IAR 89-18

# A NASA/University/Industry Consortium For Research on Aircraft Ice Protection

by


Glen W. Zumwalt

Distinguished Professor of Aeronautical Engineering



Presented:

Twenty-fourth Annual

Midwest Regional Conference, ASEE

Industry-Academe Interactions Session

Kansas State University

March 22-24, 1989



THE WICHITA STATE UNIVERSITY
INSTITUTE FOR AVIATION RESEARCH
WICHITA, KS 67208



October, 1989

## I. INTRODUCTION

From 1982 through 1987, an unique consortium was functioning which involved government (NASA), academia (Wichita State University) and twelve industries. The purpose was the development of a better ice protection system for aircraft. In this paper the circumstances which brought about this activity will be described, the formation and operation recounted, and the effectiveness of the venture evaluated.

## II. BACKGROUND

Ice accumulation on aircraft wings in flight has been a danger since the earliest days of flight. The total accumulation needs not be large to be fatal. Although ice normally is accrued only on forward facing surfaces, giving a few centimeters thickness on the front 2 percent of the wing chord, this is enough to cause flow separation and destroy lift, particularly if the aircraft slows or maneuvers. Also, drag may increase enough to exhaust fuel reserves or destabilize the flight.

Two methods have been used for ice protection of aircraft. For piston engine powered airplanes, rubber "boots" are glued to the leading edges of wings and tails. These are two sheets of a flexible material bonded together in strips so that there are many small unbonded passages. Pressurized air is forced into the passages which swell out about one centimeter (3/8 inch) and crack the ice accumulated on the surface. This surface is then de-iced as the ice debonds and is blown away by the airstream. The second method is used by gas turbine powered aircraft. It is an anti-icing technique; that is, it prevents ice from forming. This is done by taking hot compressed air from the jet engine and ducting it along the leading edge of the wing or engine inlet. The surface must be heated enough to cause evaporation of the impinging droplets. If it merely melted the ice, the water would run back along the surface to unheated locations and form ice there. In addition to these, electric resistance heating is commonly used for small regions such as windshields, pitot tubes and portions of the propeller. For larger regions, the generator weight and power required would be excessive.

The two prevailing methods have drawbacks. The pneumatic boot system is not wholly reliable. It works well only for a narrow range of ice thicknesses. The pilot must be careful not to actuate the system too early or too late. Also, the boots deteriorate due to sun rays and erosion from sand, rain, sleet, etc. So every three or four years they must be scraped off and replaced. The hot air anti-icing system has been very satisfactory, but changes in engines are threatening its elimination. Modern high-bypass turbofans are in every way superior to their predecessors except that they are becoming increasingly intolerant of the stealing of air between the compressor and turbine. Thus, in the early 1980's the stage was set for the introduction of new methods.

## III. PRIOR HISTORY

The use of electro-magnetic impulse force to remove ice was first suggested by a German national residing in London just before World War II, Rudolf Goldschmidt. He was granted a patent and a series of patent extensions in 1937 through 1939. However, there is no evidence that he ever built the devices he imagined. In about 1965, researchers in the U.S.S.R. either discovered Goldschmidt's patents or rediscovered this application independently. Electro-Impulse De-Icing (EIDI) was installed on one line of aircraft, the Il-86, and in the early 1970's Russian representatives began calling on European and American aircraft companies offering to sell their design and construction services for an EIDI system. Their lack of candor discouraged most customers, but interest was stirred and work was done on this method in France, Great Britain and the United States. All had difficulty making the system work reliably.

However, some technical leaders at NASA were intrigued by the potential of EIDI. It gave promise of being able to remove ice with only 1% the energy required for hot air anti-icing. It had no moving parts, involving only solid-state switches, and so should be almost maintenance-free and as long-lived as the aircraft. It was entirely internal to the airplane, causing no drag. In 1981, officials at NASA Lewis Research Center in Cleveland, Ohio, contacted a major airplane manufacturer and offered to help them develop the EIDI system. NASA offered to give the company all the information they had collected on the subject. They agreed to make available their Icing Research Wind Tunnel (IRT) for six weeks without charge. The IRT is the only large wind tunnel in the Western world with ice simulation capability. The company was to prepare a wing model and test the electro-impulse de-icing method.

