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INVESTIGATION OF ICE ACCRETION CHARACTERISTICS OF HYDROPHOBIC MATERIALS

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FINAL REPORT

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16. Abstract

To determine their effectiveness as anti-icing agents, 23 hydrophobic materials were evaluated in a dynamic icing environment. Each substance was examined in a manner that would determine its ice accretion characteristics and ice release properties. No attempt was made to stimulate ice release by either thermal or mechanical means during individual test runs. Ice formed on all the materials which were investigated at the same rate as on the untreated aluminum wing section which was utilized as a test bed. There was no observed release of ice due to aerodynamic forces associated with the test velocities (110 to 150 knots). The minimum ice adhesion force of any product evaluated was 1.8 pounds per square inch, with maximum values in excess of 40 pounds per square inch.

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INTRODUCTION

Purpose

The purpose of this phase of the project was to test commercially available low-cost materials under dynamic icing conditions to evaluate the effectiveness of the materials to passively prevent ice accumulation on or precipitate release of accumulated ice from the leading edge of the wings and other external surfaces of General Aviation type aircraft.

Background

This effort was the initial phase of an Aircraft Development Service (ADS) sponsored project titled "Development of Improved Method of Ice Prevention for Light Aircraft." This project was initiated by ADS as a followup to a program which produced a report titled "Engineering Summary of Airframe Icing Technical Data," Report Number ADS-4, in 1963. This referenced report is a compilation of the most significant research and experience in the area of airframe icing. Research conducted by the National Aeronautics and Space Administration (NASA), documented in over 30 separate reports, comprised the major part of the statistical data in the ADS-4 report and serves as the basis for most United States, Canadian, and British commercial and military design criteria.

DISCUSSION

Test Objectives

The objectives of the test program were to evaluate the effectiveness of hydrophobic materials to prevent ice accumulation or to precipitate automatic deicing of aircraft surfaces exposed to a dynamic icing environment and to determine the relative values of ice adhesion force of the materials tested.

Test Program

The test program was designed to evaluate selected icing conditions as set forth in Appendix C of the Federal Air Regulations, Part 25 (FAR-25). These were continuous maximum icing as illustrated in Figure 1 and intermittent maximum icing as shown in Figure 2. To accomplish this, arrangements were made with NASA to use their Icing Research Wind Tunnel located at the NASA-Lewis Research Center, Cleveland, Ohio. Calibration information on the water spray equipment installed in the tunnel was used to obtain the desired icing conditions.

Two airspeed test points were established for each of the aforementioned icing conditions. These were at 150 knots indicated, corresponding to the cruising speed of a light aircraft, and 110 knots indicated, representing the speed of a light aircraft in a holding pattern.

