FAA Tests E- and H-field Antennas to Characterize Improved Loran-C Availability During P-Static Events

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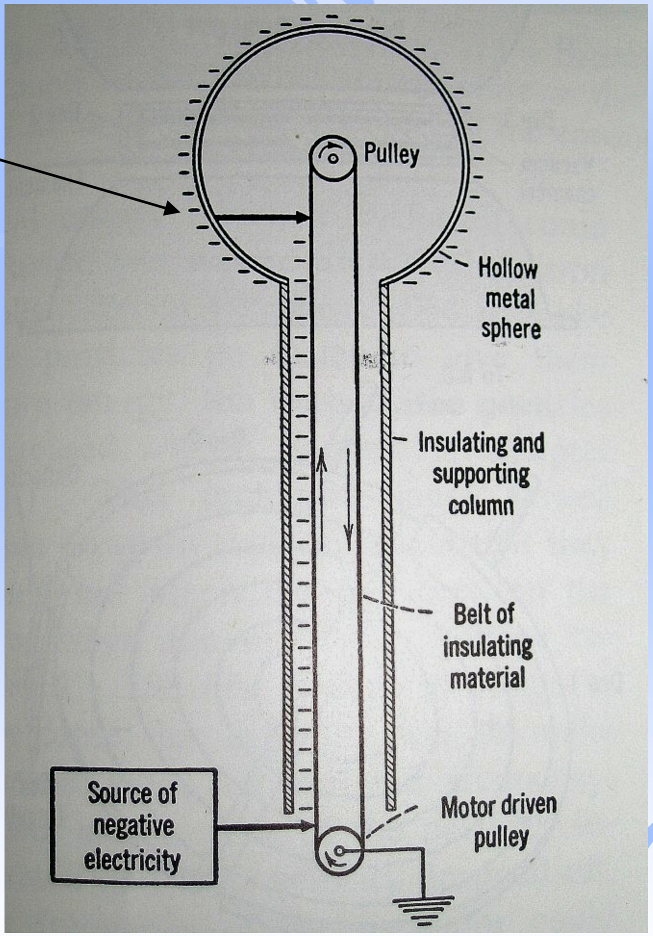
What is p-static?

- **Electrical noise generated in flight**
  - Flight in charged regions
  - Triboelectric charging (impact ionization)
  - Engine charging
- **Aircraft is an isolated conductor**
  - Stored charge increases with time, up to threshold
  - Van de Graaff generator is similar

Van de Graaff?

- **Stored charge increases**
  - E-field accelerates nearby ions
  - Ions impact neutral atoms,
  - Secondary ionization occurs,
  - Ion avalanche, critical mass,
  - Air becomes a conductor,
  - Breakdown – spark – discharge

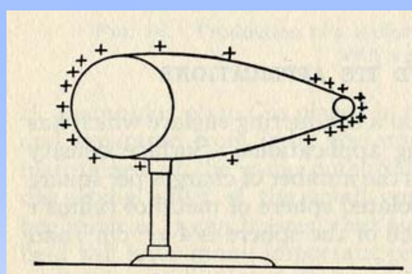
(Why use a sphere – a *big* sphere?)

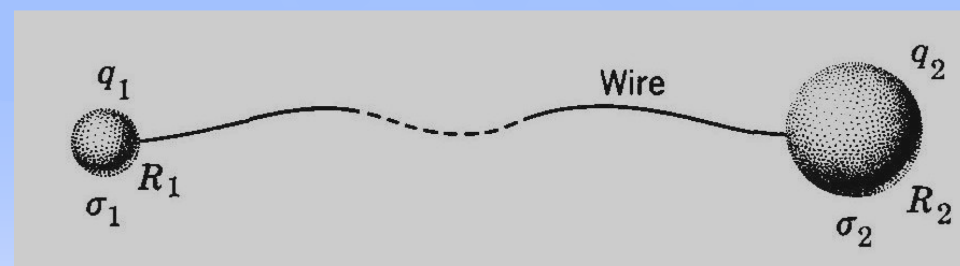


The Electric Field

Size Matters

- **Stored charge on conductor**
  - Arranges so that electrical potential is equal everywhere
  - Charge density is inversely proportional to radius
    - (Breakdown occurs at sharp points)





(So, a van de Graaf generator with a *really big sphere* avoids discharge even with high stored charge ⇒ high electric field.)

- **But a *big sphere* just does not fly very well. Real airplanes have pointy parts.**

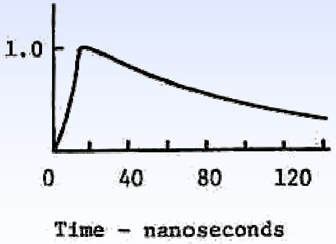
Discharge Mechanisms

- **Arcs**
  - Equalizing potential among airframe elements
    - Maintenance – bonding, loose rivets, bad antenna mount, corrosion
- **Streamers**
  - Draining stored charge from dielectric surfaces
    - Maintenance – resistive coatings, windscreen glue bypass
- **Corona**
  - Equalizing airframe and atmosphere
    - Maintenance – dischargers burnt, broken; antenna coatings pinholed, sharp points uncoated.

So, it's maintenance, maintenance, maintenance, huh?
(Wait for it; there's good news ahead!)

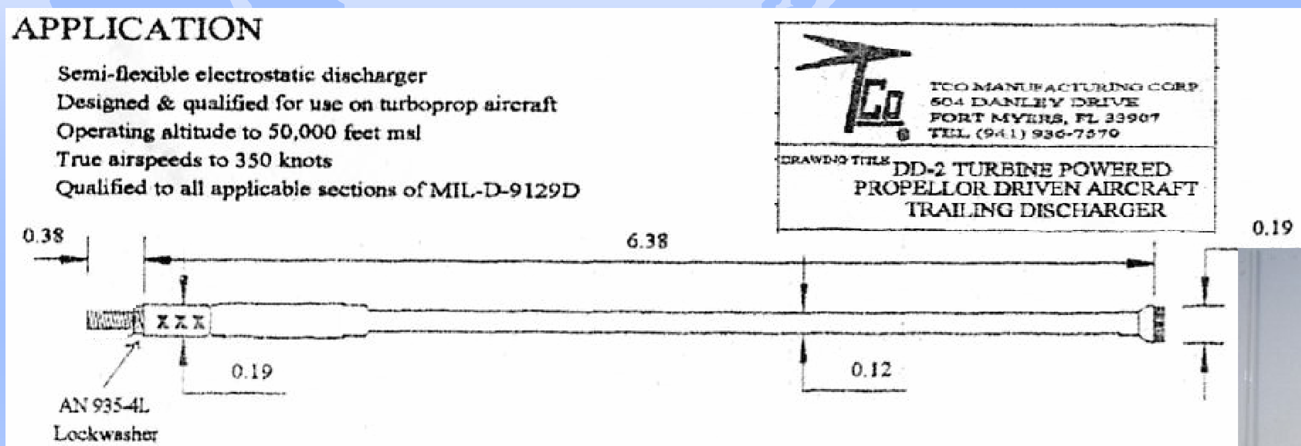
Corona Discharge

- **Arcs, Streamers can be silenced**
  - Maintenance is the key, but not unique to radio
  - Good structural maintenance will generally suffice
- **Corona <u>will</u> occur with stored charge**
  - Can couple closely to the airframe
  - Can be frequency selective – quantized ion avalanches
    - Increasing current: clicks → bacon → violins → screaming
  - Can be controlled and "quieted"



Corona Dischargers

Really Small Radius!



- TCO DD-2 discharger
- Goal is low noise, efficient discharge at low corona threshold
- Resistive; forms filter with a/c capacitance
- (4µ wires)

- ASA-3 discharger
- Same goal, different design
- Resistive wicks

How to Reduce Noise

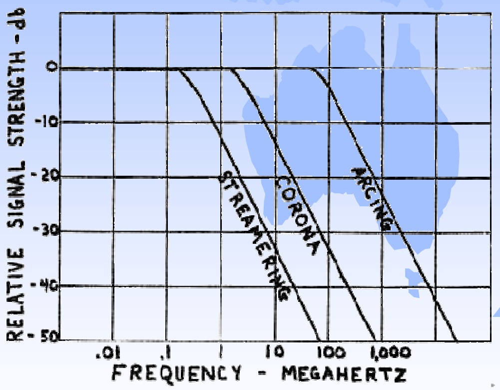
Implications, Hypotheses…

- **Stored charge can produce noise over the entire aviation spectrum.**
  - Keep airframe parts at equal potential; low re: the surroundings.
  - Antennas *themselves* must not become corona discharge points
  - Some corona noise is inevitable

- **Install discharger devices at trailing edge extremities and discontinuities**
  - Small-radius corona points
  - Enough to carry current to maintain airframe potential at the low value
  - Resistive, to decouple discharges from airframe

- **Maintain the airframe and dischargers, to preserve**
- **the electrically-quiet environment.**

- ***Then* for use in instrument conditions, install a Loran-C h-field antenna for even more protection.**



- **All three discharge mechanisms are factors, <u>and not just for Loran-C!</u>**

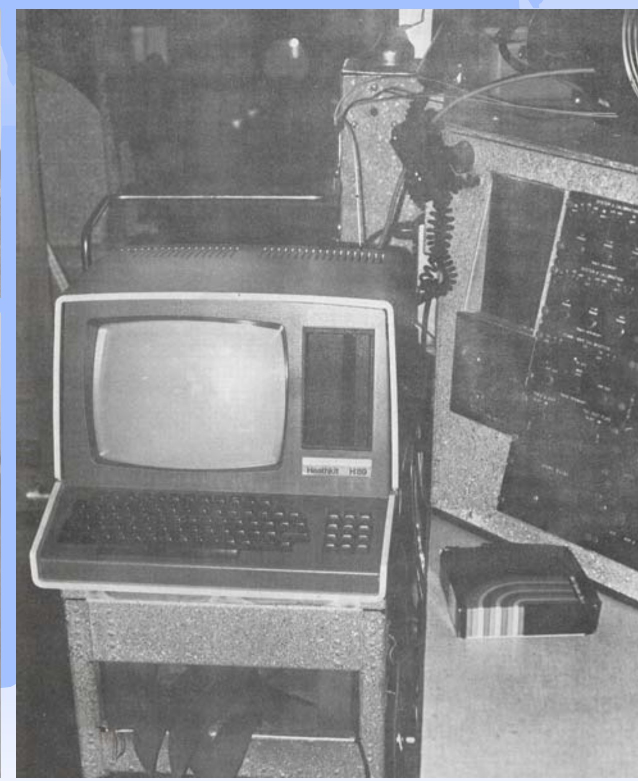
AMA

Airplanes!

