The NASA Aircraft Icing Research Program

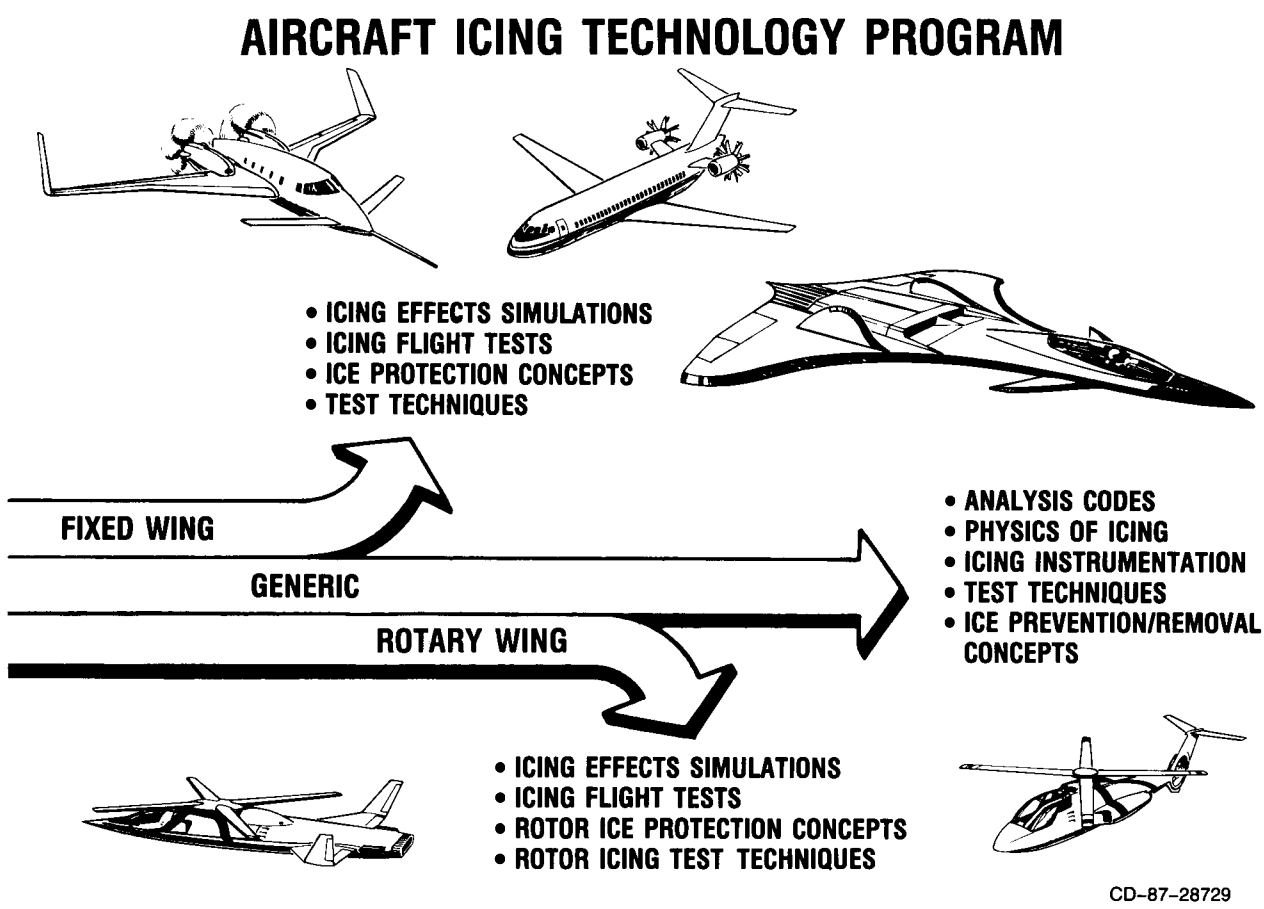
Robert J. Shaw
and
John J. Reinmann

ABSTRACT

The objective of the NASA aircraft icing research program is to develop and make available to industry icing technology to support the needs and requirements for all weather aircraft designs. Research is being done for both fixed and rotary wing applications. The NASA program emphasizes technology development in two key areas: advanced ice protection concepts and icing simulation (analytical and experimental). This paper reviews the computer code development/validation, icing wind tunnel testing, and icing flight testing efforts which have been conducted to support the icing technology development.

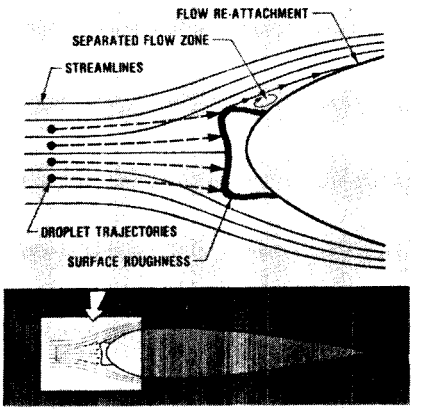
AIRCRAFT ICING TECHNOLOGY PROGRAM

The icing research program can be viewed to have a generic portion which is devoted to developing fundamental technology. This basic technology is applied with appropriate alterations and modifications to fixed wing and rotorcraft applications to develop more vehicle specific icing technology.

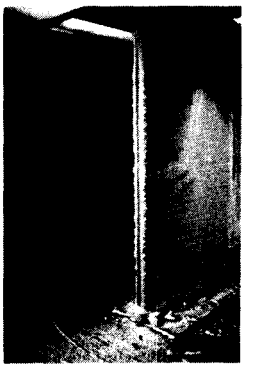


The icing research program is a balanced effort in that it contains analysis code development/validation, wind tunnel testing, and icing flight research activities.

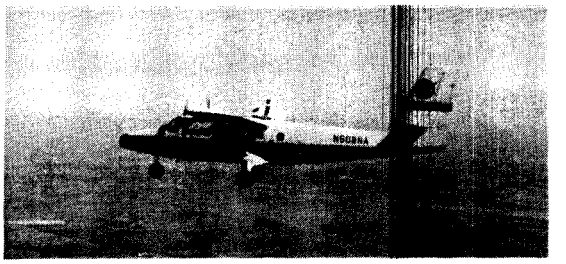
ICING RESEARCH



ANALYSIS



WIND TUNNEL TESTING



FLIGHT RESEARCH

CD-87-28730

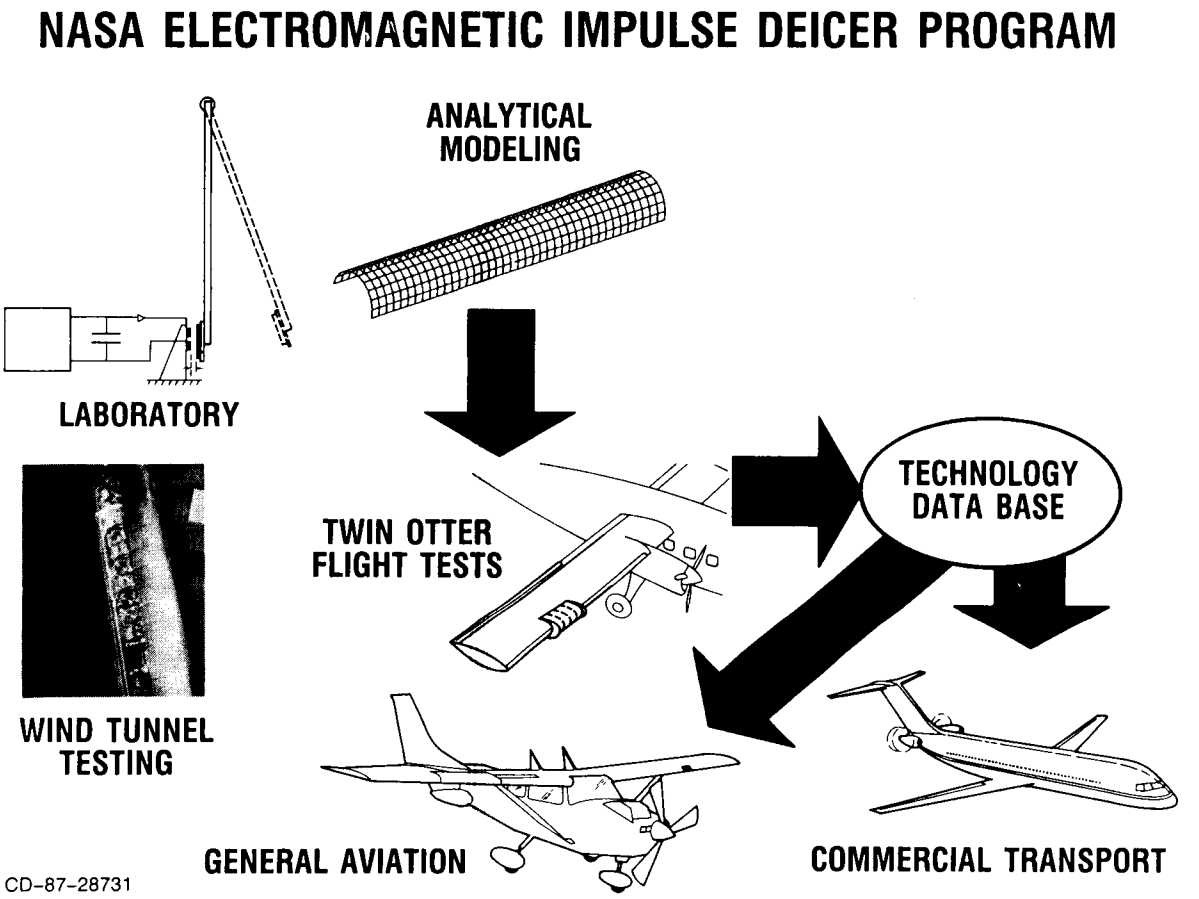
ICE PROTECTION CONCEPTS

- **LIGHTER, MORE EFFICIENT SYSTEMS FOR ADVANCED MILITARY AND CIVILIAN AIRCRAFT**

CD-87-30307

NASA ELECTROMAGNETIC IMPULSE DEICER PROGRAM

The major steps in the multi-year NASA/industry/university program to develop the required technology data base for the electromagnetic impulse deicer (EIDI) are shown. This EIDI technology now available allows manufacturers of both general aviation and commercial transport aircraft to consider EIDI for future aircraft designs.



