



AEROSPACE RECOMMENDED PRACTICE

ARP5672™

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Aircraft Precipitation Static Certification

RATIONALE

New FAA regulations require airplane electrostatic control, including precipitation static. This document provides a recommended practice for precipitation static control and verification.

ARP5672 has been reaffirmed to comply with the SAE Five-Year Review policy.

FOREWORD

Whenever a reference document appears in this Recommended Practice, it carries the minimum revision level of the reference document acceptable to meet the intended requirements. Later versions of the reference document are also acceptable but earlier versions are not acceptable. In all cases, other documents shown to be equivalent to the reference document are also acceptable.

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1. SCOPE

Aircraft surface precipitation static (p-static) charge can be generated when aircraft fly through ice particles, rain, snow and dust. However, in the context of p-static protection, this document is used for providing guidance for any thing that charges the outer surface of the aircraft (e.g. engine exhaust). P-static discharges from the aircraft can disrupt aircraft communication, navigation, and surveillance radios, and can damage aircraft radomes and windshields. This SAE Aerospace Recommended Practice (ARP) defines design considerations for aircraft p-static control and related methods to verify acceptable aircraft p-static performance. This ARP addresses p-static charging due to the aircraft flying through ice particles, rain, snow and dust. It does not address other triboelectric charging that may be present in an aircraft, such as triboelectric fuel charging or environmental control system or air conditioning static charging. It does not address electrostatic charging created by passengers or crewmembers, or electrostatic discharge hazards to electronics and systems.

The purpose of this document is to provide information and guidance concerning an acceptable means, but not the only means, of compliance with Parts 23, 25, 27, and 29 (23.867, 25.899, 27.610, and 29.610) of the Federal Aviation Regulations (FAR) and European Aviation Safety Agency (EASA), applicable to aircraft for protection against the adverse effects of precipitations static. This ARP provides general information on aircraft surface p-static charging mechanisms and the impact p-static has on aircraft systems. It addresses elements of effective aircraft p-static control design. Finally, it defines methods for verifying acceptable aircraft p-static control. Accordingly, this material is neither mandatory nor regulatory in nature and does not constitute a regulation.

Aircraft p-static control should be addressed early in the aircraft design to be effective. Effective aircraft design features and effective verification methods will result in an aircraft that can be operated in p-static charging conditions without adverse impact to the aircraft systems.

The existing reports and guidance do not provide standards for aircraft design to control p-static or standard methods to verify acceptable aircraft p-static control. This document provides acceptable approaches to design effective aircraft p-static control, and provides acceptable methods to verify the design effectiveness.

Existing aircraft certification regulations in Title 14 CFR 25.899, 27.610(d) and 29.610(d), specifically address aircraft p-static control. These regulations include the requirement to minimize the accumulation of electrostatic charge in order to reduce to an acceptable level the effects of static electricity on the functioning of essential electrical and electronic equipment. Compliance may be shown by bonding the components to the airframe, or incorporating other acceptable means to dissipate the static charge. Title 14 CFR 23 is an exception, as it does not specifically address aircraft p-static control, however p-static is considered a foreseeable operating condition, so all aircraft designed for operation in instrument meteorological conditions (IMC) should have certified p-static control. Prior to this document, the absence of specific standards or guidance material resulted in inconsistent application and verification of the requirements for aircraft p-static control.

2. RELATED DOCUMENTS

2.1 FAA Advisory Circulars (AC)

Available from the US Department of Transportation; Subsequent Distribution Office; Ardmore East Business Center; 3341 Q 75th Avenue; Landover, MD 20785

AC 23.1309-1C	System Design and Analysis
AC 25.899-1	Electrical Bonding and Protection Against Static Electricity
AC 25.1309-1A	System Design and Analysis
AC 27.1B	Certification of Normal Category Rotorcraft
AC 29.2C	Certification of Transport Category Rotorcraft

2.2 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or 724-776-4970 (outside USA), www.sae.org.

ARP1870 Aerospace Systems Electrical Bonding and Grounding for Electromagnetic Compatibility and Safety

2.3 Military Documents

Available from the Document Automation and Production Service (DAPS), Building 4/D, 700 Robbins Avenue, Philadelphia, PA 19111-5094, Tel: 215-697-6257, <http://assist.daps.dla.mil/quicksearch/>.

