NORTH ATLANTIC TREATY ORGANIZATION
ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD

NATO STANDARDIZATION AGENCY (NSA)
AGENCE OTAN DE NORMALISATION (AON)
1110 BRUSSELS

Tel : 0032 (0)2 707 55.87
Fax : 0032 (0)2 707 57.18
nsa_air@hq.nato.int
AIR BOARD

16 May 2002 NSA(AIR)0293-AE/3659

Air Board Distribution List Nº 4

STANAG 3659 AE (EDITION 4) – ELECTRICAL BONDING REQUIREMENTS FOR METALLIC AIRCRAFT SYSTEMS

References:

a. MAS(AIR)0265-AE/3659 dated 23 February 2001 (Edition 4)(Ratification Draft 1)
b. MAS(AIR)305-AE/3659 dated 20 November 1998 (Edition 3)

1. The enclosed NATO Standardization Agreement which has been ratified by nations as reflected in page iii is promulgated herewith.

2. The references listed above are to be destroyed in accordance with local document destruction procedures.

3. APP-4 should be amended to reflect the latest status of the STANAG.

ACTION BY NATIONAL STAFFS

4. National staffs are requested to examine page iii of the STANAG and, if they have not already done so, advise the Air Board, NSA, through their national delegation as appropriate of their intention regarding its ratification and implementation.

Jan H ERIKSEN
Rear Admiral, NONA
Director, NSA

Enclosure:
STANAG 3659 (Edition 4)

STANAG Nº 3659
(Edition 4)

NORTH ATLANTIC TREATY ORGANIZATION
(NATO)

NATO STANDARDIZATION AGENCY
(NSA)

STANDARDIZATION AGREEMENT
(STANAG)

SUBJECT: ELECTRICAL BONDING REQUIREMENTS FOR METALLIC AIRCRAFT SYSTEMS

Promulgated on 16 May 2002

Jan H ERIKSEN
Rear Admiral, NONA
Director, NSA

RECORD OF AMENDMENTS

No.	Reference/date of amendment	Date entered	Signature

EXPLANATORY NOTES

AGREEMENT

1. This NATO Standardization Agreement (STANAG) is promulgated by the Director NSA under the authority vested in him by the NATO Military Committee.

2. No departure may be made from the agreement without consultation with the tasking authority. Nations may propose changes at any time to the tasking authority where they will be processed in the same manner as the original agreement.

3. Ratifying nations have agreed that national orders, manuals and instructions implementing this STANAG will include a reference to the STANAG number for purposes of identification.

DEFINITIONS

4. Ratification is "In NATO Standardization, the fulfilment by which a member nation formally accepts, with or without reservation, the content of a Standardization Agreement" (AAP-6).

5. Implementation is "In NATO Standardization, the fulfilment by a member nation of its obligations as specified in a Standardization Agreement" (AAP-6).

6. Reservation is "In NATO Standardization, the stated qualification by a member nation that describes the part of a Standardization Agreement that it will not implement or will implement only with limitations" (AAP-6).

RATIFICATION, IMPLEMENTATION AND RESERVATIONS

7. Page iii gives the details of ratification and implementation of this agreement. If no details are shown it signifies that the nation has not yet notified the tasking authority of its intentions. Page iv (and subsequent) gives details of reservations and proprietary rights that have been stated.

FEEDBACK

8. Any comments concerning this publication should be directed to NATO/NSA – Bvd Leopold III - 1110 Brussels - BE.

Agreed English/French Text

STANAG 3659
(Edition 4)

NAVY/ARMY/AIR

NATO STANDARDIZATION AGREEMENT (STANAG)

ELECTRICAL BONDING REQUIREMENTS FOR METALLIC AIRCRAFT SYSTEMS

Annexes: A. Terms and Definitions
B. Application Guides

Related Documents:

STANAG 3456 AE	-	AIRCRAFT ELECTRICAL POWER SYSTEM CHARACTERISTICS
STANAG 3632 AE	-	AIRCRAFT AND GROUND SUPPORT EQUIPMENT ELECTRICAL CONNECTIONS FOR STATIC GROUNDING
AEP-29	-	PROTECTION OF AIRCRAFT, CREW AND SUB-SYSTEMS IN FLIGHT AGAINST THE ELECTROSTATIC CHARGES

AIM

1. The aim of this agreement is to specify electrical bonding performance requirements and verification provisions for metallic aircraft systems and associated support equipment.

AGREEMENT

2. Participating nations agree that:

a. Electrical bonding requirements, as stated herein for metallic aircraft and associated support equipment, shall be used as a guide to impose appropriate controls for electrical bonding.

b. DC electrical bonding measurements shall be performed as necessary to verify the electrical bond.

TERMS AND DEFINITIONS

3. Terms and definitions for the purpose of this agreement are listed in Annex A.

APPLICATION GUIDE

4. An Application Guide for the purpose of this agreement is contained in Annex B. The application guide identifies suggested production practices to:

a. Select typical standard parts and materials used for electrical bonding purposes.

b. Define an acceptable method for surface preparation for electrical bonds.

c. Define candidate bonding tests for electrical bonds, and

d. Define electrical bonding practices for lightning protection.

