BS 3G 100-2.3.10: 1974

Specification for

General requirements for equipment for use in aircraft —

Part 2: All equipment —

Section 3: Environmental conditions —

Subsection 3.10 Impact icing

Confirmed November 2011

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Contents

Foreword

This British Standard is part of a composite standard in the Aerospace Series of British Standards specifying requirements for equipment for use in aircraft. An introduction to the complete standard is given in BS 3G 100-0 "*Introduction*".

This subsection of BS 3G 100 supplements the requirements of BS 3G 100-2.3.9 "*Ice formation*".

This standard specifies requirements and gives guidance on the choice of severities for the testing of equipment which will be located external to the aircraft, where it may be subjected to impact by supercooled water droplets or ice crystals. Additional guidance is given on the conduct of impact icing tests.

This standard makes reference to the following British Standards:

BS 3G 100, *General requirements for equipment in aircraft — Part 0: Introduction.*

BS G 135, *Electrically-heated pitot and pitotstatic pressure heads*[1].

NOTE Information concerning metric (SI) units is given in BS 3763 "*The International System of units (SI)*", BS 350 "*Conversion factors and tables*" and PD 5686 "*The use of SI units*".

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Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 7 and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

[1] The latest revision is currently in preparation.

1 Scope

The test in this British Standard is applicable to equipment installed in a forward facing location external to an aircraft or in the intake ducting where it may be subjected to the impact of supercooled water droplets or ice crystals, and where under conditions of near or sub-zero temperatures ice may form or accumulate and interfere with the safe operation of the equipment or result in the shedding of ice fragments hazardous to other equipment installed downstream.

This standard should be read in conjunction with BS 3G 100-0.

2 Test procedure

2.1 The equipment shall be mounted in an icing wind tunnel at the angles of incidence and yaw specified in the relevant equipment specification.

2.2 The tunnel free stream temperature[2)], airspeed and, where required by the relevant equipment specification, the altitude, shall be adjusted to the values appropriate to the particular test, (see clause **3**), and these values maintained until the equipment temperature has stabilized.

2.3 The equipment shall then be exposed to a uniform spray of super-cooled water droplets of 20 μm nominal volume median diameter (vmd), or ice crystal conditions, as appropriate to the test for the duration(s) specified.

2.4 The equipment anti-icing or de-icing system, when fitted, shall be activated as specified in the equipment specification.

3 Test severities

Separate tests shall be made in turn at each set of test severities, defined in terms of temperature, water or ice crystal concentration, airspeed and duration, and altitude when applicable, in accordance with the relevant equipment specification.

Although it is possible to define the design icing atmosphere, it is not possible to define a simple set of test severities applicable to all equipments since the most adverse test conditions for an individual equipment depend on a number of factors, e.g. the severity of icing for which clearance is required, the performance envelope of the aircraft to which it is fitted, the type of ice protection system employed, etc. Guidance on the choice of test severities is given in Appendix A.

4 Performance evaluation

The tests are to be conducted to evaluate the performance of

1) the equipment and its anti-icing or de-icing system, or

2) the equipment when not fitted with an anti-icing or de-icing system, or

3) the anti-icing or de-icing system only.

The object(s) of the test shall be clearly stated in the relevant equipment specification.

The duty cycle of the equipment shall also be specified and shall be that found most likely to give rise to defects of performance which the test is evaluating.

5 Information to be stated in the relevant equipment specification

When an impact icing test is a requirement in the relevant equipment specification the following information shall be stated, as far as is applicable.

	Relevant clause
(1) The object of the test, i.e. whether it is a demonstration of performance or survival.	**4**
(2) The phase(s) of the test cycle when the equipment is to be operated and the performance evaluation made (if performance is to be assessed).	**4**
(3) The phase(s) of the test cycle when the anti-icing or de-icing systems are to be employed (if fitted).	**2.4**
(4) The orientation of the equipment relative to air flow and/or water spray.	**2.1**
(5) The test severities, i.e. the airspeed, altitude (where applicable), icing conditions and duration(s).	**3** and Appendix A

[2)] This term is explained in Appendix B.

