AEROSPACE INFORMATION REPORT

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Summary of Icing Simulation Test Facilities

RATIONALE

This document, when written, created a very comprehensive document listing most of the facilities capable of simulating ice accretion. Tables provide detailed information regarding facility capabilities and details of the icing cloud characterization. When written in 1999 and as updated in 2004, it was current and up-to-date. All information presented therein, to the best of the Committee's ability, was true and accurate. Nothing in this document, recognizing that it captured facility details at the snap-shot in time, is misleading or inaccurate. Therefore, upon discussion at the Spring 2013 meeting, the Committee decided this document should be stabilized. The Committee further committed to draft a new document that would keep a list of current icing simulation facilities, but focus more on questions for a potential customer to ask regarding use of the facility. This new document is AIR6247 "Guidance for Selecting Ground-Based Icing Simulation Facilities".

STABILIZED NOTICE

This document has been declared "Stabilized" by the SAE AC-9C Aircraft Icing Technology Committee and will no longer be subjected to periodic reviews for currency. Users are responsible for verifying references and continued suitability of technical requirements. Newer technology may exist.

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INTRODUCTION

Icing simulation ground testing plays an important role in the overall safety of civil and military aviation. While improvements are continually being made to icing simulation facilities and test techniques, the overall quality of the data produced in these facilities is still lower than desired. Much of this is due to the overall difficulty in producing a uniform cloud of known water droplet size and liquid water content. This is due in large part to the inherent uncertainty in the instruments available to make cloud measurements. However, by careful calibration and operation of icing simulation facilities, an improvement in data quality and repeatability may be achieved.

The quality of the data is determined by comparing ground test data with natural occurrences. Ground icing cloud uniformity along with ground test ice accretions are compared with like natural phenomena in an effort to validate testing results.

The AC-9C Icing Subcommittee of the AC-9 Aircraft Environmental Systems Committee formed an Icing Facility Characterization Panel with the objective "to better understand and to improve the quality of ground ice accretion testing." The panel assembled a list of the world's icing facilities and contacts at each facility. A special meeting for representatives of the known icing facilities and other interested individuals was held in Montreal on October 15, 1990 before the regular AC-9C meeting. The goal of the meeting was to discuss the state of icing simulation testing and identify how the panel could make a contribution. The over 20 attendees concluded the first step should be to "compile and document detailed information on how icing facilities flow/cloud property measurements are made."

This document attempts to respond to the icing simulation community's desire for a detailed documentation of icing facilities. The time and effort of those facility representatives who completed the lengthy initial and follow-up questionnaires is greatly appreciated. The members of the Icing Facility Characterization Panel hope the report is useful and that it is the first step toward the ultimate goal of improving ground ice accretion testing. This document is a summary of facilities and operational practices. It is not intended to be a recommendation of any facility nor does it judge the merits of any facility or icing simulation approach. It is intended to supplement the NASA survey, by William Olsen, entitled, "Survey of Aircraft Icing Simulation Test Facilities in North America," NASA TM 81707, 1981.

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1. SCOPE:

This SAE Aerospace Information Report (AIR) contains information on most of the major icing simulation ground facilities. An effort was made to obtain data from as many facilities as possible over a two year time period. The data in this document represents the state of the facilities in calendar year 1996. Facilities are constantly changing and upgrading and, therefore, some facility specifications may change during the life of this report.

Of the 27 facilities described in this report, the primary use is split with approximately half for engine testing and half for wind tunnel testing. The facilities are limited to ground facilities and, therefore, icing tankers have not been included.

1.1 Purpose:

The primary purpose of this document is to document the capabilities of the world's major icing simulation ground facilities. This report should be very useful for an organization interested in selecting a facility for a particular test. The usual information on facility test section size, speed, cloud parameters, etc. are provided for this purpose, along with a contact person at each facility. However, it is the purpose of this report to go beyond the information found in a list of facilities.

The operation of an icing facility is more complex than that of a non-icing facility. The instrumentation and methods used to calibrate the spray and tunnel, and that used to monitor test condition, should be very important to the facility user. Droplet size and concentration measurements are very difficult to make and the uncertainty, even in state-of-the-art measurements, is high. Therefore, data were collected and reported on the details of the calibration of the facility spray system. Data are also presented on the facility instrumentation used to monitor and document the tunnel test condition. The purpose of including these kinds of data was to document the importance of proper calibration and careful cloud measurements to the success of a test program.

This report should find application for all disciplines which use ground icing simulation facilities. This includes research, development, certification of ice protection systems, sensors, instruments, fundamental testing of aerodynamics, heat transfer, ice shedding, ice properties, and accretion physics.

2. REFERENCES:

2.1 Applicable Documents:

2.1.1 SAE Publications: Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

ARD50066 Aircraft Icing Directory

2.2 Symbols and Abbreviations:

A	cross-section area
ASME	American Society of Mechanical Engineers
ASSP	Axial Scattering Spectrometer Probe[1]
°C	degrees Celsius
cm	centimeter
D	diameter
°F	degrees Fahrenheit
FSSP	Forward Scattering Spectrometer Probe[1]
ft	feet
g	gram(s)
gr	grain(s)
H	height
kg	kilograms
kPa	kiloPascal
kt	knots
L	length
lb	pound
LWC	liquid water content
m	meters
MVD	median volumetric diameter
mph	miles per hour
NA	not available
OAP	Optical Array Probe[1]
Patm	pressure, atmospheric
PDPA	Phase Doppler Particle Analyzer
PRB	platinum Resistance Bridge
Ps	pressure, static
psia	pounds per inch absolute
Pt	pressure, total
RTD	Resistance Temperature Device
s	seconds
T/C	thermocouple
Ts	temperature, static
Tt	temperature, total
µS	microsiemen
W	width
Wa	air mass flow rate

1. Trade name of Particle Measuring Systems, Inc., Boulder, Colorado.

3. TERMINOLOGY:

CONDUCTANCE: A measure of the ability of a material to conduct electrical current; the inverse of electrical resistance. In water treatment application, conductance is a measure of the purity of the water. Reduction of the amount of solids in the water will reduce the conductance.

LIQUID WATER CONTENT: The amount of water in liquid form per unit volume of air, usually measured in grams of water per cubic meter of air, g/m^3.

MEDIAN VOLUMETRIC DIAMETER: The diameter which divides a droplet mass distribution into two equal parts, where one half of the total mass is contained in droplets smaller than this diameter and the other half is contained in droplets larger than this diameter.

4. SURVEY:

4.1 Survey Forms:

The survey forms were developed following the initial Icing Facility Characterization Panel meeting in Montreal on October 15, 1990. The objective adopted in Montreal was to address ground icing test facilities, test methods and procedures, measurements, and standardization issues. The approach used to reach the objective was to collect information by developing and distributing a survey form to panel members and all known icing facility representatives. The final “Icing Facility Characterization Survey” form was made up of the general headings on Facility Identification and Facility Description. Facility Description was broken down into several sections concerning facility size, type, cloud size and characteristics, instrumentation, measurement and calibration methods, and schematics. The survey forms were sent to the facilities in 1991. A total of 16 organizations responded with information covering the following tables under the general topics of Participant, Capabilities, Instrumentation, and Cloud Calibration. Schematics/sketches of each facility described in Tables 1 through 4 are found in Figures 1 through 27.

5. DESCRIPTION OF SUMMARY TABLES:

The following subsections describe the facility characterization summary tables. These tables were compiled using responses to an AC-9C survey sent to all known icing facility representatives. Information concerning facility location, icing environmental simulation capabilities, measurement instrumentation, and cloud calibration methods is provided.

5.1 Facility Locations:

Table 1 lists the organizations operating icing simulation facilities. Names of facility contacts, their telephone/Fax numbers, and the locations of the facilities are included in the table. The SAE AC-9C maintains an “Aircraft Icing Directory,” (ARD50066) as an alternate means to locate current points of contact for facilities.

5.2 Icing Environmental Simulation Capabilities:

Table 2 provides information on icing tunnel test parameters including test section dimension, air speed ranges, liquid water contents, and available droplet sizes. When two dimensions are given for the dimensions of the uniform icing cloud, these indicate height and width respectively. All other dimensions refer to diameter.

5.3 Facility Instrumentation:

Table 3 describes the measurement instrumentation and techniques of each icing tunnel. Temperature, pressure, velocity, and water spray parameters are among the tunnel variables listed.

5.4 Cloud Calibration:

Table 4 describes the methods used to maintain icing cloud consistency, repeatability, and uniformity. Measurement instrumentation and techniques used to determine liquid water content and droplet sizing are listed.

6. SUMMARY:

The SAE AC-9C “Aircraft Icing Technology Subcommittee” has compiled a listing of major ground based icing simulation test facilities. Survey forms were sent to all known major icing simulation facilities. The responses are summarized and tabulations of the facility locations, points of contact, icing simulation capabilities, instrumentation, and cloud calibration techniques are given. The summary is intended to be a factual resource addressing ground icing test facilities. This information report should be used in conjunction with the “Aircraft Icing Directory,” (ARD50066) to obtain more information concerning any facility.

