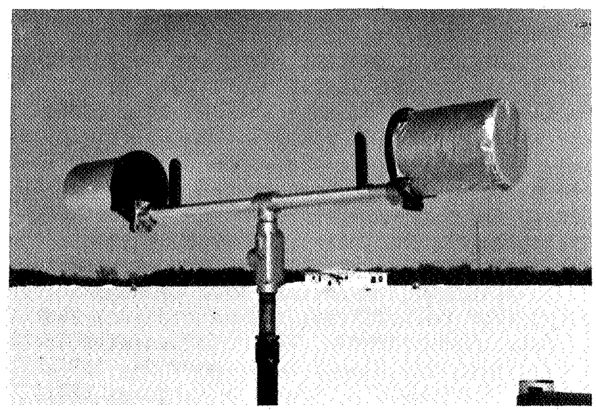
The EG&G 207 FSM has been used by the Air Force



EG&G 207 Forward-scatter Meter with Calibrator

for the last decade in a test environment. Its projector lamp sends out a cone of light with the middle blocked into the atmosphere. The receiver has the same type of beam, a cone with the middle blocked and looks at the scattered light from the ring where the two beams overlap. As the fog gets denser, the scattered light increases. Zero scattered light corresponds to very high visibility. In order to calibrate the EG&G 207 and tell if it responds in a fair visibility, a plastic scattering disc and a receiver attenuator are installed to check the response of the unit. The desired response to the calibration is determined by comparison with a transmissometer. An essential part of making the forward-scatter meter work is to have a calibration technique.

The Wright & Wright FOG-15 forward-scatter meter has virtually the same geometry as the EG&G, but is engineered to be simpler and easier to use. It is simply mounted to a post instead of a fancy tower like transmissometers because it is all self-contained.



Wright & Wright FOG-15 Forward-scatter Meter

Three other forward-scatter meters were also tested at Eglin. The Impulsephysik Fumosens-III is a downward-looking system that uses a pulsed flashlamp for its light source. The HSS VR-301 is a side-looking forward-scatter meter which uses a modulated LED as its light source. The Enertec EV-1000 is a side-looking forward-scatter meter made in France, which also uses a pulsed flashlamp. The EV-1000 scattering geometry was enclosed with light baffles which caused trouble in ice and snow. A more open geometry is needed for all-weather operation.

TECHNICAL ISSUES

There are three technical issues which need further study. The first is the selection of a high visibility standard sensor. A 1000-foot baseline transmissometer can be used, but installation and maintenance are expensive. A laser transmissometer (the FAA owns 300 of them) may also serve as a long baseline standard. It worked well on shorter baselines in the Eglin

HHS VR-301 Forward-scatter Meter

tests. It may also be useful for high visibilities. A nephelometer may also play a useful role in making high visibility standard measurements.

The second issue has to do with the high visibility response of back-scatter and forward-scatter sensors which both show some nonlinearities. In other words, the signal is not necessarily proportional to the extinction coefficient. Figures 1 through 3 show some data measured in fog which illustrate this effect. The plots compare the forward-scatter meter response (extinction coefficient) to the transmissometer response. The calibration on the forward-scatter meter in Figure 1 is slightly off. If the two sensors agreed exactly, the data would lie on a diagonal line from corner to corner. The dashed lines represent errors of ± 15 percent. The solid diagonal line is the least-square fit to the data and is within a few percent of giving exact agreement between the sensors. The sensor agreement looks very reasonable on the scale of Figure 1. Figure 2 shows a factor of five increase in the scale. It is apparent that the data do not fit the straight line very well, especially at the lower values which seem to show a difference in slope.

Figure 3 shows another factor of five increase in scale and you can see that the slope is perhaps 50 percent different from the average slope of the data for fog. The high visibility region (low extinction coefficient) where the slope seems to be different corresponds to haze. One of the tasks that lies ahead is to develop a satisfactory nonlinear instrument calibration which will be satisfactory at high visibilities.

A third technical issue needing resolution is the question of whether an estimate of visibility produced by a point measurement of a forward-scatter meter is operationally compatible with the line average measurement of a transmissometer.

