

Design of electromagnetic hazard protection of civil aircraft

Part 2. Guide to protection

ICS 33.100; 49.060

Confirmed
January 2011

NO COPYING WITHOUT BSI PERMISSION EXCEPT AS PERMITTED BY COPYRIGHT LAW

BSI
Documents



Document Sharing Hub

Committees responsible for this British Standard

The preparation of this British Standard was entrusted to Technical Committee ACE/66, Aerospace — Electromagnetic compatibility of aircraft, upon which the following bodies were represented:

- ERA Technology Ltd.
- Federation of the Electronics Industry
- Civil Aviation Authority (Airworthiness Division)
- Ministry of Defence
- Society of British Aerospace Companies

This British Standard, having been prepared under the direction of the Engineering Sector Board, was published under the authority of the Standards Board and comes into effect on 15 March 1998

© BSI 1998

The following BSI references relate to the work on this standard:
Committee reference ACE/66
Draft for comment 94/714809 DC

ISBN 0 580 29504 4

Amendments issued since publication

Amd. No.	Date	Text affected

Contents

	Page
Committee responsible	Inside front cover
Foreword	ii
Guide	1
1 Scope	1
2 Informative references	1
3 Design of the airframe	1
4 Design of the system installation	7
5 Design of the equipment	25
Tables	
1 Bond resistances	6
2 Typical signal classifications for the purposes of cable segregation	11
3 Recommended types of cables for particular applications	11
Figures	
1 The effect of airframe geometry on airframe current to effect coupling	8
2 Airframe geometries which will provide useful protection	9
3 Preferred cable routes in a typical front fuselage section	9
4 Parallel and normal electric field components	13
5 Screening mechanism against electric field component	14
6 Magnetic field component coupling with a cable loop	14
7 Magnetic field null at screen centre	14
8 The definition of cable surface transfer impedance	15
9 Test arrangement for surface transfer impedance measurement	15
10 Typical surface transfer impedance values for cable measured in figure 9	16
11 Three simple options for screen and equipment bonding	17
12 Resistive earth planes or poor bonding drives earth currents along screens	18
13 Possibilities for video signalling	18
14 Summary of cable screen terminations	19
15 The effect of pigtail terminations	20
16 Possibilities for 0V referencing	22
17 Equipment case protection	25
18 Inter-winding capacitance reduction	26
19 Typical unbalanced input	27
20 Optical isolator installation	28
21 Earthing philosophies	29
22 Combined filter and surge arrestor	31
23 Filter installation	32
24 Gasket installation in bolted joints	34
25 Gasket installation in access panel	34
26 Common impedance and its alleviation	35
27 Board layout guidelines	36
28 0V and supply track vee layout	37
29 Mounting of continuous decoupling capacitors	37
List of references	Inside back cover

Foreword

This Part of BS G 257, which has been prepared by Technical Committee ACE/66, is a design guide providing information to engineers involved at all levels in the hardening of civil aircraft and their systems against electromagnetic hazards (EMHs).

The design guide will be published in three Parts as follows:

- Part 1 *Guide to electromagnetic theory and the electromagnetic threats posed to aircraft*
- Part 2 *Guide to protection*
- Part 3 *Guide to clearance and testing*

This Part of BS G 257 provides the principles and resulting design practices which will result in a high degree of success in achieving electromagnetic compatibility (EMC). It is impossible to create a document the recommendations of which will result in complete success in all situations. This document, therefore, concentrates on the reasons for certain approaches to a problem and illustrates a design strategy by one or more practical solutions. The protection required for a given situation can only be arrived at by quantitative analysis of the electromagnetic hazard (EMH) protection design performance against the threats within the required cost, weight and volume restrictions.

Clause 3 covers the electrical design of the airframe in order to achieve an environment within the airframe which is amenable to the installation of an electronic/avionic system for survival in a hostile electromagnetic (EM) environment. The section is divided into two major parts; the design of the airframe in non-fuel areas and the design of the airframe in fuelled areas. The philosophy of design in the two areas is quite different if the airframe utilizes large quantities of carbon fibre composite (CFC).

Clause 4 covers the design of the systems installation to complement the airframe design as described in clause 3. Once again this section is divided into the design of the systems installation in non-fuel areas and design of the systems installations in fuelled areas.

Clause 5 is devoted to the design features to be considered which will result in good EMH protection performance. The issues considered include; the equipment interface, the equipment case design, printed circuit board (PCB) design and finally internal protection.

Compliance with a British Standard does not of itself confer immunity from legal obligations.

Summary of pages

This document comprises a front cover, an inside front cover, pages i and ii, pages 1 to 40, an inside back cover and a back cover.

Guide

1 Scope

This Part of this British Standard provides guidance on the design features of airframes and system installations necessary to achieve an acceptable level of EMH protection in a hostile EM environment.

2 Informative references

This British Standard refers to other publications that provide information or guidance. Editions of these publications current at the time of issue of this standard are listed on the inside back cover, but reference should be made to the latest editions.

3 Design of the airframe

3.1 General

Details of the airframe design can have major impacts on the implications of EMHs on safety or on the cost of ownership. Material choice affects screening performance and different materials also behave quite differently when a lightning arc attaches. The characteristic reactions to arc attachment and current flow from various materials should also be considered in relation to their propensity for causing hazardous situations, e.g. fuel explosion. The protection needs will depend on both the material and on the potential hazards and these are discussed separately below. Also to be considered is the distribution of highly conductive material in relation to the routing of system cables, as great benefit can be obtained by using structural materials to supply as much of the necessary attenuation in induced transients as possible.