TABLE 1 - Summary of Icing Simulation Test Facilities Participants Listing

Facility No.	Facility Identification	Organization & Location	Contact	Facility Name	Facility No.	Facility Identification	Organization & Location	Contact	Facility Name
1	ACT (Artington)	The Artington Cold Store New Pond Road Guildford, Surrey, GU31JP England	Mr. Glenn Howard Phone: 01483 566876 Fax: 01483 301949	Artington Icing Wind Tunnel	11	CEPr (R6)	Centre d'Essai des Propulseurs CEPr Saclay 91895 ORSAY CEDEX, FRANCE	Ms. Sophie Le Berre Phone: (33) 1 69 85 09 40 Fax: (33) 1 69 85 01 02	Altitude Test Cell R6
2	AERAZUR	AERAZUR 4 Rue Lesage-Maille 76320 Caudebec-les-Elbeuf France	F. Averous Phone: 33(0)1 41 23 23 23 Fax: 33(0)1 46 48 88 52	Tunnel de Givrage	12	CEPr (PAG)	Centre d'Essai des Propulseurs CEPr Saclay 91895 ORSAY CEDEX, FRANCE	Ms. Sophie Le Berre Phone: (33) 1 69 85 09 40 Fax: (33) 1 69 85 01 02	Petit Anneau Givrant
3	AIT	Aero & Industrial Technology Ltd. P.O. Box 46 Burnley BB11 4BX Lancashire, England	Mr. R. J. Park Phone: (0) 282 831199 Fax: (0) 282 415969	Altitude Test Facility	13	FluiDyne	FluiDyne Engineering Corporation 5900 Olsen Memorial Highway Minneapolis, MN 55422	Mr. Julian Idzorek Phone: (612) 544-2721 Fax: (612) 546-5617	22 X 22 Icing Wind Tunnel
4	AEDC (T-1,2,4)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Engine Test Facilities T-1, T-2, T-4	14	G.E.	General Electric Peebles Test Operation 1200 Jaybird Road Peebles, OH 45660	Mr. J. R. Bennett Phone: (513) 243-7432 Fax: (513) 243-4068	Site 6
5	AEDC (J-1,2)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Engine Test Facilities J-1, J-2	15	NASA LeRC (IRT)	NASA Lewis Research Center 21000 Brookpark Road Cleveland, OH 44135	Mr. Thomas B. Irvine Phone: (216) 433-5369 Fax: (216) 433-8551	Icing Research Tunnel
6	AEDC (C-2)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Engine Test Cell C-2	16	NRC (#4)	National Research Council Montreal Road Ottawa, Ontario Canada K1A OR6	Mr. M. S. Chappell Phone: (613) 993-9900 Fax: (613) 952-7686	Gas Turbine Icing Test Facility Test Cell #4
7	AEDC (R-1D)	Arnold Engineering Development Center Arnold Air Force Base, TN 37389-5000	Maj. J. Davis Phone: (615) 454-5853 Fax: (615) 454-7205	Altitude Chamber R-1D	17	NRC (ITF)	National Research Council Montreal Road Ottawa, Ontario Canada K1A OR6	Dr. Myron Oleskiw Phone: (613) 993-5339 Fax: (613) 954-1235	Icing Tunnel Facility
8	BFG	BF Goodrich Deicing Systems 1555 Corporate Woods Parkway Uniontown, OH 44685-1277	Mr. Thomas Wilson Phone: (330) 374-3632 Fax: (330) 374-2290	Icing Tunnel	18	NRC (HIF)	National Research Council Montreal Road Ottawa, Ontario Canada K1A OR6	Dr. Myron Oleskiw Phone: (613) 993-5339 Fax: (613) 954-1235	Helicopter Icing Facility
9	Boeing (BRAIT)	Airplane System Lab The Boeing Commercial Airplane Group P.O. Box 3707, MS 1S-HL Seattle, WA 98124-220	Mr. Ferd Reichlin Phone: (206) 662-4272 Fax: (206) 662-0453	Boeing Research Aerodynamic Icing Tunnel	19	ONERA (SIMA)	Office National d'Etudes et de Recherches Aerospatiales Centre de Modane-Avrieux BP25 73500 MODANE - France	Mr. J. Prieur Phone: 33 1 46 73 40 90 Fax: 33 1 46 73 41 44	SIMA Wind Tunnel
10	CEPr (S1)	Centre d'Essai des Propulseurs CEPr Saclay 91895 ORSAY CEDEX, FRANCE	Ms. Sophie Le Berre Phone: (33) 1 69 85 09 40 Fax: (33) 1 69 85 01 02	Altitude Test Cell S1	20	Rolls-Royce (WT)	Rolls-Royce plc P.O. Box 31 Derby De2-8BJ England	Ms. Susan Riley Phone: 332-249375 Fax: N/A	Hucknall 15 Inch Icing Tunnel

TABLE 1 (Continued)

Facility No.	Facility Identification	Organization & Location	Contact	Facility Name	Facility No.	Facility Identification	Organization & Location	Contact	Facility Name
21	Rolls-Royce (WT & AC)	Rolls-Royce plc P.O. Box 31 Derby De2-8BJ England	Mr. Keith Wakefield Phone: 332-246708 Fax: N/A	Derby ATF					
22	Rosemount	Rosemount Aerospace Division 14300 Judicial Road, M.S. F-9 Burnsville, MN 55337	Mr. Richard Feely Phone: (612) 892-4381 Fax: (612) 892-4430	Icing Wind Tunnel					
23	T & EE Pyestock	Ministry of Defense (PE) Directorate General Test & Evaluation T & EE Pyestock Farnborough, Hants GU14 OLS England	Mr. A. R. Osborn Phone: 0252-544411 Ext. 4132 Fax: 0252-373513	Pyestock Altitude Test Facility					
24	Textron ***Inactive**	Textron Lycoming Corporation 550 S. Main Street Stratford, CT 06497	Mr. Dick Norris Phone: (203) 385-2667 Fax: (203) 385-2469	Small Engine/Inlet Icing Ground Test Facility					
25	Textron ***Inactive**	Textron Lycoming Corporation 550 S. Main Street Stratford, CT 06497	Mr. Dick Norris Phone: (203) 385-2667 Fax: (203) 385-2469	Turbofan Engine Icing Ground Test Facility					
26	UQAC IWT	University of Quebec at Chicoutimi 555, boul, de Universite, Chicoutimi Quebec, G7H 2B1	Jean-Louis Laforte Phone: (418) 545-5047 Fax: (418) 545-5012	Icing Wind Tunnel					
27	UQAC FRFD	University of Quebec at Chicoutimi 555, boul, de Universite, Chicoutimi Quebec, G7H 2B1	Jean-Louis Laforte Phone: (418) 545-5047 Fax: (418) 545-5012	Freezing Rain/ Drizzle Chamber					

TABLE 2 - Summary of Icing Simulation Test Facilities Capabilities

Facility Description				Uniform Icing Cloud		Facility Capabilities (minimum/maximum)							
Facility No. & (Identification)	Type of Facility	Test Chamber Dimensions m [ft]	* Primary Use	Dimension m [ft]	± % LWC	Air Speed, m/s [ft/s] (mph) {kt}	Air Flow Rate kg/s [lb/s]	Total Air Temperature C [F]	Altitude Pressure kPa [psia]	LWC, g/m3	Drop Size, MVD, µm	Humidity	Comment
1 ACT. Ltd Arlington	Wind Tunnel	W = 0.5 [1.5] H =0.5 [1.5] L = 5.5 (18)	NA	variable	variable	6.1/183 [20/600] (13/410) {11.6/356}	20.4 45	-27/15 [-17/59]	Atmospheric	.1/5	12/100	amb to 100%	
2 AERAZUR	Eiffel Wind Tunnel	W=0.5[1.6] H=0.3[0.9] L=0.8[2.6]	Icing R&D	0.25[0.8] by0.45[1.5]	20	20-90 [66-300] (46-196) {40-170}	4-17 [8.8-37.5]	-30/20 -22/67	Atmospheric	0.5/10	10/40	ambient measured	Refrigerated by freon cycle and liquied nitrogen
3 (AIT)	Altitude Chamber	D = 4 [13] L = 12.2 [40] Duct =0.51 [1.7]	3	.46 [1.5]	20	10/142 [34/465] (22/318) {19/276}	1/5.4 [2/12]	-65/90 [-85-/194]	11.7/98 [1.7/14.2]	.2/2.5+	15/40	Dry/25g-r/lb	
4 (AEDC) (T 1,2,4)	Engine Test Cell	D = 0.9 [3], 2.1- [7], 3.8 [-12.3] L = 5.2 [17] to 22.-9 [75]	NA	55- [1.8] to 1.7- [5.4] 80% Duct	20	30/275 [100/900] (67/615) {58/534}	6/330 [13/730]	-32/38 [-25-/100]	38/100 [5.5/14.2]	.2/3.9	15/35	Dry/2gr/lb	
5 (AEDC) (J-1,2)	Engine Test Cell	D = 4.9 [16], 6.1 -[20] L = 22 [-72], 21 [69]	NA	55- [1.8] to 1.7- [5.4] 80% Duct	20	30/275 [100/900] (67/615) {58/534}	23/590 [50/1300]	-35/38 [-30-/100]	38/100 [5.5/14.2]	.2/3.9	15/35	Dry/2gr/lb	
6 (AEDC) (C-2)	Engine Test Cell	D = 8.5[28] L = 26 [85]	NA	9 [3] to2.8 [9.0] 80% Duct	20	30/275 [100/900] (67/615) {58/534}	35/745 [80/1650]	-32/38 [-25-/100]	38/97 [5.5/14.2]	.2/3.9	15/35	Dry/2gr/lb	
7 (AEDC) (R-1D)	Altitude Chamber	D = 0.9 [3] L = 2.7 [9]	NA	0.25 [.8] by.4 [1.2] 80% Duct	20	30/275 [100/900] (67/615) {58/534}	4/154 [2/70]	-29/38 [-20/100]	.56/97 [4/14.2]	.2/3.9	15/40	Dry/2gr/lb	
8 (BFG)	Wind Tunnel	H = 1.1 [3.7] W = 0.56 - [1.8] L = 1.5 [5]	1,2,4,5, 7,8c	1 x .5 [3.3 x 1.7]	20	14/85 [45/280] (32/190) {28/165}	11/39 [25/85]	-30/ambient -22/ambient	Atmospheric	.4/3.04	10/50	Dry/100%	
9 (Boeing) (BRAIT)	Wind Tunnel	H = 2.4 [8] W = 1.5 [5] or H = 1.8 [6] W = 1.2 [4] L = 6.1 [20	1,2,4 6b, 7,8b	1.5/.9 [5/3]	10	4.6/128 [15/422] (10/288) {9/250}	15.9/453.6 [35/1000]	-40/38 [-40/100]	85/100 [12.5/14.7]	.25/3.0	15/40	95%	Refrigerated for All Year Operations

* Primary Use (Key)

1 - 2D Wing
2 - 3D Wing
3 - Engine With Inlet
4 - Aspirated Inlets
5 - Non Aspirated Inlets (Free Flow)
6 - Complete Aircraft
  a. Full-scale
  b. Sub-scale
7 - Instruments
8 - Powered Rotorcraft
  a. Full-scale
  b. Sub-scale
  c. Blades

TABLE 2 (Continued)