MIL-DTL-9129E Dischargers, Electrostatic, General Specification for

MIL-STD-464A Environmental Effects, Requirements for Systems

2.4 Other Publications

J. E. Nanevicz, Precipitation Charging and Corona-Generated Interference in Aircraft, SRI Technical Report 73, 1961, Stanford Research Institute

J. E. Nanevicz, Precipitation Charging and Corona-Generated Interference in Aircraft, SRI Technical Report 77 Project 2494, 1968, Stanford Research Institute

J. P. Glecier, Aircraft Static Discharger Analysis Technique, 1999 International Conference on Lightning and Static Electricity (ICOLSE), SAE/P-99/344, 1999-01-2368, p. 239, ISBN 0-7680-0393-8

J Heeter, Precipitation Testing on Large Transport Airplanes, International Conference of Lightning and Static Electricity. ICOLSE 2005, Lightning and Static Charge Association, September 2005, PST50

P-static Protection for Jet Aircraft / A Summary", Granger Associates Report, November 1968, (Adapted from the work of J. E. Nanevicz)

R. J. Brun and R.G. Dorsch, "Impingement of Water Droplets on an Ellipsoid with Fineness Ratio 10 in Axisymmetric Flow", NACA Technical Note 3147, May 1954

2.5 Definitions and Acronyms

2.5.1 Definitions

P-STATIC: P-Static is the process of charging the aircraft with precipitation particles. It results in static electrification of the airframe by frictional charging of the precipitation particles. During triboelectric charging, the potential of an aircraft increases until a threshold is reached where electrical discharges occur. These electrical discharges generate electromagnetic noise that may interfere with both navigation and communications. Other sources that can create discharge conditions include, engine exhaust non-neutrality (at low altitudes), and exogenous electric fields (between oppositely charged cloud regions).

ARCING: An electrical discharge between surfaces at different potentials. The discharge can produce broadband noise extending through 1,000 MHz.

ELECTRICAL BOND: An electrical connection between conductive surfaces that allows charge to flow without disruption.

CORONA: A luminous discharge that occurs as a result of an electrical potential difference between the aircraft and the surrounding atmosphere. This occurs when the aircraft potential increases above the ionizing threshold of aircraft areas with small radius of curvature such as the wing tips, vertical and horizontal stabilizers and blade antennas.

CROSS CHARGING: Asymmetric charging of the aircraft due to the aircraft being in an external electric field. Cross charging is often referred to as exogenous charging.

GROUND: An electrical connection to the main airframe

STREAMERING: The branch-like ionized paths that occur as a transition phase after a corona regime. Streamers occur for instance across insulating dielectric surfaces to the metal airframe. This noise source is generated over dielectric surfaces such as radomes, fiberglass winglets and other fiberglass panels positioned on frontal impact areas of the aircraft, if not properly treated. As particles strike, they deposit charges, positive or negative, on the dielectric surface. The charge density increases until the electric field reaches the ionization threshold point producing coronas and streamers which generates broadband radio noise.

TRIBOELECTRIC CHARGING: The generation of static electricity that results from two materials coming into contact with sufficient velocity that one of the materials comes away with a positive charge; the other receives a negative charge. Tribo comes from the Latin word meaning "to rub."

INSTRUMENT METEOROLOGICAL CONDITIONS: Weather conditions below the minimums prescribed for flight under Visual Flight Rules (VFR).

2.5.2 Acronyms

AC	Advisory Circular
AMM	Aircraft Maintenance Manual
AM	Amplitude Modulated
ADF	Automatic Direction Finder (radio)
AGL	Above Ground Level
AOA	Angle Of Attack
CDL	Configuration Deviation List
CFR	Code of Federal Regulations
CMM	Component Maintenance Manual
EASA	European Aviation Safety Agency
EMI	Electromagnetic Interference
FAA	Federal Aviation Administration
HF	High Frequency (radio)
HV	High Voltage
HVPS	High Voltage Power Supply
IFR	Instrument Flight Rules
ILS	Instrument Landing System
MSL	Mean Sea Level
OEM	Original Equipment Manufacturer
RF	Radio Frequency
SAE	Society of Automotive Engineers
VFR	Visual Flight Rules
VHF	Very High Frequency (radio)
VOR	VHF Omnidirectional Range