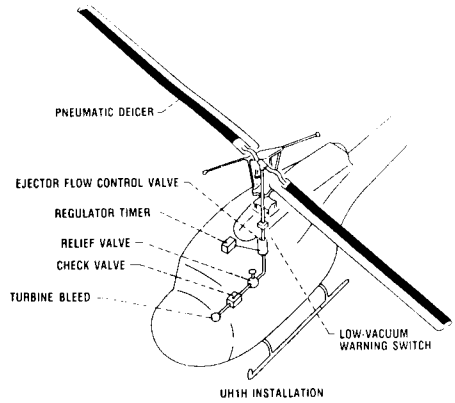
NASA/ARMY/INDUSTRY ROTOR PNEUMATIC BOOT PROGRAM

A multi-year NASA/Army/industry program has demonstrated that a conventional pneumatic boot design can be used to protect the main rotor of the UH1H helicopter. The main steps of the program are shown.

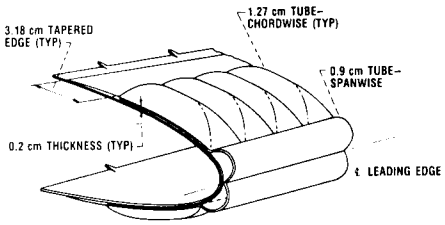
NASA/ARMY/INDUSTRY ROTOR PNEUMATIC BOOT PROGRAM

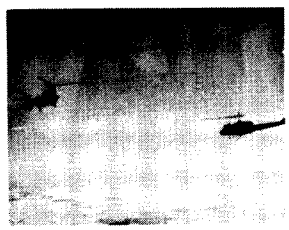
IRT TEST

OTTAWA SPRAY RIG



UH1H INSTALLATION





ARMY HISS TANKER

DEMONSTRATED ROTOR DEICING CAPABILITY

CD-87-28732

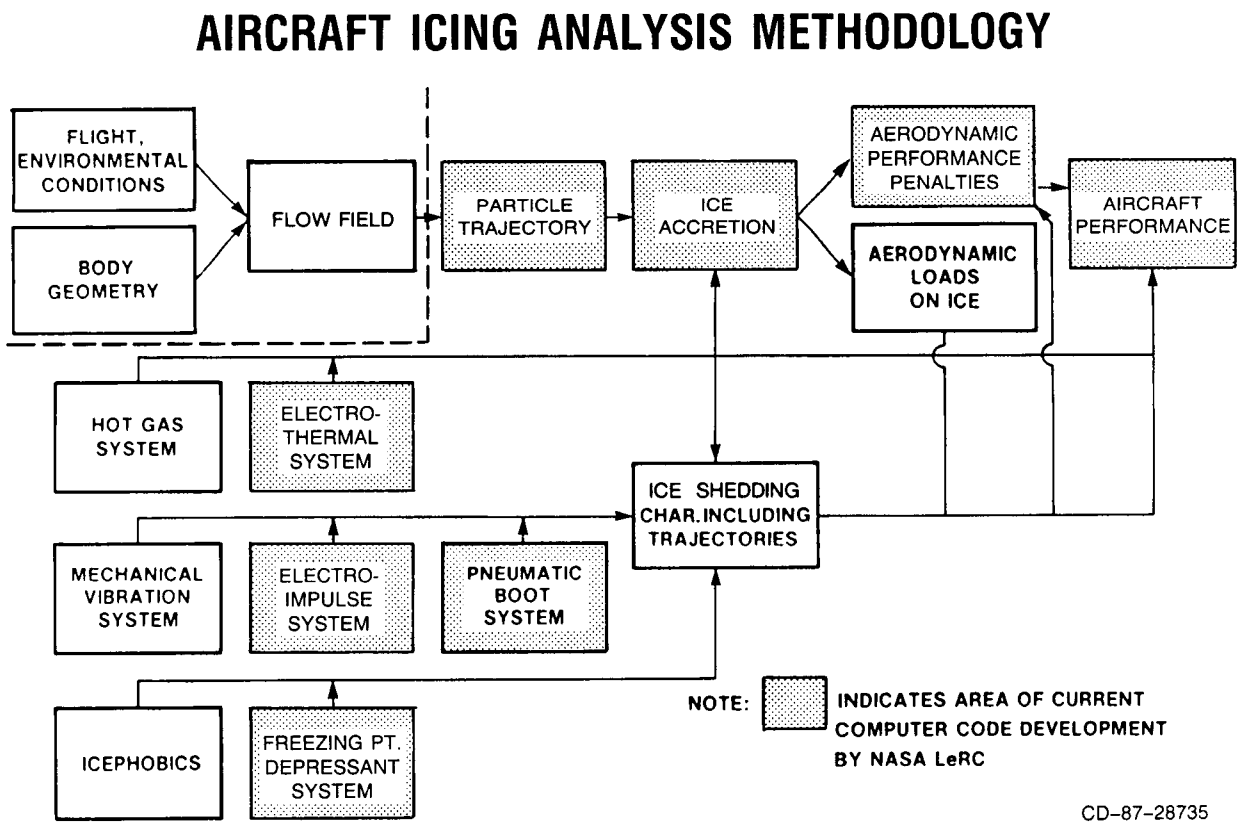
ANALYTICAL AND EXPERIMENTAL ICING SIMULATION

- DEVELOP/VALIDATE CODES TO PREDICT AIRCRAFT PERFORMANCE, STABILITY AND CONTROL IN ICING
- IMPROVE/VALIDATE ICING SIMULATION FACILITIES
- CONDUCT NATURAL/ARTIFICIAL ICING FLIGHT TESTS
- IMPROVE ICING INSTRUMENTATION

CD-87-28733

AIRCRAFT ICING ANALYSIS METHODOLOGY

The large number of computer codes and some of the required interfaces to form a comprehensive icing analysis methodology are shown.



COMPUTER CODES BEING DEVELOPED/VALIDATED

The individual computer codes currently being developed and validated are shown. This set of codes forms a core analysis capability which can be used to build the more comprehensive icing analysis capability which is desired.