PERFORMANCE REQUIREMENTS

5. General. Electrical bonding controls are necessary for management of electrical current paths and control of voltage potentials, to ensure required system performance and to protect personnel. Electrical bonding can be categorized as primary and secondary bonding. Primary bonding includes electrical bonding of the entire airframe structure without any systems within the aircraft. Secondary bonding addresses all other electrical bonding, other than primary bonding. Detailed requirements are provided for primary electrical bonding in the following section. Secondary electrical bonding details are addressed under classes of bonds associated with individual technical issues (for example, shock or lightning). Secondary bonding is identified under a separate heading. These classes also supplement the primary bonding category. There is overlap among the classes due to particular aircraft design features being associated with more than one electrical bonding concern.

PRIMARY BONDING

6. Primary bonding includes electrical bonding of the entire structure, without any systems within the aircraft. It comprises the whole of the conducting parts of the structure. Table 1 defines typical electrical bonding requirements between specific aircraft reference points (A) and various major structural elements of the aircraft (B). Table 2 defines typical electrical bonding requirements between specific aircraft reference points (A) and various sub-major or detachable structural elements of the aircraft (B).

a. Main Structure. The parts forming the structure are primarily metal conductors which allow for the migration of static charges and form current paths for the on-board electrical power system installation and lightning strikes.

TABLE 1

ELECTRICAL BONDING RESISTANCE REQUIREMENTS BETWEEN SPECIFIC REFERENCE POINT AND MAJOR STRUCTURAL ELEMENTS

No.	(A) Specific Reference Point	(B) Major aircraft Structural elements	Max. ohm
1	Part of the main metallic structure nearest the forward extremity of the aircraft	Fixed metallic part of fin nearest to the upper extremity	0.0005
2	Part of the main metallic structure nearest the forward extremity of the aircraft	Fixed metallic structure at the extremity of the right wing	0.0005
3	Part of the main metallic structure nearest the forward extremity of the aircraft	Fixed metallic structure at the extremity of the left wing	0.0005
4	Part of the main metallic structure nearest the forward extremity of the aircraft	Fixed metallic structure at the extremity of the right stabilizer	0.0005
5	Part of the main metallic structure nearest the forward extremity of the aircraft	Fixed metallic structure at the extremity of the left stabilizer	0.0005

TABLE 2

ELECTRICAL BONDING RESISTANCE REQUIREMENTS BETWEEN SPECIFIC REFERENCE POINT AND SUB-MAJOR (OR DETACHABLE) STRUCTURAL ELEMENTS

No.	(A) Specific Reference Point	(B) Sub-Major aircraft Structural elements	Max. ohm
1	Specific Reference Point	Part of the main metallic structure nearest the forward extremity of the aircraft	0.001
2	Part of the main metallic structure nearest the forward extremity of the aircraft	Fuselage: Fixed and removable parts (Pitot tubes, sensors etc.)	0.005
3	Part of the main metallic structure nearest the forward extremity of the aircraft	Fuselage: Bonding conductors of metallized insulating parts (radome etc.)	0.002
4	Part of the main metallic structure nearest the forward extremity of the aircraft	All metallic parts protruding on the exterior, etc. Nose gear under carriage, landing gear doors	0.01
5	Main aircraft structure adjacent to measurement points	Cabin door, cargo doors, any external, articulated or extensible metallic part in relation to the fuselage	0.01

No.	(A) Specific Reference Point	(B) Sub-Major aircraft Structural elements	Max. ohm
6	Fixed metallic structure at the extremity of the right wing	Right wing: Fixed and removable metallic parts (hatches, access panels wing tip lights)	0.01
7	Fixed metallic structure at the extremity of the right wing	Right wing: Bonding conductor of metallized insulating parts and all metallic attachment parts accessible on the exterior and attached	0.01
8	Fixed metallic structure at the extremity of the right wing	Main RH landing gear legs, landing gear doors	0.01
9	Fixed metallic structure at the extremity of the right wing	Right wing: articulated metallic parts (control surfaces, articulated panels, retractable, lights, etc.)	0.01
10 to 13	Refer to measurements 6 to 9 for left wing.		0.01
14	Fixed metallic structure, rear part of aircraft	Auxiliary Power Unit (APU) conduits, mobile APU components protruding on the exterior, APU air intake, access panels and removable or articulated panels, APU compartment, APU drainage holes, etc.	0.01
15	Fixed metallic structure, rear part of aircraft	Articulated stabilizer components, access panels, etc.	0.01
16	Fixed fin structure	Detachable fin components, articulated components, bonding components of metallized insulating parts	0.01

b. Detachable Parts. In principle, metallic parts (non-articulated access doors, for example) attached by a significant number of metallic screws ensure good electrical continuity and do not require the addition of bond braids. However, the metallic parts attached by quarter turn screws usually require the use of additional bonds (braids, contact arms, interposition of conducting materials, etc.).

c. Articulated Parts. Articulated parts shall be bonded, taking the following two points into consideration:

(1) The articulation can be, by its construction, made sufficiently conductive even if it is lubricated, provided that the contact pressure is sufficient.

