An International Historic
Mechanical Engineering Landmark

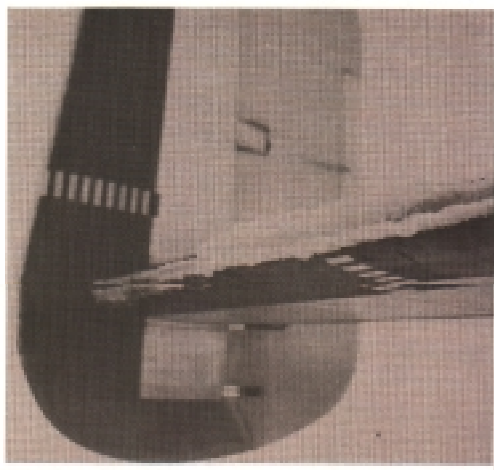
ICING *RESEARCH* TUNNEL

MAY 20, 1987 The American Society of Mechanical Engineers

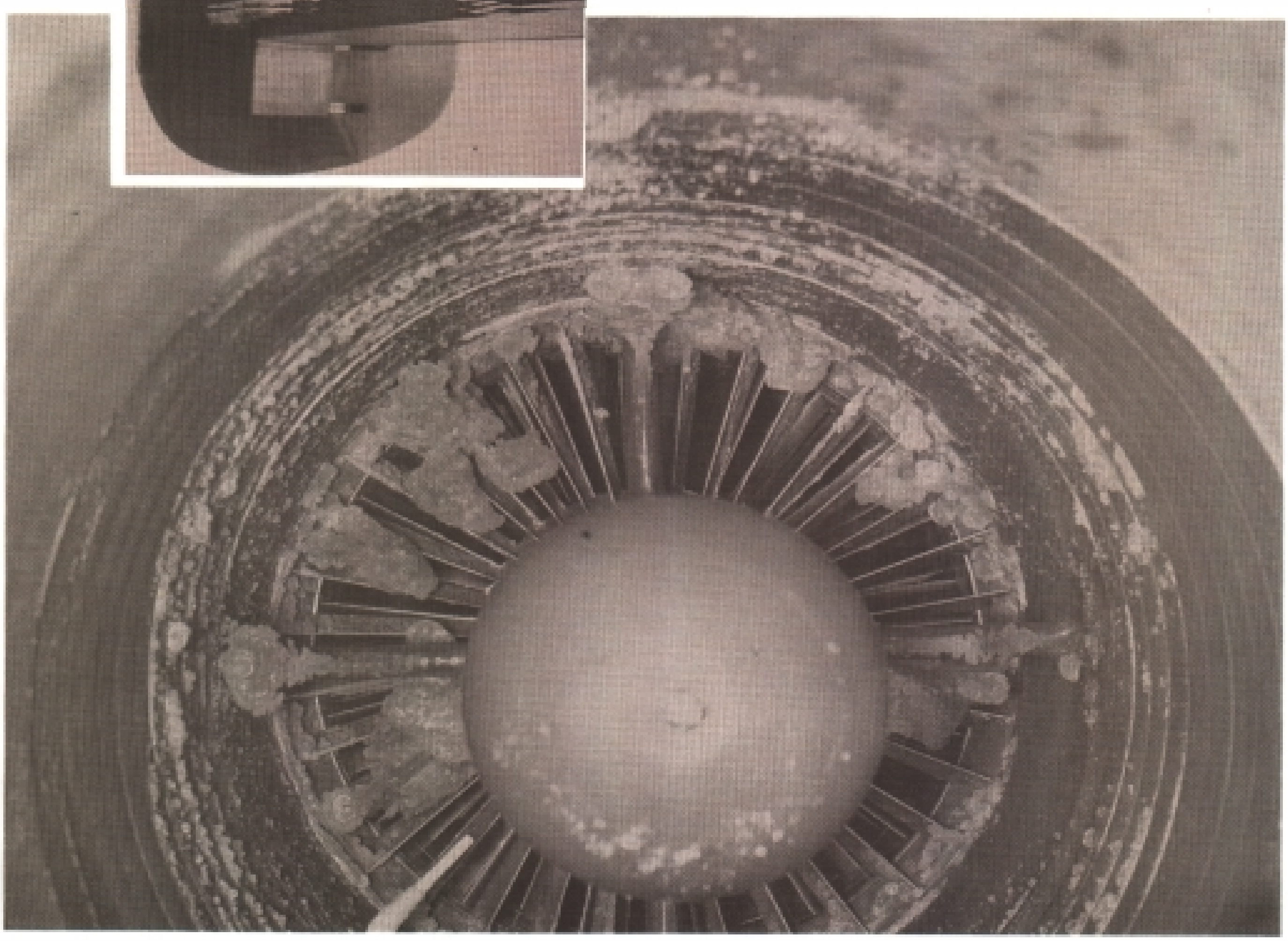
Program

Luncheon:	Lewis Main Cafeteria 1:00 to 2:15 p.m. (Ticket required)
Designation Ceremony:	Visitor Information Center Auditorium 2:15 to 3:15 p.m.
