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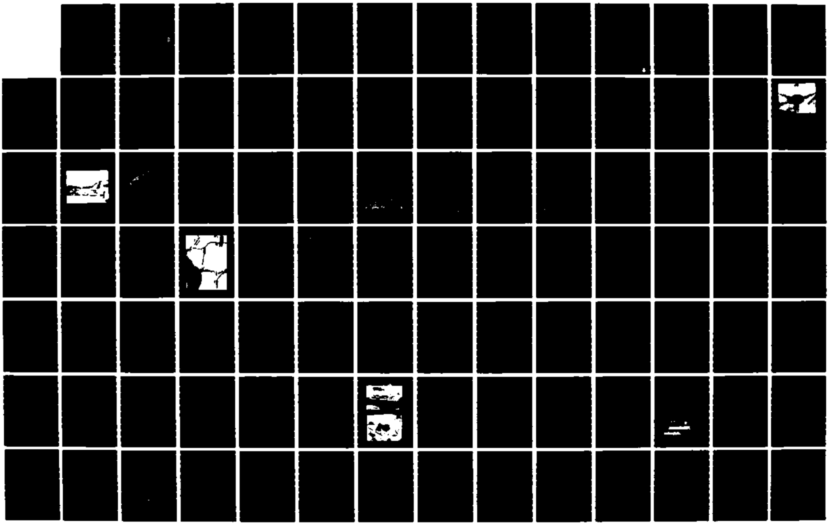

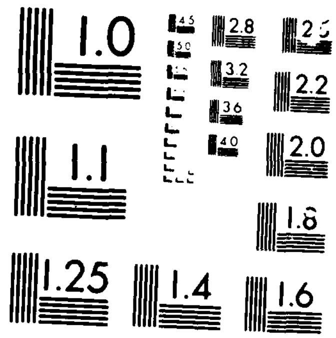
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DTIC ACCESSION NUMBER

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DOT/FAA/CT-85/340-1

PROCEEDINGS AND MINUTES OF THE NATIONAL INTERAGENCY COORDINATION GROUP MEETING

LOW ALTITUDE DIRECT STRIKE LIGHTNING CHARACTERIZATION PROGRAM

INVENTORY

(1)

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FAA Technical Center
Atlantic City Airport
N.J. 08405

Proceedings and Minutes of the National Interagency Coordination Group Meeting

Low Altitude Direct Strike Lightning Characterization Program

January 28-30, 1985

Michael S. Glynn
FAA Technical Center
Atlantic City Airport
N.J. 08405

David L. Albright
U.S. Army, AVSCOM
ST. Louis, Mo.

September 1985

Proceedings

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The meeting was held at the Kings Inn Motel, St. Louis, MO

16. Abstract

This publication is a composite of the minutes, and presentations given at the Sixth National Interagency Coordination Group on Lightning and Static Electricity meeting, held in St. Louis, MO January 28 and 29, 1985. Mr. Dave Albright of the Aviation Systems Command, U. S. Army, St. Louis, MO, was the host.

The presentations encompassed both the active and anticipated programs from each agency.

Note: Considerable latitude was exercised in the literal transcription of the proceedings to alleviate extensive delays in the publication of the document.

17. Key Words
Lightning Characterization
Rate-of-Rise
Electromagnetic Compatibility

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EXECUTIVE SUMMARY

The sixth meeting of the National Interagency Coordination Group (NICG) sponsored by the Aviation System's Command, was held at the Kings Inn, St. Louis, MO on January 28 and 29, 1985. In addition, the NICG sponsored the Low Altitude Direct Strike Lightning Characterization program on January 30, 1985. Both meetings were chaired by Mr. David Albright, AVSCOM, St. Louis, MO.

Mr. Albright opened the meeting by welcoming all participants to St. Louis and hoping the next three days would be cooperative and productive.

The primary purpose of the meeting was to have the members of the NICG present an update to the project which were presented at the meeting in Norman, OK (March 27 and 28, 1984) and to discuss the future plans of their particular agency. Reviewing such plans allows for the transfer of information and in many cases, precludes redundant efforts.

BUSINESS:

Mr. David Albright opened the meeting by having the minutes of the last meeting read. Mr. Albright made a motion that the minutes be accepted as written. Mr. John Birken seconded the motion; motion passed.

Mr. Felix Pitts made a motion that Mr. Mike Glynn be nominated to fulfill the position of NICG secretary. Mr. Larry Walco seconded the motion; motion passed.

Mr. Nick Rasch made a motion that a letterhead for the NICG be developed and a working quantity be purchased. Mr. Rudy Bevin seconded the motion; motion passed.

Secretary needs to call Dr. Andy Revay, FIT, to determaine if there are sufficient funds to purchase the letterhead.

DISCUSSION:

A committee meeting to discuss the conference committee status and plans for the 1985 and 1986 conferences was covered, and the following points brought up:

- The 1985 International Aerospace and Ground Conference on Lightning and Static Electricity which is sponsored by the NICG will be hosted by the French. The tentative time of the conference has been moved to the early part of June to coincide with the Paris Air Show.

- Mr. Andy Revay stated the balance of funds as of 12/31/84 was $25K with no more expenses.

- ORI has left the leftover 84 conference books.

- The August meeting will be in Dayton, Ohio in conjunction with the SAE4 and ADP meetings.

- Mr. Larry Walco needs a set of mailing labels (Mike Glynn will provide).

- Mr. Larry Walco will publish 86 proceedings.

- Paris conference - there appears to be a lot of phenomonology and very little "nuts and bolts" type papers.

- It was discussed as to whether we would initiate only certain type category subjects and then select the papers submitted. There were mixed emotions on this topic, it was dropped with no motion.

- It was suggested that possibly there could be a room with continuous movies/slides/tape, covering certain areas. No decision.

- Mr. Larry Walco asked who the Navy participant was: Mr. Bill Walker.

A LETTER OVERVIEW OF NATIONAL SEVERE STORM LABORATORY (NSSL) ACTIVITY AND SPRING OPERATIONS AND ANALYSIS (DR. V. MAZUR, NSSL, NOAA, NORMAN, OK)

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
ENVIRONMENTAL RESEARCH LABORATORIES

National Severe Storms Laboratory
1313 Halley Circle
Norman, Oklahoma 73069

June 3, 1985 R/E/NS:VM

Mr. Michael Glynn
FAA Technical Center
ACT-340
Atlantic City Airport
Atlantic City, New Jersey 08405

Subject: Justification of the Convair-580 flights in 1986-87

Dear Mike:

I am happy to contribute to your efforts to justify using the Convair-580 airplane for studies of direct lightning strikes in the future.

At the present time the major emphasis in investigations of lightning hazards to aircraft is made on in-flight data acquisition in electrically active thunderstorms. I think we are doing well in a sense of good statistics (especially for high altitude flights), but are lagging behind in scientific interpretation of direct lightning strike phenomena and of structures of storms where strikes occurred. From flights in thunderstorms we accumulated a valuable experience in both data acquisition technique and strategy and also learned a lot about types of strikes to aircraft. However, this work is not over yet.

As we all know, thunderstorm penetrations are not avoidable only for military aircraft during their missions or for all types of aircraft during emergency takeoff and landing. The latter makes our studies of strikes at low altitude so important. The risk of strikes could be lessened if we know how to avoid potentially dangerous storm regions. In 1984 the NASA Storm Hazards Program collected some data which related together for each penetration the storm structure from ground radar observations, the airplane penetration patterns and locations of direct strikes, nearby flashes to aircraft and cloud-to-ground flashes. The purpose was to investigate on what stage of storm development and in what part of the storm the risk of being struck by lightning and by a cloud-to-ground flash is particularly the greatest. A potential application of such knowledge is obvious for air traffic control, which usually has good quality storm information around airport areas available in real time. Because of the need to have the statistically significant number of storm observations of the type described above, and the great difficulties of obtaining these data in a single season, it will be necessary to continue such observations after 1985 (when NASA program is in serious doubt) and maybe even later. This is a good task for the Convair-580 in the scheme of low altitude flights in summer thunderstorms.

A problem which requires immediate and serious attention from the aviation and scientific community is lightning hazards to aircraft in non-stormy precipitation clouds. The reasons are following:

1. Most of reported strikes to aircraft (80-90%) do not occur in active thunderstorms.

2. We have practically no knowledge of electromagnetic characteristics of these strikes that are all triggered flashes simply by definition of being in non-storm clouds. We can expect these strikes to be different than those in stormy clouds we have some experience with.

3. The data about strikes to aircraft in non-stormy clouds point to the freezing level as a region with the highest probability of strikes. I think we should consider this conclusion as only a preliminary one to start research with, because data were not obtained in a process of systematic and statistically sound study of non-stormy penetrations.

The issue of strikes in non-stormy clouds cannot be ignored any longer, because we are absolutely not ready to cope with potentially disastrous situations when the composite aircraft will fly in such common environment. I think we are waiting for a major catastrophe to wake us up.

In preparation of this letter, I discovered a memo from Don W. Clifford (McDonnell Aircraft Co.) to Felix Pitts (NASA Langley) dated 30 May, 1980, and addressing the need for study of the triggered strikes in non-stormy precipitation clouds. Don Clifford also had several ideas to implement, which I found interesting. Unfortunately, we are still at the same point in this research five years later.

The second major problem which was overlooked for a long time is lightning hazards to aircraft in winter storms. Soviet scientists report that the ratio of number of strikes to aircraft to the number of days with thunderstorms is much higher in winter than in summertime, and a peak season for strikes to aircraft in sea coastal areas of the USSR (Black Sea Coast) is during the winter months. Winter storm studies conducted in Japan and Northern Europe indicate that the absolute majority of cloud-to-ground strikes in these storms are positive CG flashes that carry continuous currents of significant values. Both peak and continuous currents of positive CG are much greater than those of negative CG that are most common in summer thunderstorms. Because of different structure of winter storms, they represent a different category of environment from the point of view of lightning hazards to aircraft, which should be investigated separately from non-stormy clouds and summer thunderstorms.

As we know, the 100 percent protection of the new generation aircraft from lightning strikes is unrealistic. Most visible would be a compromise solution of highest possible degree of protection and an advoidance of strikes. The latter requires studying environmental conditions and structures of storms in which direct strikes occur, as well as phenomenon of interaction between aircraft and cloud which results in strike initiation.

The FAA Convair-580 would be most suitable for long-time observations within both non-stormy precipitation clouds and winter storms.

The problem of lightning hazards to aircraft is a concern of the international aviation community. Nowadays, this community benefits from studies conducted in U.S.A. without significant financial contribution into the program. This creates an understandable desire to protect the interest of American industry from pirating ideas and results of investigations conducted on American funds. At the same time, funding for lightning research programs in U.S.A. is more difficult to obtain (example, your program and NASA's program) without, to my mind, completion of all major objects of research in this area. I propose to FAA, as the largest organization of its kind in the free world, to initiate an international program of study of lightning hazards to aviation. Funds can be pooled and then distributed to support scientists' work and data acqusition. The idea of an international program could be discussed first at the forthcoming NICG meeting, and if adopted, proposed to national organizations of different countries. The U.S.A contribution into this program could include aircraft (Convair-580 and possible F-106's) and ground support facilities.

I think that we should not procrastinate in this matter any longer. I would be happy to be of any additional help to you, Mike, in your efforts.

Sincerely,

Vladislav Mazur

Vladislav Mazur
Physicist

cc Norman Crabill, NASA Langley
Felix Pitts, NASA Langley
Maj. P.L. Rustan, Jr., Wright-Patterson AFB

AIR FORCE WRIGHT AERONAUTICAL LABORATORY (AFWAL) ACTIVITY FOR THE PAST YEAR (MR. L. WALKO, ATMOSPHERIC ELECTRICITY HAZARDS GROUP, WPAFB, OH)

ATMOSPHERIC ELECTRICITY HAZARDS

ASSESSMENT FOR AIRCRAFT

MAIN ACTIVITIES

1)	Assessment Methodology	- development of simulation techniques for assessment of the AEH Threat
2)	Threat Characterization	- measurement of the major parameters associated with Aircraft/Lightning interaction
3)	Hardening Technology	- testing of hardening options

ASSESSMENT METHODOLOGY

- Focused Effort in Work Unit 24020223
- Current Activities
  1) Fast Risetime/High Current Generator Development
  2) New Portable Marx Design
  3) Expanded Computer Analysis Capability
  4) Comparison with Characterization Efforts

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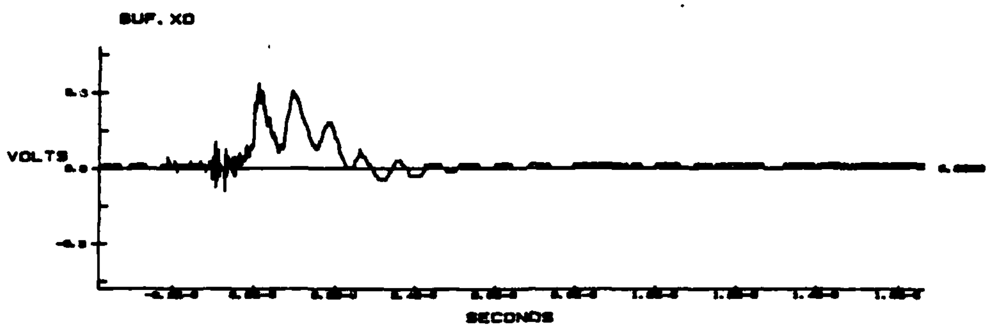

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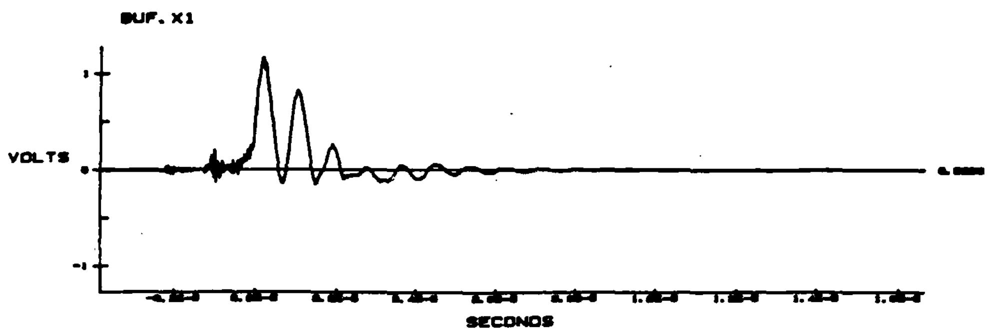


FAST RISETIME/HIGH CURRENT GENERATOR DEVELOPMENT

MILESTONES: DEMONSTRATION OF CAPABILITY

1) CYLINDER TESTS
   - FLIGHT LINE
   - 10 SHOTS
   - 36 KA RT = 180NSEC (MAX)

2) C-580 TEST
   - FLIGHT LINE
   - 67 SHOTS
   40 KA RT = 160NSEC

3) F-16 TEST
   - FLIGHT LINE
   - 27 SHOTS
   - 40 KA RT = 130NSEC

FAST RISETIME/HIGH CURRENT GENERATOR DEVELOPMENT

CURRENT ACTIVITIES

1) MODIFICATION OF PEAKING CAPACITOR
2) SET-UP ON GF-16 INDOORS
   A) DESIGN OF WHEEL STAND-OFFS
   B) REDESIGN OF RETURN PATH CONFIGURATION
3) REFINEMENT OF THE MODULAR RETURN PATH CONCEPT

NEW PORTABLE MARX

- DIVISION FOCUSED ACTIVITY
- CURRENT ACTIVITIES

1) PRELIMINARY ANALYSIS OF GENERATOR REQUIREMENTS
2) INITIAL ORDERING OF COMPONENTS
   A) HIPPOTRONIC POWER SUPPLY
   B) FIRST 15 CAPACITORS
   C) SECOND 25 CAPACITORS

NEW PORTABLE MARX

INITIAL DESIGN

1) 4 MILLION VOLTS TO BE OPERATED AT 3 MILLION VOLTS
2) 40 - 100KV CAPACITORS
3) 20 TRIGGERED SPARK GAPS
4) PORTABLE, MODULAR DESIGN

COMPUTER ANALYSIS

- To correlate lightning simulation data with actual characterization data
- To remove configuration effects from simulation data
- To predict lightning/aircraft interaction effects

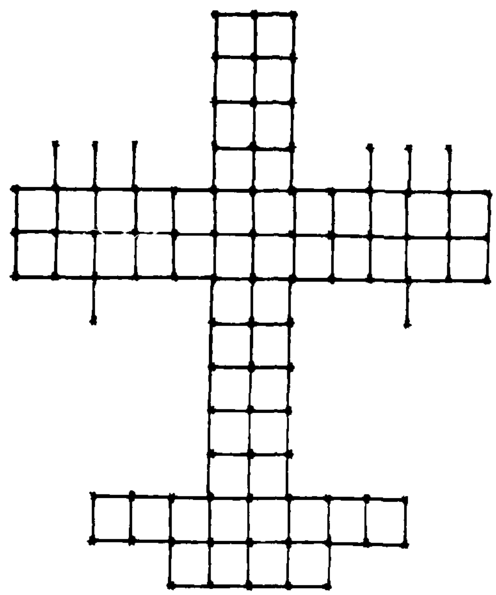
COMPUTER ANALYSIS

MILESTONES :

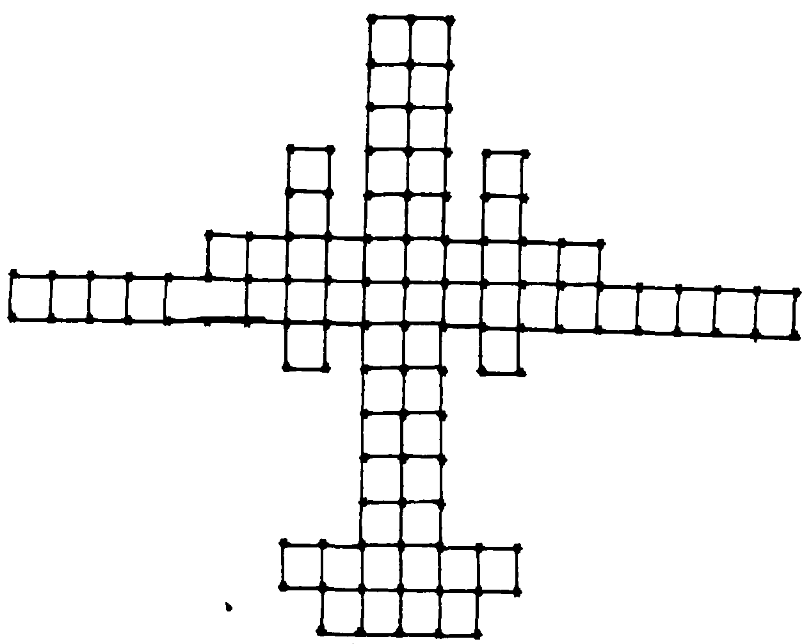
- T3DFD Implemented
  1) Verified using previous NOAA C-130 Data
  2) Programmed for the C-580 aircraft
- Preliminary Analysis of A Nose-To-Tail Strike

SIMULATION/CHARACTERIZATION COMPARISON

- To Compare Simulation Data with Data from Actual Lightning Strikes
- To Improve Simulation Techniques by Adding Computer Analysis to the Process
- To Assist in the Calibration of the C-580 Measurement Sensors



C130 y-12 Plane



CV-580 V=10 Plane

Subtask II : Lightning Characterization

Objective - To obtain quantitative data on the electromagnetic parameters that characterize the lightning - aerospace vehicle interaction.

Current Activities : Lightning Characterization

- Coordination with NASA Kennedy Space Center to participate in FY85 Rocket Triggered Lightning Program at KSC in Summer 1985.

- Participation would involve use of AFWAL RTL cylinder, sensors and instrumentation.

- Participation by AFWAL personnel would be in advisory capacity.

Subtask III : Hardening Technology 24020223

Objective - Provide data to assist in the development of design guidelines for aircraft systems requiring hardening against the atmospheric electricity lightning hazard.

Specific Objectives - (1) Perform comparative tests on similar metal and graphite composite aircraft structures to assess lightning susceptibility.

(2) Develop fuel tank hardening concepts.

Subtask III : Hardening Technology 24020223

Activities:

(1) Obtain composite forward fuselage F-16 mockup used in AEH ADP Phase I.

(2) Obtain GF-16 aircraft and set up in FIESL test area.

(3) Monitor AFWAL/Navy fuel tank program (W.U. 24020247) and interpret results for possible in-house test program.

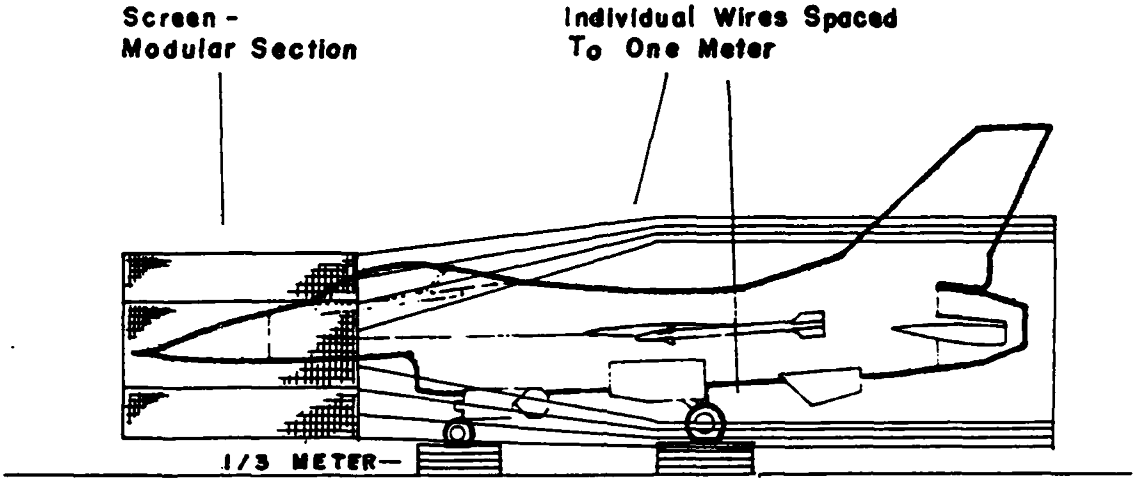
Subtask III : Hardening Technology 24020223

F-16 Composite Forward Fuselage/GF-16 Test Program

(1) Develop test plan that will include magnetic field measurements and specific internal wire measurements.

(2) If possible interchange fuselage panels from composite fuselage and GF-16 aircraft to obtain information on composite material shielding characteristics.

METHOD No.1



JGS 23 Jan 85

METHOD No.1

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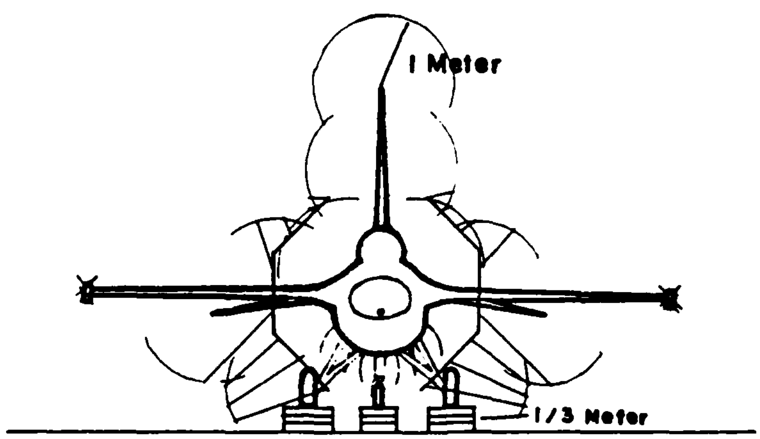

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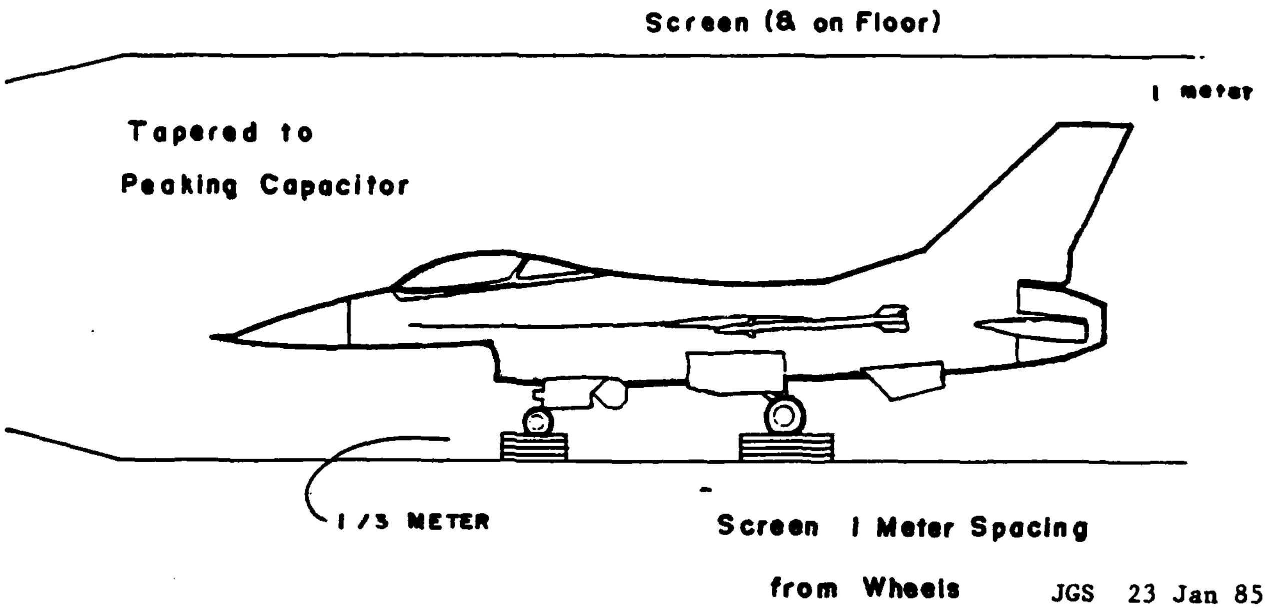
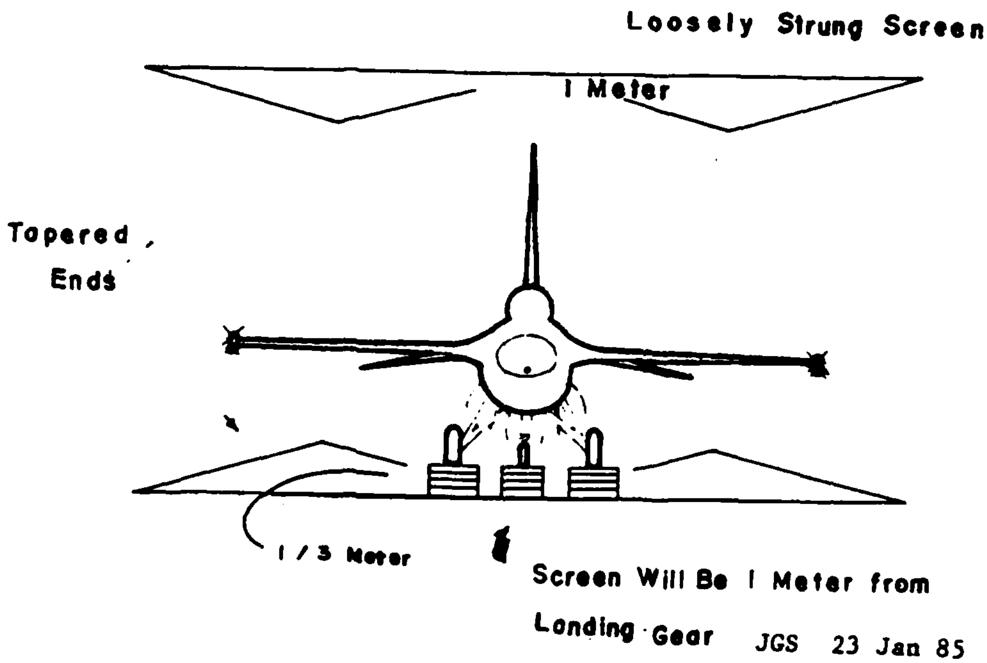
Method No. I Quasi-Parallel Plate



Method No.2 Quasi-Parallel Plate



AFWAL/FIESL TECHNICAL PUBLICATIONS

TECHNICAL PAPERS:

ELECTROMAGNETIC MEASUREMENTS OF LIGHTNING ATTACHMENT WITH AIRCRAFT
P. RUSTAN
PRESENTED AT 1983 NICG LIGHTNING CONFERENCE, JUNE 1983

AIRBORNE MEASUREMENTS OF THE RISETIMES IN LIGHTNING RETURN STROKE FIELDS
P. RUSTAN, B. KUHLMAN, J. REAZER
PRESENTED AT 1983 NICG LIGHTNING CONFERENCE, JUNE 1983

ANALYSIS OF LIGHTNING CURRENT MEASUREMENTS
P. RUSTAN, P. AXUP
TO BE PRESENTED AT 1984 NICG LIGHTNING CONFERENCE, JUNE 1984

CHARACTERIZATION OF FAST RISE TIME ELECTROMAGNETIC PULSES RECORDED IN AIRBORNE MEASUREMENTS DURING FLORIDA THUNDERSTORMS
B. KUHLMAN, P. RUSTAN, J. REAZER
TO BE PRESENTED AT 1984 NICG LIGHTNING CONFERENCE, JUNE 1984

ROCKET TRIGGERED LIGHTNING - A COMPARISON WITH NATURAL LIGHTNING
R. RICHMOND
TO BE PRESENTED AT 1984 NICG LIGHTNING CONFERENCE, JUNE 1984

ATMOSPHERIC ELECTRICITY RESEARCH FOR AIRCRAFT INTERACTIONS
L. WALKO
TO BE PRESENTED AT 1984 CONFERENCE ON ELECTROSTATICS, JUNE 1984

TECHNICAL PAPERS

EFFECTS OF TOWERS AND LIGHTNING CURRENT MEASUREMENTS
P. RUSTAN AND B. MELANDER (BOEING CO.)
IEEE POWER APPARATUS TRANSACTIONS, SUBMITTED JUNE 1984

THE ROCKET TRIGGERED LIGHTNING PROGRAM: 1983 RESULTS
R. RICHMOND
TO BE PRESENTED AT NEM SYMPOSIUM, JULY 1984

AIRCRAFT MEASUREMENTS OF LIGHTNING CURRENTS AND FIELDS
P. RUSTAN, B. KUHLMAN
TO BE PRESENTED AT XXIST URSI GENERAL ASSEMBLY (INTERNATIONAL UNION OF RADIO SCIENCE) AUGUST 1984

THE LIGHTNING THREAT TO AEROSPACE VEHICLES
P. RUSTAN
TO BE PRESENTED AT THE AIAA 23RD AEROSPACE SCIENCES MEETING
14-17 JANUARY 1985

AN UPDATE ON ATMOSPHERIC ELECTRICITY HAZARDS SIMULATION TEST FACILITIES
L. WALKO, J HEBERT
TO BE PRESENTED AT THE AIAA 23RD AEROSPACE SCIENCES MEETING
14-17 JANUARY 1985

AFWAL/FIESL TECHNICAL PUBLICATIONS

TECHNICAL REPORTS

IN HOUSE:

DATA ACQUISITION FOR EVALUATION OF AN AIRBORNE LIGHTNING DETECTION SYSTEM
L. WALKO, J. REAZER
AFWAL-TR-83-3083, SEP 1983

1981 WC-130 LIGHTNING CHARACTERIZATION DATA REVIEW
B. KUHLMAN, P. RUSTAN, J. REAZER
AFWAL-TR-84-3024, JULY 1984

CONTRACTOR:

AN EXPERIMENTAL AND THEORETICAL INVESTIGATION OF AN NEMP TYPE FAST RISE LIGHTNING SIMULATOR
J.D. ROBB, LTRI
AFWAL-TR-84-3007, MARCH 1984

ATMOSPHERIC ELECTRICAL HAZARDS PROTECTION (AEHP) ADVANCED DEVELOPMENT PROGRAM (ADP) OVERVIEW (MR. R. BEAVIN, FLIGHT DYNAMICS LABORATORY, WPAFB, DAYTON, OH)

ATMOSPHERIC ELECTRICITY HAZARDS PROTECTION

OBJECTIVE

- DEMONSTRATE EFFECTIVE PROTECTION CRITERIA FOR ELECTRICAL / ELECTRONIC SUB-SYSTEMS IN ADVANCED TECHNOLOGY AIRCRAFT

APPROACH

- PHASE I
  - DEVELOP BALANCED AEHP CONCEPTS
  - PROVIDE COST EFFECTIVE, DESIGNED-IN PROTECTION
- PHASE II
  - DEMONSTRATE PROTECTION EFFECTIVENESS
  - DESIGN CRITERIA

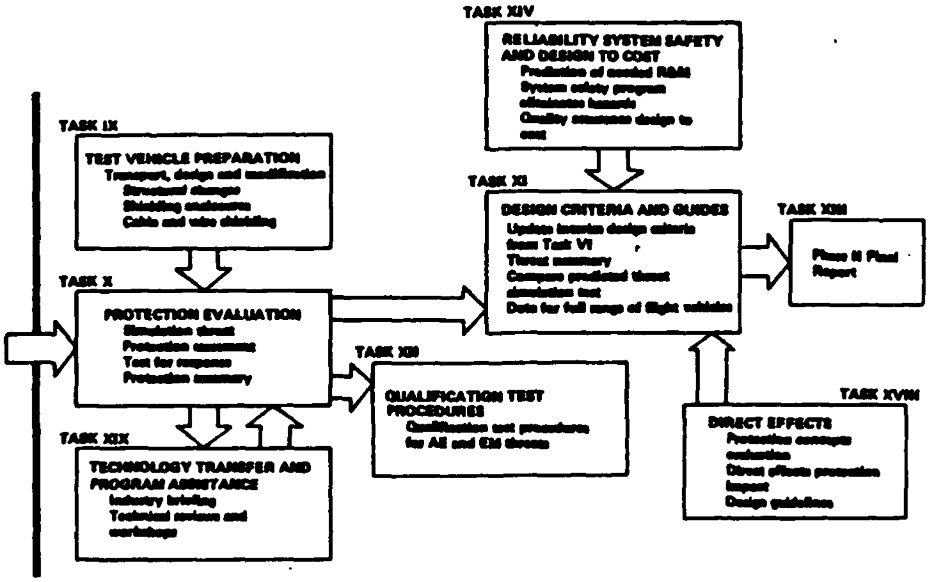
PAYOFF

- RELIABLE ALL-WEATHER OPERATION OF ADVANCED TECHNOLOGY AIRCRAFT
- PROTECTION QUALIFICATION / ASSESSMENT PROCEDURES

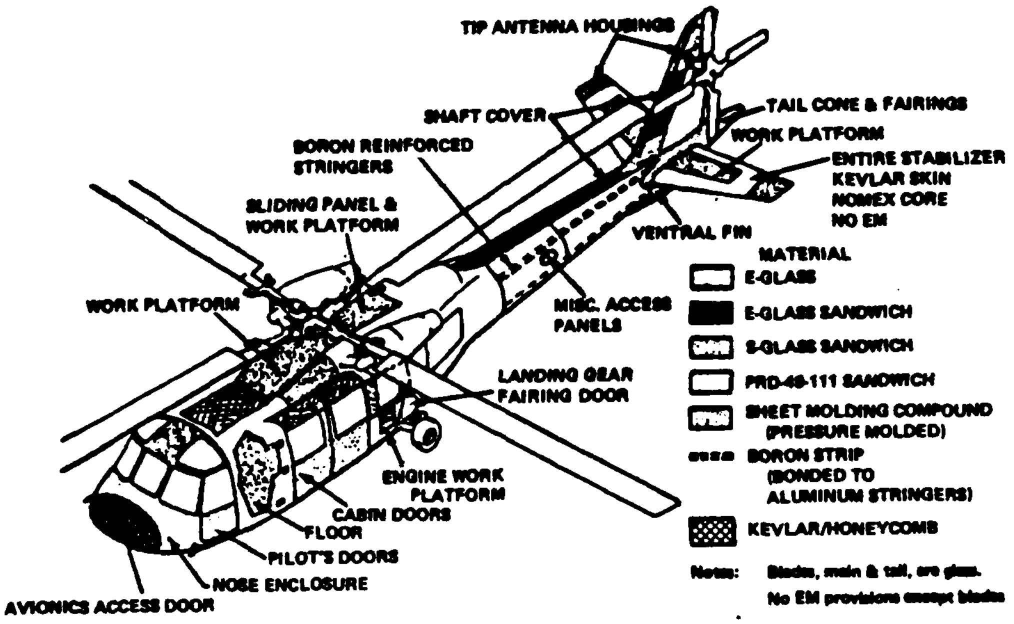
Phase II – Validation Test Approach

- Two ground testbed aircraft
  - F-14A fighter
  - YUH-61 helicopter
- Install operational test electronics, STE, and monitoring instrumentation
- Use identical special test equipment (STE) in each testbed
- Simulate lightning environments
  - Low level CW
  - Moderate level pulse
  - High level pulse
- Functionally *monitor* the operational electronics data including end function (lights, display, actuation)
- Monitor voltage and current conditions in wiring and components

Phase II – Protection Validation



Helicopter Modifications
Airframe Composite Material Usage



F-14A AEHP Modification Design

Objectives

- Prepare installation design for the test equipment in the F-14A and the AEH protection required for this equipment. Implement the modification and installation to prepare the F-14A for AEH protection validation tests.

Approach

- Establish equipment to be installed, installation locations, wire bundle routes, and installation procedures.
- Prepare modification drawings and manufacturing plans to install the equipment and modify the F-14A
- Coordinate the modification and subsequent refurbishment with the planning, manufacturing and quality assurance organizations.

Task X Protection Validation

OBJECTIVES:

- TO DETERMINE THE IMPACT OF AEH ENVIRONMENTS ON FLIGHT AND MISSION CRITICAL SUBSYSTEMS REPRESENTATIVE OF NEW ELECTRONIC TECHNOLOGY AND AIRFRAME STRUCTURES (1990-1995 IOC)
- TO OBTAIN TEST DATA FOR USE IN VALIDATING THE INSTALLED PROTECTION DESIGN APPROACH BY COMPARISON OF MEASURED DATA TO EXPECTED RESPONSES
- TO OBTAIN TEST DATA FOR USE IN VALIDATING THE ANALYTICAL TOOLS AND SIMULATION TEST TECHNIQUES USED IN THE HARDENING DESIGN EFFORT

APPROACH:

- CONDUCT THE TEST WITH TRANSFER FUNCTION, MODERATE LEVEL PULSE AND HIGH LEVEL PULSE TESTS ON ALCM FLIGHT CONTROL COMPONENTS AND DATA BUS EQUIPMENT
- MEASURE EXTERNAL SURFACE TRANSIENT CURRENTS WITH METAL PANELS FOR REFERENCE, THEN TEST WITH MODIFIED PANELS
- MEASURE OPEN CIRCUIT TRANSIENT VOLTAGES BY MEANS OF SPECIAL BRASS BOXES INE, FCSE AND MRA. ALSO MEASURE CURRENTS INDUCED IN THE INTERCONNECTING CABLES OF DATA BUS EQUIPMENT POWER AND SIGNAL CIRCUITS
- RECORD THE OPERATIONAL RESPONSES OF FLIGHT CONTROLS AND DATA BUS EQUIPMENT

CDR-TP-2
TP-10A0-2

Task X
Lightning Simulator Status

R.L. Solem
BMAC L-7170
206-241-4427

Lightning Simulator

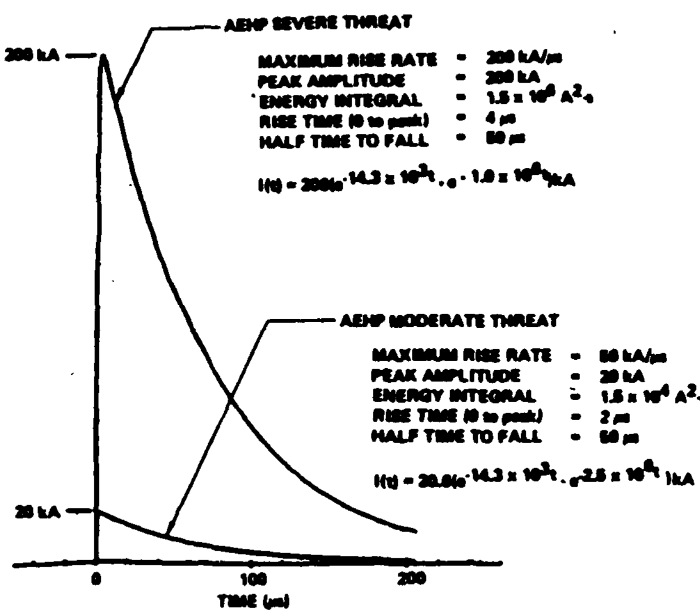
Objective:

- **To obtain the capability of producing a Zone 1A lightning strike simulation to support the indirect effects test on the F-14A.**

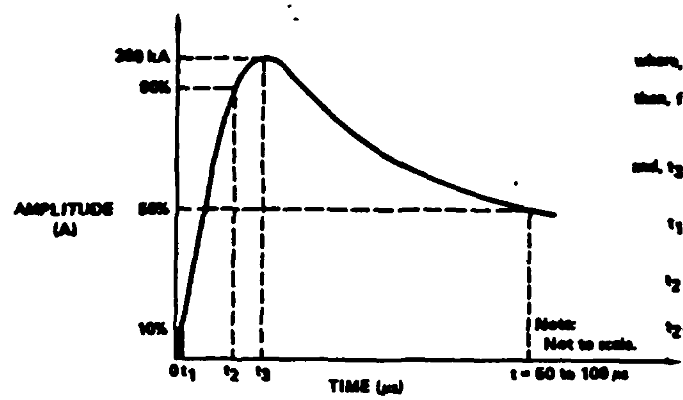
Approach:

- **Enter into subcontract with Maxwell Laboratories, Inc., directing them to build the lightning simulator.**
- **Confirm that the lightning simulator meets the specification.**
- **Coordinate Boeing Facilities and Maxwell Laboratories to provide a turn key system.**

Single Lightning Stroke Threat



Lightning Simulator Current Waveform Characteristics



where, $\omega_0\,(200{,}000) = 2 \times 10^{11}$ A/S, $\omega_0 = 1 \times 10^{6}$

then, $f_0 = \frac{\omega_0}{2\pi} = \frac{1 \times 10^{6}}{2\pi} = 159{,}236$ Hz

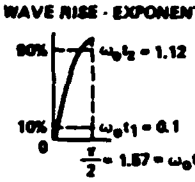
and, $t_3 = \frac{1.57}{1 \times 10^{6}} = 1.57 \times 10^{-6} = 1.57\ \mu s$

$t_1 = \frac{0.1}{1 \times 10^{6}} = 0.1 \times 10^{-6} = 0.1\ \mu s$

$t_2 = \frac{1.12}{1 \times 10^{6}} = 1.12 \times 10^{6} = 1.12\ \mu s$

$t_2 - t_1 = 1.0\ \mu s$ (time from 10% to 90% of 200 kA)

SINE WAVE RISE - EXPONENTIAL DECAY



$\omega_0 t_2 = 1.12$

$\omega_0 t_1 = 0.1$

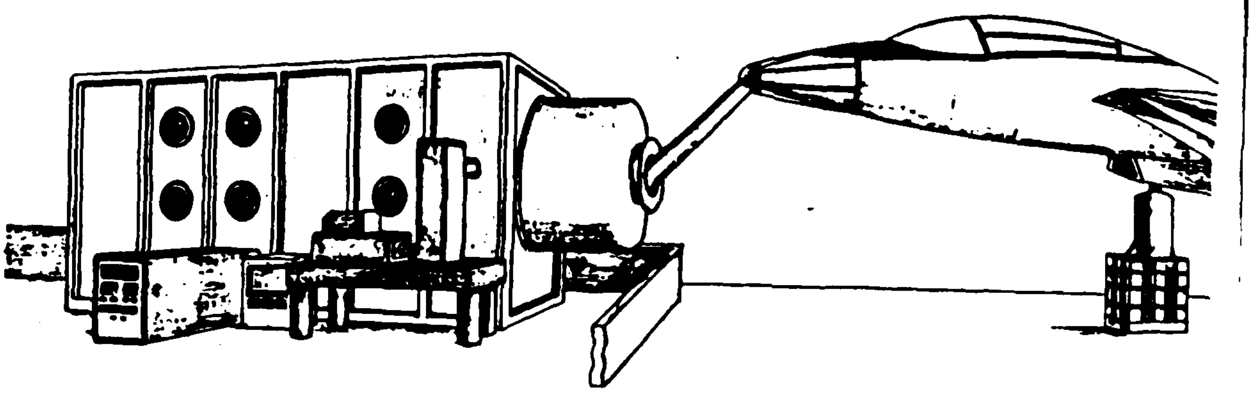
$\frac{\pi}{2} = 1.57 = \omega_0 t_3$

$i(t) = I_0 \sin(\omega_0 t)$

$\frac{di(t)}{dt} = \omega_0 I_0 \cos(\omega_0 t)$

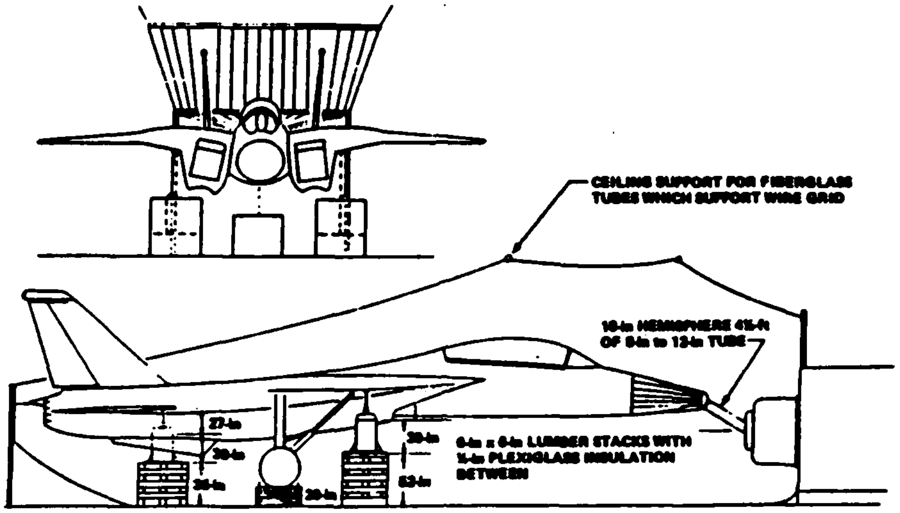
MAXIMUM RATE OF RISE $= \left.\frac{di(t)}{dt}\right|_{max} = \omega_0 I_0 = \omega_0\,(200{,}000)$