(2) The articulation is not conductive by the nature of its materials or protection used. In this case, it is advisable to ensure bonding by the use of a number of bonding jumpers. Bonding jumpers shall be as short as

possible and of sufficient cross-sectional area to carry fault or lightning currents, as applicable, without disintegration.

d. Fuel Tanks. The design of fuel tanks shall be such as to avoid sparking from lightning strikes that cause vapour ignition. This can be accomplished by adequate electrical bonding of external parts such as fuel caps, panels, drainage ports and air vents/ fuel dumps.

e. Engines, Auxiliary Power Unit (APU) and Environmental Control System (ECS). The main articulated attachments for the engines, APU and ECS components shall be shunted by a bonding jumper (braid), unless the electrical continuity between the engine, APU and ECS components and their respective structures are permanently ensured by fixed attachment points. All fixed or moveable pipes shall also be electrically bonded to the engine, APU or ECS component, respectively, by construction or braided jumpers.

f. Non-metallic External Parts. The non-metallic components, especially in areas where there is high probability of lightning (radome, wing tips, canopies, and extremities of stabilizer, fin, etc.) shall be treated to allow electrostatic charges to be discharged and provide effective protection against the effects of lightning.

g. External Protruding Parts

(1) Internal metallic parts protruding on the exterior of the aircraft (pitot tube, drain, for example) shall be bonded to the structure at a point situated as close as possible to the aircraft skin.

(2) Protruding parts connected to the on-board electrical circuit (navigation lights, sensors, pitot tubes, for example) shall be bonded or protected to reduce possible damage to the on-board electrical system.

SECONDARY BONDING

7. Secondary Bonding includes all electrical bonding other than Primary Bonding. Secondary bonding is described under various classes of electrical bonding conditions and elements, which supplement the primary bonding category.

8. Classes of electrical bonds are as follows:

Class	Description
A	Antenna Installation
C	Current Path Return
H	Shock Hazard
L	Lightning Protection
R	RF

S	Static Electricity
W	Wire, Cable or Harness Shields
X	System Earthing
Y	Site Protection

a. CLASS A ELECTRICAL BONDING (ANTENNA INSTALLATIONS): Antennas shall be sufficiently bonded to obtain required antenna patterns. When necessary, an adequate counterpoise shall be provided for antennas. The counterpoise consists of conductive elements bonded together and electrically bonded to the aircraft ground subsystem. Electrical bonding of antenna mount structural interfaces should provide a DC electrical bonding resistance of not more than 0.010 ohms when measured from the antenna mount to the aircraft ground subsystem. This requirement is intended solely to demonstrate electrical bonding continuity from the antenna to the aircraft ground subsystem. Antenna pattern testing at various frequencies shall be measured during aircraft system level verification.

b. CLASS C ELECTRICAL BONDING (POWER CURRENT RETURN PATH): Bonding provisions shall be provided for current return paths for the electrical power sources such that total voltage drops between the point of regulation for the power system and the electrical loads are within the tolerance of the applicable power quality standard (See STANAG 3456, when applicable). When subsystem enclosures are used for current return (return connected to the enclosure) electrical bonding of subsystems to the aircraft ground subsystem shall provide a resistance of not more than 0.0025 ohms.

(1) Ground Fault Conditions: Electrical bonds in the current return path for fault protection shall be adequate, to handle currents which ensure operation of circuit protection devices within 0.2 second maximum of a ground fault occurrence.

(2) Electrical Bonding in Hazard Areas. In areas prone to explosion or fire hazards, the voltage drops between the equipment case and aircraft ground subsystem shall not exceed .074 volts. The fault current is the maximum current that the electrical system is capable of delivering in the event that an internal power-to-ground fault takes place and high current passes through the equipment housing to ground. To define maximum current, the impedance of the relevant circuit and the design criteria for limiting the current in case of a short circuit, shall be considered. The maximum current may be defined by experiment on a test rig of the electrical system. Since electrical bonding in itself cannot eliminate all possible sources of ignition, the equipment shall be designed to minimize hot spots, sparking, and expulsion of molten metal when an internal power fault occurs.

c. CLASS H ELECTRICAL BONDING (SHOCK HAZARD): Electrical bonds shall be provided to protect personnel from the hazards of electrical shock. Such hazards include direct physical injuries as well as the associate injuries that may result as a secondary effect of shock-induced reflex actions (e.g., falling). Shock hazards are considered to exist at 30 Volts or higher.