3.2 Metallic airframe materials

3.2.1 Skins

3.2.1.1 Metal skins generally provide very good EM shielding, but are susceptible to damage from lightning arc attachment. Generally, aluminium skins of 2 mm thickness are necessary to prevent burn-through from any of the individual components of severe lightning. However, in trailing edge situations more metal is required. In such locations it is always advisable to design any cable routes so that puncture of the outer skin should not have an impact on the wiring, i.e. the arc, having punctured the skin should not form an attachment to the cables or cause damage to the cable insulation by heating on account of the cables being too close to potential attachment locations.

3.2.1.2 Where weight has been a problem, thin metal sacrificial foils have been glued to the outside metal skins. These provide almost unlimited protection from burnthrough for a single lightning strike, though once sacrificed, they provide no further protection until replaced. This technique is very effective where cables are constrained to routes very close to skins where arc attachment is likely, and thermal damage could be a consequence.

3.2.2 Substructure

Metal substructures beneath metal skins rarely need any protection at all since the skin effect (the effect that tends to keep electric current flowing on the outside of a conducting body) is very strong in good conductors such as aluminium, and internal structural currents are usually too small to measure.

3.3 Non-metallic airframe materials

3.3.1 General

Non-metallic structural materials in general provide very little inherent screening for systems wiring. Although non-conductive materials can, under some circumstances, provide protection from lightning arc attachment to cables and direct current injection, the isolation which they provide from an external EM environment can be generally discounted. Even CFC (carbon fibre composites) provides only limited electromagnetic screening at typical lightning frequencies (1 kHz to 10 MHz) as the resistivity of CFC necessitates large skin depths and hence penetration of magnetic fields, which may then couple transients onto wiring inside. In general, any significant magnetic field shielding should be provided by design and the consequent use of beams and webs provided for structural purposes, or by the metal included to meet the earth/power return requirements for equipment installed in the airframe.

3.3.2 Skins

3.3.2.1 Carbon fibre composite material

3.3.2.1.1 CFC skins can suffer very serious damage from a lightning strike as well as requiring additional measures to improve their EM field screening performance.

3.3.2.1.2 The poor electrical conductivity of CFC material combined with its poor thermal conductivity can give rise to apparently severe damage as a result of a lightning strike, in the form of tufting of fibres and loss of resin matrix. Heating of the CFC skins by a lightning arc root can give rise to temperatures of 200 °C and above and cables in proximity would have to survive such temperatures for periods of up to 1 min. In addition to the potential for attachment of an arc that penetrates the CFC skin (as with metal skins) there is an additional problem arising from CFC material. This involves the generation of very high resistive voltages even across inside surfaces which give rise to potential differences between wires or cable screens and structure that can puncture the insulation on the wire or cable. For this reason a voltage hold-off or insulation dielectric specification should be given for cable sheaths. Sacrificial surface metallization in the form of glued-on foils, metal flame spray or plasma spray, or metal foils or meshes cured in the surface ply are capable of giving significant protection against this type of damage.

3.3.2.1.3 Thin CFC panels (less than 0.7 mm) can be punctured by the shock-wave associated with the lightning high current return stroke causing exposure of system cables to arc attachment or airstream damage. Panels of up to 1.0 mm thickness made from layers of woven CFC fabric may show this effect. The only protection against this effect is to use sufficiently thick material.

3.3.2.2 *Non-conducting materials*

3.3.2.2.1 For non-conducting materials, there is usually a risk of puncture when a lightning arc tries to attach to conductive materials beneath the skin (including wires and cables). In some cases, sufficient protection can be provided by diverter strips, strips of metal or conductive material designed to capture the lightning arc and carry the lightning current safely back to a conductive structure. This is normal practice on radomes where covering the entire surface is impractical. Diverter strips can be sacrificial such as metal foils, or partially oxidized conductive metal particles which are apparently non-conducting and nominally radar transparent until sufficient voltage is available to cause breakdown when they become temporarily conductive. Solid metal strips will provide protection from many lightning strikes. In all cases, diverter strips should be on the outside of a non-conductive structure.

3.3.2.2.2 Where radar transparency is not required, overall coverage of the surface is an option and surface metallization will generally provide high levels of protection.

3.3.2.2.3 Non-conductive surfaces will often require anti-static paint finishes to prevent the storage of electrostatic charges and ultimate surface flashover which will cause surface degradation over a period of time, and radio noise. Static discharge problems in such cases can render some communications systems unusable.

3.3.3 *Substructure*

3.3.3.1 A CFC substructure, or any conducting substructure beneath CFC or non-conducting skins, should be expected to carry significant portions of any current flowing on the airframe. External protection involving metallization or diverters will reduce internal structure currents, but such currents will not, in general, be eliminated. Internal structures should, in such cases, be designed with sufficient current carrying capacity. No general guidelines can be formulated to ensure that this will be achieved. In general, structural needs are such that there will be sufficient conductor cross-section for expected internal currents. In cases of doubt, structural current analysis is necessary to predict the worst case conditions and sufficient cross-section should be designed-in to cater for the predicted need.