Facility Description				Uniform Icing Cloud		Facility Capabilities (minimum/maximum)							
Facility No. & (Identification)	Type of Facility	Test Chamber Dimensions m [ft]	* Primary Use	Dimension m [ft]	± % LWC	Air Speed, m/s [ft/s] (mph) {kt}	Air Flow Rate kg/s [lb/s]	Total Air Temperature C [F]	Altitude Pressure kPa [psia]	LWC, g/m3	Drop Size, MVD, µm	Humidity	Comment
10 (CEPr) (S1)	Engine Test Cell	D = 3.5 [11.5] L = 4.9 [16.1]	3,4,5,7,8c	0.7 [1.3] by 1.3 [4.3]	NA	7/270 [23/886] (16/604) {14/524}	15/130 [33/287]	-50/50 [-40/122]	30/115 [4.4/16.7]	.15/10	15/50	Dry/100%	
11 (CEPr) (R6)	Engine Test Cell	D= 5 [16.4] L= 10 [33]	1,3,4,5,8c	0.7 [1.3] by 1.8 [5.9]	NA	10/270 [33/886] (22/604) {19/524}	30/300 [66/661]	-50/50 [-40/122]	30/115 [4.4/16.7]	.05/10	15/50	Dry/100%	
12 (CEPr) (PAG)	Wind Tunnel	H= 0.2 [0.66] W=0.2 [0.66] or 0.5 [1.64] L=1 [3.28]	1,7	0.2x0.2 [0.66x0.66] or 0.2x0.5 [0.66x1.54]	NA	30/187 [98/614] (67/418) {58/364}	2/12.5 [4.4/27.6]	-40/8 [-40/46.4]	80/100 [11.4/14.2]	0.1/10	15/50	Ambient	
13 (FluiDyne)	Wind Tunnel	H = 0.6 [1.83] W = 0.6 [-1.83] L = 1.5 [5]	NA	.46 x .46 [1.5x1.5]	15	30.5/274 [100/900] (68/613) {59/532}	13.4/76.2 [30/168]	-31.7/30 [-25/86]	98.6/98.6 [14.3/14.4]	.1/5+	10/35	.000-1/ .83-gr/lb	
14 (G.E.)	Outdoor Engine	H = 9.8 [32] W = 11.3 [37]	3,5,7	9.8 [32] Dia.	5	0/30 [0/100] (0.68) {0/59}	3853 NA/1362 8500	-18 to ambient [0 to 32/ambient]	1100 ft.	.3/3.6	14/40	30 to 90%/ ambient	
15 (NASA LeRC)	Wind Tunnel	H = 1.8 [6] W = 2.7 [9] L = 6.1 [20]	1, 2, 4, 5, 6b, 7, 8b	.9/1.2 [3/4]	20	22/134 [73/440] (50/300) {43/260}	NA/NA	40/4 [-40/40]	90/101 [13/14.7]	.2/5	10/40	95%	Refrigerated for All-Year Operation
16 (NRC) (#4)	Engine Test Cell	D = 7.6 [25] L = 10 [33]	NA	NA	NA	5/125 [17/415] (11/280) {10/243}	NA/136 [NA/300]	-30/30 [-22/86]	Atmospheric	.1/2	15/40	ambient	
17 (NRC) (ITF)	Wind Tunnel	H = 0.57 [1.89] W = 0.57 [1.89] L = 1.83 [6]	NA	.46 [1.5]	25	5/90 [16/295] (11/201) {10/174}	2/35.9 [4.4/70]	-30/30 [-22/86]	42/101 [6.1/14.7]	.1/1.7	10/35	100%	
18 (NRC) (HIF)	Outdoor Facility	H = 5 [16.4] W = 23 [75.4]	NA	4.5 x 22.9 [15 x 50]	NA	2.2/13.4 [7.3/44] (5/30) {4/26}	NA	-17/0+ [3/32+]	Atmospheric	.1/1.0	30/60	100%	
19 (ONERA)	Wind Tunnel	D = 8 [20.2] L = 14 [46]	1,2,4,5,6, 7,8b	2x2 [6.6 x 6.6] or 4 x 1 [13.1 x 3.2]	NA	10/100 [32.8/328] (22.4/224) {19.4/194}	550/5500 [1212/12125]	-15/0 [5/32]	88/83 '[12.7/12]	.4/10	10/300	Atmospheric Condition/ Saturation	

* Primary Use (Key)

1 - 2D Wing
2 - 3D Wing
3 - Engine With Inlet
4 - Aspirated Inlets
5 - Non Aspirated Inlets (Free Flow)
6 - Complete Aircraft
 a. Full-scale
 b. Sub-scale
7 - Instruments
8 - Powered Rotorcraft
 a. Full-scale
 b. Sub-scale

TABLE 2 (Continued)

Facility Description						Facility Capabilities (minimum/maximum)							
				Uniform Icing Cloud									
Facility No. & (Identification)	Type of Facility	Test Chamber Dimensions m [ft]	* Primary Use	Dimension m [ft]	± % LWC	Air Speed, m/s [ft/s] (mph) {kt}	Air Flow Rate kg/s [lb/s]	Total Air Temperature C [F]	Altitude Pressure kPa [psia]	LWC, g/m3	Drop Size, MVD, µm	Humidity	Comment
20 (Rolls-Royce) (WT)	Wind Tunnel	D = 0.46 [1.5]	NA	Fills Tunnel	Fills Tunnel	0/152 [0/500] (0/340) {0/295}	NA/13.6 [NA/30]	-34/12.2 [-30/10]	Atmospheric	.1/5	10/50	NA	
21 (Rolls-Royce) (WT & AC)	Wind Tunnel & Altitude Chamber	D = 4 [12]	NA	Fills Tunnel	Fills Tunnel	NA	NA/180 [NA/400]	-22/284 [-30/140]	NA	NA	10/50	NA	
22 (Rosemount)	Wind Tunnel	H = 0.25 [.8] D = 0.25 [.8] L = 0.61 [2]	7	.015 [.5 x .5]	25	15.4/92.6 [50.6/303] (34/207) {30/180}	NA	-30/30 [-22/86]	Atmospheric	.1/3	15/40	NA	
23 (T & EE) (Pyestock)	Engine Test Cell	D1 = 7.6 [25] L1 = 12.2 [40] D2 = 6.1 [20] L2 = 17.1 [56]	3,4,5,8a	.9 [3] by 2.6 [8.7]	5	15/180 [50/600] (34/403) {30/350}	15/364 [50/800]	-37/20 [-35/60]	14/93 [2/13.5]	.3/2.5	15/40	100%	
24 (Textron) (Small)	Component/ Engine Test Cell	D = 0.9 [2.75]	3,4,5	(Same as Chamber) D = .9 [2.75]	Poor Nonuniform Icing Cloud in Plenum is Attenuated in Engine Inlet	3/200 [10/600] (7/447) {6/388}	1/3.3 [3/10]	-40/90 [-40/190]	87/108 [12.6/15.7]	.5/3+	15/40	90%	*Facility inactive
25 (Textron) (Turbofan)	Engine Test Cell	D = 1.25 [4]	3	(Same as Chamber) D = 1.25 [4]	Poor Nonuniform Icing Cloud in Plenum is Attenuated in Engine Inlet	3/200 [10/600] (7/447) {6/388}	5/110 [10/250]	-50/90 [-58/194]	100/100 [14.7/14.7]	.2/3+	15/40	90%	*Facility inactive
26 UQAC (IWT)	Wind Tunnel	W = 0.5 [1.5] H =0.6 [2] L = 1.6 [5.2]	NA	.4 [1.3] by .4 [1.3]	10	1/60 [3.3/197] (2.2/132) {1.9/116}	.3/22 [.66/48]	-40/30 [-40/86]	98/100 [14.4/14.7]	.05/3.0	10/500	20%/98%	
27 UQAC (FRFD)	Freezing Rain /Drizzle Chamber	W=1.8 [6] H=8 [26.2] 1.8 [6]	NA	0.9[2.95] by 0.9[2.95]	20	0.2/2 [.66/6.6] (0.14/4.5) {0.12/3.9}	0.8/8 1.76/17.6	-30/30 [-22/86]	100	.5mm/hr to 10mm/hr	200/2000	30%to90%	Very low speed vertical tunnel

* Primary Use (Key)

1 - 2D Wing
2 - 3D Wing
3 - Engine With Inlet
4 - Aspirated Inlets
5 - Non Aspirated Inlets (Free Flow)
6 - Complete Aircraft
 a. Full-scale
 b. Sub-scale
7 - Instruments
8 - Powered Rotorcraft
 a. Full-scale
 b. Sub-scale

TABLE 3 - Summary of Icing Simulation Test Facilities
Facility Instrumentation

Facility No. & (Identification)	Facility Measurements			Spray Measurements						
	Velocity	Temperature	Pressure	WaterFlow	Water Pressure	Water Temperature	AirFlow	Air Pressure	Air Temperature	Comment
1 (ACT,Ltd.) (Arlington)	Pitot Static Probe	T/C	Barometer	Rotameters	Gauges	Temperature probes	NA	Gauges	Temperature probes	
2 (AERAZUR)	Calculated from Ps, Pt, Tt or Pitot	T/C upstream of spraybars	Transducer	Turbine & calibrated tank	Transducer at each Spraybar	Transducer in storage tank	NA	Transducer in manifold	T/C in manifold	
3 (AIT)	Calculated from Ps, Tt, Wa, A or Pitot/Static Rake	T/C Upstream Sprays	Transducer & Manometer	Float in Tube & Turbine Total & Calibrated Tank	Gage on Tank	T/C in Sprayer Stem	Air Metering Nozzle	Transducer in Nozzle Stem	T/C in Water Spray Stem	
4 (AEDC) (T1,2,4)	Calculated from Ps,Tt,Wa	T/C Rake in Plenum	Transducer in Plenum	Turbine Flow Meter	Transducer in Manifold	Measures in Storage Tank		Transducer in Manifold	T/C on NozzleMount	
5 (AEDC) (J1,2)	Calculated from Ps,Tt,Wa	T/C Rake in Plenum	Transducer in Plenum	Turbine Flow Meter	Transducer in Manifold	Measures in Storage Tank		Transducer in Manifold	T/C on Nozzle Mount	
6 (AEDC) (C-2)	NOT AVAILABLE									
7 (AEDC) (R-1D)	NOT AVAILABLE									
8 (BFG)	Calculated from Pt,Ps,Ts	T/C & RTD in Settling Chamber	Transducer	Thermal Flow Meter	Transducer in Spray Bars	T/C in Nozzle Ports		Transducer in Spray Bar	T/C in Nozzle Ports	
9 (Boeing) (BRAIT)	Ps,Pt (aspirating heated probes)	RTD Rake Upstream of Spraybar	Total at Contraction Entrance. Static at Test Section Entrance	Turbine Flow-meter at each Spraybar	Transducer at each Spraybar	T/C at each Spraybar	NA	Transducer at each Spraybar	T/C at each Spraybar	

TABLE 3 (Continued)