- **Prior art:**
  - Ohio University Avionics Engineering Center
    - 1981-82 Douglas DC-3
    - 2000 Piper Saratoga
    - 2000 Beech Bonanza (J. Edwards; ILA-29, 2000)
  - Ground Electrostatic Surveys
    - Technique similar to the 2004 FAA tests
  - DC-3 Flight Tests
    - p-static measurements agreed with ground test
    - Onboard artificial charging

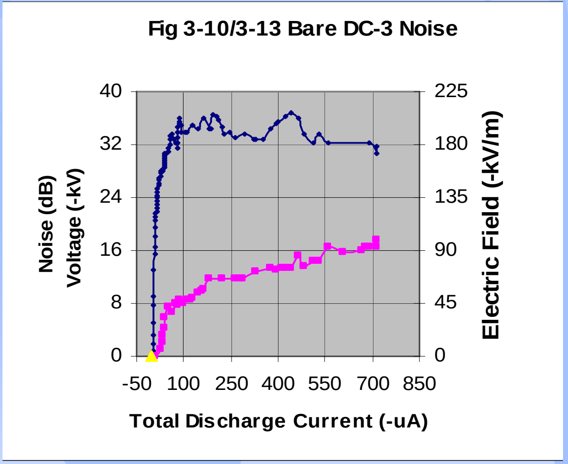
DC-3 N7AP Gallery

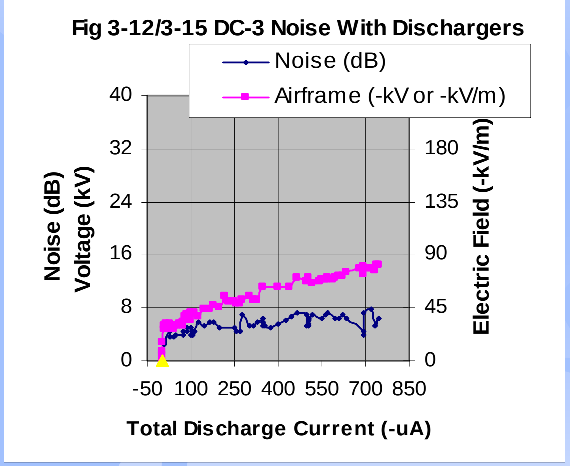
… Flying History



DC-3 Test Results

- **Ground Electrostatic Survey, 1982**



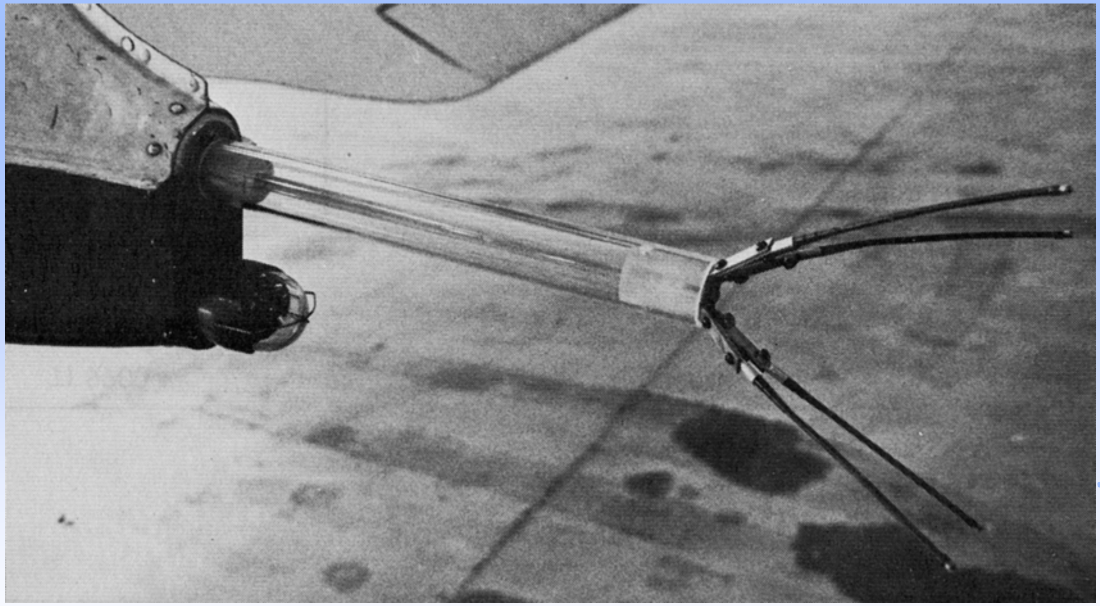


- Shows the ~29 dB quieting obtained with dischargers installed, compared to bare airplane.
- Noise receiver, operating in the Loan-C band.

DC-3 Flight Tests

- **Flight Tests in 1982, in weather**
  - Difficult to find p-static when desired
  - Results agreed with ground survey data