Reception:	Icing Research Tunnel 3:15 to 4:30 p.m.

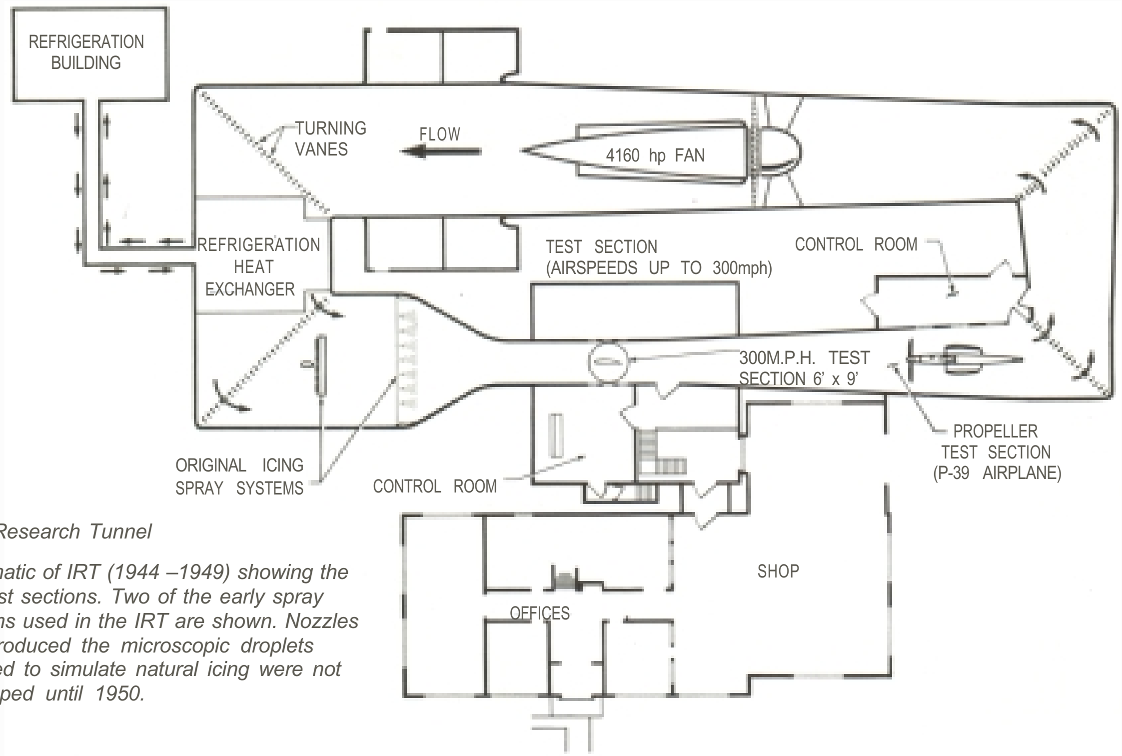
Transcontinental and transatlantic flying over the northern route can never be entirely safe until a problem (icing) which has thus far baffled ingenuity has been solved.
—Commentary on attempts to solve icing problems, New York Times, April 9, 1931.



Severe icing on B-24 stabilizer (no deicing protection).