3. BACKGROUND

P-static is the term used to describe electrostatic or triboelectric charging of aircraft surfaces that collide with dust, ice crystals, rain, sand, smoke, snow and other particles during flight. Contact with these particles transfers charge at the point of impact on the aircraft exterior surface, which results in an electrostatic charge accumulation on the aircraft [2.4]. The charge accumulation, if not properly managed, will continue to develop on aircraft exterior surfaces until an electrostatic discharge occurs by high voltage corona typically at the enhanced electric field locations at the extremities of the aircraft. Also, if untreated surfaces are exposed to precipitation impingement streamer across dielectric surfaces and discharging of unbonded metal surfaces may occur. These discharges consist of extremely short pulses. These short pulses with fast rise times radiate radio frequency energy, which may have spectral content that extends into the hundreds of megahertz. When aircraft radio receivers receive the energy from these pulses, the noise-like signals can be strong enough to interfere with the radio receivers and other sensitive electronics. The result can be loss of, or interference with, the communication, navigation or surveillance functions performed by the radios or other aircraft electronics.

4. P-STATIC PROTECTION DESIGN AND COMPLIANCE

The following six activities are elements of an iterative process for design and verification of aircraft with respect to control of p-static interference on the communication and navigation systems. The order of activities, and the iterative application of them for a particular situation, is left to the applicant and strict adherence to the order in the list is not intended.

1. Define aircraft configuration, operating conditions and materials (Section 5.0).
2. Establish the aircraft p-static charging environment (Section 6.0).
3. Define aircraft p-static protection design (Section 7.0).
4. Verify p-static protection effectiveness (Section 8.0).
5. Implement corrective measures (Section 9.0).
6. Maintenance (Section 10.0)

5. DEFINE AIRCRAFT CONFIGURATION, OPERATING CONDITIONS AND MATERIALS

Prior to considering p-static protection for a new design, the aircraft configuration, operational environment and materials should be defined. This allows an estimation of the potential locations and magnitude of p-static charge accumulation and the possible threat to the aircraft systems from the resulting static discharges. It is then possible to determine the appropriate p-static control methods in order to mitigate any possible adverse affects. The appropriate verification process can then be determined, and agreed with the authorities, in order to demonstrate compliance to the p-static requirements. Some items to consider include:

- The p-static environment, control methods and verification process will be different for airplane and for rotorcraft, due to their unique configurations and operations.
- For airplanes, the maximum p-static environment will be dependent upon the airplanes speed in various phases of flight as well as the aircraft frontal area, which will vary with the size and configuration of the airplane. This determines the number of static dischargers that may be required.
- For rotorcraft the maximum charging occurs from particulates impinging on the rotating blades. Charging rate is also influenced by proximity of the rotorcraft to the ground as a result blowing ground particles into the air.
- The ability of the airframe structure and components to dissipate static charge will be dependent upon the bonding technology and upon the materials used, i.e. aluminum, fiberglass, carbon fiber, etc., which may determine the need for the appropriate conductive coatings to be applied. Materials known to accumulate and store charge should be addressed to prevent discharge that may interfere with aircraft systems.

- The potential accumulation of electrostatic charge and its effects on aircraft functions will depend upon the intended operational environment. Airplanes or rotorcraft intended only for VFR operation must avoid flight under Instrument Meteorological Conditions in which significant p-static build up can occur and may not be equipped with systems that could be affected by p-static dissipation. Airplanes or rotorcraft intended for IFR operation will not be able to avoid the meteorological conditions in which significant p-static build up can occur. Some of the systems that perform functions essential for IFR operation are potentially susceptible to p-static interference and additional verification may be appropriate for these systems.
- Some aircraft systems are inherently more susceptible to RF emissions from p-static discharges, such as ADF, VHF receivers etc. However other systems such as digital electronic systems, that are not designed to be receivers, may also be susceptible unless the appropriate considerations are made in the aircraft and equipment design and installation.