3.3.3.2 Since composite internal structures can be expected to carry large currents, metal parts (good conductors) may be expected to carry proportionally greater portions of structural lightning currents. In practice, currents of up to 20 kA have been measured in cable conduits in largely CFC structures, and analysis suggests that where CFC skins are thin and whole structure cross-sections are small, currents up to 40 % or 50 % of the total lightning current might flow in cable conduits. The more inductive nature of braided cable screens will slightly reduce the effect, and many cables routed in a common location will certainly lower the requirement made on each individual cable, though the very fact that there is increased current-carrying capacity from more cables will increase the portion of current carried collectively by the group.

3.4 *Bonding measures*

3.4.1 *General*

In non-fuelled regions of an airframe, bonding is required for the reduction of damage when severe lightning currents flow and to improve the shielding performance of the structure. This provides a quieter EM environment inside the structure for electrical/electronic systems and associated wiring. In airframes comprising a significant proportion of composite materials, there may be a requirement for the bonding of the metal structure available to supply some of the earth return conductivity for electrical power distribution within the aircraft. The cross-section of a metal conductor used as a power return will depend on the power requirements and the tolerance of ripple in equipments of installed systems. The metal available can be used to provide considerable protection for systems wiring. However, the relatively high conductivity of such metal will attract more lightning current to flow both inside a structure and in any cables routed close to the metal. It should be noted that taking advantage of greatly reduced common-mode induced voltages and currents may generate significantly increased differential-mode induced transients. Screening and twisting of wires will usually reduce this problem to tolerable levels.

3.4.2 *Metallic materials*

3.4.2.1 *Skins*

For metal skins there is little that can be done to improve bonding, either between skin panels or between skin and substructure, because of the need to reduce corrosion from moisture ingress into the joint. However, there are generally so many fasteners between a large metal structural component and its surroundings that a little conduction from each gives a satisfactory performance against lightning characteristic frequencies.

3.4.2.2 Substructure

Where specific bonding requirements are needed from internal structural joints, or metal to metal joints (e.g. bonding strap tag to metal structure) then the contacting surfaces should be:

- a) cleaned of all insulant, oxides and grease;
- b) have a steel fastener inserted and tightened;
- c) be oversealed to prevent ingress of moisture.

Generally in non-fuelled zones there will be a need for such measures only where specific bonding is needed, e.g. between moving parts, or between demountable bodies and structure.

3.4.3 Non-metallic materials

3.4.3.1 Skins

The bonding of non-metallic skins is not considered practicable in general. Bonding of non-conductors is not meaningful, and conductive contact with CFC is subject to so many variables of the material and its construction that reliable bonding has proved to be possible only by setting a quality target (in terms of a direct current (DC) resistance measurement) and the removal and reinsertion of a fastener repeatedly until a satisfactory reading has been obtained. The value of the DC resistance should be set for the particular materials and fasteners involved since unachievable targets can easily be specified by default. This may be done by constructing dry joints and measuring the resistance from a number of bolts and the surrounding CFC structure. Values that deviate by more than 5 times the norm should be ignored and a mean of the lower figures used as a quality level.

3.4.3.2 Substructure

Where there is no corrosion implication for a fastener in contact with a composite material, then dry installation and oversealing may be attempted to provide bonding between CFC and CFC, or CFC and metal inside a structure.

3.5 Additional metal

3.5.1 General

It may be advantageous to provide additional non-structural metal in some cases where the composites used in the structure cannot provide the EM performance necessary, or where it has been shown that extra weight in the structure will off-set a larger weight penalty in the systems installation (in additional cable screening for instance). It is then necessary to consider all the implications of the extra metal for the aspects of the other EM hazards. For example, the provision of a volume in a fuselage for avionics equipment with a reduced EM environment capability may necessitate the supply of a metal film over the entire inside or outside surface of that volume.

3.5.2 Advantageous locations

Metal added for lightning protection is generally best situated outside the airframe where fusing, sparking, debonding or deforming will not cause damage to anything else. Metal provided to enhance EM shielding performance is generally best situated inside the airframe where the sealing requirements for joints are less difficult to combine with the requirements for good electrical contact. In both cases, metal and joints should be designed to comply with natural current flow directions and routes, as high frequency currents will always flow along low impedance (wide) paths rather than simply along low resistance paths. This is not true for low frequency currents which will be controlled entirely by the provision of conductive paths.

3.5.3 Cross-sections

Where lightning currents are to be carried, the cross-section of additional conductive material should be capable of carrying the current that might flow via the material in the expected worst case. This may be calculated for the particular case or, as a general guide, provision should be made for the total lightning current event to pass. In this case 9 mm² of copper or 14 mm² of aluminium alloy (not aluminium lithium) are required to keep the temperature rise of the conductor below 200 °C, though very high resistive voltages will be induced along such a slim conductor. Where a specification of resistive voltage that could be developed in associated wiring can be defined, then a suitable cross-section may be calculated. In general, there will be a requirement for earth/power return inside a composite airframe with typical cross-sections of 1500 mm² of aluminium.

3.5.4 Electrical features of installation

3.5.4.1 For shielding enhancement it will usually be necessary to provide a good, low resistance joint over the whole length of the interfaces between additionally provided metal and other metal, whether structural or screening, to avoid penetration of EM fields through gaps.

3.5.4.2 Additional metal provided for lightning protection should be bonded to avoid excessive sparking and erosion, and to avoid the effects of magnetic forces arising from current flow, which can cause breakage or bending. Whip-lash of a bonding strap, which snaps as a result of magnetic forces, can cause secondary damage when the strap impacts on other materials. Long, high current arcs are drawn out on these occasions which can cause heating and burning damage.