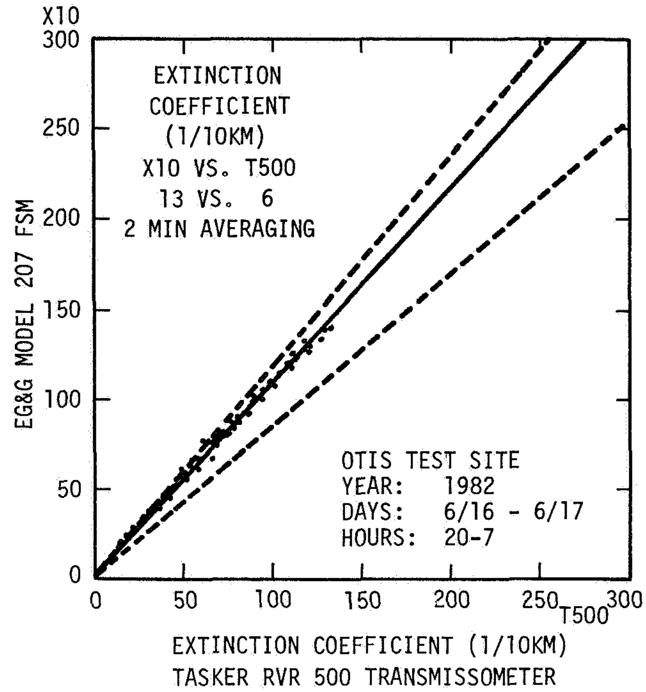


Figure 1. Scatter Plot Comparing a Forward-Scatter Meter Measurement to a 1000-foot Baseline Transmissometer Measurement.

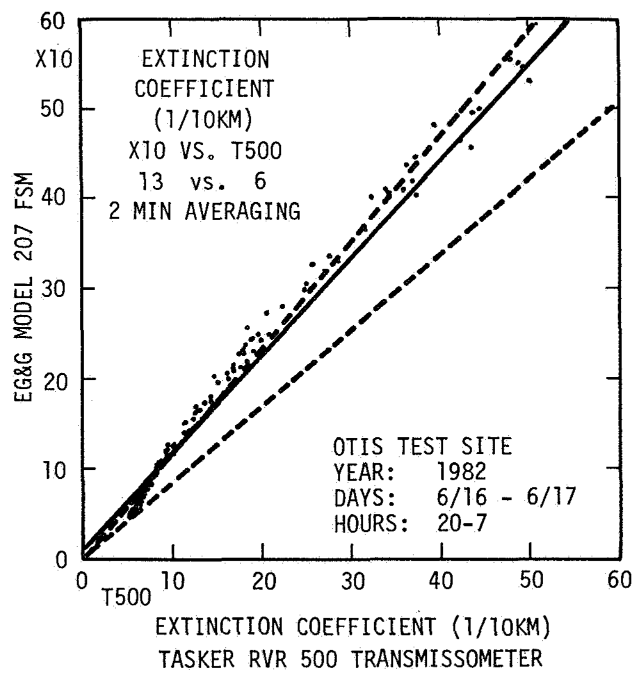


Figure 2. Figure 1 Expanded by a Factor of Five.

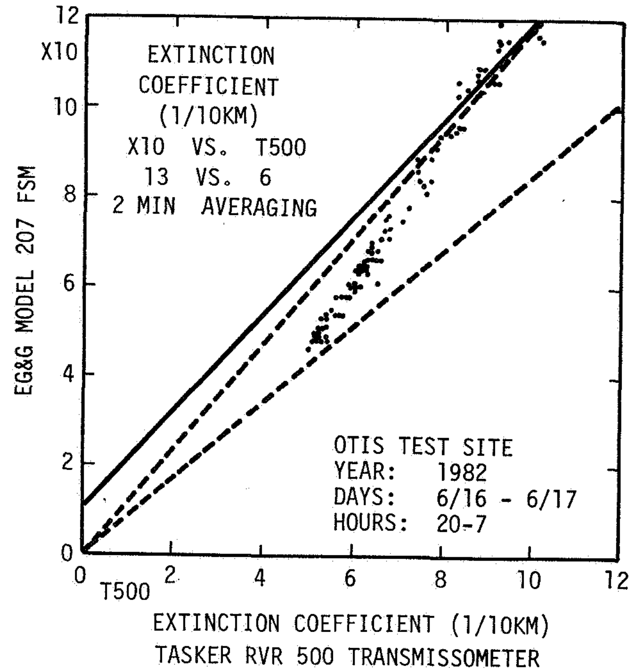


Figure 3. Figure 1 Expanded by a Factor of 25.

The NASA Aircraft Icing Research Program

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The NASA Aircraft Icing Research Program has three major program elements as indicated in Figure 1. The major thrust of the program is to improve the understanding of the details of aircraft icing encounters for both fixed and rotary wing vehicles and how to minimize the impact of these encounters on aircraft safety. This requires a balanced research program which contains natural icing flight testing as well as more controlled simulation experiments. The simulation experiments can be conducted in ground or flight test facilities as well as by using computational fluid dynamics tools.

As Figure 1 attempts to indicate, it is extremely important to understand how the various simulation approaches relate to each other and most importantly to natural icing.

The following discussion will present some examples of NASA icing research currently being conducted within each of the three major program elements.

The aircraft icing problem is one which is ripe for the application of computational fluid dynamics tools. The NACA/NASA aircraft research effort was terminated before adequate computational capabilities were available, and thus that effect focused attention on experimental research in the NACA/NASA Icing Research Tunnel (IRT). In the succeeding years, various aerospace companies developed analytical tools for handling certain aspects of the icing problem, but these computer codes in general are not available in the open literature.

It is NASA's intention to develop a series of computer codes which will analyze various aspects of the icing problem, verify the accuracy of the code predictions by comparison with appropriate experimental data, and then make the codes available to the industry.

