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ABSTRACT

This paper delineates the process for analytically determining the quantity of passive static dischargers that optimize the electrostatic protection of general aviation aircraft from the undesirable phenomenon known as precipitation static (P-static).

P-static, a form of electromagnetic (EM) energy, is typically created by the frictional charging of an aircraft as it impacts ice crystals, rain, snow, dust or other particles during flight resulting in a discharge of energy that interferes with avionics systems.

The static discharger analysis technique presented in this paper (refer to Figure 1) was demonstrated on the Beech Model 1900D Airliner, which is a high performance, T-tail, pressurized, twin-engine turboprop of conventional aluminum skin design.

INTRODUCTION

P-static is attributed to the electrostatic or tribolelectric charging of aircraft surfaces that collide with dust, ice crystals, rain, sand, smoke, snow and other particles during flight. Contact with these particles transfers (i.e., deposits) a charge at the point of impact on the aircraft exterior surface, which results in an electrostatic charge accumulation. These charge accumulations, if not properly managed, will continue to develop on aircraft exterior surfaces until an electrostatic discharge occurs (i.e., corona), which emit broadband Radio Frequency (RF) EM energy. This spectrum of EM energy is capable of degrading or disrupting the operational capabilities of avionics systems (e.g., communications & navigation), which may impair flight safety.

These corona discharges can be mitigated by the strategic placement of passive static dischargers at locations were aircraft typically experience corona discharge (e.g., antenna, trailing edge extremities, wingtips, winglets, and other protrusions). Since static dischargers have a lower corona threshold than the aircraft structure, static dischargers quietly transfer this charge away prior to an aircraft structure going into corona. As a result, the corona energy is decoupled from the aircraft trailing edges by approximately 50dB.