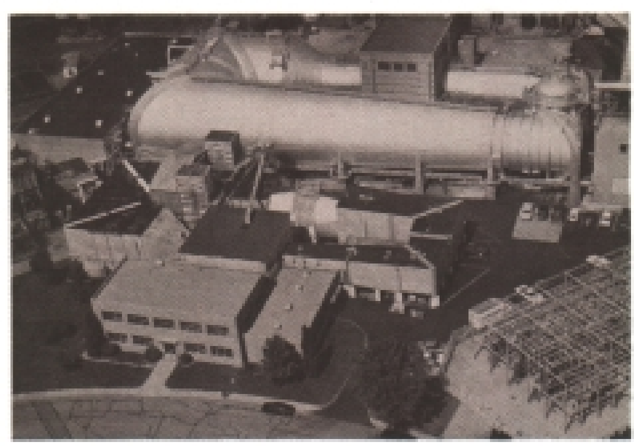


Ice on inlet guide vanes of an early jet engine (no deicing protection)



Icing Research Tunnel

Schematic of IRT (1944 –1949) showing the two test sections. Two of the early spray systems used in the IRT are shown. Nozzles that produced the microscopic droplets required to simulate natural icing were not developed until 1950.



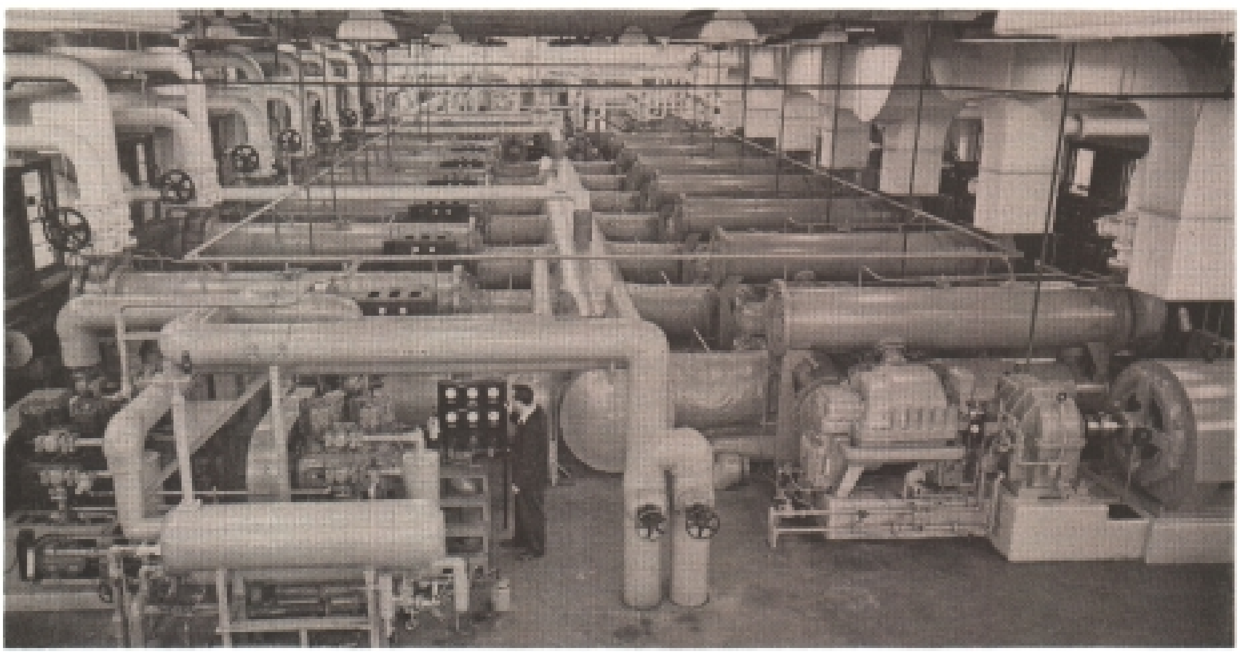
Aerial view

The IRT is similar to other subsonic wind tunnels in that a wing or other aircraft component placed in the test section can be subjected to various airspeeds, the airflow being created by a motor-driven fan. From its inception, however, the IRT had several unique features. For example, to simulate the aircraft icing environment, several additions were made to the basic subsonic wind tunnel design: a heat exchanger and a refrigeration plant to achieve the desired air temperatures and a spray system to generate a cloud of microscopic droplets of unfrozen water. The IRT is thus capable of duplicating the icing conditions (liquid water content, droplet size, and air temperature) that aircraft could encounter. Today, the IRT remains the world's largest refrigerated icing tunnel. Developing this unique capability, however, required unusual ingenuity to solve several critical technical problems.