Appendix A Choice of test severities

A.1 Introduction

Although icing atmospheres have been derived for design purposes relating liquid water and ice crystal content to ambient air temperature, it is clearly unnecessary to test an equipment at all temperatures, altitudes and airspeeds within the performance envelope of the aircraft to which it is fitted. It is therefore necessary to select the minimum number of test conditions which will satisfy the Approving Authority[3)] that adequate performance has been demonstrated. This requires that for each equipment a review is made of its performance over the entire operating envelope within the icing atmospheres to determine the most adverse operational conditions. Guidance in the transposition of these conditions into sets of test severities compatible with the limits of the test equipment defined in terms of altitude, air temperature, air speed, water or ice crystal concentrations and duration is given in **B.7** and **B.8** of Appendix B.

A.2 Icing atmospheres

For design purposes four icing atmospheres, i.e. continuous icing conditions, intermittent icing conditions for supercooled water droplet cloud, ice crystal conditions and mixed conditions, are stated in **A.2.1** to **A.2.4**:

A.2.1 *Continuous icing conditions.* The continuous icing conditions are as defined in Table 1, except that at altitudes less than 1 200 m (4 000 ft) it is assumed that there is linear variation of liquid water content with altitude to zero content at sea level, except that below 300 m (1 000 ft) the content for 300 m (1 000 ft) is assumed.

Table 1 — Continuous icing conditions

Air temperature	Altitude range		Liquid water content	Mean water droplet size
°C	m	ft	g/m³	µm
0	0–6 100	0–20 000	0.8	20
– 10	1 200–7 600	4 000–25 000	0.6	
– 20	1 200–9 100	4 000–30 000	0.3	
– 30	1 200–9 100	4 000–30 000	0.2	

A.2.2 *Intermittent icing conditions.* The intermittent icing conditions for:

1) altitudes above 9 100 m (30 000 ft) shall be 2.5 nautical miles of the appropriate condition of Table 2, alternating with 20 nautical miles of clear air;

2) altitudes below 9 100 m (30 000 ft) shall be 2.5 nautical miles of the appropriate condition of Table 2, alternating with 2.5 nautical miles of the appropriate continuous icing condition, except that at altitudes less than 4 600 m (15 000 ft) the liquid water content of Table 2 may be assumed to decrease linearly with altitude to zero at sea level.

Table 2 — Intermittent icing conditions

Air temperature	Altitude range		Liquid water content	Mean water droplet size
°C	m	ft	g/m³	µm
0	1 500–6 100	5 000–20 000	2.5	2.0
– 10	1 500–7 600	5 000–25 000	2.2	
– 20	3 000–9 100	10 000–30 000	1.7	
– 30	4 600–10 700	15 000–35 000	1.0	
– 40	6 100–12 200	20 000–40 000	0.2	

[3)] The Approving Authorities for aircraft equipment are the Civil Aviation Authority, Airworthiness Division for civil aircraft and the Procurement Executive, Ministry of Defence for military aircraft, or a design authority approved by them.

A.2.3 *Ice crystal conditions.* The ice crystal conditions are as defined in Table 3.

Table 3 — Ice crystal conditions

Air temperature	Altitude range		Ice content	Extent	Mean crystal size
°C	m	ft	g/m^3	nautical miles	mm
0 to – 20	3 000– 9 100	10 000– 30 000	8.0 5.0 2.0 1.0	0.5 2.5 50 300	1
– 20 to – 40	4 600– 12 200	15 000– 40 000	5.0 2.0 1.0 0.5	2.5 10 50 300	1

A.2.4 *Mixed conditions.* The mixed conditions are as defined in Table 4.

Table 4 — Mixed conditions

Air temperature	Altitude range		Ice content	Water content	Extent	Mean crystal size	Max.water droplet size
°C	m	ft	g/m^3	g/m^3	nautical miles	mm	mm
0 to – 10	3 000–9 100	10 000– 30 000	7 4 1 0.5	1 1 1 0.5	0.5 2.5 5.0 300	1	2

A.2.5 *Duration.* The assumed duration of an icing encounter should be:

1) continuous icing conditions: 30 min;

2) intermittent icing conditions: a total duration of 10 min with the durations of alternative liquid water concentrations appropriate to the airspeed and horizontal extents;

3) ice crystal and mixed conditions: a total time of 30 min with the durations of the different contents appropriate to the airspeed and horizontal extents. The durations at the lower contents shall be equally divided about the times at the higher concentrations.