3.6 Non-fuel zones

3.6.1 The potential for damage in non-fuelled regions of an airframe is less than in fuel zones but, whilst specific electromagnetic field screening is not likely to be a requirement in fuel tanks, it will usually be desirable, if not essential, in non-fuelled regions. It is desirable to protect any electrical or electronic circuit or system from actual damage from voltage or current transients and from physical damage to cables and wires. In fuel zones, it is essential to prevent voltage arcing between points at different potentials and sparking at the arc root.

3.6.2 From a mechanical point of view, any puncture of the skin in pressurized sections of an airframe may have serious consequences with airframe wiring being sucked out, or exposed to aerodynamic pressures. In unpressurized regions, a puncture may generate an undesirable repair liability and the possibility of damage to airframe wiring through exposure to the airstream.

3.7 Fuel zones

3.7.1 General

The materials commonly used in aircraft and aircraft component manufacture are all pyrophoric (emit sparks when scratched or struck) and will burn when heated to sufficiently high temperatures by excessive current densities. The sparks of incandescent material seen flying from such a source are actually on fire with continuous or rising temperatures rather than being cooled by contact with the cooler surrounding air and, consequently, are capable of igniting fuel. Wherever possible, the choice of material for any component in contact with fuel or fuel vapour should be of a non-pyrophoric nature.

3.7.2 Metallic materials

3.7.2.1 Skins

Skin effect prevents current flow inside a metallic structure to such an extent that puncture is generally the only cause for concern relating to lightning attachment to metal skins. Provided that the skin thickness is greater than 2 mm, puncture of aluminium alloy is unlikely, but slightly greater thickness of aluminium-lithium alloys may be required. Hot-spots on the inside of a skin panel opposite to the lightning arc channel could cause ignition of fuel or fuel vapour. Special protection may be needed in these cases. Tests on aluminium alloy skins have demonstrated that the necessary conditions are not maintained for long enough, and that fuel ignition from such a cause is unlikely. Protection of skins less than 2 mm thick may be achieved using sacrificial metal as described in 3.3.2.2.

3.7.2.2 Substructure

3.7.2.2.1 Metal substructure to metal skin bonding is seldom the cause of any fuel related problems, since skin effect keeps current on the outside of a structure as described in 3.3.3.

3.7.2.2.2 Metal substructure to CFC skin bonding can be a cause of serious problems because the high conductivity of the metal in comparison to that of the CFC causes very large currents to flow in the metal substructure. The major problem is allowing the lightning current from the skin near a lightning attachment to enter the substructure without generating sparks which could ignite the fuel. A common approach to solving this problem is to provide some form of surface metallization for the external skin to divert current from the internal metal. New types of anti-sparking fastener may provide adequate protection, but they should be tested on a case-by-case basis.

3.7.3 Non-metallic materials

3.7.3.1 Skins

Non-metallic fuel tank skins can be found both on integral tanks and auxiliary tanks. In these cases, it is essential that puncture of the skin should not occur. The diverter technique described in 3.3.2.2 will seldom be sufficient as a finite probability of puncture remains. Whole surface metallization is generally essential and the skin should be sufficiently tough to prevent any possibility of penetration caused by the lightning attachment shock wave.

3.7.3.2 Substructure

A CFC substructure can present problems, as can a metallic substructure, when lightning current flows from CFC skins to a substructure near a lightning arc attachment where current densities are high.

3.7.4 Bonding measures

3.7.4.1 General

The principal aim of electrical bonding of the structure in fuel tank regions is prevention of voltage arcing (where voltages build up to the point of breakdown), or thermal sparking which is the emanation of incandescent particles from a point of contact carrying a current density beyond its capacity without heating the materials at the contact above their melting point. Either of these phenomena is capable of igniting fuel vapour. An important consideration in the provision of any conductivity in a joint, or through the application of specific bonding techniques, is the implication of the conduction of currents from sources other than the intended one. For example, it is easy to provide conductivity sufficient for static electricity dispersion (ESD) with very small cross-section conductors. However, if there is a possibility of lightning current flowing via the same route then the very small conductor required for static electricity would be fused by the respective portion of lightning current.

3.7.4.2 *Metallic materials*

3.7.4.2.1 *Skins*

Little attention is required for bonding of metallic skins, except where they join onto CFC or low conductivity materials while still over fuelled regions. In such cases the same measures as required for joining CFC skins should be applied (see 3.7.4.4).

3.7.4.2.2 *Substructure*

A metallic substructure presents no problems beneath metallic skins, but under CFC skins specific attention should be paid to prevent sparking of the fasteners and sparking between the skins and substructure. It is easier to achieve non-sparking joints between CFC skins and the metal substructure than between CFC skins and CFC substructure, and this has been done in some cases by a combination of anchor nuts rivetted to the substructure and surface metallization in the form of metal mesh on the outside skins. In general, however, it is best to treat this situation in the same way as CFC skins over a CFC substructure.

Providing a bonding joint between metal and metal is much easier than between metal and CFC. The metal surface should be abraded clean of any insulating material or oxides and a cleaned washer and fastener inserted and tightened. Sealants and anti-corrosion agents may be applied subsequently to the whole joint. In general, such joints can be checked for quality using a DC resistance check, (see 3.7.5.4).