Wind tunnels have been a part of aviation research since the days of Wilbur and Orville Wright. The IRT was designed by a group of engineers with wind tunnel design experience at NACA's Langley and Ames Laboratories. At least two icing tunnels existed prior to the IRT (at Massachusetts Institute of Technology and B.F. Goodrich) but they were much smaller. The technology to create a larger icing wind tunnel that could operate year round simply did not exist in the early 1940's. The IRT designers and contractors had to create new systems.

The refrigeration plant, originally built for the AWT, is still the largest direct-expansion system in the world with a 21,000-ton capacity (at 40 °F). The designs for the heat exchangers used in the AWT and the IRT were revolutionary. The IRT heat exchanger differs from that of the AWT primarily in its much wider fin spacing making it less sensitive to icing. Engineers familiar with air conditioning have said that there was never a more difficult, more exacting, or more vital refrigerating system than the one designed and built by the Carrier Corporation for the wind tunnels in Cleveland. The Air Force said that Carrier's solution shortened World War II by several months because the AWT was able to test the B-29 engine at the very cold temperatures and low pressures of high altitudes. This simulated high-altitude testing permitted timely corrections of serious engine design problems.

The IRT heat exchanger has also proven to be very successful: it can maintain a very spatial uniform air temperature over a very large range of airspeeds and temperatures, even when subjected to severe icing and frost conditions. This type of heat exchanger is used today in many of the world's refrigerated wind tunnels.



AWT/IRT refrigeration plant

Although icing had always bean recognized as a serious condition encountered in flight, little had been done to develop icing research wind tunnels to work on deicing problems. As a result, little or no data existed relative to the design and operational problems that resulted in the early days of calibrating the icing Research Tunnel. Only time and experience solved these problems.

—William Gowan, Jr.
NACA Operations Engineer

The wind tunnel air speed and resulting wind tunnel shape were the only known design premises that NACA could zero in on from previous knowledge and expert-ence. the remaining design problems were, for the most part, without precedent, and logic, theroy, and speculation were only design tools that were available.

—Charles Zelenko, NACA IRT designer

Willis H. Carrier and a team of engineers from the Carrier Corporation accepted the challenge to design the AWT and IRT cooling systems. Virtually every phase of the design of the cooling systems involved breaking new technical ground. Carrier and his engineers developed new ideas, tested them, and redesigned those that did not work. All this work was accomplished under wartime restrictions and time pressures.

The system required went far beyond the state-of-the-art and, in fact, verged on the undoable.

—Carlyle Ashley, Carrier Crop.

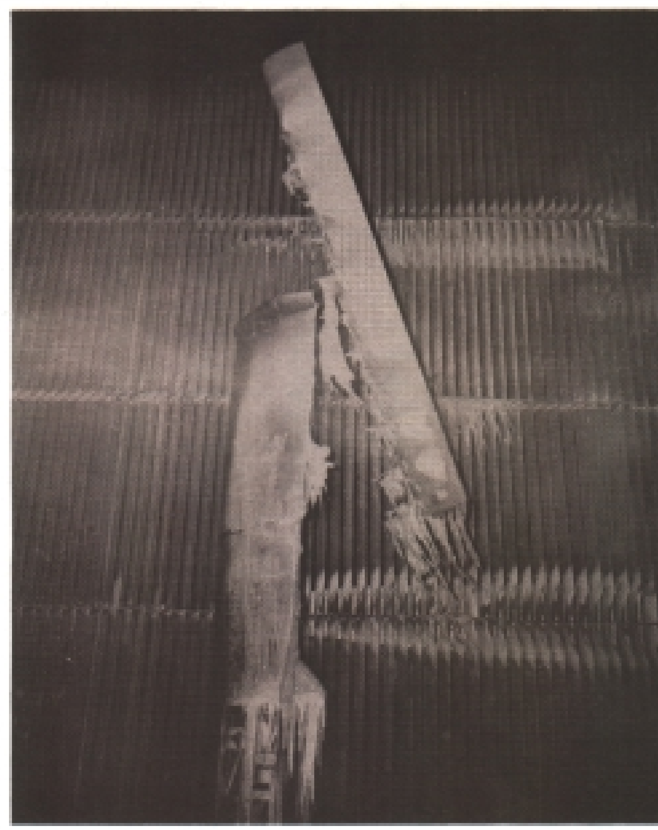
No one in the country would supply the eight bellows-type flexible joints required in this lines. Without batting an eye, Wills Carrier said, "I'll design them and we'll build them in our shops." He did, we did, and they worked.