The aircraft company came to the Lewis Lab in 1981 with a beautifully made model, a semi-trailer truck load of instrumentation, and 14 engineers and technicians. They ran tests for six weeks but were unable to de-ice the wing over the range of air temperatures and icing conditions needed. The company's management refused to spend the time and money to reduce the data, since the test was not considered to be a success. They indicated that they were not interested in educating their competitors by publishing the results. The NASA officials were understandably disappointed with this attempt to do a joint development project with an industry. Also, this test series convinced almost everyone that the method was a fluke, or at best, unreliable.

At a meeting of the General Aviation Advisory Board of NASA, representatives from several small plane makers complained that NASA should do something about the need for a better de-icing system to replace pneumatic boots. One NASA man still believed in the EIDI concept and suggested a possible joint NASA-Industry project, but the memory of the previous failure made NASA reluctant to enter another joint venture. Representatives from Cessna and Beech in Wichita suggested that the project could be guided by a University, and the data would be available to the public. These men had long-standing connections to the WSU Engineering College.

## IV. THE FEASIBILITY DEMONSTRATION

A faculty member at WSU met with the two men from Beech and Cessna and they agreed to develop a joint proposal to NASA. It was clear that an electric equipment maker was needed for making the power supply, capacitors and sequencing system. NASA steered them to a Western New York aviation electric equipment maker, Simmonds-Precision Co., whose vice-president had seen some of the European EIDI tests.

The proposal asked for $72,000 for a six-month period, starting 15 May, 1982. Beech and Cessna were to each provide a wing model to go into the NASA Icing Research Tunnel. Simmonds-Precision was to design and build a power and sequencing box to the specifications set by WSU. WSU was to research the phenomenon, design and install the electric coils in the wing models, and conduct the tunnel test. This was to determine whether EIDI had a future.

Professor Glen Zumwalt of the WSU Aeronautical Engineering Department was Project Director. He immediately recruited an electrodynamicist, Prof. Robert Schrag of Electrical Engineering, and a structural-dynamicist, Prof. Walter Bernhart, of Aeronautical Engineering. These two and their graduate students quickly did what the various aircraft companies had failed to do: they made a thorough study of the phenomena involved when a high voltage capacitor is discharged through a ribbon-wire coil rigidly supported close to a metal sheet, resulting in a hammer-like force to the sheet (the airplane skin). Within a few weeks, we were able to define the electrical parameters. A post-masters student with a wide engineering background was hired to develop a means of fabricating coils and their insulated supports.

In October the team from Wichita, four from WSU and one each from Beech and Cessna, met two men from Simmonds-Precision at the Icing Tunnel. The power box and models also met there for the first time. We were met with much skepticism from those at NASA who had seen the previous year's attempt to make the system work, but soon the doubters were converted. For two weeks the system was demonstrated on two wings of very different structural characteristics, and it removed ice at all temperatures, icing rates, ice thicknesses and air speeds. The door was opened to go for a complete development project.

## V. THE CONSORTIUM

It was agreed by NASA and WSU people that a consortium of companies spanning the whole range of U.S. aircraft should be formed. NASA would fund the project at about $250,000 per year to WSU for three years. WSU would be responsible for the research and for leading the industry efforts. In a departure from usual NASA practice, WSU was given free rein to control the industry participation. No funds were to go to the companies except for funds for some requested travel, usually for the tunnel tests. WSU was given the privilege of "bribing the industries with NASA facilities." That is, we could arrange to test the company's models in the NASA icing wind tunnel without charge. Our plans were to aim for flight tests within two years.

## Philosophy

The relations with the aerospace companies was guided by the following philosophy. If a company is sufficiently interested, it should bear the costs of the time spent on the project by its personnel. In addition, it should agree to provide some service to the project; examples of these are providing instrumentation, performing flight tests, building models, assisting in computer modeling and making computer runs. To avoid the impression that the company had exclusive access to the data, companies were generally selected in pairs, so that a company's most direct competitor was also privy to the information. The companies benefited from early access to the development data, opportunity to get their own models tested with an EIDI system fitted to their needs, and the opportunity to influence the direction of the project.

The advantage of having the wide range of industries participate in the project were:

1. The whole range of applications would be brought to our attention: engine inlets, rotor blades, etc.
2. The realistic problems of installation, servicing and operations would be considered. These varied among the industries.
3. A wide range of expertise became available.
4. All data and results are kept available to NASA and the consortium members.