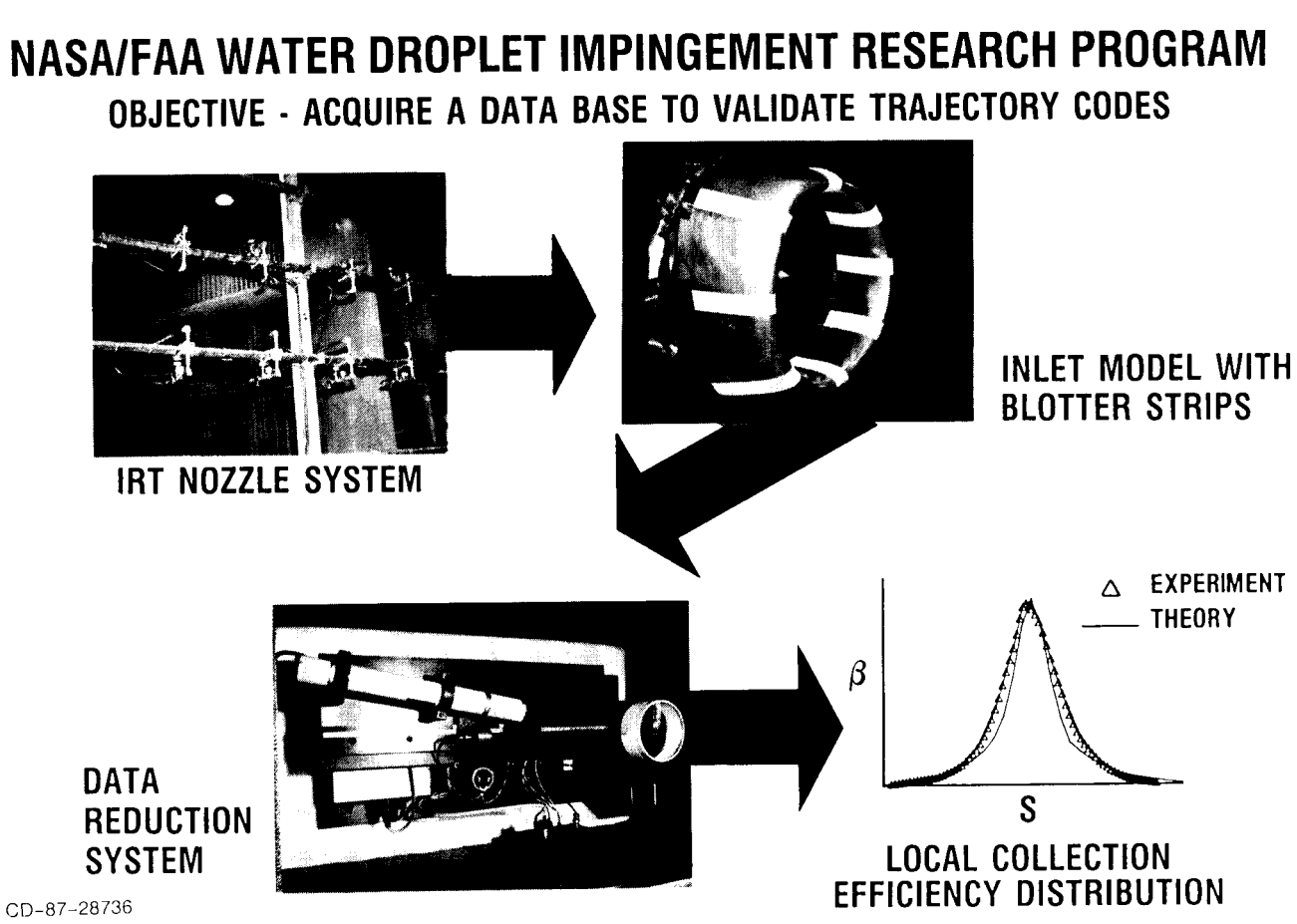
COMPUTER CODES BEING DEVELOPED/VALIDATED

- TRAJECTORY ANALYSES
  - TWO DIMENSIONAL
  - THREE DIMENSIONAL
- AIRFOIL ICE ACCRETION
- AERODYNAMIC PERFORMANCE-IN-ICING
  - AIRFOIL
  - PROPELLER, ROTOR (APPROXIMATE)
  - COMPLETE AIRCRAFT (APPROXIMATE)
- ICE PROTECTION SYSTEMS
  - ELECTROTHERMAL
  - ELECTROIMPULSE
  - FLUID FREEZING POINT DEPRESSANT
  - PNEUMATIC BOOT

CD-87-28734

NASA/FAA WATER DROPLET IMPINGEMENT RESEARCH PROGRAM

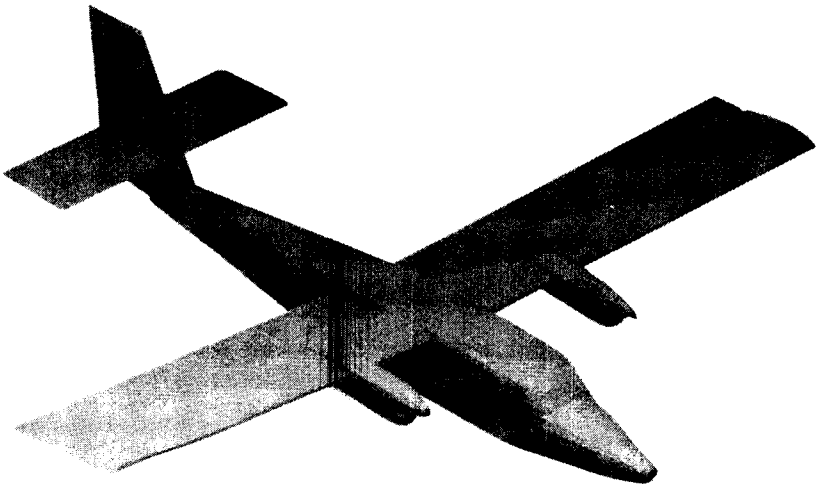
The major steps of the NASA/FAA program to acquire a validation data base for water droplet trajectory codes are shown.



TWIN OTTER TRAJECTORY ANALYSIS

A computer graphics representation of the NASA icing research aircraft, a deHavilland DHC6 Twin Otter, is shown. This computer model is being used to calculate three-dimensional trajectories of water droplets about the aircraft to help in interpreting icing cloud instrument data.

TWIN OTTER TRAJECTORY ANALYSIS

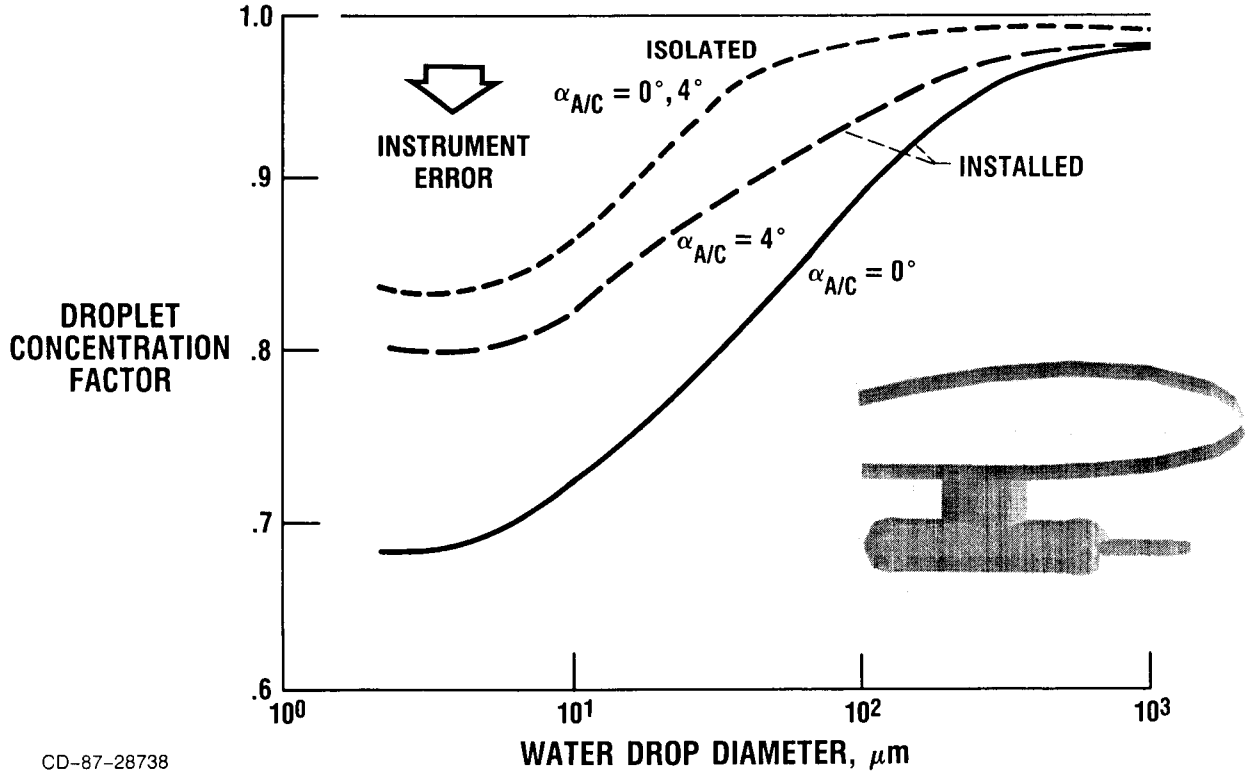


CD-87-28737

TRAJECTORY ANALYSIS FOR LASER SPECTROMETER

Selected results for trajectory analysis studies of the laser spectrometer droplet sizing instrument are shown. The results show that significant error can occur when the instrument is mounted beneath the main wing of the aircraft. This error is attributed to the three-dimensional flowfield effects on the trajectories of the water droplets. The curves indicate that, for the droplet sizes of interest (~10 to 100 μm), the instrument will sense that fewer droplets/m^3 exist than actually do exist in the "freestream" icing cloud.

TRAJECTORY ANALYSIS FOR LASER SPECTROMETER



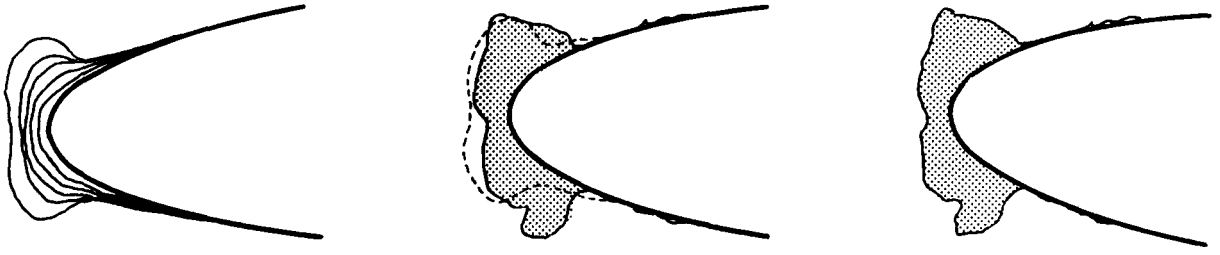
CD-87-28738

An indication of the capability of the NASA ice accretion code (LEWICE) to predict the growth of ice on an airfoil is shown.