- **Active charging**
  - Onboard high-voltage power supply and tail boom



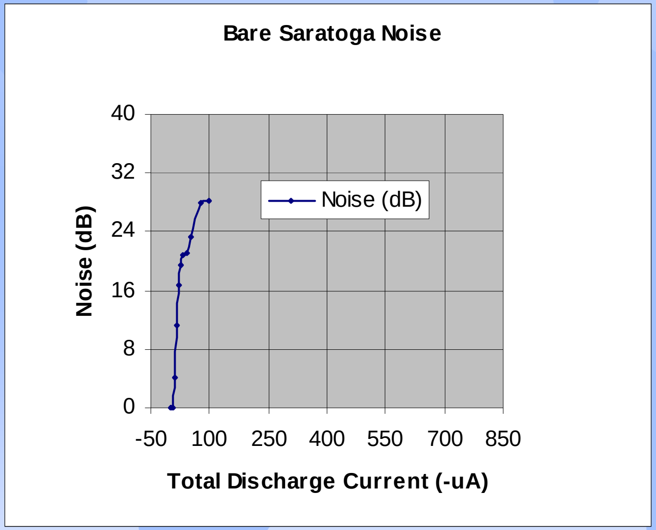
Saratoga N8238C Test

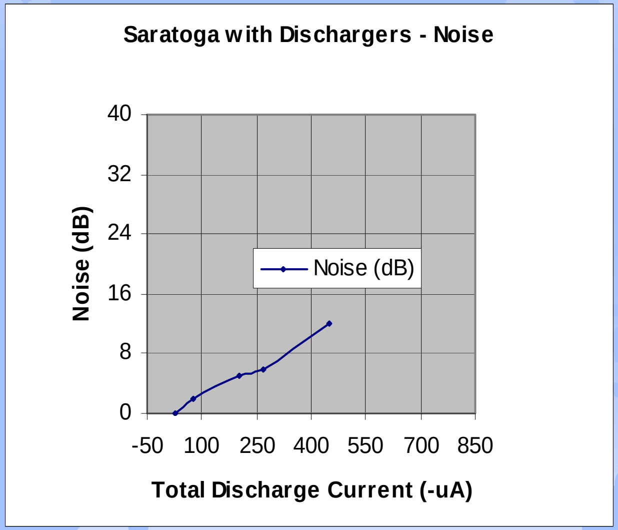
- **Ground Electrostatic Survey**

Saratoga Test Results

Airframe Noise

- **Ground Electrostatic Survey, 1999**



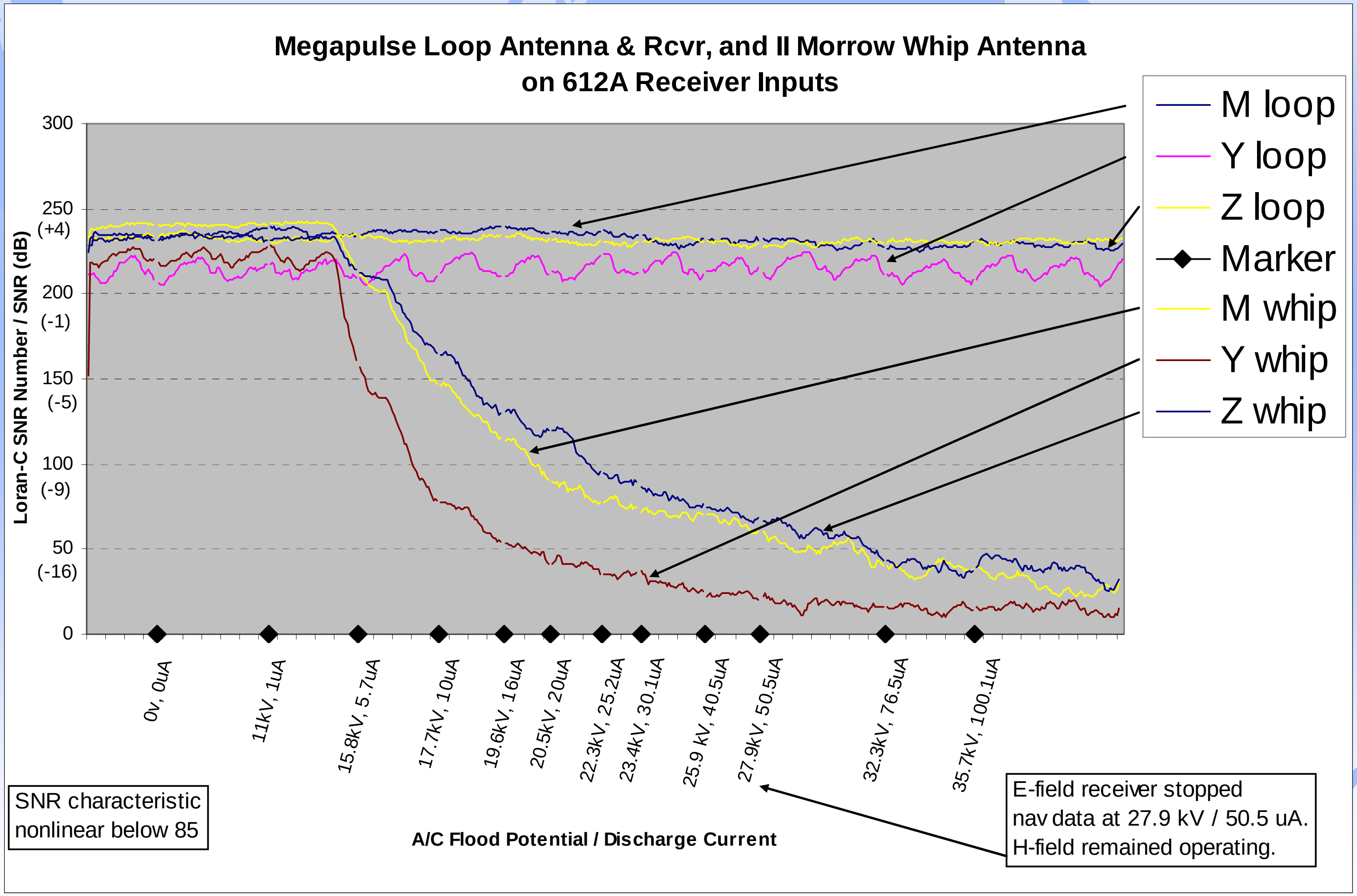


- Shows the ~25 dB quieting obtained with dischargers installed, compared to bare airplane.
- No field mill was available for this test.

Saratoga Test Results

Loran-C SNR: e-field vs h-field

- "Bare" airplane: brass rods replace dischargers
- No decoupling from corona, large radius compared to dischargers
- Legacy receivers –
- II-Morrow Apollo™ 612



FAA Technical Center

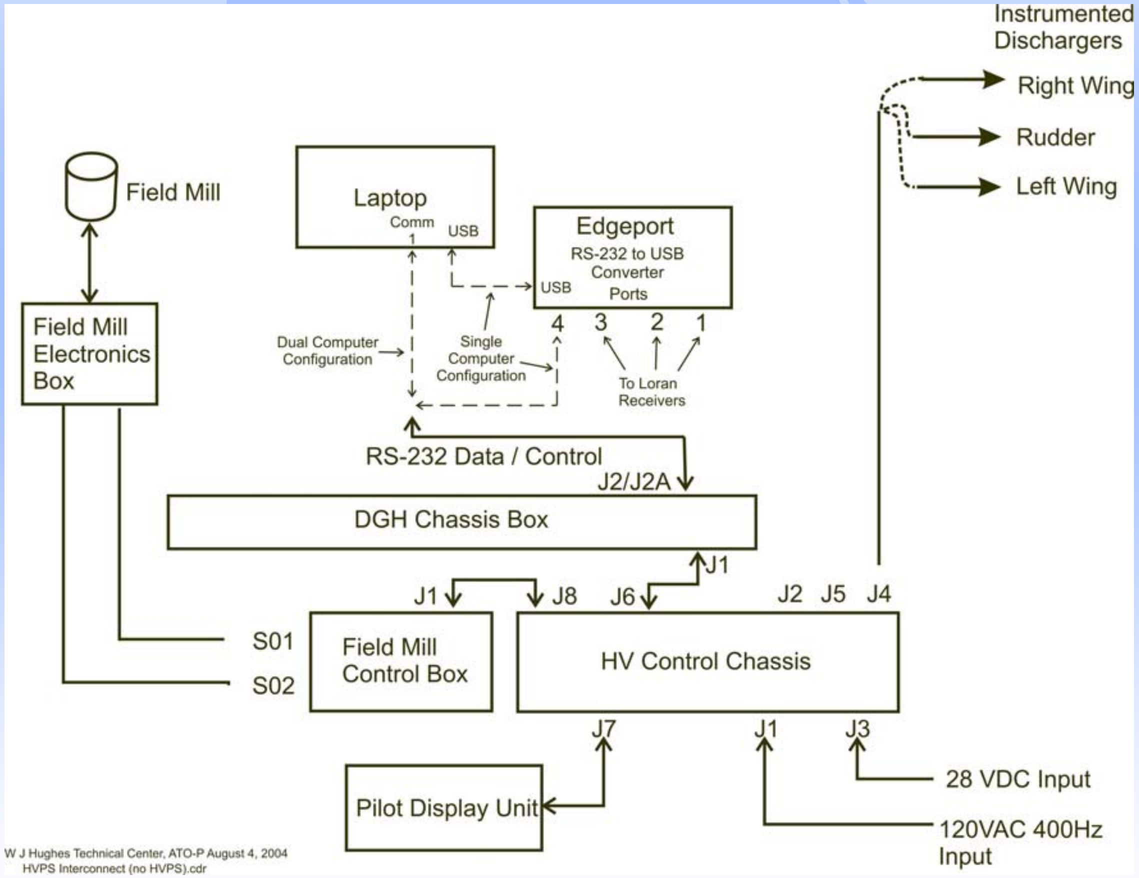
Ground Confirmation, Extension to Flight

- **Preparations for March 2004 Tests**
  - Modifications to N-50, Aero Commander 680
  - Ground Equipment Configuration
  - Calibration, Coordination with FAATC support

A/C Instrumentation

Field Mill

- **Field Mill added, to monitor airframe electric field / potential**

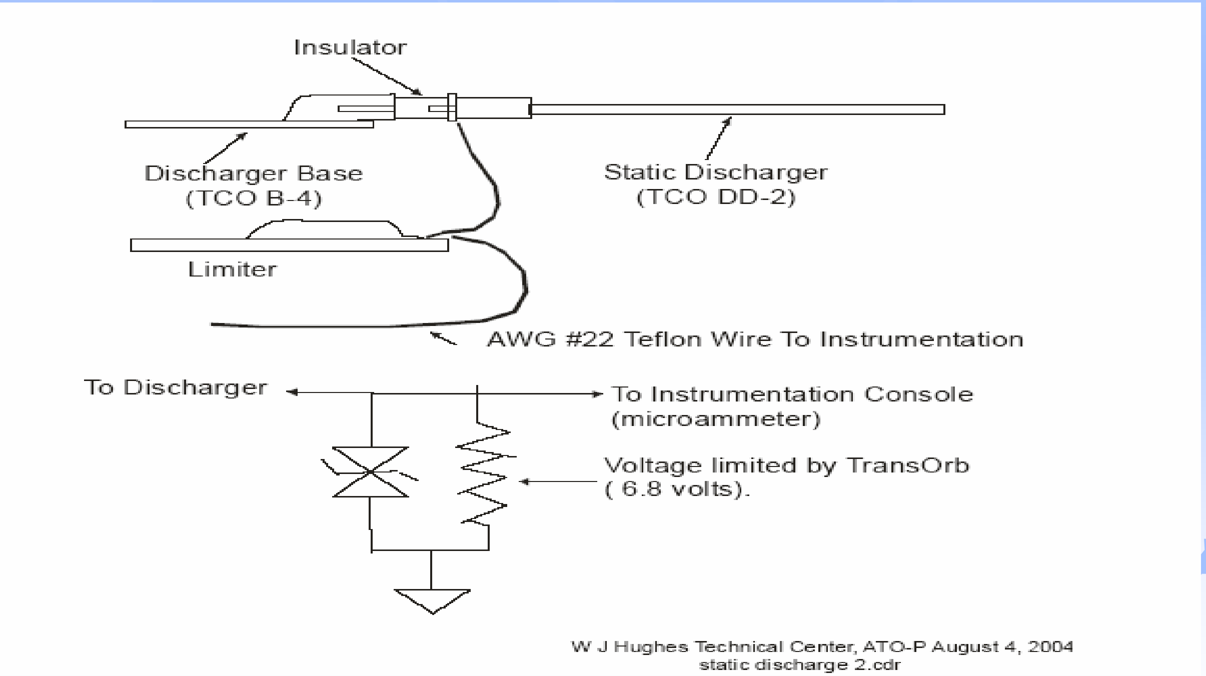


A/C Instrumentation

Instrumented Discharger Bases

- **Bases at wingtips and tail tip**
- **Sample and record total a/c current**
- **(These dischargers expected to conduct first.)**