—Everett Palmatier, Carrier Corp.

The second major innovation in the IRT was the spray system. Designing the spray system proved to be even more complicated than designing the refrigeration system. The designers of the cooling system knew their eventual goal. But to conduct realistic icing tests, the IRT had to have a spray system that would duplicate severe natural icing cloud conditions.

To duplicate atmospheric icing, the water droplets had to be extremely small and, in 1943, no one knew just how small natural cloud droplets were or how to measure them. Droplets larger than those found in natural clouds would not duplicate icing patterns found in actual flying. Droplet size distribution and cloud liquid water content were also significant factors. Tests that did not duplicate natural cloud conditions would be of little practical value.

Preliminary data regarding droplet size were gathered in the early 1940's by a research group at Mount Washington, New Hampshire, and from samples taken during flight. By the mid-1940's, the IRT team had enough data to know what atmospheric conditions had to be duplicated. Actually duplicating them was another matter. Several spray systems using commerically available nozzles were tried in the mid-1940's, including a rotating spray bar, but none could produce droplets small enough to duplicate a natural icing cloud. To be acceptable, a nozzle had to be able to produce small droplets, resist clogging, be protected from freezing, and be able to be used in a large enough array to provide for a spatially uniform icing cloud in the test section.



First icing spray system—a rotating spray bar. Ice formed on the bar from spraying droplets upstream. Spray nozzles produced droplets that were much too large to simulate natural icing.

Since there was no existing nozzle system capable of producing droplets small enough for reliable icing research, the IRT staff had to design their own. NACA designer personnel decided the nozzle needed to produce a shock wave to tear a stream of water into extremely small particles which then had to be rapidly dispersed to prevent coalescence into large drops. An atomization system was chosen as the energy source because the violent shock wave produced by such a system would tear the water into very tiny droplets.

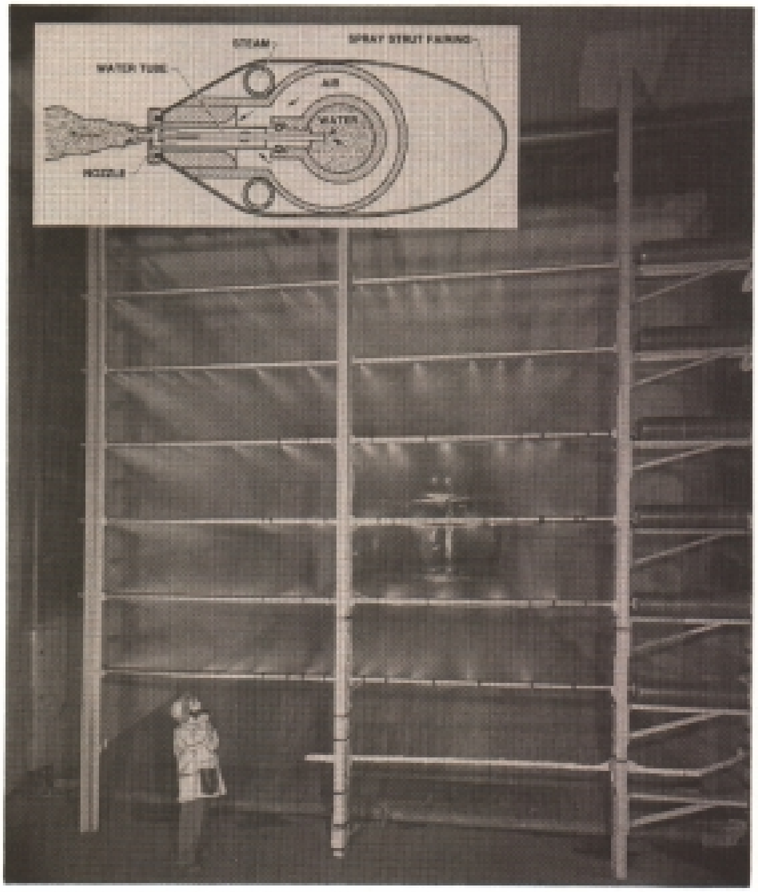
Another problem in producing a nozzle was the necessarily small size of the holes. Small holes were hard to produce by drilling, and it was also difficult to achieve good reproducibility. In addition, the material had to be wear and corrosion resistant to keep the hole size uniform. Stainless steel hypodermic tubing offered many desirable qualities. Drilled holes were limited to 0.0135 inch, the size of the smallest drill commercially available.