3.7.4.3 *Non-metallic skins*

3.7.4.3.1 *Skins*

Non-metallic skins are the major source of problems as they allow current to penetrate to the substructure. In lightning attachment zones, fasteners should be able to withstand the incident lightning threat for the zone without any observable sparking inside the fuelled volume. Even in areas where lightning is most unlikely to attach to a fuselage, fasteners should be able to carry the conducted lightning current in that part of the structure assuming the worst possible combination of lightning entry and exit points.

3.7.4.3.2 *Substructure*

The same conditions apply to a non-metallic substructure beneath non-metallic skins as are applied in 3.7.4.4. Beneath metal skins, it is unlikely that any special measures would be required.

3.7.5 *Additional metal*

3.7.5.1 *Advantageous forms*

3.7.5.1.1 It is very important that spark sources are not introduced into fuel containing regions made predominantly of composite materials. It is, therefore, unlikely that additional metal will be added inside the fuel or fuel vapour containing

volume. It is extremely difficult to manufacture a reliable joint that will not spark when high currents are carried, and metal inside a composite structure will carry a disproportionately large part of the structural current. In these cases it is strongly recommended that any additional metal required is applied outside the fuelled volume. If additional metal is used, the requirements of 3.6.1 should apply.

3.7.5.1.2 No general rules can be formulated for cases where additional metal has to be provided in a fuel containing region. These cases should be designed on a one-by-one basis and testing is essential to prove the adequacy of the design. In general, the problems of designing any mechanical or electrical component that will always be safe inside an explosive environment are so great that the issue is best avoided by using external mounting. It is essential that any penetration of the fuelled regions for gauging, fuel pumping and the like complies with non-sparking requirements.

3.7.5.2 *Cross-section*

3.7.5.2.1 Cross-sections of additional metal should always be sufficient to carry expected lightning currents without fusing, except in the case of external sacrificial foils where some local loss is expected and desirable. If satisfactory analysis of current distribution is not available, then a useful guide is that 9 mm² of copper or 14 mm² of aluminium alloy (not lithium-aluminium alloy) is required to carry a lightning initial return stroke current with a temperature rise of 200 °C.

3.7.5.2.2 Cross-section requirements at joints are difficult to define. If contact areas could be maintained as defined above, then current carrying capability will also be maintained, but only a butt-jointed weld would be safe from sparking. For joints using fasteners, the cross-section of the current path through the joint should be assumed to be limited to the contact between fastener head and surface, fastener shank cross-section and the area of contact between the bolt and washer, or whichever component has been used to clamp the fastener. The area so formed will generally have to be far greater than the limits given in 3.7.5.2.1 to prevent sparking. Twice the area or more may be required and any new technique should be tested if it is to be used in a fuel/fuel vapour region.

3.7.5.3 *Electrical features of installation*

Any bonding or additional metal in fuel zones should be inherently of a non-sparking nature, therefore bonding straps that are made of multi-wire or braided construction should be avoided, even when they are provided for electrostatic purposes.

3.7.5.4 *Bond resistance*

The typical orders of magnitude of bond resistances are given in table 1.



Table 1. Bond resistances	
Points of measurement	Resistance mΩ
Aircraft structure	
Between the foremost metal extremity of the aircraft and every other metal extremity	10
Reference ground points	
Between any common reference ground points attached to the metal aircraft structure (measured with 150 A DC)	1
Individual connections	
Between any cable termination and the metal base on which it is mounted	0.1
Current returns through aircraft structure	
Between any cable termination used as a current return and the nearest point on the aircraft's metal structure	0.1
Equipment cases	
Between the metal case of any equipment producing or using electromagnetic energy at radio frequencies, and the aircraft metal structure.	10
Between the metal case of any equipment producing or using electrical energy at DC or at power frequencies, and the aircraft's metal structure	10
Fuels and flammable gases	
All metal parts, including aluminium alloy pipes, in contact with fuels and flammable gases, and the aircraft's metal structure	1000
Hydraulic fluids or air circuits	
All metal pipes and equipment carrying hydraulic fluid or air, and the aircraft's metal structure	500
Electrical shock hazard	
Between metal conduit carrying electrical cables and the aircraft's metal structure.	10
Between all metal parts and equipment which can be touched by personnel and the aircraft's metal structure.	10
Static charging	
All isolated conducting items (except antennas) mounted externally on the aircraft, and the aircraft's metal structure.	100
Antennas	
Dependent on particular design. In general the impedance between the antenna flange and the aircraft's metal skin or structure should be small compared with the operational impedance.	1
NOTE. Due to the diversity of situations arising, these figures cannot be expected to be applicable in all circumstances.	

4 Design of the system installation

4.1 General

4.1.1 In clause 3, an airframe design strategy was discussed that would produce an airframe with the electrical properties necessary to allow the installation of electrical and electronic systems without excessive penalties of protection in terms of cable screening and interface filtering within equipment. Clause 4 provides advice for the installation of electrical and electronic systems within, or attached to, an airframe whose electrical properties result from the application of the design strategy in clause 3.

4.1.2 Very special conditions apply to circuits concerned with the firing of electro-explosive devices (EEDs), the object being to avoid inadvertent operation even in the presence of electromagnetic interference.

4.1.3 Within the airframe the systems installation advice is broadly divided into:

- a) non-fuelled areas; and
- b) fuelled areas of the airframe (or those areas which could contain fuel vapour).