## Objectives

The objectives of the project were agreed upon quite early. These were:

1. Develop computer models for the structural dynamics of aircraft components to provide design guidance for coil locations, coil size, impulse intervals and coil spanwise spacing. An alternative approach was also desired: development of a standard measurement method for existing structures to extract the structural dynamics characteristics needed for the design.

2. Develop a computer model for the electro-dynamics and provide detailed design data for the electro-impulse equipment, including coil design, power, voltage, insulation, pulse duration, and switching equipment.

3. Test wing sections and engine inlets in the IRT to guide and prove EIDI designs.

4. Consider practical aspects of retro-fitting the EIDI system to existing aircraft.

5. Devise methods for optimal design of a wing structure for using the system.

6. Estimate and attempt to minimize the cost of the EIDI system in terms of weight, maintenance and capital outlay.

7. Details to be considered are:
   (a) Limits of application (size, stiffness, etc.)
   (b) Standardization of components
   (c) Fatigue of skin, mountings, switching gear, bondings.
   (d) Electro-magnetic interference problems and solutions.
   (e) Use with composite materials.
   (f) Integration with present avionics and electrical systems

8. Conduct flight demonstrations using aircraft from NASA and participating industries.

9. Carry out at least the first stages of FAA certification.

Consortium Members

Small Aircraft: Beech Aircraft Co., Wichita, KS (1982-86)
Cessna Aircraft Co., Wichita, KS (1982-86)

Business Jet Aircraft: Gates-Learjet Corp., Wichita, KS (1982-86)
Cessna-Wallace Div., Wichita, KS (1982-86)

Composite Aircraft: Learfan Ltd., Reno, NV (1983-85)

Transport Aircraft: Boeing Commercial Aircraft Co., Seattle, WA (1983-86)
McDonnell-Douglas Co., Long Beach, CA (1983-87)

Aviation Electrical Equipment: Simmonds-Precision, Norwich, NY (1983-86)
Electro-Delta, White Oak, TX (1984-86)

Engine Nacelles: Rohr Industries, Chula Vista, CA (1983-86)

Helicopters: Sikorsky Aircraft Co., Stratford, CT (1984-86)
Boeing-Vertol Co., Philadelphia, PA (1985-86)
Bell Helicopter Co., Ft. Worth, tX (1985-86)

At the beginning of each new contract year, each company was sent a letter of agreement from WSU which stated the expectations of services to be performed by the company and the services to be given by WSU. Copies were signed by both parties.

## VI. WORK PERFORMED BY THE CONSORTIUM

### Ground Tests

The WSU team conducted both theoretical and experimental studies. Computer modeling of the phenomena was developed to permit design without trial-and error. Much laboratory testing was done. Both electro-dynamic and structural dynamic tests methods had to be developed to deal with very short, high energy impulses (one millisecond and 1500 volts at 2500 amps.) Simmonds-Precision measured electromagnetic emissions from one of the WSU models.

The main development effort was in nine test periods in the Icing Research Tunnel in Cleveland, OH. These are summarized below:

| Dates | Items Tested | Companies Involved |
|---|---|---|
| 10/82 | Low speed wings | Beech, Cessna, Simmonds. |
| 4/83 | Low speed wings | Cessna |
| 8/83 | Wing glove for NASA plane | Simmonds |
| 11/83 | Wing glove and composite wing | Learfan |
| 5/84 | Business Jet wing; tail section | Learjet, Cessna, Simmonds. |
| 8/84 | Transport wing; semi-cylinder | Boeing, McDonnell-Douglas, Learjet, (Lockheed-observers). |
| 9/84 | Transport wing; engine inlet | Rohr, Boeing, Cessna, Learjet. |
| 11/84 | Low speed tail, wing struts, wings, helicopter blade | Cessna, Simmonds, (Kaman Aerospace-observers). |
| 6/85 | Engine inlet, semi-cyl. | Rohr |

## Flight Tests

Following the IRT tests of Nov. 1984, flight tests were conducted in January, 1984 over Lake Erie in the NASA icing research airplane flying from the NASA Lewis Center. A WSU engineer flew with the tests of a system constructed at WSU and previously tested in the icing tunnel. Simmonds-Precision provided a flight-weight power supply. Twenty-one flights were made and good de-icing was achieved for several different icing conditions. About a month later, fifteen flights were made over Wichita, KS. Twelve of these were flights behind a water spray plane and three had natural icing. Only the right wing of a Cessna 206 was equipped with EIDI. Again, ice expulsions was very good. Cessna, WSU and Kansas Advanced Technology Corp. formed a partnership for these flights. Cessna, with WSU assistance, later equipped the airplane with EIDI on both wings, struts, horizontal tails and vertical tails. Flights were made in 1985 and 1986 with continuing success.