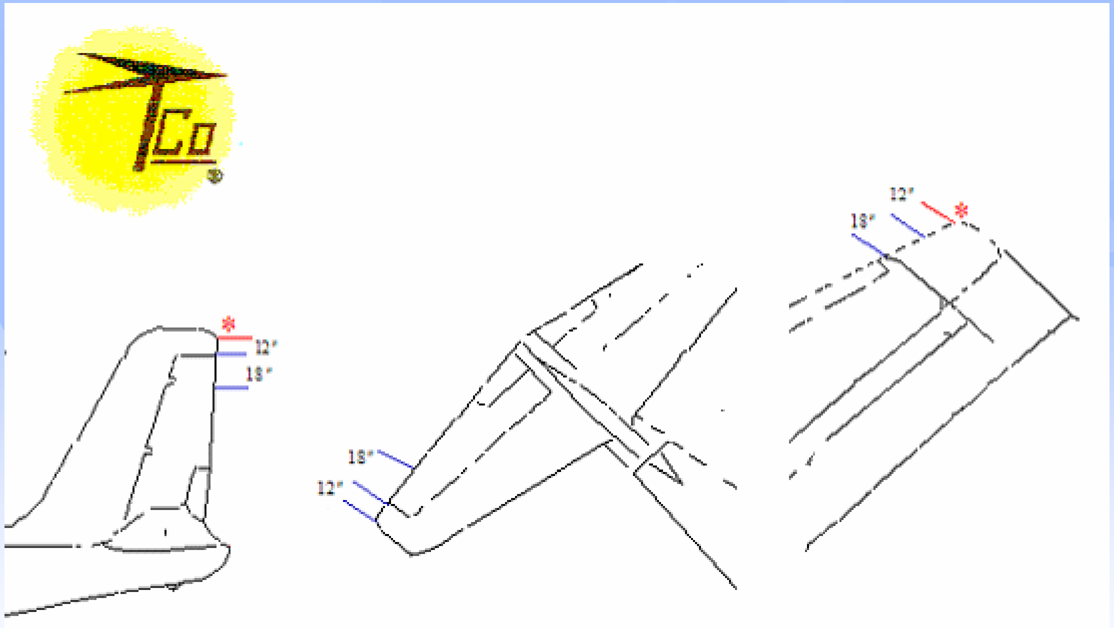
- **Equipped with**
  - TCO DD-2 dischargers for the "optimized a/c" test
  - 1/8" brass rods for the "bare a/c" test



A/C Instrumentation

Instrumented Discharger Bases

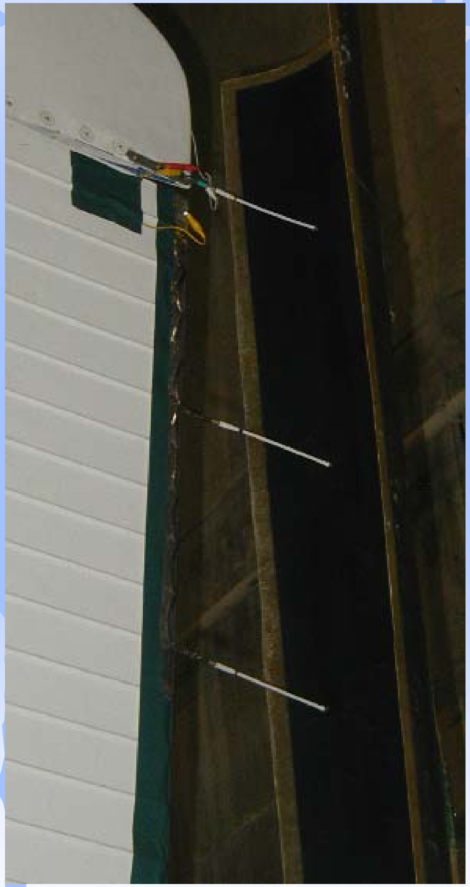
- **The "optimized" aircraft plan, from TCO Mfg.**
  - Includes instrumented dischargers (*)



Dischargers

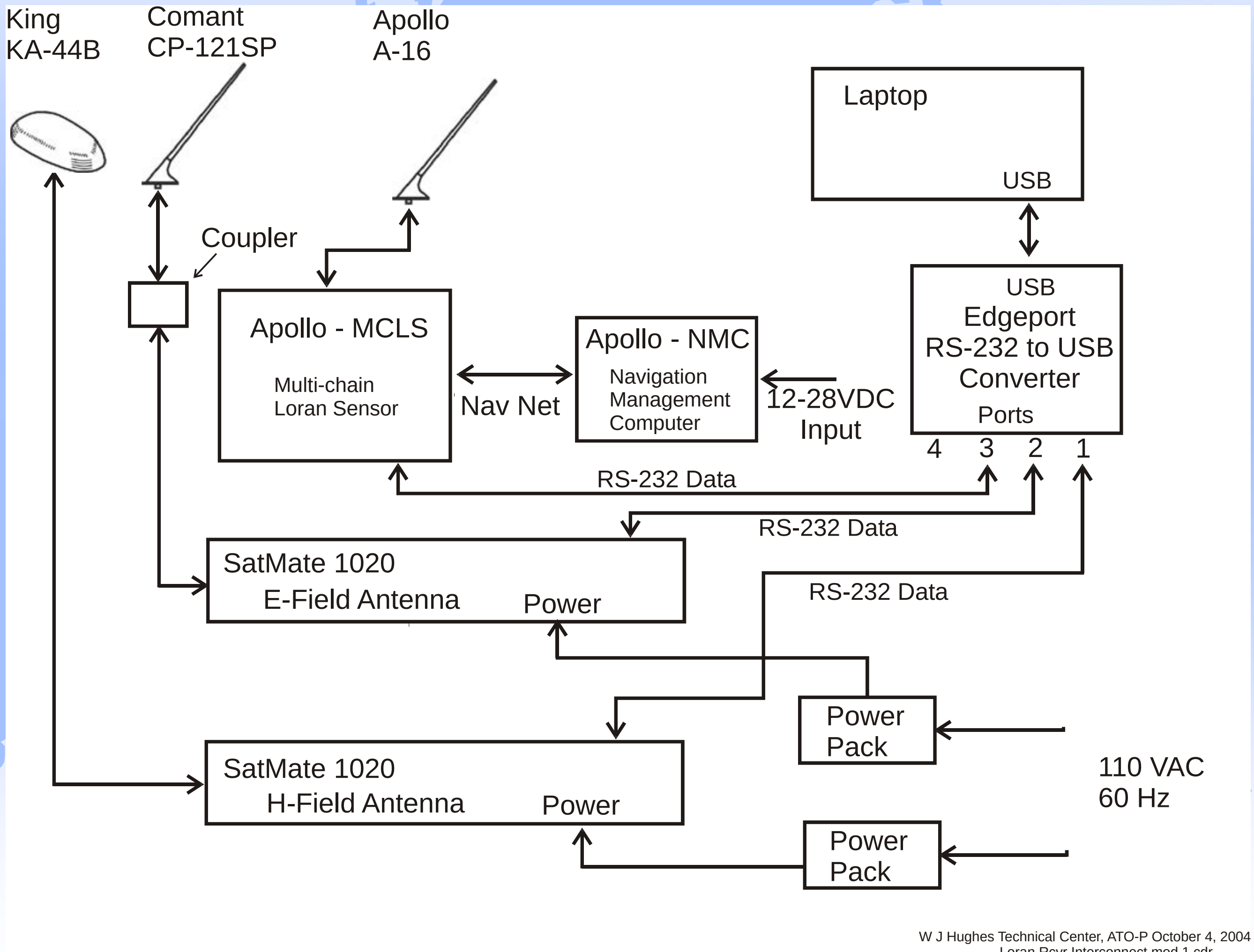
“Optimized” Rudder and “Bare” Elevator

- **Instrumented dischargers at tips**



...and Loran Receivers

- **KA-44B enclosure with Loran-C h-field antenna**
- **Locus SatMate 1020 e- and h-field**
- **Apollo 2010 “legacy”**