After many 12- and 16-hour days of experimentation, the designers decided to use a concentric nozzle to avoid a water buildup on the nozzle surface, which could cause large droplets to form and then be shed. The test nozzle was made by machining the air orifice in a pipe cap and soldering a piece of hypodermic tubing into a larger water supply tube. Once the nozzle was assembled the only test method available was trial and error. Droplet samples were collected in a petri dish over a mixture of warmed petroleum jelly and kerosene. The samples were then photographed through a microscope and painstakingly counted. The nozzles were adjusted and droplets counted until a basic nozzle design and an evaluation method were determined.

The next major step was to build a full spray system for the IRT. Multiple horizontal struts were installed in the bellmouth of the tunnel, which is just upstream of the test section. The struts were designed so that many nozzles could be installed along the span of each strut. Each strut was equipped with water and air manifolds, steam heat to prevent freezing, and a water pressure regulator. These regulators maintained equal water pressure levels in all struts. Once the spray system was operational, considerable testing was required to determine the locations of the nozzles on the various struts to generate spatially uniform icing conditions in the test section. This testing was a trial and error effort since no techniques existed for predicting proper nozzle placement.

By early 1950, after 5 years of painstaking research and trial-and-error testing, the IRT spray system was capable of producing droplets small enough to reproduce realistic icing patterns on aircraft components.

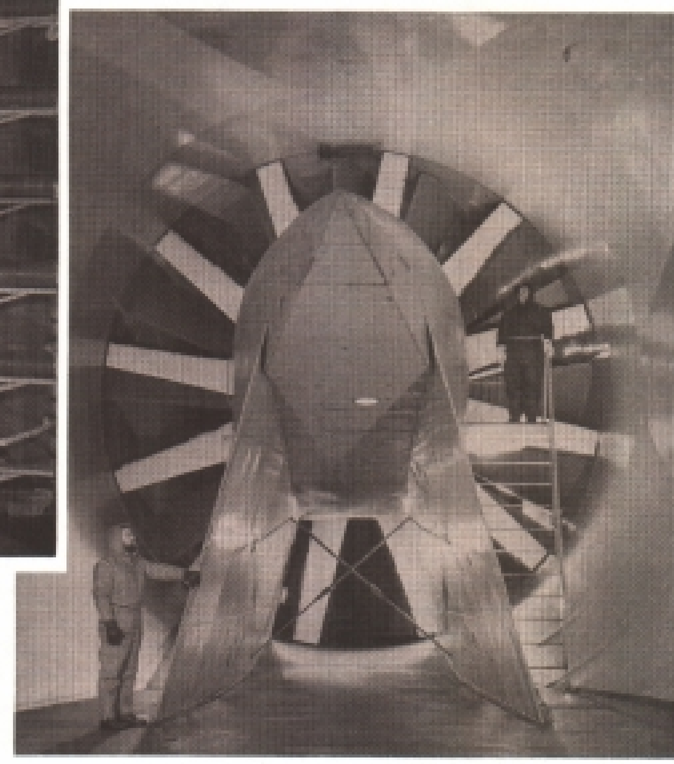
Dr. Lewis looks on as Willson Hunter explains to General Arnold the need for propeller ice protection. At the time, 1944, Dr. Lewis was head of NACA (NASA Lewis Research Center later named for him), General Arnold was head of Army Air Force, and W. Hunter was head of NACA icing research.



Spray system completed in 1950 and sketch of present spray nozzle. This system produces the proper microscopic-sized droplets.

It was really a program which required considerable ingenuity and a lot of testing. retesting, revising, and rebuilding to get it to a point of reasonable success.

—Halbert Whitaker
NACA Fluid Systems Engineer



4100-Horsepower drive fan (24-ft diameter) for IRT (looking upwind).

It should be noted that changes and modifications of the spraying equipment were being made on a daily basis. Trail and error was the method of development.

—Halbert Whitaker
NACA Fluid Systems Engineer

Between 1950 and 1958, with this adequate spray system, the IRT was used for extensive testing of civilian and military aircraft components. Among other techniques, the hot-air anti-icing technology used on today's commercial transports was largely developed in the IRT.