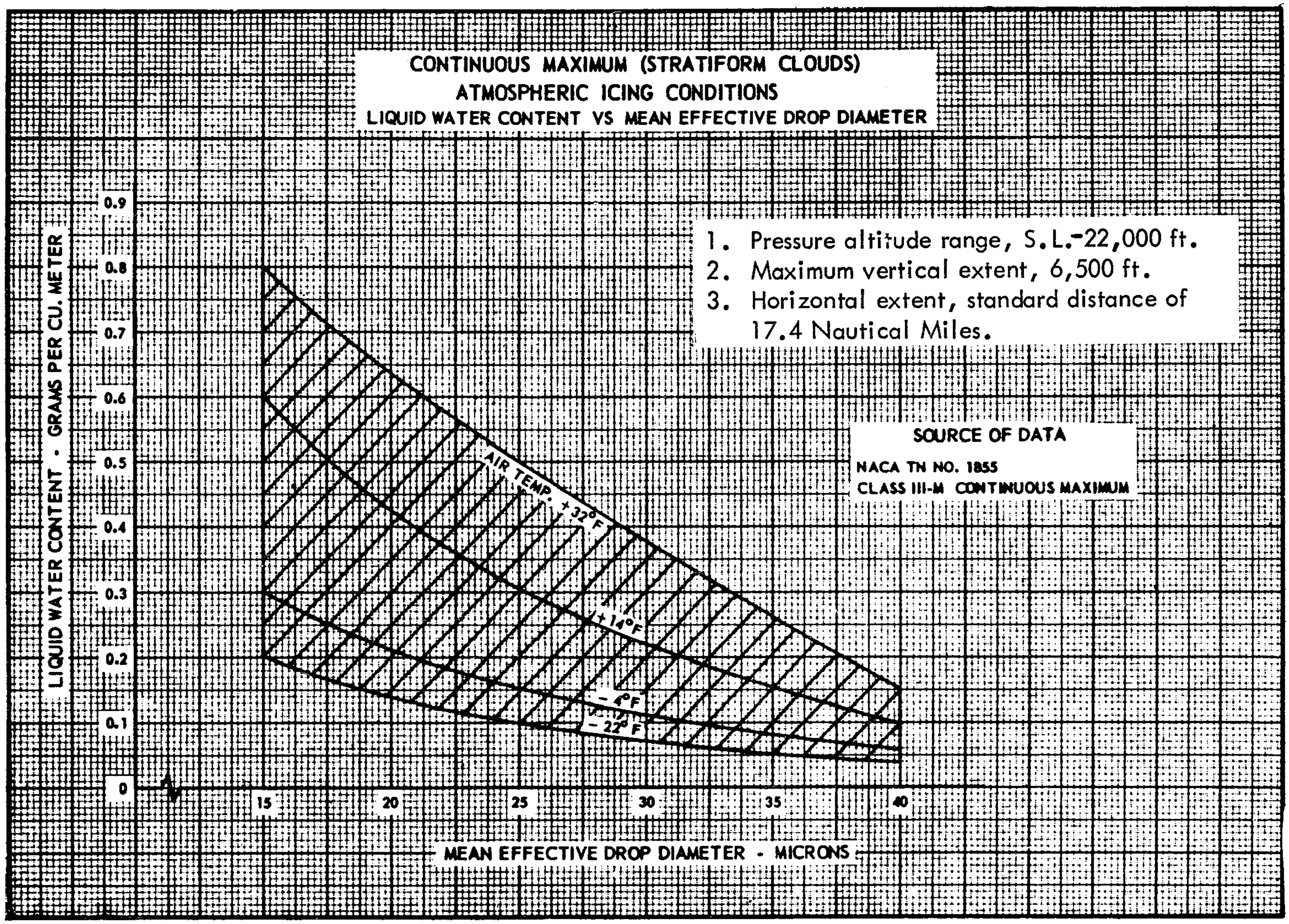

FIG. 1 CONTINUOUS MAXIMUM ATMOSPHERIC ICING CONDITIONS - STRATIFORM CLOUDS (From FAR-25)