A.3 Selection of test severities

The derived test severities will depend on a number of features but the type of ice protection system employed will probably have the largest influence. For example, in the case of a thermal anti-icing system, increase in speed increases the kinetic temperature of the surface but it also increases the catch efficiency and the rate of liquid water catch. The effect is such that a speed results at which the thermal requirements are at a maximum, at a particular temperature. If the heating is by hot air, as opposed to electric heating, the air supply may be affected by engine setting, which is a function of speed and altitude and therefore may result in an additional adverse speed condition.

NOTE An example of an icing test in accordance with the requirements of this British Standard, is specified in BS G 135 for electrically-heated pitot and pitotstatic pressure heads.

Appendix B Guidance on impact icing test

B.1 General introduction

B.1.1 The purpose of the test is to check the performance of exposed forward facing equipments during simulated flight through ice forming conditions: to check the performance of an anti-icing or de-icing system, to ensure that the maximum size of ice accretion does not interfere with the safe operation of the equipment or result in the shedding of ice fragments hazardous to other equipments downstream.

B.1.2 A sophisticated test facility is required for accurate simulation of flight through cloud. The construction, and especially the calibration, of an icing tunnel requires both considerable expertise and expenses recourse should be made, where possible, to established icing wind tunnels for tests of this nature.

B.2 Icing tunnels

Essentially, an icing wind tunnel consists of a working section within which a velocity controlled low temperature airstream is supplied with a homogeneous spray of supercooled water droplets, ice crystals or water droplet/ice crystal mixture of controlled size and concentration. Free stream temperatures (see **B.7**) in the range 0 °C to – 40 °C are required and this is usually achieved by heat exchangers situated in a low velocity section of the tunnel or by the injection of liquid nitrogen. Closed or open circuit tunnels can be used but precautions must be taken to ensure that frost or liquid water condensation on the heat exchangers does not affect the flow or the temperature during long uns, or enhance the supercooled water concentration in the working section or provide ice forming nuclei. Since the icing case at – 40 °C is not normally the critical design case, a free stream tunnel temperature range of 0 °C to – 30 °C is usually adequate.

B.3 Droplet size and size distribution

The size of the droplets in the spray is defined in terms of a vmd of 20 µm. In a droplet spectrum 50 % of the volume of water is contained in droplets of diameter smaller than the vmd and 50 % in droplets of diameters larger than the vmd. The size distribution should be reasonably similar to that in natural cloud given in Table 5.

Table 5 — Droplet size distribution

Droplet dia. ratio d_F/d_V	0.27	0.55	0.83	1.1	1.39	1.67	1.95	2.22
% by weight of total water content contained in droplets of dia. d_F	3	8	20	30	20	10	5	4

where d_F is the particular droplet diameter under consideration and
d_V is the volume median droplet diameter.

B.4 Droplet production

various methods can be used to produce liquid water droplet sprays but gas-atomizing spray nozzles have proved to be the most successful for icing work and can be made to approximate closely the required droplet size distribution. Care must be taken to avoid static temperatures that are in the order of – 40 °C or below in the spray or spontaneous formation of ice crystals may result. This is usually achieved by pre-heating the air, water or both, which also reduces the risk of freezing up of the nozzles.

B.5 Spray calibration

Periodic calibration of the droplet spray is required to ensure its adequacy. Various methods can be used for this, some of which are listed below.

Heated intake and hygrometer	Samples of the cloud are heated to evaporate the droplets, the dew point determined by hygrometer and the water content calculated.
Proprietary water content meters or icing rate meters	Various instruments are available which indicate liquid water content in g/m^3.