In the 1960's, jet engines with adequate supplies of bleed air available to provide hot-air anti-icing protection seemed to solve the problems of commercial and military aircraft icing. NACA had become the National Aeronautics and Space Administration (NASA), and the Agency's research efforts turned to space exploration and away from aviation. The IRT was used very little and many thought that perhaps it would be closed, having served its purpose.

Wing in IRT test section before ice has been shed from a pneumatic boot deicer.

The recent renewal of interest in flight Icing may be surprising to many, but it probably should have been expected. Our experience with safety and operating problems research has been that problems are "solved" for a time, and then, as aircraft designs and operating practices change, these problems reemerge and call for renewed effort, often in terms of a finer-scale solution than was offered earlier.

—John H. Enders, former Aircraft Icing Program Manager, NASA Headquarters

Technology, however, has a way of creating a new problem for every old one that it solves. For example, helicopters were finding increased use in both military and civilian aviation and were exhibiting unique icing problems. And, the fuel shortages and price increases of the 1970's demonstrated that, while the bleed air from a jet engine was an effective anti-icing technique, it was also an expensive one. In addition, an increased demand for ice protection systems appropriate for general aviation aircraft was being experienced, and advanced military aircraft configurations required new ice protection concepts compatible with unique design requirements.

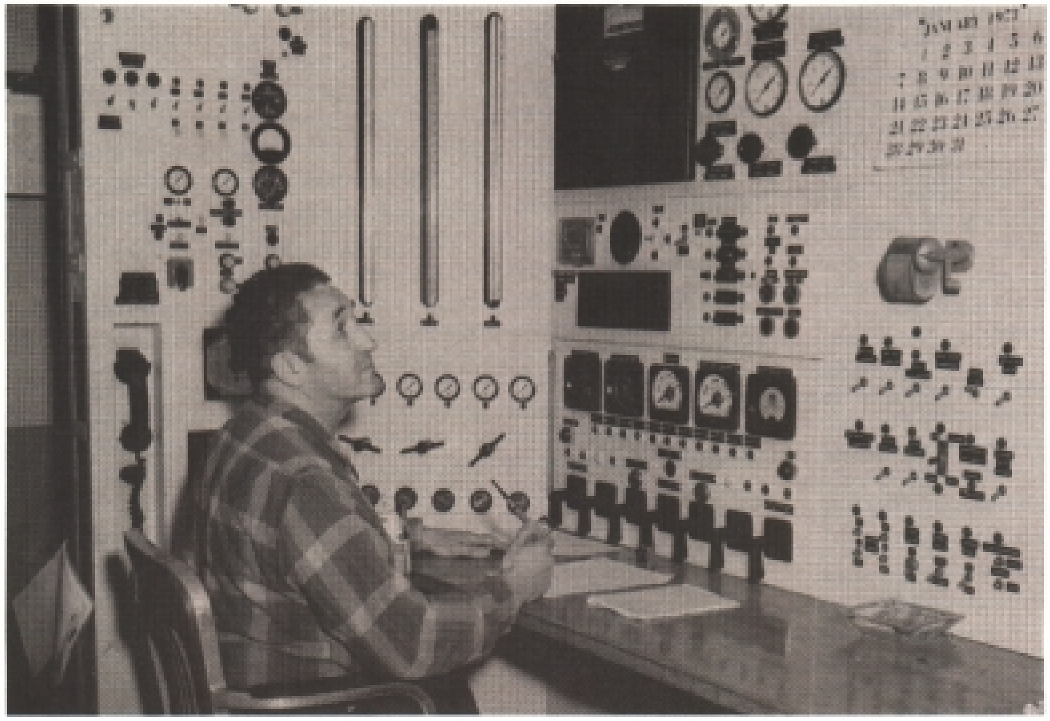
In 1978 NASA reinstituted an icing research program to address the needs for new and future aircraft designs. In 1986 the IRT underwent a $3.6 million renovation to cope with its increased workload and to expand its capabilities. Currently the IRT is again in heavy demand from government and industry to solve these new icing problems.

In 1987, the American Society of Mechanical Engineers (ASME) designated the Lewis Research Center's Icing Research Tunnel an International Historic Mechanical Engineering Landmark for its leading role in making aviation safer for everyone. As aviation technology continues to change in the future, the IRT will continue to solve the icing problems that will arise. The IRT is a historic facility that is as much a part of the future as it is of the past.