Figure 2 presents a list of the computer codes currently being developed. They fall into the areas of trajectory analysis, ice accretion analysis, aerodynamic performance degradation and ice protection system performance. It is not meant to be implied that the computer codes currently being developed will treat all aspects of the icing problem; however, it is felt that these codes are the necessary building blocks from which additional analytical capabilities can be developed.

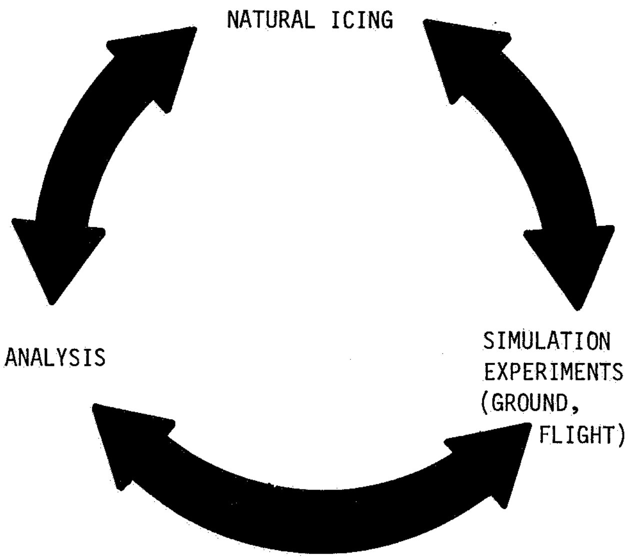


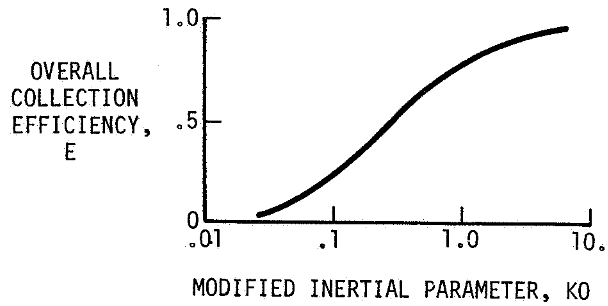
Figure 1. NASA Aircraft Icing Research Program Elements

- COMPUTER CODES BEING DEVELOPED
  - 2-D TRAJECTORY ANALYSIS FOR
    - AIRFOILS
    - INLETS
  - 3-D TRAJECTORY ANALYSIS FOR
    - WINGS
    - WING/BODY COMBINATIONS
    - COMPLETE AIRCRAFT
  - 2-D ICE ACCRETION ANALYSIS
  - AIRFOIL, PROPELLER, ROTOR PERFORMANCE DEGRADATION DUE TO ICING
  - AIRCRAFT PERFORMANCE DEGRADATION DUE TO ICING
  - ELECTROTHERMAL DE-ICER ANALYSIS
  - FLUID FREEZING-POINT DEPRESSANT SYSTEM ANALYSIS
  - ELECTROMAGNETIC IMPULSE SYSTEM ANALYSIS
- VERIFICATION EXPERIMENTS ARE BEING PLANNED AND CONDUCTED TO EVALUATE VARIOUS CODE CAPABILITIES

Figure 2. Computer Code Development and Verification

An example of the use of the aircraft icing analytical capabilities already developed is shown on Figure 3. The general aviation community indicated to NASA that the water drop collection efficiency information for general airfoil shapes available in the FAA ADS-4 document was insufficient since the airfoil designs of interest today are often times significantly different from those studied by NACA icing researchers during the 1940-60 time period.

To satisfy this request, NASA funded a study at Ohio State University to perform a detailed set of collection efficiency calculations for some 30 airfoil sections which are of current interest. The calculations were performed with a water droplet, two-dimensional trajectory code. The accuracy of the code had already been established by comparison of predictions with available experimental collection efficiency data. The results of the study will be published as a NASA Contractor Report.



- USE 2-D TRAJECTORY ANALYSIS CODE TO CALCULATE IMPINGEMENT LIMITS, COLLECTION EFFICIENCIES FOR 30 "MODERN" AIRFOILS FOR A VARIETY OF CONDITIONS.
  - NACA 63 SERIES
  - NACA 64 SERIES
  - NACA 65 SERIES
  - NACA 4 DIGIT SERIES
  - NACA 5 DIGIT SERIES
  - NASA LS SERIES
  - NASA MS SERIES
  - SUPERCRITICAL
  - EPPLER
- RECOMMENDED BY THE GENERAL AVIATION AIRCRAFT MANUFACTURERS

Figure 3. 2-D Airfoil Water Drop Collection Efficiency Calculations

A three-dimensional trajectory code has been developed which will predict water drop trajectories about complete aircraft configurations. The code is envisioned to have many uses; one of which is to aid in proper placement of icing instrumentation on aircraft. This code is currently being used to study the droplet trajectory characteristics about the NASA Twin Otter icing research aircraft (as Figure 4 shows) and to asist in interpreting the experimental results.