NASA AIRFOIL ICE ACCRETION CODE (LEWICE)

COMPARISON OF GLAZE ICE SHAPES

NACA 0012 AIRFOIL, 21 in. CHORD



THEORETICAL

EXPERIMENTAL

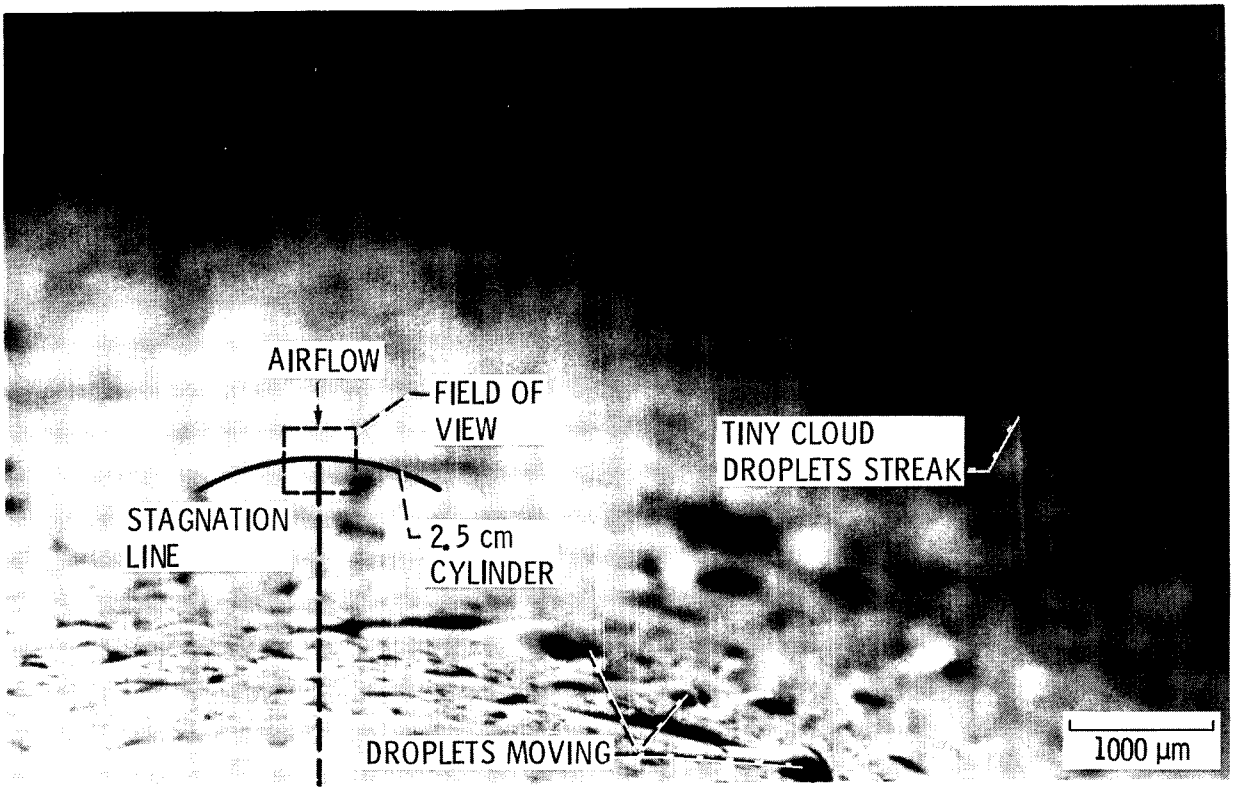
VELOCITY, m/sec	89.40
TEMPERATURE, ^{o}C	-10.65
PRESSURE, kPa	94.20
HUMIDITY, percent	100
LWC, g/m^{3}	1.20
DROP DIAMETER, μm	20
TIME, sec	240

CD-87-28739

CLOSE UP FLASH PICTURE OF DROPLET IMPINGEMENT

A close up flash picture of droplet impingement on a surface is shown. These photographic studies are being done to better understand the physics of the ice accretion process. An improved understanding of the basic physics will result in improved ice accretion prediction capabilities.

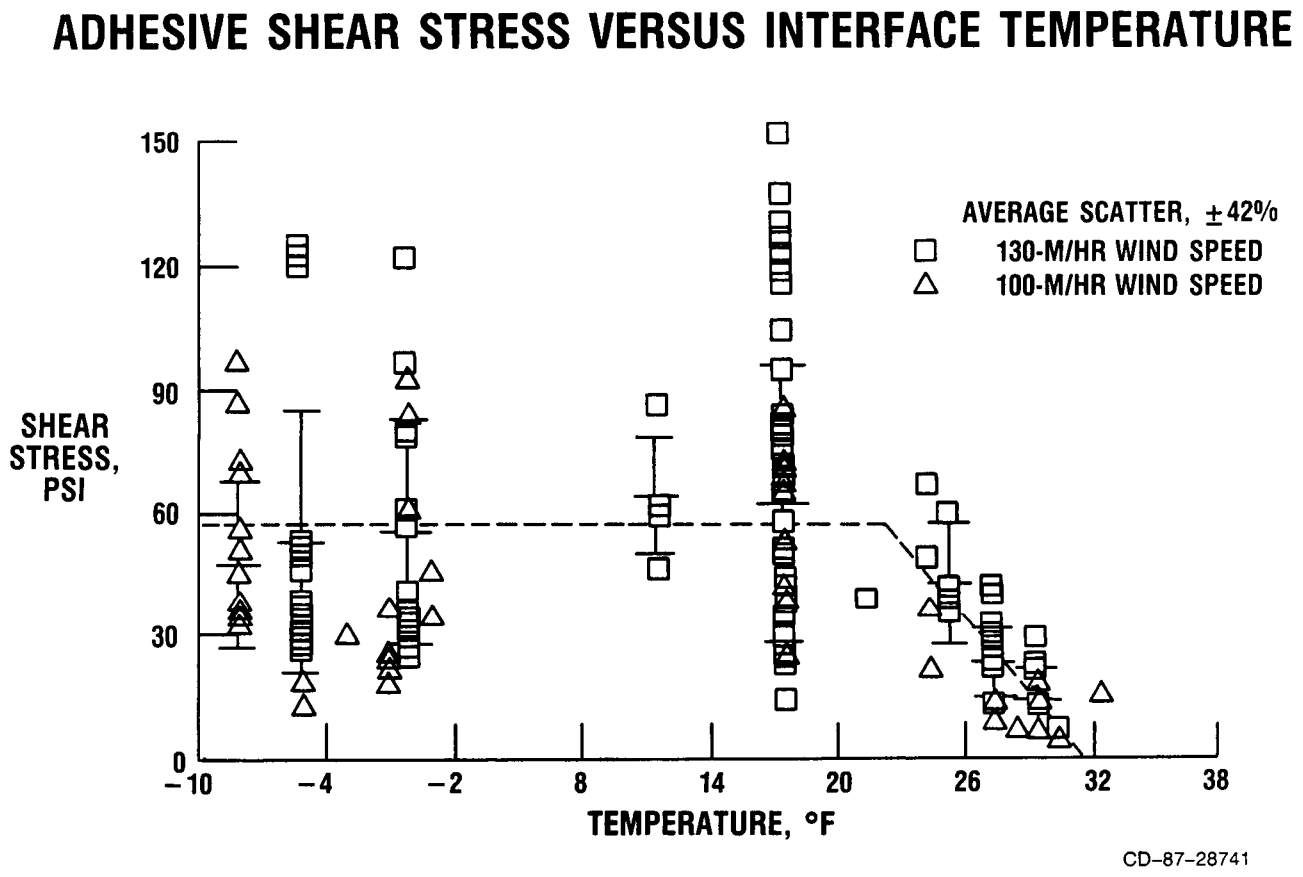
CLOSE UP FLASH PICTURE OF DROPLET IMPINGEMENT



CD-87-28740

ADHESIVE SHEAR STRESS VERSUS INTERFACE TEMPERATURE

Improved values for impact ice structural properties as well as adhesion strengths are required inputs to computer models of mechanical and thermal deicing systems. Fundamental experiments are being conducted to acquire such data and a representative sample of the data being acquired is shown.