This distinction results from a particular problem that arises in the case of the installation of systems containing long lengths of conducting material in CFC airframes, e.g. wiring in electrical systems, metallic pipes, conduits, control rods and driveshafts. All these system components can result in the flow of very high currents, or the development of very high voltages across small gaps during excitation of the airframe by high-level pulse threats such as lightning. These currents and voltages can cause electrical arcing and sparking with enough energy to ignite a fuel/air mixture. It is unusual, though not unknown, to have such a situation in a metallic airframe. In such unusual cases the measures outlined for the installation of systems in CFC integral fuel tanks may be considered for some situations in metallic airframes.

4.2 System installation in non-fuelled areas of the airframe

4.2.1 General

The majority of cases are covered in 4.2 because most of the system installation will be in areas of the aircraft where electrically induced sparking due to lightning, though undesirable, will not be a hazard. The design strategy attempts to keep such sparking to a minimum in the interest of reliability. There are parts of the system that carry explosive or flammable mixtures in pipes through non-fuelled areas of the airframe; these will be covered in clause 4.3.5. Together with systems being installed in areas of the airframe that are not intentionally fuelled but, as a result of seepage, contain flammable mixtures.

4.2.2 Cable routing

4.2.2.1 General

In the case of an all metal aircraft, preferred cable routes in the airframe can be identified by inspection. The actual induced voltage and current resulting from that routing can be obtained by complex computational analysis. In the case of mixed CFC and metallic airframes, the best routes are not always so clear. However, there are some general rules that can be applied to reduce the threat posed by EMHs.

4.2.2.2 Cable routing in an all-metal airframe

4.2.2.2.1 It can be shown that cable routes giving low induced voltages and currents in the case of lightning will also be acceptable for higher frequency threats. However, the advantage of a particularly well chosen cable route over a less advantageous route becomes less distinct at higher frequencies and, above 100 MHz, the mechanisms are more localized and overall cable routing becomes a less dominant issue.

4.2.2.2.2 In the case of an all-metal airframe carrying lightning current, the coupling between the current on the airframe and the cables located within the airframe results from aperture coupling provided the cable route does not cross any areas of poor airframe bonding. Two-dimensional analysis of such coupling mechanisms can be undertaken and typical results are shown in figures 1a) and 1b). In this case, a simple situation of a circular cross-section tube with a slot along the length is analysed for the current flowing along the line (i.e. into the paper). The lines shown are plots of constant coupling factor which indicate the open circuit voltage that would be induced in a cable at that position for a particular rate of rise of current flowing in the tube. By duality of fields, it can be shown that the regions of low magnetic field coupling will also be regions of low coupling to the electric field as a result of an external charge distribution.

4.2.2.2.3 Figure 1 shows that the deeper into the tube the lower the coupling factor, and therefore the lower the open-circuit voltage (and short-circuit current). For the geometry shown in figure 1a), such that the longitudinal slot is smaller for a given diameter relative to figure 1b), the penetrating flux will also reduce. This indicates that the more the local structural component can surround the wire, the more protection it will offer. Figure 2 shows the types of geometry that can be found in airframes and which can be used advantageously in the routing of cables. The shaded areas show the limit of usefulness for the location of cables.