Facility No. & (Identification)	Facility Measurements			Spray Measurements						
	Velocity	Temperature	Pressure	WaterFlow	Water Pressure	Water Temperature	AirFlow	Air Pressure	Air Temperature	Comment
10 (CEPr) (S1)	Calculated from Ps, Pt, Tt, Wa or Anemometer	Probes in Plenum	Rake in Bellmouth	Turbine Flow Meter	Transducer	T/C in Grid	Not Measured	Transducer	T/C in Spray Grid	
11 (CEPr) (R6)	Calculated from Ps, Pt, Tt, Wa or Anemometer	Probes in Plenum	Rake in Bellmouth	Digital Valve	Transducer	T/C in Grid	Not Measured	Transducer	T/C in Spray Grid	
12 (CEPr) (PAG)	Calculated from Ps, Pt, and Tt	T/C	Transducer	Coriolis Mass Flowmeter	Transducer	T/C	Not Measured	Transducer	T/C	
13 (FluiDyne)	Pitot/Static Survey	T/C Type J	NA	Float in Tube in Line	Transducer	T/C		Transducer	T/C	
14 (G.E.)	Pitot/Static Hot Wire	T/C	Ps, Pt	Turbine Meters/ Mass Meters	Transducer	T/C	Venturi	Transducer	T/C	
15 (NASA LeRC)	Pitot/Static at Test Section Entrance	T/C Rake Upstream Spray Type T	Transducer, Pitot	Coriolis Mass Flowmeter	Transducer in each Spray Bar	T/C in each Spray Bar	Not Measured	Transducer in each Spray Bar	T/C in each Spray Bar	
16 (NRC) (#4)	Calculated from Ps,Tt, Patm	T/C	Barometer, Transducers	Float in Tube	Gage	T/C in Line		Gage	T/C in Line	
17 (NRC) (ITF)	Calculated from Ps,Tt,Pt	T/C in Settling Chamber	Transducers Test Section Static Settling Chamber Total	Float in Tube	Float in Tube	NA	T/C in Line	Gage	T/C in Line	
18 (NRC) (HIF)	Cup Anemometer	Ventilation RTD	Barometer	Float in Tube	NA	NA		Gage	T/C in Line	

TABLE 3 (Continued)

Facility No. & (Identification)	Facility Measurements			Spray Measurements						
	Velocity	Temperature	Pressure	WaterFlow	Water Pressure	Water Temperature	AirFlow	Air Pressure	Air Temperature	Comment
19 (ONERA)	Calculated from Ps, Pt, Tt	T/C in Stilling Chamber	Transducer Pitot in stilling chamber Static test section	Turbine Flow Meter	NA	T/C in Arm Spray Grid	Not Measured	Transducer in Arm Spray Grid	T/C in Arm Spray Grid	
20 (Rolls-Royce) (WT)	Gage, Manometers	RTD	NA	Flow Meters	Gage	NA		Gage	Resistance T/C	
21 (Rolls-Royce) (WT & AC)	NA	NA	NA	NA	NA	NA	NA	NA	---	
22 (Rosemount)	Ps, Pt Pitot	T/C	NA	Float in Tube	Transducer	T/C	Transducer	Transducer	T/C	
23 (T & EE) (Pyestock)	Calculated from Ps, Tt, Wa	PRB in Duct	Transducer Total Pressure Probes	Turbine Flow Meter	Transducer in Spray Rake	T/C in Spray Rake	Transducer in Spray Rake	T/C in Spray Rake		
24 (Textron) *Inactive	Calculated from Wa, Ps, Tt, A	T/C in Inlet	Transducer in Plenum	Turbine Flow Meter	Gages in Spray Bar Inlet	T/C in Spray Bar Inlet	Is not Measured but is known from Calibration vs ASME Orifice	Gage in Spray Bar Inlet	T/C in Spray Bar Inlet	Spray Bar inserted at Test Start & Retracted at Test End
25 (Textron) *Inactive	Calculated from Wa, Ps, Tt, A	T/C in Inlet	Transducer in Plenum	Turbine Flow Meter	Gages in Spray Bar Inlet	T/C in Spray Bar Inlet	Is not Measured but is known from Calibration vs ASME Orifice	Gage in Spray Bar Inlet	T/C in Spray Bar Inlet	
26 (UQAC) (IWT)	NA	T/C, RTD, and Thermistors	Static Pressure Gage	Rotamer w/Peristaltic pump	Bourdon Gage	T/C	NA	Bourdon Gage	T/C	
27 (UQAC) (FRFD)	Pitot tube and hot wire probe (w/o droplets)	T/C, RTD and Thermistors	Not Measured	Water Volume Differential	Bourdon Gage	T/C	NA	Bourdon Gage	T/C and RTD	

TABLE 4 - Summary of Icing Simulation Test Facilities
Cloud Calibration

		LWC					Droplet				
		Measurement		Uniformity			Measurement		Uniformity		
Facility No. & (Identification)	Water Treatment (Conductance, µS/cm)	Instrument	Procedure	Instrument	Procedure	LWC Instrument Calibration (Frequency)	Instrument	Procedure	Instrument	Procedure	Droplet Instrument Calibration (Frequency)
1 (ACT, Ltd) (Arlington)	Demineralized	Icing Blades and rods	Micrometer/ stopwatch	Icing Blades and rods	Mirometer and stopwatch	6 months	Malvern/oiled slide	Microscope camera and projector	Malvern/oiled slide	Microscope camera and projector	6 months
2 (AERAZUR)	Filtered and Demineralized	Rotating cylinder/ calculated	Calculation	Rotating Cylinder	Ice Accretion measurement at multiple locations	Annual or after a mod	Oiled slide/ laser (off-line)	Off-line calibration	Oiled slide	Multiple point measurement (off-line)	As required
3 (AIT)	Deionized	NA	Calculation	Grid	Ice Accretion Thickness Measurement	NA (Prior to each Test Series)	Malvern 2600C	Line of Sight (Off-Line)	Malvern 2600C	Vertical Scan	Reticle (Prior to each Test Series)
4 (AEDC) (T-1,2,4)	Demineralized	NA	Calculation Includes Evaporation	Grid	Ice Accretion Thickness Measurement	NA	Fiber Optic Sizer	Single Point (Off-Line)	Holography	NA	Wire Gauges (Daily)
5 (AEDC) (J-1,2)	Demineralized	NA	Calculation Includes Evaporation	Grid	Ice Accretion Thickness Measurement	NA	Fiber Optic Sizer	Single Point (Off-Line)	Holography	NA	Wire Gauges (Daily)
6 (AEDC) (C-2)	NOT AVAILABLE										
7 (AEDC) (R-1D)	NOT AVAILABLE										
8 (BFG)	Filtered & Deionized	Icing Blade/ Hot-Wire Water Flow	Single Point Measurement (Off-Line) Calculation	Grid	Ice Accretion Thickness Measurement	Compare LWC Measurement to Water Flow (Bi-Annual)	Phased Doppler Particle Analyzer	Single Point (Off-Line)	NA	NA	Monodispense Droplet Generator (Bi-Annual)
9 (Boeing) (BRAIT)	Demineralized	Icing Blade (Off Line)	Single Point (Off Line)	7 Horizontal Bars	Ice Accretion (Off Line)	NA	Phased Doppler Particle Analysis System	Real Time Measurement	PDPA	3 Axis Transverse	Vibrating Orifice Aerosol Generator (Twice Yearly)

TABLE 4 (Continued)

		LWC					Droplet				
		Measurement		Uniformity			Measurement		Uniformity		
Facility No. & (Identification)	Water Treatment (Conductance, µS/cm)	Instrument	Procedure	Instrument	Procedure	LWC Instrument Calibration (Frequency)	Instrument	Procedure	Instrument	Procedure	Droplet Instrument Calibration (Frequency)
10 (CEPr) (S1)	Demineralized	NA	Calculation Wa,Ww Air Saturated	Grid	Visual Check	NA	FSSP/OAP Malvern	Single Point (Off-Line)	FSSP/OAP	Vertical/Horizontal Scan	Glass Beads
11 (CEPr) (R6)	Demineralized	NA	Calculation Wa,Ww Air Saturated	Grid	Ice Accretion Thickness	NA	FSSP/OAP Malvern	Single Point (Off-Line)	FSSP/OAP	Vertical/horizontal scan	Glass Beads
12 (CEPr) (PAG)	Demineralized	NA	Calculation Wa, Ww	Grid	Ice Accretion on cylinder	NA					
13 (FluiDyne)	Deionized	Blade/Rotating Cylinder	Single Point Each Test (Blade)1/yr (Cylinder)	Grid	Measure Ice Accretion on Grid	Water Flow Calculation	Oil-Slide	Single Point (Off-Line)	NA	NA	Comparison to Rotating Cylinders (Annual)
14 (G.E.)	Demineralized	Rotating Cylinder/ FSSP/OAP	Calculate LWC From FSSP/OAP & Rotating Cylinder	Grid (Chain Link Fence)	Visual Inspection of Iced Grid	FSSP/OAP Compared to Rotating Cylinder	Oil-Slide/ Rotating Multi-Cylinder/ FSSP/OAP	Off-Line Measurements Establish Calibration Curves On-Line Possible	FSSP/OAP	Multiple Point Measurements	Prior to Use (FSSP/OAP)
15 (NASA LeRC)	Filtered & Deionized (.06 to .5)	Blade/ Hot-Wire	Single Point Measurement Off-Line(2/yr)	9 Vertical Cylinders	Ice Accretion Measurement (Off-Line)	NA	FSSP-/OAP	Single Point (Off-Line)	FSSP/OAP	Horizontal/ Vertical Traverse	Rotating Pinhole Rotating Reticle (Daily When Used)
16 NRC (#4)	Demineralized	NA	Calculation Includes Evaporation	Grid	Ice Accretion Thickness Measurement	NA	Oil Slide	Single Point (Off-Line)	NA	NA	NA
17 (NRC) (ITF)	Distilled	Rotating Cylinder/ Hot-Wire	Single Point (Off Line)	Grid (Hot-Wire)	Ice Accretion Thickness Measurement	NA Hot-Wire Compared to Cylinder	Oil Slide(FSSP)	Single Point (Off-Line)	Oil Slide (FSSP)	Multiple Points	(FSSP) Glassbeads
18 (NRC) (HIF)	Softened	Rotating Cylinder/ Hot Wire	Calculate LWC from Weight of Ice, Exposure Time(Off-Line)	Rotating Cylind-er/ Hot-Wire	Multiple Point Measurements (Off-Line)	Hot-Wire Compared to Rotating Cylinder	Oiled-slides FSSP (Planned)	Analyze Photomi-crograph (Off-Line)	Oiled-Slide FSSP (Planned)	Multiple Point Measurements (Off-Line)	NA

TABLE 4 (Continued)