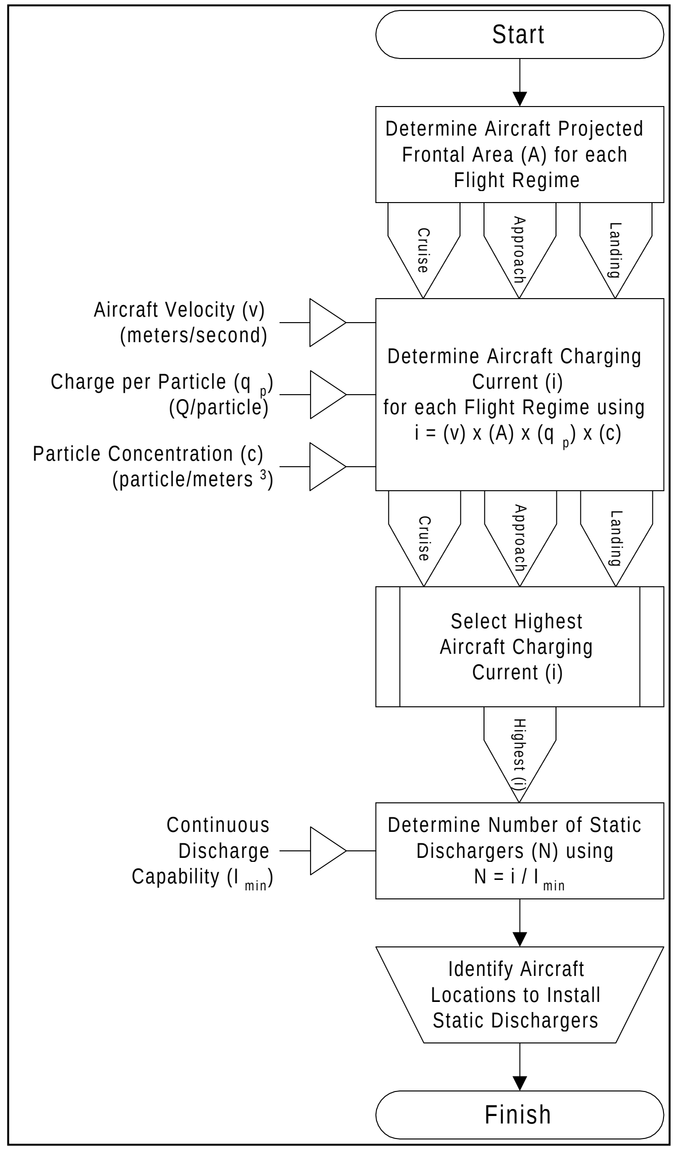

Figure 1. Discharger Analyses Flow Diagram

THEORY

ELECTROSTATIC CHARGING IN FLIGHT – Electrostatic or tribolelectric charging of an aircraft is due to impact with particles (e.g., dust, ice crystals, rain, sand, smoke, snow, etc.) during flight. Contact with these particles transfers (i.e., deposits) a negative or positive charge at the point of impact on the airframe, and can be expressed mathematically as:

Equation 1 \= Aircraft Charging Current [1]

$$i = v \times A \times q_p \times c$$

where:

- i = aircraft charging current (amperes)
- v = aircraft velocity (meters/second)
- A = projected aircraft frontal area (meters^2)
- q_p = charge per particle (Q/particle)
- c = particle concentration (particle/meters^3)

ELECTROSTATIC DISCHARGING IN FLIGHT – The electrostatic charge accumulation on an aircraft exterior surface/structure can bring about three types of electrostatic discharges (i.e., arcing, corona & streamering), which emit broadband RF EM energy. This spectrum of energy is capable of degrading or disrupting avionics systems (e.g., communications & navigation), that may impair flight safety. Therefore, it is necessary to implement protective measures for each discharge type. Table 1 provides a description of each electrostatic discharge type and corresponding preventative measures.

Table 1. Electrostatic Discharge Types & Prevention

Discharge Type & Description	Prevention
1. *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.
2. 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 were aircraft typically experience corona discharge. Since static dischargers have a lower corona threshold than aircraft structure, static dischargers quietly transfer this charge away prior to aircraft structure going into corona. As a result, corona energy is decoupled from aircraft trailing edges by approximately 50dB.
3. Streamering 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.	Streamering can be prevented by coating the exterior dielectric surface with an electrically resistive paint. The resistive coating provides 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.

ANALYSIS

This static discharger analysis, which was performed on the Beech Model 1900D aircraft, was accomplished as follows:

1. Determine Projected Frontal Area (A) of Aircraft
2. Determine Aircraft Charging Currents (i)
3. Determine Number of Static Dischargers (N)
4. Identify Static Discharger Locations on Aircraft

DETERMINE PROJECTED FRONTAL AREA (A) OF AIRCRAFT – The total frontal area of the Beech Model 1900D aircraft was determined for each of the following flight regimes:

- Cruise (flaps & landing gear retracted)
- Approach (flaps extended)
- Landing (flaps & landing gear extended)

The projected frontal area (A) of each significant aircraft exterior surface was determined by analyzing the computer aided design (CAD) model (refer to Figure 2). Then each item was tabulated (refer to Table 2) in order to determine the effective intercepting area (A) for each flight regime by combining only the aircraft component frontal areas specific to a flight configuration.

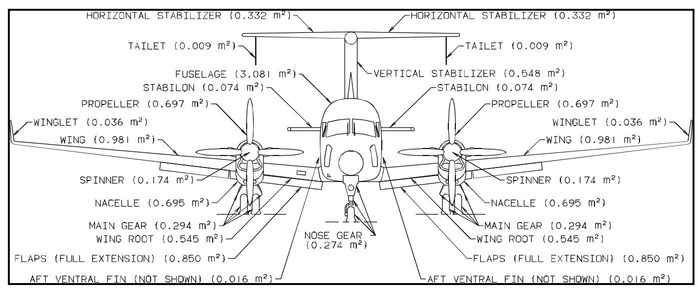

Figure 2. Cross Sectional Area (Model 1900D)

Table 2. Projected Aircraft Frontal Area (A)