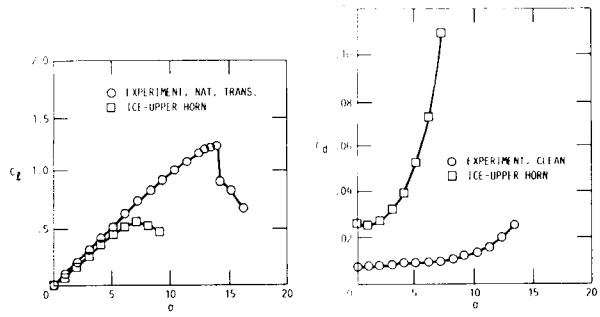


CODE VALIDATION STUDIES - ICED AIRFOIL ANALYSIS

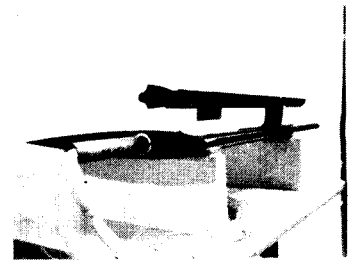
Detailed data are required to evaluate the various codes being developed to predict airfoil aerodynamic performance degradation due to leading edge ice accretions. A summary of the data being acquired for a NACA 0012 model with an idealized leading edge ice accretion is shown.

ORIGINAL PAGE IS
OE POOR QUALITY

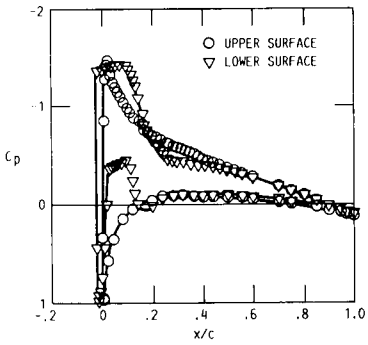
CODE VALIDATION STUDIES—ICED AIRFOIL ANALYSIS



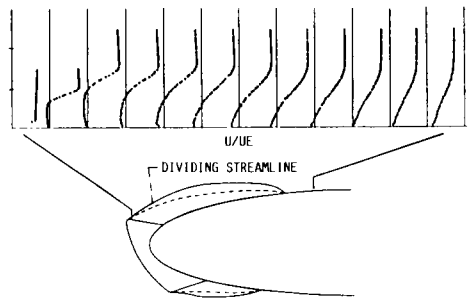
FORCE AND MOMENT DATA



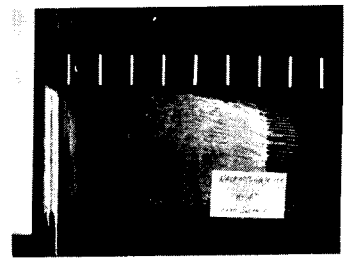
NACA 0012 MODEL



DETAILED SURFACE PRESSURES



BOUNDARY LAYER PROFILES

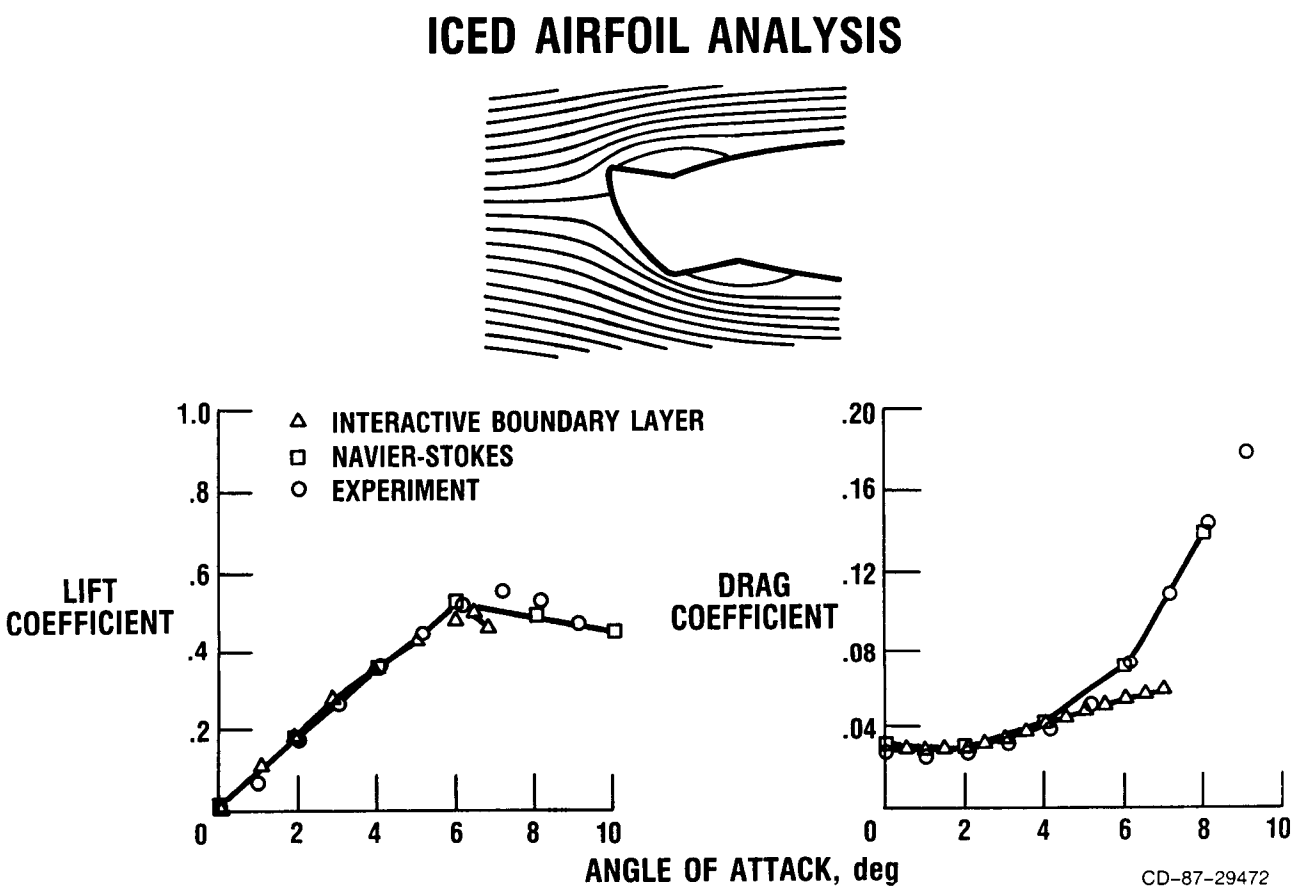


FLOW VISUALIZATION

CD-87-28742

ICED AIRFOIL ANALYSIS

The "iced" airfoil predictions of the Navier-Stokes and interactive boundary layer codes are compared to the code validation data shown in the previous figure. The agreement is judged to be generally good for both codes.

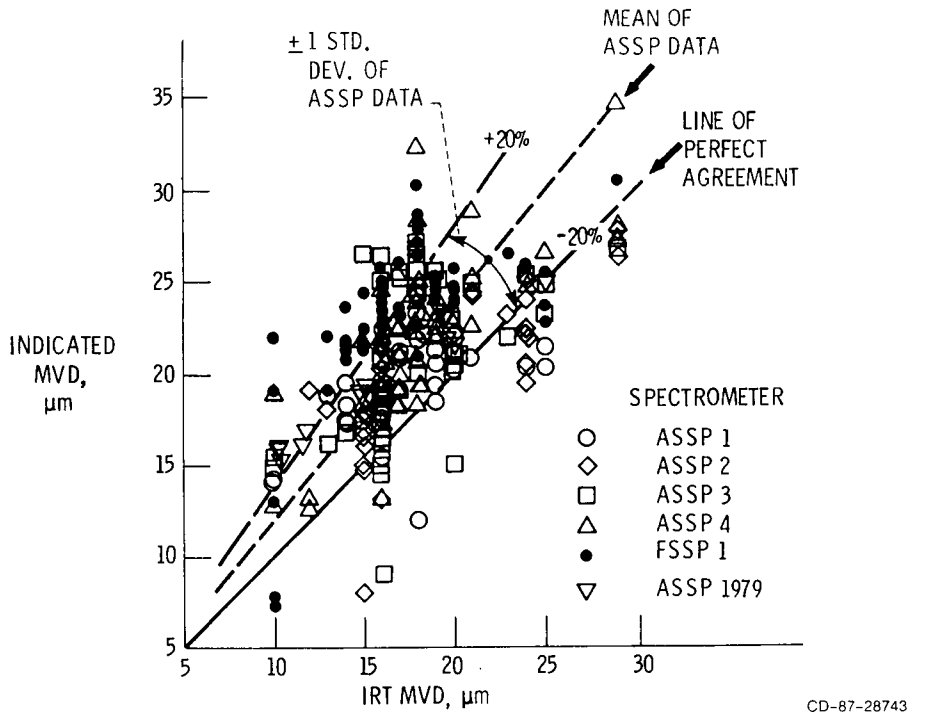


COMPARISON OF LASER SPECTROMETER DROP SIZE INDICATIONS TO OLD IRT CALIBRATION

Droplet size measurements made in the Icing Research Tunnel (IRT) using various laser spectrometer probes are compared to the group of cloud droplet sizes using the facility calibration developed by NACA. The wide spread of the data away from the line of perfect agreement suggests the need for improvements in the accuracy of droplet sizing instrumentation. The data taken in this test program suggested current instrumentation accuracies of no better than ± 4 μm (on a volume median diameter (VMD) basis).