		LWC					Droplet				
		Measurement		Uniformity			Measurement		Uniformity		
Facility No. & (Identification)	Water Treatment (Conductance, µS/cm)	Instrument	Procedure	Instrument	Procedure	LWC Instrument Calibration (Frequency)	Instrument	Procedure	Instrument	Procedure	Droplet Instrument Calibration (Frequency)
19 (ONERA)	None	NA	Calculation from Water Flow	Laser Slat	Visual Inspection of laser slat	NA	ASSP/ OAP (Off-Line) PDPA	Off-Line Measurement Establish Calibration Curves On line measurements	Icing of Cylinders PDPA	Examination of catch angle on iced cylinders Multiple point measurement	Daily when used
20 (Rolls-Royce) (WT)	Distilled	NA	Calculation from Water Flow	NA	NA	NA	Oiled Slide/ Malvern (Off-Line)	NA	Oiled Slide/ Malvern (Off-Line)	NA	NA
21 (Rolls-Royce) (WT & AC)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
22 (Rosemount)	Deionized	1/4 Inch Rotating Cylinder	Measure Mass of Ice Accretion, Exposure Time (Off-Line)	Icing Blade 10 Inch Long, 0.005 Inch Wide	Measure Iced Thickness Along Length of Blade (Off-Line)	NA	Oiled-Slide	Use Image Analyzer to Measure Captured Droplets (Off-Line)	Oiled-Slide	Multiple Point Measurements (Off-Line)	Reticle Image Stored in Analyzer
23 (T & EE) (Pyestock)	Demineralized	NA	Calculated from Water Flow & Air Flow	Grid	Visual Check	NA	Malvern	NA	Malvern	Nozzle Measured Before Installation In Facility (Off-Line)	Reticle (6 Month)
24 (Textron) *Inactive	Distilled (Not Measured)	NA	Calculated from Water Flow & Air Flow	Grid	Visual Inspection of Iced Grid Thickness	NA	Oiled-Slide	Image Analysis (Off-Line) with Statistic Analysis Procedure	NA	NA	Prior to Each New Series of Tests. Sometimes During Critical Test
25 (Textron) *Inactive	Demineralized (Not Measured)	NA	Calculated from Water Flow & Air Flow	Grid	Visual Inspection of Iced Grid Thickness	NA	Oiled-Slide	Image Analysis (Off-Line) with Statistic Analysis Procedure	NA	NA	Prior to Each New Series of Tests. Sometimes During Critical Test
26 (UQAC) (IWT)	Filtered and Demineralized	Rotating cylinder	Measurement mass and thick ness of ice	Meshed Grid-horizontal and vertical cylinders	Measure thickness of ice	Before each run and as required	Oiled glass slide/ OAP	Expose slide then photograph	Oiled slide	Expose slide then photograph	Before each run and as required
27 (UQAC) (FRFD)	Filtered and Demineralized	Balance	Measure mass of collected ice	Balance	Measure mass of collected ice	Before each run and as required	Oiled glass slide/ OAP	Expose slide then photograph	Oiled slide	Expose slide then photograph	Before each run and as required