There appears to be an increased desire within the aircraft industry to use ice protection only on those aircraft components for which ice accretion could seriously endanger the aircraft performance and stability/control characteristics. When a component is not protected, it is thus mandatory to determine the resulting aerodynamic performance degradation due to ice accretion.

The first step in gaining that understanding is to determine the ice accretion shape characteristics. This can be done either experimentally or by using computational techniques. Currently, no computational techniques exist to predict ice accretion characteristics for general air-

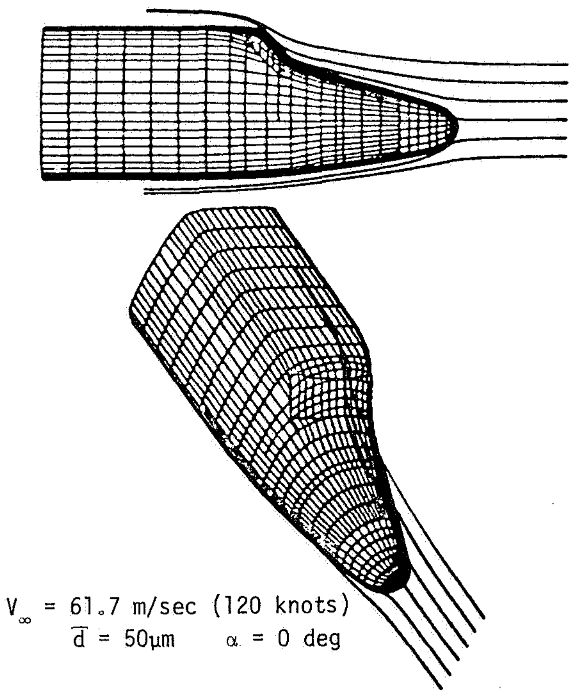


Figure 4. 3-D Trajectory Predictions Twin Otter Icing Aircraft

foil shapes. Rather the approach has been to correlate key ice accretion shape characteristics for the limited experimental data available for a few airfoil geometries as functions of known aerodynamic and environmental variables. The generality of these correlations is doubtful.

A more desirable approach is to develop a computer code which predicts ice accretion shapes based upon a solution of the governing energy equation for local water freezing rates. Such an airfoil ice accretion code is being developed by the University of Dayton and some preliminary code results are presented in Figure 5. While the two results shown indicate reasonable agreement between predicted and experimentally observed ice shapes, much work remains to be done before the ice accretion code accuracy has been verified. However, the long-term possibilities that such a code would possess make it an attractive alternate to existing experimental data correlations.

Once the ice accretion shape is known, the final and most important step is to predict the aerodynamic performance degradation due to that ice growth. Figure 6 indicates the currently demonstrated analytical capability to predict airfoil performance degradation with ice accretion shape. For this study, the Eppler airfoil code was used since it represents a state-of-the-art low speed airfoil analysis/design capability.

As Figure 6 indicates, the Eppler code predictions matched the experimental wind tunnel data for the clean airfoil which is to be expected. However, when the airfoil with the simulated rough rime ice shape was tested, the drag values measured significantly exceeded the levels pre-