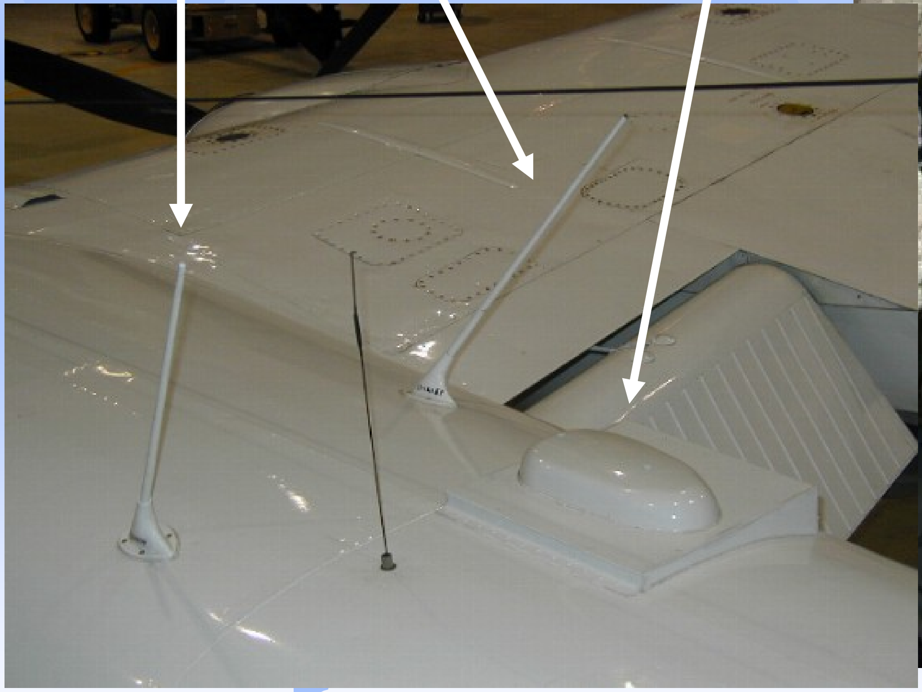


N-50 Inside and Out

II-Morrow A-16 Apollo e-field

Comant C-121SP – Locus e-field receiver

King KA-44B enclosure with Locus h-field

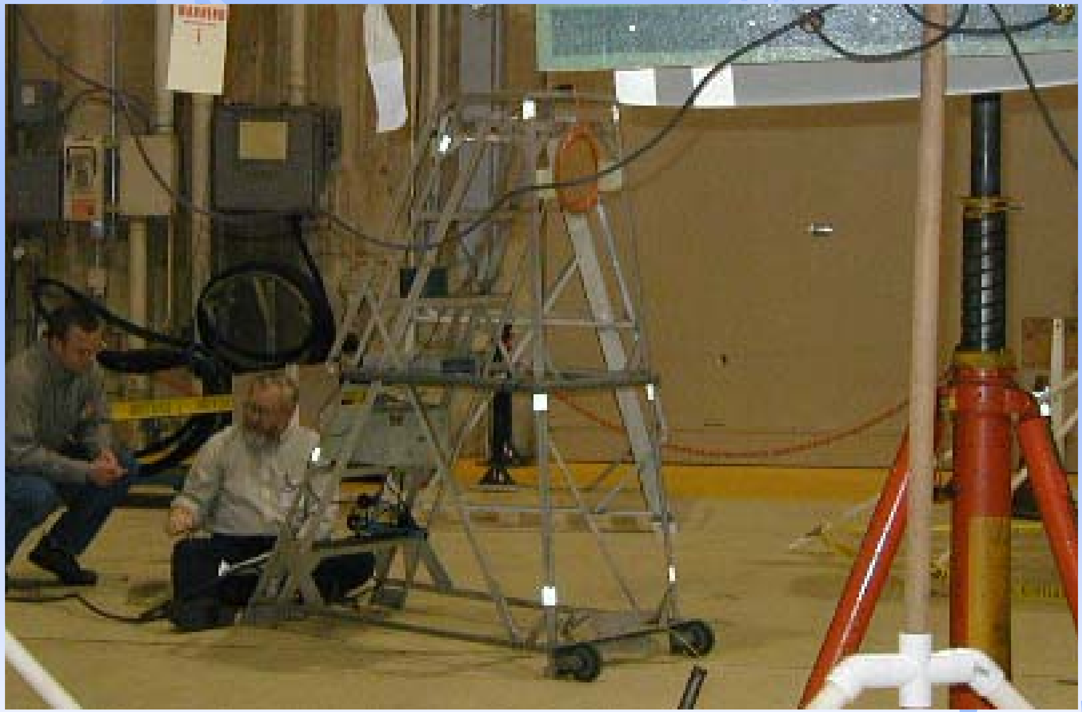


Ground Test Equipment

Loran-C Simulator

•Simulates 9940 chain to avoid interference form on-air signals.

•Calibration and tests confirm realistic signals radiated in the near field



Isolate, and Purge

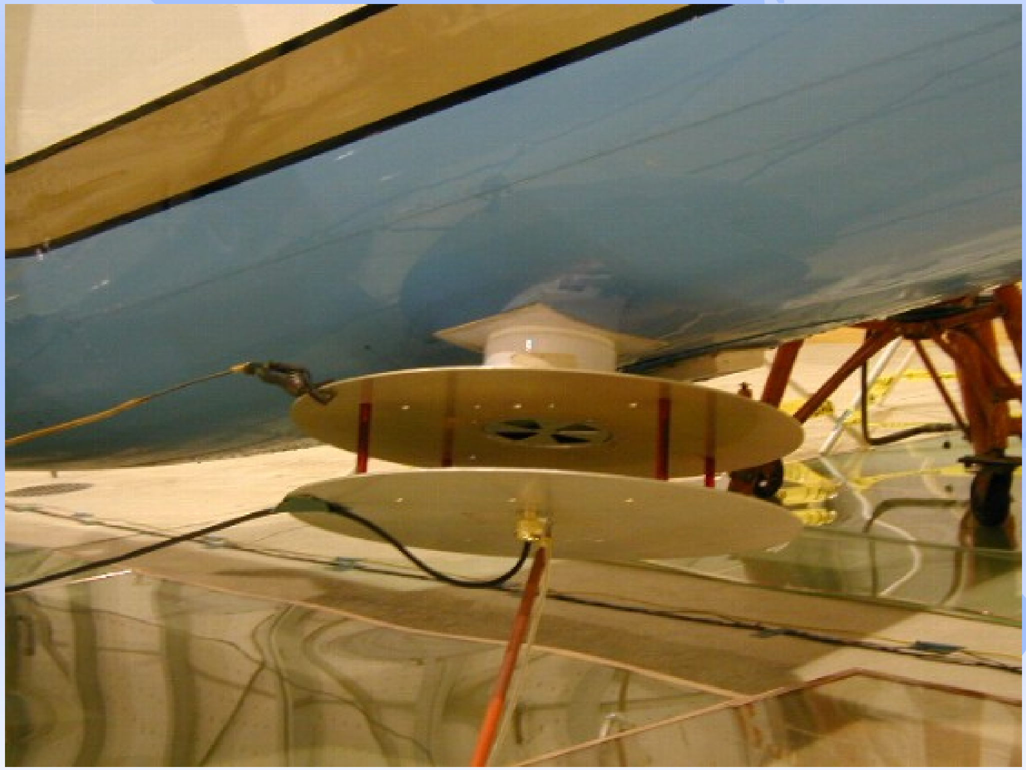
- Isolate the aircraft from ground to avoid unmeasured currents

- Purge the fuel system with nitrogen for safety.

Field Mill Calibration

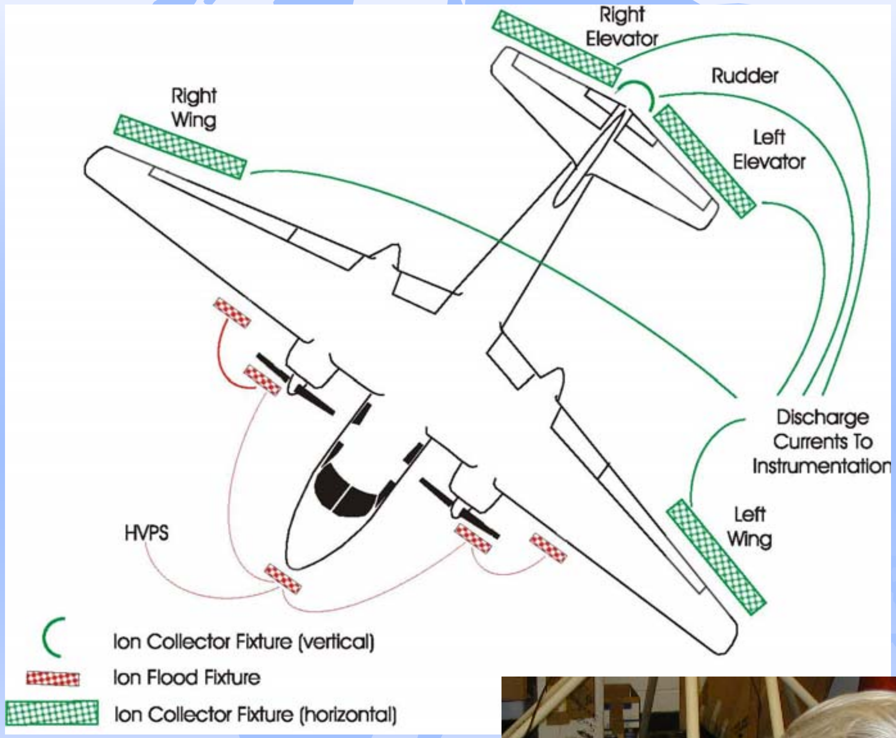
Electric Field, and Potential

- **Aircraft grounded**
- **High-voltage applied to plate 10 cm from field mill face**
- **Field in V/m is 10 times applied voltage**



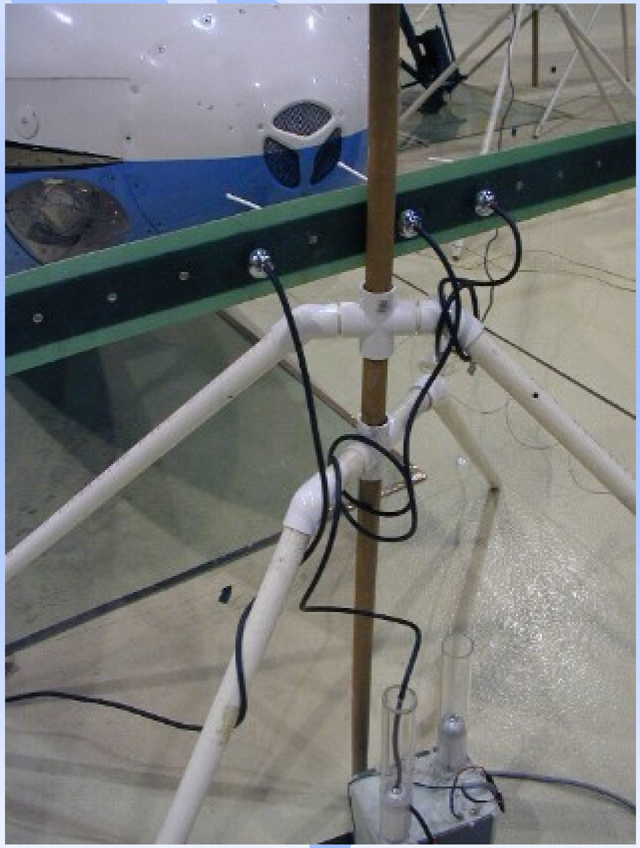
Ion Floods and Collectors

- **High-voltage deposits ions on leading edges through “reversed” dischargers**
- **Airframe stores charge**
- **Discharges from trailing edges collected for measurement using resistive collectors**
- **Flood and collection currents all monitored, recorded**



Ion Flood

Wing, Nose and Props are Impacted



Ion Collection

- General view of the resistive (low-noise) collectors at the rear of the aircraft.
- Collectors are placed behind wing and elevator tips, and along vertical stabilizer (almost two stories high!)