(1) Electrical Bond Resistance. Shock hazards can be minimized by controlling the bonding resistance. Exposed conduction frames or parts of electrical or electronic equipment shall have an electrical bond resistance of less than 0.1 ohm to the aircraft ground subsystem. Metallic conduit protecting electrical wiring shall have a low DC resistance electrical bond of less than 0.1 ohm to the aircraft ground subsystem at each termination and at each break point. The electrical bonding path may be through the equipment case in which the conduit terminates.

(2) Grounding. If the equipment design includes a ground terminal or pin, which is connected to such exposed parts, a ground wire connection to such a terminal or pin shall be provided. Electrical panels or other equipment accessible to the occupants of the aircraft (circuits with voltages of over 30 volts) shall be bonded to avoid the danger of electrical shock. Articulated panels shall be bonded by design; or failing this by bond braids. The articulated panels which are not detachable, attached by screws or similar metallic components, are only provided with braids if the contact ensured by the attachments is considered uncertain or inadequate.

d. CLASS L ELECTRICAL BONDING (LIGHTNING PROTECTION) Electrical bonding shall be provided across joints which may carry lightning currents. Electrical bonding requirements for lightning shall protect flight control functions and limit voltages within the aircraft to 500 volts for protection of flight critical electronics and minimise sparking for prevention of fuel ignition.

e. CLASS R ELECTRICAL BONDING (RF POTENTIAL): Electrical bonding should be provided to minimize the RF potentials existing between conductive structures not intentionally placed at high RF potential during normal equipment operation. All electrical and electronic units or components that produce electromagnetic energy should provide a DC resistance path of 0.0025 ohms or less from the equipment enclosure to the aircraft ground subsystem.

f. CLASS S ELECTRICAL BONDING (ELECTROSTATIC CHARGE): Electrostatic charging should be controlled to the extent necessary to prevent performance degradation of electronics, avoid fuel ignition and protect personnel from shock. STANAG 3856 shall be considered in achieving the performance requirements contained herein.

(1) External Items. All electrically conducting items (except antennae) which are external to the aircraft, should have an electrically bonded connection to the vehicle ground subsystem with a resistance of less than 1 ohm. Dielectric surfaces should be treated with an electrically conductive finish which is bonded to the ground subsystem. The electrical bond resistance of conductive coatings on a radome or

transparency should not degrade the equipment or personnel performance below acceptable operational levels.

(2) Fluid Lines. All metallic pipes, tubes, and hoses that carry petroleum products or other fluids should have an electromechanically secure connection to the aircraft ground subsystem that will measure 1 ohm or less. The pipe, tube, or hose installation should be so designed that it will not be a primary path for electrical power currents under normal or fault conditions. Non-metallic plumbing installations should be designed so that the static voltage generated by fluid flow will not exceed 350 volts, with respect to the ground subsystem, at any point outside the pipes, tubes, or hoses.

g. CLASS W ELECTRICAL BONDING (WIRE, CABLE AND HARNESS SHIELDS): Wire, cable, and harness shields should be electrically bonded to meet the electromagnetic environmental effects (E^3) requirements detailed in the individual system specification. The following requirements form a basis for shield termination treatment unless specifically waived in the individual system or equipment specification.

(1) Individual Wire Groups. Individual wire group shields within a cable or harness shall be electrically bonded to the connector backshell. The electrical bond shall provide a resistance path of 0.0025 ohms maximum between shield and connector body. Shielding integrity on the wire shall be maintained to within 1.5 inches (40mm) of the connector pin. The electrical bonding path to the backshell shall be maintained at minimum length. The use of backshell accessories designed for "zero" length terminations produce optimum results.

(2) Gross Cable Shields. Gross shields, i.e., shields which enclose an entire wire bundle or harness, shall be electrically bonded about the circumference of the connector in which the wire bundle terminates. The electrical bonding value of 0.0025 ohms should be achieved in such a manner that the shield integrity is maintained and no apertures in the shield are created. When metallic conduit is used for shielding purposes, a bonding resistance of 0.0025 ohms shall apply. When the conduit is supplied only for mechanical protection, only the requirements of other sections apply.

(3) Receptacles. All bulkhead or enclosure-mounted receptacles should be electrically bonded to the aircraft ground subsystem. The electrical bonding should provide a resistance path of 0.0025 ohms or less to the aircraft ground subsystem or enclosure.

h. CLASS X ELECTRICAL BONDING (AIRCRAFT SYSTEM EARTHING): Grounding receptacles in accordance with STANAG 3632 should be used to permit electrical bonding of the aircraft ground subsystem to earthing points during maintenance, fuelling, stores handling, and while parked. The grounding receptacle electrical bonding to the aircraft ground subsystem should provide a DC resistance path of one ohm or less.

i. CLASS Y ELECTRICAL BONDING (SITE PROTECTION AND EARTHING POINTS): Aircraft maintenance, refuelling, ordnance loading, and parking areas shall be provided with system earthing points and electrical bonding paths to assure safe and proper system operation from all electromagnetic environmental effects (E^3).

BONDING METHODS

9. GENERAL: There are two types of bonding: direct bonding, where there is metal-to-metal contact between the members to be bonded; and indirect bonding through the use of conductive jumpers.