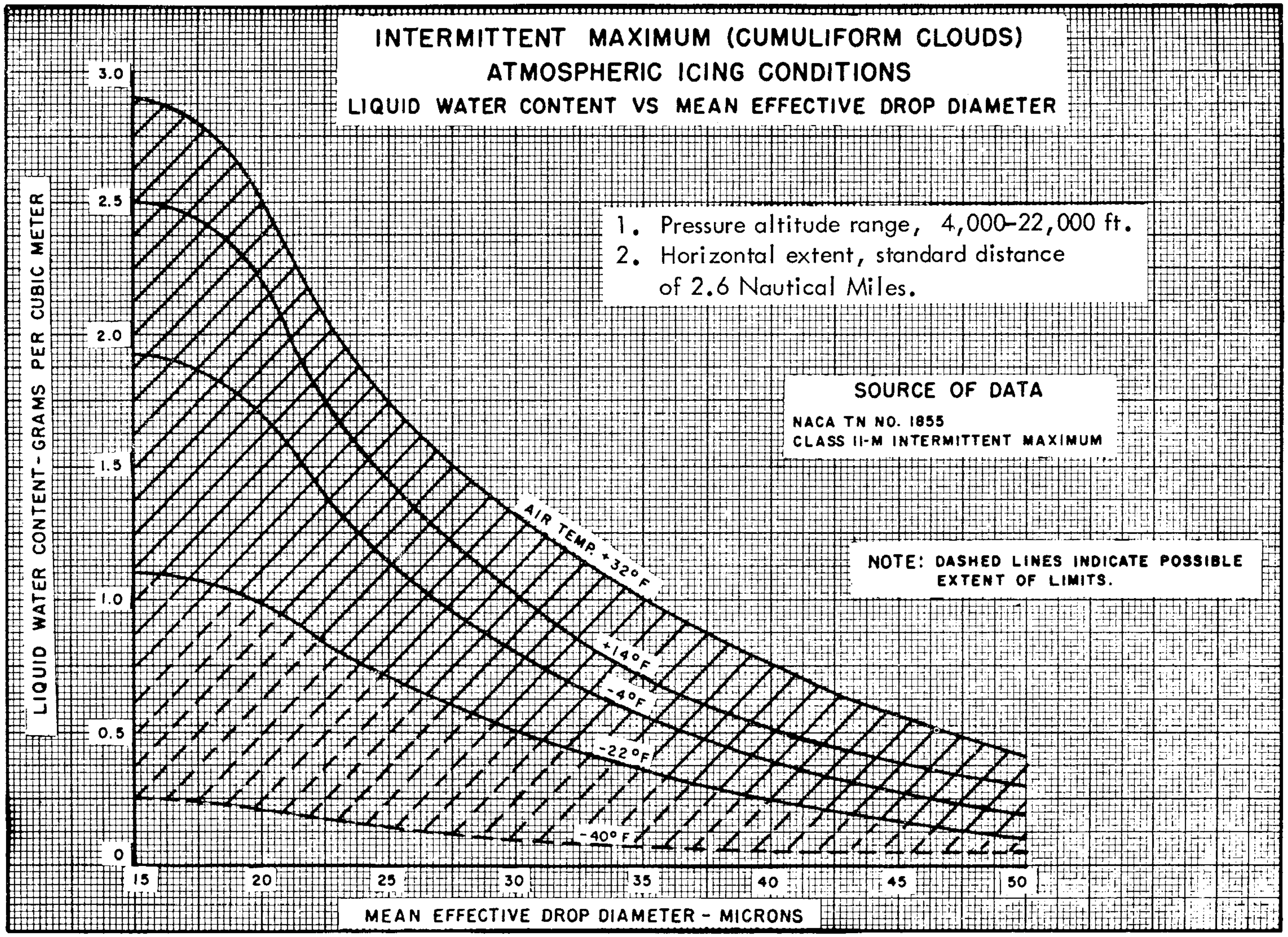

FIG. 2 INTERMITTENT MAXIMUM ATMOSPHERIC ICING CONDITIONS - CUMULIFORM CLOUDS (From FAR-25)

TABLE 1

FAA ICING PROGRAM
STANDARD TEST SERIES

NASA-LEWIS ICING RESEARCH TUNNEL

Run No.	IAS (knots)	IAS (mi/h)	Total Temp. (°F)	Liquid Water Content (gms/m^3)	Liquid Drop Diameter (microns)	Spray Duration (min)	FAR 25, Appendix C Conditions
1	110	127	25	0.7	15	9.5	Maximum Continuous
2	150	173	25	0.7	15	7.0	Maximum Continuous
3	110	127	14	1.5	25	2.0±	Intermittent Maximum
4	150	173	14	1.5	25	1.5±	Intermittent Maximum

It was planned to subject each material tested to a series of four operating conditions. Table I is a summary of the standard test series developed for the program.