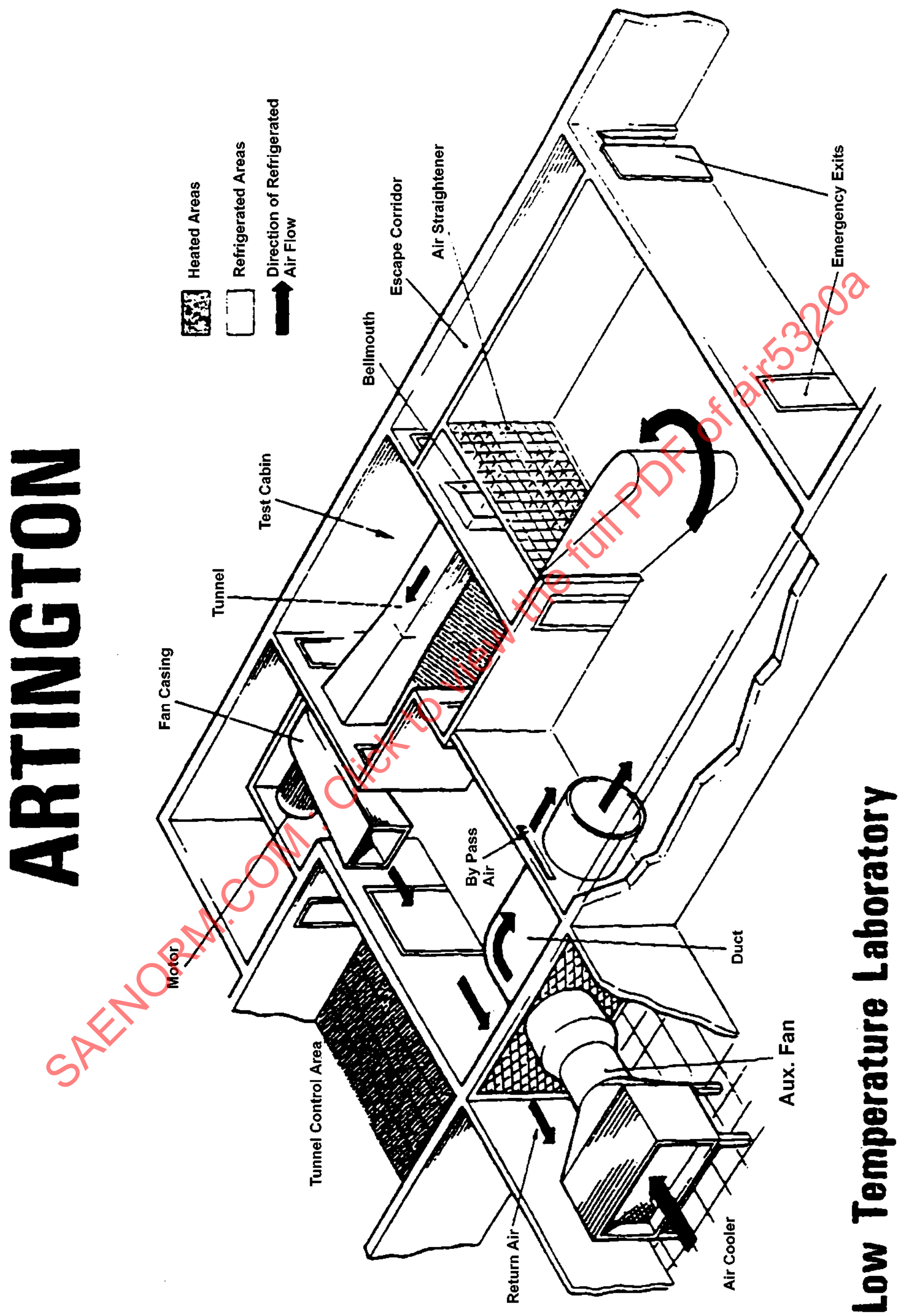


FIGURE 1 - Artington Icing Wind Tunnel

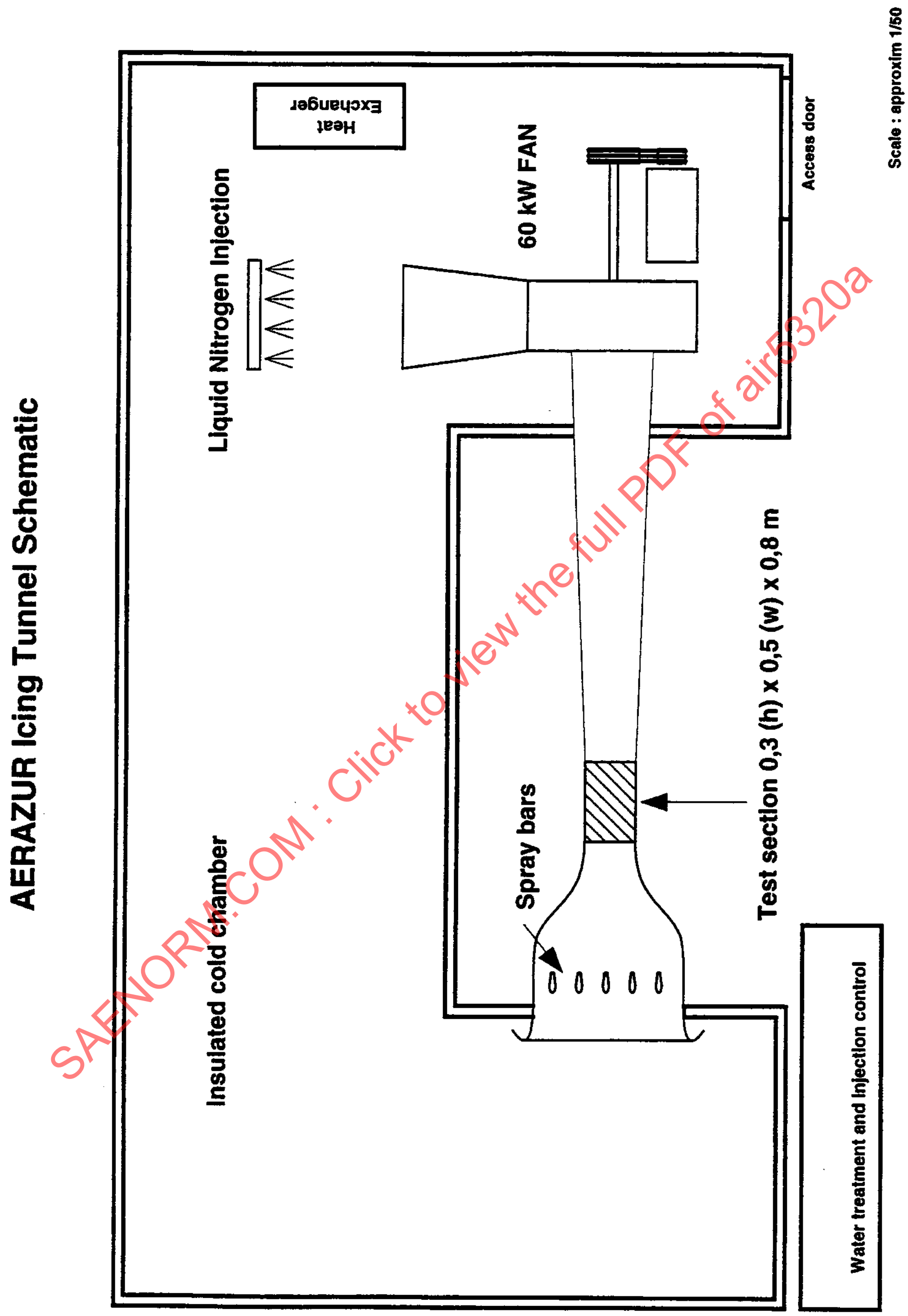


FIGURE 2 - AERAZUR Tunnel de Givrage

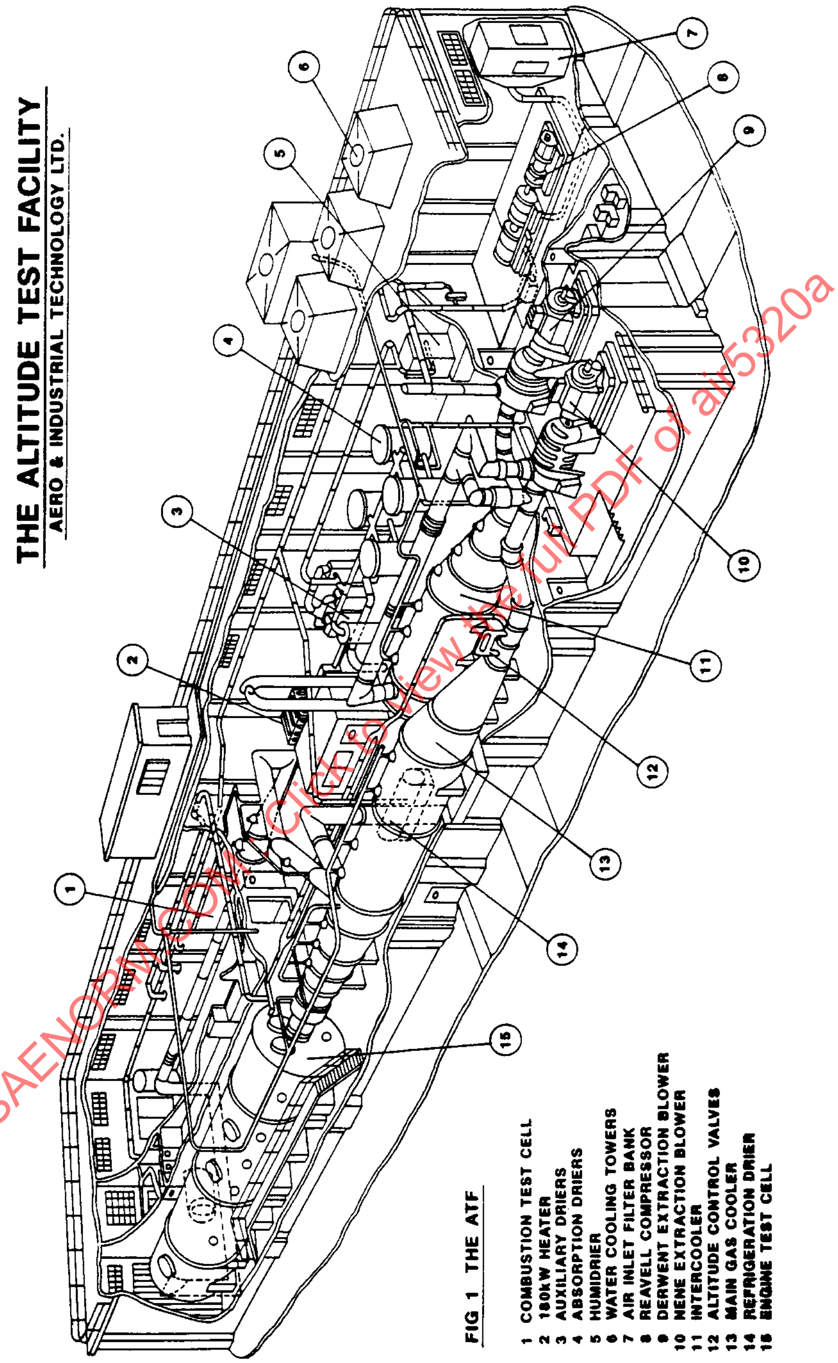
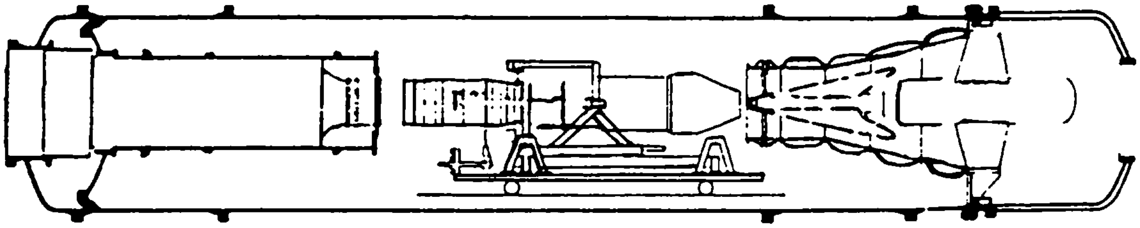
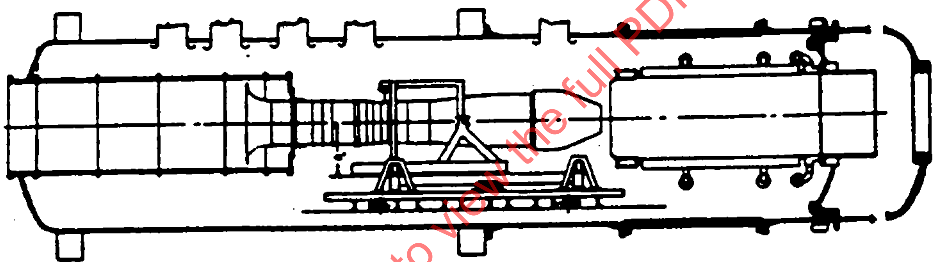