High Energy Lightning Simulator

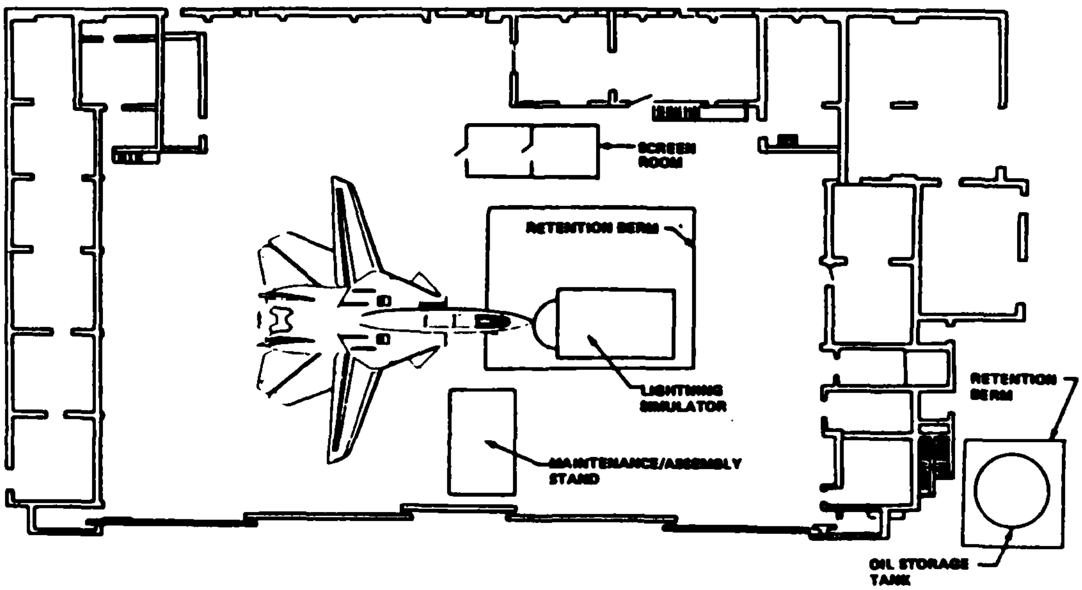


- 200 kA
- 2×10^{11} A/S
- 600 kJ

F-14A Return Circuit Arrangement



Lightning Simulator (Proposed Location)



Task IX

Vehicle Preparation

D. Walen

F. Hekel

Vehicle Prepration Progress

- Completed wire bundle and equipment installation drawings
- Started wire bundle fabrication
- Received Grumman graphite/epoxy overwing fairings and turtle deck panels
- Started wire bundle
- Started equipment mounting bracket fabrication
- Prepared ground support equipment connection design

Task X

Protection Evaluation - Test Planning

T. A. Prestwood

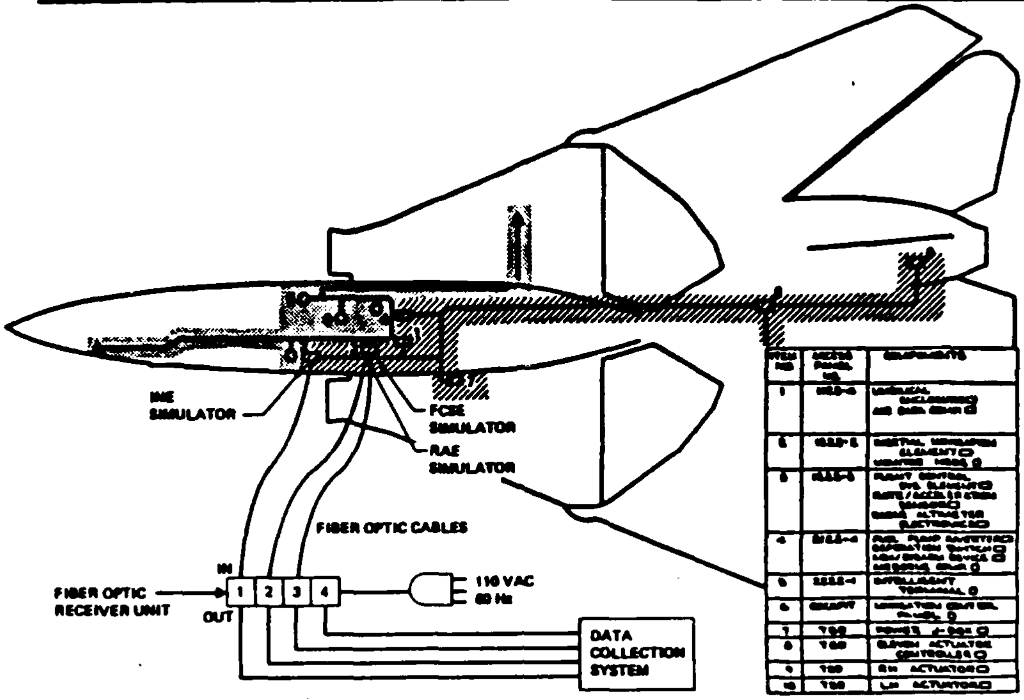
Progress

- TEST MATRIX COMPLETED
- TEST POINTS CHOSEN
- TEST EQUIPMENT DETERMINED
- TEST PROCEDURE ROUGH DRAFT
- PRELIMINARY TEST SCHEDULE PREPARED

F-14A Test Matrix– Nose-to-Tail

CONFIGURATION / TEST POINTS	CONFIGURATION 1		CONFIGURATION 2			CONFIGURATION 3		CONFIGURATION 4		
	All Metal Panels Installed		Gr/Ep Turtle Deck Panels Installed			Turtle Deck Panels Removed		Gr/Ep Turtle Deck Panels Installed and Forward Panels Removed		
	CW	20 kA	CW	20 kA	200 kA	CW	20 kA	CW	20 kA	200 kA
LEVEL 1 Vehicle Characterization										
• DC Resistance	X									
• Input Impedance	X									
• Structural Voltage	X	X	X	X	X	X	X	X	X	X
• Surface Current	X	X	X	X	X	X	X	X	X	X
LEVEL 2 Avionics Transient Response										
• Open Circuit Voltage	X	X	X	X	X	X	X	X	X	X
• Cable Bundle Current	X	X	X	X	X	X	X	X	X	X
LEVEL 3 Avionics Functional Response										
• Data Bus Equipment Response				X	X					
• ALCM Equipment Response				X	X					

Transient Monitoring Setup



F-14A Test Matrix—Nose-to-Wingtip

CONFIGURATION / TEST POINTS	CONFIGURATION 1: All Metal Panels Installed		CONFIGURATION 4: Gr/Ep Turtle Deck Panels Installed and Forward Panels Removed		
	CW	20 kA	CW	20 kA	200 kA
LEVEL 1					
DC Resistance	X				
Input Impedance	X				
Structural Voltage Drop	X	X		X	X
Surface Current	X	X		X	X
Level 2					
Open Circuit Voltage		X		X	X
Cable Bundle Current		X		X	X
LEVEL 3					
Data Bus Equipment Response		X		X	X
ALCM Equipment Response		X		X	X

Atmospheric Electricity AEHP Hazards Protection Advanced Development Program

TASK XI

DESIGN CRITERIA AND GUIDES

DISCUSSION

- **OUTLINE**
  - I Introduction
  - II Definitions
  - III Program Requirements
  - IV Protection Methodology
  - V Environments
  - VI Aircraft Definition
  - VII Assessment Techniques
  - VIII Protection Schemes
  - IX Verification
  - X Life Cycle Concerns
  - XI References And Bibliography

PROGRESS

- Preliminary Outline Completed
- Inputs For F-14 Test Provided
- Initial Review And Sorting Of Data And Documentation Started

SCHEDULE

	1985 AUG	1986 OCT
Design Criteria Update	▽	
Criteria/Guides Complete		▽

TASK XVIII

DIRECT EFFECTS

Glenn O. Olson
BMAC L-7170
206-655-1283

J.A. Plumer
Lightning Technologies, Inc.
413-499-2135

TASK XVIII - AEHP DIRECT EFFECTS PROTECTION

I. <u>GOALS</u>

A. DEFINE AND DEVELOP DESIGN GUIDELINES FOR

1. INCORPORATION OF ELECTROMAGNETIC HAZARD PROTECTION INTO AIRFRAMES

2. INCORPORATION OF DIRECT EFFECTS PROTECTION INTO AIRFRAMES

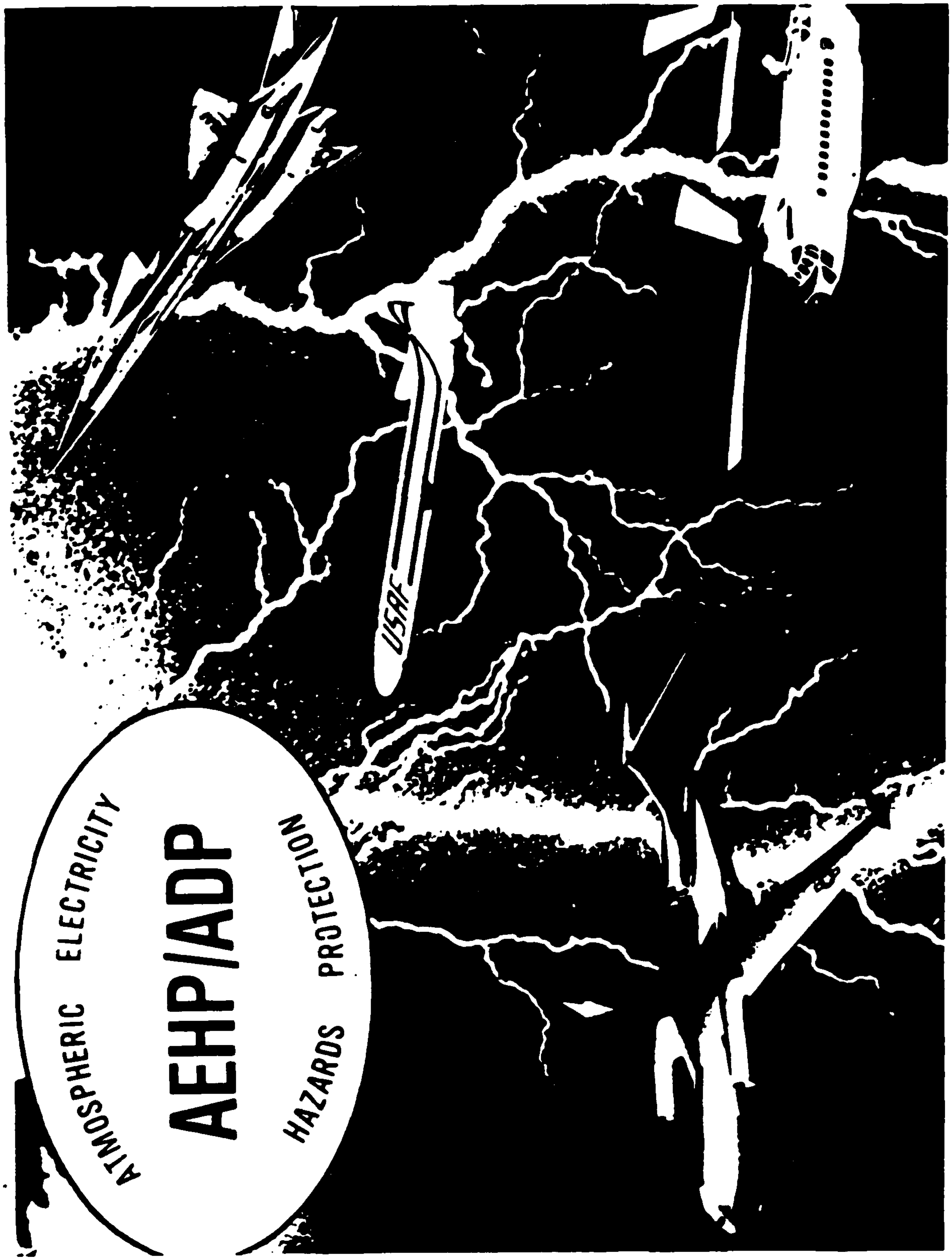
II. <u>RESPONSIBILITIES</u>

A. PROTECTION OF LOW RCS TECHNOLOGY (RAM/RAS) - BOEING

B. REMAINING PROTECTION ACTIVITIES - LIGHTNING TECHNOLOGIES, INC. AND BOEING

SUMMARY

- SUBTASK I- IDENTIFY SPECIFIC PROBLEM AREAS - COMPLETED BY LTI OCTOBER 1, 1984
- SUBTASK II- STATE-OF-THE-ART REVIEW BY LTI COMPLETED NOVEMBER 1, 1984
- SUBTASK III- IDENTIFY TECHNOLOGY NEEDS AND DEVELOP R & D PLANS
  Outline submitted November 1, 1984.
  Subtask III will be completed January 7, 1985
- SUBTASK IV- DIRECT EFFECTS ASSESSMENT TESTING BY BOEING THIRD QUARTER 1985


ATMOSPHERIC ELECTRICITY
AEHP/ADP
HAZARDS PROTECTION
USAF

LIGHTNING PROTECTION STANDARD FOR MILITARY AIRCRAFT - AN OVERVIEW (AERONAUTICAL SYSTEM DIVISION WPAFB MR. L. WALKO, ATMOSPHERIC ELECTRICITY HAZARDS GROUP, WPAFB, OH)

LIGHTNING PROTECTION STANDARD FOR MILITARY AIRCRAFT

1978 - SAE AE4L "BLUE BOOK" REPORT, "LIGHTNING TEST WAVEFORMS AND TECHNIQUES FOR AEROSPACE VEHICLES AND HARDWARE"

- 6 QUALIFICATION TESTS
- 3 ENGINEERING TESTS

1980 - MIL-STD-1757, "LIGHTNING QUALIFICATION TEST TECHNIQUES FOR AEROSPACE VEHICLES AND HARDWARE"

- 4 TEST METHODS FOR DIRECT EFFECTS
- 1 TEST METHOD FOR INDIRECT EFFECTS

1983 - MIL-STD-1757A

- APPLICATIONS GUIDANCE ADDED IN APPENDIX
- MINOR CHANGES/CORRECTIONS MADE

1986 - MIL-STD-XXXX, "LIGHTNING PROTECTION FOR AEROSPACE VEHICLES"

- LIGHTNING PROTECTION PLAN (LPP) AND DESIGN REQUIREMENTS
- LIGHTNING PROTECTION VERIFICATION PLAN (LPVP)
- LIGHTNING PROTECTION VERIFICATION REPORT (LPVR)

PLANNED - MIL-B-5087B REVISION

- TO INCLUDE ONLY ELECTRICAL BONDING REQUIREMENTS
- TO DELETE LIGHTNING PROTECTION REQUIREMENTS

AIRCRAFT LIGHTNING PROTECTION

- PRESENT AIRCRAFT (LARGELY METALLIC)
  - NO FUNDAMENTAL LIGHTNING DEFICIENCIES
  - OVERLOOKED AREAS FIXED THROUGH RETROFIT
  - ANY FUEL A POTENTIAL HAZARD
  - METAL FUEL TANKS CAN BE SPARK-FREE
  - RADOME PROTECTION NOT MANDATORY
  - CARBON FIBER COMPOSITES PRESENT DESIGN CHALLENGE
  - INDUCED EFFECTS PROBLEMS MINIMAL
  - FLY-BY-WIRE SYSTEMS PRESENT DESIGN CHALLENGE
  - RETROFITS/MODIFICATIONS MAY BE OVERLOOKED AREA

AIRCRAFT LIGHTNING PROTECTION (CONT'D)

- FUTURE AIRCRAFT (LARGELY COMPOSITE)
  - BONDING/GROUNDING TECHNIQUES NOT ADEQUATELY ESTABLISHED
  - COMPOSITE INTEGRAL FUEL TANKS IN R&D STAGE
  - COMBINED USE OF ANALYSIS/TESTING FOR VERIFICATION TO INCREASE
  - INDUCED VOLTAGE/CURRENT LEVELS MAY EXCEED INTERFACE LIMITS
  - REVISED TEST METHODS NEEDED FOR DIGITAL UPSET/DAMAGE MECHANISMS
  - NEW ADVANCED MATERIALS NOT YET ADEQUATELY ASSESSED
  - CORROSION CONTROL/ELECTRICAL BONDING MAY BE INCOMPATIBLE
  - LOW CROSS-SECTIONAL/ABSORBING MATERIALS NOT YET ASSESSED
  - IMPROVED PERFORMANCE TESTS AND VERIFICATION TECHNIQUES NEEDED
  - REPAIR/MAINTENANCE TECHNIQUES NEED TO BE DEVELOPED
  - NON-DESTRUCTIVE TESTS FOR WEAK LINKS NEED TO BE DEVELOPED
  - CUMULATIVE EFFECTS NEED TO BE ASSESSED

NEW APPROACHES TO AIRCRAFT LIGHTNING PROTECTION

- NEED TO CONSIDER
  - PROBABILITY OF STRIKE OCCURRENCE
  - AIRCRAFT MISSION
  - COST OF PROTECTION
  - AIRCRAFT SAFETY
  - WEIGHT PENALTY
  - REPAIR/MAINTENANCE
  - SUSCEPTIBILITY/VULNERABILITY OF AIRCRAFT EQUIPMENT/SYSTEMS
  - RISK/PENALTY TRADEOFFS
  - ELECTRONICALLY-CONTROLLED FLIGHT-ESSENTIAL SYSTEMS
  - LIGHTNING THREAT LEVELS/RATES OF RISE
  - LIGHTNING WARNING SYSTEMS

US ARMY PROGRAM FOR PROTECTION OF AIRCRAFT AGAINST NATURAL EM HAZARDS, A PROGRESS REVIEW (MR. D. ALBRIGHT, AVSCOM, ST. LOUIS, MO)

1. Overview.

a. Today I'm going to discuss some of the past year's activities in specifying design requirements for protection of U.S. Army aircraft, most notably helicopters, against such natural hazards as lightning strikes and electrostatic discharges as well as requirements for analysis and tests to demonstrate that such protection has been provided. Tomorrow I'll address lessons learned, needs, and some activities for the coming year. One interesting highlight of the past year was the lightning strike of a UH-60A (BLACK HAWK) helicopter during flight over Germany. I'll say a few words about that .

b. Most of what I have to say pertains to activities with which I have been directly involved at HQ, U.S. Army Aviation Systems Command (AVSCOM) in St. Louis. Tomorrow's presentation will include some details of the ongoing Advanced Composite Aircraft Program (ACAP) which is being directed by AVSCOM's Applied Technology Laboratory out of Ft Eustis, VA.

2. Background.

a. To repeat what I have stated in the past, the Directorate for Engineering is primarily a regulatory agency in that we specify design and test requirements to produce military qualified flightworthy aircraft systems. We participate in design reviews, review test plans, witness tests, and review test reports. We also provide engineering support for fielded systems.

b. Technology research is conducted by our various laboratories which are located elsewhere around the country.

3. Current Activities.

Protection against lightning and static electricity hazards is a specific part of the following programs:

a. The Air-to-Air STINGER missile weapon system which is being designed for use on OH-58C/D scout helicopters.

b. The Volcano mine dispensing system which is being designed for use on UH-60 utility helicopters.

c. A 230-gallon filament wound external fuel tank which is being designed for use on UH-60A, AH-64A (APACHE), and HH-60D (Air Force Night Hawk) helicopters.

d. The Mast Mounted Sight portion of the OH-58D scout helicopter.

e. A composite rear fuselage (transition section) which is being designed to replace the aluminum one on the UH-60 and HH-60D helicopters.

4. STINGER and Volcano Weapon Systems.

a. One of the problems here has been the one of selling the requirement to protect against lightning strike hazards while the basic aircraft themselves have not specifically been lightning hardened.

b. As a compromise, the minimum requirement agreed to has been to preclude inadvertent detonation, launch or jettison of the weapon for a direct strike in both the parked and airborne conditions.

c. Emphasis has been placed on analysis of direct and induced effects while the requirement to test has not been ruled out.

d. An upcoming meeting between one of the contractors, their consultant, Lightning and Transients Research Institute, and the Army will address lightning test requirements for the Volcano mine dispensing system which might involve the use of a simulated aircraft fuselage. Testing of the STINGER installation is not yet certain.

e. Some testing has already been conducted on some of the basic weapon system components but for ground-use hazards only. The airborne application poses additional hazards such as direct lightning strikes and higher static charge potentials.

f. The static discharge hazard of 25,000 volts due to personnel handling is fairly acceptable; however, the 300,000 volt hazard associated with a hovering aircraft is not only overly stringent for smaller aircraft, it is also a less obvious hazard.

5. <u>230-Gallon External Fuel Tank</u>.

a. This is a filament-wound fuel tank with nomex honeycomb core, inner layers of Kevlar and glass, outer layers of interwoven graphite and Kevlar, and a plastic liner. The Army and Air Force configurations differ only in plumbing and controls. Fibertek is the manufacturer.

b. Lightning and static charge tests were completed late last year at Lightning and Transients Research Institute.

c. Bonding measurements were made between all metal parts and ranged from 4 to 55 ohms.

d. Resistance and capacitance measurements were made between various points on the inner liner and the grounding jack for estimates of charge relaxation times. Values of RC time constant of the order of seconds were obtained.

e. The inner liner was also charged to various voltage levels up to a maximum of 30KV, the source removed, and the charge level monitored with time. Decay times of 20 seconds or less were measured. Earlier experiments involved charging to 150KV and slower discharges were evident which was postulated as being due to overstressing the plastic liner.

f. Lightning testing began with induced effects (high di/dt) measurements on wiring entering the tank. The wire outside the tank was initially unshielded. An induced voltage of 800 volts was measured, which reduced to 55 volts after shielding was added.

g. The last test involved the application of high current strikes to the graphite shell itself as well as to various metal parts penetrating the surface.

h. All strikes to the graphite resulted in relatively superficial damage such as burnt paint, torn surface fibers, and some surface delamination. No structural damage occurred.

i. The only metal parts exhibiting damage were the vent valves and the metal ring surrounding the filler cap. The only internal sparking occurred at the drain plug which is spring-loaded.

6. Mast Mounted Sight (MMS).

a. The mast mounted sight subsystem, which was designed by McDonnell Douglas Astronautics Co. out of Huntington Beach, CA, is a spherical package housing a FLIR, TV, and laser rangefinder/designator, which rotates on a pedestal, all of which is mounted atop the mast of an OH-58D helicopter. Both sphere and pedestal are made of carbon epoxy, which is covered with aluminum tape using a conductive adhesive.

b. Lightning tests were conducted late last year by Douglas Aircraft.

c. High voltage attachment tests were performed which resulted in attachment to the nearest point on the sphere, minor pitting of paint and no internal arcing.

d. Induced effects (high di/dt) measurements were made on internal wiring with the maximum voltage being 25 volts, which when extrapolated (appears to be aperature coupling) computed to be 125 volts. Even if diffusion coupling were assumed the voltage would compute to be 200. A pass/fail criterion of 500 volts was used. There was no internal arcing.

e. Finally, a high current strike was applied which resulted in some peeling of tape and subsequent burning of same (components B and C). A maximum voltage of 450 was measured which appeared to be diffusion coupled.

f. An earlier version of MMS was tested which was covered by aluminum flame spray (partial on pedestal). One instance of internal sparking and some large aperature coupling was observed prior to incorporation of some additional insulation and 100 percent flame spraying of the pedestal.

7. Composite Rear Fuselage (CRF).

a. This involves replacing the aluminum transition fuselage section (skin and stringers) between the main cabin and the tailcone of the UH-60A (and HH-60D). The skin of the CRF is comprised mostly of Kevlar panels covered with aluminum screen mesh. Some graphite and aluminum panels are also used. Sikorsky Aircraft is the contractor.

b. Sikorsky did extensive testing of panels and joints for conduction of lightning currents and shielding effectiveness prior to selection of the final design. Much of this work was done earlier in conjunction with the ACAP program. No additional lightning testing is planned; although some avionics tests are planned which includes measurements of any increased noise level due to static discharges.

c. Emphasis is being placed on producibility, repairability,and maintainability. Attempts are being made to also include tracking of the quality of electrical bonding with time.

8. Lightning Strike of UH-60A.

a. The reason why any lightning strike of an Army helicopter is so noteworthy is that only four airborne strikes have been recorded since 1970. The latest occurred on 11 May 1984 and involved a UH-60A flying over Germany and under the following conditions: IFR in the clouds, at 7000 feet, and during very light icing conditions.

b. The crew reported a loud bang and a bright flash; several warning horns sounded and a number of caution and warning lights came on. Not knowing the extent of damage, the crew reduced rotor system loading, retarded engine controls, and accordingly put the aircraft into autorotation. The aircraft broke out of the clouds at 6500 feet and powered control was resumed at 800 feet. The crew flew a short distance and landed with no further damage. There were no injuries.

c. Several Sikorsky engineers were dispatched to Germany to interview the pilots and obtain damage information first hand.

d. Preliminary results of their findings are as follows:

(1) This appeared to be a cloud-to-cloud discharge with physical damage being concentrated in the main and tail rotor systems. No damage evident in the landing gear.

(2) Although the electrical power system remained operational, the use of various subsystems was lost.

(3) Most of the damage observed was predictable; except for the tail rotor blade, which sustained damage more extensive than that observed during any worst case lightning testing.

(4) The lightning current path was tracked between one tail rotor blade and one main rotor blade via blade linkages, gear boxes, and drive trains. Tracing of the path was facilitated by evidence of residual magnetism, arc burns, melting and pitting. The other blades were essentially undamaged.

(5) The primary visible damage was to the one tail rotor blade where the outer 18 inches of honeycombed trailing edge was missing. Much of the damage may have occurred after the strike due to airloads.

(6) The current plan is to have selected mechanical, electrical, hydraulic, avionic, and AFCS components sent to Sikorsky for a detailed tear-down analysis. The lightning damanged aircraft is currently located at Scott Air Force Base in Illinois awaiting further disposition.

9. I'll continue to report on activities such as these as well as provide whatever account I can of actual lightning strikes to Army aircraft.

DESIGN GUIDE FOR LIGHTNING PROTECTION OF ADVANCED FUEL SYSTEMS - A PROGRESS REVIEW (NAVAL AIR DEVELOPMENT CENTER, MR. D. SNEDAKER, LAKEHURST, NJ)

AIRCRAFT FUEL SYSTEM
LIGHTNING PROTECTION DESIGN AND QUALIFICATION
TEST PROCEDURES DEVELOPMENT

PROGRAM PLAN

BY

LIGHTNING TECHNOLOGIES, INC.

PREPARED FOR

NAVAL AIR DEVELOPMENT CENTER

WARMINSTER, PENNSYLVANIA

CONTRACT N62269-83-C-0066

PROGRAM OBJECTIVES

DEVELOP AND VERIFY A SET OF DESIGN AND QUALIFICATION TEST PROCEDURES FOR THE VALIDATION OF AIRCRAFT FUEL SYSTEM PROTECTION

PRIME CONTRACTOR

LIGHTNING TECHNOLOGIES, INC.
K.E. CROUCH, PRINCIPAL INVESTIGATOR

SUB-CONTRACTOR

LIGHTNING & TRANSIENTS RESEARCH INSTITUTE
J.D. ROBB, PRINCIPAL INVESTIGATOR

APPROACH

PHASE I - STATE-OF-THE-ART REVIEW

PHASE II - REVIEW OF BASIC MINIMUM IGNITION

PHASE III - DEVELOPMENT OF PROCEDURES AND CRITERIA

PHASE IV - EVALUATION AND DEMONSTRATION OF PROPOSED PROCEDURES AND CRITERIA

PHASE V - PUBLICATION OF TEST PROCEDURES AND CRITERIA SPECIFICATIONS

PHASE I

REVIEW OF PRESENT TEST PROCEDURE AND CRITERIA

OBJECTIVE

DETERMINE PRESENT STATE-OF-THE-ART OF LIGHTNING TEST PROCEDURES AND PASS/FAIL CRITERIA FOR AIRCRAFT FUEL SYSTEMS

APPROACH

- MANUFACTURERS/AGENCY SURVEY
- REVIEW OF SPECIFICATIONS
  - MIL-STD-1757A
  - FAA AC 20-53A
  - AFWAL AEHP
- DETERMINE BASELINE CRITERIA
  - ALUMINUM CONSTRUCTION
  - 200 MICROJOULE SPARK
  - PROPANE/AIR DETECTION TECHNIQUE
  - PHOTOGRAPHIC DETECTION TECHNIQUE
  - MARGIN OF SAFETY/ERROR CONSIDERATIONS

PHASE I

PASS/FAIL CRITERIA

APPROACH

- LITERATURE SEARCH
- USER COMMENTS
- TEST EXPERIENCE

FINDINGS

- FUEL/AIR MIXTURES (PROPANE)
  - LOTS OF SPARK STUDY DATA

    LEWIS AND VON ELBE
    BARRETTO
  - VERY LITTLE WORK ON

    HOT SPOTS
    HOT PARTICLES
    CORONA
  - 0.2 mJ REPRESENTS LOWER LIMIT

    1-10% OCCURRENCE LEVEL
  - NO FORMAL DEVELOPMENT STUDY
- PHOTOGRAPHIC TECHNIQUE
  - DEVELOPED TO AVOID EXPLOSIVE TESTING
  - NO FORMAL DEVELOPMENT STUDY
  - THEORY GOOD-IMPLEMENTATION VERY DIFFICULT
  - NOT USEFUL WITH TRANSLUCENT SAMPLES

PHASE I

FINDINGS (WORK COMPLETED NOVEMBER 1984)

- THREAT DEFINITIONS ADEQUATE
- PROCEDURES ADEQUATE
- PASS/FAIL CRITERIA INADEQUATE
- MARGIN OF SAFETY/ERROR ASSESSMENTS NOT POSSIBLE

PHASE II

REVIEW AND ESTABLISHMENT OF BASIC MINIMUM IGNITION CRITERIA

OBJECTIVE

DETERMINE AND ESTABLISH MINIMUM IGNITION LEVELS FOR HYDROCARBON CONSTITUENTS OF AIRCRAFT FUELS IN A RESEARCH LABORATORY ENVIRONMENT

APPROACH

- REVIEW OF SPARK IGNITION STUDIES
- REPEAT SPARK IGNITION LEVEL EXPERIMENTS
- PERFORM RESEARCH INTO IGNITION BY:
  - ARC PLASMA
  - HOT PARTICLES
  - HOT SPOTS
  - CORONA
- DETERMINE STATISTICAL RELATIONSHIPS
- CONSIDER EFFECTS OF:
  - INITIAL TEMPERATURE
  - ELECTRODE MATERIALS
  - OXYGEN CONTENT
  - FUEL TYPES
  - AREA (HOT SPOTS)

PHASE II

PROGRESS (25% COMPLETED AS OF JANUARY 1, 1985)

- VACUUM CHAMBER TEST BED SYSTEM ESTABLISHED
- PROPANE/AIR SPARK IGNITION DATA TAKEN
  - 200 MICROJOULE IGNITION PROBABILITY BETWEEN 1/100 AND 1/1000 (PRELIMINARY)
- OXYGEN RICH PROPANE SPARK TESTS UNDER WAY
  - INCREASE O_2 SIGNIFICANTLY REDUCES IGNITION ENERGY
- PENTANE, ETHENE, ETHYNE/AIR SPARK TEST PLANNED
- ARC, PARTICLE, HOT SPOT AND CORONA WORK TO FOLLOW
- TIME AND FUNDING LIMITATIONS MAY REQUIRE OMISSION OF SOME ASPECTS

PHASE III

DEVELOPMENT OF TEST PROCEDURES AND PASS/FAIL DETECTION CRITERIA

OBJECTIVE

DEVELOPMENT OF METHODS AND CRITERIA FOR DETECTING IGNITION SOURCES QUANTIFIED IN PHASE II, PROPOSED PROCEDURES AND CRITERIA WILL BE PUBLISHED

APPROACH

REPRODUCE MINIMUM IGNITION LEVELS IN LIGHTNING LABORATORY REPRESENTATIVE ENVIRONMENTS AND DEVELOP METHODS OF DETECTING THE IGNITION SOURCE

- DEVELOP LIGHT TIGHT BOX
- EVALUATE DETECTION METHODS
  - FUEL/AIR
  - PHOTOGRAPHIC
  - TEMPERATURE SENSORS
  - PHOTO MULTIPLIERS
  - FIBER OPTICS
- IGNITION SOURCES
  - SPARKS
  - ARCS
  - PARTICLES
  - HOT SPOTS

PHASE IV

EVALUATION AND DEMONSTRATION OF PROPOSED AIRCRAFT FUEL SYSTEM TEST PROCEDURES AND PASS/FAIL DETECTION CRITERIA

OBJECTIVE

THE TEST PROCEDURES AND PASS/FAIL DETECTION CRITERIA DEVELOPED IN PHASE III WILL BE DEMONSTRATED AND EVALUATED BY SEVERAL OF THE POTENTIAL LABORATORY USERS DURING THIS PHASE

APPROACH

- INDUSTRIAL REVIEW
  - SAE AE4L COMMITTEE COMMENTS
- DEMONSTRATION OF TECHNIQUES BY TESTS
  - LTI
  - LTRI
- USER EVALUATION ROUND ROBIN TESTS
  - MCDONNELL
  - BOEING
  - LTI
  - LTRI

PHASE V

DOCUMENTATION OF RESULTS AND PUBLICATION OF AIRCRAFT FUEL SYSTEM LIGHTNING PROTECTION DESIGN AND QUALIFICATION TEST SPECIFICATION

OBJECTIVE

PUBLICATION OF THE TEST SPECIFICATION WITH PASS/FAIL CRITERIA AND THE REPORT SUBSTANTIATING THE BASIS FOR ITS ADOPTION ALONG WITH GUIDELINES FOR USE INCLUDING MARGIN OF SAFETY ASSESSMENTS

APPROACH

RESULTS OF PREVIOUS PHASES WILL BE INCORPORATED INTO THE FINAL DOCUMENT WITH RETEST VERIFICATIONS PERFORMED AS NEEDED

NAVY BASIC RESEARCH PROGRAM ON LIGHTNING - AN OVERVIEW (DR. L. H. RUHNKE, NAVAL RESEARCH LABORATORY, WASHINGTON, DC)

1750 TO 1780

PROBLEM	BASIC RESEARCH	SOLUTION
LIGHTNING PROTECTION OF BUILDINGS AND PEOPLE	STATIC ELECTRICITY FAIR WEATHER MEASUREMENTS	LIGHTNING ROD PROTECTION RULES FOR PEOPLE

1920 TO 1930

PROBLEM	BASIC RESEARCH	SOLUTION
POWER TRANSMISSION LINE PROTECTION	LIGHTNING WAVEFORM PEEK CURRENT STATISTICS ELECTRIFICATION THEORIES	AUTOMATIC SWITCHES GROUNDING WIRES

1940 TO 1950

PROBLEM	BASIC RESEARCH	SOLUTION
AIRCRAFT COMMUNICATION SYSTEMS	ELECTRIFICATION THEORIES THUNDERSTORM DYNAMICS (1ST THUNDERSTORM RESEARCH PROGRAM) ELECTRICAL BREAKDOWN PROCESSES	VHF AND UHF COMMUNICATION SYSTEMS ELECTROSTATIC DISCHARGERS THUNDERSTORM AVOIDANCE RULES WEATHER RADAR

1975 TO 1985

PROBLEM	BASIC RESEARCH	SOLUTION
MICROCIRCUITS	ELECTRIFICATION THEORIES	HAZARD ASSESSMENT
CARBONCOMPOSITES	LIGHTNING STRUCTURE	WARNING SYSTEMS
VEHICLE SIZE	THUNDERSTORM MEASUREMENTS (2ND THUNDERSTORM RESEARCH PROGRAM)	

CHIEF OF NAVAL RESEARCH

NAVAL RESEARCH LAB. (NRL)
in-house research

OFFICE OF NAVAL RESEARCH (ONR)
contract research

Past substantial support on lightning research by ONR:

New Mexico Inst. Mining & Tech. (Workman, Brook, Moore)

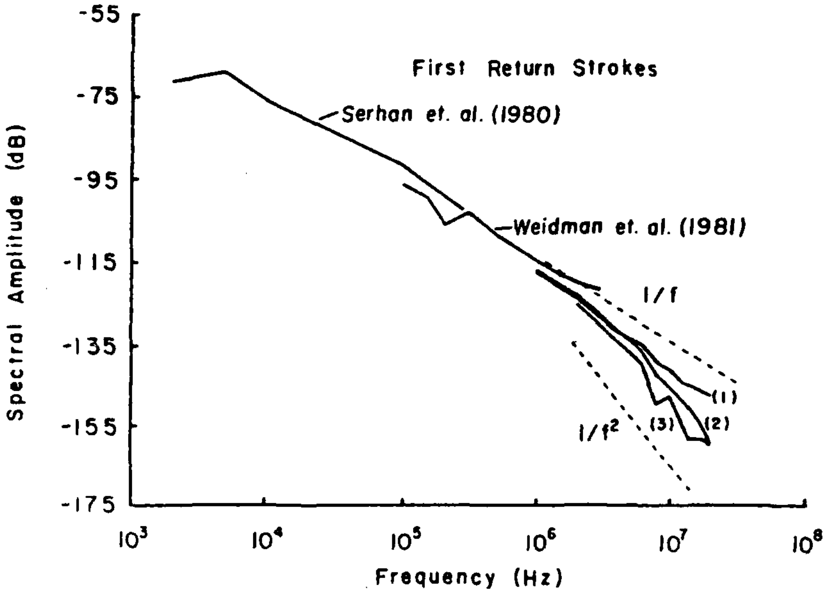
SUNY, Albany (Vonnegut, Orville)

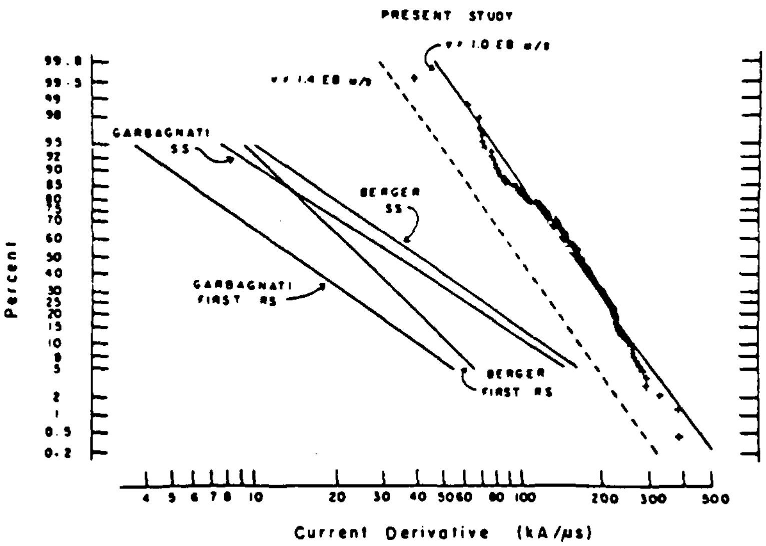
Univ. Arizona (Krider)

Univ. Florida (Uman)

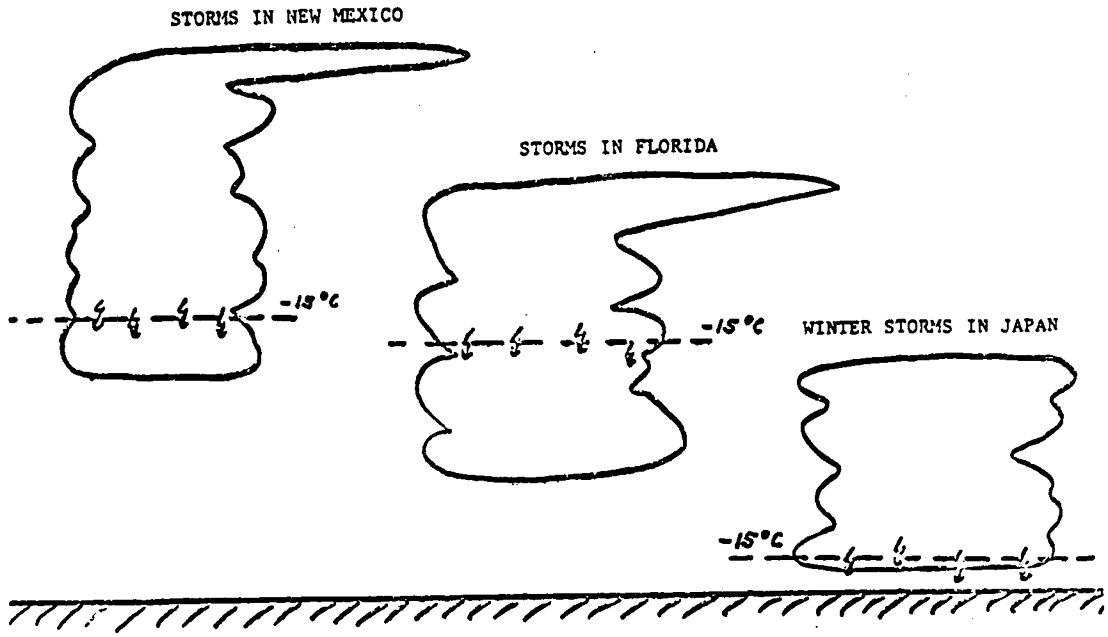
Rice Univ. (Few)

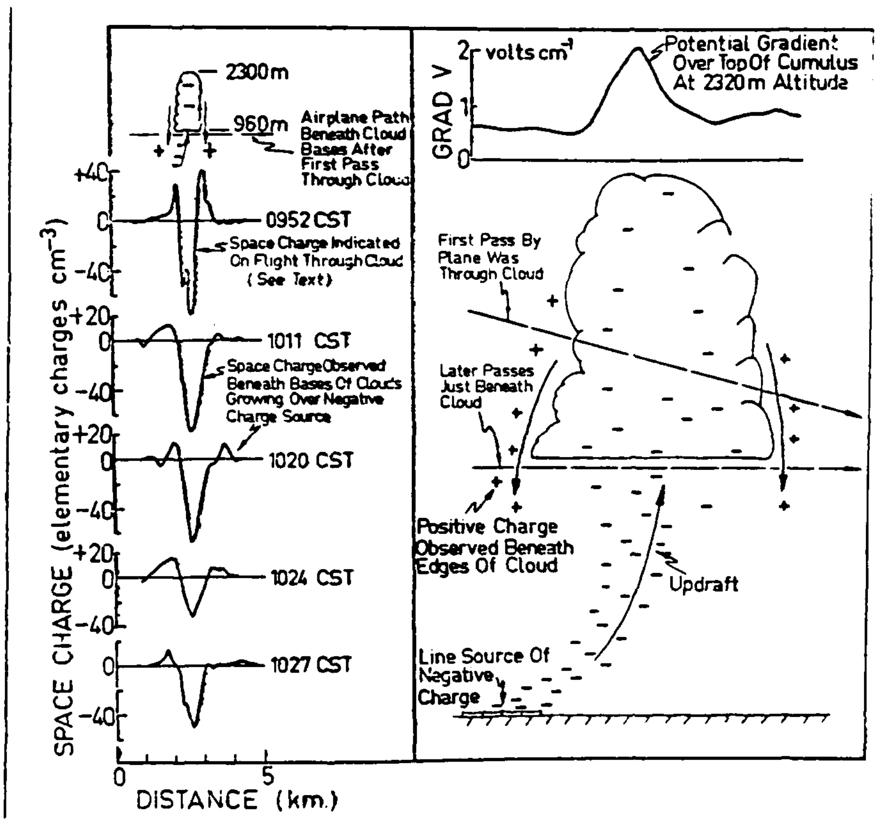
Univ. Minnesota (Freier)


First Return Strokes
Serhan et. al. (1980)
Weidman et. al. (1981)
1/f
1/f²
(1)
(2)
(3)
Spectral Amplitude (dB)
Frequency (Hz)


PRESENT STUDY
GARBAGNATI SS
BERGER SS
GARBAGNATI FIRST RS
BERGER FIRST RS
Percent
Current Derivative (kA/μs)

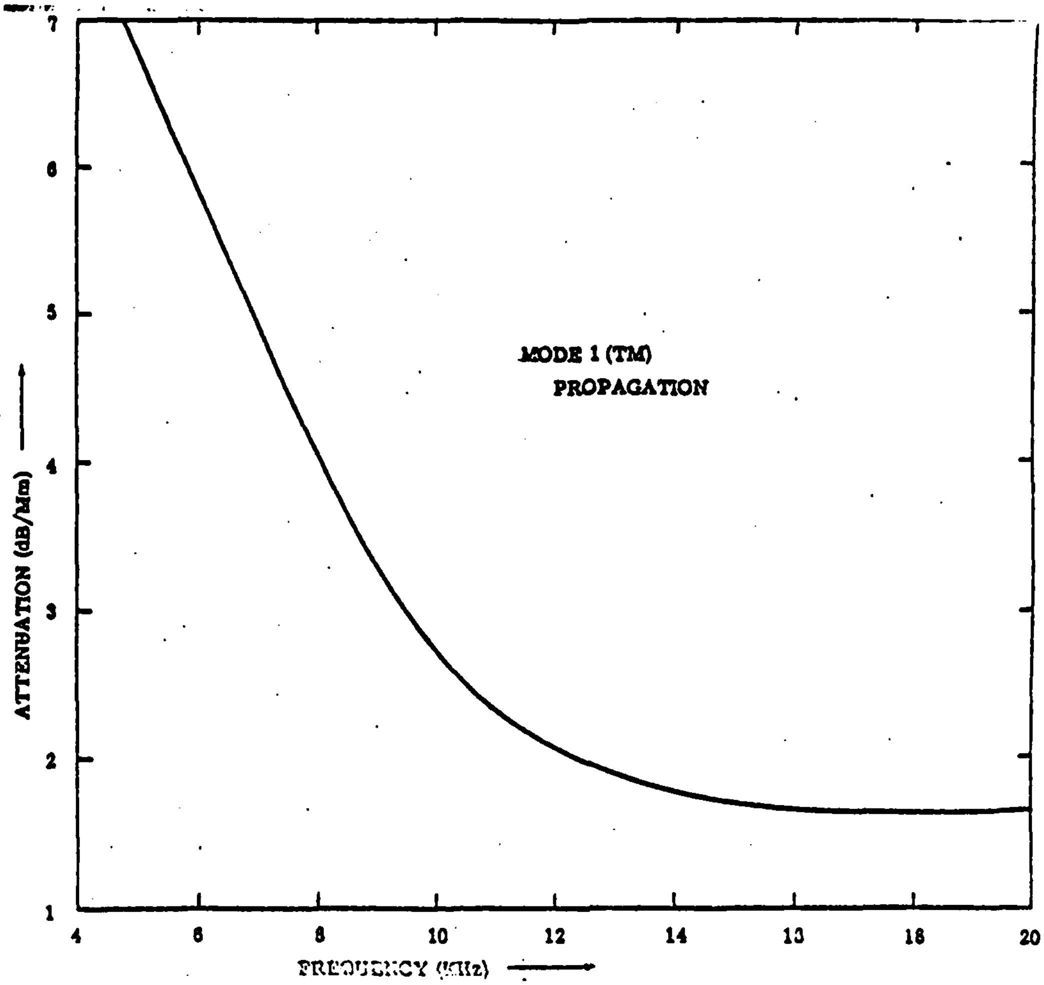
LIGHTNING INITIATION ALTITUDES



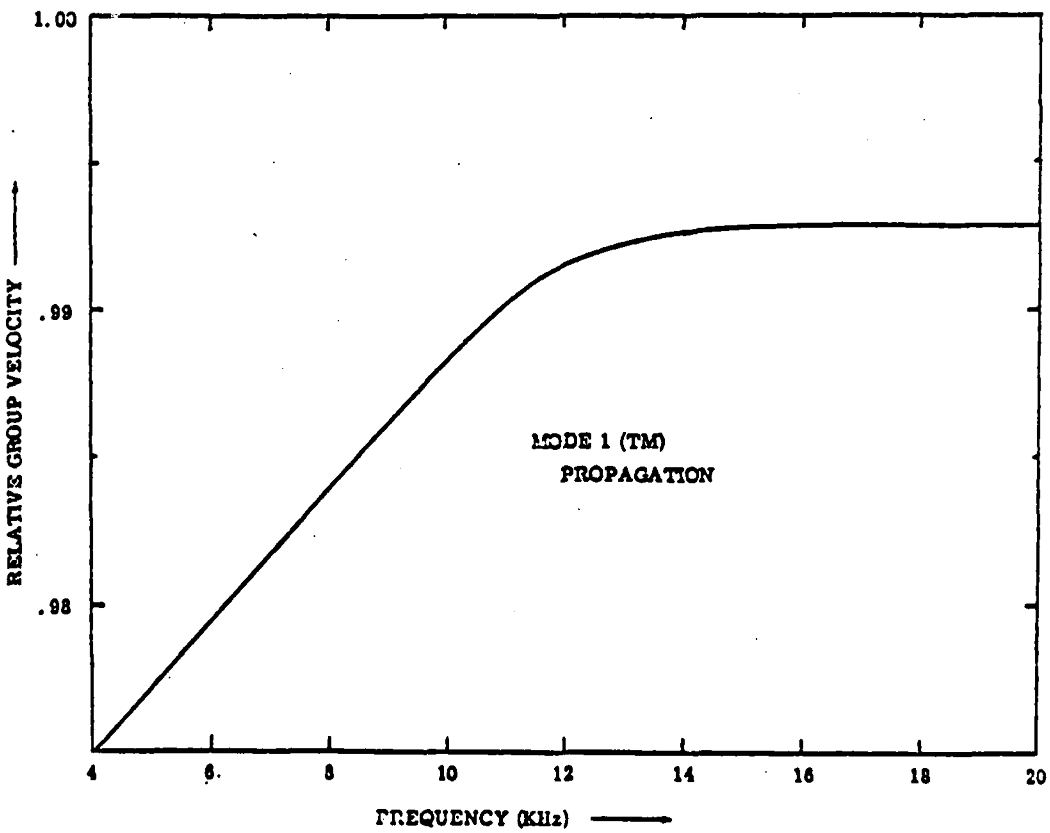


ONR presently supports:

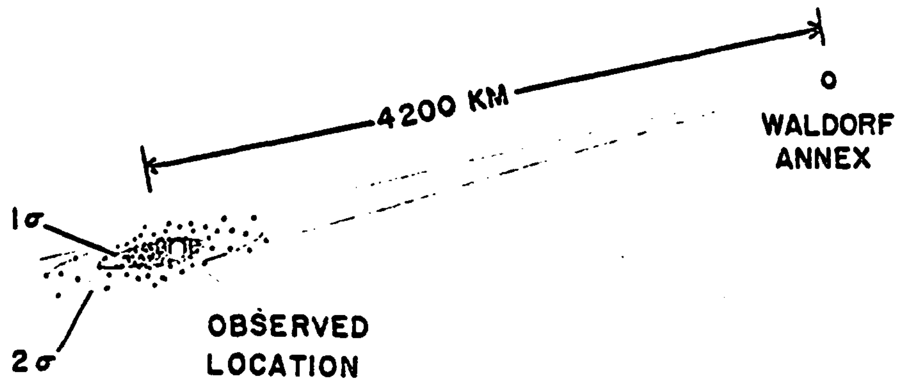
SUNY:	Barreto
	Kim
	Vonnegut
NMIM&T:	Moore
	Brook
U.Minn.:	Olson
R.D.Hill, Inc.	