Ready to Test

- **N50 on jacks, isolated…**

- **Test Director Robert Erikson briefs the fire and EMT crew**

Candid Shots

- He's going to do *what*?

- Everybody be ready; we may have to grab him…

…where they needed me…

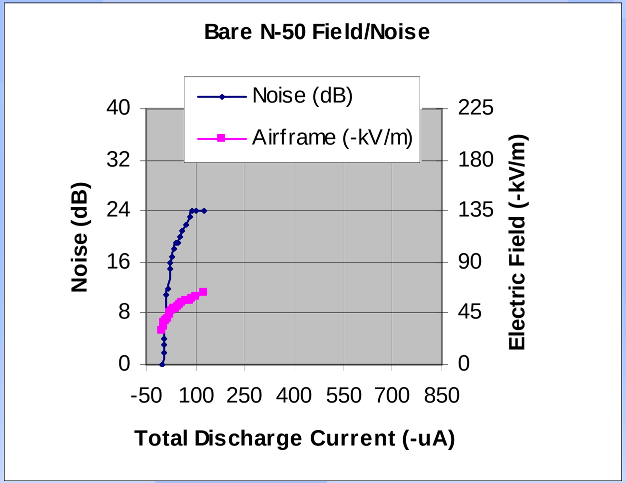
- **First step is a preliminary high-voltage test to detect and correct any arcs or streamers.**
- **During tests, continue to listen for arcs / streamers, and detect any corona from non-discharger locations.**

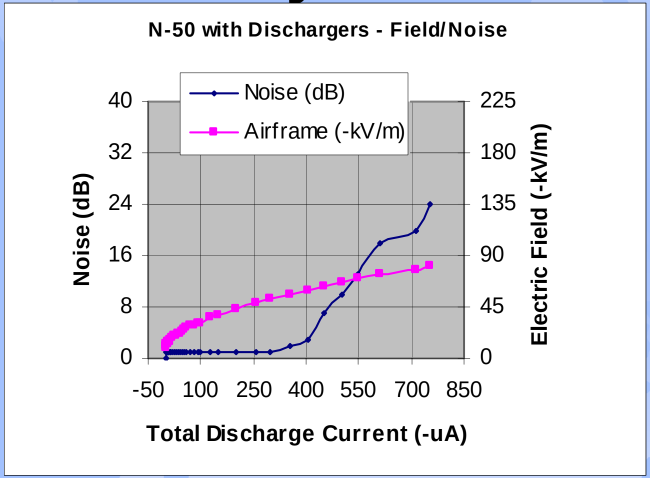
Test configurations

- **“Bare” aircraft – large-radius trailing edge rods**
  - Simulates a/c with missing or broken dischargers; should observe high stored charge and relatively low discharge current (high corona threshold).
- **“Optimized” aircraft – purpose-built dischargers at optimum locations**
  - Dischargers should keep the a/c/ stored charge lower, by liberating more current at lower field strength

N-50 Test Results

- **Ground Electrostatic Survey, 2004**



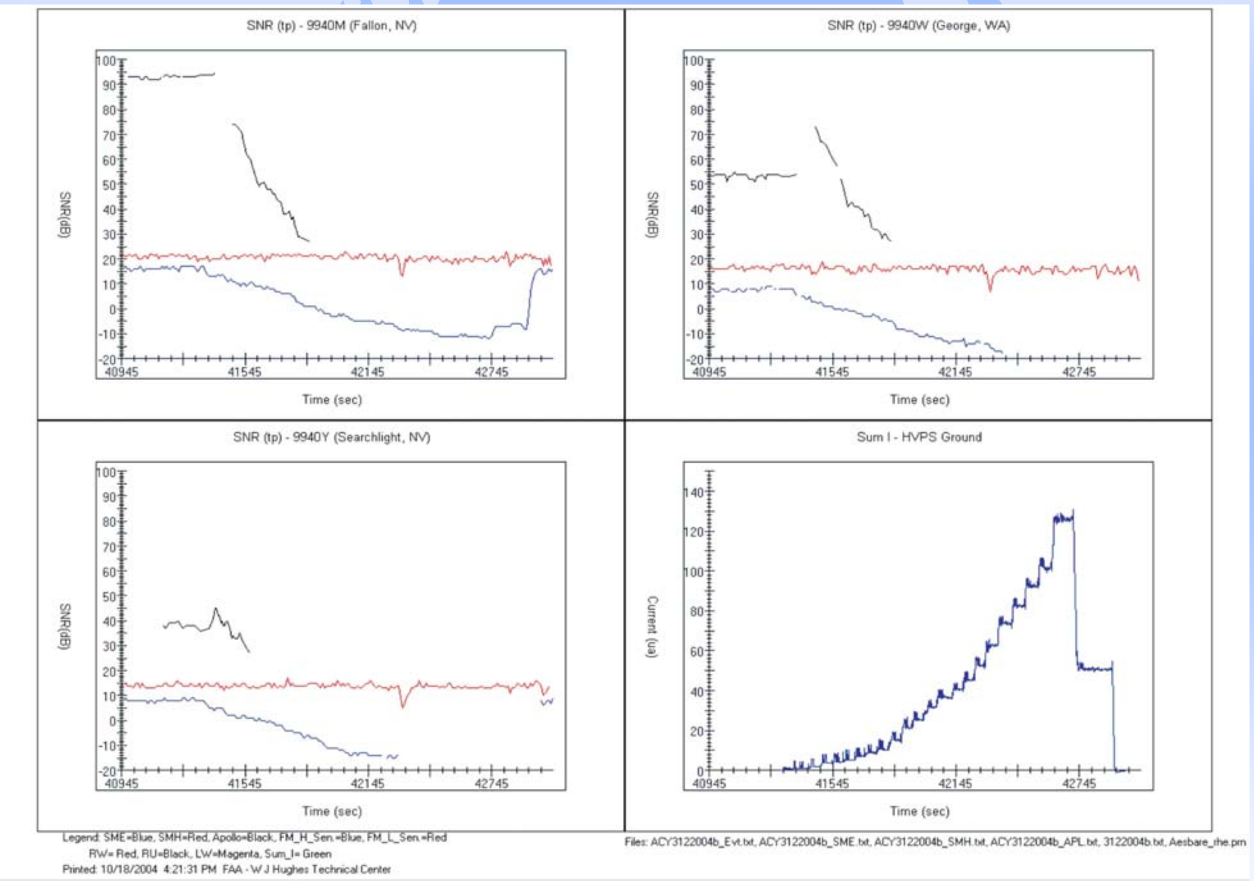


- Shows the ~23 dB quieting obtained with "optimized" dischargers installed, compared to "bare" airplane.
- Field mill was operating during this test.

N-50 Test Results

Loran-C SNR: e-field vs h-field

- **“Bare” aircraft**
- **P-static effect (blue) on SatMate with e-field antenna**
- **No significant effect (red) on Satmate with h-field antenna**
- **Apollo e-field receiver lost track**
- **Compares with Saratoga 1999 results**



Ground Test Summary

- **Three different airplanes**
  - Different times, different places
  - Noise comparison at -100 uA discharge current

Noise @ 100 µA	DC-3	Saratoga	N50
Bare aircraft	33.9 dB	28.1 dB	24.0 dB
With dischargers	4.5 dB	2.6 dB	1.0 dB
Difference	**29.4dB**	**25.5 dB**	**23.0 dB**

Some test procedures may be lost with the passage of time and place.

Further work is planned to understand the differences here.

  - Similar enough to suggest that total current a predictor of noise increase
  - Could we move toward a general rule, not installation-specific?

Maintenance does make a difference!