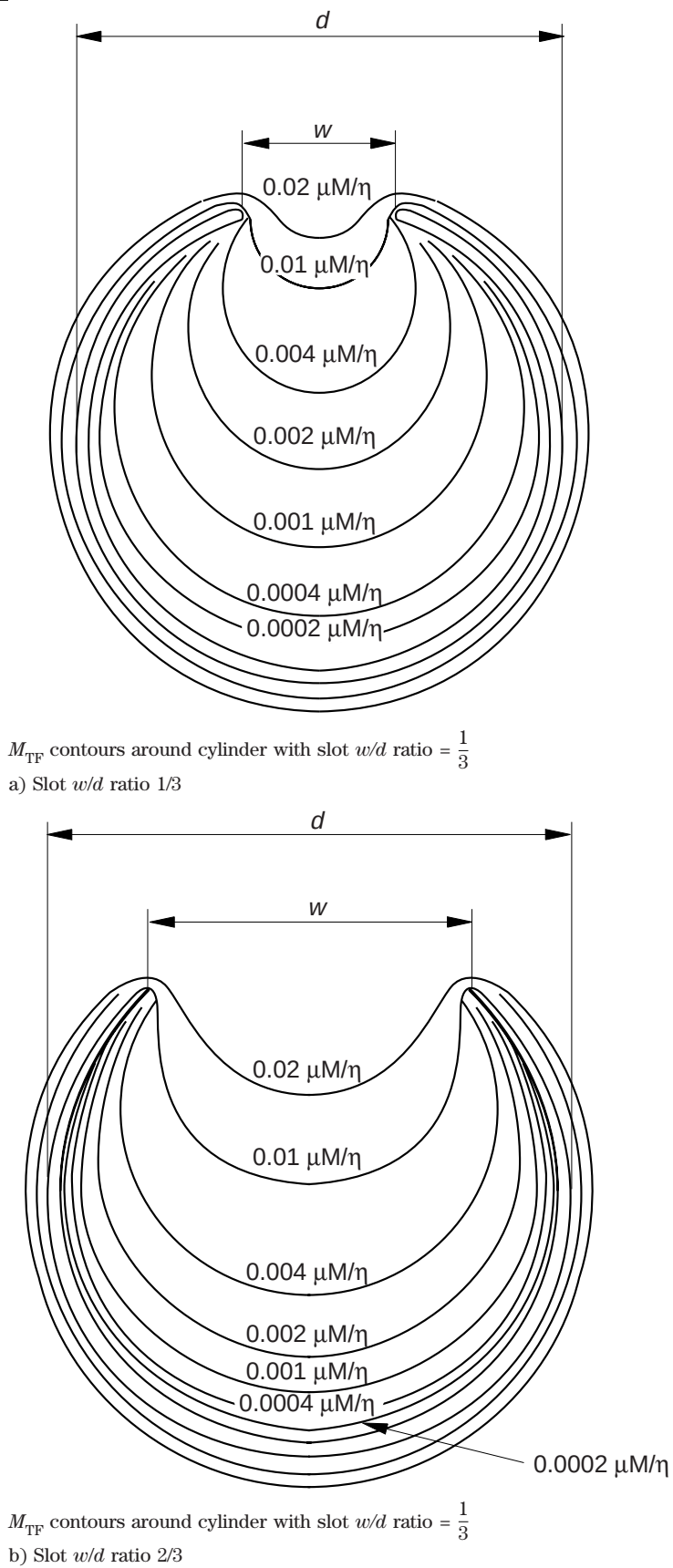


Figure 1. The effect of airframe geometry on airframe current to effect coupling

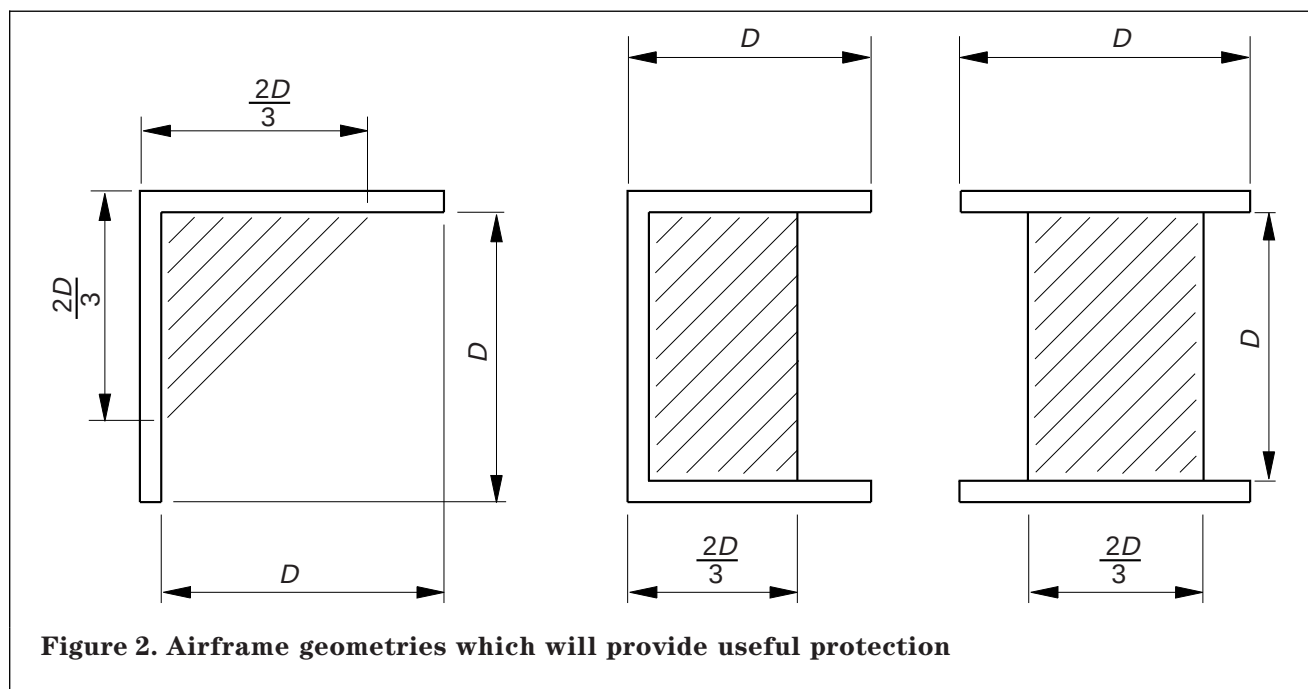


Figure 2. Airframe geometries which will provide useful protection

4.2.2.2.4 In the case of the total cross-section of an all metal airframe, the likely sites for cable screening can be identified as shown in figure 3. The assumption is made that there is electrical bonding at the corners into which the cables have been placed and this is usually the case for fastened joints in a metallic airframe.