Rotating cylinders	The collection efficiency of cylinders moving in icing cloud has been calculated. By exposing several sizes of cylinders simultaneously and rotating them so that each builds up to a uniform coating of ice, it is possible to evaluate the water content and droplet size from the weights of ice collected.
Photographic techniques	Photographic techniques can be used to obtain photographs of cloud samples from which droplet spectrum can be evaluated.
Oil slide	A transparent slide is coated on one surface with a suitable oil, exposed for a short period to the cloud and then photographed at suitable magnification. Droplet spectrum can then be evaluated.

B.6 Ice crystal conditions

Ice crystal spray can be obtained from specially designed nozzles or by injection of previously ground and sized ice particles into the airstream. Precautions may be required to ensure that the ice particles do not melt during injection at high airspeeds, where the dry kinetic temperature rise can raise the injector temperature above 0 °C.

B.7 Temperature

The temperature of the surface of a body travelling through the air is increased because heat is generated in the boundary layer by the action of viscosity. In clear air the increase in temperature above t_1, the temperature at the edge of the boundary layer where velocity is V_1, is

$$\Delta t = \frac{V_1^2 \, P_r^{1/2}}{2gJC_p}$$

where

V_1 is the velocity at the edge of the boundary layer

P_r is the Prandtl number

J is the joules equivalent

C_P is the specific heat of air at constant pressure

for the case of laminar flow; for turbulent flow the exponent of P_r is 1/3.

The change in velocity from the free stream condition $V_o t_o$ to V_1 t_1 is an isentropic condition so that

$$t_1 = t_o + \frac{(V_o^2 - V_1^2)}{2gJC_p}$$

The surface temperature t'_s is therefore

$$t'_s = t_1 + \Delta t$$

$$= t_o + V_o^2 \, \frac{\left[1 - \dfrac{V_1^2 \,(1 - P_r^{1/2})}{V_o^2}\right]}{2gJC_p}$$

for laminar flow: for turbulent flow the exponent of P_r is 1/3.

At the stagnation point V_1 is zero and

$$t'_s = t_o + \frac{V_o^2}{2gJC_p}$$

Free stream temperature t_o can be obtained from the reading t_s' of a thermometer exposed in the dry air stream of an icing tunnel from the relationship

$$t_o = t'_s - \frac{V_o^2}{2gJC_p}$$

Considering now the conditions of a surface within the cloud spray, although the air may be saturated at free stream conditions it will not be saturated at the surface due to the temperature rise from t_o to t_s' and if the surface is wetted some water will be evaporated thus decreasing the surface temperature to t''_s, the wet kinetic temperature. It can be shown that

$$t''_s = t'_s - \frac{0.622\ L'_2\ (e''_s - e')}{P_1 C_p}$$

where

L_s'	is the latent heat of evaporation at temperature t_s'
e''_s	is the saturation water vapour pressure at temperature t''_s
e'	is the water vapour pressure at temperature t_s'
P_1	is the atmospheric pressure at the edge of the boundary layer.

Carpets of wet kinetic temperature, in terms of free stream velocity and temperature, are presented in Figure 1 for sea level and 6 100 m (20 000 ft) altitudes and tunnel free stream velocities up to 240 m/s (800 ft/s).

B.8 Effects of speed or altitude mismatch

Icing tunnels, except the most sophisticated and hence most expensive to operate, have no altitude facilities and many are speed restricted. It is often necessary to make tests at conditions not precisely those experienced in flight and compromise test conditions are required to ensure acceptable results. Various methods are used depending on the object of the test and the type of de-icing or anti-icing system fitted. Test duration or water content can be factored by the inverse of the tunnel velocity/true velocity ratio. Tests can be made at the equivalent wet kinetic temperature with either duration or water concentration factored. Tests can also be made at the equivalent aerodynamic loading with time or water concentration factored. The acceptability of the compromise adopted will require discussion with the Design Authority for the equipment.

B.9 References

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(3) MESSINGER, B L. Equilibrium temperature of an unheated surface as a function of aircraft speed. *J Aero. Sci.* Jan, 1953: Vol 20, No. 1.