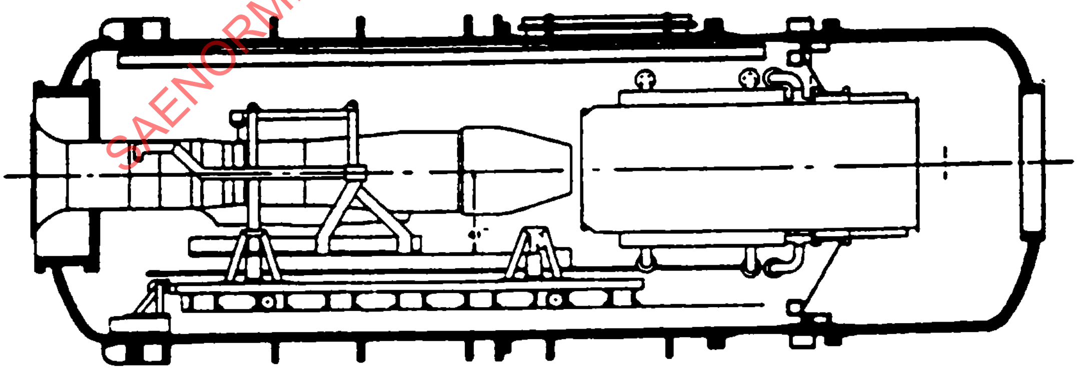
FIGURE 3 - AIT Altitude Test Facility



T-1 TEST CELL
ELEVATION VIEW

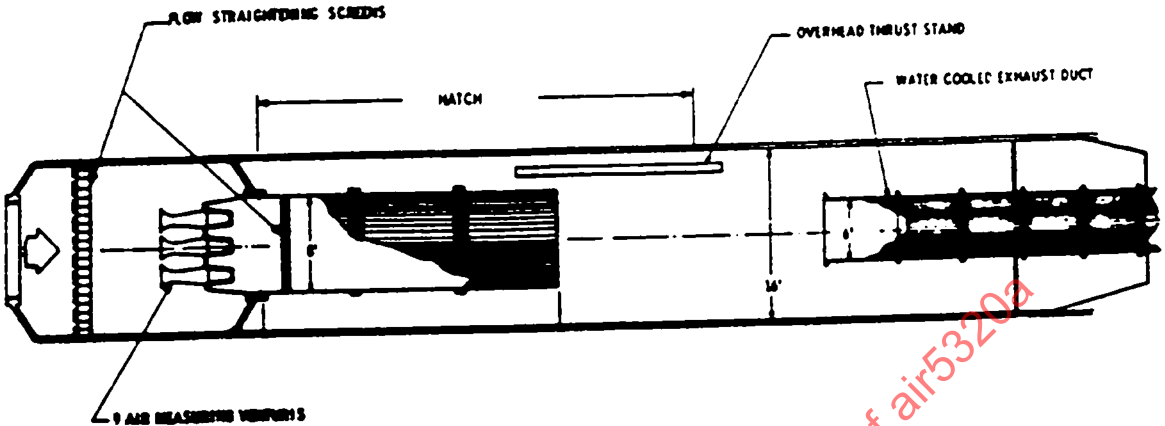


T-2 TEST CELL
ELEVATION VIEW

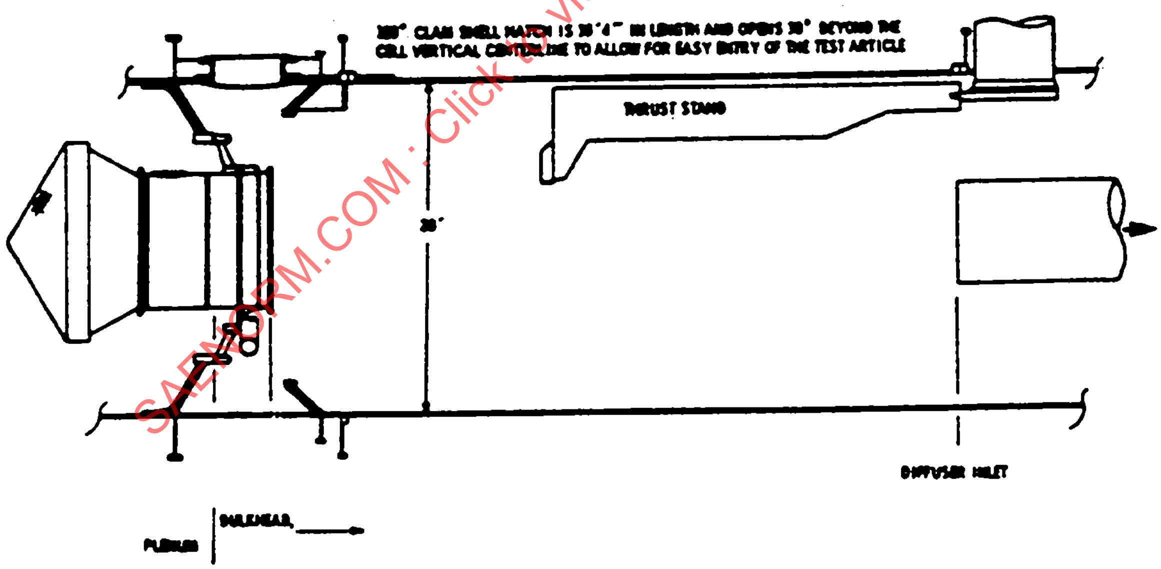


T-4 TEST CELL
ELEVATION VIEW

FIGURE 4 - AEDC Engine Test Facilities
T-1, T-2, T-4



J1 TEST CELL
ELEVATION VIEW



J2 TEST CELL
ELEVATION VIEW

FIGURE 5 - AEDC Engine Test Facilities
J-1, J-2

NOT AVAILABLE

FIGURES 6 & 7 - AEDC Engine Test Cell
& Icing Tunnel

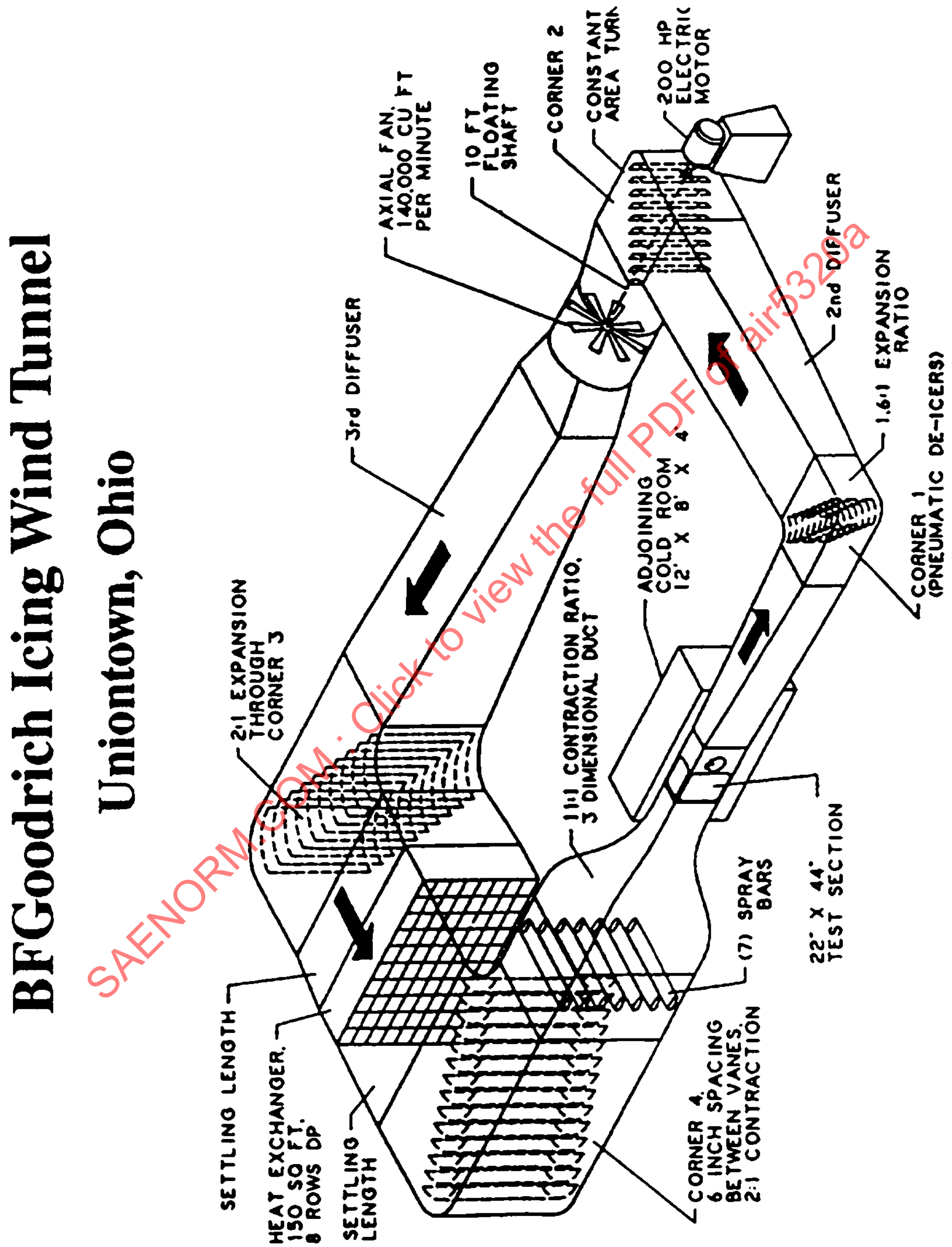


FIGURE 8 - BFG Icing Tunnel

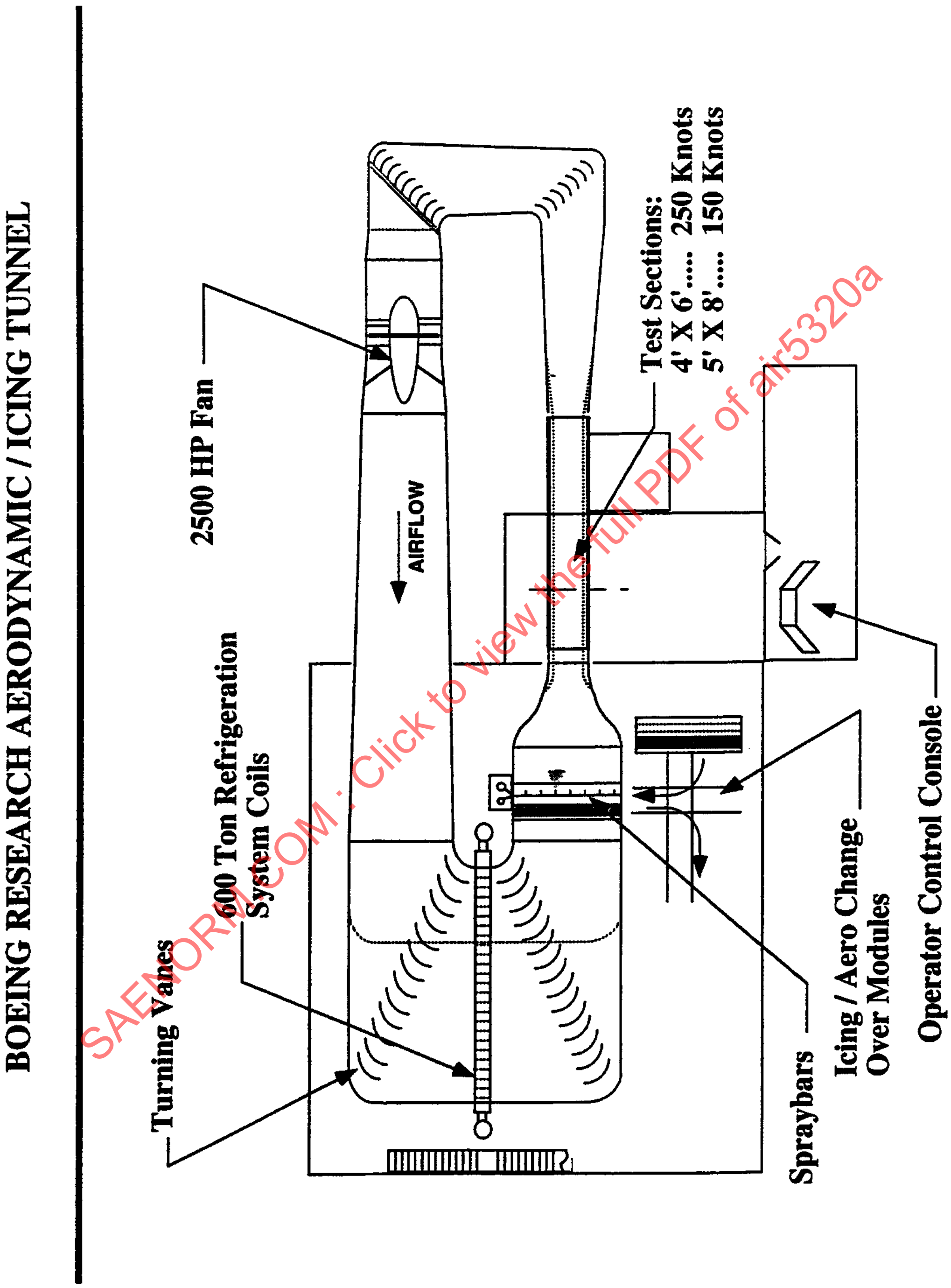
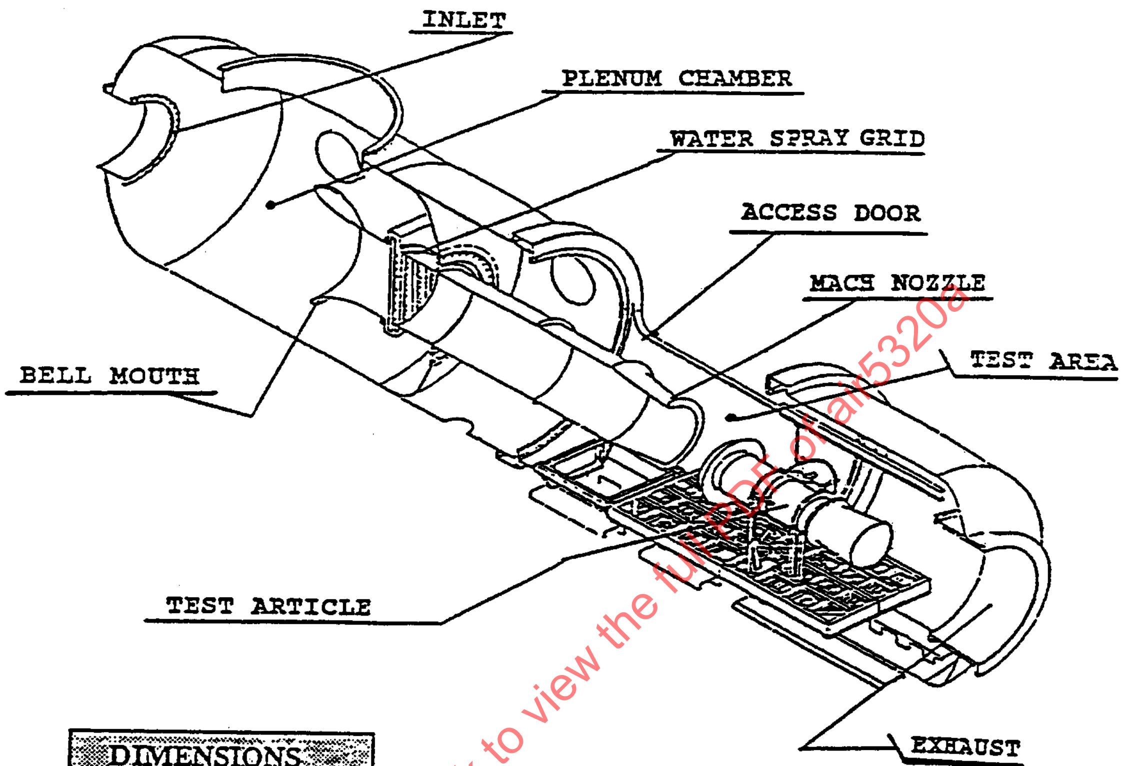