ATTENUATION (dB/Mm)
7
6
5
4
3
2
1
4
6
8
10
12
14
16
18
20
FREQUENCY (KHz)
MODE 1 (TM)
PROPAGATION

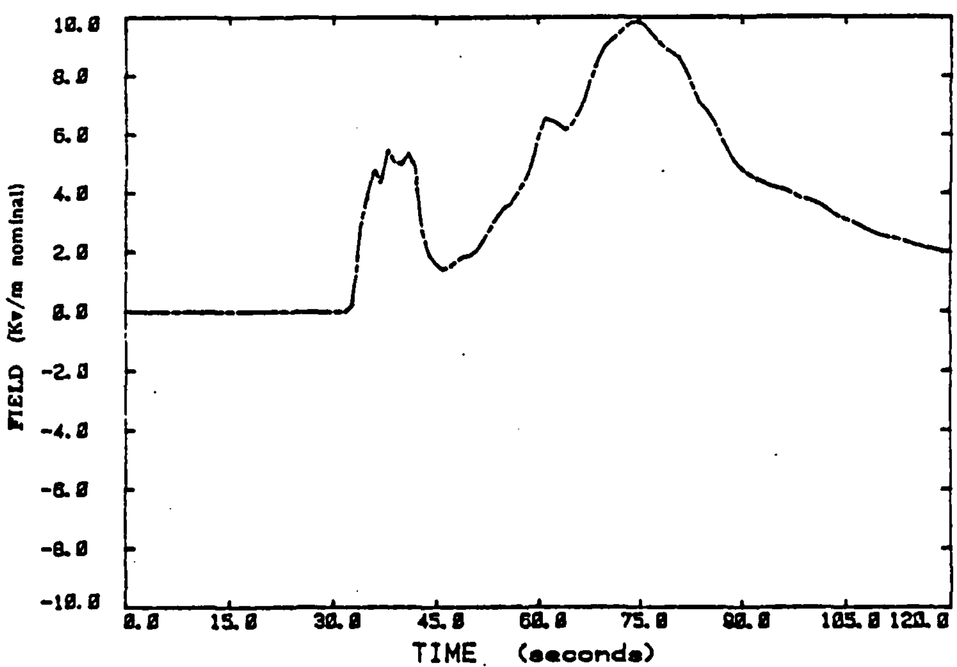


RELATIVE GROUP VELOCITY
1.00
.99
.98
4
6
8
10
12
14
16
18
20
FREQUENCY (KHz)
MODE 1 (TM)
PROPAGATION

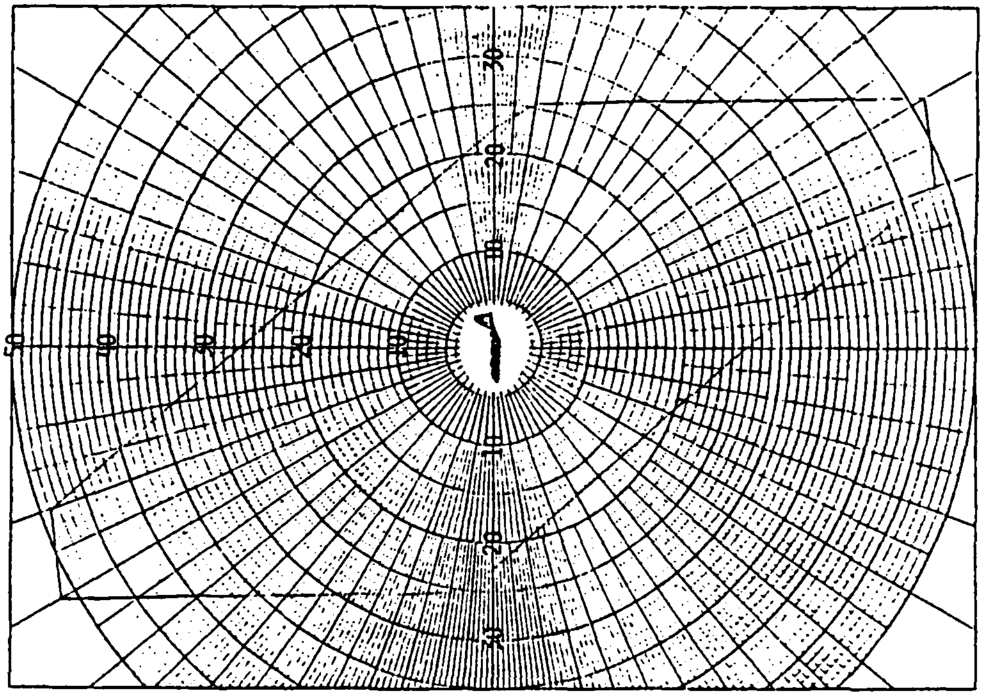


23 NOVEMBER '83

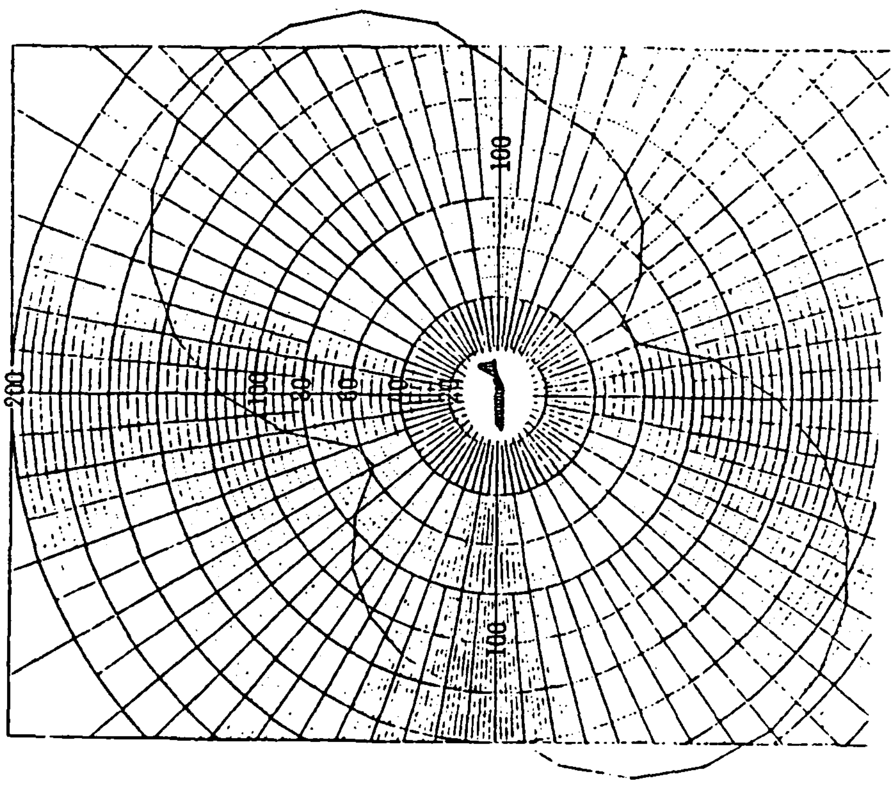
ELECTRIC FIELD at 4000'



Field to Trigger

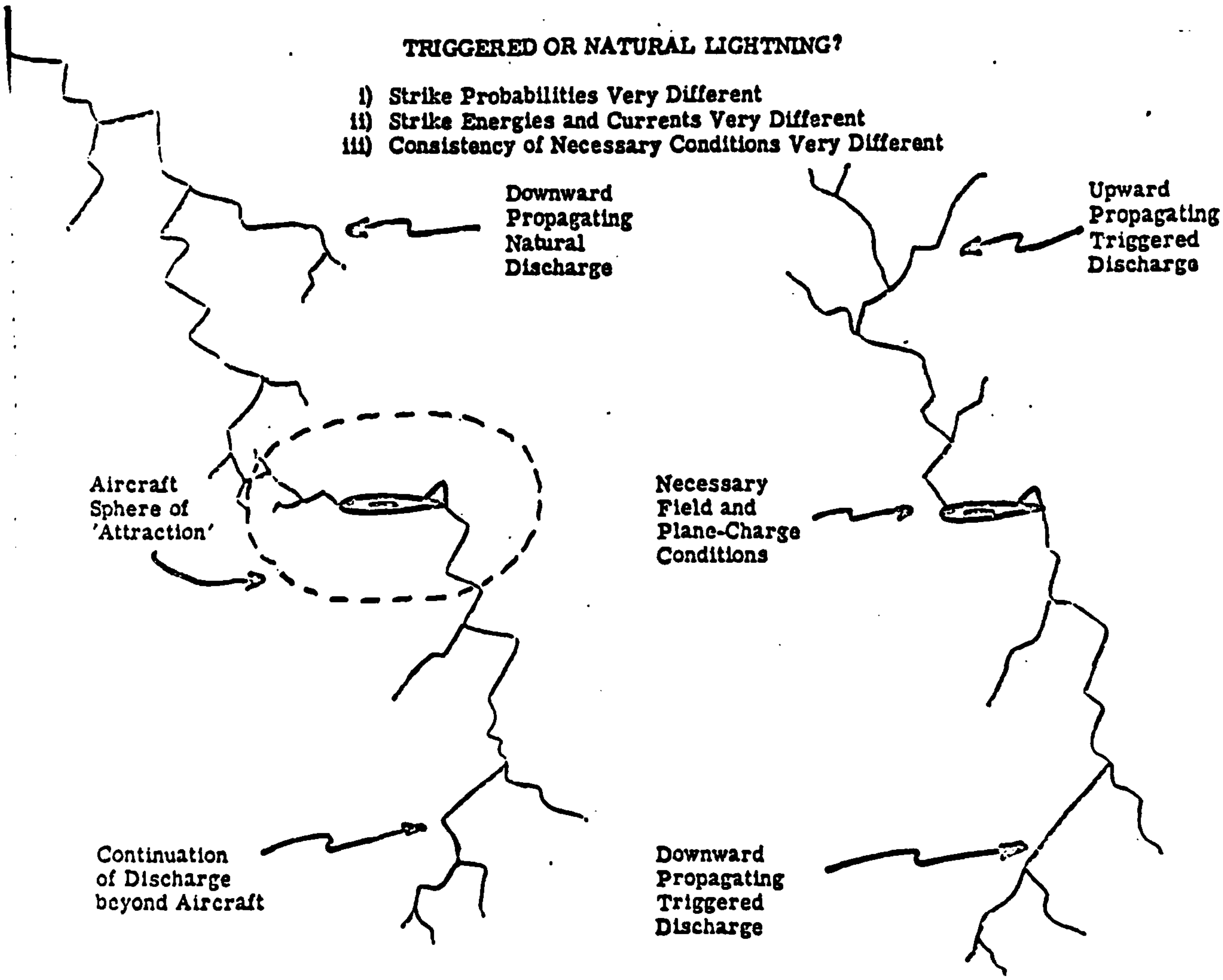


Field Concentration Factor



TRIGGERED OR NATURAL LIGHTNING?

i) Strike Probabilities Very Different
ii) Strike Energies and Currents Very Different
iii) Consistency of Necessary Conditions Very Different



SUMMARY: PRACTICAL RESULTS

1) Strike Probabilities under Various Conditions
   (Avoidance and Regulation)

2) Strike Intensity Distribution
   (Hardening and Regulation)

3) Necessary Conditions for (Triggered) Strike
   (Warning and Regulation)

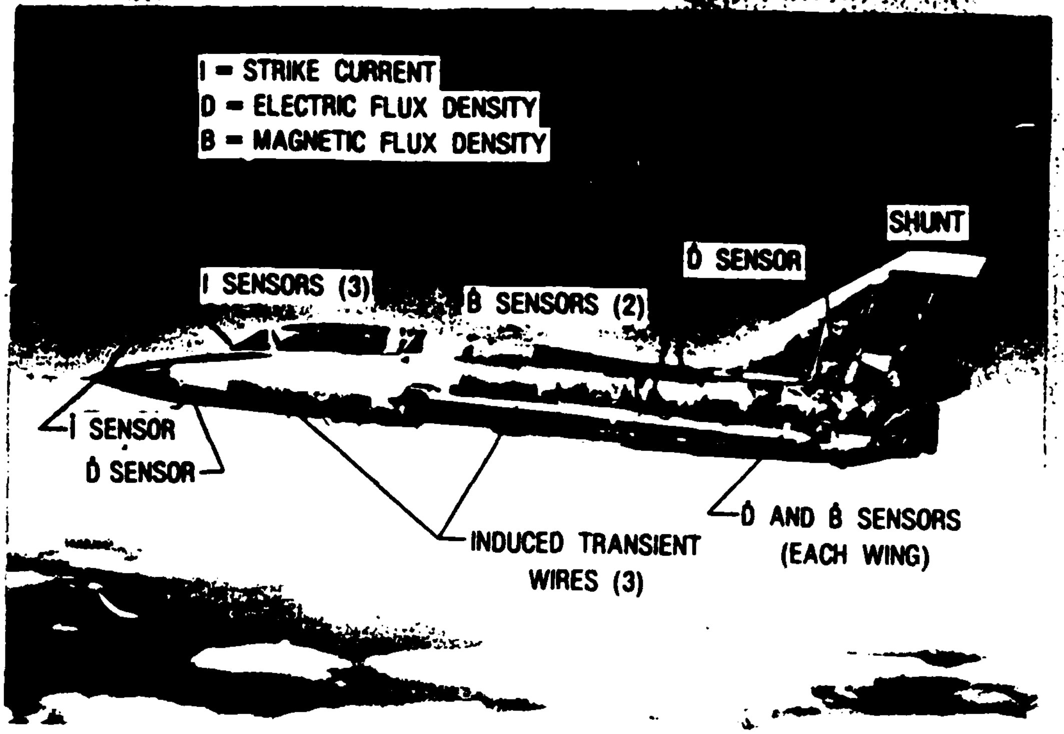
THE CASE FOR TRIGGERING

1) Aircraft Strikes More Frequent in Flight

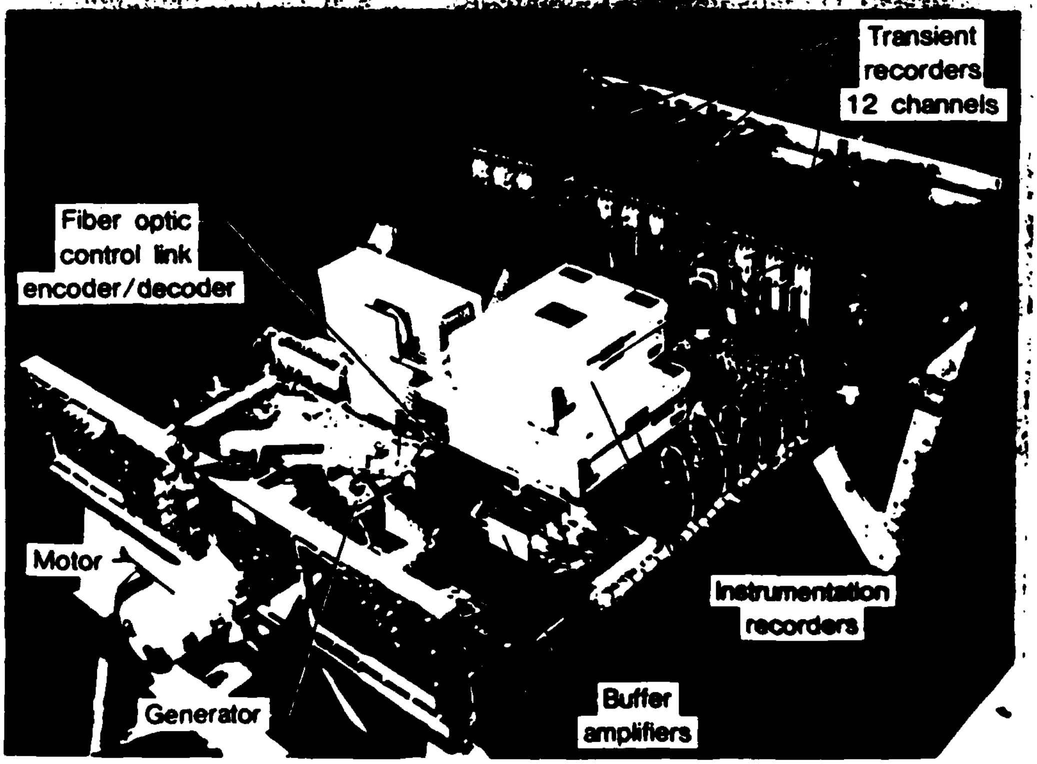
2) Measured Currents Lower than Expected

3) Large Conducting Objects Should Trigger

LOCATION OF ELECTROMAGNETIC SENSORS ON THE F-106B



LIGHTNING INSTRUMENTATION



NAVAL AIR SYSTEMS COMMAND ACTIVITIES
A PROGRESS REVIEW*

(MR. J. BIRKEN, NAVAIRSYSCOM, WASHINGTON, DC)

*Presentation not submitted for inclusion into the minutes

SUMMARY OF NASA LaRC LIGHTNING CHARACTERIZATION AND EFFECTS
(MR. F. PITTS, NASA-LANGLEY RESEARCH CENTER, HAMPTON, VA)

LIGHTNING CHARACTERIZATION AND EFFECTS

Felix L. Pitts

NASA Langley Research Center

LIGHTNING CHARACTERIZATION

- Summarize acquired data
- Review statistical data analysis
- Assess completeness of high altitude data set
- Review data interpretation
- Coordination summary
- Summary and plans

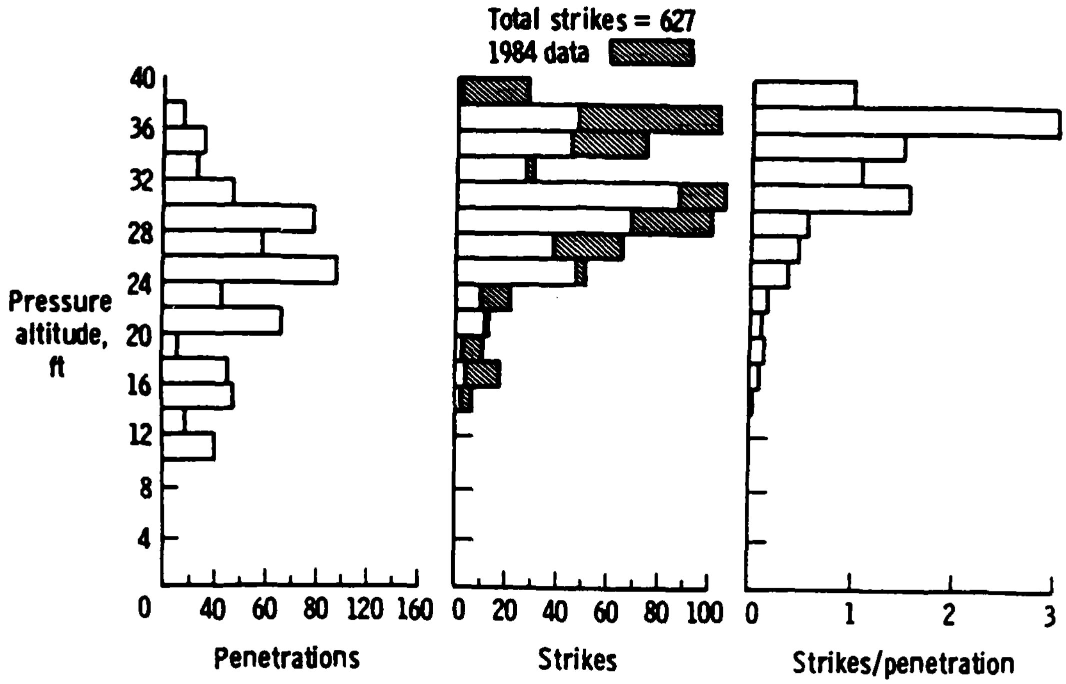
LIGHTNING CHARACTERIZATION AND EFFECTS

- Objective

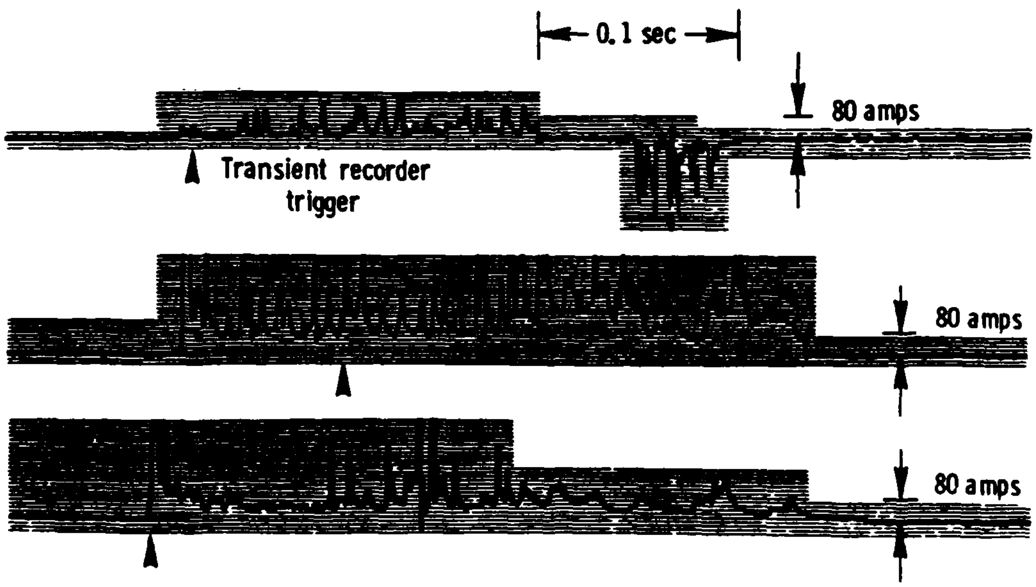
  Develop techniques for assessing digital system performance in the lightning environment aboard aircraft

  - Collecting in SITU direct-strike data using F-106B
  - Developing lightning and aircraft interaction models for use in data interpretation
  - Conducting analytical and laboratory digital system upset investigations

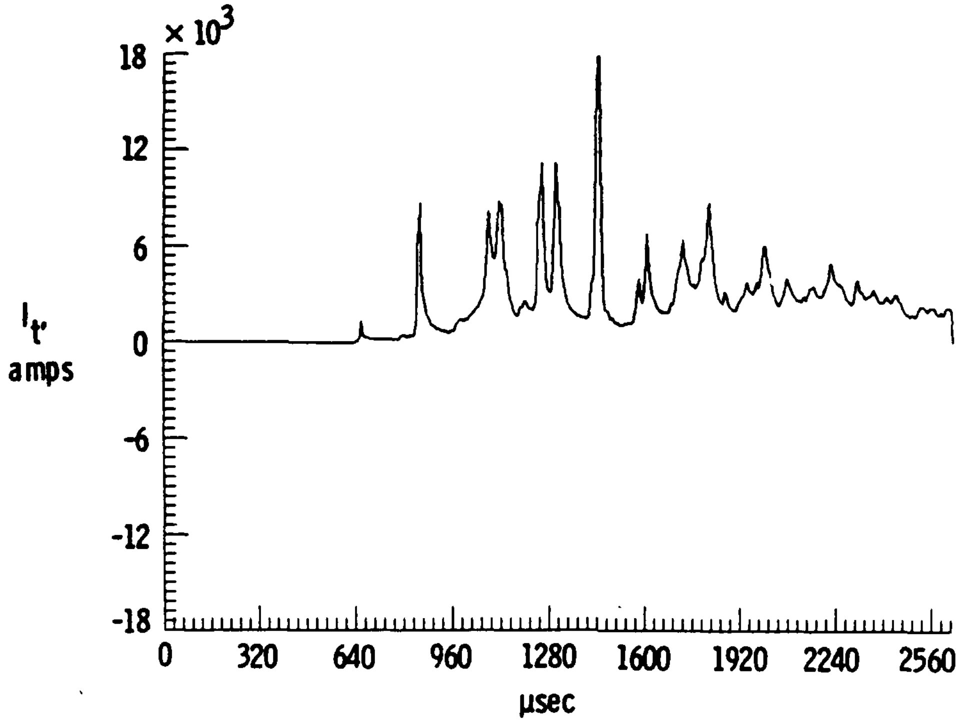
STRIKE SUMMARY VERSUS ALTITUDE



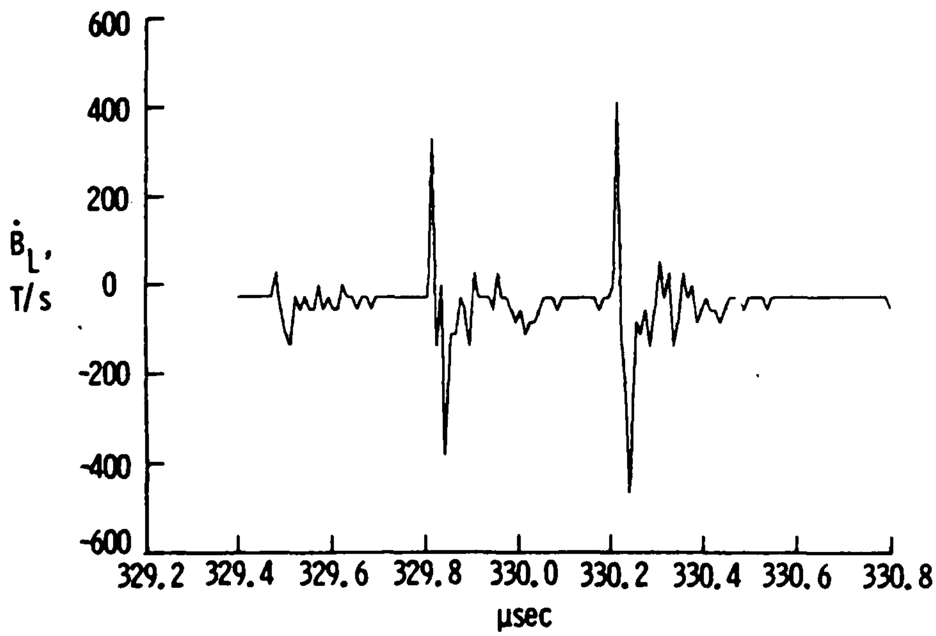
VERTICAL FIN CURRENT
(DC-400Hz)



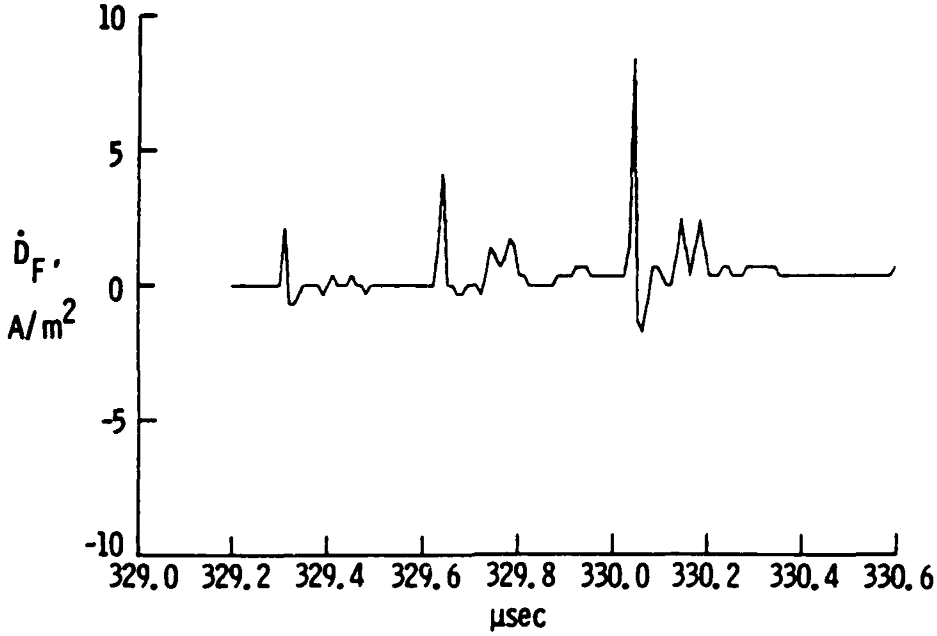
VERTICAL FIN CURRENT



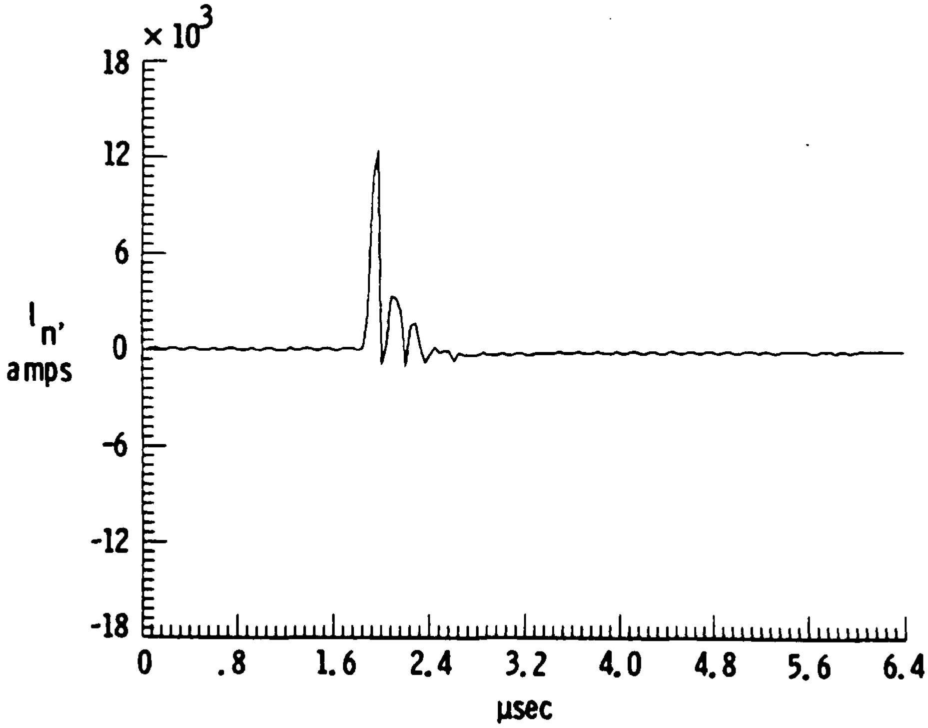
RATE OF CHANGE OF MAGNETIC FLUX DENSITY



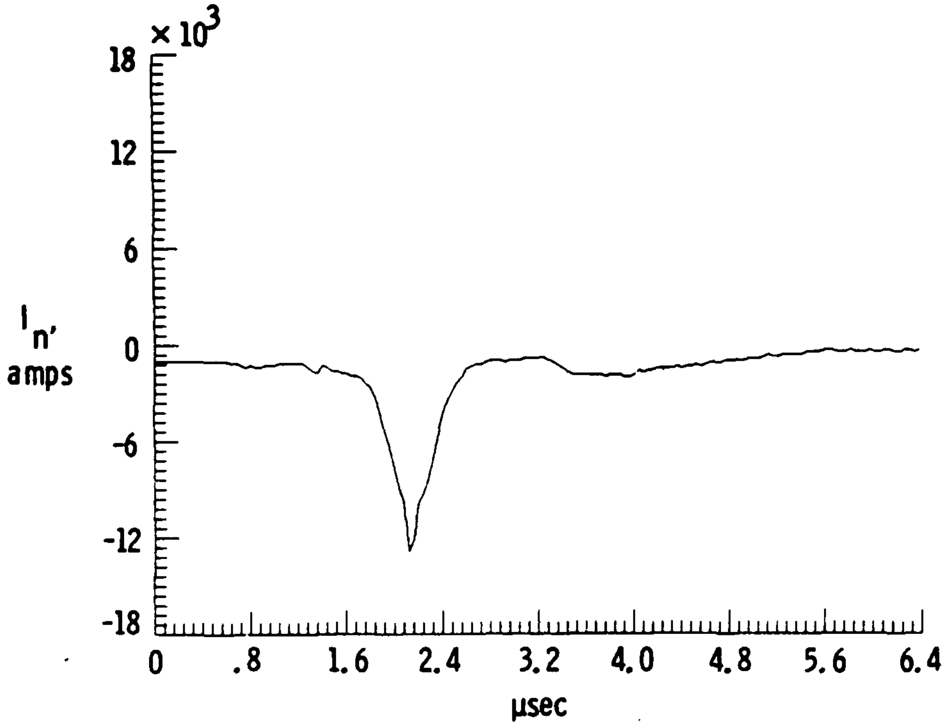
RATE OF CHANGE OF ELECTRIC FLUX DENSITY



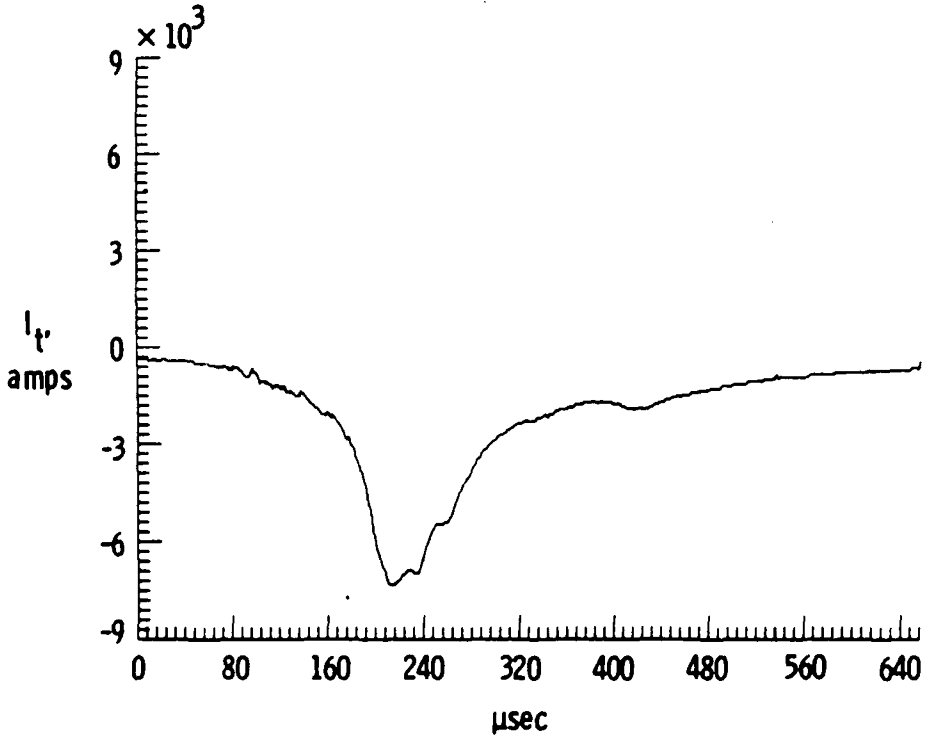
NOSE BOOM CURRENT



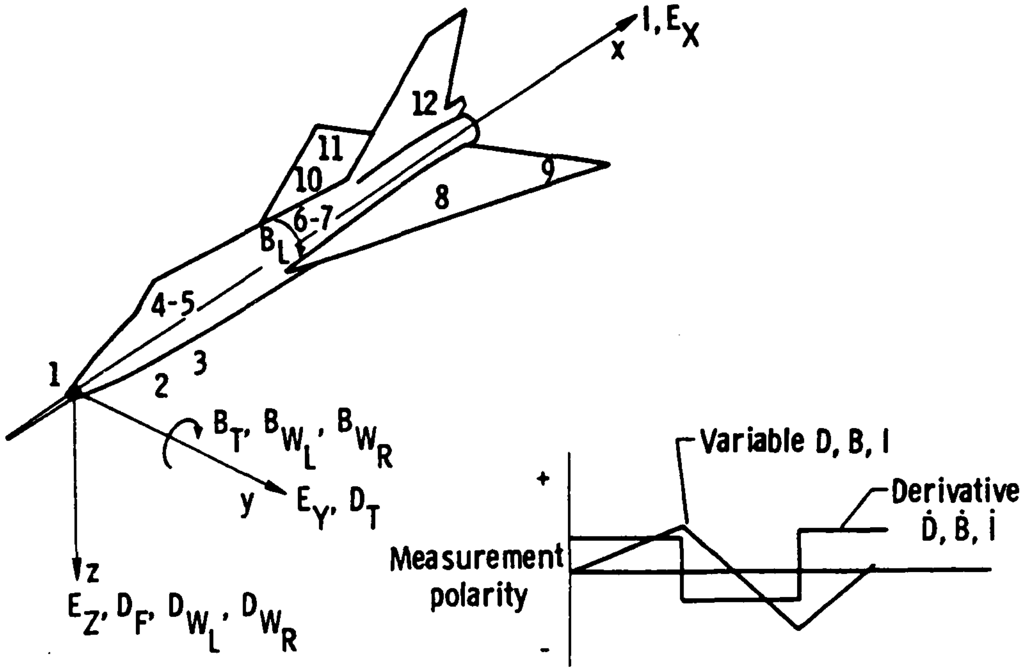
NOSE BOOM CURRENT



VERTICAL FIN CURRENT



ELECTROMAGNETIC SIGN CONVENTION AND SENSOR LOCATION



TOTAL DATA BASE THROUGH 1984

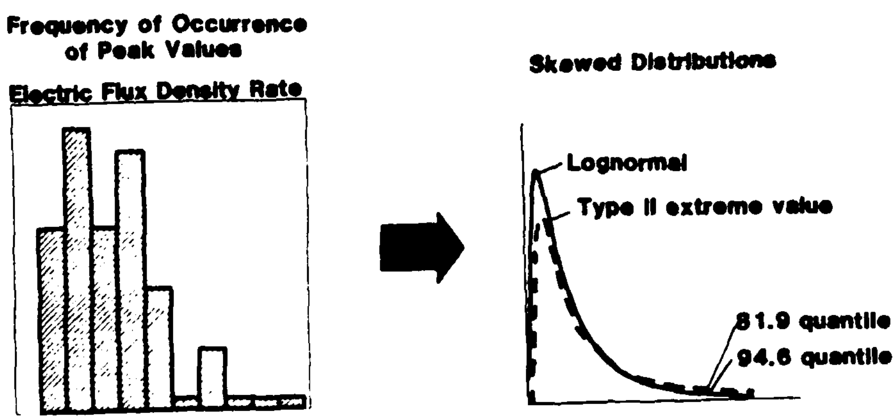
- 627 strikes/2171 transients

	$\dot{B}_L$	D_F	$\dot{D}_F$	I_B	$\dot{I}_B$	$\dot{B}_T$	$\dot{D}_T$	$\dot{D}_{WL}$	D_{WR}	$\dot{D}_{WR}$	B_{WL}	$\dot{B}_{WL}$	$\dot{B}_{WR}$	I_{VF}	V_{WW}	V_{FW}
• 1982 and prior	46		93	27	8											
• 1983	166		216	17	56	23	56	24	15		16	34	48	39	5	24
• 1984	119	117	105	120	126		125	105		91		43	37	120	74	76
• Total waveforms	331	117	414	164	190	23	181	129	15	91	16	77	85	159	79	100
• 370 strikes, 94 peaks (strikes)			46 (341)		45 (370)									3 (29)		

STATISTICAL ANALYSIS SUMMARY

- Statistical analysis of direct strike lightning data (1980 to 1982) NASA TP 2252
  - Probability plotting method and formal statistical test used to check adequacy of log normal and type II extreme value models
  - Robust estimation method used to compute quantile estimates (Quantile estimates valid without assumption of parametric models)
  - Approximate confidence limits are determined for the quantiles
  - Tables constructed showing how the sample size depends on the precision of the estimates.