COMPARISON OF LASER SPECTROMETER DROP SIZE INDICATIONS TO OLD IRT CALIBRATION

RANGE OF CONDITIONS: $10 < DVM < 30$ μM; $0.3 < LWG < 3$ G/M^3; $80 < V < 460$ KM/HR

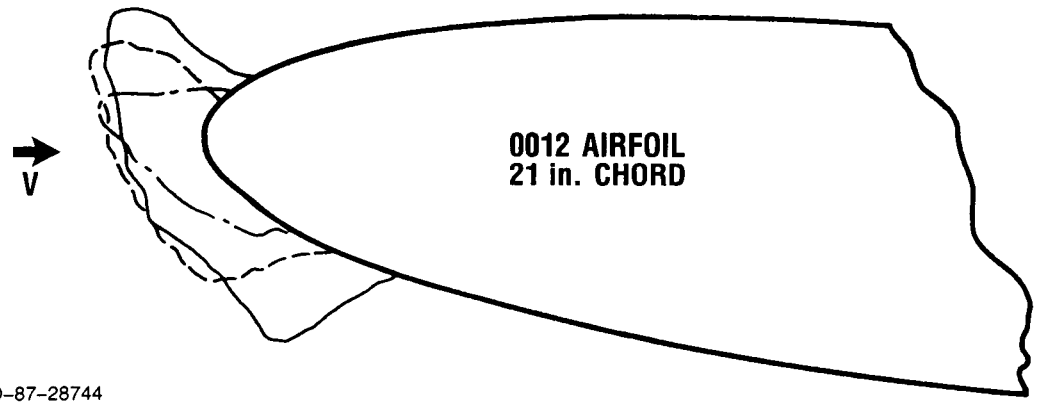


EFFECTS OF DROP SIZE MEASUREMENT ERRORS

The effect of a ± 4 μm variation of volume median diameter (VMD) on ice accretion shape and resulting airfoil drag increase are shown. The figure suggests the effects can be significant and that the accuracy of droplet sizing instrumentation must be improved.

EFFECTS OF DROP SIZE MEASUREMENT ERRORS

	DROP SIZE, μm	DRAG COEFFICIENT C_d
———	25	0.074
— — —	21	.039
— · —	17	.015
	DRY	.0085



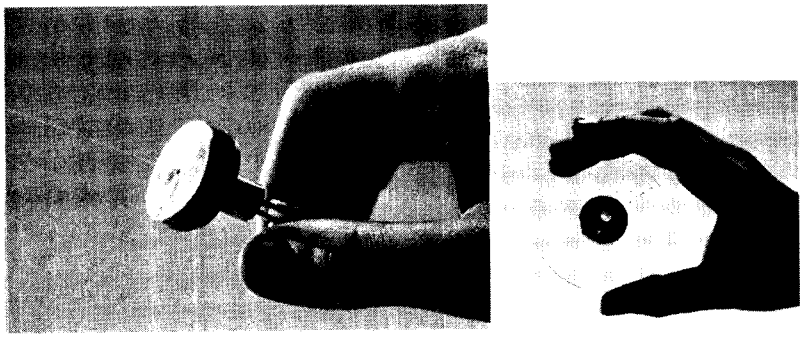
CD-87-28744

PARTICLE SIZING INSTRUMENTATION RESEARCH

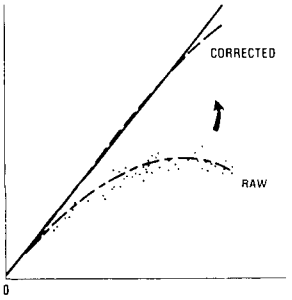
The current activities to improve the accuracy of existing droplet sizing instrumentation are shown.

ORIGINAL PAGE IS
OF POOR QUALITY

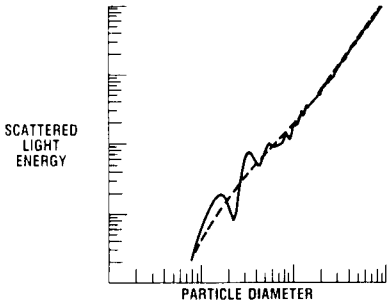
PARTICLE SIZING INSTRUMENTATION RESEARCH