Aircraft Structure (refer to Figure 2)	Port (m^2)	Fuselage (m^2)	Starboard (m^2)	Total Area (m^2)
1. Horizontal Stabilizer	0.332		0.332	0.664
2. Tailet	0.009		0.009	0.018
3. Stabilon	0.074		0.074	0.148
4. Winglet	0.036		0.036	0.072
5. Wing	0.981		0.981	1.962
6. Wing Root	0.545		0.545	1.090
7. Engine Nacelle	0.695		0.695	1.390
8. Spinner	0.174		0.174	0.348
9. Propeller Blades	0.697		0.697	1.394
10.Vertical Stabilizer		0.548		0.548
11.Fuselage		3.081		3.081
12.Ventral Fin (aft)	0.016		0.016	0.032
13.Flaps	0.850		0.850	1.700
14.Landing Gear	0.294	0.274	0.294	0.862
Cruise (add 1-12)	3.559	3.629	3.559	10.747
Approach (add 1-13)	4.409	3.629	4.409	12.447
Landing (add 1-14)	4.703	3.903	4.703	13.309

DETERMINE AIRCRAFT CHARGING CURRENTS (I) – In order to determine the optimum number of static dischargers required for the Beech Model 1900D aircraft, it was necessary to determine the highest (i.e., worst case) aircraft charging current (i). Therefore, the aircraft charging currents (i) were calculated for each flight regime as follows:

1. Obtain the true airspeed (TAS) velocity (v) for each flight regime and enter into Table 4.
2. Substitute the Total Frontal Area (A) for each flight regime from Table 2 into Table 4.
3. Substitute the particle parameter values q_p and c for each flight regime from Table 3 into Table 4.

Table 3. Precipitation Particle Parameters for Subsonic Aircraft [1]

Flight Regime	Parameter	Description	Range	Cloud Type
Cruise	q_p	Charge per Particle	(1 to 10) X 10^{-12} Q/particle	Cirrus
	c	Particle Concentration	2 X 10^4 particle/m^3	Cirrus
Approach or Landing	q_p	Charge per Particle	(1 to 35) X 10^{-12} Q/particle	Thunderstorm Anvil
	c	Particle Concentration	5 X 10^4 particle/m^3	Thunderstorm Anvil

Note: 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 X 10^{-12} Q/particle & 2 X 10^4 particle concentration) were selected from Table 3.

Note: Since subsonic aircraft do not penetrate thunderstorm anvils during the approach (≤10,000 feet MSL) or landing (≤2,000 feet AGL) phase of flight, an intermediate charge per particle value (i.e., 30 X 10^{-12} Q/particle) was selected from the range in Table 3 in lieu of the worst case shown for thunderstorm anvils (i.e., 35 X 10^{-12} Q/particle).

Calculate aircraft charging current (i) using Equation 1 for each flight regime and enter into Table 4.

Table 4. Determine Aircraft Charging Current (i)

Flight Regime	v (m/s)	A (m^2)	q_p (Q/particle)	c (particle/m^3)	i (μA)
Cruise	149	10.747	10 X 10^{-12}	2 X 10^4	320.26
Approach	62	12.447	30 X 10^{-12}	5 X 10^4	1157.57
Landing	57	13.309	30 X 10^{-12}	5 X 10^4	1137.91

DETERMINE NUMBER OF STATIC DISCHARGERS (N) – Substitute the highest aircraft charging current (i) from Table 4 and the minimum continuous discharge current (I_{min}) capability of an individual static discharger into Equation 2 and solve for the number of static dischargers (N).

Note: The continuous discharge capability of a static discharger shall be a minimum of 50mA for a period of not less than 24 hours. [2]

Equation 2 - Number of Static Dischargers

$$N = \frac{i}{I_{\min}} = \frac{1157.57\mu\text{A}}{50\mu\text{A} / \mathit{discharger}} \approx 23 \mathit{dischargers}$$

where:
N = number of static dischargers
i = aircraft charging current (amperes)
I_{min} = continuous discharge capability of discharger

IDENTIFY AIRCRAFT LOCATIONS – The concentration of electrostatic discharges (i.e., corona) is greatest at the trailing edges of all extremities (e.g., winglets, wingtips) and descends at the trailing tips of the vertical and horizontal stabilizers. Since the horizontal stabilizer on the Beech Model 1900D aircraft is attached to the top of the vertical fin, the charge is similar to that of the wings. The strategic placement of passive type static dischargers at the points of electrostatic charge concentrations will effectively provide a high resistance path for the electrostatic charges to gradually transfer away from the aircraft in an orderly fashion and at a non-interfering level. The static discharger layout for the Beech Model 1900D aircraft is illustrated in Figure 3.