The technology for the electromagnetic impulse deicer, a promising low-power-consumption ice-protection concept for future aircraft designs, was largely developed in the IRT.

Unique icing problems associated with the helicopter are resulting in many IRT tests by government and industry. The test of the rotor section shown here was to evaluate proposed electrothermal deicing designs.

IRT Control Room



1945-1986

Present

Mechanical Specifications of the Icing Research Tunnel

The IRT is a closed-loop refrigerated wind tunnel with a test section 6 feet high and 9 feet wide. The airspeed in the test section can be varied from about 25 to 300 mph at essentially a sea-level pressure. The total air temperature can be independently varied from about 30 to –45 °F. The heat exchanger is the key to the success of the IRT because it is able to maintain a uniform airspeed and uniform air temperature (±1 °F) even after several hours of testing at severe icing conditions. The heat exchanger also serves the important function of preventing droplets from going around the tunnel loop where they might partially freeze and reenter the test section.

Spray nozzles produce the icing spray cloud of very small, unfrozen, subcooled droplets. The liquid water content can be varied from about 0.2 to 3.0 g/m^3, and the drop size can be varied independently from about 5 to about 40 microns (volume medium diameter). The previously stated limits of airspeed, temperature, and icing cloud permit most natural icing conditions to be simulated.

Icing Research Tunnel Chronology

1942-1944:	IRT designed and built under wartime conditions.
June 9, 1944:	First icing test conducted in the IRT at –45 °F.
1945-1947:	Various propeller ice protection systems were tested on a P-39 fighter plane in the IRT.
1944-1950:	Extensive tests of ice protection systems were performed for propeller engine inlets, wings, antennae, etc.
1950:	New spray system achieved the required tiny drop sizes of unfrozen water occurring in nature.
1950-1958:	Extensive icing research tests were conducted using this unique IRT spray system.
1958-1970:	IRT was used very little because jet engines seemed to solve icing problems.
1970:	Civilian and military rotorcraft as well as general and military aviation began to find new uses for the IRT.
1978:	NASA reinstitutes the icing research program.
1986:	IRT is modernized to keep up with its heavy workload and to expand its capabilities.
1987:	ASME designates the IRT an International Historic Mechanical Engineering Landmark.

Principal Designers and Builders of the Icing Research Tunnel

Tunnel designers at NACA Cleveland:

- B. Gulick, A. Young, C. Zalenko, and M. Pollyea

Builders of IRT:

- Tunnel structure—Pittsburgh DeMoines Steel Co.
- Turning vanes—Truitt Co.
- Drive motor and controls—General Electric Co.

Designer and builder of tunnel fan:

- NACA Langley
  Principal designer—B. Corson

Designer and builder of cooling heat exchanger and refrigeration plant:

- Carrier Corporation
  Principal designers—W. Carrier, W. Anderson, M. Wilson, and R. Zulinke

Designer and builder of icing cloud spray nozzles and spray system:

- NACA Cleveland
  Principal designers—H. Whitaker, H. Christensen, and G. Hennings

History and Heritage Program of the ASME

The History and Heritage Program of the ASME began in September 1971. To implement and achieve its goals, ASME formed a History and Heritage Committee, composed of mechanical engineers, historians of technology, and the Curator of Mechanical Engineering at the Smithsonian Institution. The Committee provides a public service by examining, noting, recording, and acknowledging mechanical engineering achievements of particular significance. For further information on the ASME History and Heritage Program, contact the Public Information, American Society of Mechanical Engineers, 345 East 47th Street, New York, NY 10017, 212-705-7740.

The NASA Lewis Icing Research Tunnel is the 21st International Historic Mechanical Engineering Landmark to be designated. Since the ASME program began, 85 National and 9 Regional Landmarks have been recognized. Each reflects its influence on society, either in its immediate locale, nationwide, or worldwide.

An ASME landmark represents a progressive step in the evolution of mechanical engineering. Site designations note an event or development of clear historical importance to mechanical engineers. Collections mark the contributions of a number of objects with special significance to the historical development of mechanical engineering.

The ASME Historic Mechanical Engineering Program illuminates our technological heritage and serves to encourage the preservation of the physical remains of historically important works. It provides an annotated roster for engineers, students, educators, historians, and travelers. It helps establish persistent reminders of where we have been and where we are going along the divergent paths of discovery.

Acknowledgements

The American Society of Mechanical Engineers

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