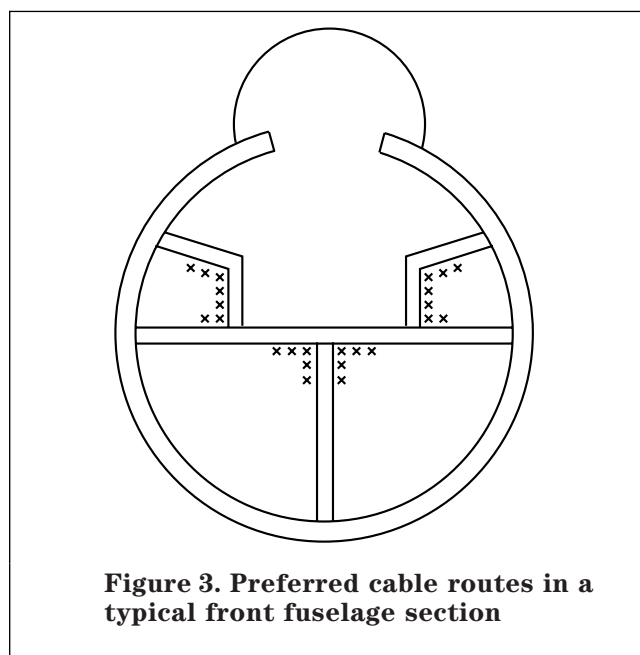


Figure 3. Preferred cable routes in a typical front fuselage section

4.2.2.2.5 The general recommendations for routing cables in all-metal airframes can be stated quite simply:

- It should be ensured that the cable routes are towards the centre of the airframe, away from the apertures in the skin of the aircraft (e.g. canopies, access doors etc.).
- Where possible, cables should be run along concave, longitudinal geometries (i.e. keeping the cable in the corners) since this can reduce the screening required.

4.2.2.3 Cable routing in mixed CFC/metal airframes

4.2.2.3.1 Due to the reduced electrical conductivity of CFC, currents of low frequency flowing on the outside surface also flow, virtually unattenuated, on the inside surface. E.g. for CFC of thickness 1 mm, such a statement is true for frequencies of less than 10 MHz. The electric fields that are normal to the surface of the aircraft and which result from charge distributions on a CFC airframe, will behave in a very similar manner to their behaviour on metal, therefore cable routing policies are still valid in the case of electric field coupling.

4.2.2.3.2 Another aspect of CFC airframes which should be considered, and which is a direct result of the transparency of CFC to magnetic fields and the associated currents, is the significant voltage drop in the direction of current flow. This arises from two compounding effects; the large current density that occurs on the inside surface and the low conductivity of CFC to that current. Resultingly high voltages are produced.

4.2.2.3.3 The problem of large potential differences across the surface of CFC is avoided by either ensuring that the cable routing is designed to be as close as possible to longitudinal metallic components of the airframe, or by using a single-point system earthing philosophy.

4.2.2.3.4 The current distribution in airframes consisting of substantial amounts of CFC combined with metallic components, particularly those that have significant length in the direction of the major axis, is difficult to predict by a simple inspection and an analytical technique should be used. However, some general observations can be made. In clause 3 it was shown that by having at least 1500 mm of metal running the entire length of each of the major airframe components containing electrical systems, a reduction of the internal voltage (imposed on the system) from one end to the other will be achieved. However, such metallic current paths will carry significantly higher currents than would be expected in the all-metal case. Routing cables close to such metallic components will reduce the voltages impressed on those cables (as a common mode voltage), but the magnetic field around the cable will be significant. This can be alleviated in a number of ways including the choice of geometry of the metallic component, proximity of the signal cable and its associated return cable (e.g. twisted pairs or coaxial cable) and screening. The choice of cable will be discussed later in 4.2.3.2. The subject of interest in this clause is the geometry of the metallic components along which the cable is to be routed. From the discussions in 4.2.1.1, it is clear that metallic geometries which contain concave corners are advantageous in protecting the cables from coupling fields.

4.2.2.3.5 The discussions above lead to the following simple recommendations for good cable routing from the point of view of reduced coupling with electric and magnetic fields:

- a) cables should be routed close to metallic components having their major axis parallel to the major axis of the airframe component under consideration. The effect is enhanced with the length over which this criteria can be satisfied;
- b) the areas of the aircraft made from CFC and of thickness < 1 mm can be considered to be almost transparent below 10 MHz and, therefore, should be treated as apertures for the sake of cable routing;

c) those metallic components against which cables are to run should be considered for their cross-sectional geometry. The designing into the component a concave cross-section in order to reduce the requirements for cable screening and equipment filtering should be considered.

d) if suitable metal does not exist in the airframe design the provision of metal should be considered, purely from the point of view of reducing common mode voltage. If the metal added can have the correct geometry (a metal conduit is the ideal but there may be a clash with maintainability requirements), then differential mode coupling can be reduced also.

4.2.2.4 Cable segregation

4.2.2.4.1 Cable routing in the airframe was discussed in 4.2.1.1. Following those guidelines will reduce the coupling between the external fields and the cables of a system for a given airframe and system installation design. In addition, the advice given will also reduce the coupling between systems on the aircraft resulting from the use of common return paths and, to some extent, cable to cable field coupling. This arises because the cables should be routed next to a metallic component resulting in reduced common-mode impedance in the shared return of the airframe.

4.2.2.4.2 Cable segregation also provides considerable isolation between the cables of separate systems. Optimization is achieved by analysis of the system installation. Some simple rules that can be applied are explained and summarized in 4.2.2.5 and 4.2.2.6.

4.2.2.5 Cable segregation within the same system

4.2.2.5.1 The same general routing for all cables arriving at the same piece of equipment should be chosen to ensure that they are referenced to the same piece of the structure and to reduce differences in the common-mode interference voltage between different parts within the equipment. It is also worth dividing the cabling into bundles that can be categorized as Susceptible (S), Emissive (E) or Either (X). These bundles should be placed in locations in the route in relation to the field levels and the ranking of their susceptibility, i.e. $S > X > E$. The geometrical separation can be arrived at by analysis, or from advice from the equipment manufacturer. However, some general guidelines are given in table 2 for EMC categorization and in table 3 for recommended cable types.