Installation Guidelines – The static dischargers should be installed in accordance with the following guidelines:

- Install static dischargers at the points of static charge accumulation.

Do not place static dischargers closer than 0.3m (12 inches) apart due to mutual shielding.

- Locate outboard static discharger as close to airfoil tip as possible & second static discharger inboard approximately 0.3m (12 inches).
- Place third static discharger inboard approximately 0.6m (24 inches) from number two static discharger & use approximately 0.6m (24 inch) spacing for remainder, if any.
- Mount static dischargers on structurally sound airframe members. If aircraft mounting surface is nonconductive, provide an electrical connection between static discharger mounting base and nearest conductive surface of aircraft.
- Ensure mounting surface preparation & treatment is compatible with operational environment.

Note: Faying surface electrical bonding is not required for static discharger retainers riveted to electrically conductive aircraft structure.

Note: Static dischargers do not protect the aircraft from the direct effects of lightning nor reduce the probability of an aircraft from encountering a lightning attachment. However, when an aircraft is struck by lightning, improperly installed static dischargers can enhance the damaging effects.

<u>DC Electrical Bonding/Resistance Requirements</u>

DC Electrical Bonding

- Discharger Mounting Base to Aluminum Aircraft Surface
  - The direct current resistance, as measured with a milliohmmeter, between the discharger mounting base (i.e., trailing retainer) and aluminum aircraft surface shall be ≤0.1Ω. [3]
- Discharger Mounting Base to Aircraft Composite Surface
  - Dischargers mounted on aluminum flame spray surfaces shall be ≤0.1Ω;
  - Dischargers mounted on resistive composite surfaces shall be ≤1.0Ω;
  - Dischargers mounted on nonconductive composite surfaces shall be electrically connected to the nearest conductive aircraft structure via an aluminum strip and shall be ≤0.1Ω.

DC Electrical Resistance

- Discharger Mounting Base to Discharger Point
- The direct current resistance, as measured with a 500V megommeter, between the discharger mounting base (i.e., trailing retainer) and the discharger point (i.e., tip) shall be as follows: [2]

Aircraft Location	Resistance (MΩ)	Temperature
Trailing Edge Mounted (e.g., ailerons & elevators)	6 - 200	25°C
Tip Mounted (e.g., winglet tip, elevator tip)	6 - 120	25°C

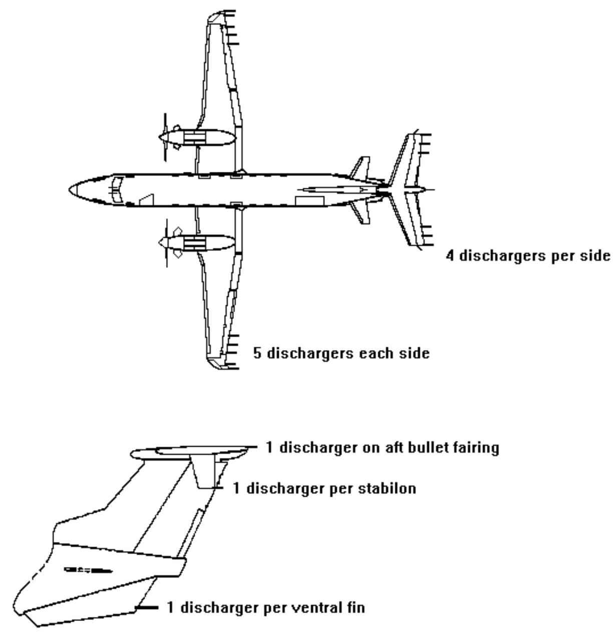

Figure 3. Static Discharger Layout (Model 1900D)