Table II lists the products evaluated during this test program with a description of significant characteristics. These materials were applied to the wing surface test area by either the manufacturer's representative or by Federal Aviation Administration (FAA) personnel according to the manufacturer's specifications.

Along the leading edge of the test bed, two test areas were maintained. One ran 2 feet spanwise down from the midspan position and 1 foot back chordwise on the upper and lower wing surface. The other test surface was of similar dimensions, but was located above the midspan position.

Due to scheduling requirements and erosion characteristics of certain materials evaluated, a complete test series as described in Table I was not conducted in all cases. Some products were evaluated only under one condition due to the inability to reapply the material in the proper environment during a scheduled test day. Although it was technically desirable to conduct four separate tests for any one product, the program objectives were not compromised by the failure to accomplish this goal.

Description Of Test Installation

A representative light aircraft wing was utilized as a test bed for the evaluation studies at the NASA-Lewis Research Center, Cleveland, Ohio. This particular wing assembly has a NACA 2412 section, 64-inch chord and a 6-foot span with a wing surface fabricated of 0.050-inch thick 2024 T-3 Alclad aluminum. The test bed was installed vertically in the icing research tunnel test section as shown in Figure 3. A turntable to which the base of the wing was attached provided the capability of varying the angle of attack prior to or during the test runs. Windows along both sides and the top of the tunnel test section allowed for observation of the wing surfaces. In addition, a motion picture camera operating at 8 frames per second compiled film of selected tests.

A portable hydraulic ram/template device was used to determine the ice adhesion force of the materials tested. Upon the completion of an icing run, the tunnel airspeed was decreased to approximately 15 knots and an area of 10 square inches was prepared for measuring the adhesion force. Ice was removed from the perimeter of the desired area with a steam-heated/vacuum implement. As ice was melted, the liquid water was removed by suction ports in this tool which prevented disturbance of the test area. The ram/template assembly was engaged along the lower boundary of the ice surface and hydraulic pressure applied until the ice was dislodged. Utilization of calibration curves for this device provided ice adhesion values. Figure 4 shows test personnel operating this equipment.

TABLE II

SUMMARY OF PRODUCTS TESTED

PRODUCT	SUPPLIER	DESCRIPTION OF MATERIAL AND/OR APPLICATION
Teflon S Series 954-101	Aluminum Company of America	A 0.003-inch-thick aluminum sheet with a pressure-sensitive adhesive backing and coated with a 0.0007-inch-thick layer of Teflon-S
Teflon-S Series 958-211	Aluminum Company of America	Same as above
FEP Teflon	Lamcote Division of Arvey Corporation	A 0.002-inch-thick Teflon film with a pressure-sensitive backing
Polyolefin Grade u.h.m.w. No. 990	Formica Corporation	Polyolefin ultrahigh molecular weight sheeting 0.030-inch thick
Xaton MSX	Xaton Distributing Company	Proprietary chemical treatment for metal surfaces in liquid form
Xaton PRX	Xaton Distributing Company	Proprietary chemical treatment for painted surfaces in liquid form
Polyurethane Astrocoat RM 115 (Type 1)	U.S. Air Force	Polyurethane coating developed for the U.S. Air Force by Olin Mathieson Corporation to protect surfaces from sand and dust erosion
Polyox	Union Carbide Corp.	A 0.001-inch-thick high-molecular weight polyethylene oxide film
Y-4112 Silicone	Union Carbide Corp.	Solvent solution of reactive silicone
Y-4828 Silicone	Union Carbide Corp.	A cationic silicone
CAB-O-Sil ST-D	Cabot Corporation	A superhydrophobic amorphous colloidal silica
S.P.C.	Scientific Products Corp.	A proprietary metal surface treatment in liquid form
2-D-10A Compound	Product Development Co.	A proprietary grease composition

TABLE II (continued)