N-50 Flight Testing

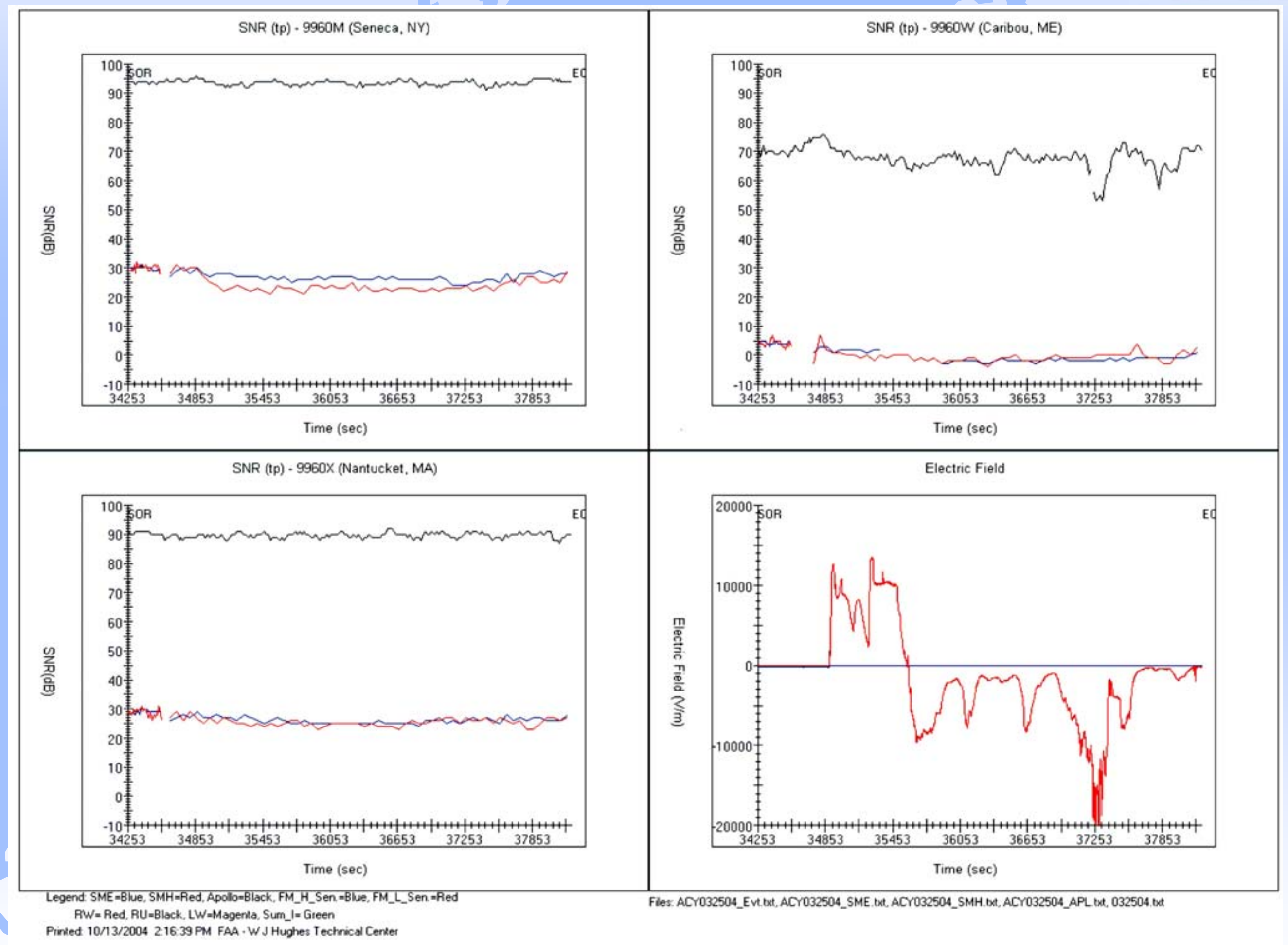
Natural Charging in Weather

- **The search for p-static conditions:**
  - March 25, 2004
    - Small amount of charge/discharge activity
    - Agrees well with "optimized a/c" ground data
    - No receiver effects observed
  - August 16, 2004
    - Encountered charged environment
    - Selective discharger activity
    - Legacy and modern e-field Loran receivers affected

N-50 Flight 3/25/04 (a)

Loran-C effects

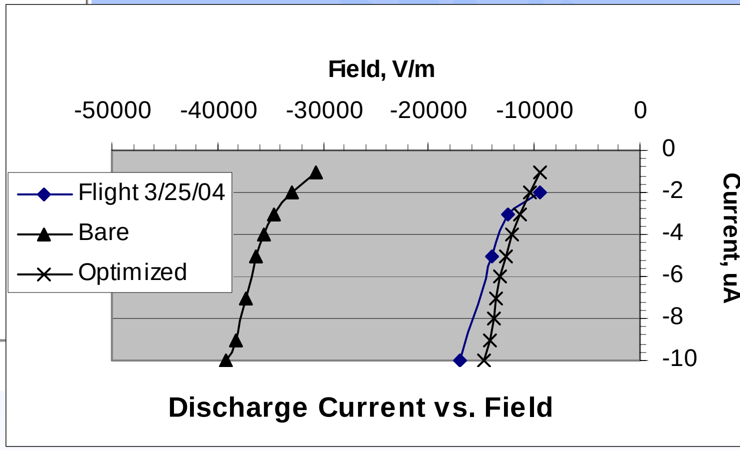
- **DD-2 dischargers at wingtips and tail tip**
- **Only 10 ua discharge current**
- **3-dB SNR loss noted on Apollo e-field receiver**



N-50 Flight 3/25/04 (b)

Corona threshold; agreement with ground

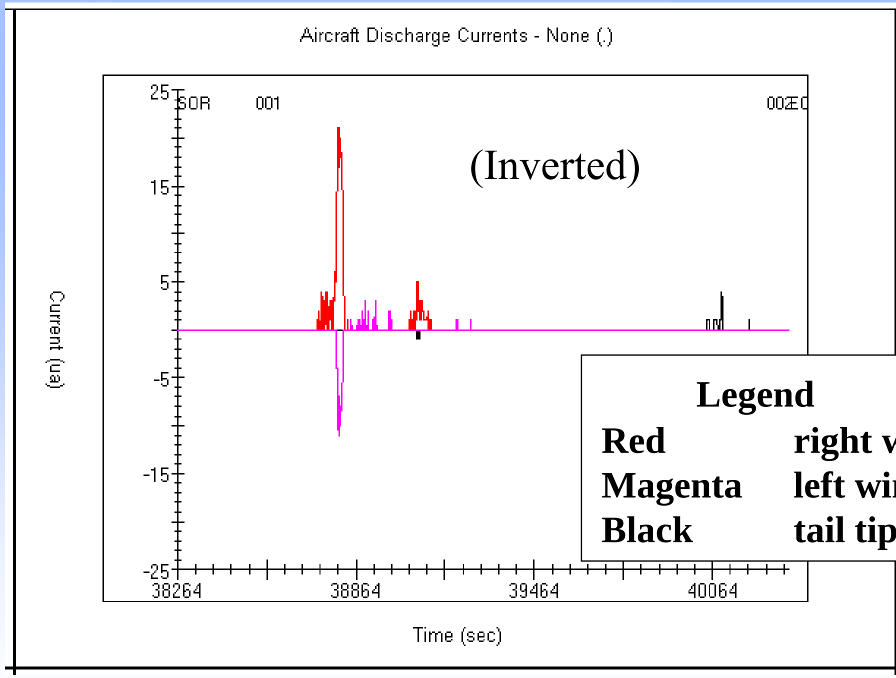
- 9.5 kV/m corona threshold observed
- Individual dischargers plus absolute-value sum shown
- Low currents; agree with ground “optimized” data; few dischargers conducting

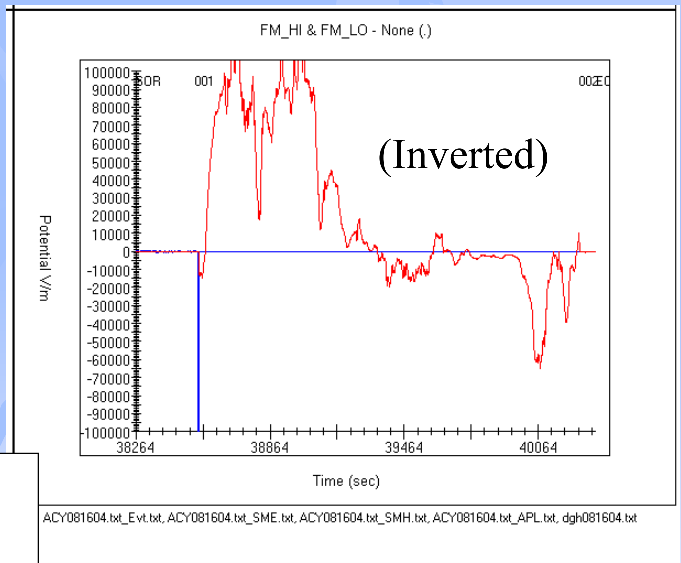


N-50 Flight 8/16/04

We encounter external fields

- **External field alters airframe stored charge – a/c motion complicates graph.**
- **Selective discharge from instrumented brass rod “dischargers” – “bare” airplane**
- **Field mill output less useful quantitatively**
- **Discharge current predicts Loran-C effects**





Legend

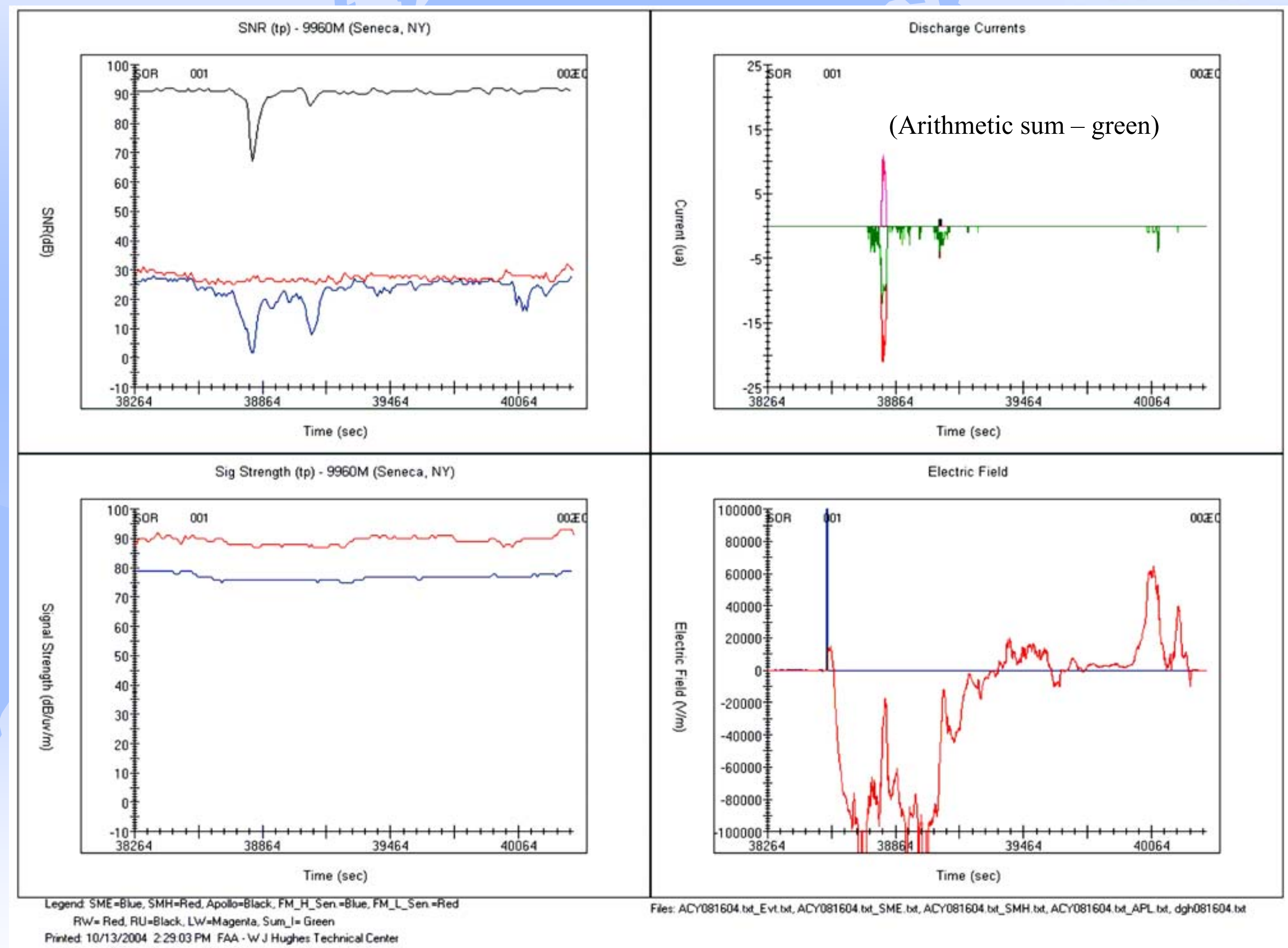
Red	**right wingtip**
Magenta	**left wingtip**
Black	**tail tip**