(4) BOWDEN, D T., et al. Engineering summary of air frame icing technical data. *FAA Tech Report ADS.* USA Federal Aviation Agency. March, 1964.

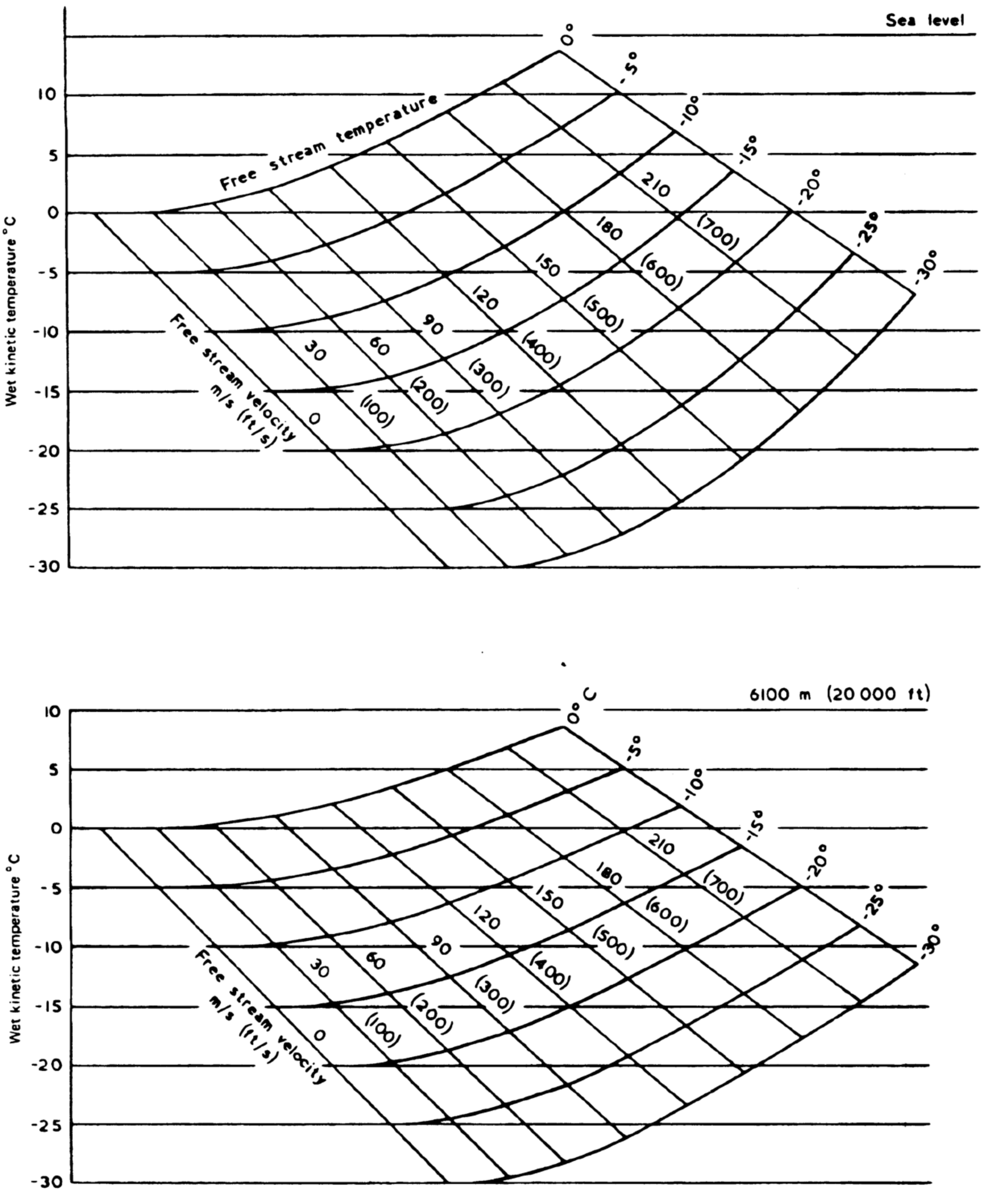

Figure 1 — Variation of wet kinetic temperature with free stream velocity and temperature

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