CALIBRATION DEVICES

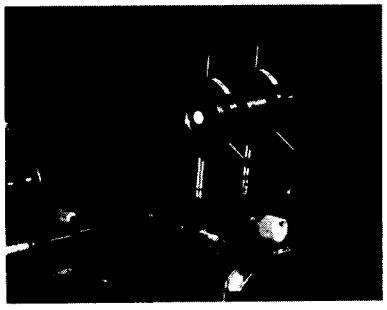


DATA CORRECTION ALGORITHMS

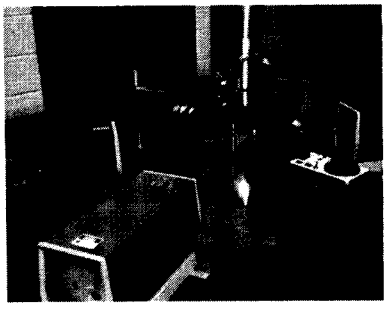


THEORETICAL MODELING

CD-87-28745



FUNDAMENTAL RESEARCH

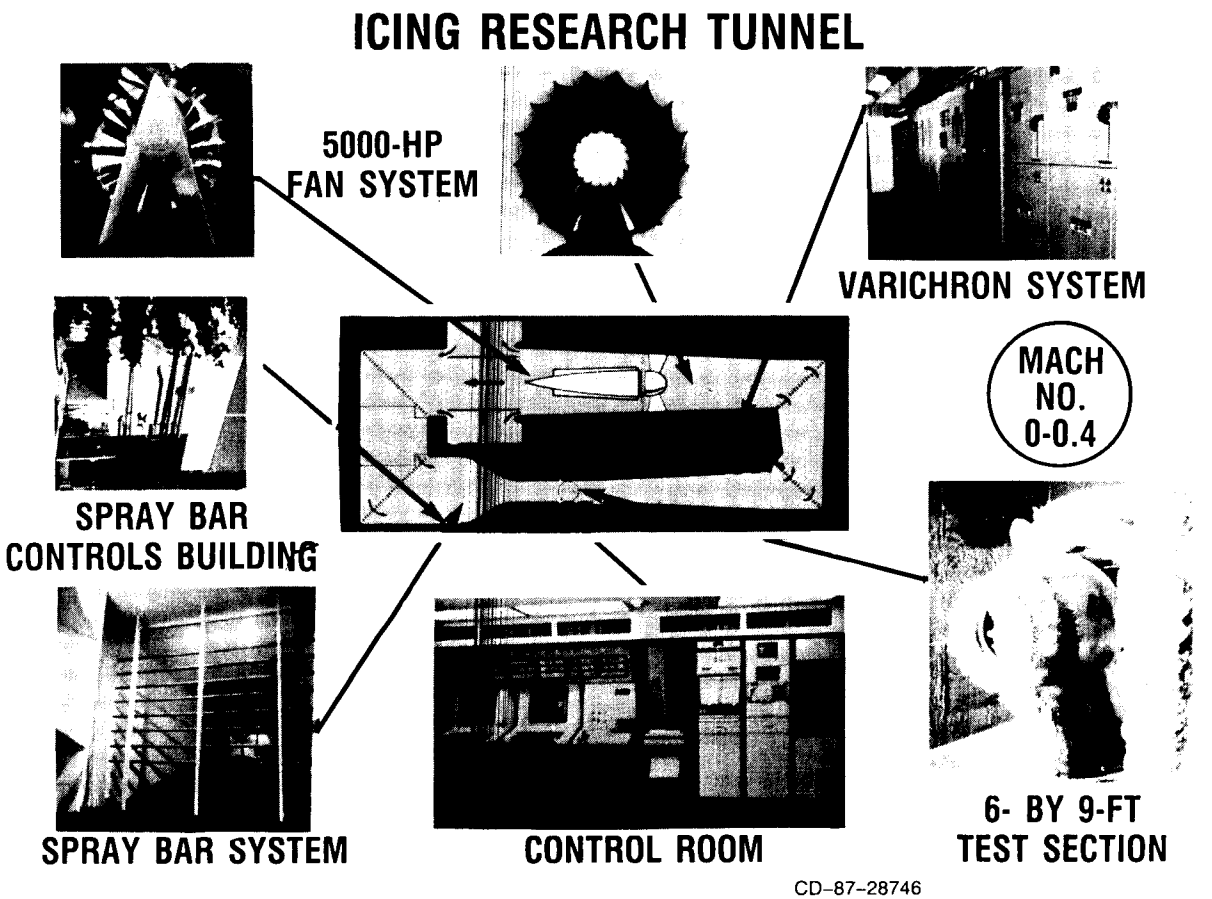


INSTRUMENT COMPARISONS

ICING RESEARCH TUNNEL

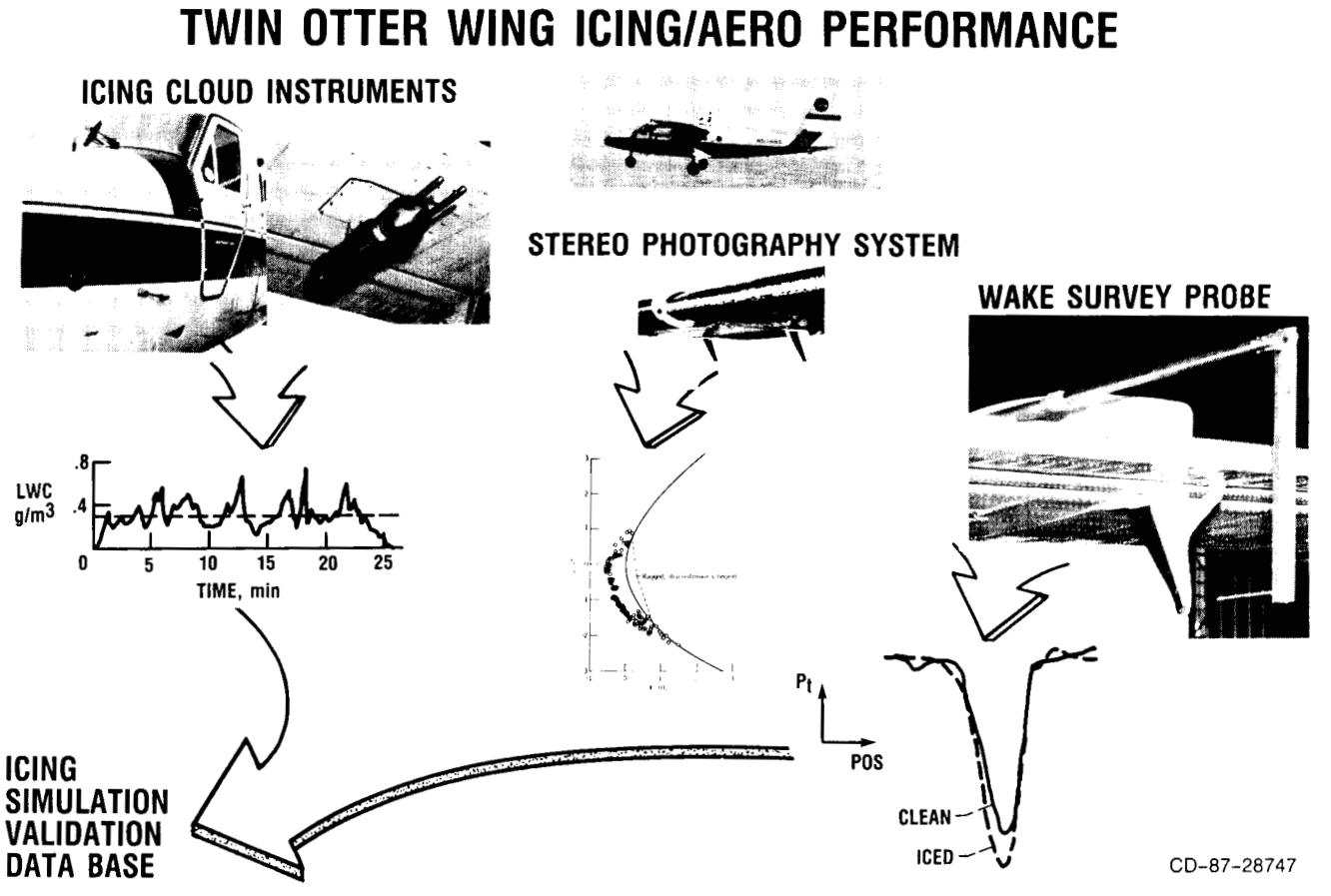
The NASA Icing Research Tunnel (IRT), the largest refrigerated icing wind tunnel in the world, recently underwent a $3.6M upgrade to modernize the facility which began operation in 1944. The key features of the "new" IRT are shown.

ORIGINAL PAGE IS
OF POOR QUALITY



TWIN OTTER WING ICING/AEROPERFORMANCE

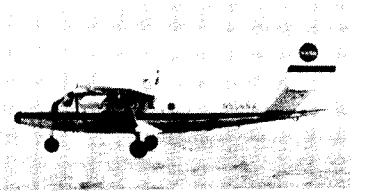
The major objective of the icing flight research portion of the program is to acquire a data base which can be used to validate experimental and analytical simulations of icing. The key components of the data base being acquired are shown.



The aircraft is also being used to acquire aircraft performance/stability control changes due to icing. Representative samples of data acquired are shown.

AIRCRAFT PERFORMANCE IN NATURAL ICING

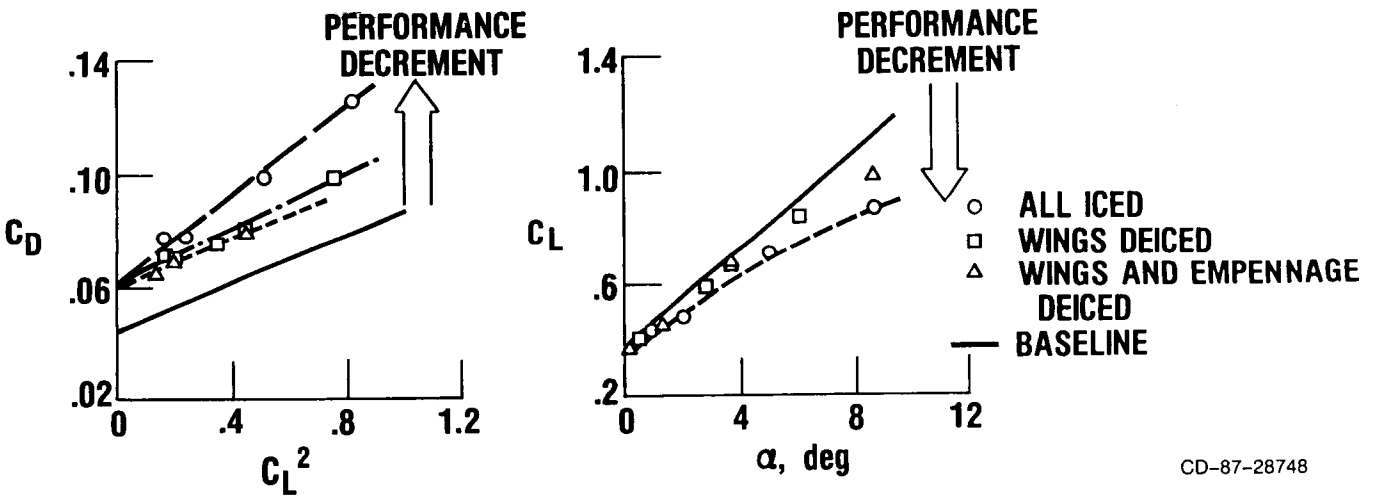
EXPERIMENTAL DATA BASE IS BEING ACQUIRED, RELATING AIRCRAFT PERFORMANCE DEGRADATION TO A MATRIX OF MEASURED NATURAL ICING CONDITIONS



NASA DHC-6 TWIN OTTER ICING RESEARCH AIRCRAFT

GLAZE ICING ENCOUNTER

MVD - 13μm ICING TIME - 26 min
LWC - 0.31 g/m^3 STATIC TEMP. - -4 °C

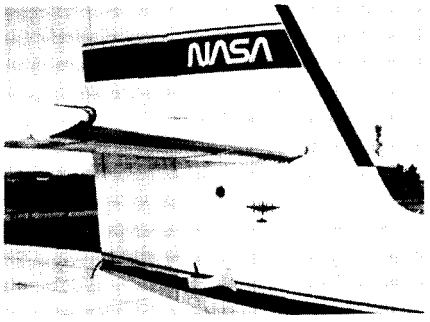


CD-87-28748

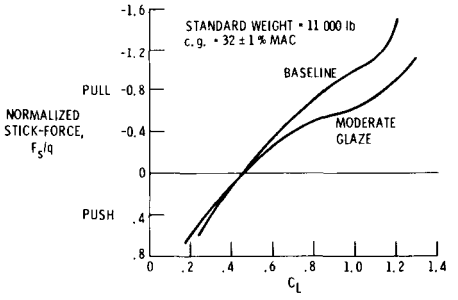
REDUCTION OF AIRCRAFT STATIC LONGITUDINAL STABILITY DUE TO ICING

OBJECTIVE: EMPLOY STATIC LONGITUDINAL FLIGHT TEST METHODS TO A DHC-6 AIRCRAFT WITH AN ARTIFICIAL ICE SHAPE ATTACHED TO THE HORIZONTAL TAIL PLANE TO MEASURE THE CHANGE IN STATIC MARGIN

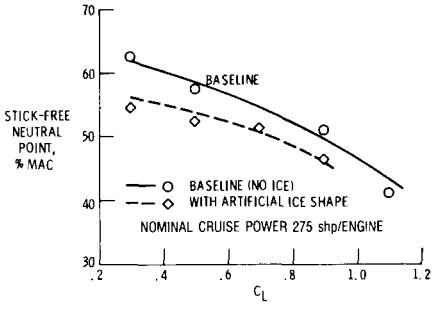
RESULTS: A REDUCTION IN STATIC MARGIN WAS MEASURED THROUGHOUT THE NORMAL FLAPS-UP CRUISE ENVELOPE