STATISTICAL CHARACTERIZATION OF LIGHTNING DATA



- Statistical Distributions Established
- Extreme Quantiles Estimated

SAMPLE SIZE VERSUS PRECISION FOR 95% CONFIDENCE LEVEL

☐ Data samples through 1982
( ) Data samples through 1984

Quantile ξ	$U/_L$ ratio	$N(\dot{B}S)$	$N(\dot{D}S)$	N(I)
.99	1.5	592 (331)	421 (414)	222 (164)
	2.0	202	144 ☐93	76
	2.5	116	82	43
	3.0	81	57	30
.95	1.5	188	134	70 ☐27
	2.0	64 ☐46	46	24
	2.5	37	26	14
	3.0	26	18	10

DATA ASSESSMENT

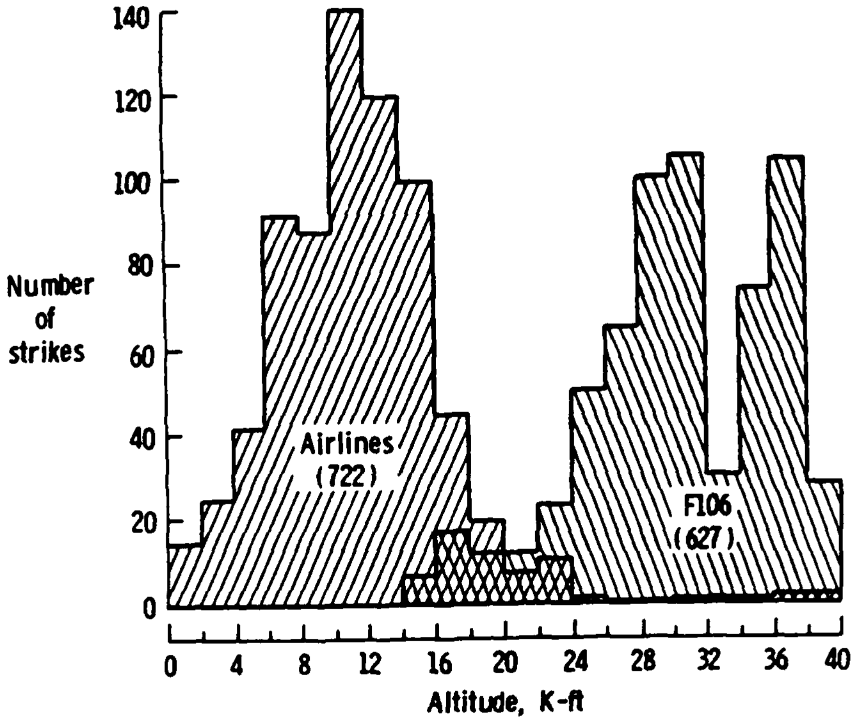
High altitude

- Assuming 82 and prior distribution families hold
  - Can estimate 99th quantiles with 95% $U/_L$ confidence ratios:

	1982	1983	1984
$\dot{B}$	--	2.0	1.75
$\dot{D}$	2.5	1.7	1.5
$\dot{I}$	--	2.5	1.75

  - Have 190 $\dot{I}$ waveforms and 45 peaks to establish $\dot{I}$ distribution
  - Precision for smaller samples can be estimated from table

STRIKES VERSUS ALTITUDE



DATA ASSESSMENT

Low altitude

- Need 50 to 100 samples to test adequacy of usual distribution models
- Example:
  Requires 100 samples to reject lognormal when true is extreme value

Sample size	20	50	100
Probability of rejecting log normal	31	63	93

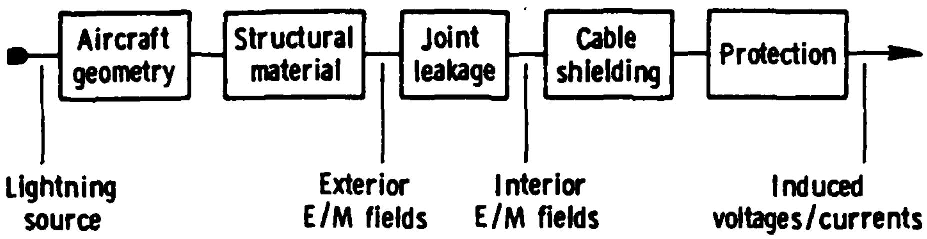
PEAK RECORDED VALUES

ELECTRIC FLUX DENSITY RATE	76 ampere per square meter
CURRENT RATE	1.9 E11 ampere per second
CURRENT	54 kiloampere

LIGHTNING THREAT CRITERIA

		Peak current	Max current rise rate
● Old criteria:			
• SAE AE-4L (1978)		200 kA	100 kA/μs
• MIL B-5087 (1978)		200 kA	100 kA/μs
• JSC-07636-Shuttle (1975)		200 kA	100 kA/μs
● NASA F-106B finding:	(1983)	14 kA	190 kA/μs
	(1984)	54 kA	
● New criteria:			
• Boeing AEHP (1984)			
Cloud-cloud:	Severe	20 kA	200 kA/μs
	Moderate	5 kA	50 kA/μs
Cloud-ground:	Severe	200 kA	200 kA/μs
	Moderate	20 kA	50 kA/μs

LIGHTNING EFFECTS ON AIRCRAFT DIGITAL ELECTRONICS



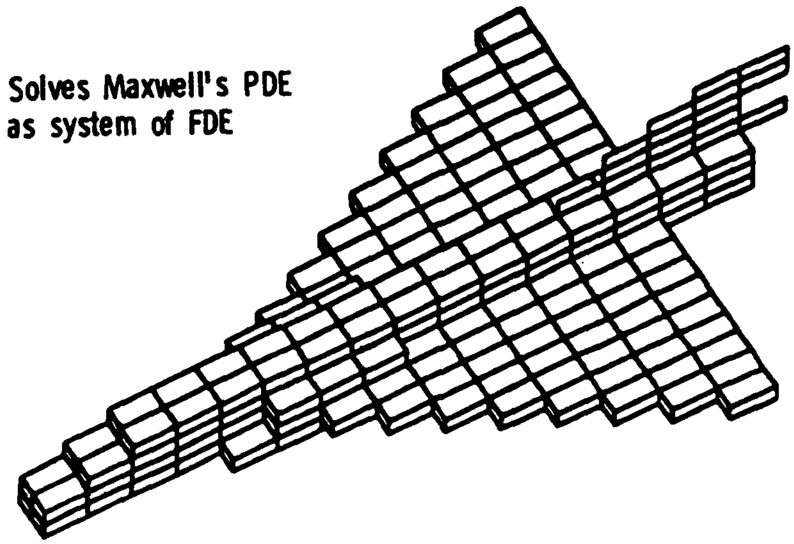
Data analysis objective

Methodology to predict transients in generic composite aircraft systems for use in upset assessment studies

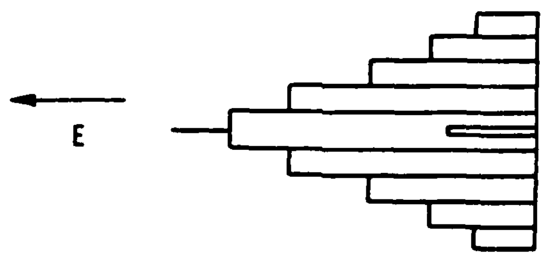
DATA INTERPRETATION - GENERAL PROBLEM

- F-106 data specific to F-106, i.e., are responses
- Require characterization of generic lightning processes applicable to composites/transports
- Approach:
  - Computer modeling (EMA)
  - Laboratory modeling (Texas Tech)
  - Simple analytical models (LuTech)
- Status:
  - Methodology not completely established - some progress/problems
    - Natural lightning/linear modeling
      - Channel model parameters and uniqueness issues
    - Triggered lightning/non-linear modeling
      - Air breakdown model shows promise

ELECTROMAGNETIC COUPLING CODE F-106 MODEL



NONLINEAR DATA INTERPRETATION METHODOLOGY



$$\nabla \times \vec{E} = -\vec{B}$$

$$\nabla \times \vec{H} = \vec{D} \quad \sigma\vec{E}$$

$$\sigma = q\left[n_e\mu_e + (n_- + n_+)\mu_i\right]$$

$$\frac{\partial n_e}{\partial t} + \nabla\cdot(n_e\mu_e\vec{E}) + \beta n_+ + \alpha_e - G)n_e = \dot{Q}$$

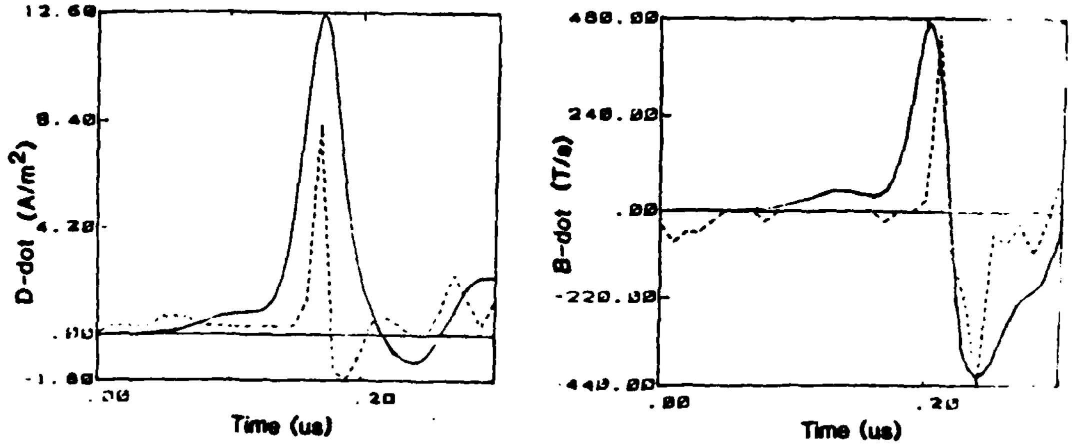
$$\frac{\partial n_-}{\partial t} + \nabla\cdot(n_-\mu_i\vec{E}) + \delta n_+ n_- = \alpha_e n_e$$

$$\frac{\partial n}{\partial t} + \nabla\cdot(n\ \mu_i\vec{E}) + (\beta n_e + \delta n_-)n_+ = \dot{Q} + Gn_e$$

TRIGGERED LIGHTNING NONLINEAR MODEL RESULTS VERSUS FLIGHT DATA

$E = 1 \times 10^5$ V/m NOSE TO TAIL $Q = -Q_m/2$

——— MODEL RESULTS
------ FLIGHT DATA



PARAMETERS IN DATA INTERPRETATION METHODOLOGY

q = Charge in electron

n_e, n_-, n_+ = Electron and ion densities

μ_e, μ_i = Electron and ion Mobilities

β = Recombination rate (e - i)

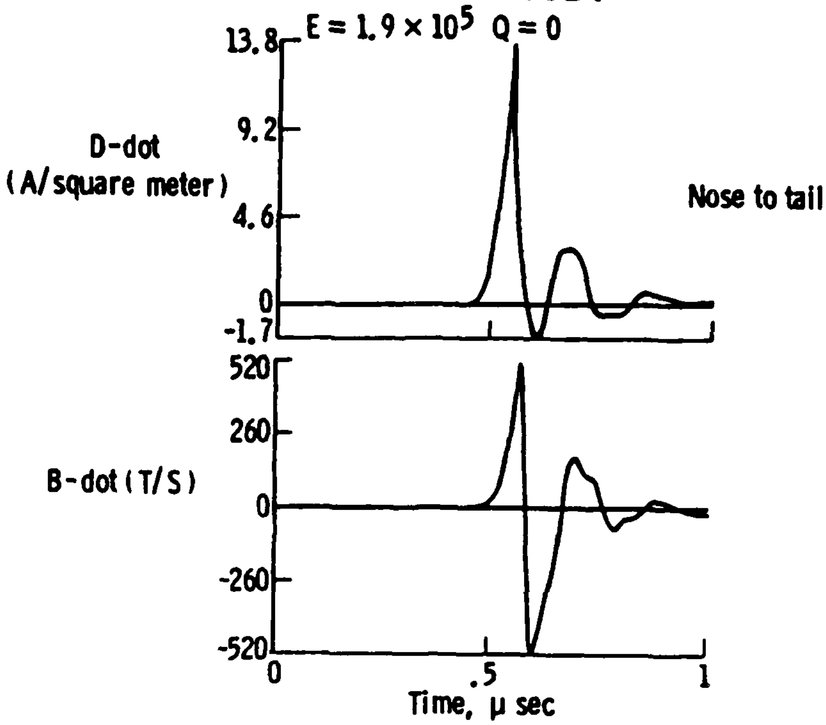
δ = Recombination rate (i - i)

α_e = Attachment rate - $f_1(\vec{E})$

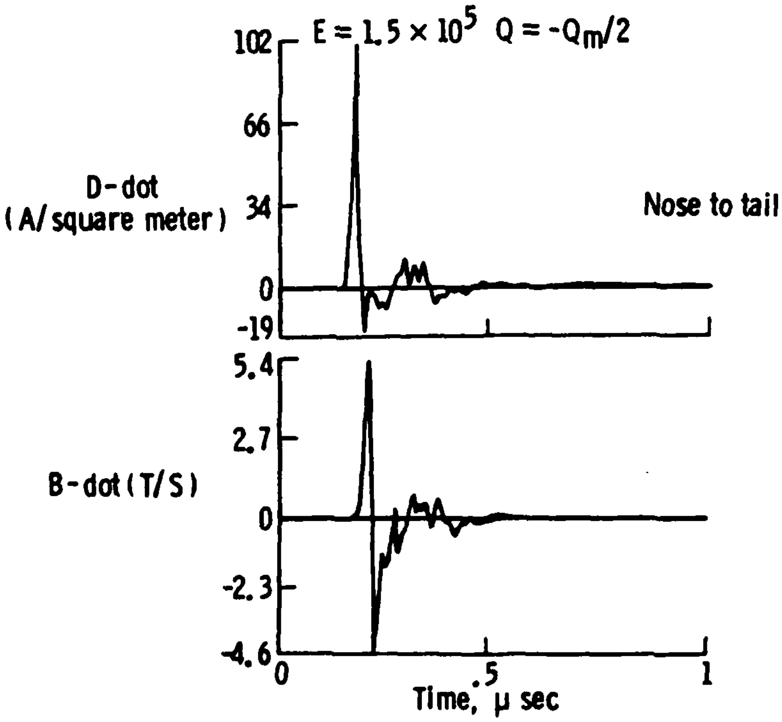
G = Avalanche rate - $f_2(\vec{E})$

$\dot{Q}$ = Ambient ionization rate

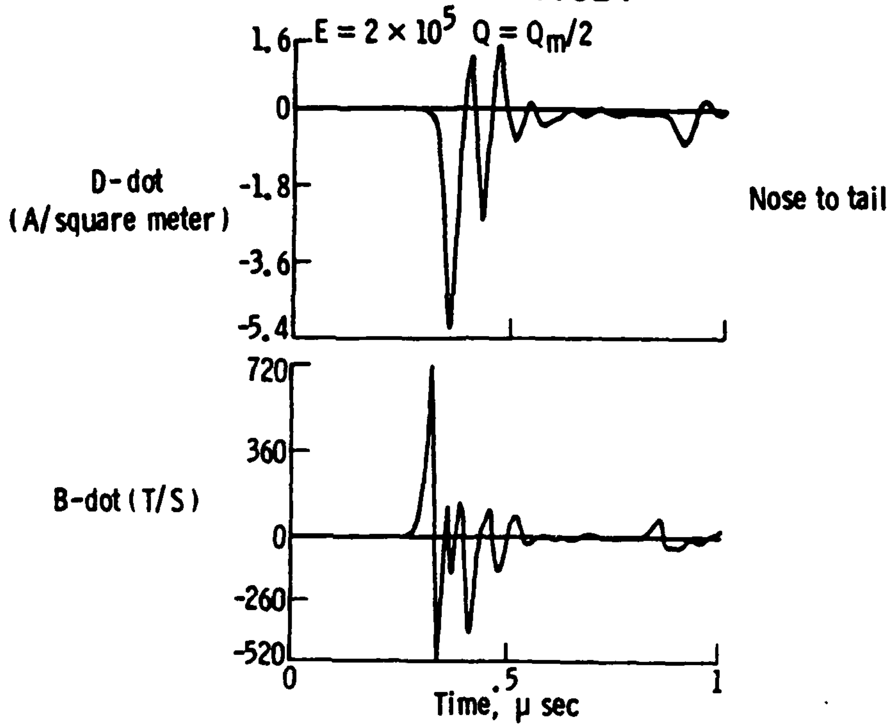
TRIGGERED LIGHTNING NONLINEAR MODEL PARAMETRIC STUDY



TRIGGERED LIGHTNING NONLINEAR MODEL PARAMETRIC STUDY



TRIGGERED LIGHTNING NONLINEAR MODEL PARAMETRIC STUDY



CONSERVATION OF ENERGY IN NONLINEAR MODEL

Conservation of momentum: electrons, ± ions

$$n_e \frac{\partial \vec{v}_e}{\partial t} + n_e(\vec{v}_e \cdot \nabla)\vec{v}_e = \frac{n_e q_e}{m_e}\left(\vec{E} + \frac{1}{c}\vec{v}_e \times \vec{B}\right) - \frac{1}{m_e}\nabla p_e - n_e \vec{v}_e \nu_c$$

Conservation of Energy: electrons

$$\frac{\partial \epsilon_e}{\partial t} + (\vec{v}_e \cdot \nabla)\epsilon_e = q_e n_e \vec{E} \cdot \vec{v}_e - \frac{m_e}{m_H}\nu_c(\epsilon_e - \epsilon_e^{0}) + G n_e\left(\frac{1}{2} m_e v_+^{2} - \epsilon_{ion}\right)$$

$$+ e_Q - \alpha_e \epsilon_e - \beta n_+ \epsilon_e + H_e - K_{excitation}$$

Conservation of Energy: ± ions

$$\frac{\partial \epsilon_H}{\partial t} + (\vec{v}_+ \cdot \nabla)\epsilon_H = q_+(n_+ + n_-)\vec{E} \cdot \vec{v}_+ + \frac{m_e}{m_H}\nu_c(\epsilon_e - \epsilon_e^{0}) - \frac{1}{2} G m_e n_e v_+^{2} + K_{excitation}$$

ENERGY CONSERVATION PARAMETERS

V_e - species velocity

m_e - mass of electron or ion

c - velocity of light

p - partial pressure

ν_c - species collision frequency

ϵ - species energy density; H → heavy particle; e → electrons

ϵ^o - ambient species energy density

ϵ_q - energy density due to ambient ionization

ϵ_{ion} - energy to ionize neutral particle

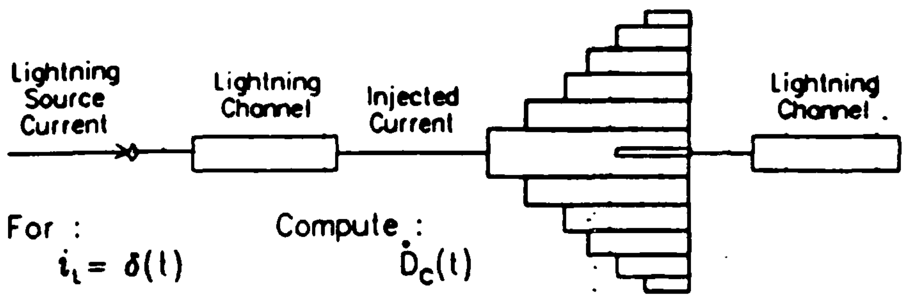
H_e - energy density diffusion

$K_{excitation}$ - energy density transfer between species due to vibrational modes

NASA
National Aeronautics and
Space Administration

NO

LINEAR DATA INTERPRETATION METHODOLOGY -
Current Injection Approach



For :
$i_L = \delta(t)$

Compute :
$\dot{D}_C(t)$

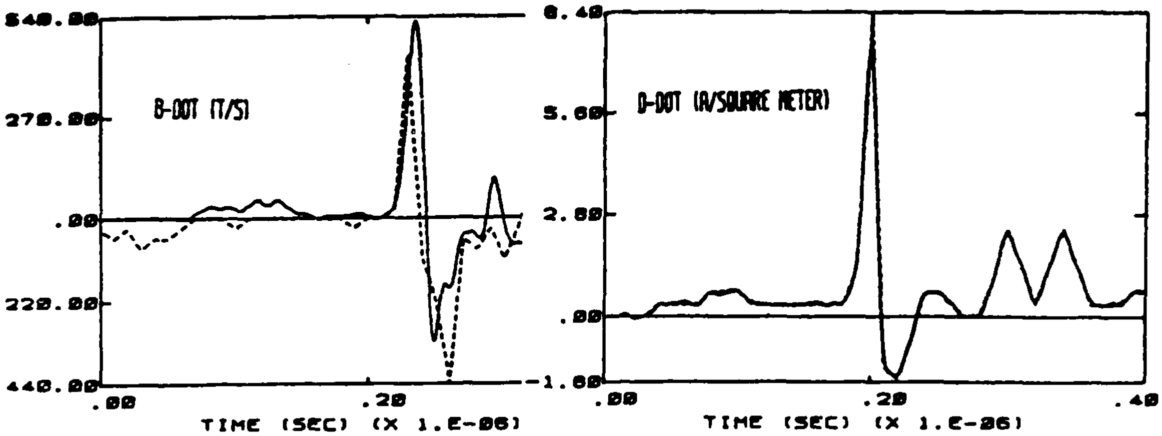
Develop Transfer Function Relating Sensor Response to Source Current

$$G(s) = \frac{\mathcal{L}[\dot{D}_C(t)]}{\mathcal{L}[\delta(t)]}$$

Then use G(s) along with $\mathcal{L}[\dot{D}_r(t)]$ to compute Lightning Source Current

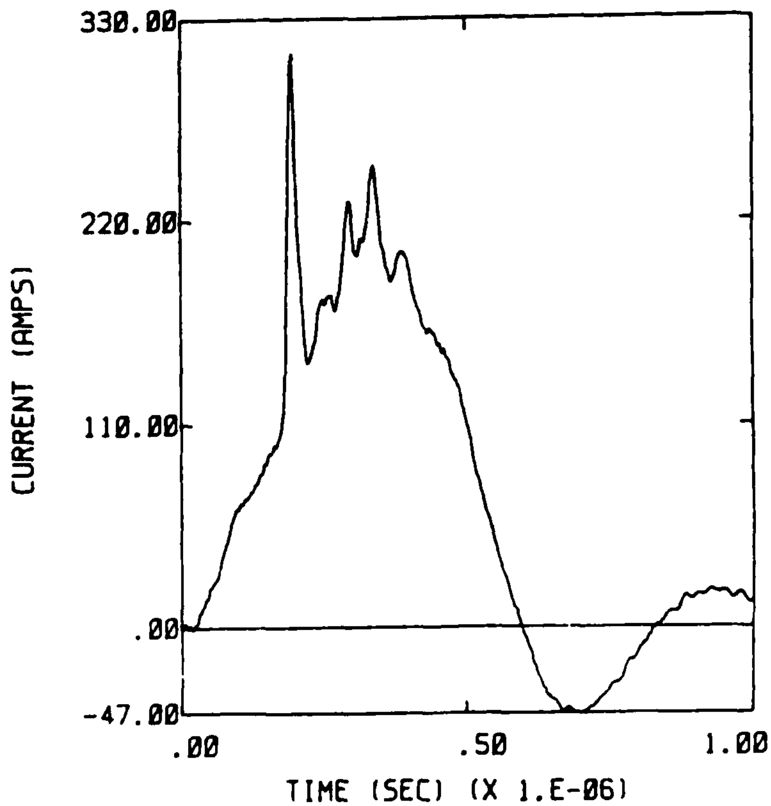
$$I_L(s) = \frac{\mathcal{L}[\dot{D}_r(t)]}{\ldots}$$

LINEAR MODEL RESULTS VERSUS FLIGHT DATA

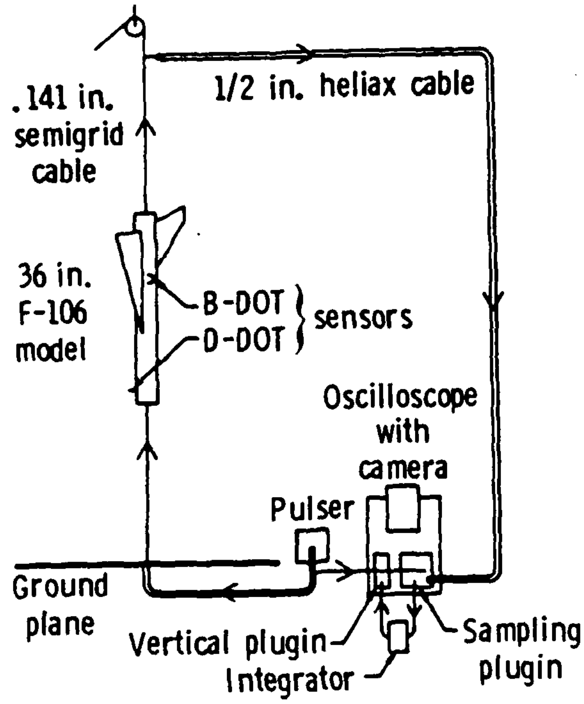


Responses from Linear Triggered Lightning Model (Solid Lines). D-Dot Forced to Match Measured Data Using Transfer Function Method. Measured Data from Flight 82-037, Run 4 (Dashed Lines)

LINEAR MODEL INJECTED CURRENT



APPARATUS FOR AIRCRAFT-LIGHTNING MODELING



SCALE MODEL VERSUS FLIGHT RESONANCES

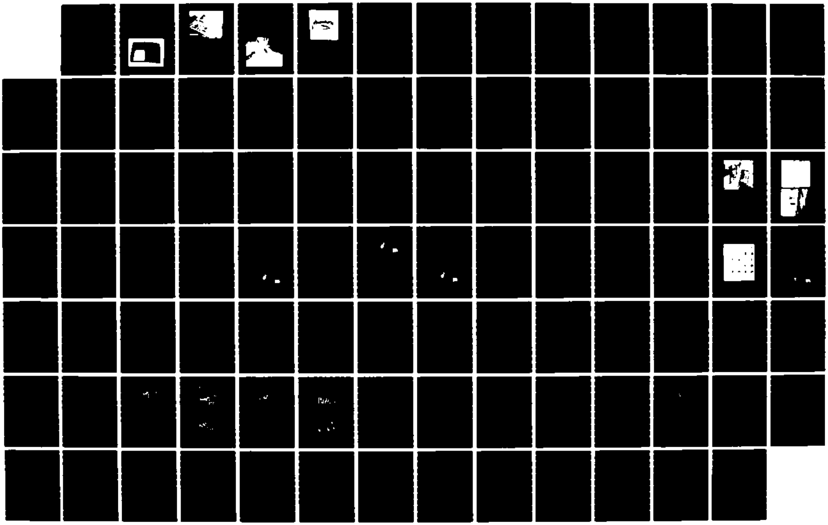
<u>TEXAS TECH GRANT NAG1-28</u>

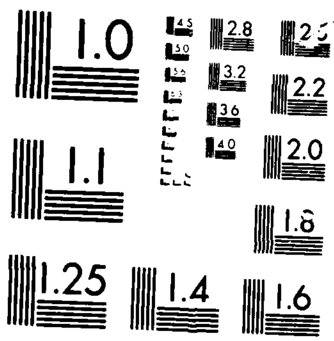
o USE OF HIGH RESISTIVITY WIRES IN LAB MODEL IMPROVED AGREEMENT OF RESONANCE DAMPING COMPARED TO FLIGHT DATA

	DAMPING		RESONANT FREQUENCY MHZ	
POLE NUMBER	MODEL	AIRCRAFT	MODEL	AIRCRAFT
FIRST	-0.27	-0.18	7.51 MHZ	6.50 MHZ
SECOND	-0.24	-0.20	14.80 MHZ	13.44 MHZ
THIRD	-0.18	-0.25	18.56 MHZ	20.55 MHZ
FOURTH	-0.23	-0.25	24.15 MHZ	28.05 MHZ
FIFTH	-0.35	--	30.72 MHZ	--
SIXTH	-0.20	-0.19	36.22 MHZ	36.40 MHZ
SEVENTH	-0.16	-0.14	40.01 MHZ	41.40 MHZ

AD-A169 048 PROCEEDINGS AND MINUTES OF THE NATIONAL INTERAGENCY COORDINATION GROUP ME..(U) FEDERAL AVIATION ADMINISTRATION TECHNICAL CENTER ATLANTIC CIT.. 2/2

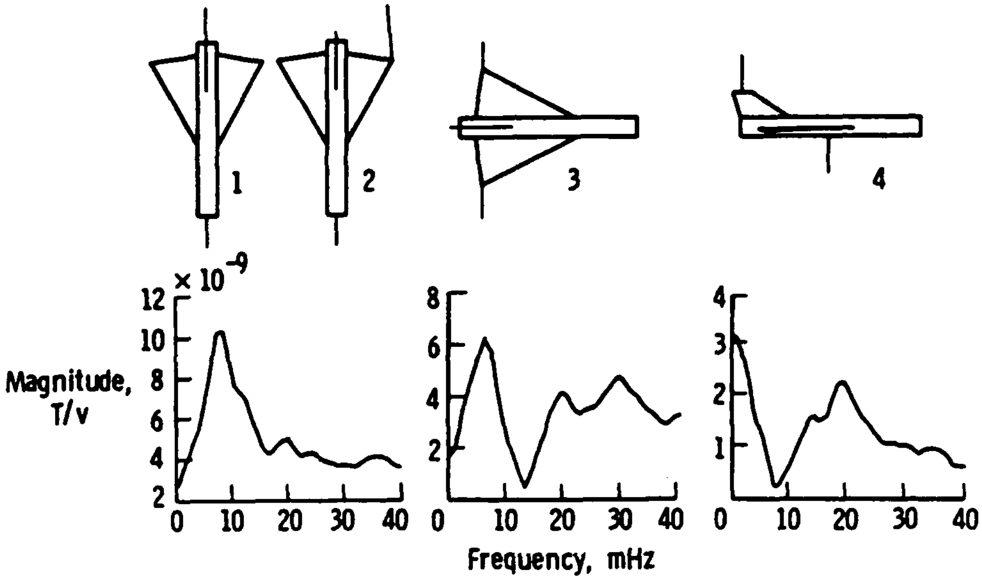
UNCLASSIFIED M S GLYNN SEP 85 DOT/FAA/CT-85/340/1 F/G 4/1 NL

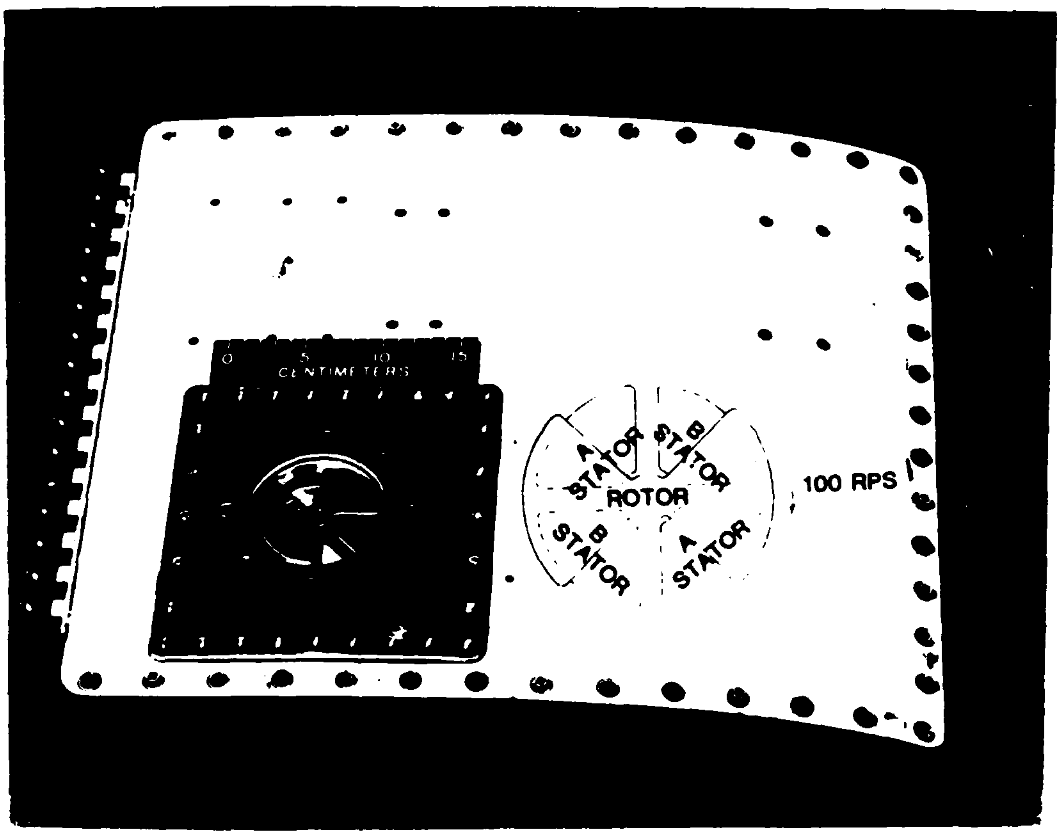


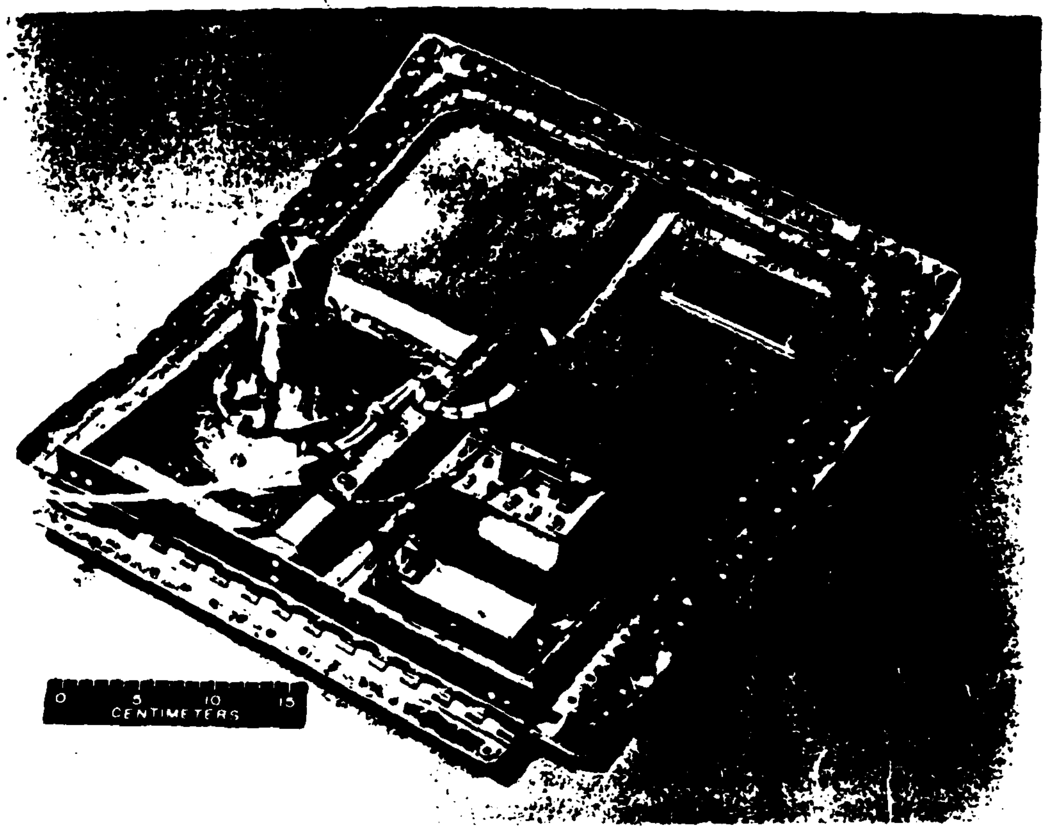


MICROCOP

RESONANCES VERSUS ATTACHMENT POINTS



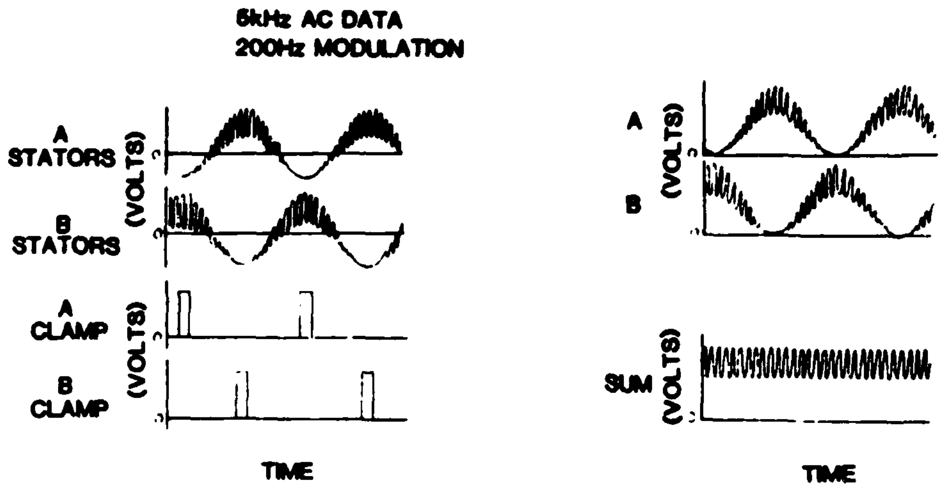


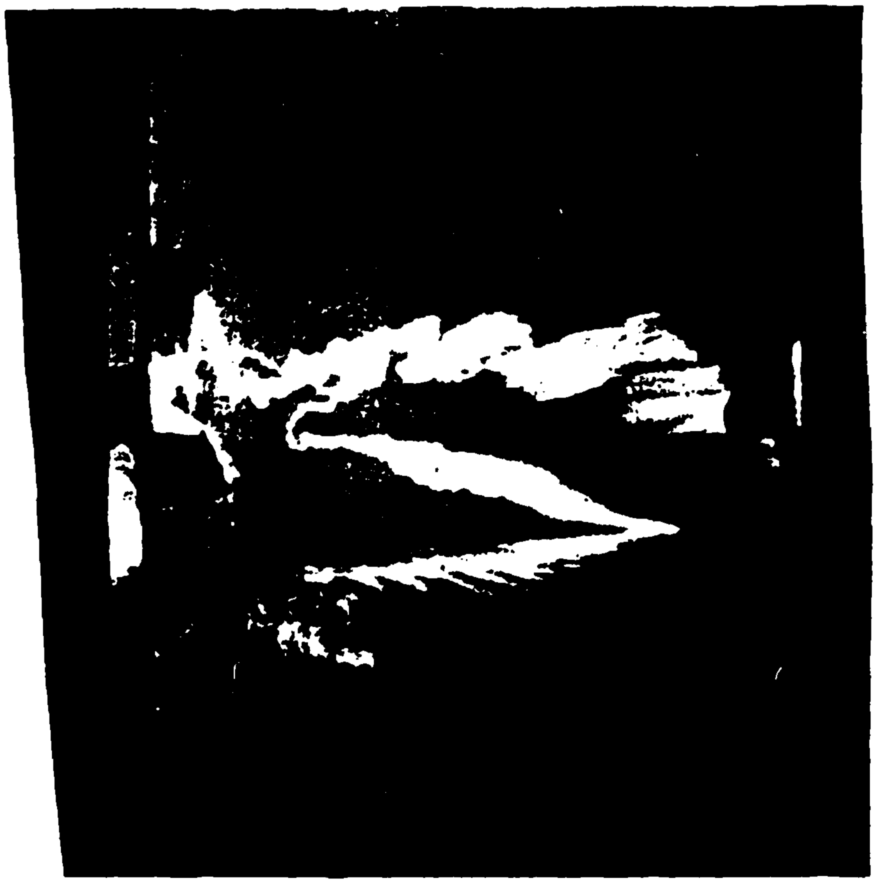


FIELD MILL ATTRIBUTES

- TWO INDEPENDENT DETECTION CIRCUITS
  - SYNCHRONOUS DEMODULATION: 400 SAMPLES/SEC
    - — W. P. WINN, NEW MEXICO TECH
  - CLAMPED DETECTION: DC TO 100kHz
    - — L. G. SMITH, AF CAMBRIDGE RESEARCH LAB, 1953
    - — RESTORES DC LEVEL LOST BY CHARGE AMP
    - \- COMPLEMENTARY STATOR PAIRS ACHIEVE CONSTANT AREA
- WIDE ROTOR-TO-STATOR SPACING LESSENS RAIN SHORTING

CLAMPED DETECTION
(L. G. SMITH, AFCRL, 1953)





COORDINATION SUMMARY

- AFWAL/FDL, Wright-Patterson AFB, Ohio
  - Atmospheric Electricity Hazards Protection for aircraft (AEHP) program
  - Convair 580 direct strike initiative
- FAA Technical Center, Atlantic City, New Jersey
  - Interagency Agreement FA77WAI-756
  - Convair 580
- AFWL, Kirtland AFB, New Mexico
  - F-106 simulated NEMP tests
  - Compare lightning/NEMP

COORDINATION SUMMARY

- National Interagency Coordination Group on Lightning and Static Electricity (NICG)
  - USAF, USA, USN, NOAA, FAA, NASA
  - International Lightning Conference
- Society of Automotive Engineers SAE AE-4L
  - Test standards and techniques

SUMMARY AND PLANS

- High altitude essentially complete

  Specific experiments for model verification
- Complete direct strike data base
  - Obtain direct lightning strike data representative of currents with large magnitudes and fast rates of rise expected of low-altitude discharges and return strokes based on existing ground-based measurements
  - 50 to 100 strikes correlated with simultaneous ground-based measurements
  - Approximately 3 years
- Complete development of data interpretation/analysis methodology
  - Capable of modeling lightning interaction with generic composite aircraft
  - Laboratory investigation of spark initiation

UPDATE OF LIGHTNING SIMULATION FACILITIES SURVEY, JANUARY 29, 1985
(LAWRENCE C. WALKO, AIR FORCE WRIGHT AERONAUTICAL LABORATORIES)

Update of Lightning Simulation Facilities Survey
29 January 1985

Lawrence C. Walko
Air Force Wright Aeronautical Laboratories

The use of sophisticated avionics systems and non-metallic structures has enhanced aircraft susceptibility to, and the need for protection from, the lightning threat. Some lightning aspects may be simulated and this has established lightning simulation as a valuable aid in aircraft design. The following is an overview of lightning simulation facilities in the United States and Europe.

Table 1 - U.S. Government Lightning Test Facilities

Facility	Type of Simulator	Peak Current or Voltage	Total Energy	Application
U.S. Air Force Wright Aero-nautical Labs	High Voltage Marx	300 kV	250 joules	general use
	" "	1.5 MV	26.3 kJ	arc attachment
	" "	6.0 MV	192 kJ	arc attachment
	High Current	1 kA	2 kJ	induced effects
	" "	10 kA	24 kJ	induced effects
	" "	30 kA	36 kJ	induced effects
	" "	250 kA	300 kJ	high energy, structural damage
U.S. Navy Naval Air Test Center Patuxent River, MD	High Voltage	2 MV	33 kJ	arc attachment
	High Current	120 kA	50 kJ	high energy structural damage
Sandia National Laboratories	High Current	200 kA	224 kJ	full threat induced effects

Table 2 - Airframe Manufacturers Lightning Test Facilities

Facility	Type of Simulator	Peak Current or Voltage	Total Energy	Application
Boeing Aircraft Company Seattle, WA	High Current	20 kA	6.4 kJ	indirect effects
	" "	200 kA	680 kJ	indirect effects testing for AEH ADP
	High Coulomb Transfer	3 kA 10 msec to 1.0 sec		1 to 300 coulombs
	High Energy	square and ramp wave		current vs. time relationships
	CW or contin-uous wave			transient analysis transfer function
McDonnell-Douglas St. Louis, MO	High Voltage	4 MV	40 kJ	full scale component large model tests
	" "	1.65 MV	4 kJ	induced voltage test
	" "	1.5 MV	2.4 kJ	remote induced tests
	" "	800 kV	24 kJ	arc attachment
	" "	400 kV	1 kJ	general lab use
	High Current	30 kA	240 kJ	indirect effects
	" "	300 kA	660 kJ	high current damage
	" "	150 kA	192 kJ	high current restrike
	" "	10 kA	480 kJ	intermediate and continuing current
	" "	1 kA 50 kA	240 kJ 6 kJ	continuing current restrike tests
Lockheed-Georgia	High Voltage	500 kV	7.2 kJ	arc attachment
	High Current	200 kA	100 kJ	direct effects
	High Coulomb	200 A		3 to 5 sec duration
Northrop Corp	High Voltage	1.2 MV		attachment studies

Table 3 - Independent Laboratory Lightning Test Facilities

Facility	Type of Simulator	Peak Current or Voltage	Total Energy	Application
Lightning Technologies Inc.	High Voltage	0.5 MV	6 kJ	attachment studies
	higher voltage generator under construction			
	High Current	200 kA	50 kJ	high current damage
Lightning & Transients Research Inst.	High Voltage	2.4 MV	29 kJ	arc attachment
	" "	4 MV	64 kJ	arc attachment
	High Current	270 kA	87.5 kJ	initial return stroke
		180 kA	60 kJ	initial and subsequent strokes
	Intermediate Current	6.6 kA	65 kJ	physical damage
	Continuing Current	1 kA		physical damage

Table 4 - European Laboratory Lightning Test Facilities

Facility	Type of Simulator	Peak Current or Voltage	Total Energy	Application
Culham Laboratory Abingdon United Kingdom	High Current	200 kA	140 kJ	initial stroke
	" "	50 - 100 kA	600 kJ	intermediate and continuing currents
	" "	100 kA	40 kJ	fast rise subsequent return strokes, induced measurements
Centre D'Essais Aeronautique De Toulouse (C.E.A.T)	High Voltage	5 MV	62.5 kJ	arc attachment
	High Current	200 kA	100 kJ	induced effects, composite materials testing

Lightning Simulation Facilities

McDonnell Douglas Aircraft Company
Long Beach, California

High Voltage Power Supplies
60 kV, 75 kV, 100 kV, 150 kV

Lightning Generators

- High Voltage Impulse	1,600 kV,	160 Kilojoules,	1,350 kV/μ sec	60 kA
- Very High Rate-of-Rise	50 kV,	11 Kilojoules,	100 kA/μ sec	110 kA
- High Rate-of-Rise	150 kV,	5.6 Kilojoules,	40 kA/μ sec	60 kA
- High Current	75 kV,	256 Kilojoules,	85 kA/μ sec	400 kA
- High Energy	390 V,	100 Kilojoules,		700 A, 500 Coulombs

P-Static Test Simulator

- Uniform Charge Spray Fixture, 4 by 8 ft, 150 kV

Simulation Test Fixtures

- Welded Solid Aluminum Coaxial Cylinder, 10 ft Diameter, 12 ft High
- Full Scale Mock-Up of Wing-Root/Fuselage
- Wire Cylinder, 50 ft in Diameter, 50 ft Long

Instrumentation

- Computerized Digital Waveform Processing System
- Digital and Analog Transient Recording Equipment
- Four-Channel Fiber-Optic Signal-Transmission System
- Solid Metal Shielded Enclosure, 8 by 11 ft

LIGHTNING TEST CAPABILITIES

Lightning Technologies, Inc.
10 Downing Parkway
Pittsfield, Massachusetts 01201

High Current

Component A - MIL-STD-1757
30 μF at 100 kV
150 kJ

We can inject a 180 kA, $1.6 \times 10^6 A^2$ s into a test circuit containing 75 milliohms and 5.4 μH. The test generator contains a nominal 1.5 μH and 12 milliohms of impedance, thus the test item can contain 63 milliohms and 4 μH of impedance. The test item inductance is configuration dependent and can be controlled to some extent.