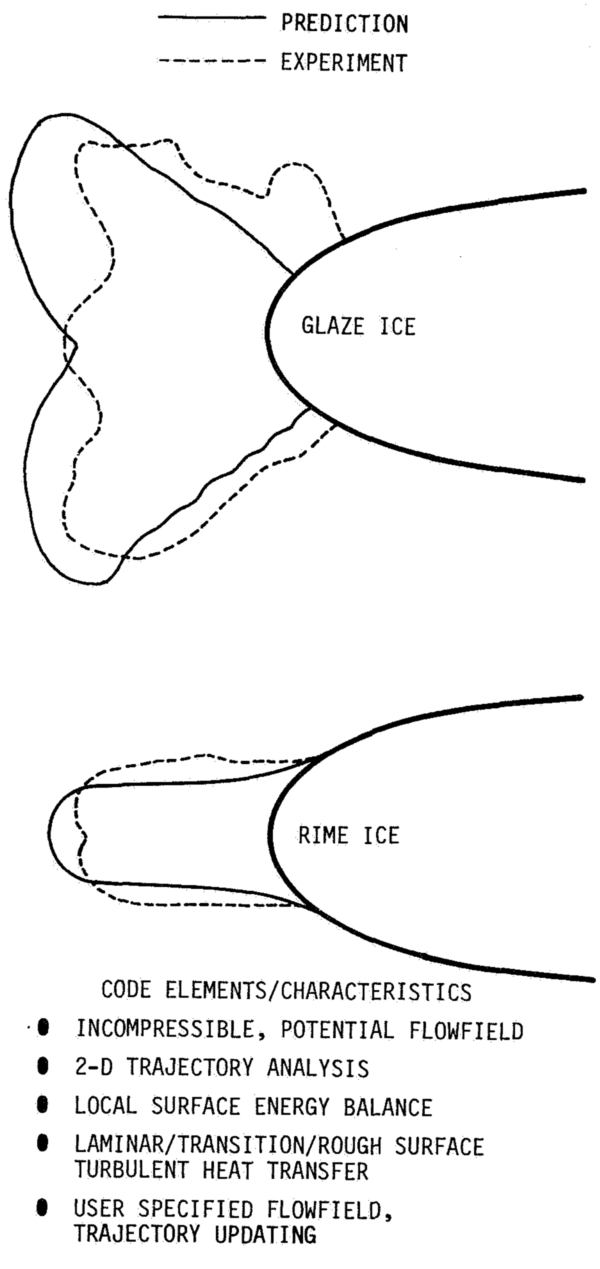


Figure 5. NASA Airfoil Ice Accretion Prediction Results

dicted by the original version of the Eppler code. In fact, it became necessary to modify the Eppler code predictions for drag by developing an empirical correlations using existing icing wind tunnel data for drag increase on an airfoil caused by rime ice accretions. The resulting agreement is shown in Figure 6.

Currently, effort is underway to remove the need for the drag correlation by modifying the boundary layer calculational procedure to incorporate the effects of the rough surface texture of the rime ice growth on the boundary layer characteristics. It is felt that an inadequate modeling of the surface roughness effects is the major cause of the disagreement between theoretical predictions and experimental results.

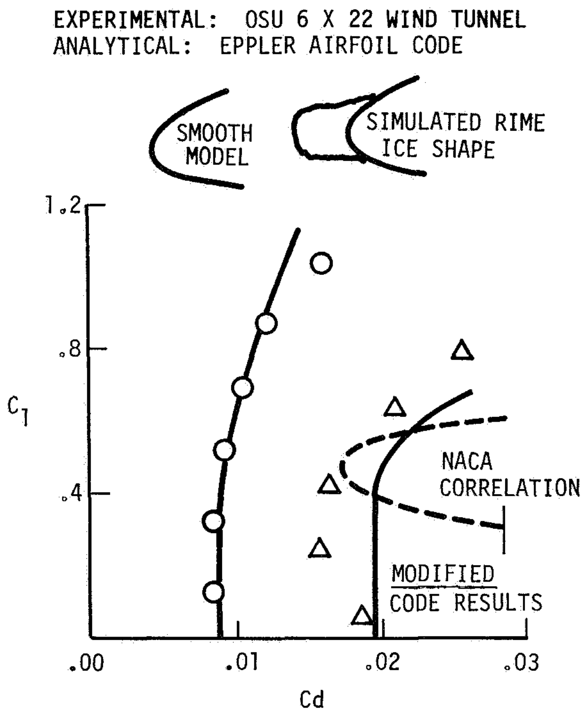


Figure 6. NACA 65A413 Airfoil Performance with Simulated Rime Ice

Work is also underway to develop analytical capabilities for predicting the details of the aerodynamic flowfield for the more serious glaze ice shapes. An adequate treatment of the glaze ice flowfield must include a treatment of the boundary layer separation-reattachment zone which can occur on either or both surfaces of the airfoil downstream of the ice accretion shape.

Figure 6 also shows the lift-drag polar predictions using the NACA performance correlations developed by NACA researchers. These correlations were developed from available experimental icing data for airfoils to give expressions for change in airfoil lift, drag and pitching moment due to ice accretion. The agreement for this particular case is not very good.

It is important to note that these performance correlations are still being used today to predict airfoil performance degradation due to ice accretions since no other correlations or analytical prediction capabilities currently exist.

Figure 7 shows comparisons for two general aviation airfoil sections tested in the NASA IRT of the experimentally measured drag increases due to icing with predictions made using the NACA correlation. Again, the scatter is seen to be large especially for the solid symbols which represent the high liquid water content data. However, with the exception of this high liquid water content data, the figure also indicates that the scatter in the results is no worse than the scatter for the original data upon which the correlation was based.