ARTIFICIAL MODERATE GLAZE ICE SHAPE ATTACHED TO HORIZONTAL TAIL



VARIATION IN NORMALIZED CONTROL FORCE FOR THE "ICED" VERSUS BASELINE TAIL

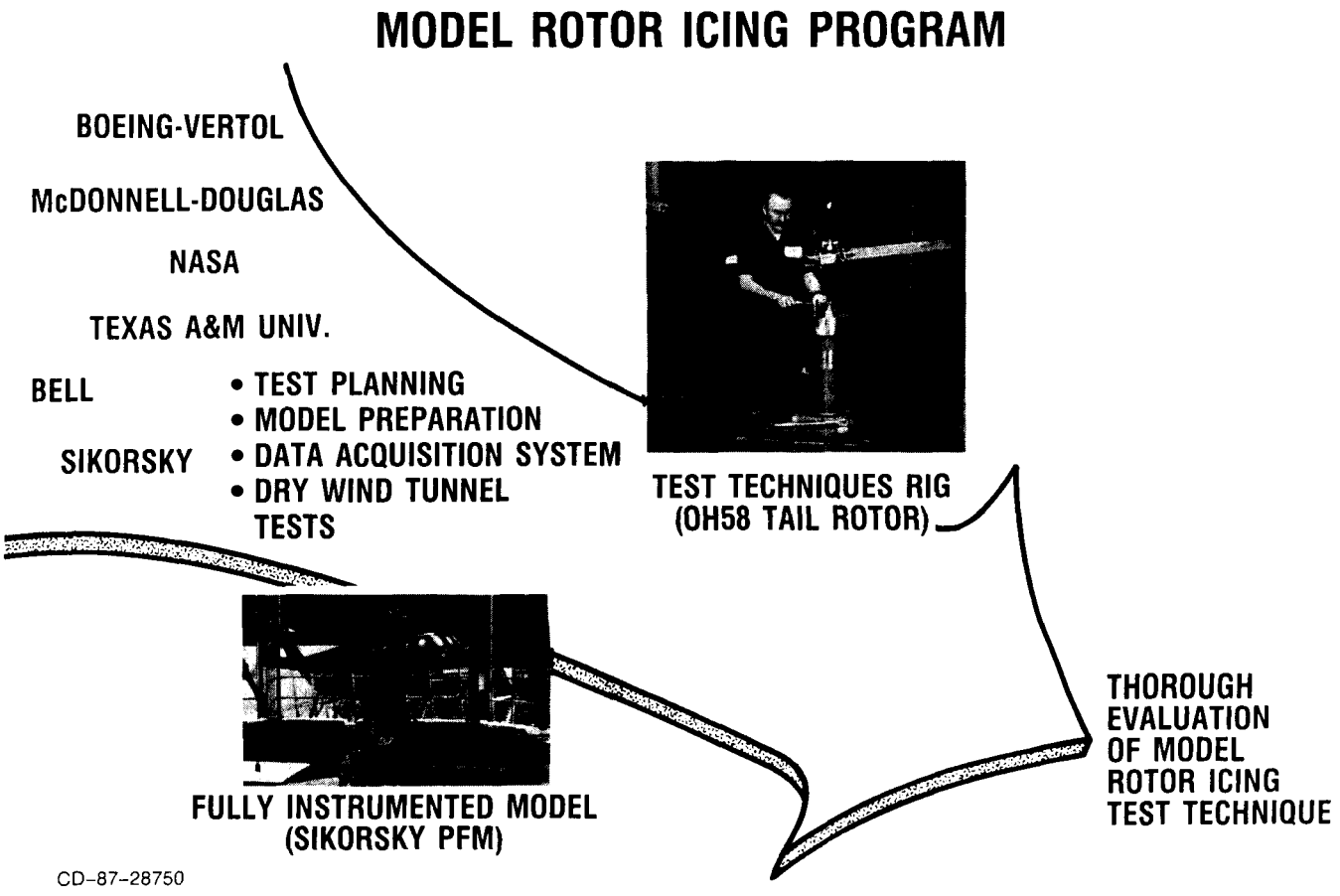


REDUCTION IN STICK-FREE STATIC MARGIN DUE TO TAIL ICE

CD-87-28749

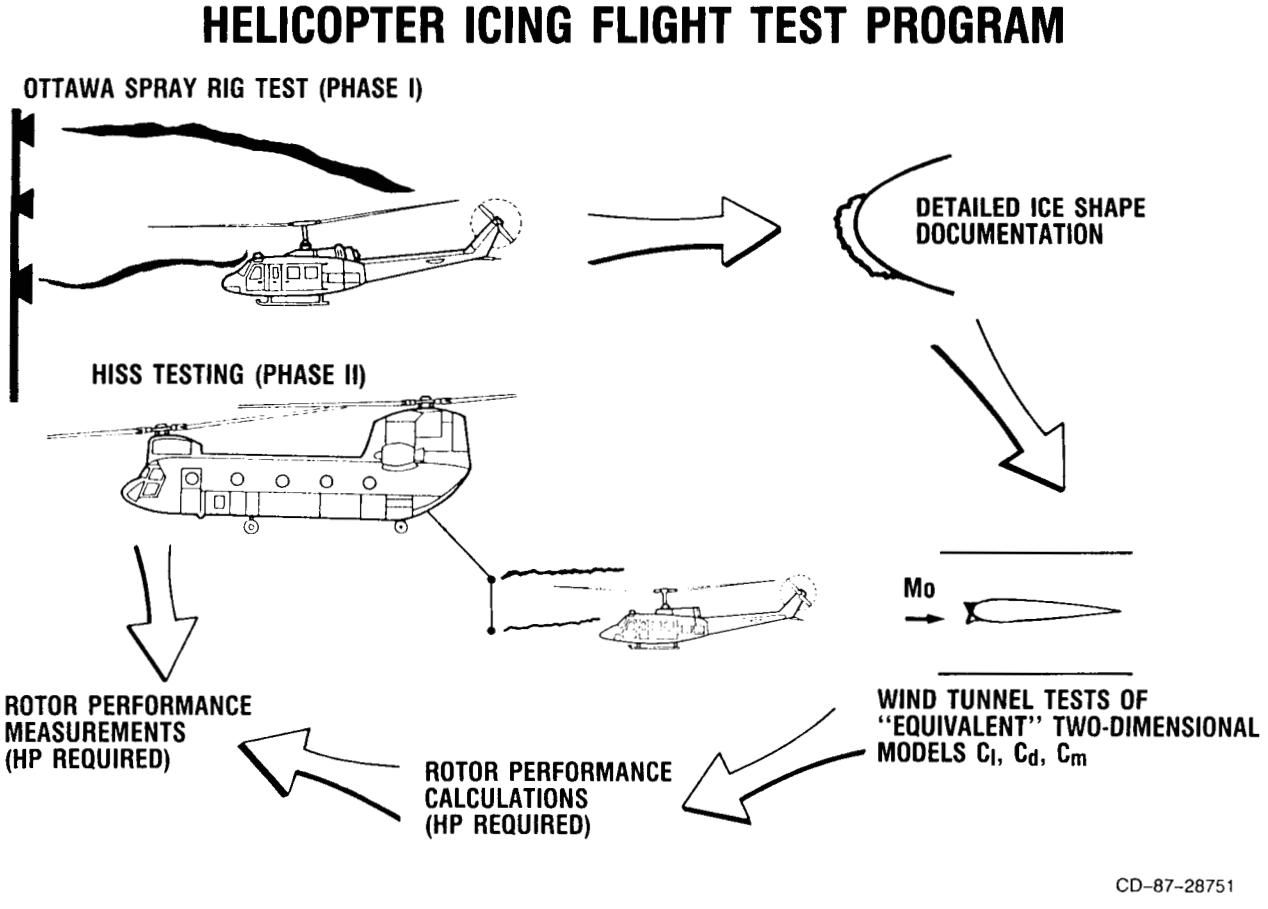
MODEL ROTOR ICING PROGRAM

The evaluation of the technique of testing model helicopter rotors in the IRT is the current focus of the helicopter related icing research. This effort is a joint NASA/industry/university program, and the key elements of the initial phases of the multi-year program are shown.



HELICOPTER ICING FLIGHT TEST PROGRAM

The NASA/Army/industry/university helicopter icing flight test program was a multi-phase effort to acquire unprotected helicopter rotor ice accretion and aerodynamic performance data for both hover and forward flight conditions. The test techniques developed will be used in a proposed future program to acquire flight data for comparison with scale model rotor data which will be acquired.



AIRCRAFT ICING TECHNOLOGY PROGRAM

The areas of future emphasis in the program are shown in this figure. The basic or generic icing research activities will be continued and this technology will be applied to the fixed wing aircraft to develop icing effects simulations. These simulations will be computer based and validated through appropriate wind tunnel and flight test programs. In the longer term, the emphasis will switch toward rotorcraft applications where again icing effects simulations will be developed and validated. In addition, rotor icing test techniques will be developed and validated and alternate concepts for rotor ice protection will be sought.