Component B - MIL-STD-1757
520 F at 20 kV
100 kJ, 10 coulombs

The circuit contains 1.6 mH of inductance and 3.6 ohms of resistance which can be removed to accommodate a high impedance test item.

Component C - MIL-STD-1757

Eighty-one series 12 volt automotive batteries connected through 1.8 ohms and 3 mH. Various circuit resistors can be added to increase resistance from 1.8 and 3.2 ohms and the breaker can b. timed to give durations of 0.1 to 1.4 seconds.

High Voltage

Waveform A - MIL-STD-1757

1500 kV at 16.7 nF is capable of providing a 1000 kV/μs breakdown for one meter. Test items requiring two meters or more, 1000 kV/μs tests are tested at the General Electric High Voltage Laboratory where two 5 MV and one 6.2 MV generators are available.

Miscellaneous

Circuits and experience available to perform various tests including but not limited to the following:

Aircraft Lightning Induced Voltage Tests
Electric Field Tests 500 kV/m pulse, 100 kV/m DC
Magnetic Field Tests 0-5000 A/m single pulse
(1MHZ Damped Sine) 0-100 A/m repetitive pulse
Equipment (black box) Transient Design Verification Tests

UPDATE OF THE ICOLSE CONFERENCE IN PARIS, JUNE 1985
(MR. L. WALKO)

ElectroMagnetic Engineering, Inc.

December 19, 1984

Mrs. Danielle Kerneur, Manager
SCTTV Transatour Passages
34,rue R. Giraudineau 94300 Vincennes
Paris, France

Reference:"ICOLSE"-International Conference on Lightning and Static Electricity.

Good Morning Mrs. Kerneur:

Before getting down to the business at hand, Kaye and I thank you and Peter for the wonderful hospitality you both extended to us on our recent visit to your beautiful city. We thoroughly enjoyed the social activities with you, Paul and Peter. It was rather like being at home, away from home.

Peter offered me many special "Introductions", several of which I am returning herewith as we simply did not have the time to enjoy all these activities. Perhaps you have other uses for them. Tell Peter the show at the Latin Paradise was simply GRAND. He should not hesitate to recommend the show to anyone. It didn't even matter what language the guests spoke, all can fully understand the entire program.

Now, down to business.

● By copies of this letter, I am strongly recommending to Jean-Michel Contant and Joseph Taillet that they consider that the Awards Banquet be held on the river cruise we took together. The size of the boat is right, the food is outstanding and the atmosphere is perfect for any visitor to the conference. Further, they will have a captive audience, for the right amount of time. And if the price of the dinner cruise is in the conference fee, all will attend.

●The Hotel arrangements seem to be at the right price. This will let us offer a choice of costs to the traveler. While the Monparnasse Park Hotel was 1st Class, we were not impressed with the efficiency of their operations, considering the cost. I should add that I have plenty of Hotel Mercure brochures, but only one for the Eiffel Kennedy. I need about 250 of each of the hotels that are to be recommended. Will you send them to me?

●Transfers from the airport to the hotel on arrival will be most difficult to arrange. I think it best to recommend that the traveler take the Air France bus to downtown, then a Taxi to their hotel. Returning to the airport from a hotel may be easier to plan. After the conference, departures can be identified, and arrangements can be made. We will "attack" this during the conference.

Consultants in ElectroMagnetic Effects

● Concerning the Ladies' Program (we refer to this as the SPOUSES' Program), we will detail the information you have provided in a brochure for a future mailing in North America. The respondors will have to indicate the tours they will want, and pay for them in advance. This way we will have a count, and can plan the event.

● The "Post Tours" will be handled the same way, in advance. However it may be that some visitors will decide to join the tour when they are already in Paris. I suppose this can be handled?

● I agree that the Hotel Nikko is outrageously expensive, and from people we know that stayed there very recently, not worth it. There seems to be quite a few three star hotels around that you might look into. For instance, we stayed the last three days we were in Paris at the Terrass Hotel, just one block above the Hotel Mercure. It was clean, efficient, comfortable and I might add, inexpensive.

I believe I have covered all the points that we must "go" with. If you have any corrections, additions or deletions please let me know before February 1st, 1985.

Thank you again for your kind assistance. Our very best to Paul and Peter.

Sincerely,
Electromagnetic Engineering Inc.

Walter D. Mc Kerchar, P.E.
President

cc: Jean-Michel Contant, AAAF
Dr. Joseph Taillet, ICOLSE
Jill, First Class Travel- Poulsbo, Wa.
G.A.M. Odam, European Coordinator, NICG
L.C. Walko, 1986 Chairman, L&SE Conference
Steering Committee, National Interagency Coordinating Group (NICG)

S.C.T.T.V TRANSATOUR PASSAGES

S. A. R. L. AU CAPITAL DE 185.000 F.
34, RUE ROBERT GIRAUDINEAU - 94300 VINCENNES
LICENCE Nº 1484 R.C. PARIS B 778741487

December 10th, 1984

Mr Walt B. McKerchar P.E.,
President,
Electro Magnetic Engineering, Inc.
P.O.Box 1888,
POULSBO Wa 98370-0269
Etats Unis

ISOLAB

Dear Mr McKerchar,

This is to confirm what we planned for the american delegation.

<u>Hotel reservations</u>
From June 2nd to 9th (Air Show)
As Montparnasse Park Hotel overbooked, we had to change our plans and we found a nice, cheap hotel.
Hotel Eiffel Kennedy : 10 rooms
Price : single or double, including continental breakfast : 430 Frs
From June 9th to 15th (Congress) * *
Hotel Eiffel Kennedy
(as above)
Hotel Mercure Montmartre
10 double rooms and 40 single rooms
Prices : single 445 Frs
double 476 Frs
american breakfast 35 Frs per person
one child under 12 in parents' room : free

<u>Transfert</u>
From CDG Airport to hotel or vice-versa (minimum 25 persons)
Per person : 60 Frs

<u>Ladies' programme</u> (minimum 25 persons)
Monday June 10th
9.30am - 12am - Historical Paris
Per person : 60 Frs
2.30pm - 5pm - Modern Paris
Per person : 75 Frs
Tuesday June 11th
9am - 5pm - Versailles and Thoiry castels
Including lunch
Per person : 300 Frs
Wednesday June 12th
9.30am - 12am - Boat trip on the Seine including bus transfers
Per person : 75 Frs
after noon - Fashion show

<u>Post tours</u>
- Reims and Champagne, one day
  lunch not included
  Per person : 300 Frs
- Loire Valley, two days
  (including meals and accommodation)
  Per person : 1440 Frs
- Normandy and Mt St Michel, two days
  (including meals and accommodation)
  Per person : 1560 Frs

* * We have an optional booking in Hotel Nikko (four star) for 20 rooms from June 9th to 15th
Prices : single 1025 Frs } including continental breakfast
double 1060 Frs }
Its very expensive and we suggest to cancel this optional booking.
What do you think about it ?

Sincerely yours

Danielle Karacour (Mrs)
Manager

FAA TECHNICAL CENTER R&D OVERVIEW AND
PLANNED FUTURE ACTIVITIES (MR. MIKE GLYNN)

FAA TECHNICAL CENTER

R&D

OVERVIEW & PLANNED

FUTURE ACTIVITIES

- DIRECT STRIKE LIGHTNING

  84

  - C-130/F-106/CV-580
  - FLORIDA '84'
  - ANALYSIS

  FUTURE

  - TAIL BOOM
  - ADDITION INSTRUMENTATION
  - FLORIDA '85'
  - LANGLEY/WALLOPS
  - LEMP
  - NEMP
  - BEYOND 86
    - FLIGHTS
    - DECOMMISSION

- HIGH ALTITUDE DIRECT STRIKE

  PAST
  FUTURE
  NASA BRIEFING

- GEOGRAPHIC STUDIES

  INTENT
  MANPOWER & DOLLARS
  WORLDWIDE

- HISTORICAL STUDY

  LTI
  CONSOLIDATED DATA BASE
  EXPANDED AREA
  DATA

- INDIRECT EFFECTS (ADP)

  USAF - BRIEFING
  FAA SUPPORTS
  ACAP

- DIRECT STRIKE HAZARDS DEFINITION

  SHORT MANPOWER & DOLLARS
  COMBINES
    F-106
    CV-580
    GEOGRAPHIC
    HISTORICAL
  COMPLIMENTS ADP/INDIRECT

- SEA (DR. COOLEY)

  LIGHTNING SIMULATION TECHNOLOGY
  COMPOSITE - ELECTRICAL PROPERTIES ANALYSIS
  BALLANCA MODEL

- NASA AMES (BILL LARSEN)

  BUS INTEGRITY
  LATENT FAULT MEASUREMENT METHOLOGY
  SOFTWARE SYSTEMS ERRORS
  DETECTION AND CORRECTION
  SOFTWARE RELIABILITY ASSESSMENT
  SOFTWARE MONITORING REDUNDANCY
  AIRCRAFT GENERATED EMI

- DIGITAL SYSTEM VALIDATION HANDBOOK

  VOLUME I
  UPDATE
  SOHAR

- STATIC DISCHARGE

  LTRI

- CONCLUSION

  LIMITED RESOURCES
  COMPOSITES
  DEICING SYSTEMS - ANTENNAS

NAVY ISSUES ON LIGHTNING RESEARCH* (DR. L. RUKNKE)

*Presentation not submitted for inclusion into minutes

PROTECTION OF U. S. ARMY AIRCRAFT FROM NATURAL ELECTRICAL HAZARDS - FUTURE NEEDS AND ACTIVITIES - (MR. DAVID ALBRIGHT DIRECTORATE FOR ENGINEERING US ARMY AVIATION SYSTEMS COMMAND ST. LOUIS, MO)

PROTECTION OF U.S. ARMY AIRCRAFT

FROM

NATURAL ELECTRICAL HAZARDS

- Future Needs and Activities -

DAVID L. ALBRIGHT
Directorate for Engineering
US Army Aviation Systems Command
St. Louis, MO 63120-1798
28-29 January 1985

1. Recapitulation.

Yesterday I spoke about the past year's activities at AVSCOM, and in those discussions touched on several problems with regard to specifying design and test requirements for protection against lightning and static electricity hazards that continue to be troublesome. I'll restate them more explicitly today, discuss some solutions, and finish up my presentation by giving you a brief status report on the Advanced Composite Aircraft Program (ACAP).

2. Specifying Lightning Protection.

a. Need for a Requirements Document.

(1) Problem. We lack an adequate lightning protection requirements document with the result that we currently have to generate many words in lieu of one concise reference to a military standard. The problem with the current approach is the potential lack of consistency among programs as well as the danger of under-/over-specifying the requirement.

(2) Solution. The current solution is the ongoing development of a lightning protection requirements military standard being developed by SAE Committee AE4L for the Air Force, and for eventual acceptance by all of the other services. It is hoped that this standard can be used in the Army's upcoming LHX program.

b. Protection for Aircraft Modifications.

(1) Problem. How to specify lightning protection design and qualification test requirements for a modification to an existing aircraft design when the basic aircraft itself has not been specifically lightning hardened.

(2) Solution. One current solution pertains to the weaponization of helicopters and simply states that a direct lightning strike to the aircraft shall not arm, detonate, launch, or jettison the weapon for both the parked and airborne conditions. Most lightning strikes to Army helicopters have been on the ground. Variations involve precluding inerting of the weapon as well, or protection from nearby strikes versus direct strikes. The weapons themselves generally get lightning tested during their basic development, but sometimes only to nearby strikes and not direct strikes, e.g., a weapon initially designed for ground use only.

c. Lightning Protection Demonstrations.

(1) It is one thing to sell the notion of including lightning protection in the design requirements document for a program, and quite another to have hardware set aside for actual tests. Program Managers generally object to subjecting one of their scarce prototypes or initial production articles to lightning tests due to cost and schedule limitations.

(2) Solution. The general pass-fail criterion for lightning protection is that there be no loss of aircraft or injury to crew. Accordingly, all new rotor blade and external fuel tank designs are lightning tested; since the material failure of one of these subsystems would generally be catastrophic. The UH-60A utility helicopter program did have a low-level induced effects test funded whereby the entire aircraft was tested; and the results, while being revealing, became expensive in the aftermath due to required maintenance actions. To date, no such test has been scheduled for other major aircraft systems. At best, what has been required is a lightning protection survey which involves some analyses, model testing, and an itemization of potential hazards with proposed fixes. If any service is really serious about producing an aircraft with an all-weather capability, lightning testing of full-scale aircraft is required; and the pass-fail criterion must be more than just being able to make a safe emergency landing.

d. Lightning Induced Transients.

(1) Problem. If one were to levy a lightning protection specification against induced effects for an entire aircraft, one need not get quantitative; since it would be up to the prime contractor to make trade-offs between shielding in the airframe and hardening in the subsystem. This becomes a problem, however, when government furnished equipment (GFE) is involved; whereby the GFE is developed independent of the aircraft. This could even be a problem for the prime contractor, since he needs to make early decisions regarding the above trade-offs.

(2) Solution. What is needed is a MIL-STD-704 or MIL-STD-461 type document for induced effects. Some Army programs have used the 500-volt pass-fail criterion of MIL-B-5087; but, as all of you know, this doesn't ensure that interfacing hardware will not be damaged.

3. Specifying Static Electricity Protection. The big problem here is that there is not only no comprehensive design requirements document, there is also no test requirements document. What is needed is an improvement over the one-liners in MIL-E-6051; namely, an effort similar to that being carried out for lightning.

(a) Need for a Requirements Document.

(1) Problem. We need a checklist for the myriad of potential hazards associated with static buildup and discharge for both ground operations (e.g., personnel handling, rearming, and refueling) and airborne operations (e.g., sling-load operations and avionics performance). As with lightning protection, lack of a static electricity protection requirements document requires that many words have to be generated in lieu of a concise reference to a military standard; with the result that requirements may not be consistent among different programs or even complete.

(2) Solution. Develop a static electricity hazards protection requirements document. It should be noted that MIL-B-5087 (the bonding specification) is just as inadequate for static electricity hazards as it is for lightning hazards.

b. Need for a Test Document.

(1) Problem. There are several sources which cite the personnel handling threat as being 25,000 volts and that due to a hovering helicopter as being 300,000 volts; however, there are numerous other hazards and circumstances which are not addressed by the above. Not only are the above criteria inadequate, they are not readily available for citation.

(2) Solution. Develop a static electricity hazards protection test document. This document should address such effects as vehicle construction and operational scenario. Recent experience with an external fuel tank of non-metallic construction pointed to the need for inclusion of specialized component testing as well as general aircraft testing.

4. Advanced Composite Aircraft Program (ACAP).

a. A Brief Review.

(1) To provide a technology base for engineering development of advanced composite airframes; e.g., LHX, JVX, and replacement of metal structures on current Army aircraft.

(2) Currently in competition: Sikorsky Aircraft and Bell Helicopter Textron (BHT).

(3) Each contractor built one static test article (STA), one tool proof article (TPA), and one flight test article.

(4) All nonconductive exposed composite surfaces have aluminum wire mesh. Composite joints are also metalized; except that Sikorsky uses foil and BHT uses wire mesh.

(5) The STA's and TPA's have the same degree of metalization as the flight test article, except that Sikorsky's TPA has no metalization.

b. Current Plans.

(1) Negotiations are currently underway between Applied Technology Laboratory (Ft Eustis) and the Air Force to test both designs as a part of the Atmospheric Electrical Hazards Protection Advanced Development Program. Use of the TPA's would be desirable; however, the BHT TPA would not be available until sometime in 1986. Since the Sikorsky TPA has no metalization, the Sikorsky STA is being considered; which wouldn't be available until it has met other commitments in the coming years.

(2) Lightning electromagnetic pulse (LEMP) testing is planned for both STA's; Sikorsky's will be tested later this summer and BHT's will be tested the middle of next year. The flight test articles might be more desirable, but they have prior test commitments.

(3) Direct strike lightning testing is possible in the outyears, which would probably be performed on the STA's after LEMP testing. The order of consideration would be high voltage (low current) attachment tests, high curent - average strike (20,000 amperes) tests, and lastly high current - severe strike (200,000 ampere) tests.

5. Concluding Remarks.

Most of you here present are engaged in various types of research on lightning and static electrification. We here at AVSCOM are more involved with using the results of your research. Accordingly, I thought it would be of value to you for me to relate some of the experiences, frustrations, lessons learned, and needs which have become evident in the day-to-day applications of the results of such research.

DIRECT STRIKE LIGHTNING OVERVIEW (MR. MIKE GLYNN, FAA TECHNICAL CENTER, ATLANTIC CITY AIRPORT, NJ)

Federal Aviation Administration
Technical Center Atlantic City Airport, New Jersey 08405

FLIGHT SAFETY RESEARCH BRANCH

MICHAEL S. GLYNN

FAA TECHNICAL CENTER
AIRCRAFT AND AIRPORT SYSTEMS
TECHNOLOGY DIVISION
FLIGHT SAFETY RESEARCH BRANCH

(609) 484 - 4138

Federal Aviation Administration
Technical Center Atlantic City Airport, New Jersey 08405

FLIGHT SAFETY RESEARCH BRANCH

LOW ALTITUDE

DIRECT STRIKE

LIGHTNING CHARACTERICATION

PROGRAM

Federal Aviation Administration
Technical Center Atlantic City Airport, New Jersey 08405

FLIGHT SAFETY RESEARCH BRANCH

BEFORE

YOU CAN SOLVE

A PROBLEM,

YOU MUST FIRST

UNDERSTAND IT.

Federal Aviation Administration
Technical Center — Atlantic City Airport, New Jersey 08405

FLIGHT SAFETY RESEARCH BRANCH

PURPOSE

TO OBTAIN A DATA BASE OF LIGHTNING DIRECT STRIKES TO AIRCRAFT WHICH CAN BE ANALYZED FOR USE IN DEVELOPING CRITERIA FOR AIRCRAFT PROTECTION

Federal Aviation Administration
Technical Center — Atlantic City Airport, New Jersey 08405

FLIGHT SAFETY RESEARCH BRANCH

APPROACH

CONDUCT A TWO-YEAR TEST PROGRAM IN AN INSTRUMENTED CV-580 AIRCRAFT TO OBTAIN LIGHTNING MEASUREMENTS

DIRECT-STRIKE FLORIDA	JULY-AUGUST	84 - 85
NEMP KIRKLAND AFB	FALL	85
LEMP WRIGHT-PATTERSON AFB		84 - 85

Federal Aviation Administration
Technical Center

FLIGHT SAFETY RESEARCH BRANCH

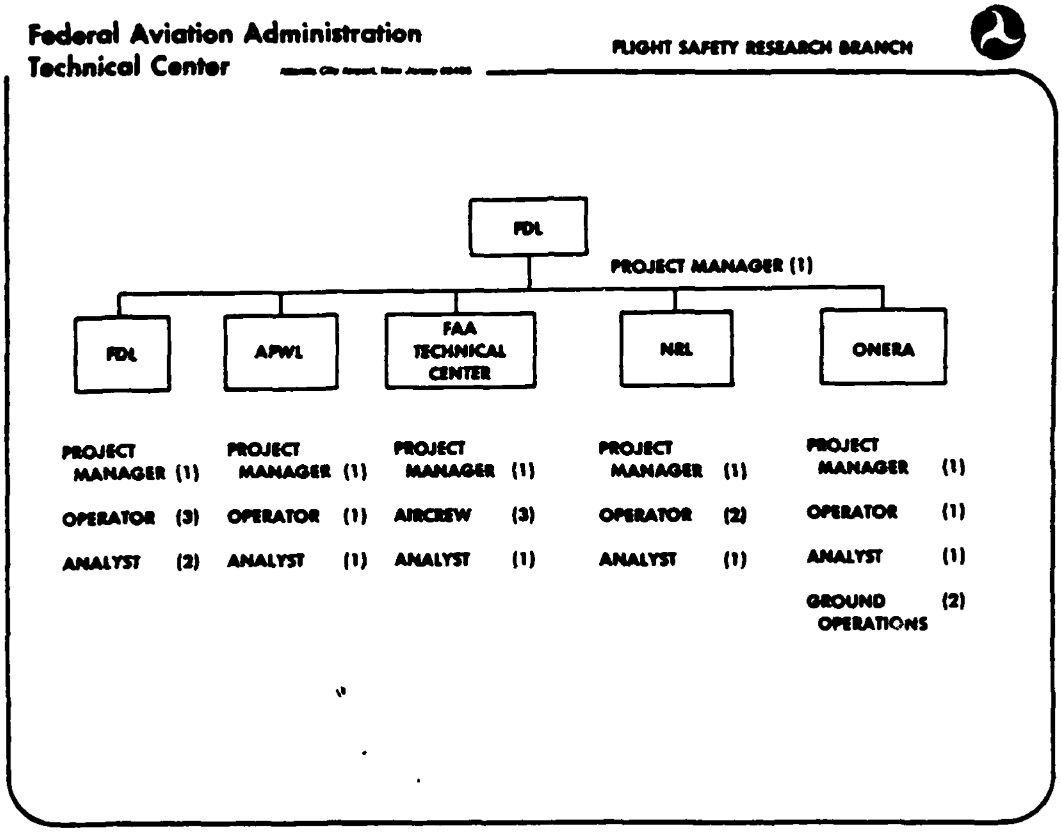
- F-106 PROGRAM
  - HIGH ALTITUDE
    - NASA-LANGLEY
      - STRIKES
        - CLOUD-TO-CLOUD
        - INTRA-CLOUD
- C-580 PROGRAM
  - LOW ALTITUDE (UP TO 20K)
    - FLORIDA AND NEW MEXICO
      - STRIKES
        - CLOUD-TO-GROUND
- ROCKET TRIGGERING PROGRAM
  - LOW ALTITUDE
    - FLORIDA
      - STRIKES
        - CLOUD-TO-GROUND

Federal Aviation Administration
Technical Center

FLIGHT SAFETY RESEARCH BRANCH

DATA BASE BENEFITS

- FAA
  - CERTIFICATION
  - REGULATORY
  - ADVISORY
  - VALIDATION
  - PROCEDURES AND GUIDANCE
- INDUSTRY
  - DESIGN
  - MANUFACTURING
  - VALIDATION
  - MAINTENANCE



SENSOR LOCATIONS ON THE AIRCRAFT

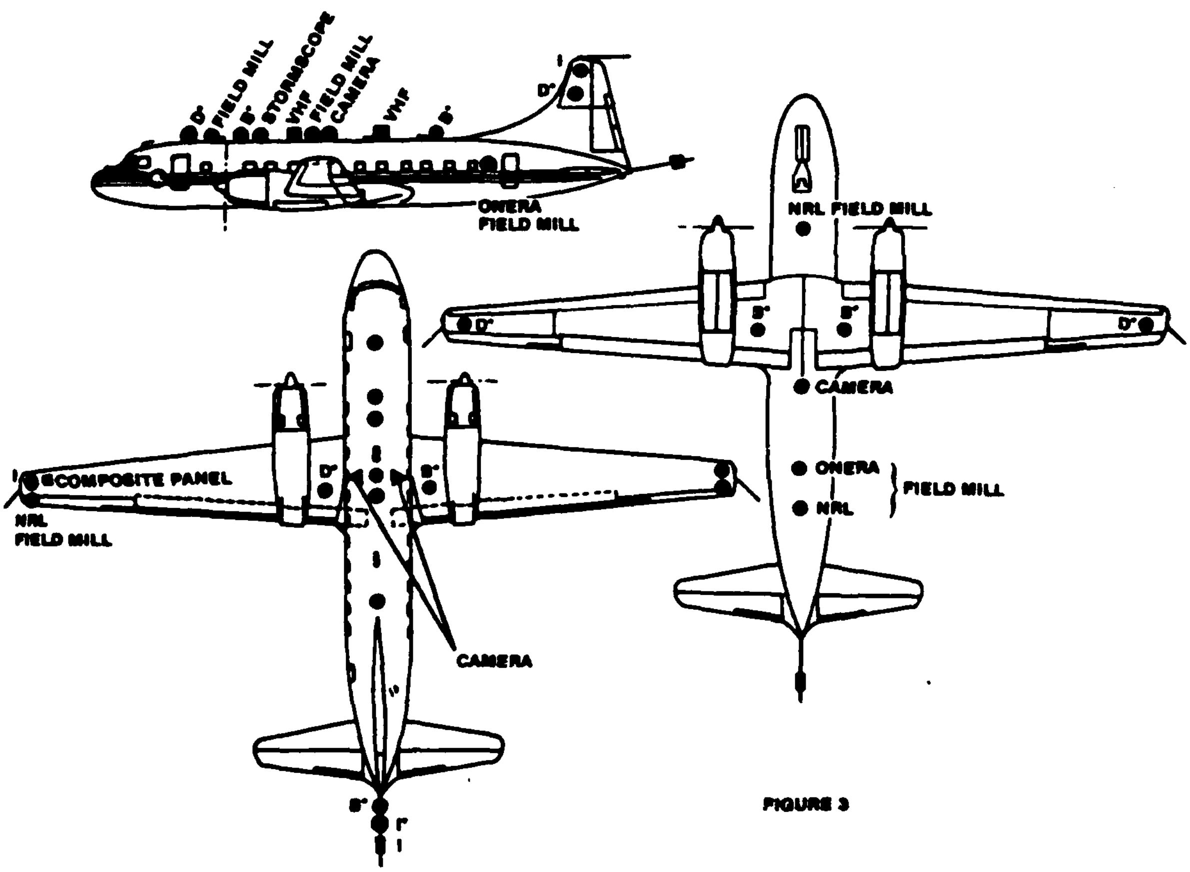


FIGURE 3

SUMMARY - 1984 DIRECT STRIKE LIGHTNING DATA COLLECTED
(MAJ. P. RUSTAN, USAF, WRIGHT PATTERSON AFB, OH)

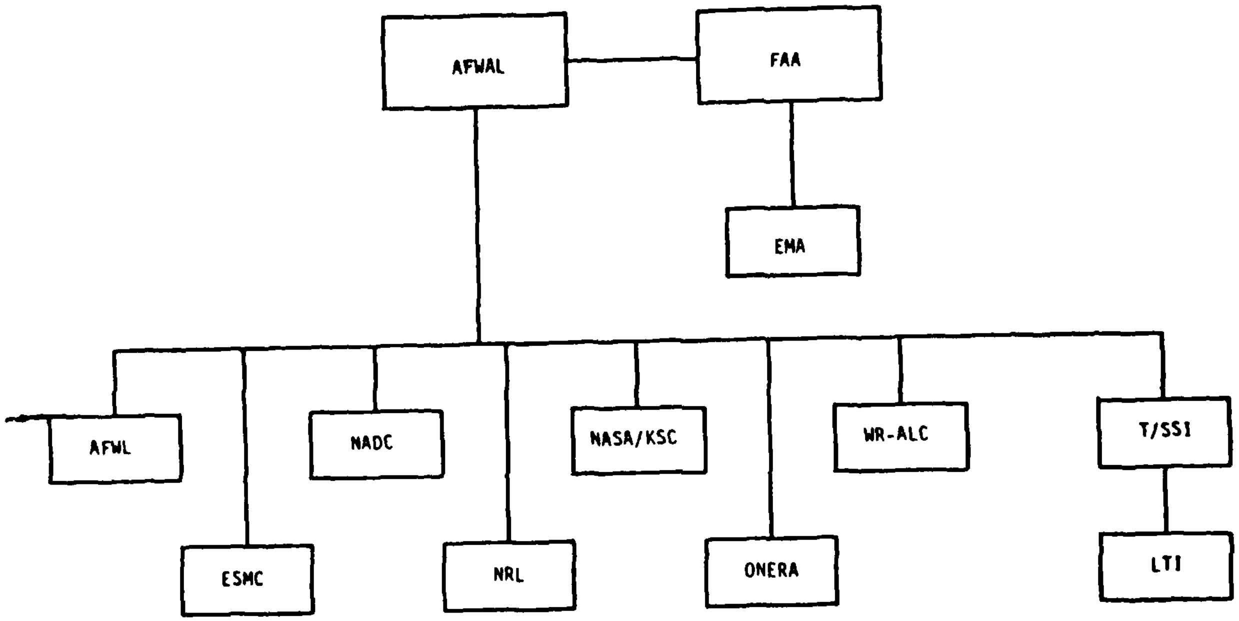


Table 1. ORGANIZATIONAL BLOCK DIAGRAM OF AGENCIES INVOLVED IN THE PROGRAM

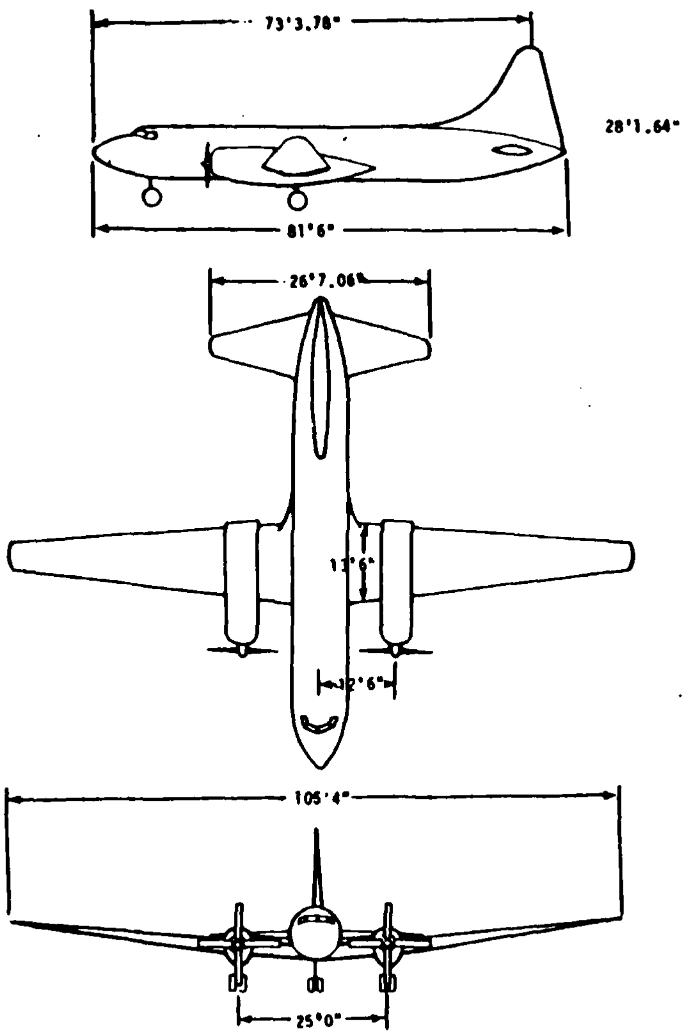
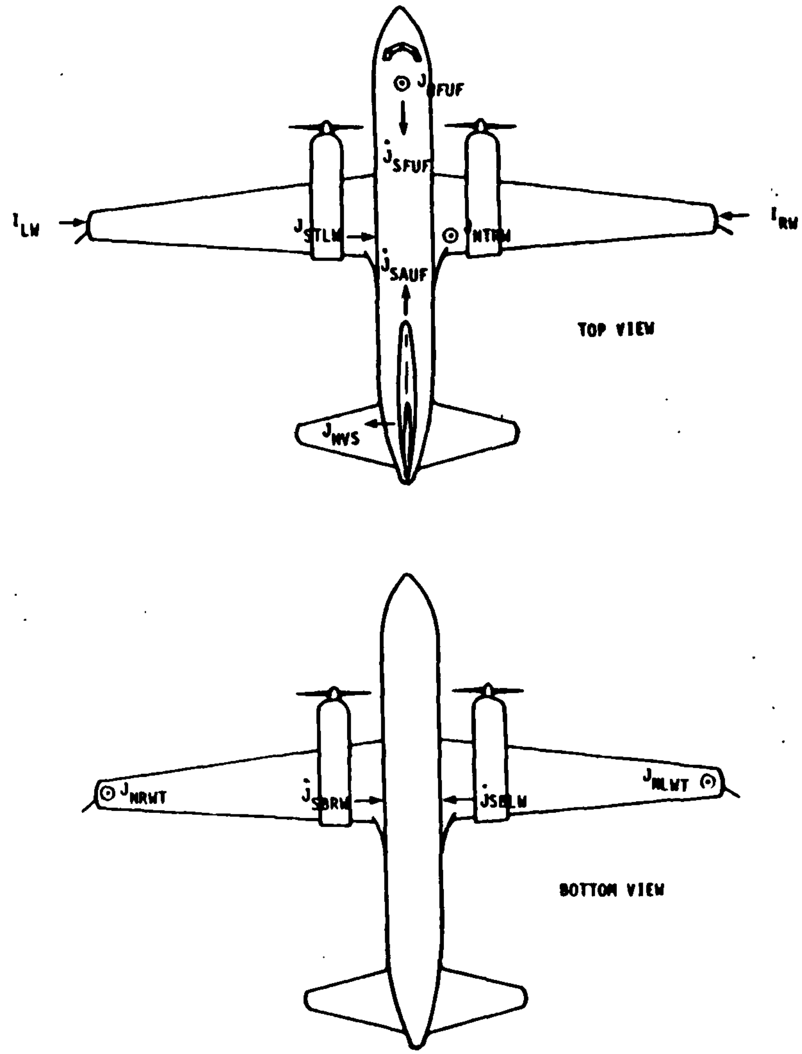


Figure [illegible]. THREE VIEW DRAWINGS OF CV-580 AIRCRAFT AND OVERALL DIMENSIONS



CV-580 TRANSIENT ELECTROMAGNETIC SENSOR LOCATIONS (ARROWS INDICATE DIRECTION OF POSITIVE CURRENT FLOW)

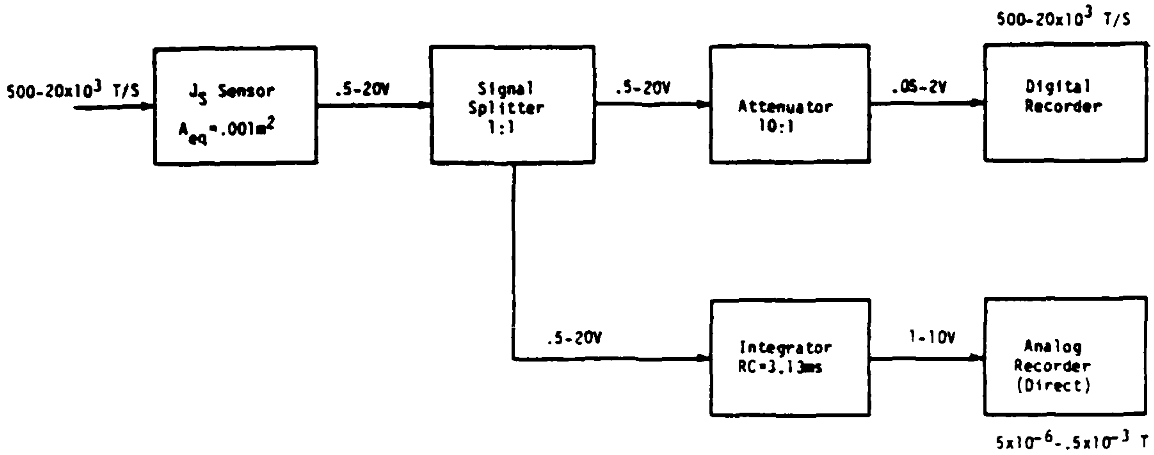


Figure 5. SURFACE CURRENT INSTRUMENTATION BLOCK DIAGRAM

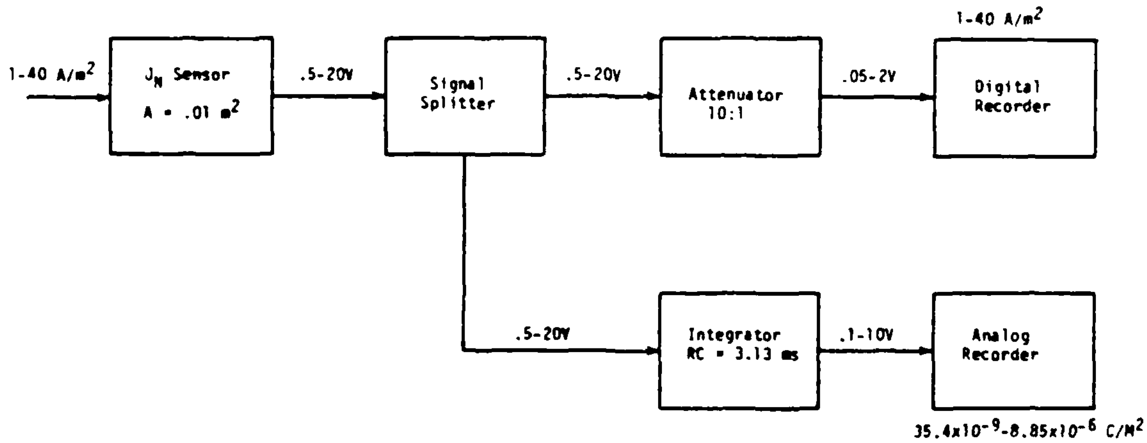


Figure 7. DISPLACEMENT CURRENT INSTRUMENTATION BLOCK DIAGRAM FOR J_{NRWT}, J_{NLWT}, and J_{NVS}

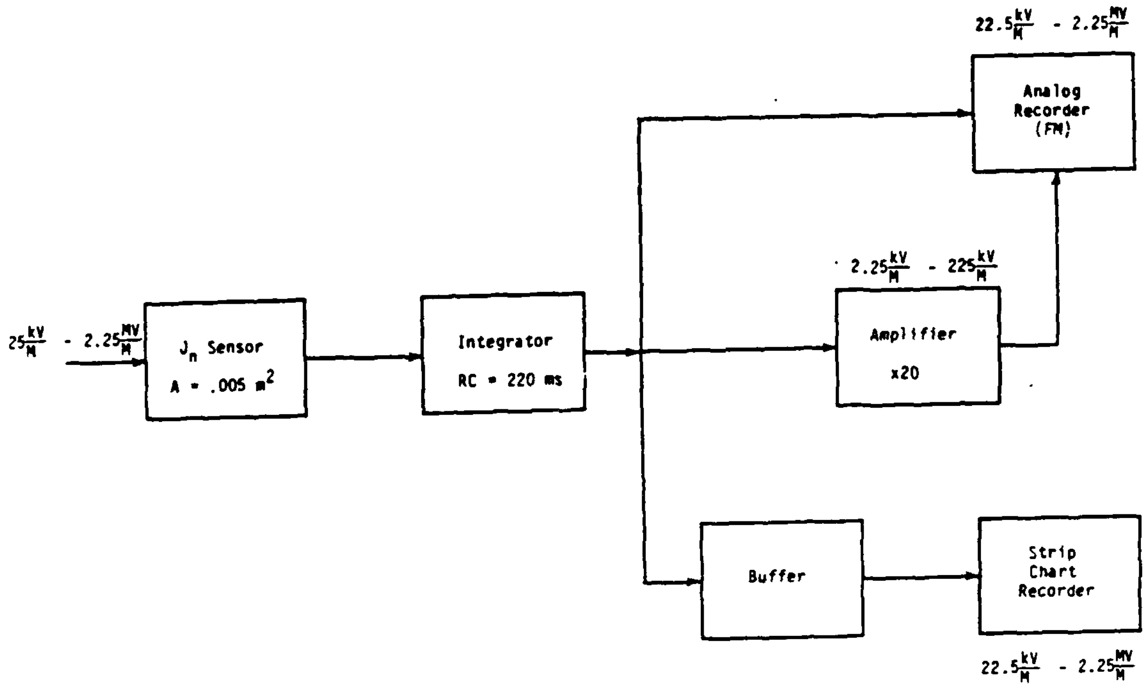


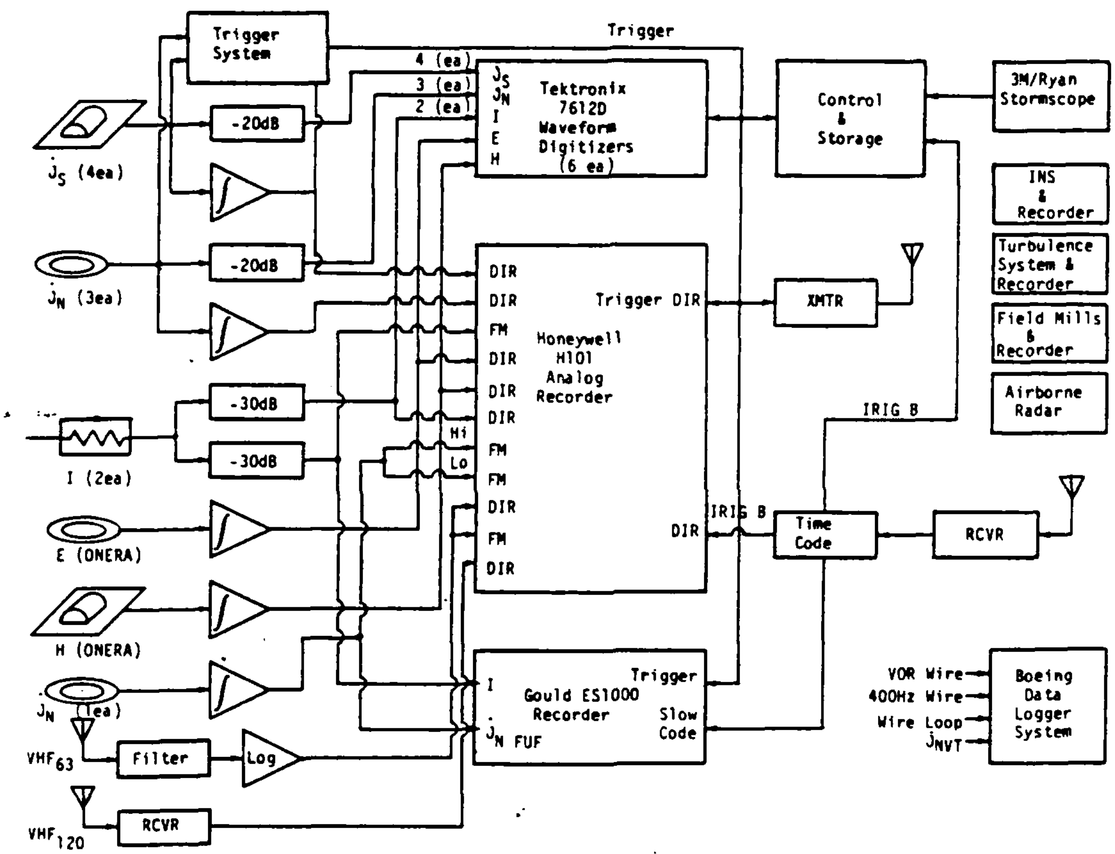
Figure 8. DISPLACEMENT CURRENT INSTRUMENTATION BLOCK DIAGRAM FOR J_{NFF}