10. ELECTRICAL BONDING INSTALLATIONS: Direct electrical bonding installations are considered as being permanent and inherently electrically bonded when utilizing metal-to-metal joints by welding, brazing, sweating or swaging. Insulating finishes need not be removed if the resistance requirement is met without such removal. Semi-permanent joints of machined metallic surfaces rigidly held together provide excellent direct bonds as long as the contact areas are clean and all non-conductive coatings are removed prior to assembly. Dissimilar metals in direct contact should be avoided. In particular, sheet metal type screws are not acceptable for use in bonding. Joints that rely on press-fitted floating nutplates for the current path cannot be relied upon to provide a low-impedance bond at high frequencies. Riveted joints, on 3/4" (19mm) centers are acceptable if the rivet holes are bare of insulating materials. More rivets will be needed as current requirements are increased. Examples of semi-permanent installations are:

a. Bare metal-to-metal joints of machined surfaces held together by thread locking devices.

b. Riveted joints with a minimum of three rivets.

c. Tie rods.

d. Structural wires under tension.

e. Pinned fittings driven tight.

f. Normally permanent and immovable clamp fittings which have been assembled after all insulating finishes have been removed from the contact area.

11. ELECTRICAL BONDING CONNECTIONS: Electrical bonding connections should be installed so that vibration, expansion, contraction, or relative movement incident to normal service use will not break or loosen the connection to such an extent that the resistance will vary during movement. Electrical bonding connections shall be located in a protected area, insofar as practicable, and whenever possible near a hand-hold, inspection door, or other accessible location to permit rapid inspection or replacement. The following conditions should also apply:

a. Parts should be electrically bonded directly to the aircraft ground subsystem rather then through other bonded parts.

b. Indirect bonding through the use of electrical bonding jumpers should be installed so that moveable components are not impeded in their operation by the jumper.

c. Electrical bonding connection should not be compression-fastened using non-metallic materials.

d. Electrical bonds on plumbing lines should not be dependant on mounting clamps due to differential thermal expansion. Clamp and jumper assemblies should be used for all electrical bonding purposes.

e. All current returns and electrical bonds established per paragraph 8.b.(2) should be verified by measurement, to avoid explosion hazards.

12. PARTS IMPRACTICAL TO BOND WITH JUMPERS: The use of conductive epoxy resin is permitted if it conforms to the performance requirements of the aircraft specification. When electrical bonding by jumpers causes fouling or mechanical malfunction, other suitable electrical bonding means shall be employed which conform to the performance requirements of the aircraft. Such means shall be subject to approval by the design authority.

13. CIRCULAR CONDUCTORS: Electrical bonding of cylindrical or tubular conduction members, not inherently bonded, should be accomplished by a clamp and jumper. Electrical bonding clamps, when required on metallic conduit or hose, should not crimp or damage the conduit or hose when installed.

14. CORROSION CONTROL: Jumpers and other elements of the electrical bonding connection should be selected to minimize the possibility of corrosion when joining dissimilar metals. If corrosion does occur, only replaceable hardware items, such as jumpers, bolts, nuts, washers, or separators, shall be affected rather than the permanent ground subsystem. Washers should not be surface treated or coated in any manner that will impair electrical conductivity. Unprotected, nonstainless steel shall not be used as a washer. Determination of the compatible coupling of dissimilar metals should be defined by the design authority.

15. REFINISHING: When it is necessary to remove any protective coating on metallic surfaces to conform with this specification the completed assembly should be refinished with its original finish or other suitable protective finish within 24 hours after inspection completion. In no case should refinishing be delayed more than seven days after removal of the finish. A clear lacquer with suitable mechanical, chemical, and optical properties may be used if desired to facilitate subsequent inspection.

16. INTERMITTENT ELECTRICAL CONTACT: Intermittent electrical contact should be prevented either by electrical bonding or by insulation (if electrical bonding is not necessary to conform to the equipment specification) between conducting surfaces which may become a part of a ground plane or current path.

17. UNAPPROVED ELECTRICAL BONDING METHODS: Anti-friction bearings, wire-mesh vibration cushion mounts, or lubricated bushings should not be used as an electrical bonding path. Piano hinges may not be used as an electrical bonding path if a non-conductive lubricant, dry-lube, or other non-conductive element is used in conjunction with the piano hinge.