FIGURE 9 - Boeing Research Aerodynamic Icing Tunnel



DIMENSIONS

Internal diameter : 3.7 m

Total length : 16 m

-Plenum chamber length : 5.9 m

-Test area length : 4.9 m

Access doors

-Plenum chamber : circular diameter = 2.5 m

-Test area : frontal,length= 4.2 m, delta alpha=140°

Manifolds diameters

-Inlet : 1.3 m

-Exhaust : 2 m

FIGURE 10 - CEPr Altitude Test Cell S1

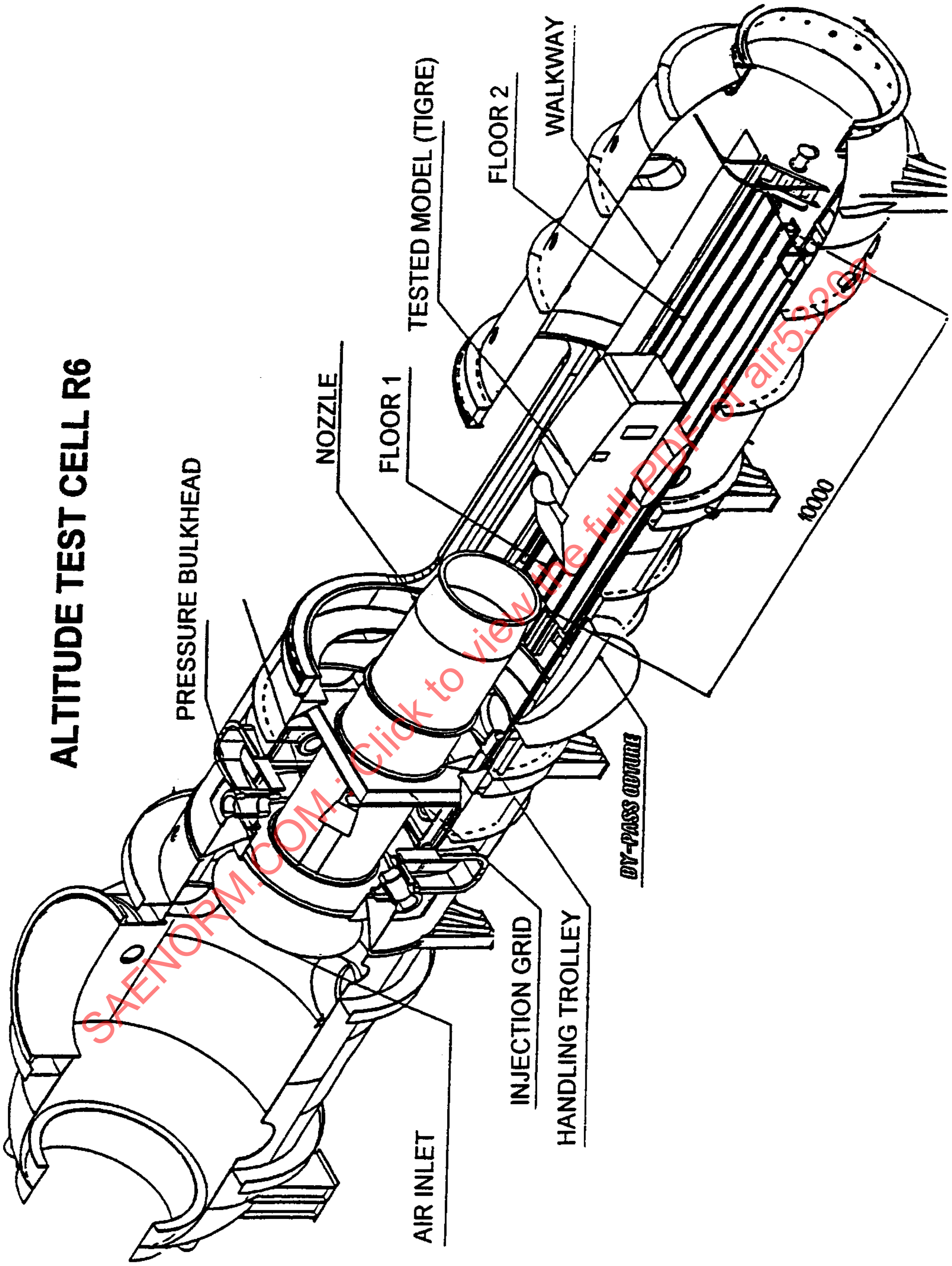


FIGURE 11 - CEPr Altitude Test Cell R6

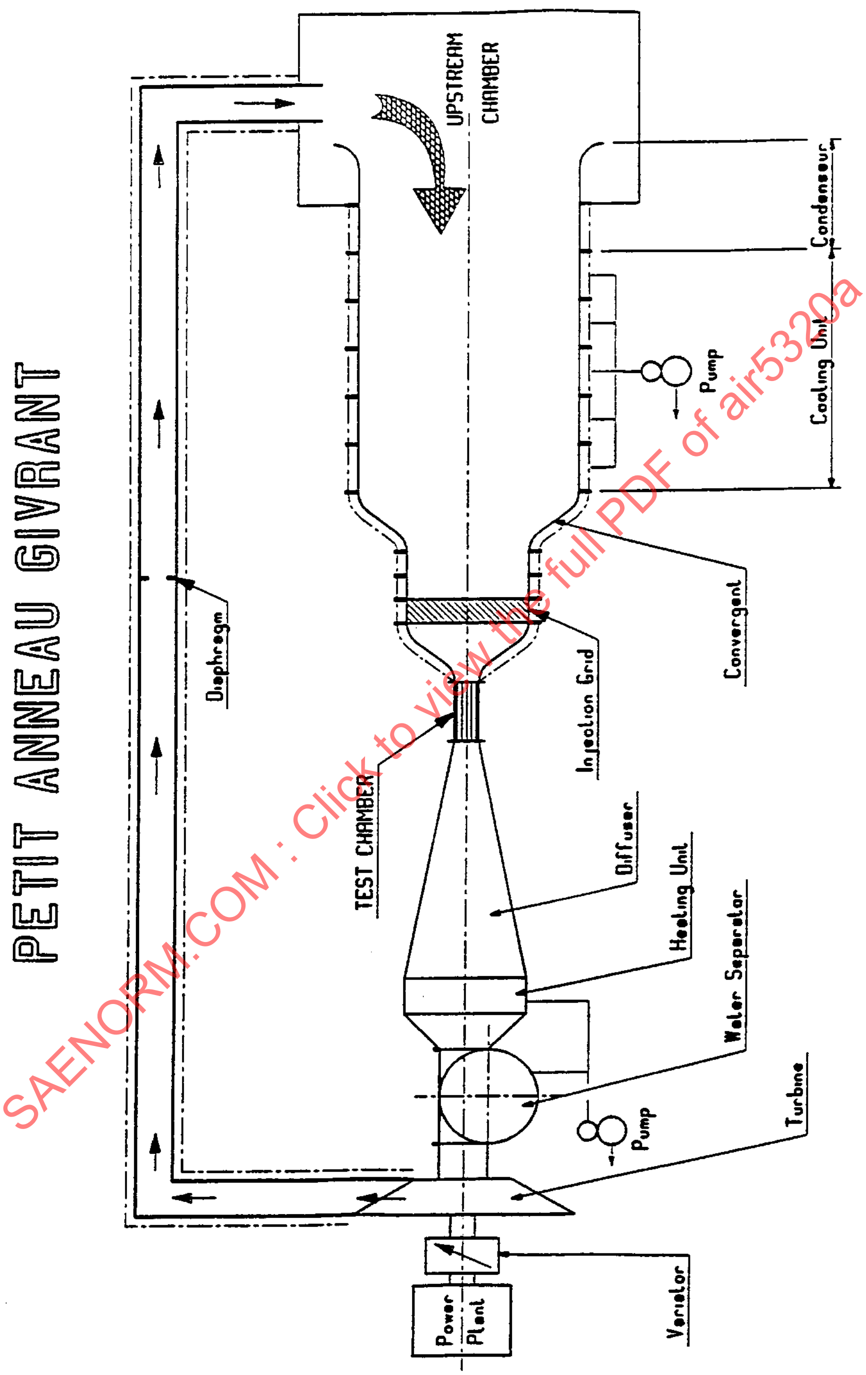


FIGURE 12 - CEPr Petit Anneau Givrant

NOT AVAILABLE

FIGURE 13 - Fluidyne Icing Wind Tunnel

NOT AVAILABLE

FIGURE 14 - General Electric Site 4

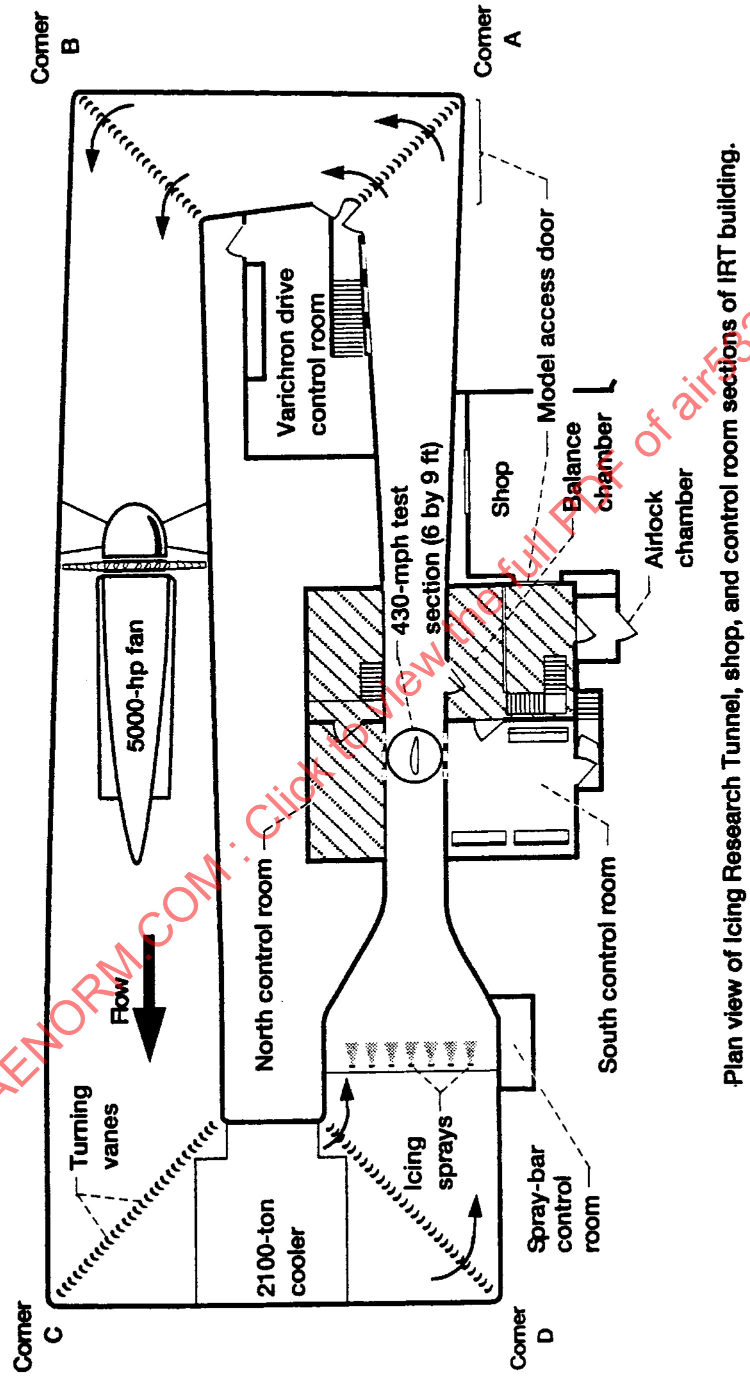


FIGURE 15 - NASA LeRC Icing Research Tunnel