SUMMARY OF PRODUCTS TESTED

PRODUCT	SUPPLIER	DESCRIPTION OF MATERIAL AND/OR APPLICATION
TFE-LOK	Forester Plating & Mfg. Company	Patented process involving the deposition of Teflon particles into minute fissures on a metal surface
E-1044-32-1	Dow Corning	A cationic silicone
XZ-83071	Dow Corning	A cationic silicone
XZ-83057	Dow Corning	Solvent solution of reactive silicone
3889-1045	Coating Applicators	A Teflon paint
4010X	Coating Applicators	A Teflon paint
Glidair Ice Repellant No. 17-A	The Glidden Company	A proprietary aerosol spray
G.E. No. 624 Insulgel	General Electric Co.	An aerosol silicone compound
G.E. No. G-635	General Electric Co.	A silicone compound in grease form
G.E. No. G-660	General Electric Co.	A silicone compound in grease form

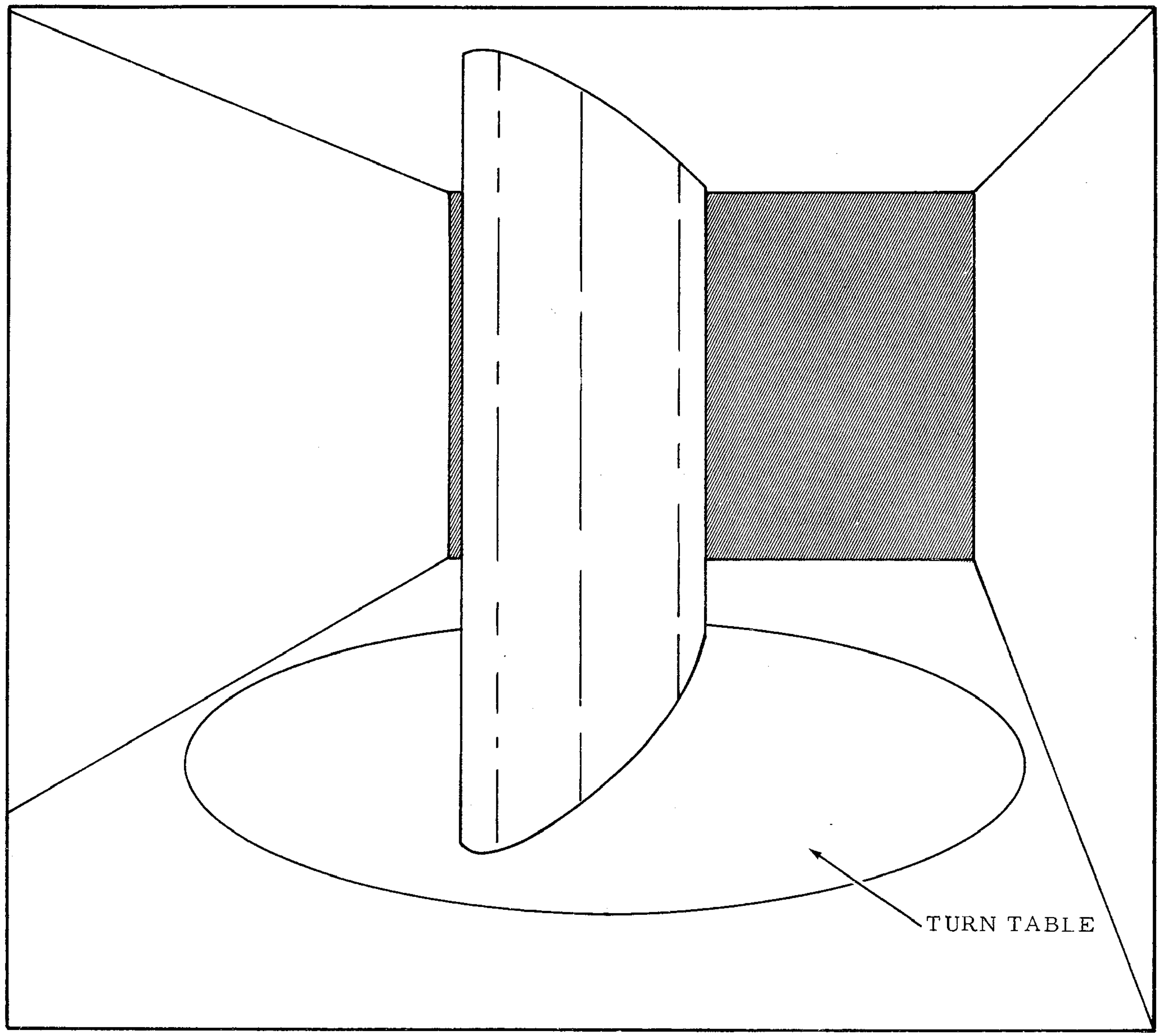

FIG. 3 TEST BED INSTALLED IN ICING TUNNEL TEST SECTION

FIG. 4 OPERATION OF TEST EQUIPMENT

SUMMARY OF RESULTS

Anti-icing Properties Of Materials

No material evaluated during the test program exhibited any anti-icing properties. Initiation of ice formation on the test bed commenced simultaneously on both the unprotected surface and the treated area during each of the individual runs.

Ice Adhesion Forces

None of the accumulated ice was shed from the test bed while any test was in progress. However, there was a significant reduction in the force required to dislodge ice depositions from treated surfaces of the wing in comparison to that necessary for removal of ice deposits on the bare aluminum test area. The aforementioned statement is subjective in nature as test personnel were unable to obtain acceptable values for the ice adhesion force to the bare aluminum wing surface. Table III lists the relative values obtained during the course of the program for all products which were investigated. Previous researchers have reported ice adhesion forces to untreated metal surfaces of the type utilized for this test effort as on the order of 200 pounds per square inch.