VERIFICATION PROVISIONS

18. GENERAL: Compliance with electrical bonding requirements should be verified by test, analysis, or inspection as appropriate for the particular bonding provision and as approved by the procuring activity. Verification of measures for electrical bonding is necessary to ensure that adequate controls are implemented. The adequacy of most electrical bonds can be evaluated through DC resistance measurements and inspections. The following sections detail issues associated with specific areas of electrical bonding. Annex B provides alternative techniques for performing bonding tests.

a. Primary Bonding. Primary bonding should be verified through DC resistance measurements. The testing is performed on the assembled structure before installation of the aircraft subsystems. Electrical Bonding measurement results should be in accordance with the stated performance requirements of this STANAG.

b. Class A Antenna Installation. Antenna bonding should be verified through test and analysis to demonstrate that required antenna coverage is obtained. The most effective demonstration that an antenna is adequately bonded is that required antenna patterns are obtained. Other system requirements documents normally impose range and angular coverage requirements for antenna-connected subsystems. Electrical bonding measurement results should be in accordance with paragraph 8.a.

c. Class C Power Current Return Paths. Bonding for power current return should be demonstrated through analysis of electrical current paths, electrical current levels, and bonding impedance control levels. Voltage drops present in power current return paths must be evaluated to ensure that electrical power utilization equipment receives power in accordance with power quality standards; and that fuel and fire hazards are avoided. On most military aircraft, aircraft structure is used as the current return path for electrical power. Electrical bonding measurement results should be in accordance with paragraph 8.b.

d. Class H Shock Hazard. Bonding for shock hazard shall be verified through test, analysis, and inspection as appropriate for the particular application. Verification is primarily achieved by demonstrating that voltages in excess of 30 Volts are protected from inadvertent contact by personnel and that faults to electrically conductive surfaces will not result in voltages greater than 30 Volts on the surface. These type of faults should normally trip circuit protection equipment. Bonding measurements demonstrating that 0.1 ohms or less exists between a conducting surface and the ground subsystem provides a degree of assurance that a shock hazard will not exist.

e. Class L Lightning Protection. Electrical bonding for lightning protection for direct effects shall be verified by qualification tests, analyses based on development test data, basic principles, previously verified designs or a combination of these methods. A lightning protection verification program is essential to demonstrate that the design protects the aircraft from lightning threat environment. There is no single approach to verifying the design. A well structured test programme supported by analysis is generally necessary. Flight testing of aircraft often occurs prior to verification of the immunity of the vehicle to lightning. Under this circumstance, the flight test programme must include restrictions to prohibit flight within a specified distance from thunderstorms, usually 25 miles (40km). Lightning flashes sometimes occur large distances from the thunderstorm clouds.

f. Class R RF Potentials. Bonding for RF potentials should be demonstrated by tests. Testing is the only acceptable method to demonstrate that the bonding requirement is satisfied. The measurement is made from an enclosure surface to the next major assembly. For example, in an installation with an enclosure mounted in a tray, separate measurements would be applicable from the enclosure to the tray and from the tray to structure. DC measurements have proven to provide a good indication of the quality of a bond. Bonding measurements often require that a protective finish be penetrated with electrical probes to obtain good electrical contact. Care should be taken so that a corrosion problem is not introduced.

g. Class S Electrostatic Charge. Adequate control of electrostatic charging shall be verified by test, analysis, or inspection as appropriate and as approved by the procuring activity. The selected verification method must be appropriate for the type of structural material being used and the particular type of control being verified. Relatively poor electrical connectors are effective as discharge paths for electrostatic charges. Therefore, inspection would normally be appropriate for verifying that metallic structural members are adequately bonded provided that electrically conductive hardware and finishes are being used. For dielectric surfaces, which are treated with conductive finishes, testing of the surface resistivity and electrical contact to a conductive path would normally be more appropriate. For demonstration that the aircraft will adequately discharge precipitation static charge build-up during flight, actual flight through likely charging conditions might be necessary. For all structural components, this verification must be done during air vehicle assembly to verify that all components are adequately bonded to each other. Examples of electrical bonding measurements as they relate to electrostatic charging for specifically susceptible areas are illustrated below.

(1) Fuel System. Bonding measurements are required for the following configurations:

(a) between light alloy fuel lines and the aircraft ground subsystems;

(b) between stainless steel lines and the aircraft ground subsystem;

(c) between any metallic part of equipment (electrical or otherwise) inside or outside the compartments concerned with fuel, (pumps, valves, drainage, water drains, clack valves, fuel, jettison, gauges) and the aircraft ground subsystem;

(d) between the fuelling connectors, tank air vents; any fuel-related equipment and the aircraft ground subsystem; and

(e) between the connection components permitting equi-potential connections between the refuelling boom and the aircraft ground subsystem.

(2) Hydraulic System. Bonding measurements should be taken for the following configurations:

(a) between all light alloy lines and in stainless steel longer than 1 meter;

(b) between any metallic equipment and the aircraft ground subsystem;

(c) on flight controls and various mechanical elements controlled by linkage and cables in pressurized areas; and

(d) between any parts or metallized equipment and the aircraft ground subsystem.

(3) Air Conditioning, Pneumatic and Air Speed System. Bonding measurements should be taken: between any portion of tubing equal to and over 0.3 meters in length and the aircraft ground subsystem and between any equipment with a dimension greater than 0.2 meters in any direction (and not consisting of an electrical system), and the aircraft ground subsystem.

(4) Oxygen System. Bonding measurements should be taken: between any metallic part of the oxygen system and the aircraft ground subsystem.