TABLE 2

AIRCRAFT EXTERIOR TRANSIENT MEASUREMENTS

Sensor	Type	Area/ Sensitivity	Measurement Range	Frequency Range
I_{LW} I_{RW}	Resistive	5mΩ	10 A - 2kA 2kA - 25kA 100A - 25kA	DC - 500KHz(1) 400Hz - 2MHz(2) 40Hz - 80MHz(3)
J_{SBLW} J_{SBRW} J_{SFUF} J_{SAUF}	Multi-Gap Loop	$10^{-3}m^2$	$5x10^{-6}$ - $0.5x10^{-3}$T $5x10^2$ - $2x10^4$ T/S	400Hz - 2MHz(2) 40Hz - 80MHz(3)
J_{STLW} (ONERA)	Multi-Gap Loop	-	265 mA/m - 839 A/m	400Hz - 2MHz(2) 100Hz - 80MHz(3)
J_{NLWT} J_{NVS} J_{NRWT}	Flush Plate Dipole	$10^{-2}m^2$	$3.54x10^{-8}$ - $8.85x10^{-6}$ C/m^2 1 - 40 A/m^2	400Hz - 2MHz(2) 40Hz - 80MHz(3)
J_{NFUF}	Flush Plate Dipole	5 x $10^{-3}m^2$	2.25kV/m - 2.25MV/m	0.5Hz - 500KHz(1)
J_{NTRW} (ONERA)	Hollow Spherical Dipole	-	100V/m - 316 kV/m	400Hz - 2MHz(2) 6kHz - 80MHz(3)
VHF_{63} VHF_{120}	VHF Blade Antenna	-	63MHz, 6MHz B.W. 120MHz	DC - 500kHz(1) 400 - 2MHz(2) 400 - 2MHz(2)

(1) FM Record on Honeywell H101 Instrumentation Recorder
(2) Direct Record on Honeywell H101 Instrumentation Recorder
(3) Recorded on Tektronix 7612D Waveform Digitizer



CV-580 AIRCRAFT INSTRUMENTATION BLOCK DIAGRAM

Figure 14. CV-580 Aircraft Rack Layout

TYPE	ANDREW CORD HELIAX FSJ1-50	RG8/U	RG58C/U	RG174/U
Cutoff Freq, GHz	19	12	25	50
Impedance, Ohms	50	52	50	50
Velocity, % c	78	66	66	66
Atten, dB/100FT @100MHz	1.72	2.0	5.3	8.8
Nominal Size, Inch	0.25	0.405	0.195	0.10
Center Conductor	Copper	Copper	Copper	Copper
	Solid,Corrugated	Copper	Copper	Copper
Outer Conductor	Copper	Braided	Braided	Braided

Table 3. COAXIAL CABLE SPECIFICATIONS

Figure 16. Picture of the Ground Station Trailer

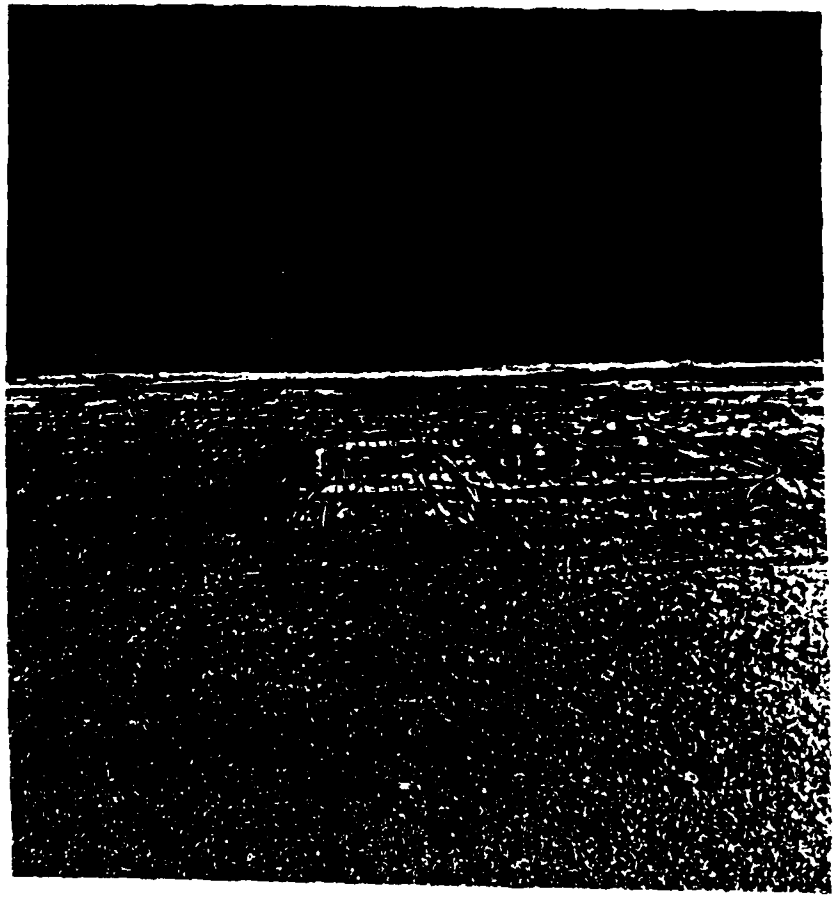
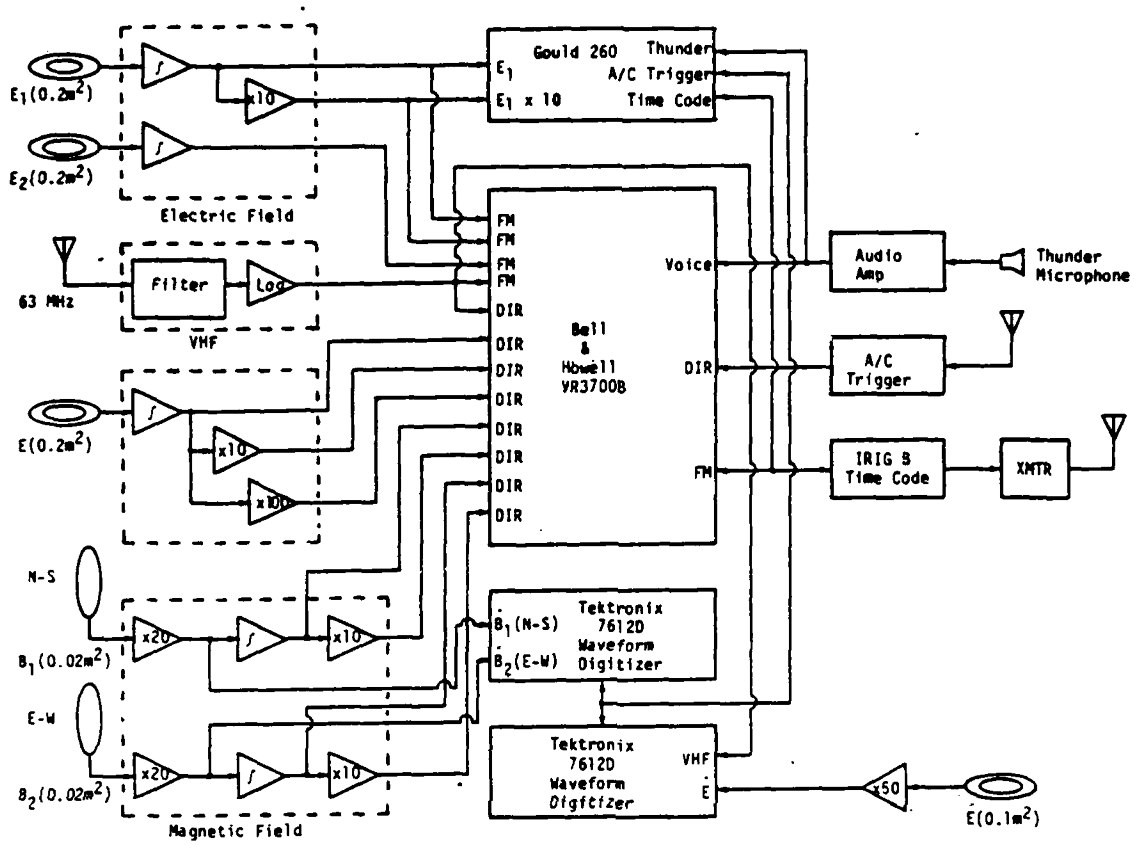


Figure 17. Electric and Magnetic Field Antennas Near the Ground Station Trailer

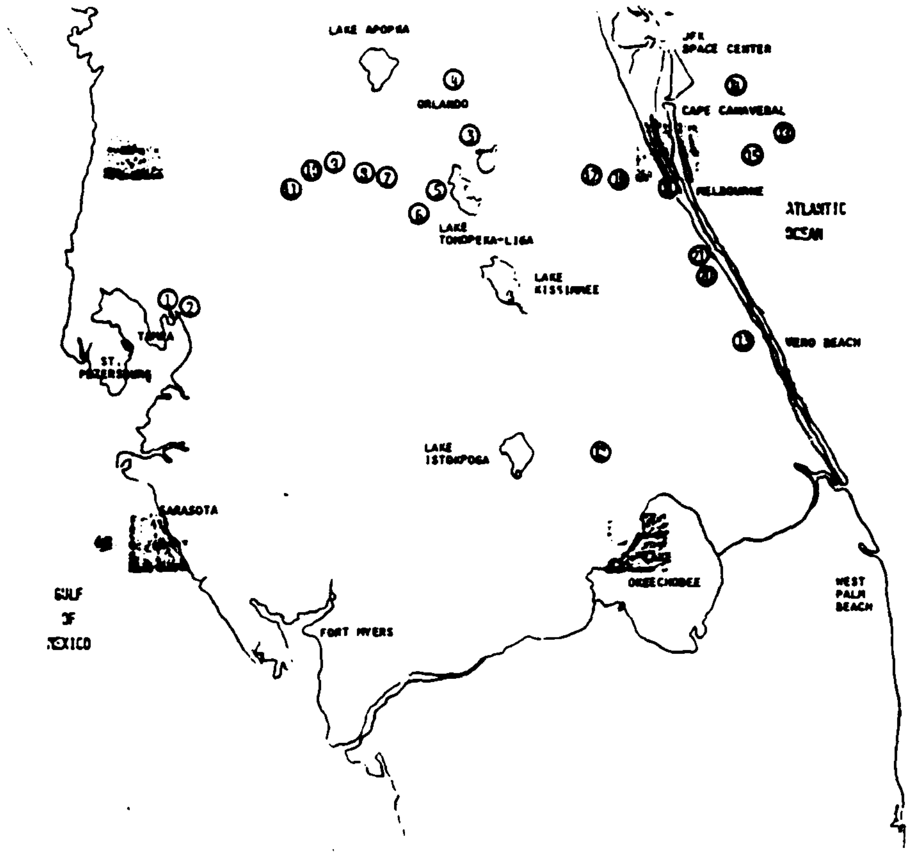


GROUND STATION INSTRUMENTATION BLOCK DIAGRAM

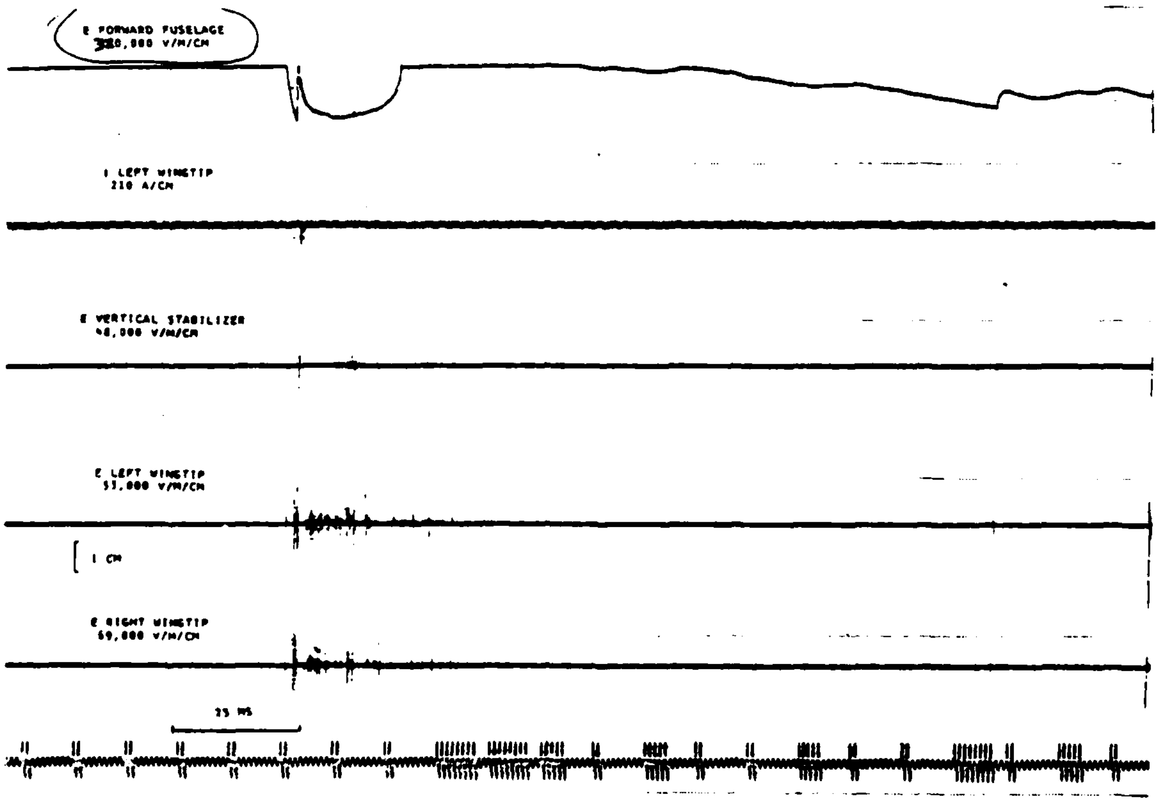
GROUND STATION MEASUREMENTS

Sensor	Type	Area	Measurement Range	Frequency Range
E1	Flat Plate	$0.05m^2$	500 V/m - 100 kV/m	0.1-500 kHz(1)
E2	Flat Plate	$0.2\ m^2$	50 V/m - 1 kV/m	0.1-500 kHz(1)
E3	Flat Plate	$0.1\ m^2$	$2 \times 10^7 - 5 \times 10^9$ V/m/s	50 Hz - 25 mHz(2)
E4	Flat Plate	$0.2\ m^2$	2 V/m - 2 kV/m	50 Hz - 2 mHz(3)
VHF	Flat Plate	$0.06m^2$	63 mHz, 6 mHz B.W.	50 Hz - 2 mHz(3)
				DC - 500 kHz(1)
				DC - 25 mHz(2)
B1	Cylindrical Moebius Loop	$0.02m^2$	0.02 - 5 A/m $10^5 - 2.5 \times 10^7$ A/m/s	500 Hz - 2 mHz(3) 500 Hz - 25 mHz(2)
B2	Cylindrical Moebius Loop	$0.02m^2$	0.02 - 3 A/m $10^5 - 2.5 \times 10^7$ A/m/s	500 Hz - 2 mHz(3) 500 Hz - 25 mHz(2)

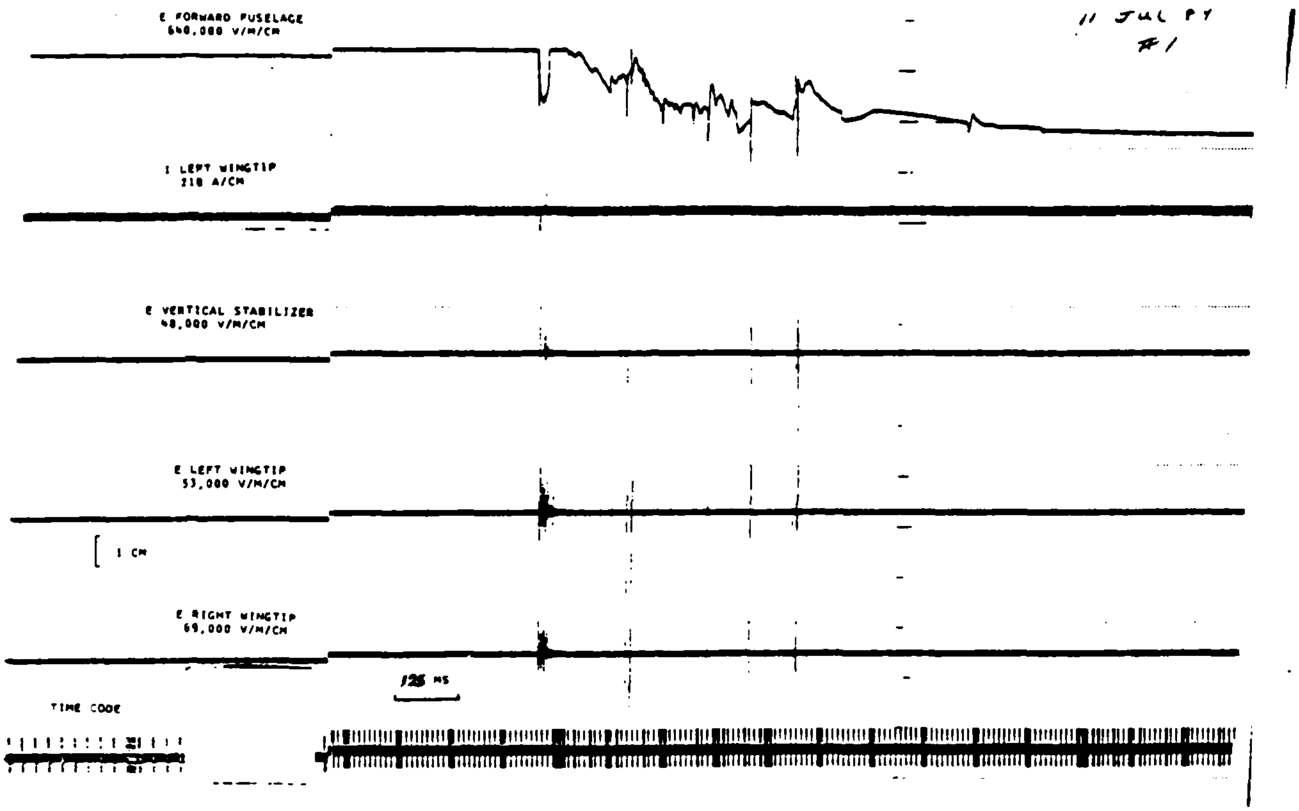
(1) FM Record on Honeywell M101 Instrumentation Recorder
(2) Recorded on Tektronix 7612D Waveform Digitizer
(3) Direct Record on Honewell M101 Instrumentation Recorder

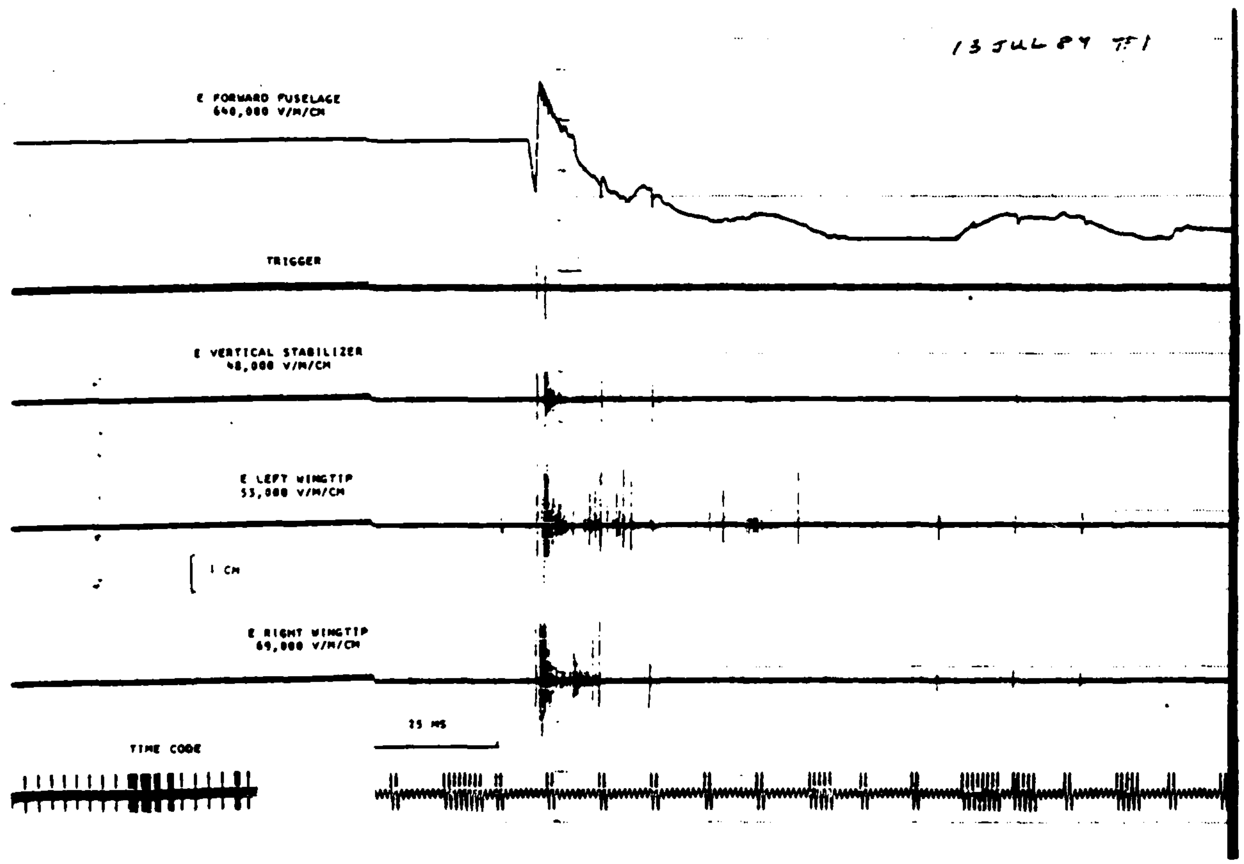


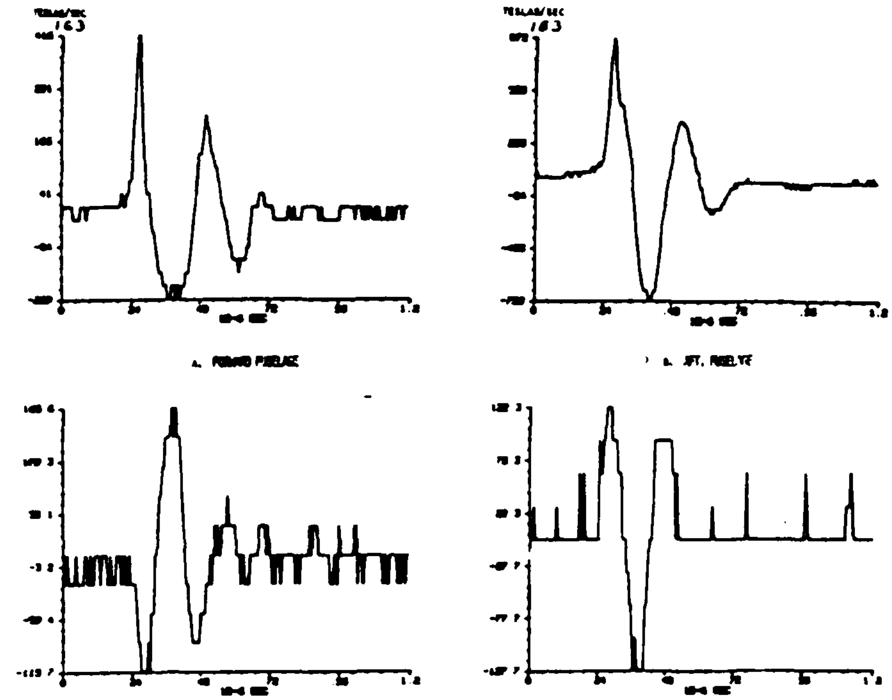
LAKE APOPKA
ORLANDO
JFK SPACE CENTER
CAPE CANAVERAL
MELBOURNE
ATLANTIC
OCEAN
LAKE
TOHOPEKA-LIGA
LAKE
KISSIMMEE
TAMPA
ST.
PETERSBURG
VERO BEACH
LAKE
ISTOKPOGA
SARASOTA
OKEECHOBEE
WEST
PALM
BEACH
FORT MYERS



E FORWARD FUSELAGE
I LEFT WINGTIP
210 A/CM
E VERTICAL STABILIZER
E LEFT WINGTIP
1 CM
E RIGHT WINGTIP
25 MS


E FORWARD FUSELAGE
640,000 V/M/CM
I LEFT WINGTIP
E VERTICAL STABILIZER
48,000 V/M/CM
E LEFT WINGTIP
53,000 V/M/CM
1 CM
E RIGHT WINGTIP
69,000 V/M/CM
TIME CODE


E FORWARD FUSELAGE
640,000 V/M/CM
TRIGGER
E VERTICAL STABILIZER
48,000 V/M/CM
E LEFT WINGTIP
53,000 V/M/CM
1 CM
E RIGHT WINGTIP
69,000 V/M/CM
25 MS
TIME CODE



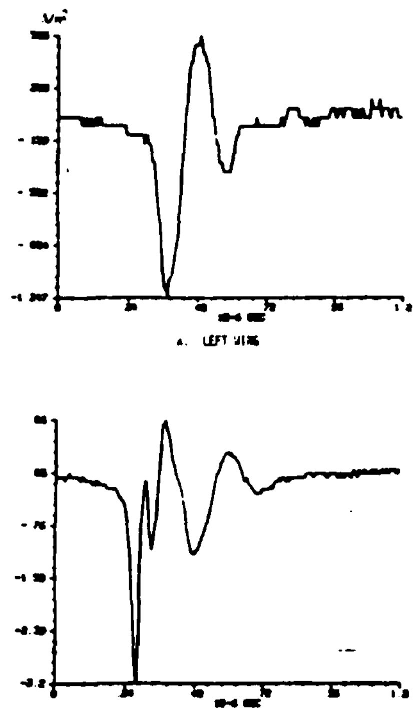
a. FORWARD FUSELAGE

b. AFT FUSELAGE

c. LEFT WING

d. RIGHT WING

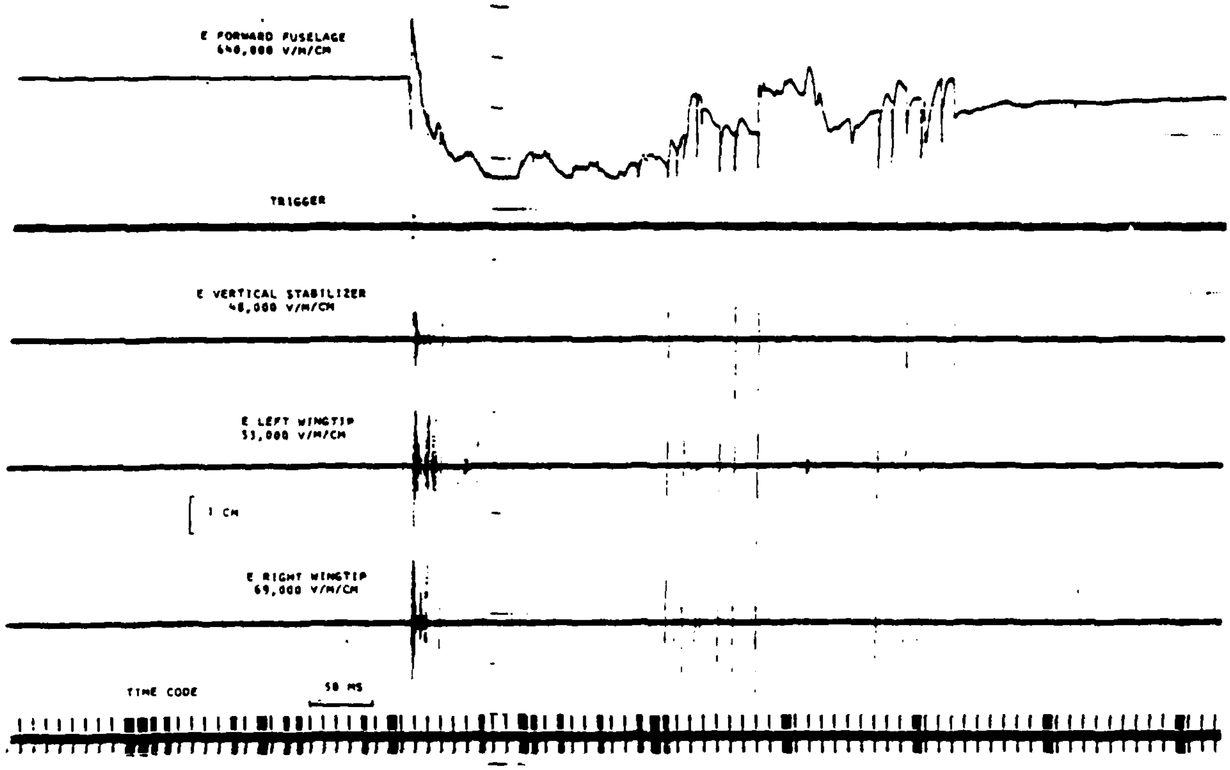
SURFACE CURRENT DENSITY (TESLAS/SEC) DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 13 JUL. 84 AT 20:46:23. EXPANSION OF 10.24 MICROSECOND WINDOW.

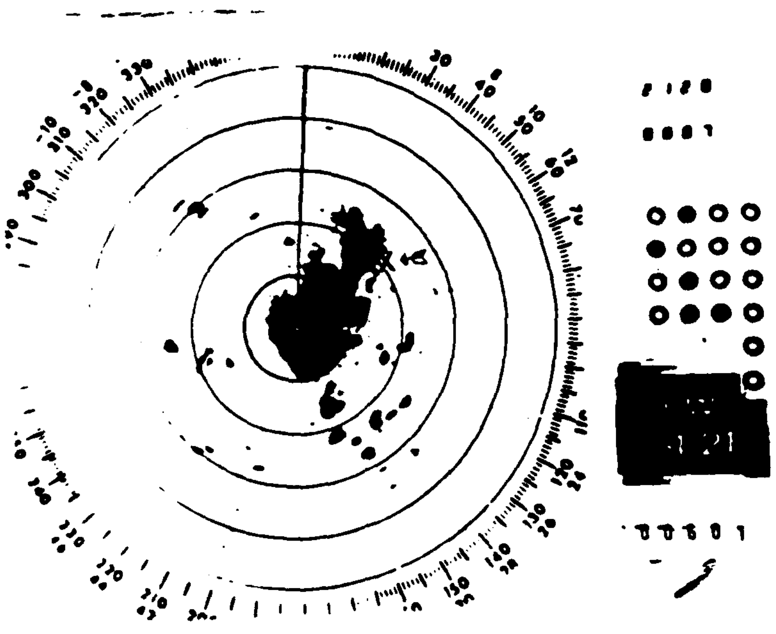


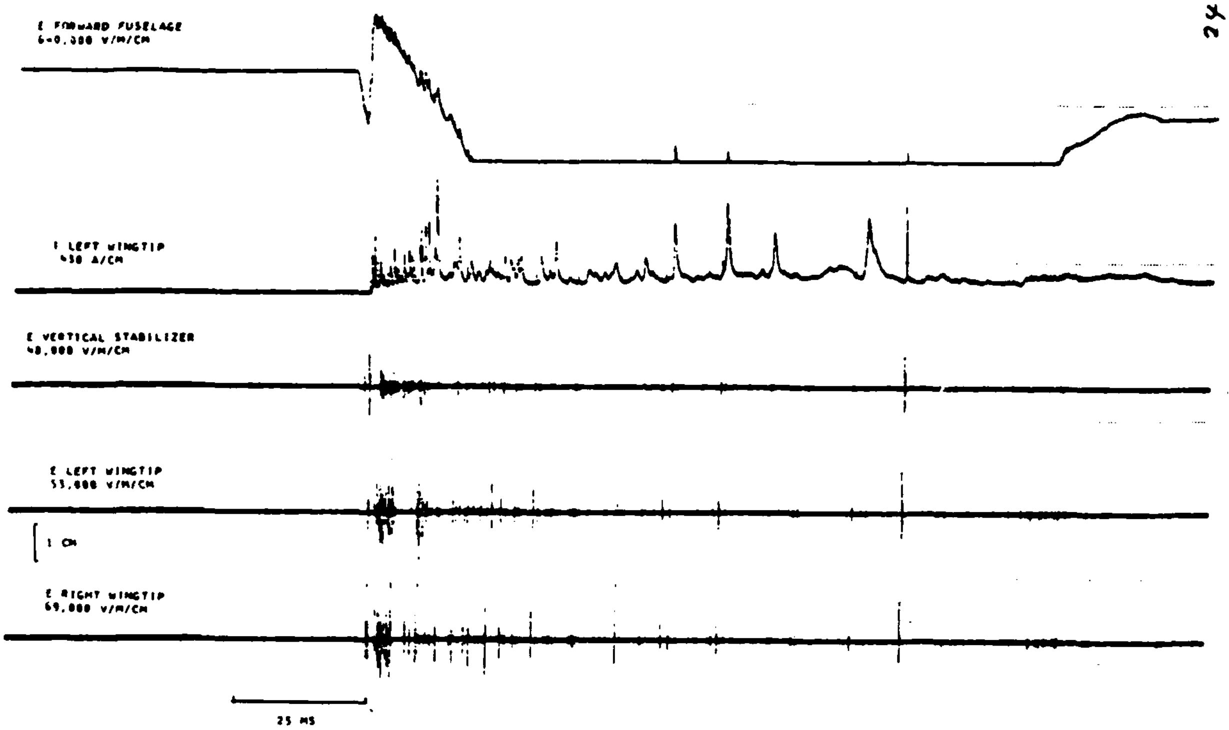
a. LEFT WING

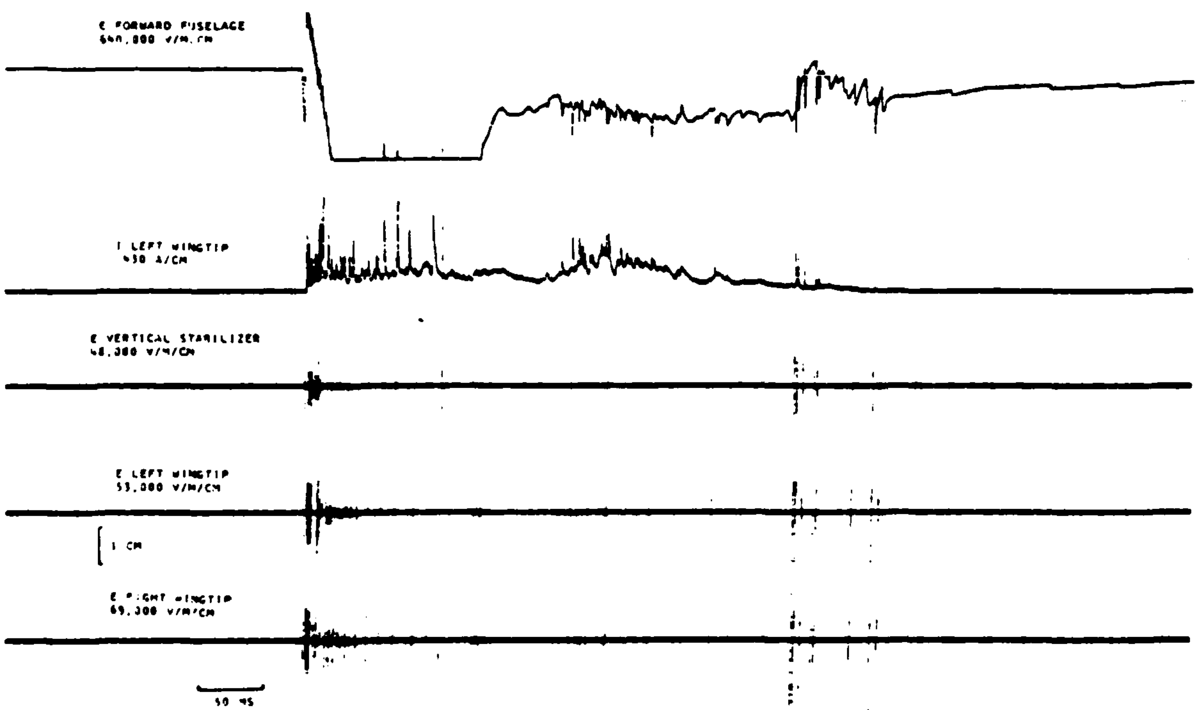
b. VERTICAL STABILIZER

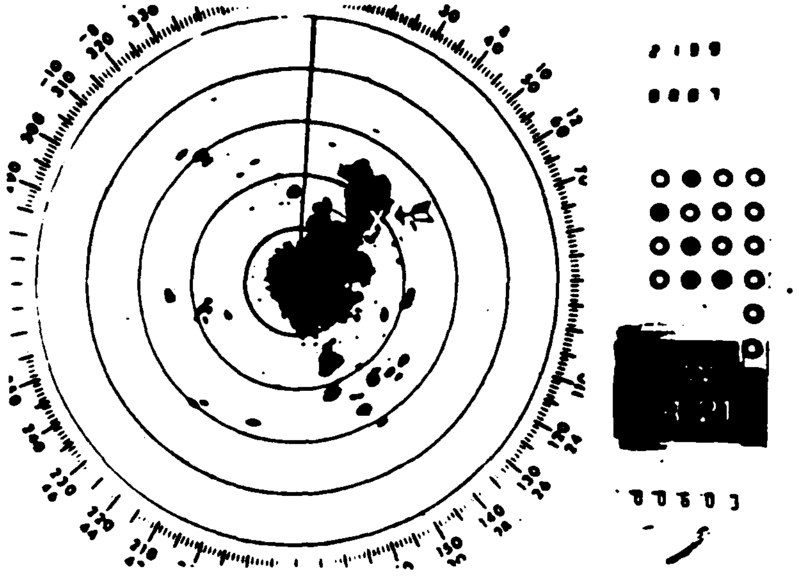
DISPLACEMENT CURRENT DENSITY IN A/m^2 DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 13 JUL. 84 AT 20:46:23. (RIGHT WING IN NOISE LEVEL). EXPANSION OF 10.24 MICROSECOND WINDOW.

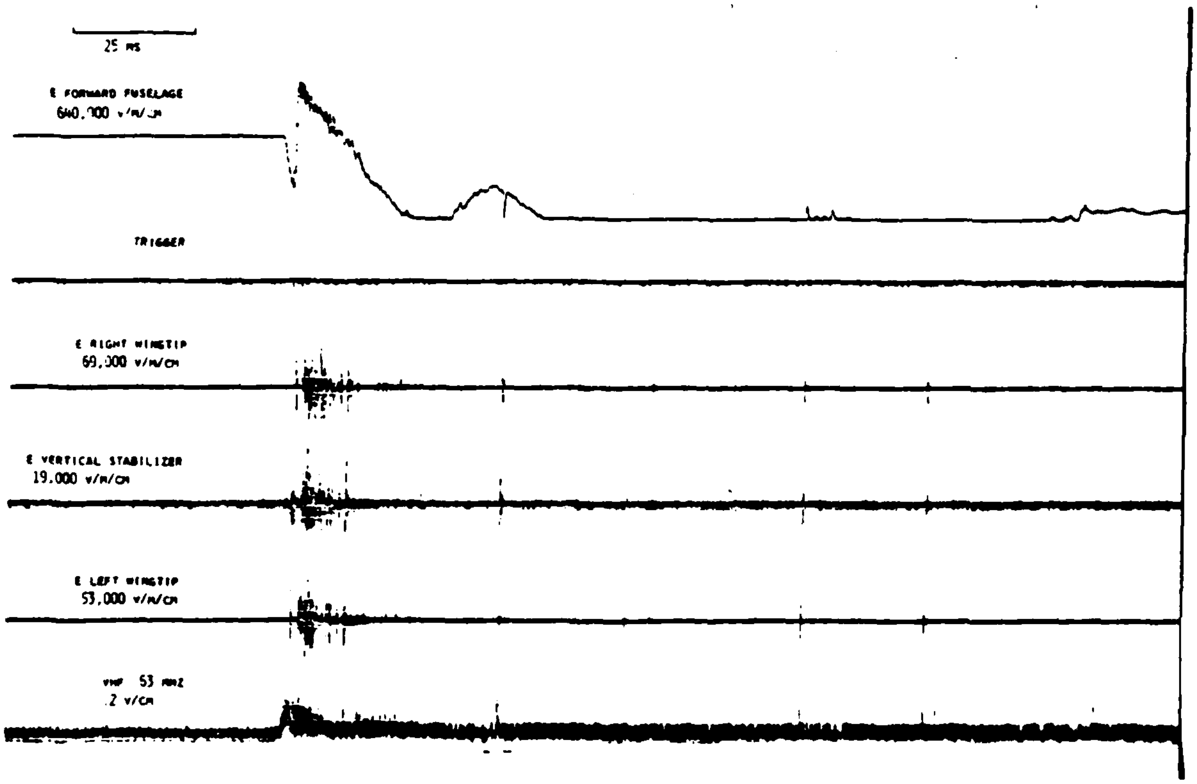

E FORWARD FUSELAGE
640,000 V/M/CM
TRIGGER
E VERTICAL STABILIZER
48,000 V/M/CM
E LEFT WINGTIP
53,000 V/M/CM
1 CM
E RIGHT WINGTIP
69,000 V/M/CM
TIME CODE
50 MS

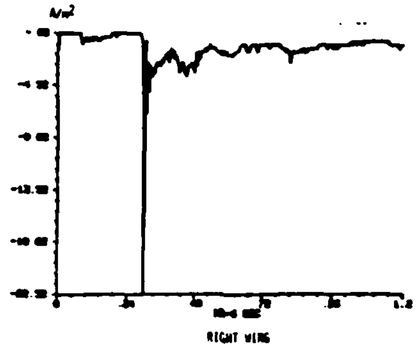



E FORWARD FUSELAGE
640,000 V/M/CM
I LEFT WINGTIP
450 A/CM
E VERTICAL STABILIZER
48,000 V/M/CM
E LEFT WINGTIP
53,000 V/M/CM
1 CM
E RIGHT WINGTIP
69,000 V/M/CM
25 MS

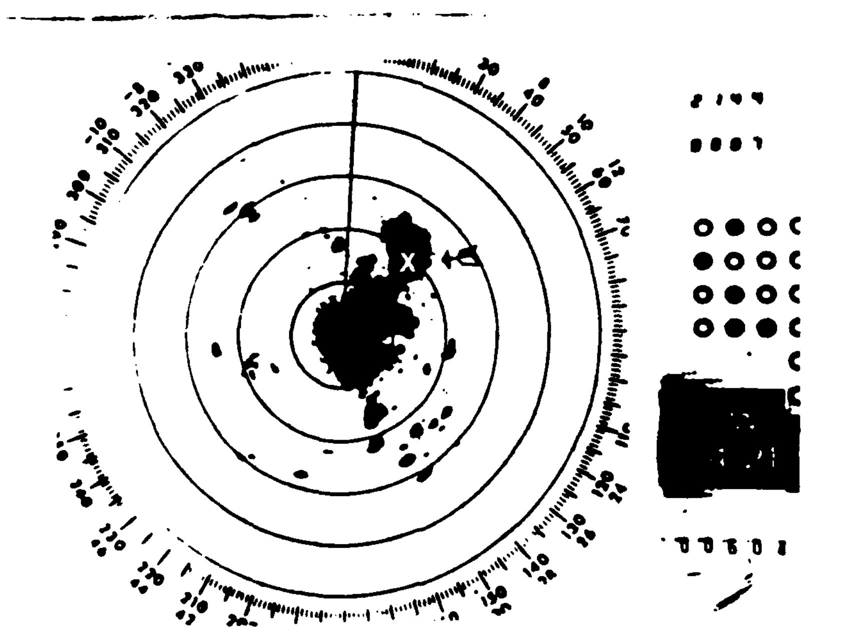

E FORWARD FUSELAGE
640,000 V/M/CM
I LEFT WINGTIP
450 A/CM
E VERTICAL STABILIZER
48,000 V/M/CM
E LEFT WINGTIP
53,000 V/M/CM
1 CM
E RIGHT WINGTIP
69,300 V/M/CM
50 MS

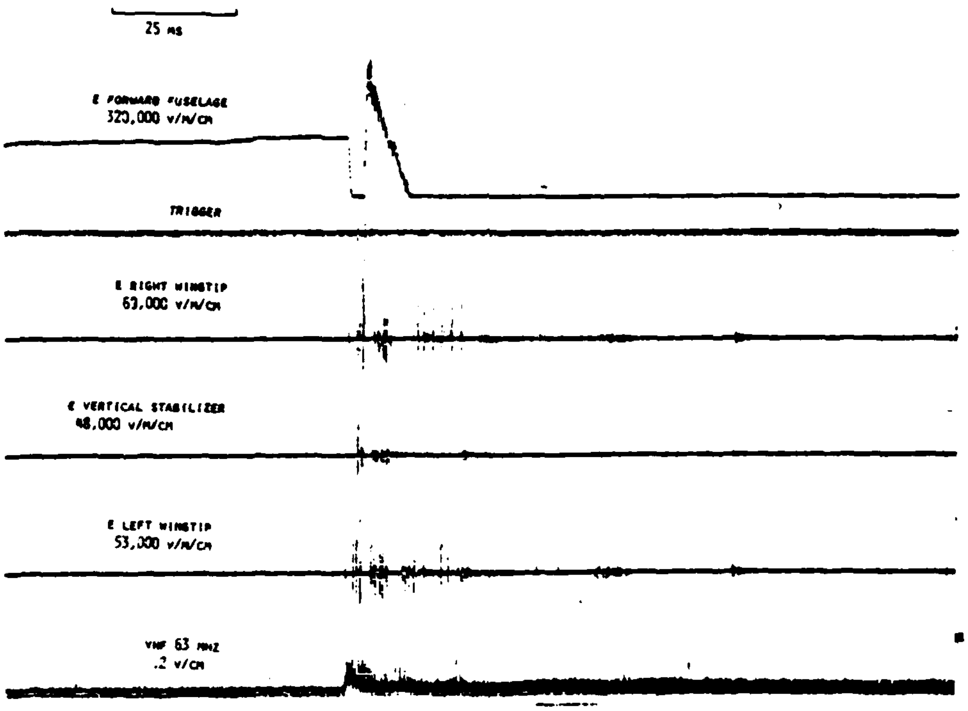


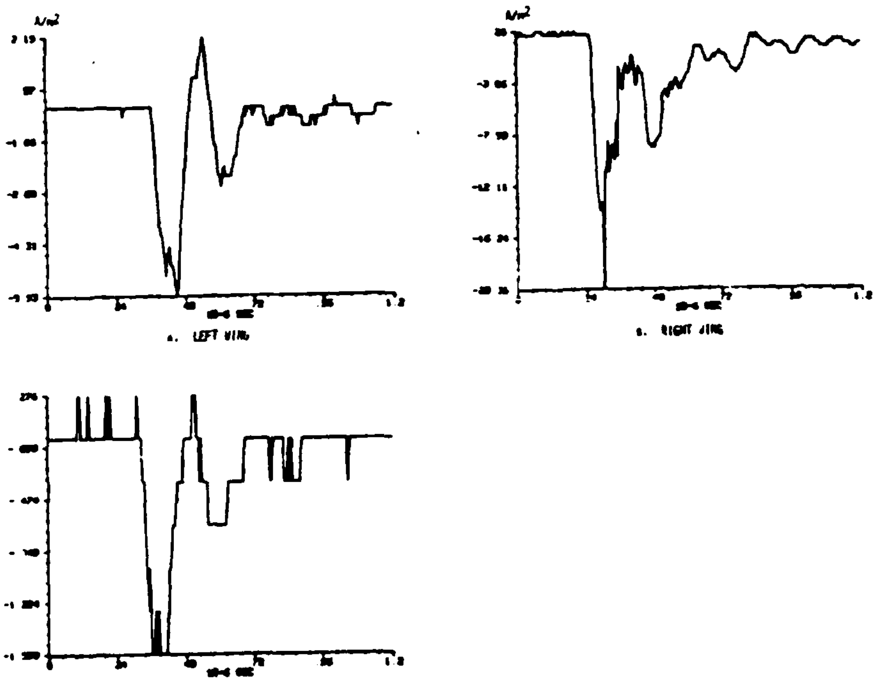

25 ms
E FORWARD FUSELAGE
640,000 V/M/CM
TRIGGER
E RIGHT WINGTIP
69,000 V/M/CM
E VERTICAL STABILIZER
19,000 V/M/CM
E LEFT WINGTIP
53,000 V/M/CM
VHF 63 MHZ
.2 V/CM



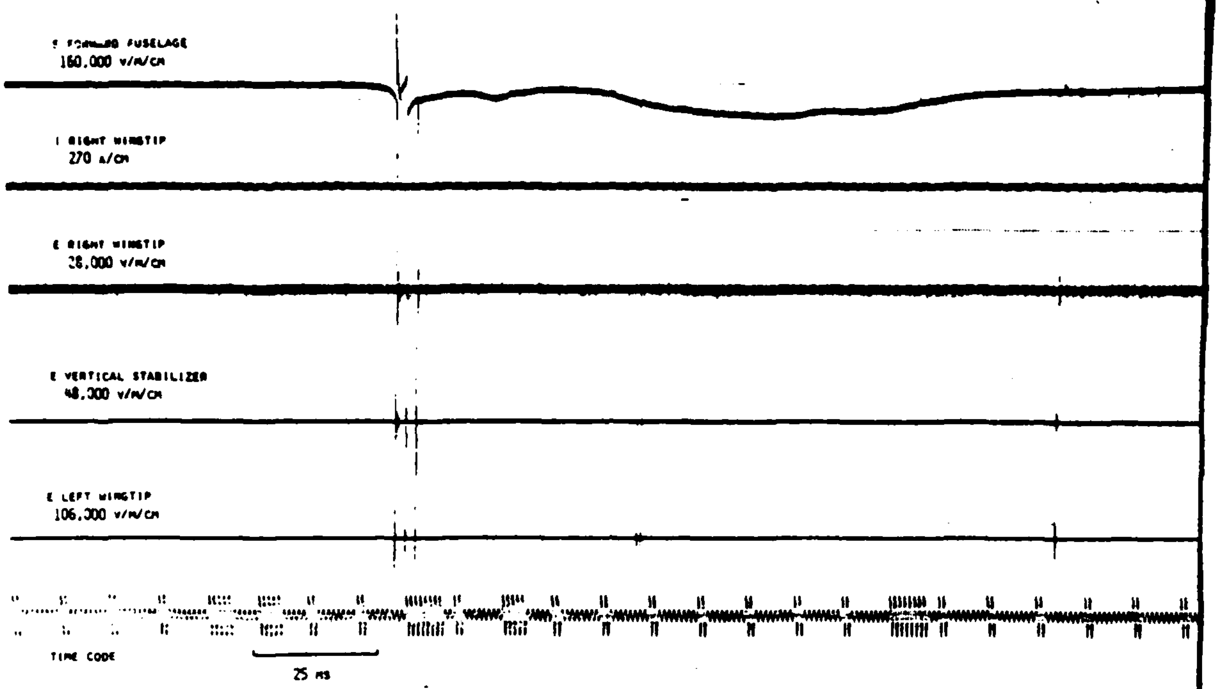
DISPLACEMENT CURRENT DENSITY IN A/m² DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 7 AUG. 84 AT 21:41:23. (LEFT WING AND VERTICAL STABILIZER IN NOISE LEVEL). EXPANSION OF 10.24 MICROSECOND WINDOW.