6. ESTABLISH THE AIRCRAFT P-STATIC CHARGING ENVIRONMENT

6.1 Aircraft Environment

The p-static charging on an airplane is governed by the speed of the airplane, the particle concentration in which the aircraft is flying and charge transfer per particle. The maximum p-static environment will occur when the aircraft encounters the maximum charging environment. The net charging current is the difference between the charging current and discharging current. Since the capacitance of the airplane is small (less than 1 μF), and the net charging current is of some tens of microamperes, the aircraft potential increases almost immediately, producing electrical field at the aircraft extremities which reaches the corona threshold. The charging current I_T of the airplane can be expressed by the following equation. Equation (1) can be used to predict the theoretical maximum charging rate of the airplane. This value can be used as a measure for design of the static discharger system.

$$I_T = q_p \cdot v \cdot c \cdot A_{eff} \quad (1)$$

where:

I_T	aircraft charging current (amperes)
v	aircraft velocity (meters/second)
A_{eff}	effective charging area (meters ²)
q_p	charge deposited per particle (Coulomb/particle)
c	particle concentration (particle/meters ³)

And

$$A_{eff} = A_{pf} \cdot k \quad (2)$$

where:

A_{pf}	actual projected frontal area (meters ²)
k	effective area factor (≤ 1)

The term A_{eff} in equation 2 is related to the actual precipitation impingement area taking into account aircraft speed, precipitation particle size and type, and the geometry of the impingement surface. This term is not constant but varies with speed and particle size by a complex relationship of how precipitation particles impinge a curved surface like the leading edge of an airfoil or a nose radome. As the airplane speed increases, the effective charging area (A_{eff}) approaches the limit of the actual projected frontal area of the airplane (A_{pf}). However this limit occurs at speeds higher than the maximum speed of subsonic airplanes. Also, thinner airfoil geometry incurs a relative higher precipitation particulate impingement rate resulting in a higher effective area factor (Reference: J.E. Nanevicz: Precipitation Charging and Corona Generated Interference in Aircraft). An example in applying this term includes data taken from an instrumented Boeing 707 airplane flying in precipitation. The results yielded an effective p-static charging area ranging from 7% to 10% when the airplane was traveling 500 mph [2.4].

TABLE 1 - PRECIPITATION PARTICLE PARAMETERS FOR SUBSONIC AIRCRAFT

Flight Regime	Parameter	Description	Range	Cloud Type
Cruise	q_p	Charge Deposited per Particle	$(1 \text{ to } 10) \times 10^{-12}$ Coulomb/particle	Cirrus
	c	Particle Concentration	2×10^4 particle/ m^3	
Approach Or Landing	q_p	Charge Deposited per Particle	$(1 \text{ to } 35) \times 10^{-12}$ C/particle	Thunderstorm Anvil
	c	Particle Concentration	5×10^4 particle/ m^3	

Since subsonic aircraft flying at cruise altitudes can readily circumnavigate thunderstorms, which are typically 15 miles in diameter and last an average of 30 minutes, the worst case particle parameters for the cirrus cloud type (i.e., 10×10^{-12} Coulomb/particle & 2×10^4 particle concentration) can be selected from Table 1. Since subsonic aircraft do not penetrate thunderstorm anvils during the approach ($\leq 10,000$ feet MSL) or landing ($\leq 2,000$ feet AGL) phase of flight, an intermediate charge deposited per particle value (i.e., 30×10^{-12} Coulomb/particle) was selected in lieu of the worst case shown for thunderstorm anvils (i.e., 35×10^{-12} Coulomb/particle).

Experience has shown that heavy cirrus and heavy frontal snow produce the highest amounts of triboelectric charging on fixed wing aircraft surfaces.

6.2 Rotorcraft Environment

Due to their relatively small frontal area, low airspeeds and the effects of the rotor blades p-static charging on rotorcraft is significantly different from that on fixed wing aircraft. For rotorcraft the rotation of the main rotor blades is the main factor in the generation of p-static, rather than forward airspeed, and p-static interference can occur with zero airspeed in a hover.

Rotorcraft usually operate at lower altitudes and experience has shown that p-static problems for rotorcraft tend to be most severe in dry particle conditions such as blowing sand or dry snow, and to some extent heavy precipitation, rather than in the higher altitude cloud conditions that are of concern for fixed wing aircraft. The potential of a hovering rotorcraft can reach up to 300kV.