IMPLEMENTATION OF THE AGREEMENT

19. This STANAG is implemented when the provisions above have been included in national orders, specifications, standards, instructions or regulations, as appropriate.

TERMS AND DEFINITIONS

1. The following terms and definitions are used for the purpose of this agreement.

a. Articulated Parts. Parts which are joined and placed permanently or temporarily on the exterior of the aircraft such as control surfaces, doors, hatches, gear legs.

b. Earthing. The process of making a satisfactory electrical connection between the structure, including the metal skin, of an object or vehicle, and the mass of the earth, to ensure a common potential with the earth.

c. Electrical Bond (noun). An electrical bond is any fixed union existing between two conducting objects that results in electrical conductivity between the objects. Such union occurs either from physical contact between conductive surfaces of the objects or from the addition of a firm electrical connection between them.

d. Electrical Bonding. Electrical bonding is defined as the means of obtaining a specified electrical conductivity between conductive components, such as between units, between a unit and the aircraft ground subsystem, between elements of the aircraft ground subsystem, or between conductive composite structural element and the aircraft ground subsystem. For the purposes of this STANAG, electrical conductivity shall be specified by measuring DC resistance between conductive surfaces.

e. Electrical Bonding Jumpers. An electrical bonding jumper is a braided wire or metal strap that provides a specified electrical conductivity between the unit and vehicle structure when other means of electrical contact are not sufficient.

f. Conducting Surfaces or Objects. Conducting surfaces or objects include all objects having a surface resistivity of less than 1 megohm per square.

g. Detailed Specification(s). A detailed specification(s) is defined as the document or documents which specifies in detail the requirements of the weapon system, subsystem, or equipment.

h. Ground. A conducting connection, whether intentional or accidental, by which an electric current or equipment is connected to the earth, or to a ground subsystem that serves a function similar to that of an earth ground (for example, a metallic structure such as a frame of an air, space or land vehicle that is not conductively connected to earth).

i. Ground Subsystem. A system of conductors providing a ground reference. It may provide power current returns and fault-current return paths. It will provide lightning current paths, and paths by which static electricity reaches the dischargers. In metal aircraft, structure is the ground subsystem.

j. Isolated Surfaces or Objects. An isolated conducting object is one that is physically separated by intervening insulation from the ground subsystem and from other conductors which are bonded to the ground subsystem.

k. Structure. The mechanical frame and skin of an aircraft.

APPLICATION GUIDES

1. The application guides are suggested production practices to achieve electrical bonding performance requirements for metallic aircraft systems and associated support equipment. Member nations are not bound by these practices. They are encouraged to use the information contained herein, to complement or supplement their national production practices and methodologies.

2. The application guide contains four sections. The sections contain information in the following areas:

a. Parts and materials.

b. Surface preparation.

c. Bonding tests.

d. Lightning protection.

PARTS AND MATERIALS

3. The following data can be used in selecting hardware for electrical bonding purposes:

a. Standard Parts. Standard NATO parts shall be used wherever suitable for the purpose intended, and shall be identified on drawings or in other documents by their part numbers. Commercial standard parts, such as screws, bolts, washers, nuts and cotter pins may be used provided they do not have downgrading effect on the equipment during or after environmental tests.

b. Bolts, Nuts, Screws and Washers

(1) Cadmium plated steel. Not recommended above 285°C due to sublimation of cadmium.

(2) Corrosion resistant steel. For all applications, including high temperature.

(3) Titanium. High temperature and weight savings. (Do not use bolts coated with insulant when bolt must carry current).

(4) Aluminium. General usage at temperature up to 150°C.

(5) Self-tapping screws. Prohibited.

(6) Zinc plate. Prohibited.

(7) Anodized Washers. Prohibited for washers.

(8) Unplated. Prohibited for washers.

(9) Star. Prohibited for washers.

c. Jumpers. All electrical bonding jumpers shall be kept as short and direct as possible. The design for the number of jumpers to be installed shall be kept to a minimum and shall conform with the purpose of this specification. The use of two or more standard length jumpers in series to provide the required overall length will not be permitted.

d. Clamps. Clamps shall be the plain uninsulated type. Non-standard clamps may be used only where standard clamps are not suitable.

ELECTRICAL BONDING SURFACE PREPARATION

4. Surface preparation for an electrical bond shall be accomplished by removing all anodic film, grease, paint, lacquer, or other high-resistance surface coatings or treatments from the immediate area to ensure a low impedance between adjacent metal parts. Abrasives which cause corrosion, if embedded in the metal, should not be used. If abrasives or scrapers are used to remove any protective finish they shall be of such a nature that produces a clean, smooth surface without removing excessive material under the protective finish. Chemical cleaning and surface preparation shall be in accordance with standard practice with each individual nation. The following preparations can be used as guidelines.