## Symposium

In June, 1985, a Symposium was held at NASA-Lewis to present the EIDI work to the American aerospace companies. Over 40 companies sent representatives, as well as a number of government agencies. The work of the past three years was presented by various Consortium members and the Cessna EIDI-equipped plane was available for inspection, having flown through icing conditions the night before between Wichita and Cleveland. A 200 page report was given to attendees.

## Continuing Work

The work continued at a reduced rate under some NASA funding, and in 1986-88 the Federal Aviation Administration funded continuing tests of fatigue life and electromagnetic compatibility in metal and composite wings. Boeing installed an EIDI system in the left wing of a Boeing 757 aircraft and completed many icing flights in 1987. These tests confirmed that ice protection was good, noise and electro-magnetic interference were not problems, and the energy required was about the same as that required by the landing lights in that same aircraft.

## VII. EVALUATION OF THE CONSORTIUM

The Consortium had many successes. From NASA's viewpoint, a great deal of R & D work was instigated and sustained for a relatively modest cost, since the participating industries contributed all of their manpower and equipment. From the industries' point of view, they profited from access to the results of many workers outside their own company. They were also able to influence the direction of the research so as to insure that it was applicable. Also, the facilities of NASA were made available to them. WSU profited in many ways. Almost one million dollars in research funds came from NASA for this project, all of which was spent in Wichita except for the travel costs. Two Ph.D. dissertations and three M.S. theses were completed on this project. Nine conferences papers and several journal articles were published. A great deal of favorable publicity, and much exposure to industry resulted. Several engineering students were able to participate in icing wind tunnel tests at NASA.

Unexpected benefits to WSU came from "spin-off" research projects. Directly related work came from industry consortium members toward the end of the NASA funding. These included an $88,000 model for McDonnell-Douglas, $227,000 in EIDI development funding from FAA, and $37,600 in miscellaneous work for three other Consortium members. NASA also gave a grant of $206,800 for study, design and testing of EIDI for another NASA application. A $131,500 project jointly supported by the Electric Power Research Institute and Kansas Power & Light and Kansas Advance Technology Corporation (predecessor to KTEC) studied the de-icing of electric power lines. Two related research projects were procured due to contacts made in this work. One of these was writing for the FAA Aircraft Icing Handbook ($11,000) and the other two were joint projects with Boeing Military Airplanes in Wichita with funding of $554,000 from FAA, the Air Force and NASA. One of these is described in another paper at this conference.

The key to the successes was the assurance of adequate funding for a three year period. A very helpful feature was the freedom of WSU to direct the project rather than leaving the decision making power with NASA.

The project was not without problems and limitations. The helicopter companies joined the Consortium too late to make a significant contribution. It was clear, however, that the need for a new ice protection system is even greater than for fixed wing craft. The logical supporters of helicopter icing research should be the military, but funding has not been forthcoming. The rotorcraft makers feel that if their customers, the military services, were really concerned, they would pay for the development, so this phase is stalled.

One lesson learned is that the companies that participate well are those which have a commitment from an official sufficiently high in the company. Rohr, Simmonds-Precision and Cessna had commitments at the Vice-Presidential level. Working with them was much easier than for those companies where the interest was concentrated a the "working" level. Continuous communication is essential for such a Consortium.

One advantage of being in Wichita was the availability of highly skilled technicians. Two men worked on our project who had recently retired from Wichita aircraft companies. They each had 30 years in experimental aircraft and their services were invaluable.

Although the Consortium has formally disbanded, several of the participating industries are continuing development and testing work. Boeing equipped a 757 aircraft and made numerous icing flights. McDonnell-Douglas is scheduled in the NASA icing tunnel soon for tests relating to use of EIDI in their next generation transport aircraft. Rohr is working with an engine maker for implementing nacelle applications. Cessna and Beech are not currently producing the light airplanes which were intended for using EIDI, but it is hoped that a recovery of the general aviation industry will see active use of EIDI in these aircraft. FAA has outlined the procedures for certifying the system.

NASA's original objective has been met. The technology for design and implementation of this advanced ice protection system is now available to the U.S. aviation industry. A 344 page report is being distributed by NASA to American companies who request it.