Visual and Film Analysis

Following initial ice formation of a monomolecular layer on any material, the surface properties which result in additional ice accretion are a function of this surface (ice). Visual observation of ice buildup during individual test runs and analysis of motion picture film compiled showed that none of the products evaluated inhibited initiation of ice formation.

Ice Release Observations

Ice was not sloughed from the test bed during any test runs. Therefore, the adhesion forces acting at the ice/material interface were sufficient to maintain integrity of accrued ice under the dynamic conditions maintained for this test series.

Effect Of Tunnel Parameters

During certain of the 110-knot test runs, the tunnel airspeed was increased to 150 knots, in addition to which the angle of attack was decreased from 8° to 1°. These actions did not cause any ice shedding from the test article.

TABLE III

SUMMARY OF ICING TESTS

Material Tested	Range of Ice Adhesion Forces (pounds per square inch)
Teflon-S 954-101	10-11
Teflon-S 958-211	11-13
FEP Film	13-17
Formica Polyolefin	7-14
Xaton MSX	7-12
Xaton PRX	13-22
Polyurethane	23-36
Polyox	18*
Y-4828 Silicone	25*
Y-4112 Silicone	8*
CAB-O-SIL ST-D	31*
SPC	13-15
2-D-104	13-25
TFE-LOK	7-10
E-1044-32-1 Silicone	1.8-2.2
XZ-83071-Silicone	1.8-2.2
XZ-83057-Silicone	6-10
3889-1045 Teflon Paint	12-25
4010X Teflon Paint	5-17
GLIDAIR	5*
G-624 Silicone	10*
G-635 Silicone	3-11
G-660 Silicone	5-11

* One Test Run Only

CONCLUSIONS

On the basis of the tests conducted, it is concluded that:

1. None of the materials exhibit either passive anti-icing qualities or tendencies to precipitate the release of accumulated ice.

2. All of the materials reduce the force required to release ice from a treated aluminum surface. The ice adhesion forces range from a minimum of 1.8 pounds per square inch for cationic silicones to over 40 pounds per square inch for polyurethane coatings.