CONCLUSION

Since the continuous discharge capability is a minimum of 50mA per discharger for a period of not less than 24 hours without material breakdown or other damage [2], it was rationalized that static dischargers can safely and adequately perform temporarily beyond the minimal requirement. For example, static dischargers have the capacity to routinely discharge currents on the order of 100µA and the resistive portion of the static discharger is capable of carrying 5 successive applications of a 400µA current for a 5 second duration [2].

The capacity of static dischargers to operate beyond the minimum requirement ensures that an adequate safety margin of electrostatic protection inherently exists in the event that the aircraft penetrates a thunderstorm anvil or static dischargers are missing, damaged or non-functional. For example, a decrease in the number of functioning static dischargers (i.e., from 23 to 17) on the Beech Model 1900D aircraft would require that the remaining static dischargers increase their discharge capability 26 percent (i.e., from 50µA to 63µA), which is still below the routine capability of a 100µA discharge rate. However, a caveat exists in that electrostatic noise (i.e., P-static) will gradually increase as the discharge rates increase.

Therefore, it was concluded that no spare static discharger requirement be imposed on subsonic aircraft that implement this static discharger analytical approach. This was based upon the rationale that an adequate level of continued p-static protection would inherently prevail (i.e., static dischargers temporarily operating at the higher discharge rate) for those rare times when aircraft unintentionally penetrate electrical rain storms.

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CONTACT

The author, *Jack P. Glecier*, who is a Senior Certification Engineer at the Raytheon Aircraft Company (Wichita, Kansas), was awarded a Bachelor of Science degree in Electrical Engineering in May 1983 from Purdue University (West Lafayette, Indiana). He has been a NARTE Certified Electromagnetic Compatibility Engineer since February 1991. He was appointed by the Federal Aviation Administration (FAA) to act in the capacity of Designated Engineering Representative (DER) on October 28, 1998.

Mr. Jack Glecier is an active commercial/instrument rated single engine and multi-engine pilot and Certified Flight Instructor.

Mr. Jack Glecier can be contacted at e-mail addresses:

- jack_glecier@raytheon.com
- glecier@worldnet.att.net

DEFINITIONS, ACRONYMS, ABBREVIATIONS

Corona: A blue electrical discharge (current) from a conductor into the air. At nighttime this effect is seen as a glow around sharp pointed metallic objects.

Corona Threshold: A voltage level at which the airframe begins to discharge its accumulated electrical charge.

Dielectric Surface: An electrically non-conductive material that retains accumulated charge.

Electromagnetic Compatibility (EMC): The ability of a system or equipment to operate within design tolerances in its intended environment, with adjacent systems and equipment, and with itself.

Electromagnetic Interference (EMI): Any electromagnetic disturbance that interrupts, obstructs, or otherwise degrades or limits the effective performance of electronics/electrical equipment. It can be induced intentionally, as in some forms of electronic warfare, or unintentionally, as a result of a spurious emissions and responses, intermodulation products, and the like. Additionally, EMI may be caused by atmospheric phenomena, such as lightning and precipitation static and non-telecommunication equipment, such as vehicles and industry machinery.

Electromagnetic Vulnerability (EMV): The undesired response of a system or equipment to the Electromagnetic Environment or the threshold above which a system or equipment may be undesirably influenced by other electromagnetic energy.

Electrostatic discharge (ESD): A transfer of electrostatic charge between bodies at different electrostatic potentials caused by direct contact or induced by an electrostatic field.

Precipitation Static (P-static): Precipitation static consists of charged precipitation particles that strike antennas and gradually charge the antenna, which ultimately discharges across the insulator, causing a burst of static.

Triboelectric Charging: Electrostatic charge generated by friction (e.g., fluids in motion, airflow, adhesive forces during separation, particle contact between two dissimilar materials, etc..).