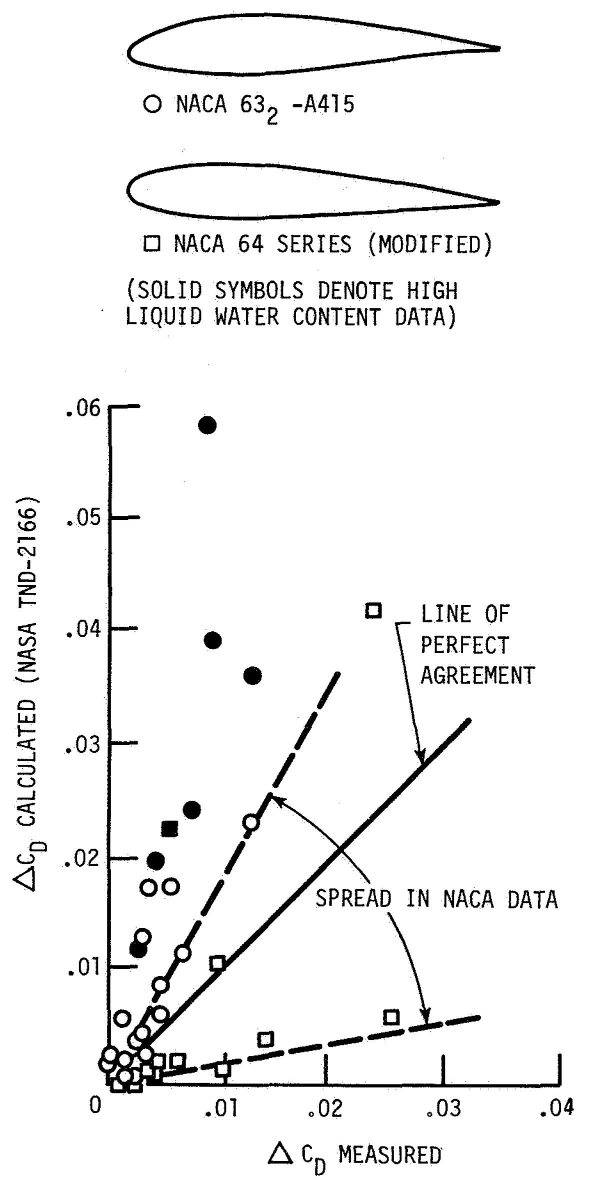


Figure 7. Predicted Drag vs. Measured Drag

Research efforts are continuing not only to develop analytical performance prediction techniques already mentioned, but to re-examine the correlation approach to see if more accurate correlations could be developed.

An ice protection system of great interest to sections of the aerospace community today is the electromagnetic impulse system. Figure 8 shows a closeup view of the leading edge of a wing section with the electromagnetic impulse system installed.

The electromagnetic impulse system employs a surface deflection approach to shedding the accreted ice. The heart of the system consists of a series of flat, spirally wound coils of wire shown in Figure 8 which are installed inside the leading edge. When a capacitor is discharged through the coil, the magnetic field of the coil induces eddy currents in the wing skin, causing it to deflect rapidly.

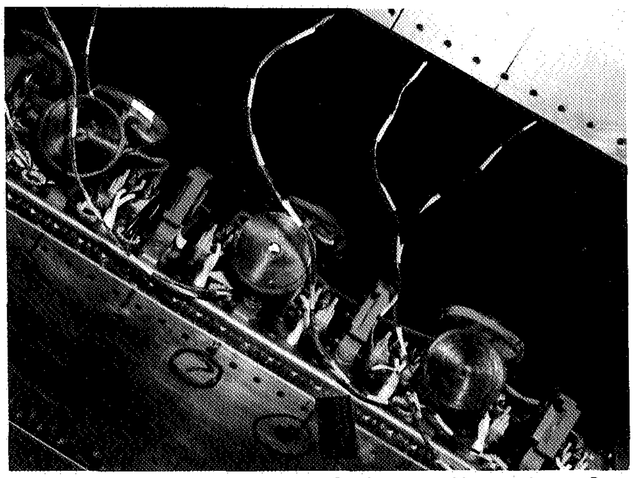


Figure 8. Closeup View of the Leading Edge of a Wing Section with the Electromagnetic Impulse System Installed

An electromagnetic impulse system for commercial transports was recently tested in the IRT in a joint Lewis/industry program. Data gained from that program is currently being analyzed.

Lewis has also assembled a NASA/university/industry team to develop the impulse system for both general aviation and commercial transport aircraft. Figure 9 shows the organization of this joint effort. The goal of this effort is to blend the talents and expertise of NASA, industry and university personnel to develop a fundamental data base for the electromagnetic impulse system which can be used by the aerospace industry for ice protection system selection and design.

Lewis has a joint program with the Air Force Flight Test Center (Edwards Air Force Base, California) to compare a number of old and modern icing cloud instruments using the IRT. The results to date of the study are summarized in Figure 10. The liquid water content indicated by the instruments and compared with the IRT calibration varied by about ± 20 percent. A similar comparison for the drop size instruments indicated a variation of about ± 4μm. It is felt that the scatter in the instrument results must be reduced, especially if the data is to be used in conjunction with computer code verification studies.

Since the NASA IRT has a maximum test section speed of 300 mph, ice accretion and aerodynamic performance degradation data for airfoils at high free stream velocities cannot be obtained in that facility. Such high speed data is required if the icing problems of the helicopter rotor are to be better understood.

In order to acquire such data, NASA has sponsored an eight-week test program in the Canadian National Research Council's (CNRC) high speed icing wind tunnel. The major tasks of the program are shown in Figure 11. The prime contractor on the effort, Sikorsky Aircraft, tested seven reduced scale (chord ≤ 6 inches) rotor geometries over a range of aerodynamic and environmental conditions for both fixed and oscillating angles-of-attack. The geometries selected are representative of current and future rotor airfoil sections.