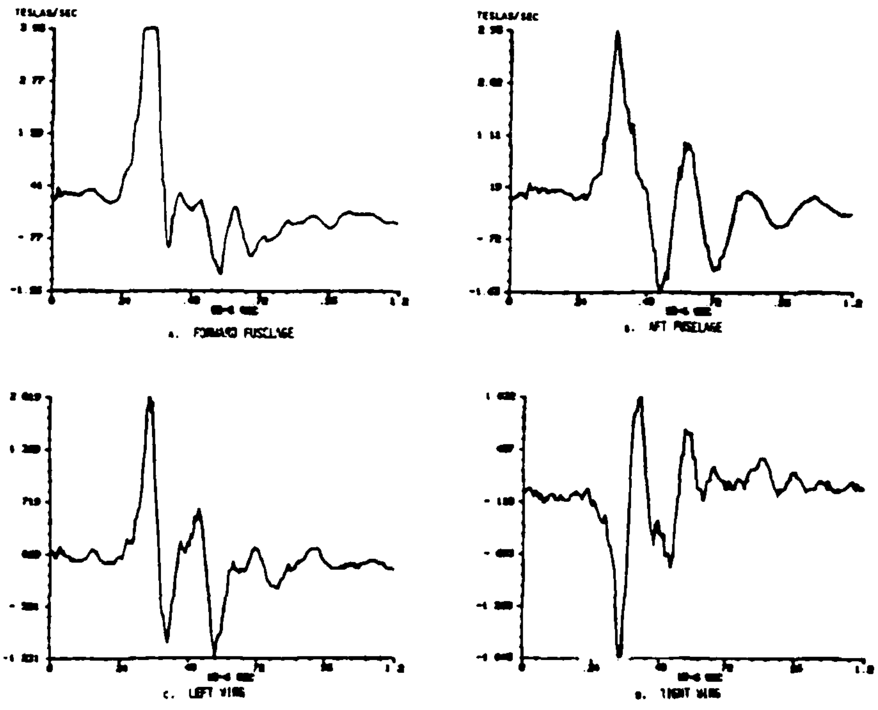




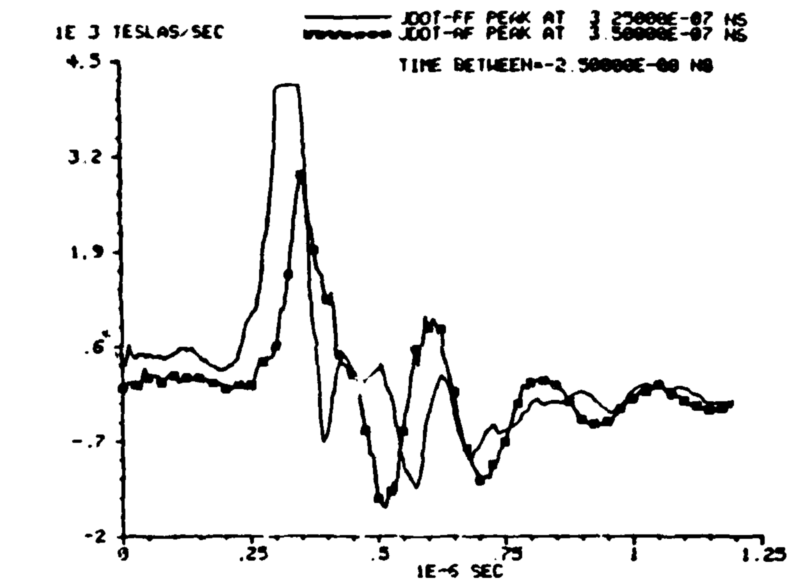


DISPLACEMENT CURRENT DENSITY IN A/m^2 DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 7 AUG. 84 AT 21:43:26. EXPANSION OF 10.24 MICROSECOND WINDOW.

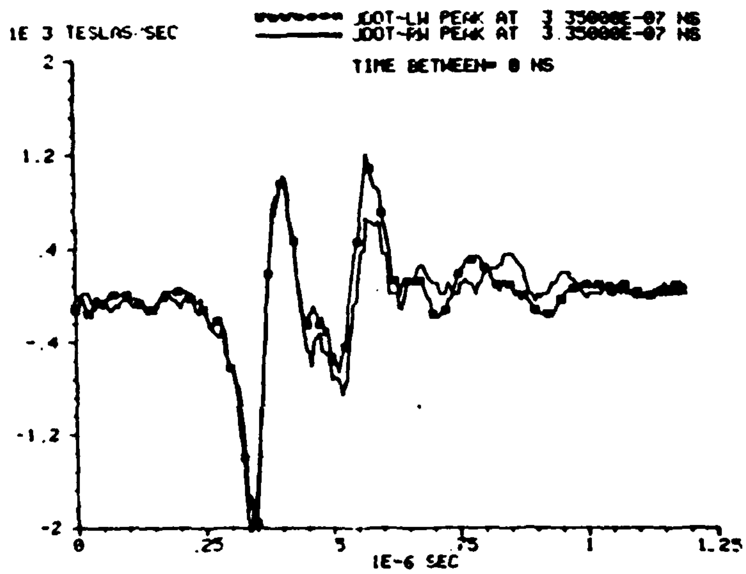




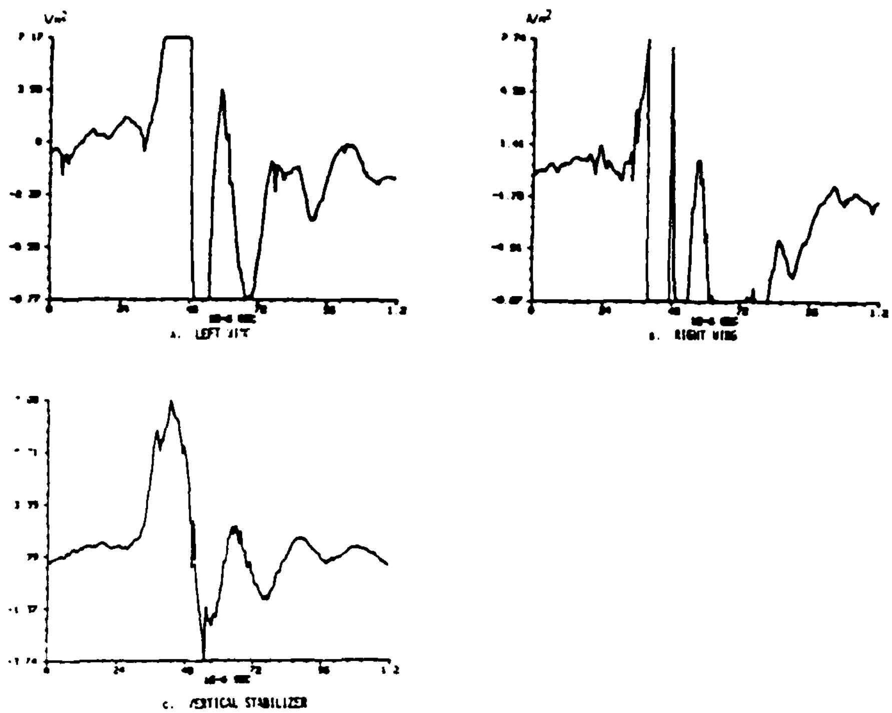
SURFACE CURRENT DENSITY (TESLAS/SEC) DURING THE TRIGGERED PULSE IN THE DIRECT LIGHTNING ATTACHMENT ON 17 AUG. 84 AT 21:36:01. EXPANSION OF 10.24 MICROSECOND WINDOW.



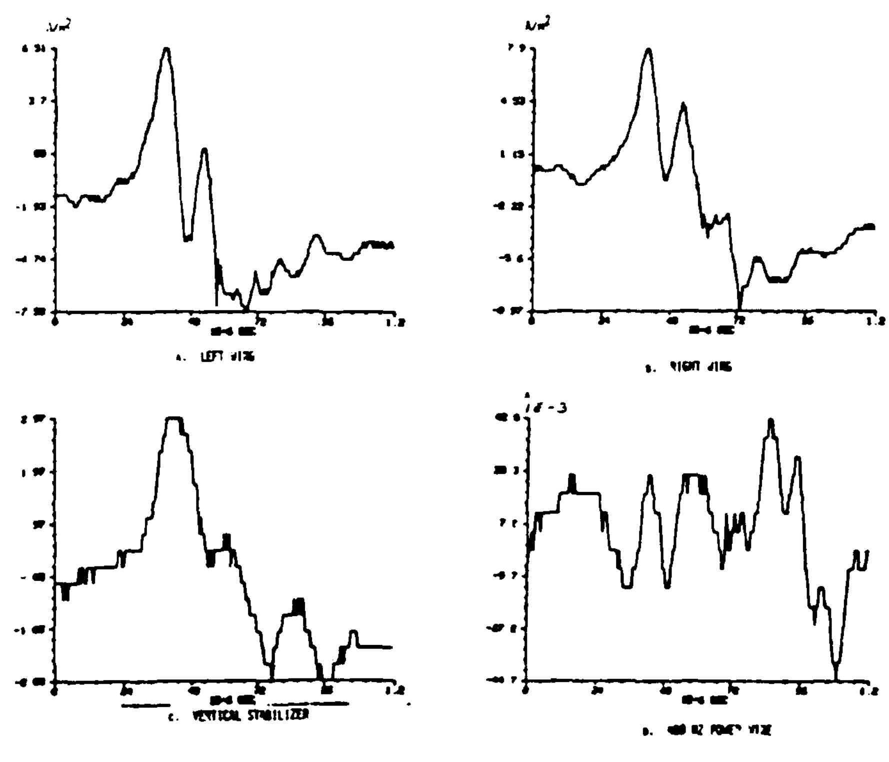
Overlays of the Surface Current Density at the Forward and Aft Fuselage Sensors Showing the Time Delay as the Current Propagated from the Attachment Point at the Nose Through the Fuselage and into the Wings. Flash on 17 Aug 84 at 21:36:01.



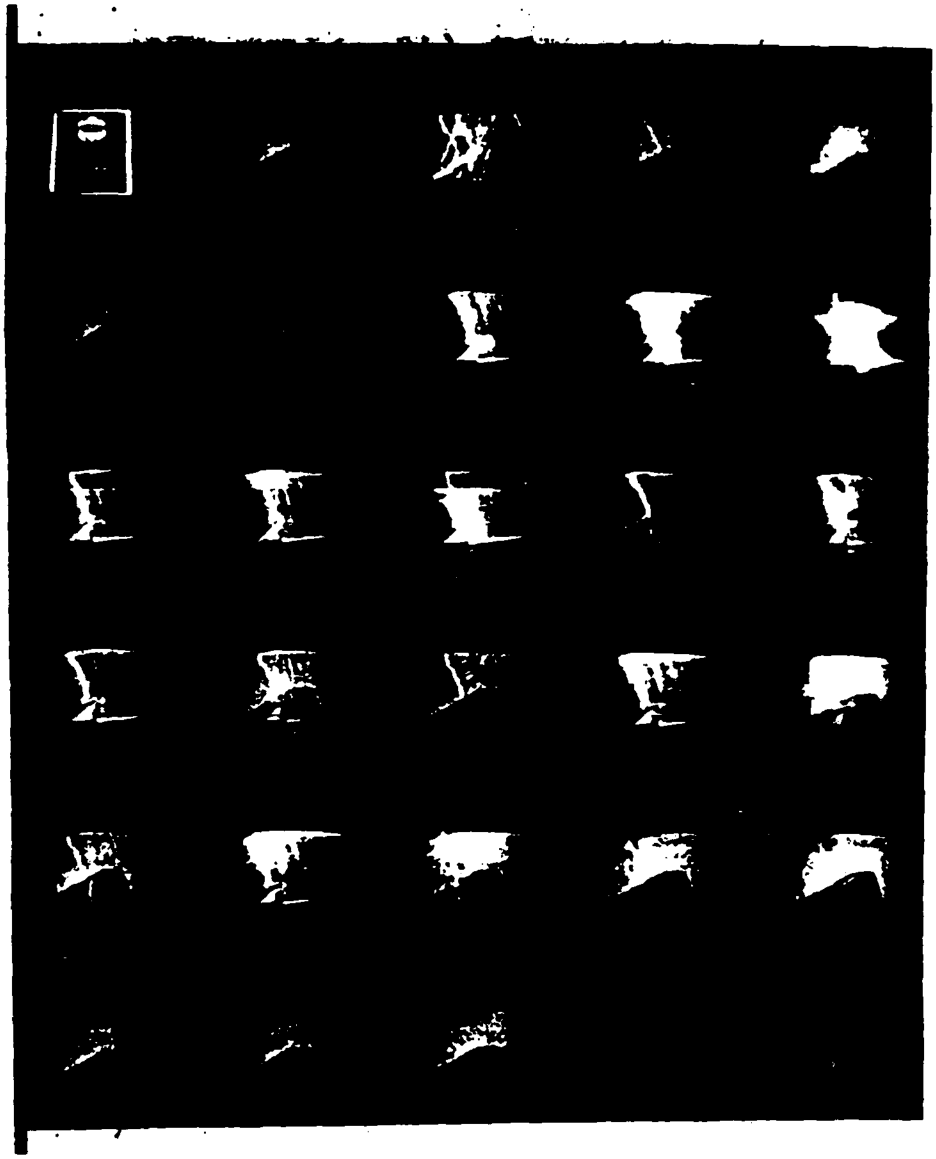
Overlays of the Surface Current Density at the Left and Right Wing Sensors Showing the Time Delay as the Current Propagated from the Attachment Point at the Nose Through the Fuselage and into the Wings. (Right Wing Trace Is Inverted.) Flash on 17 Aug 84 at 21:36:01.

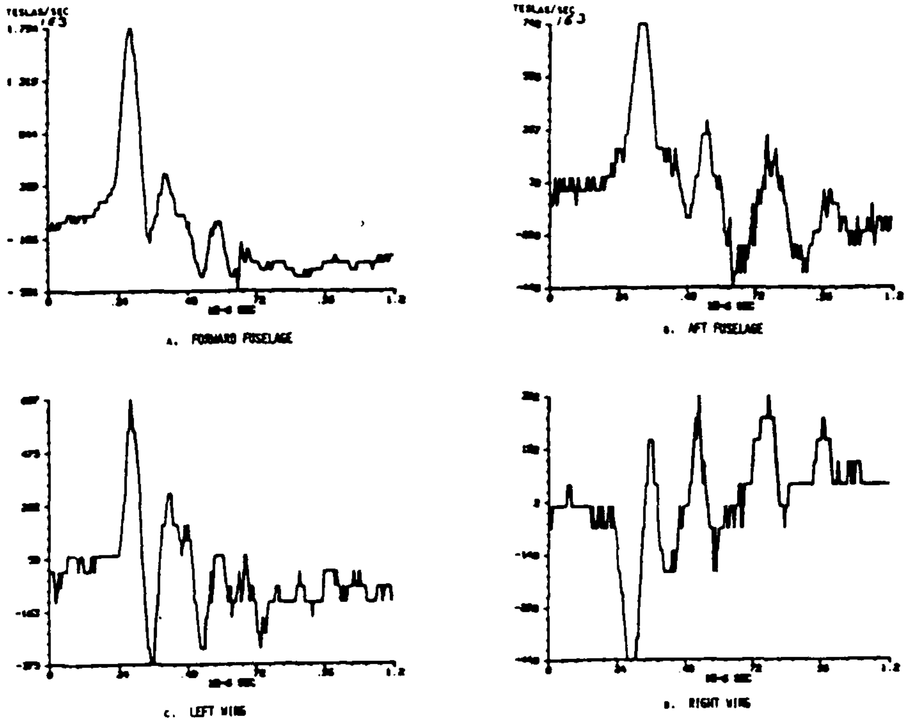


DISPLACEMENT CURRENT DENSITY IN A/m² DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 17 AUG. 84 AT 21:36:01. EXPANSION OF 10.24 MICROSECOND WINDOW.

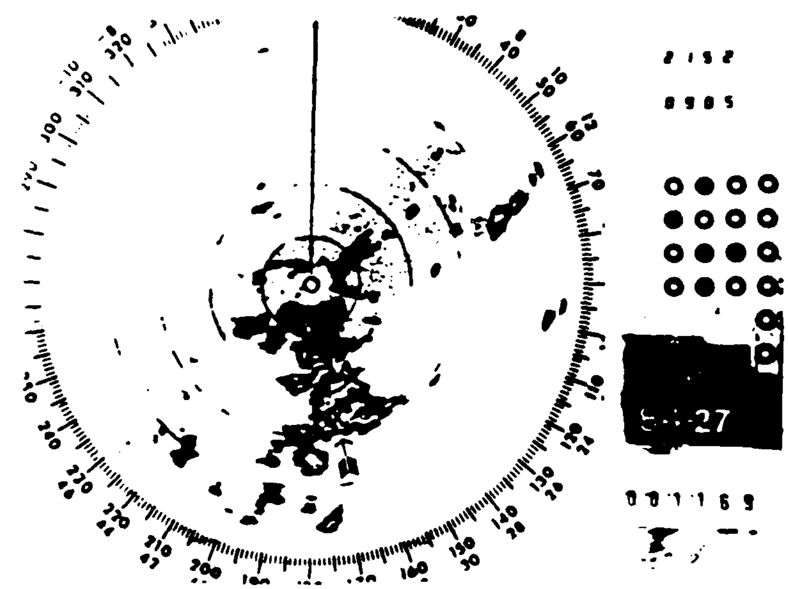


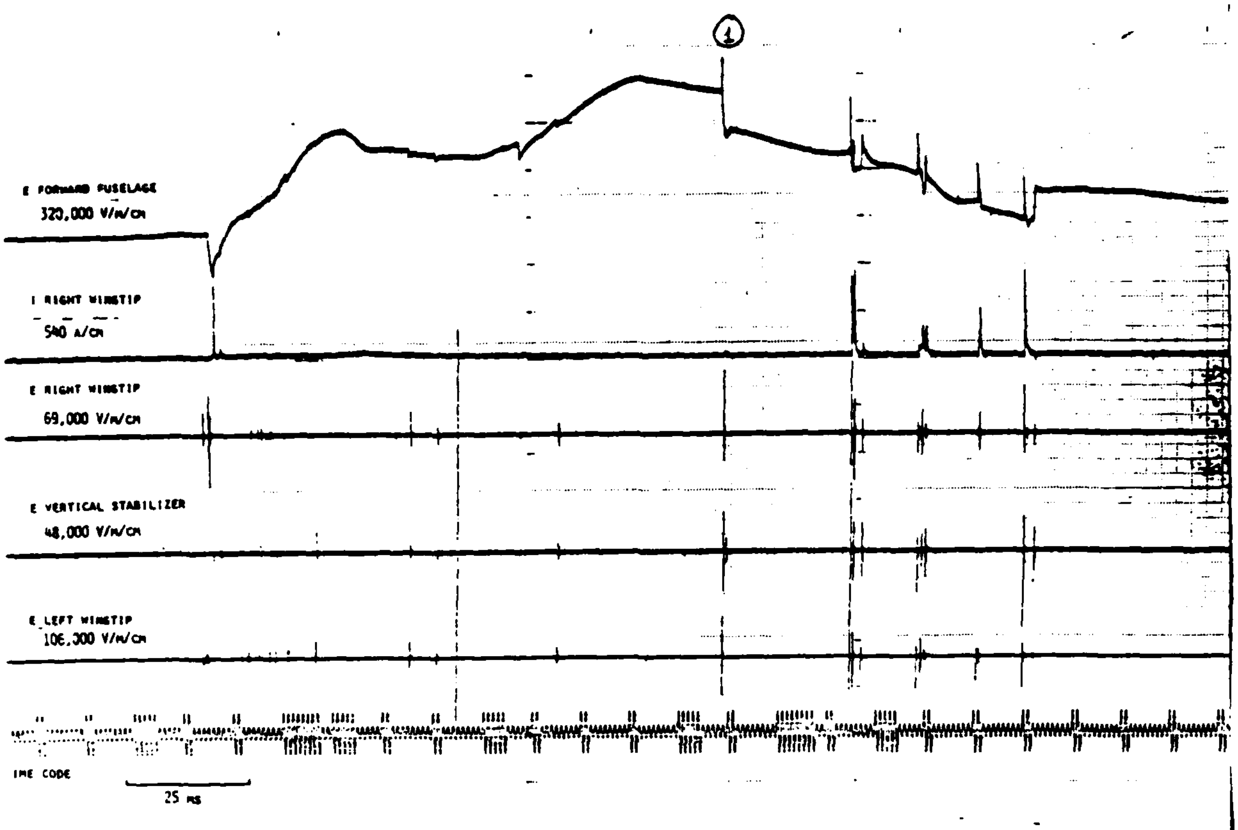
DISPLACEMENT CURRENT DENSITY (a,b,c) IN A/m² AND INDUCED CURRENT IN THE 400 HZ POWER WIRE DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 20 AUG. 84 AT 15:37:41. EXPANSION OF 10.24 MICROSECOND WINDOW.

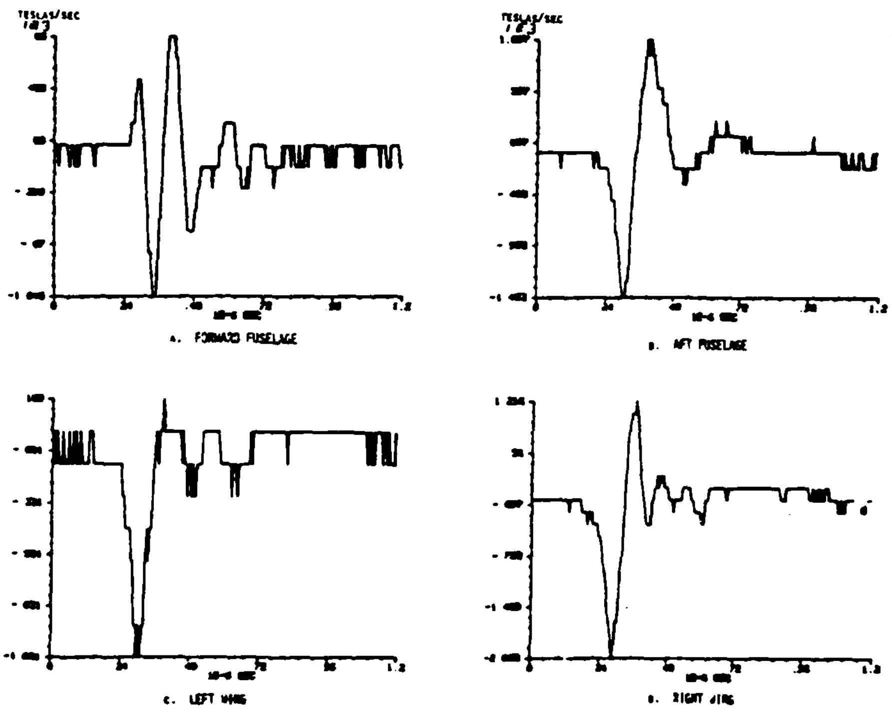




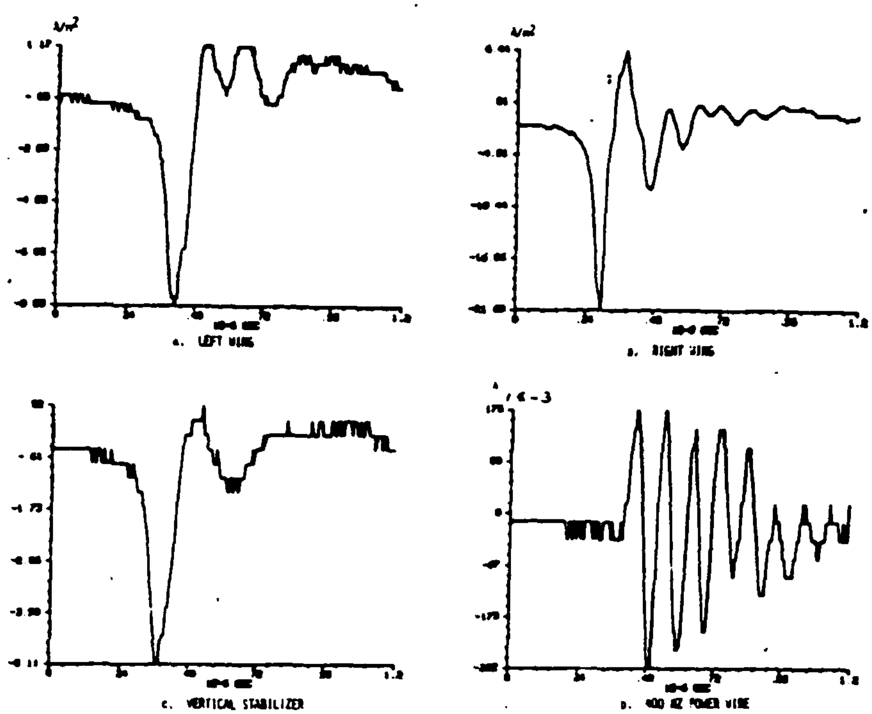
SURFACE CURRENT DENSITY (TESLAS/SEC) DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 20 AUG. 84 AT 15:37:41. EXPANSION OF 10.24 MICROSECOND WINDOW.



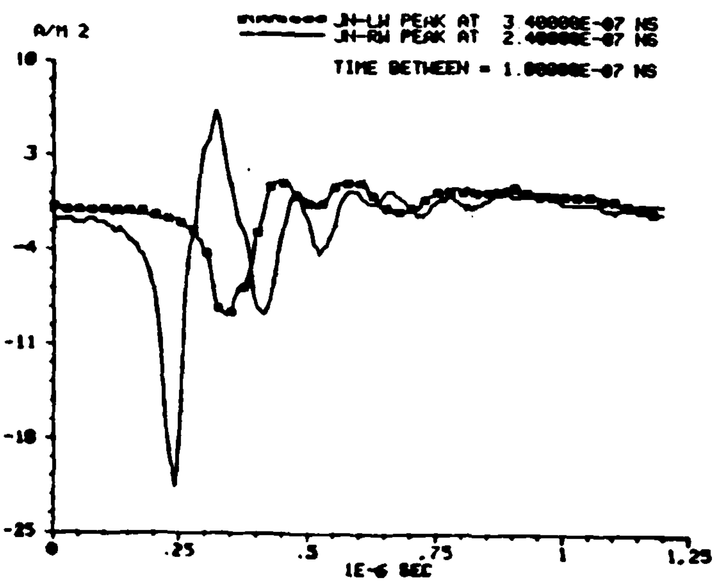




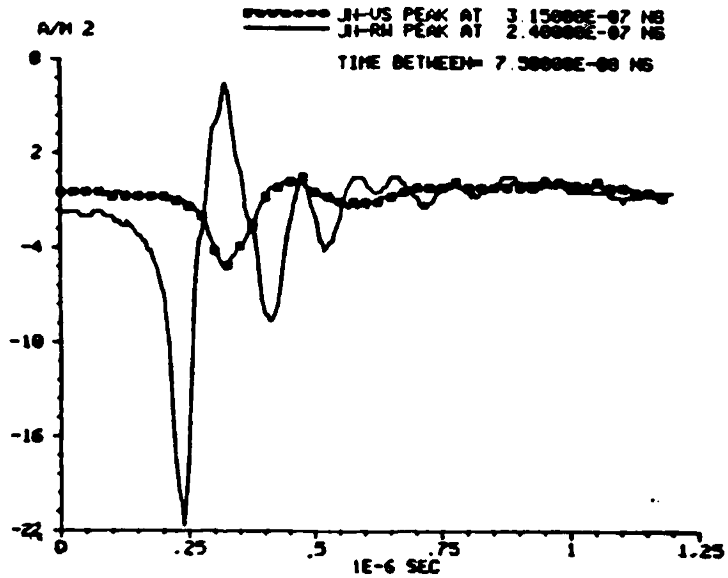
SURFACE CURRENT DENSITY (TESLAS/SEC) DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 5 SEP. 84 AT 21:53:05. EXPANSION OF 10.24 MICROSECOND WINDOW.



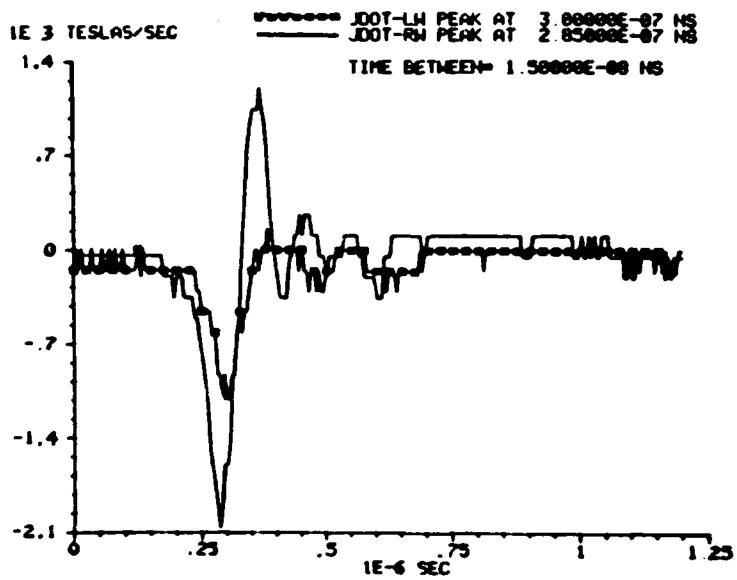
DISPLACEMENT CURRENT DENSITY (a,b,c) IN A/m² AND INDUCED CURRENT IN THE 400 HZ POWER WIRE (d) DURING THE TRIGGERED PULSE OF THE DIRECT LIGHTNING ATTACHMENT ON 5 SEP. 84 AT 21:53:05. EXPANSION OF 10.24 MICROSECOND WINDOW.



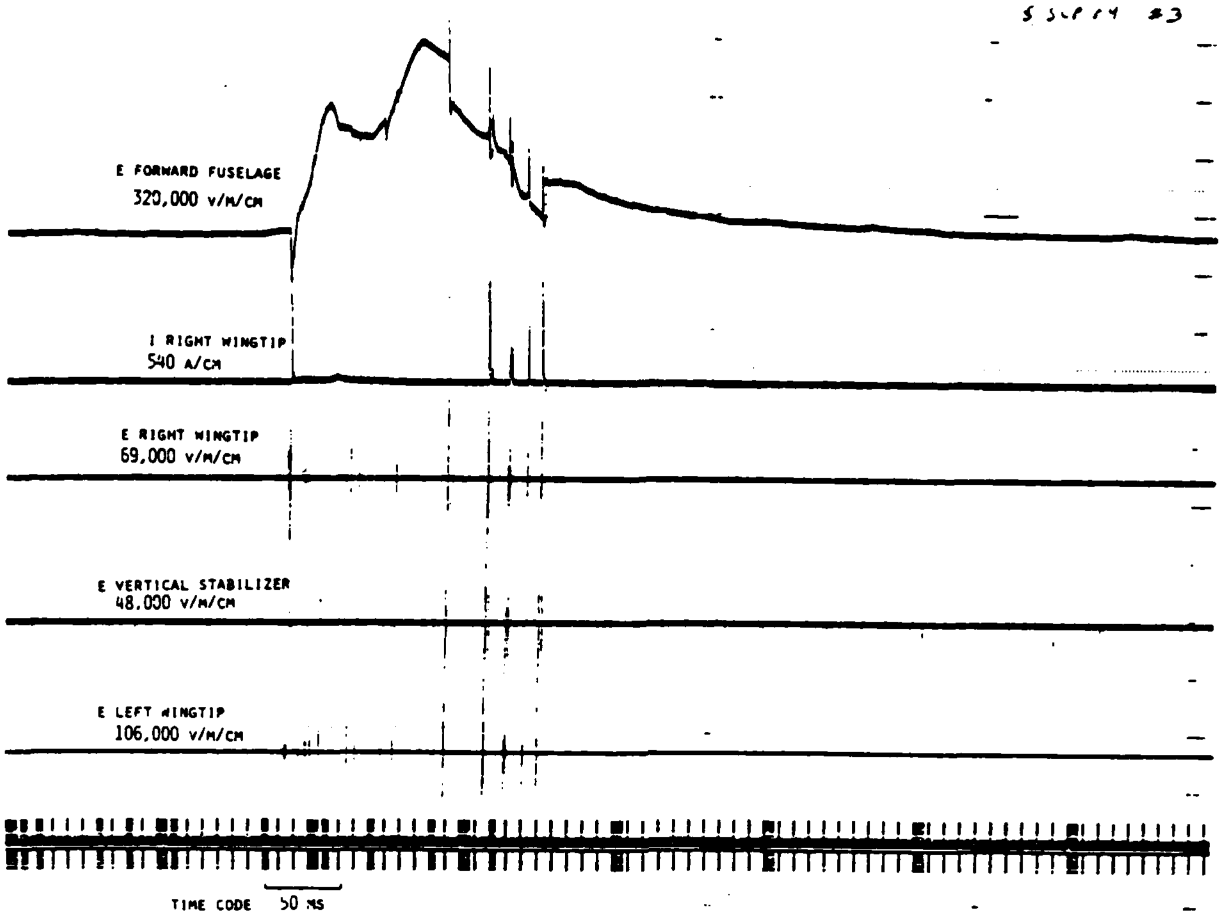
Overlays of the Displacement Current Density at the Right and Left Wingtip Sensors Showing the Time Delay as the Current Propagated from the Right Wingtip Attachment Point to the Left Wing and Fuselage. Flash on 5 Sep 84 at 21:53:05.

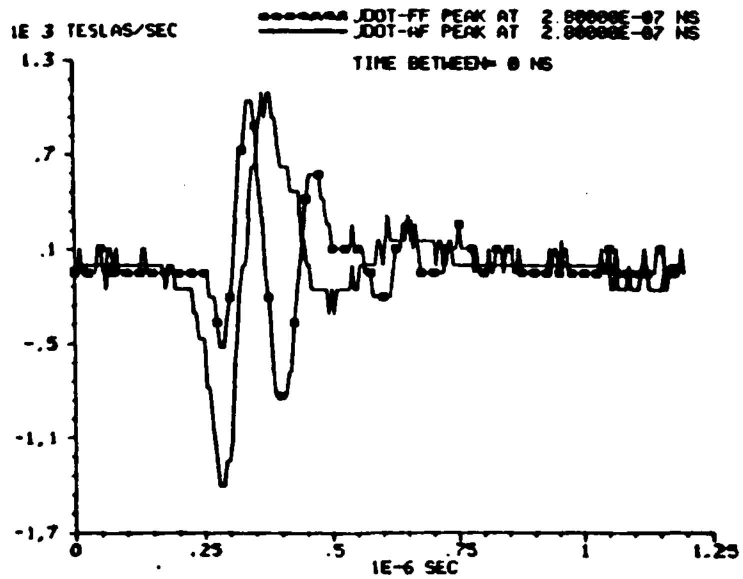


Overlays of the Displacement Current Density at the Right Wingtip and Vertical Stabilizer Sensors Showing the Time Delay as the Current Propagated from the Right Wingtip Attachment Point to the Left Wing and Fuselage. Flash on 5 Sep 84 at 21:53:05.



Overlays of the Surface Current Density at the Left and Right Wing Sensors Showing the Time Delay as the Current Propagated from the Right Wingtip Attachment Point to the Left Wing and Fuselage. Flash on 5 Sep 84 at 21:53:05.



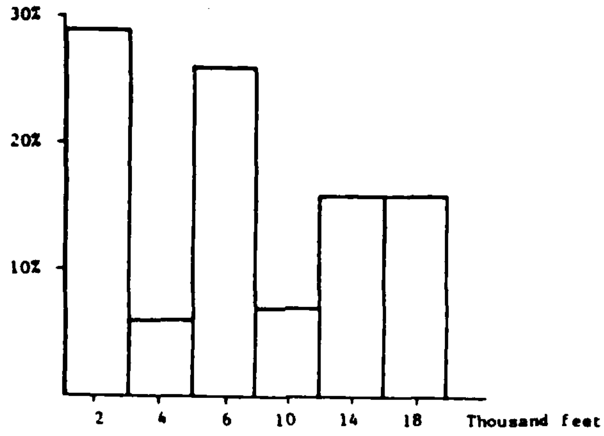


Overlays of the Surface Current Density at the Forward and Aft Fuselage Sensors Showing the Time Delay as the Current Propagated from the Right Wingtip Attachment Point to the Left Wing and Fuselage. (Forward Fuselage Trace Is Inverted.) Flash on 5 Sep 84 at 21:53:05.

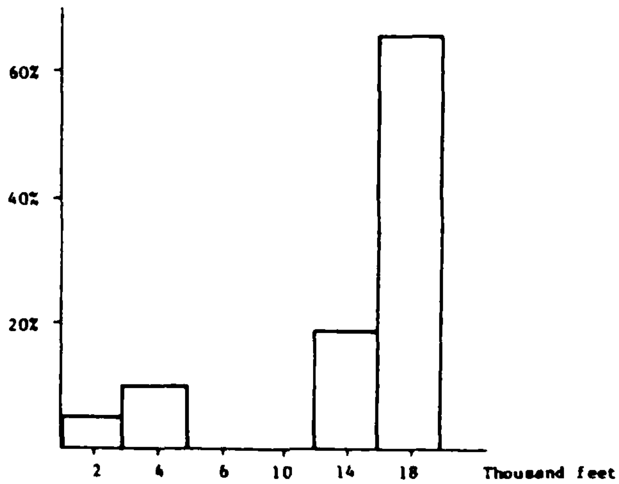
Flash No	Height (ft)	Triggered Discharge	Aircraft Charged	Leader Duration (ms)	Distance to Charged Region (m)	Streamers Propagated from Aircraft
1	14,000	Yes	Yes	2.1	315	Yes
2	14,000	Yes	Yes	2.7	405	Yes
3	14,000	Yes	No	1.7	255	No
4	14,000	Yes	No	-	-	-
5	18,000	Yes	No	2.1	315	No
6	18,000	Yes	No	2.2	330	No
7	18,000	Yes	No	2.1	315	No
8	18,000	Yes	No	2.1	315	No
9	18,000	Yes	Yes	2.2	330	No
10	18,000	Yes	No	2.1	315	No
11	18,000	No	No	20.0	3000	No
12	4,000	No	No	4.7	705	No
13	4,000	No	No	-	-	No
14	2,000	No	No	-	-	No
15	18,000	-	-	-	-	-
16	18,000	Yes	No	~~2.0~~ 1.1	~~300~~ 240	No
17	18,000	INT*	No	5.0/1.0	750/150	Yes
18	18,000	-	-	-	-	-
19	18,000	~~No~~ INT*	No	21.0/1.8	3150/270	No
20	18,000	Yes	No	1.6	240	No
21	18,000	INT*	No	21/0.7	3150/105	Yes

INT* - The discharge was not triggered by the presence of the aircraft but its path was affected by the aircraft.