N-50 Flight 8/16/04

Loran-C effect predicted by corona current

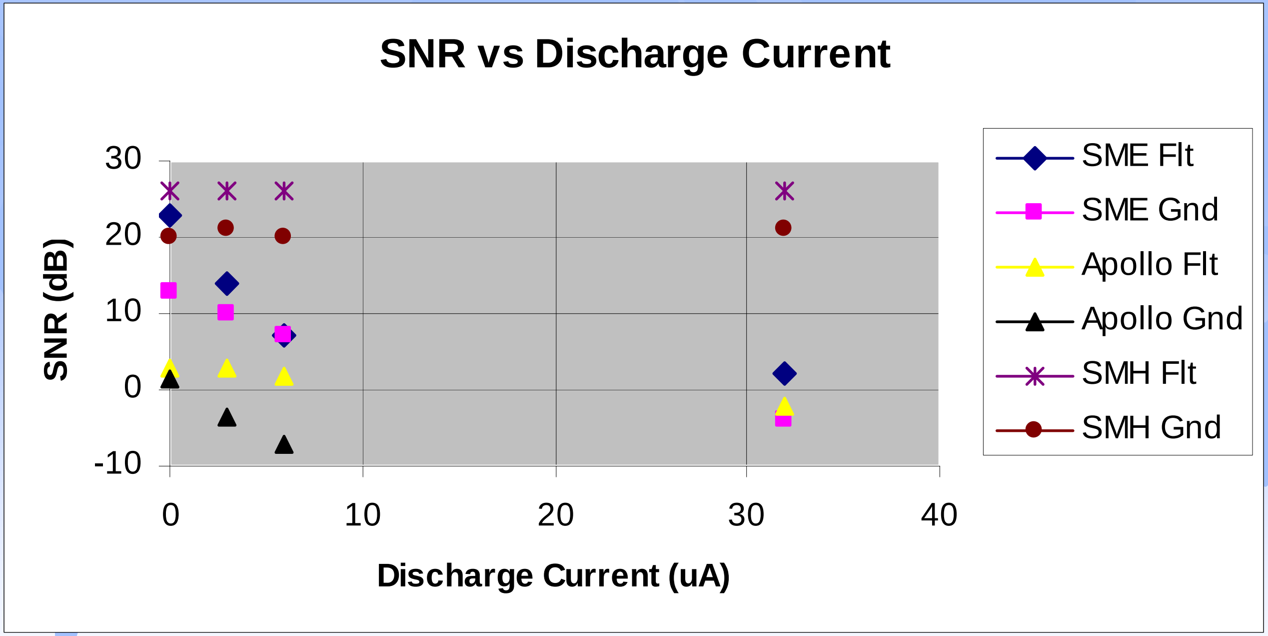
- **Positive and negative corona***
- **Constant Loran-C signal strength**
- **Only e-field receivers affected**

*More analysis later for Loran-C effect – positive corona should be more energetic than negative corona



Flight vs. Ground

- SatMate e-field – SME
- SatMate h-field – SMH
- Legacy e-field – Apollo



Maintenance is good, and the h-field antenna gives even more performance margin!

Conclusions (a)

Electricity

- **FAATC ground survey and flight tests to date confirm and replicate previous work.**
  - The survey data also agree broadly with many uncontrolled or anecdotal observations of p-static interference reported by pilots and others.
- **Three different instrumented aircraft show consistency in p-static noise vs. total discharger current**
  - (Toward a general standard rather than installation-specific approvals?)
- **We can "quiet" the airframe greater than 20 dB using careful maintenance and purpose-built dischargers.**
  - (E-field antennas can work well in these quieted circumstances. Careful airframe and discharger maintenance required.)

P-static is not a lurking demon – it's just noise!

Conclusions (b)

Loran-C

- **Loran-C receivers using e-field antennas see >20 dB SNR reduction in mid-severity charging scenarios.**
  - The h-field antenna offers another >20 dB performance margin against a maintenance-related rise in p-static noise over time.
- **Modern receiver using h-field antenna shows greater than 20 dB more “immunity” to p-static than the same receiver using an e-field antenna.**
  - Even at levels of charge/discharge considered “severe” in practice, there was little or no reduction in SNR from receivers with h-field antennas.
- **A retrofit h-field antenna is desirable.**
  - Legacy e-field receiver was affected at lower p-static levels than the “modern-design” e-field receiver.
  - Legacy receiver with an h-field antenna performed normally in mid-severity p-static conditions.

Do both! Maintain the airplane for safe IFR operation; then add Loran-C plus an h-field antenna for peace of mind!

The Future

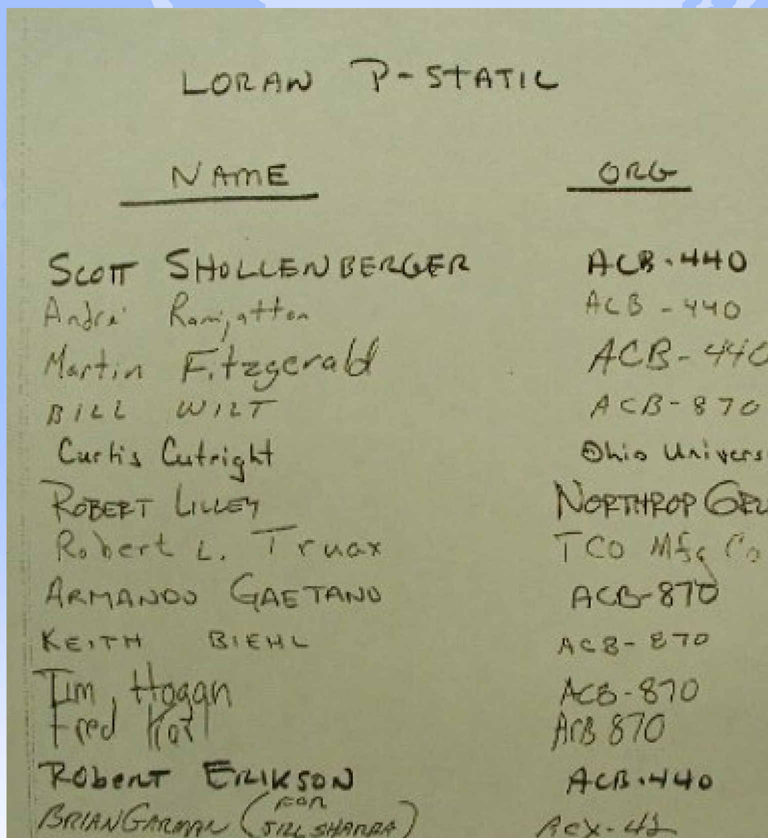
- **"P-static on demand" is needed to resolve finally the questions:**
  - Does use of Loran-C in aviation require extraordinary airframe maintenance?
  - Are unique approval processes required? (must every *installation* be inspected?)
  - Is specialized equipment required? (e.g. h-field antennas)

- **Continue / complete data analysis of the FAATC electrostatic survey**

- **Continue and complete the FAATC flight testing program**
  - Natural charging flights can confirm the previous ground tests
  - Determine if ground tests suffice for certification/approval of antennas/receivers

- **Bring the knowledge down to Earth.**
  - Establish high-voltage laboratory for test and approval
  - Support Loran-C certification/commissioning path development
  - Benefits non-aviation Loran-C users, users of other systems.

Kudos



LORAN P-STATIC 3/8/04

NAME	ORG
SCOTT SHOLLENBERGER	ACB-440
Andre' Ramjattan	ACB-440
Martin Fitzgerald	ACB-440
BILL WILT	ACB-870
Curtis Cutright	Ohio Universi
ROBERT LILLEY	NORTHROP GRU
Robert L. Truax	TCO Mfg Co
ARMANDO GAETANO	ACB-870
KEITH BIEHL	ACB-870
Tim Hoggan	ACB-870
Fred Kost	ACB 870
ROBERT ERIKSON	ACB-440
BRIAN GARMAN (FOR JILL SHARMA)	ACX-42