The dissipation of static from rotorcraft by the use of static dischargers is limited by the lack of surfaces on which static discharges can be located and by the variability of the airflow. Generally rotorcraft must discharge the accumulated charge on landing, via the landing gear to the landing surface, but common practice for rotorcraft involved in transporting external cargo, or hoisting, is to discharge the rotorcraft via the cargo/hoist cable prior to coming into contact with personnel on the ground.

For rotorcraft it is necessary to ensure that the p-static build up that is generated does not interfere with the performance of essential receiver systems even under severe p-static conditions. This can be achieved by minimizing the accumulation of uneven static charge on the aircraft structure, by providing homogenous and stable static discharge paths to maintain a common potential throughout the airframe. Any difference between this common aircraft potential and the ground is negated upon landing by the contact of the landing gear with the landing surface.

7. DESIGN AIRCRAFT P-STATIC PROTECTION

7.1 Design of Aircraft Structure and Parts

The electrostatic charge accumulation on aircraft exterior surfaces, structures and parts can result in electrostatic discharges through arcing, corona, and streamering. These electrostatic discharges radiate broadband radio frequency (RF) energy, which may have spectral content that extends into the hundreds of megahertz. This energy is capable of degrading or disrupting avionics systems, particularly communications, navigation, and surveillance radio receivers. Therefore, it is necessary to implement protective measures for each discharge type. Table 2 provides a description of each electrostatic discharge type and corresponding preventative measures.

TABLE 2 - ELECTROSTATIC DISCHARGE TYPES AND PREVENTION

Discharge Type and Description	Prevention
1. Corona at sharp points and edges on the aircraft exterior surfaces (e.g., antenna, wingtips, winglets, and other protrusions) occurs when electrostatic charge transfers away from the trailing edge surfaces of the aircraft during flight, which generates broadband RF emissions.	Corona can be mitigated by strategic placement of passive static dischargers at locations where aircraft typically experience corona discharge. Since static dischargers have a lower corona threshold than aircraft structure, the corona current from the static discharger is initiated at a lower aircraft potential and this corona current is much less than the corona current which will otherwise occur naturally from the aircraft. Therefore the intensity of the RF radiation is reduced. Static dischargers quietly transfer this charge away prior to aircraft structure going into corona
2. Arcing between conductors (e.g., an electrically isolated metal component on the aircraft may develop a charge potential capable of producing an arc or spark that jumps the gap from conductive aircraft structure to the electrically isolated conductive object).	Arcing can be avoided by ensuring that all conductive components, which are exposed to the impact airstream, are electrically bonded to the primary structure of the aircraft. Bonding values less than 100 kohms are usually sufficient to prevent arcing.
3. Streamer over insulating or dielectric surfaces (e.g., radomes, windshields, and fiberglass panels positioned on frontal impact areas) develops as particles strike the aircraft during flight, which transfer an electrical charge on the dielectric surfaces. This charging process continues until a threshold point is reached where a spark discharge occurs across the dielectric surfaces, which generates broad band RF emissions. Basically, the charge becomes captive to the surface and cannot freely migrate as would be the case for a charge deposited on a conductive surface. The charge will intensify as long as the charge rate exceeds the discharge rate, until puncture of the dielectric or surface flashover occurs to the surrounding conductive aircraft structure.	Streamer can be prevented by coating the exterior dielectric surface with an electrically conductive paint or conductive coatings under very thin painted surfaces. The conductive coating must be properly bonded to structure providing an electrical path that drains away the charge to airframe structure as rapidly as it arrives, and prevents the voltage build-up that produces the streamer discharges.

7.1.1 Electrical Bonding of Exposed Structure or Parts

P-static charging of an electrically-isolated conducting structure or parts may result in arcing to an adjacent conducting structure. This electrical arcing can be prevented by electrically bonding the structure or parts to adjacent structure. Electrical bonding can be accomplished by face surface electrical contact, bonding straps or jumpers, or conducting fasteners. The manufacturer should define electrical bonding design requirements for each type of bond used to connect conducting parts or structure to adjacent structure. Electrical bonding resistance to prevent p-static arcing should be less than 100 kilohms.

Appendix A includes a list of structure and parts that may require electrical bonding.