5. Preparation of Electrical Mating Surfaces. The following procedures have been found satisfactory in the preparation of metals for electrical mating surfaces and are recommended for use, as applicable:

a. Grease, oil, and/or other non-conductive films shall be removed with solvent.

b. Non-soluble films shall be removed by sanding and polishing with garnet paper, using caution so as not to remove excessive metal. The area should be brushed clean.

c. After cleaning, the surfaces should be treated as follows:

(1) Magnesium Alloys:

(a) Wash the bare metal areas with a corrosion-protection solution for a minute, then rinse in clean water within 5 seconds. Dry thoroughly, reassemble the parts, and seal within 24 hours.

(b) If paint finish has been removed and a paint finish is required on the final assembly, seal with the original finish.

(c) If a paint finish is not required after reassembly, seal with a sealant compound.

(2) Aluminium Alloys. Aluminium alloys, not subject to exposure to fuels, should receive a brush coating of a suitable surface treatment applied to the mating surfaces after polishing; parts shall then be reassembled.

BONDING TESTS

6. The following types of bonding tests are identified as candidate methods to be used by Nations:

a. DC Resistance Measurement. This test is intended to give design personnel a general indication of bond adequacy after installation, based on the DC resistance of the bond. The test is often performed to establish whether or not the bond resistance is within pre-established design limits.

b. Kelvin Bridge Method. The constant current generator in the Kelvin Bridge shall be 1% accurate or better. In the case of the constant voltage method, the variable resistance must be adjusted to different values each time a measurement is taken. Choosing measurement current values such as 1 amp or 10 amps can allow the millivoltmeter to read resistance directly times a power of 10. The minimum current value used shall be 25 milli-amps. Each end item shall have the maximum electrical bonding resistance between any two selected points specified in the end item bond specification.

c. Primary Bonding Measurements. Any of the above methods can be used for primary bonding measurements.

LIGHTNING PROTECTION

7. Electrical bonding across aircraft joints is especially critical to protect against the direct and indirect effects of the lightning threat. Typical entry and exit points for the lightning threat include, but are not limited to the following:

a. Navigation lights.

b. Fuel filler caps.

c. Fuel gauge covers.

d. Refuelling booms.

e. Fuel vents.

f. Antennae.

g. Radomes.

h. Canopies.

i. Pitot-static booms.

j. Electrical wiring and mechanical controls, cables, rods not protected by metal structure.

k. Rotor blades.

l. Wing tips and aircraft tail section.

m. Pylons.

8. The following production practices are recommended to minimize the performance degradation of the lightning threat.

a. Size of conductor. Individual electrical bonding jumpers for lightning protection should not be less than size 12 AWG conductor for tinned stranded copper wire or a size 10 AWG conductor for stranded aluminium wire. These wire sizes are valid only when an adequate number of jumpers are installed in order to carry the lightning current. When the jumpers are subjected to full lightning current, a minimum wire size 2 AWG conductor is required for protection against multiple strikes.

NOTE: Soldered connections. Soldered connections should not be used on jumpers that are required to carry lightning currents.

b. Control surfaces. Control surfaces and flaps shall have an electrical bonding jumper across each hinge except for installations having a single hinge. In the case of a single hinge, a minimum of two jumpers are required. Where necessary, additional jumpers should be used between the control surface and structure to protect the control cables and levers. The length of discharge path through the control system shall be at least 10 times the length of the path through the jumper or jumpers. A piano-type hinge may be considered self-bonded, provided the resistance across the hinge is less then 0.01 ohm.

c. Panels, Covers, Doors, and Hatchways. Conductive structures designed to be opened or removed during normal operation or routine maintenance, and located in zones of likely lightning attachment should be provided with electrical bonds to the main aircraft structure capable of carrying lightning currents.

d. Protrusion Electrical Bonding. All external electrically isolated conducting objects, which protrude above the vehicle surface, excluding antennas, should have an electrical bond to a conductive structural element in order to convey lightning currents. Large non-conducting projections essential to flight or housing personnel, such as vertical stabilizer parts, wing tips, radomes, fairings, and canopies, shall have multiple conducting paths, externally distributed over their surface. These conducting paths should be capable of conveying lightning currents to a major structural element. A protruding electrical conductor can be designed to protect other objects – including personnel – within its "protective zone" from direct lightning strikes.

(1) A conductor will form a cone-shaped zone of protection. The conductor will extend vertically outward from a conducting major structural element (to which the conductor is bonded). The axis of this cone will be the conductor itself, and the apex of the cone will be located at the free end of the conductor. The apex of the cone will incorporate an angle of 120 degrees.

(2) A relatively larger zone of protection will be formed by a straight conductor which is parallel to a conducting, major structural element (which is bonded to it – at each end – by a vertical conductor). Each vertical conductor will have a cone-shaped zone of protection (as described in paragraph 8.d.(1)). The conductor parallel to the major structural element will further protect the entire volume between these two cones. Vehicle flight safety, flight characteristics, crew visibility, and equipment performance shall take precedence over these requirements. The conductive path should not affect the structural integrity of the protrusion.

e. Riveted Skin Construction. Close riveted skin construction which divides any lightning current over a number of rivets is considered adequate to provide a lightning discharge current path.