As already indicated, a flight research program is a necessary part of a balanced aircraft icing research program. NASA initiated a flight icing program during the 1981-82 icing season using a Twin Otter aircraft shown in Figure 12. The objectives of the program are shown in Figure 13 with the two main goals being to provide data to verify the IRT and analytical simulations of the natural icing process.

Helicopter rotor icing presents some rather difficult icing problems many of which are not currently understood. To gain a better understanding of the rotor icing problem, NASA and the U. S. Army have initiated a Helicopter Icing Flight Test (HIFT) program. The major elements of the HIFT program are given in Figure 14. An unprotected UH1H helicopter will be flow behind the Canadian Natural Research Council's Ottawa spray and the main rotor system will be allowed to accrete ice. The helicopter will then be moved out of the cloud and rotor performance measurements will be taken. Once the helicopter has landed, detailed documentation of the rotor ice accretion characteristics will be undertaken.

The Ottawa spray rig test will be followed by dry transonic wind tunnel tests of UH1H rotor sections with artificial ice shapes which have been modeled using the ice shape documentation information obtained during the spray rig test.

The rotor section aerodynamic performance levels measured will then be used as inputs to an appropriate rotor performance code to predict the rotor aerodynamic performance with ice accretion and compare with the measured values.

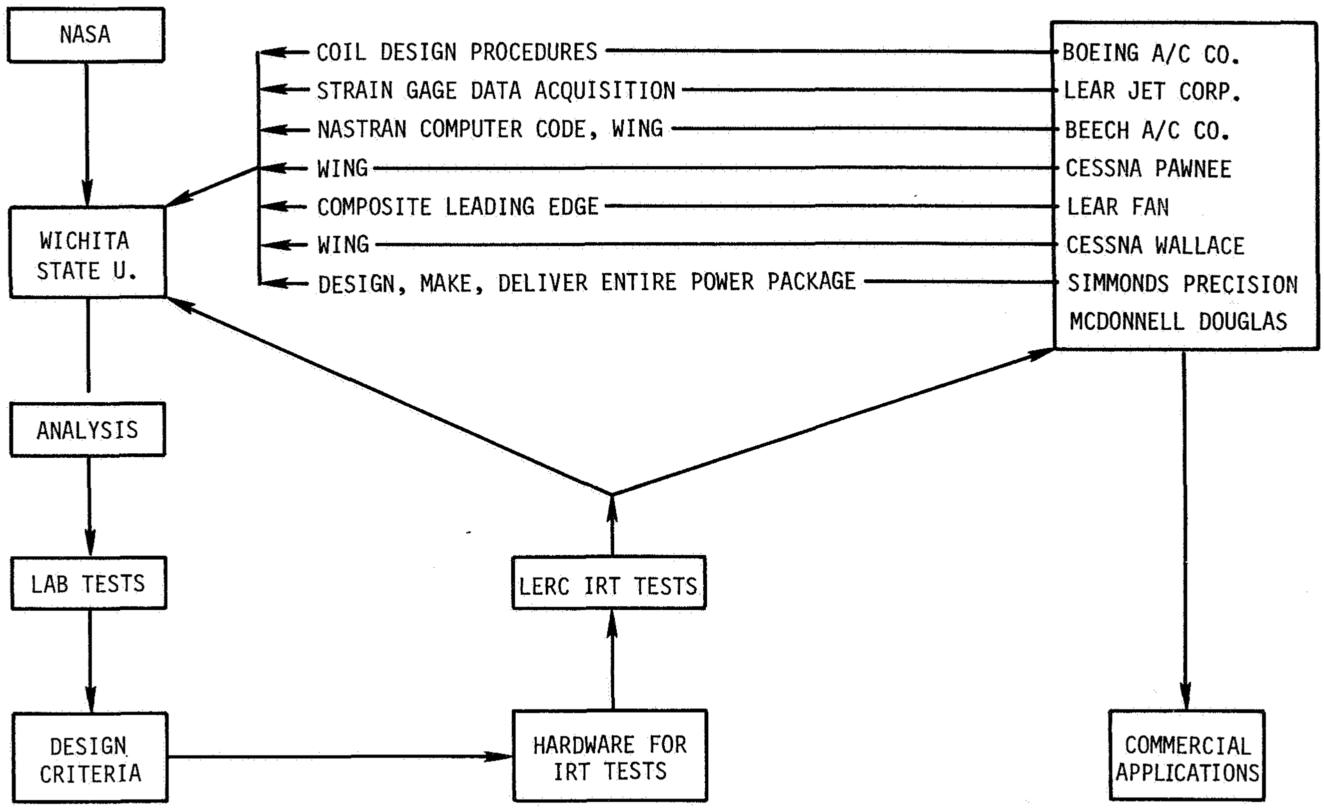


Figure 9. Electromagnetic Impulse De-Icing Joint Research Team

- MODERN AND OLD INSTRUMENTS WERE TESTED IN THE IRT
- SPREAD IN LWC INSTRUMENTS: $\pm$ 20%
- SPREAD IN DROP SIZE INSTRUMENTS: $\pm$ 4 MICRONS

Figure 10. Icing Instrumentation Research Results

Figure 12. NASA Twin Otter Icing Research Aircraft

- TEST PROGRAM IN CANADIAN NRC 1' X 1' HIGH SPEED ICING WIND TUNNEL
- TEST REDUCED SCALE (C = 6") ROTOR AIRFOIL GEOMETRIES FOR FIXED AND OSCILLATING ANGLES-OF-ATTACK
- MEASURE ICE ACCRETION, AERODYNAMIC PERFORMANCE ($\Delta C_\ell, \Delta C_d, \Delta C_m$)
- CORRELATE PERFORMANCE MEASUREMENTS WITH AERODYNAMIC AND ENVIRONMENTAL VARIABLES, i.e.,

$$\Delta C_\ell, \Delta C_d, \Delta C_m = f\left\{V_\infty, \alpha, LWC, \bar{d}, T_{t_\infty}, E, \beta_{max}, \tau\right\}$$

- TEST PROGRAM IN OXU 6 X 22 TRANSONIC WIND TUNNEL OF AIRFOILS WITH ARTIFICIAL ICE SHAPES TO MAKE DETAILED FLOW MEASUREMENTS AND COMPARE WITH NRC TEST RESULTS
- ROTOR PERFORMANCE DEGRADATION IN ICING CALCULATIONS AND COMPARISON WITH AVAILABLE ICING FLIGHT DATA

Figure 11. Airfoil High-Speed Ice Accretion, Aerodynamic Performance Studies

- PROVIDE DATA TO VERIFY ADEQUACY OF IRT SIMULATION
- PROVIDE DATA TO VERIFY COMPUTER CODE PREDICTIONS
- STUDY EFFECTS OF ICING ON AIRCRAFT PERFORMANCE, HANDLING CHARACTERISTICS
- PROVIDE ATMOSPHERIC ICING CLOUD DATA

Figure 13. Icing Flight Research Program Objectives

The NASA aircraft icing research program, some elements of which have been briefly described in this paper, is a broad-based program. The major goal of the program is to enhance the icing technology data base over that developed by former NACA and industry research efforts and to make this technology available to the industry in a timely manner.

- FLY AN UNPROTECTED UH1H HELICOPTER BEHIND CANADIAN NRC'S OTTAWA SPRAY RIG
- DETAILED DOCUMENTATION OF ROTOR ICE ACCRETION CHARACTERISTICS
- MEASUREMENT OF ROTOR PERFORMANCE DEGRADATION DUE TO ICING
- TESTS OF 2-D AIRFOIL MODELS WITH ARTIFICIAL ICE SHAPES TO DETERMINE C_ℓ, C_d
- ANALYTICAL PREDICTIONS OF ROTOR PERFORMANCE IN ICING USING PERFORMANCE CODE AND EXPERIMENTAL 2-D AIRFOIL DATA
- COMPARISONS WITH FLIGHT DATA TO ASSESS METHODOLOGY

Figure 14. NASA/Army Helicopter Icing Flight Test Program

Existing Wind Observation Network

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There is an ambiguity in the title, "Existing Wind Observation Network". Before everyone rushes off for coffee, let me reassure you that I'm not going to talk about the balloon system. A better title would be, "A Real-Time Wind Observation Network". (Figure 1)

"Real Time Wind Observation Network For Fuel Efficient Flight Planning and Air Traffic Control"

Figure 1. Proposed Experimental System

At the last workshop, our office presented a paper describing the need for better meteorological systems for fuel efficiency. We are an aviation energy organization, so that is our natural concern and perspective. Taking nothing away from safety concerns, we do believe that there is a woeful inattention in meteorology to the benefits that could accrue from fuel savings. So, we have turned our attention to this problem. The Energy Division figuratively backed into the subject of meteorology because we were developing flight planning programs that would be fuel efficient; and we soon found that you really cannot do much with high technology flight planning programs if you don't know what are the actual wind and temperature fields.

I would like to emphasize that this discussion is about a proposed system. It is for real-time wind observations and its purpose is fuel efficient flight planning and air traffic control. Let me show you an example of the kind of benefits that can accrue (Figure 2). Notice in this Figure, which was produced by the NASA/Lockheed TCV Program, that they investigated the possibilities of travelling several ways, including a great circle route, a more or less straight-line route, and following wind circulation patterns. It is interesting that the longest route actually uses the least fuel, some 14 percent less than the great circle route. This is an example of the kinds of fuel savings that are possible. I think this is an isolated example and probably not one you would expect routinely. To put this into perspective, just one percent of the air carrier fuel is 100 million gallons per year. So we think that improving the observation system has an enormous potential and probably could easily pay for itself in a year. That is, pay for itself in terms of reduced fuel bills.

The solution we see to the observation problem is the profiler instrumentation being developed at the NOAA/ERL/PROFS Program in Colorado. I need not go into the details of the program here. Some broad characteristics of the instrumentation and of the program can be seen in Figure 3. Importantly, the instrumentation can function in clear air as well as cloudy air.