Flash No	Digital System Threshold Level (T/s)	Digital System Triggered	DIGITIZER DATA: Largest Surface Current Density Pulse (T/s)	DIGITIZER DATA: Largest Displacement Current Density Pulse (A/m²)	ANALOG DATA: Largest E Field Transient (kV/m)	Duration of Flash (ms)
1	1500	No	-	-	165	780
2	1500	No	-	-	132	400
3	400	Yes	822	3.2	160	430
4	400	Yes	1251	2.5	-	-
5	4000	No	-	-	135	450
6	4000	No	-	-	170	940
7	400	Yes	683	22.5	140	780
8	400	Yes	2900	19.7	130	680
9	400	Yes	254	20.4	150	1300
10	400	Yes	415	0.8	200	240
11	400	Yes	465	1.6	140	500
12	800	Yes	3950(Sat)	8.77(Sat)	130	140
13	1200	Yes	2560	1.5	-	-
14	1200	Yes	1794	9.0	-	-
15	1500	No	-	-	-	-
16	1500	No	-	-	140	360
17	1500	Yes	2065	20.9	150	310
18	1500	No	-	-	-	-
19	1500	No	-	-	110	130
20	1500	Yes	-	-	190	750
21	1500	No	-	-	140	200

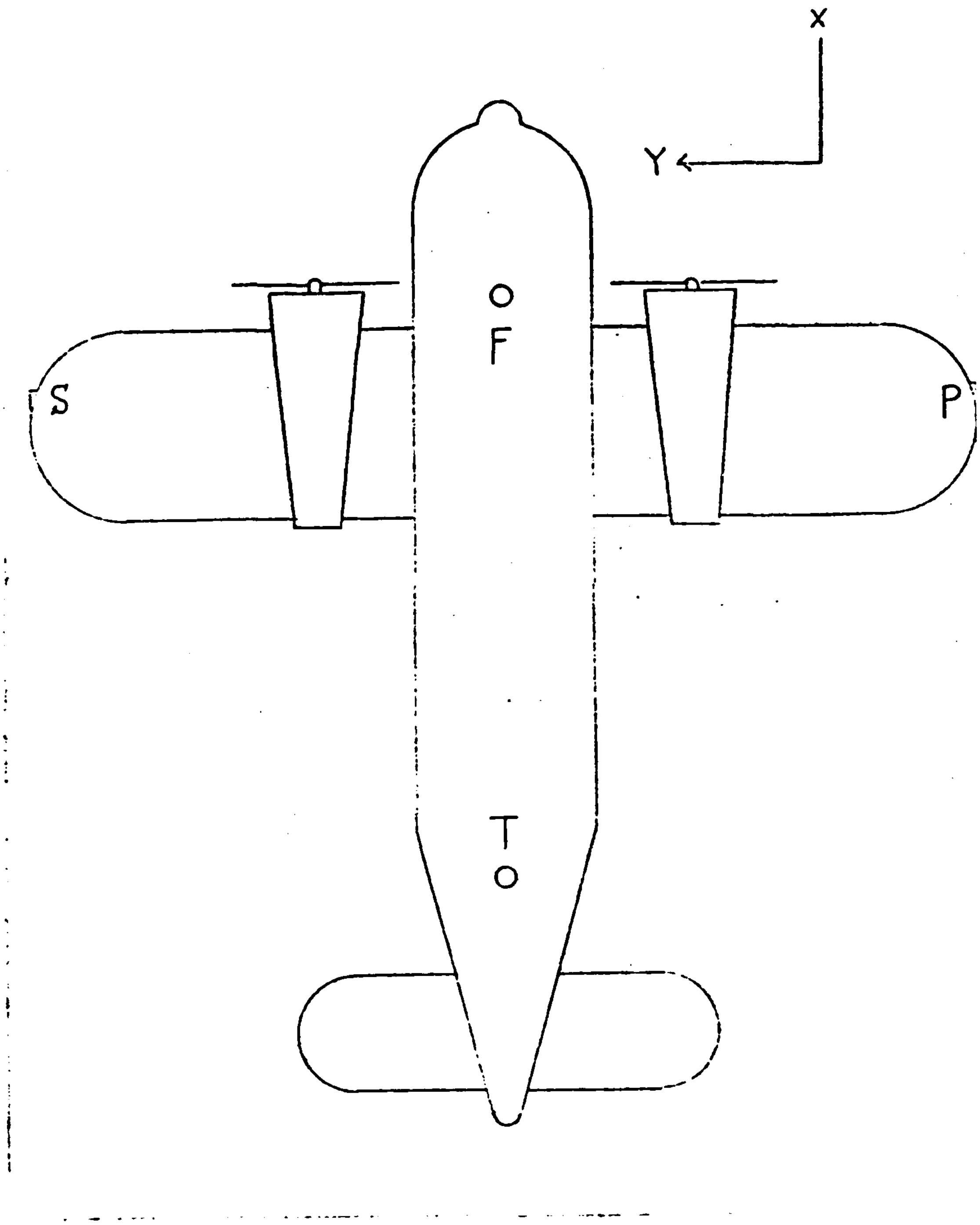


Histogram showing the percentage of hours flown at different altitudes



Histogram showing the percentage of lightning strikes at different altitudes

SUMMARY OF 1984 FIELD MILL DATA
(MR. R. ANDERSON, NRL)


X
Y
F
S
P
T

$$\varepsilon_p = p_x \varepsilon_x + p_y \varepsilon_y + p_z \varepsilon_z + p_q Q$$

$$\varepsilon_s = s_x \varepsilon_x + s_y \varepsilon_y + s_z \varepsilon_z + s_q Q$$

FROM SYMMETRY

$$\varepsilon_s = p_x \varepsilon_x - p_y \varepsilon_y + p_z \varepsilon_z + p_q Q$$

But:

$$p_x \ll p_y$$

$$p_z \ll p_y$$

So

$$\varepsilon_p \approx p_y \varepsilon_y + p_q Q$$

$$\varepsilon_s \approx -p_y \varepsilon_y + p_q Q$$

Then

$$\varepsilon_p - \varepsilon_s \approx 2 p_y \varepsilon_y$$

$$\varepsilon_p + \varepsilon_s \approx 2 p_Q Q$$

$$\varepsilon_F = f_x \varepsilon_x + f_z \varepsilon_z + f_q Q$$

$$\varepsilon_T = t_x \varepsilon_x + t_z \varepsilon_z + t_q Q$$

($f_y = t_y = 0$ from symmetry)

Now:

$$Q \approx \frac{\varepsilon_p + \varepsilon_s}{2 p_Q}$$

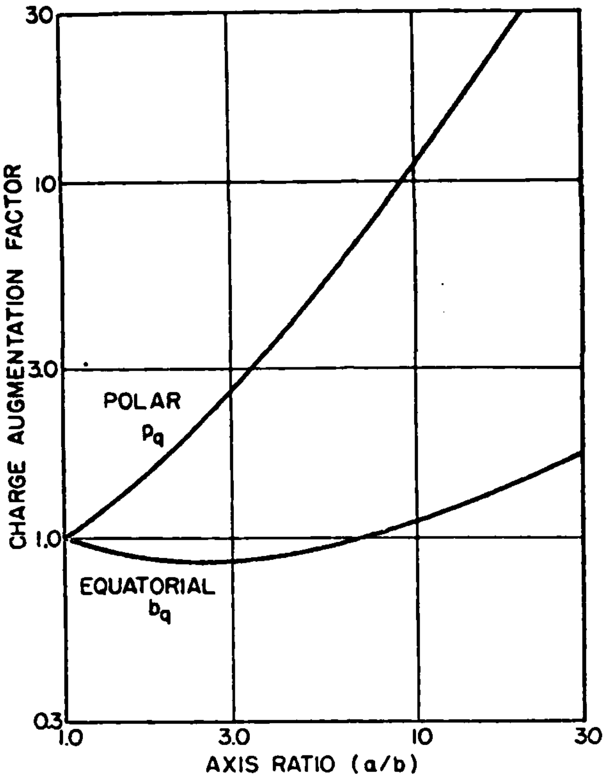
Add $(-f_q Q)$ to ε_F

Add $(-t_q Q)$ to ε_T

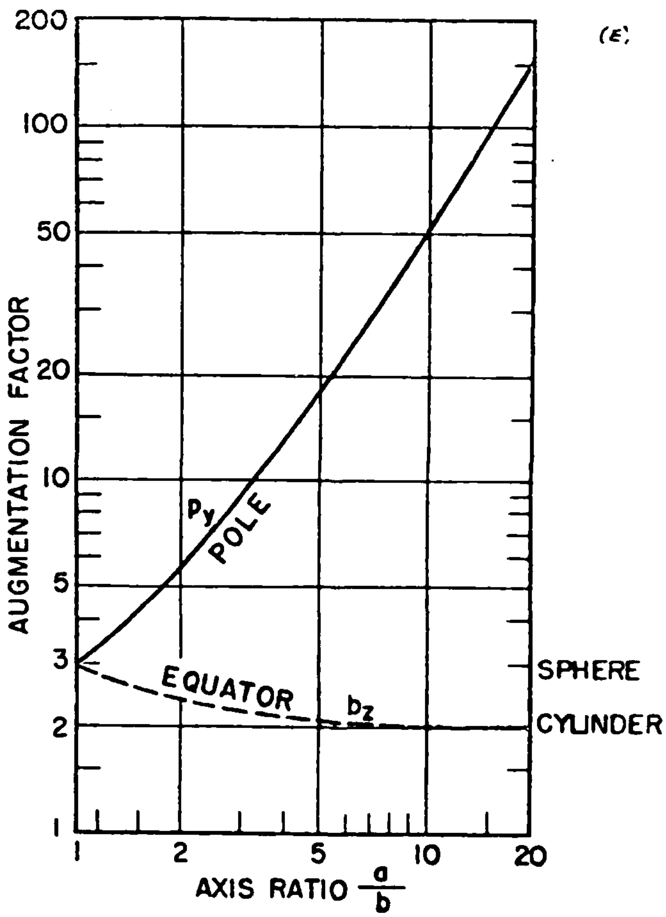
SEPARATION OF ε_x and ε_z

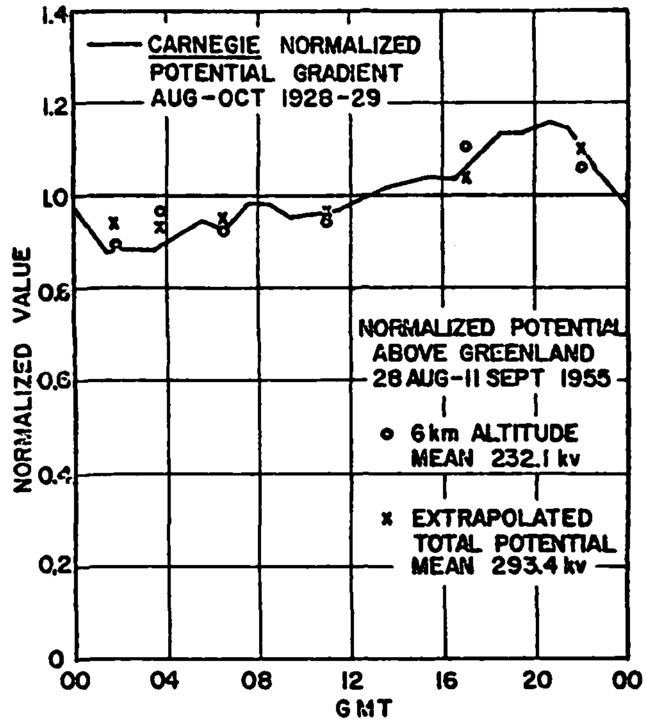
1. ORTHOGONALITY
2. $\frac{\partial \varepsilon_x}{\partial \theta} = 0$ IN ROLL

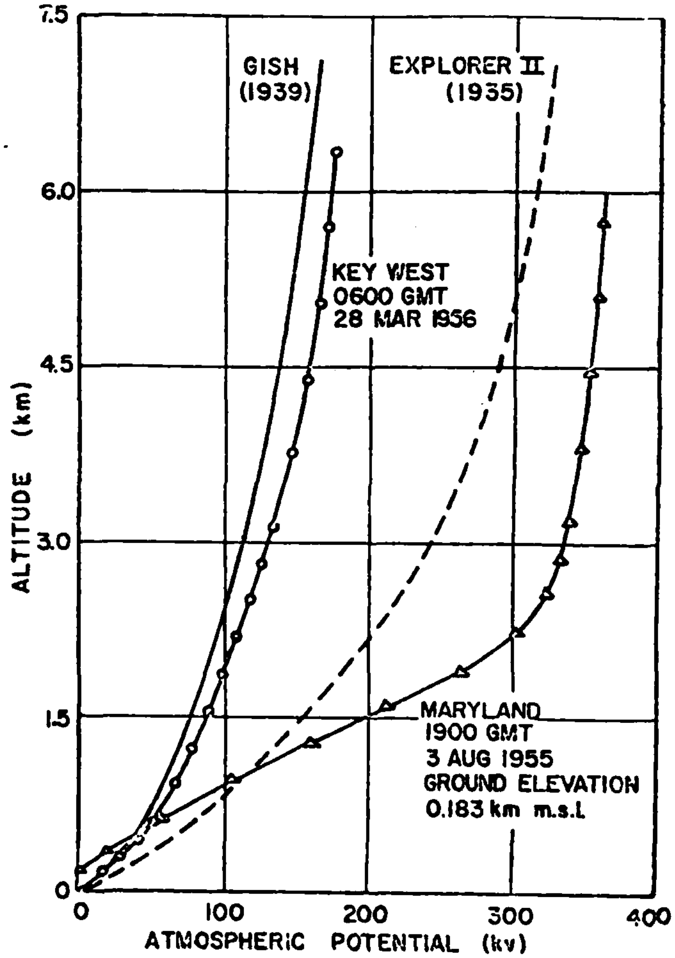
(d)


30
10
3.0
1.0
0.3
CHARGE AUGMENTATION FACTOR
POLAR
p_q
EQUATORIAL
b_q
1.0
3.0
10
30
AXIS RATIO (a/b)

(E)


200
100
50
20
10
5
3
2
1
AUGMENTATION FACTOR
p_y
POLE
EQUATOR
b_z
SPHERE
CYLINDER
1
2
5
10
20
AXIS RATIO $\frac{a}{b}$


CARNEGIE NORMALIZED POTENTIAL GRADIENT AUG-OCT 1928-29
NORMALIZED POTENTIAL ABOVE GREENLAND 28 AUG-11 SEPT 1955
o 6 km ALTITUDE MEAN 232.1 kv
x EXTRAPOLATED TOTAL POTENTIAL MEAN 293.4 kv
NORMALIZED VALUE
GMT
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
00
04
08
12
16
20
00

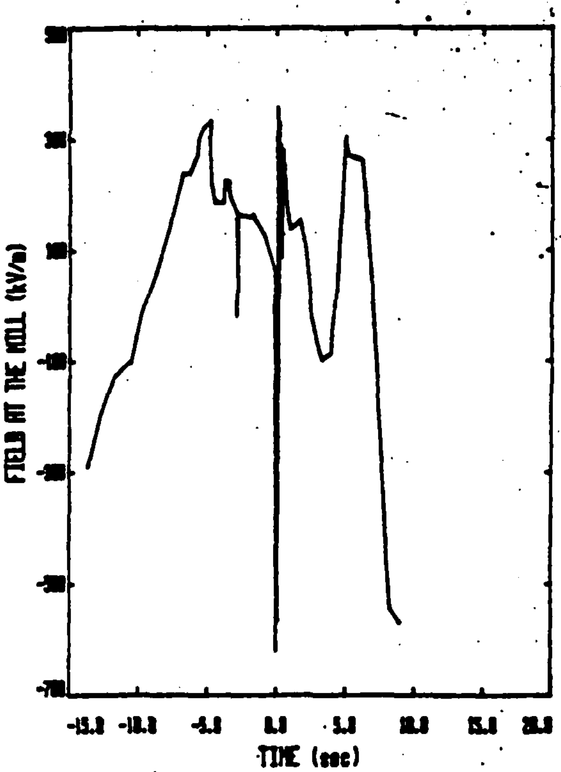

GISH (1939)
EXPLORER II (1935)
KEY WEST 0600 GMT 28 MAR 1956
MARYLAND 1900 GMT 3 AUG 1955 GROUND ELEVATION 0.183 km m.s.l.
ALTITUDE (km)
ATMOSPHERIC POTENTIAL (kv)
7.5
6.0
4.5
3.0
1.5
0
0
100
200
300
400

		PORT WING TIP				STBD WING TIP				FORWARD BELLY				REAR BELLY			
DATE	GMT	BEFORE	AFTER	NEG	POS	BEFORE	AFTER	NEG	POS	BEFORE	AFTER	NEG	POS	BEFORE	AFTER	NEG	POS
7/11	2122:07	159	143	-620	359	172	158	-578	402								
	2131:01	-593	-241	-639	83	294	268	-599	169								
7/13	2046:23	-617	-593	-623	427	241	191	-549	307	+	34	-	+	+	63	-	+
8/6	2144:04	160	206	-569	322	-546	-240	-546	131	+	5	-	8	+	-15	-	-4
8/7	2120:57	-287	-466	-537	304	-96	-516	-581	330	70	64	-	+	38		-	+
	2138:24	-233	-184	-534	379	-158	-177	-546	355	+	31	-	+	+	70	-	49
	2141:24	-30	-301	-488	163	-186	-478	-606	257	55	-	-	60	-64	+	-	+
	2141:59	-211	-217	-491	436	112	-472	-535	489	64	-	-	+	66	70	-	+
	2143:26	95	-108	-515	244	273	-385	-581	388	63	-23	-67	+	-73	-70	-	68
	2202:01	-171	-127	-369	154	216	259	-573	295	+	63	-	+	68	9	-	73
	2212:41	-22	5	-247	157	314	136	-478	412	-57	3	-	63	34	-74	-	+
8/17	2136:01	-134	145	-139	253	-169	106		427	-38	10	-59	56	-44	-7	-76	58
8/20	1737:54	-93	-211	-265	308	-24	104	-326	216	-3	-13	-22	59	-20	-25	-66	31
9/5	2144:	27	410	-514	459	0	-305	-509	428	-7	44	-74	69	-7	17	-77	84
	2152:05	131	-328	-602	438	305	-458	-611	458	64	51	-79	64	61	-45	-89	75
	2153:07	-274	-164	-574	438	178	229	-611	331	-42	-15	-79	54	-3	-14	-89	67
	2234:42	219	-109	-492	219	-611	-255	-611	433	-37	-25	-79	-12	-84	-84	-84	-22
	2306:07	-219	-274	-509	-126	-407	290	-636	356	-74	-74	-82	1	11	-73	-88	64
	2320:36	0	-410	-547	328	-204	-204	-356	438	1	-20	-39	5	0	11	-54	11
	2326:53	16	164	-383	219	51	356	-662	407	-10	-6	-46	-6	-12	-17	-45	-1

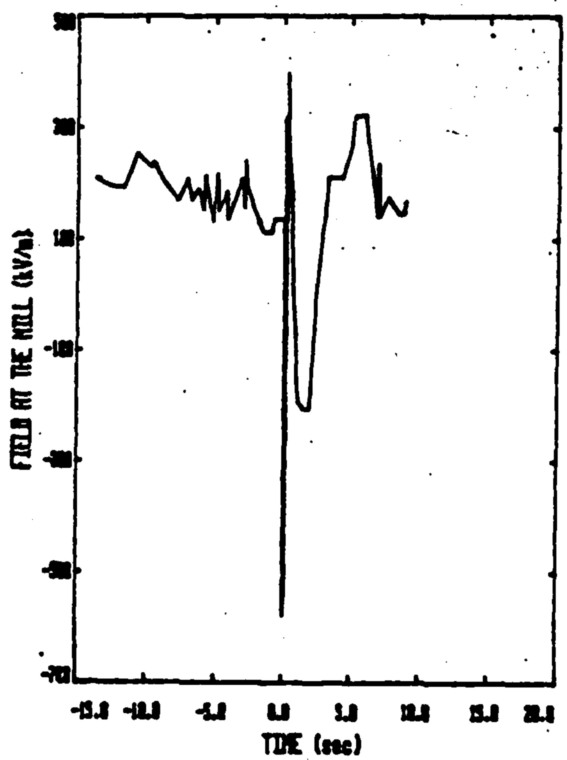
Table 1. Electric field data for 20 direct lightning strikes in 1984.

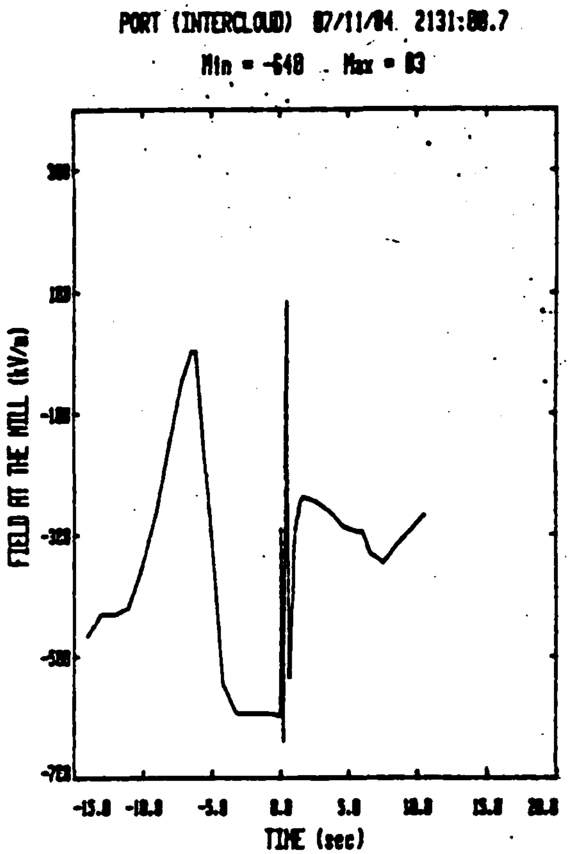
NO.	DATE	TIME	CHARGE FIELD (E_P+E_0) [K
1	7/11	2122:07	331
2		2131:01	-299
3	7/13	2046:23	-391
4	8/6	2144:04	-386
5	8/7	2120:57	-383
6		2138:24	-391
7		2141:24	-216
8		2141:59	-99
9		2143:26	368
10		2202:01	45
11		2212:41	292
12	8/17	2136:01	-303
13	8/20	1737:54	-117
14	9/5	2144:	27
15		2152:05	436
16		2153:07	-96
17		2234:42	-392
18		2306:07	-626
19		2320:36	-204
20		2326:53	67

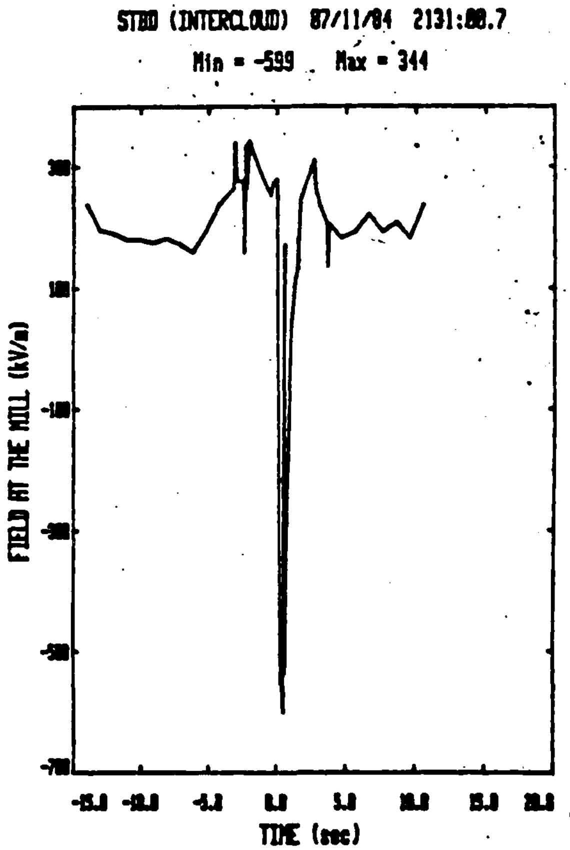
PORT (INTERCLOUD) 07/11/84 2122:15.5
Min = -621 Max = 357



STBD (INTERCLOUD) 07/11/84 2122:15.5
Min = -570 Max = 396




PORT (INTERCLOUD) 07/11/84 2131:00.7
Min = -648 Max = 83
300
100
-100
-300
-500
-700
-15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0
TIME (sec)
FIELD AT THE MILL (kV/m)


STBD (INTERCLOUD) 07/11/84 2131:00.7
Min = -599 Max = 344
300
100
-100
-300
-500
-700
-15.0 -10.0 -5.0 0.0 5.0 10.0 15.0 20.0
TIME (sec)
FIELD AT THE MILL (kV/m)

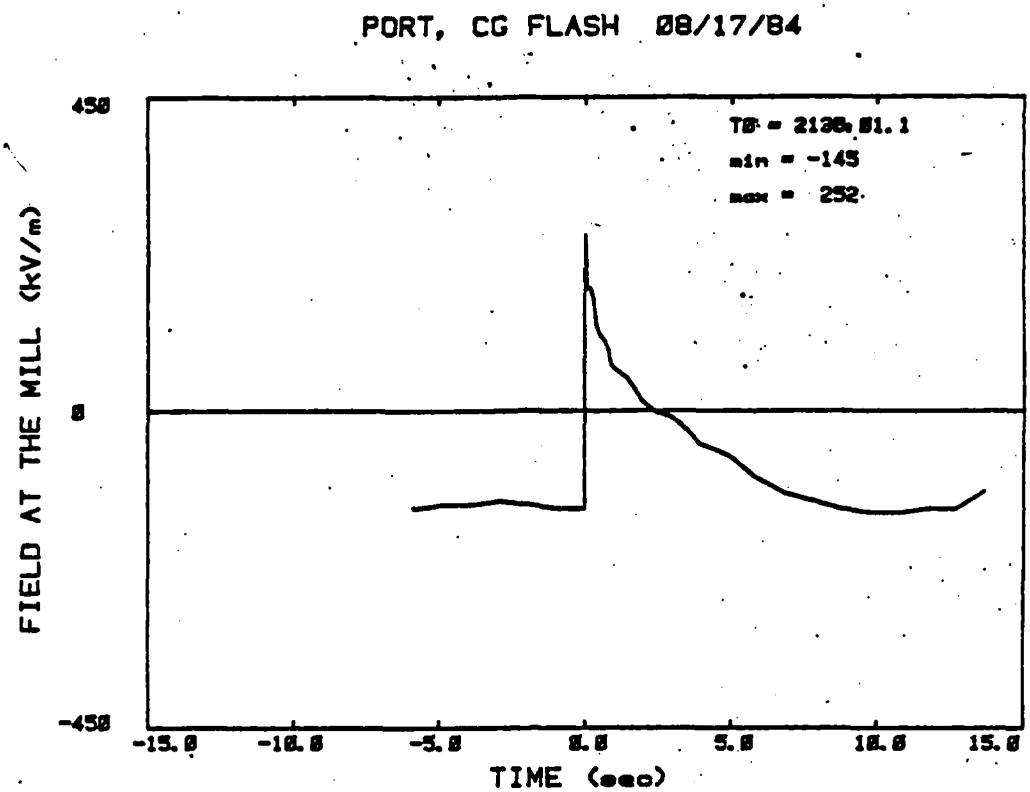


Figure 1

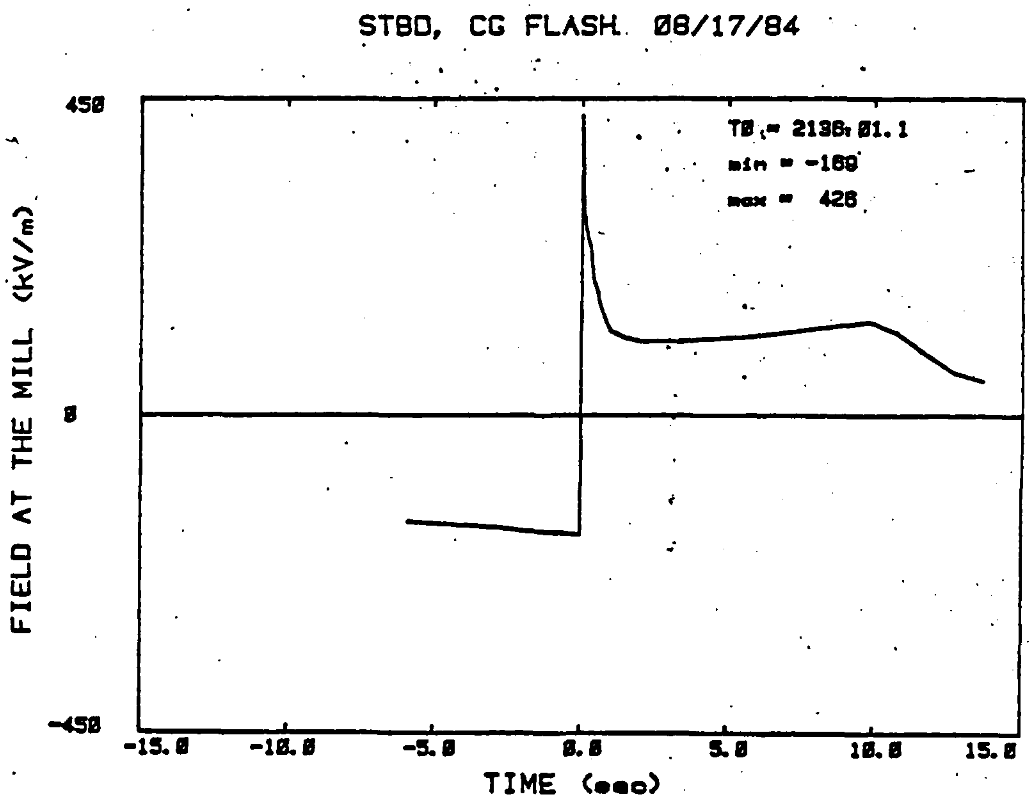
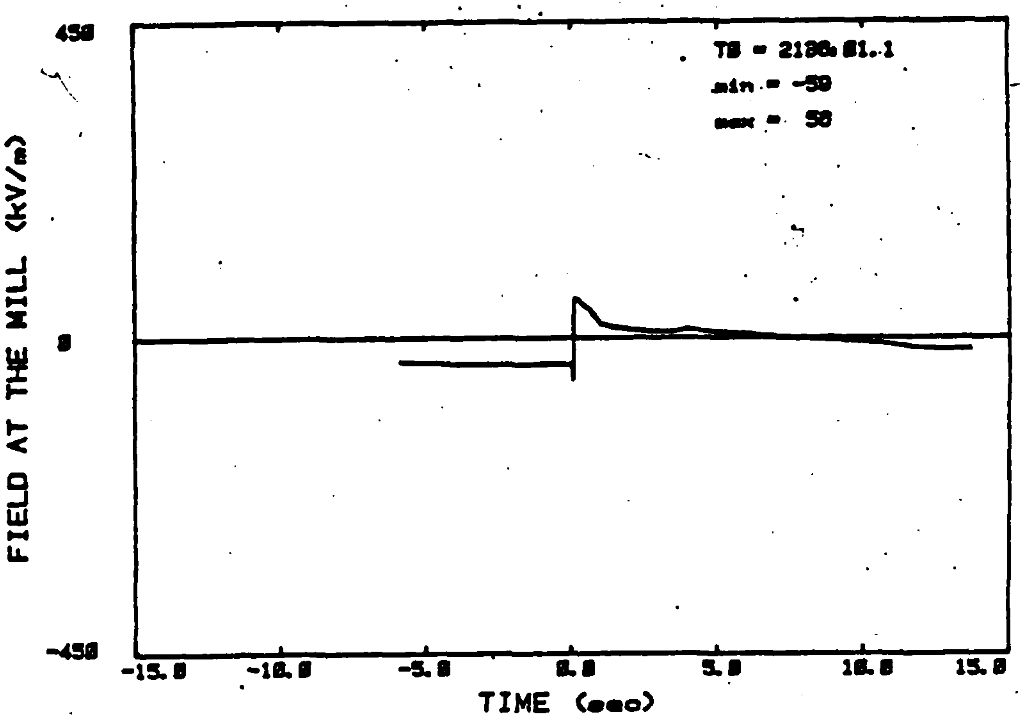
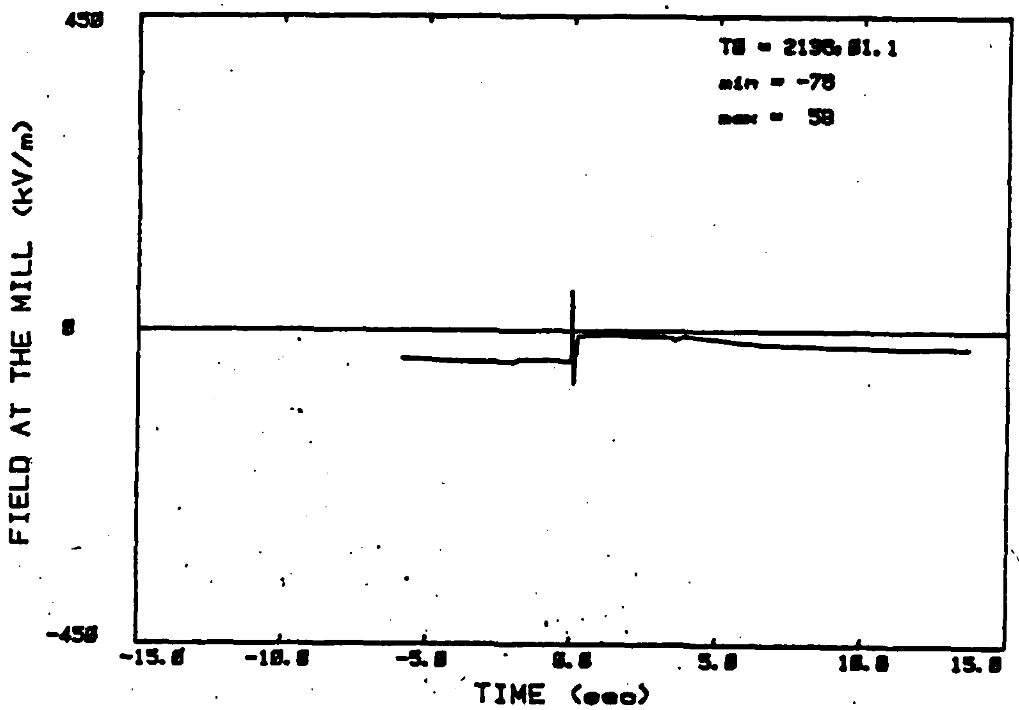


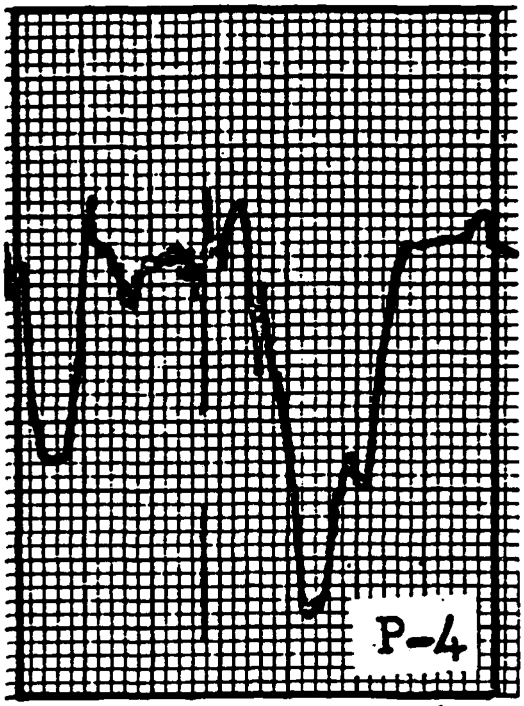
Figure 2

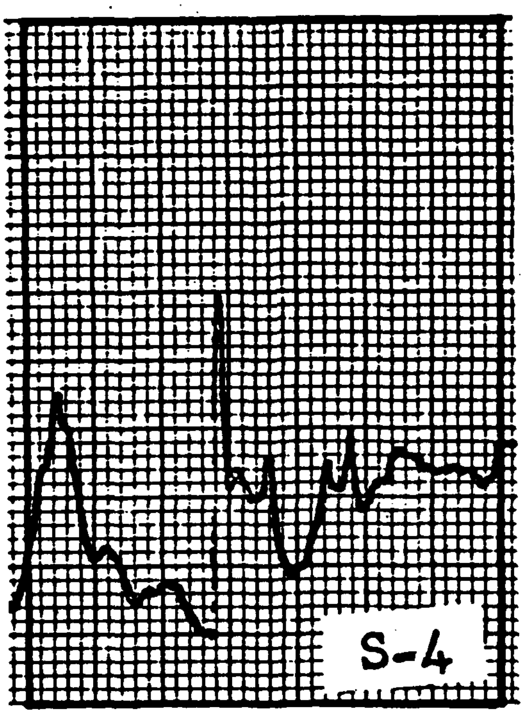
FWD, CG FLASH 08/17/84

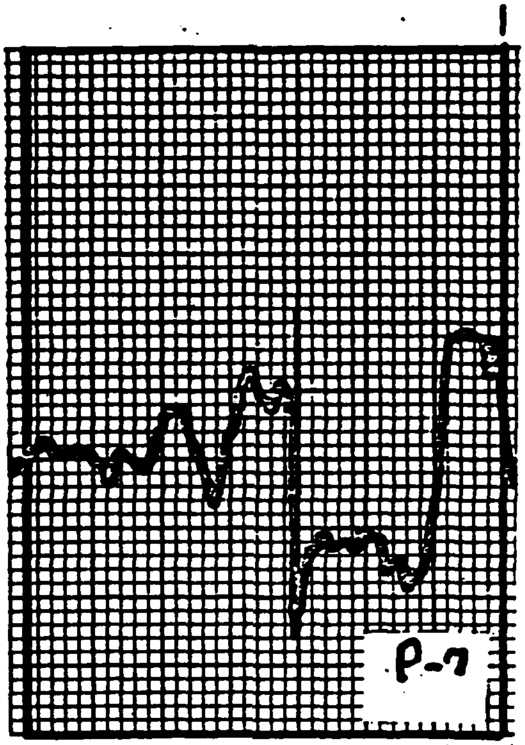


TAIL, CG FLASH 08/17/84




P-4


S-4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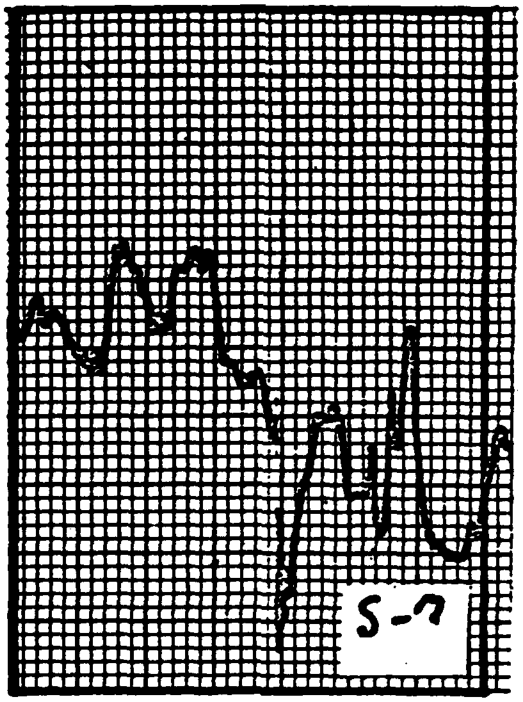
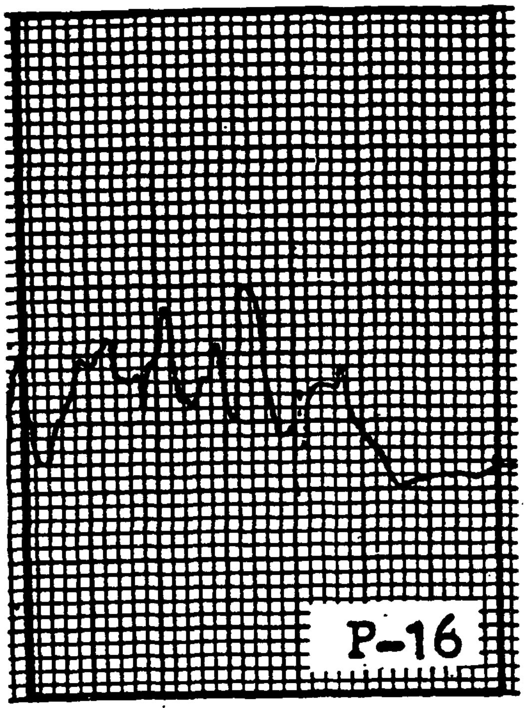

S-7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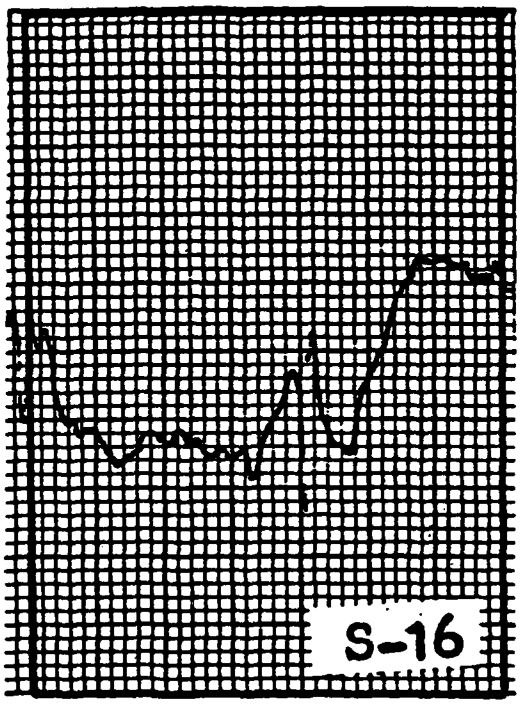
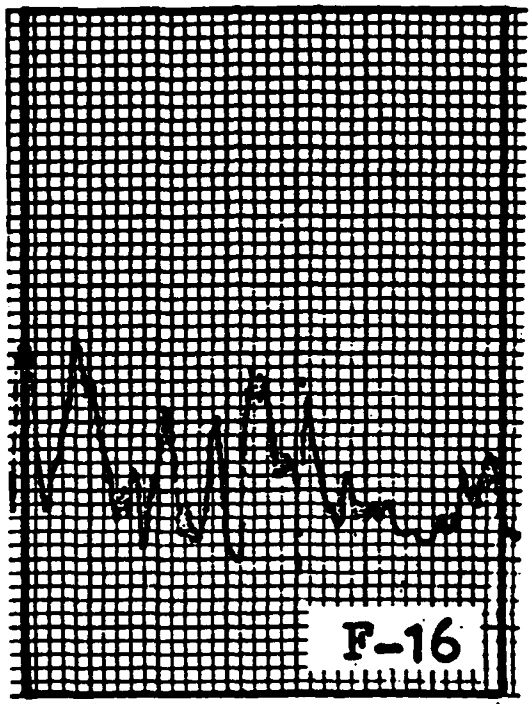
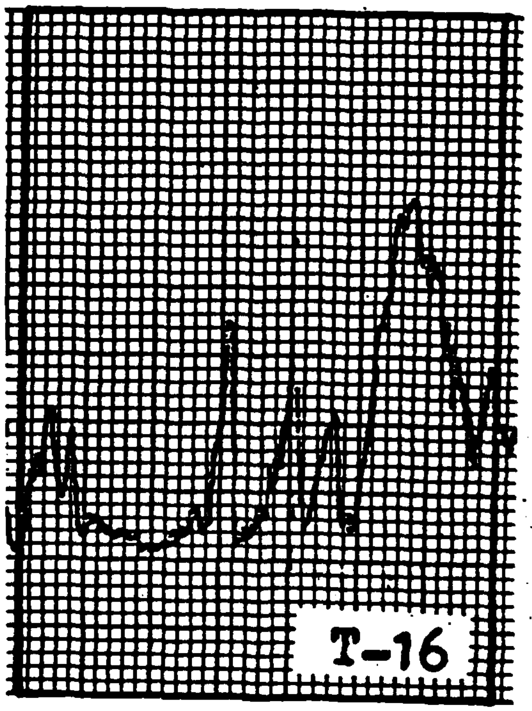

S-16


F-16


T-16

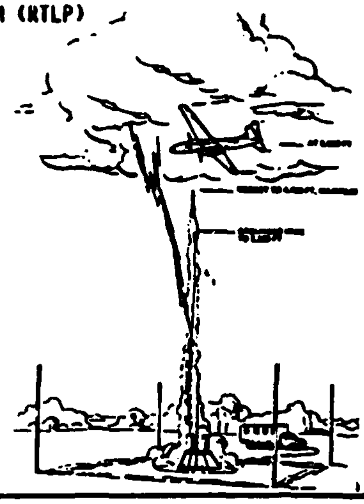
ROCKET TRIGGERED LIGHTNING PROGRAM
(MR. W. JAFFERIS, NASA, KSC)

KSC SHUTTLE OPERATIONS	KENNEDY SPACE CENTER ROCKET TRIGGERED LIGHTNING PROGRAM (RTLP)	NAME: W. JAFFERIS ORG. SO DATE: 1/17/85

KENNEDY SPACE CENTER

ROCKET TRIGGERED LIGHTNING PROGRAM (RTLP)

JANUARY 17, 1985



KSC SHUTTLE OPERATIONS	KENNEDY SPACE CENTER ROCKET TRIGGERED LIGHTNING PROGRAM (RTLP)	NAME: W. JAFFERIS ORG. SO DATE: 1/17/85

INTRODUCTION

- O AIR FORCE WRIGHT AERONAUTICAL LABORATORIES A/B LIGHTNING MEASURING PROGRAM
- O KSC NEEDS
- O RESEARCH INTEREST
- O RTLP 1984 RESULTS
- O RTLP 1985 STATUS
- O RECOMMENDATIONS

KSC SHUTTLE OPERATIONS	AIR FORCE WRIGHT AERONAUTICAL LABORATORIES A/B LIGHTNING MEASURING PROGRAM	NAME: W. JAFFERIS ORG: SO DATE: 1/17/85

AFWAL AIRBORNE LIGHTNING MEASURING PROGRAM

- O OBJECTIVE
  - O INTER-AGENCY PROGRAM TO CHARACTERIZE LIGHTNING DANGER TO AEROSPACE VEHICLES
- O PARTICIPANTS
  - O AIR FORCE, FAA, US NAVY; CNET, ONERA & CENG (FRANCE), U OF A, U OF F, & SUNYA
- O SCOPE
  - O A TWO YEAR EFFORT THAT WILL USE GROUND BASED INSTRUMENTED ROCKET TRIGGERED LIGHTNING SITE AND AN INSTRUMENTED AIRCRAFT
- O KSC/ESMC PARTICIPATION
  - O PROVIDE A TEMPORARY TEST SITE FOR LIGHTNING TRIGGERING, POWER, COMMUNICATION, AND ACCESS. ACCOMPLISH OPERATION WITHIN ENVIRONMENTAL AND SAFETY GUIDELINES
  - O WEATHER FORECASTING AND OBSERVATIONS AND DATA
  - O VECTOR CONTROL, TRACKING OF A/C OVER KSC AND FLORIDA

3

KSC SHUTTLE OPERATIONS	AIR FORCE WRIGHT AERONAUTICAL LABORATORIES A/B LIGHTNING MEASURING PROGRAM (CONTINUED)	NAME: W. JAFFERIS ORG: SO DATE: 1/17/85

AFWAL AIRBORNE LIGHTNING MEASURING PROGRAM (CONT.)

- O ANTICIPATED RESULTS
  - O DETERMINATION OF CURRENT AND FIELDS RECIEVED BY AN AEROSPACE VEHICLE STRUCK BY LIGHTNING AND COMPARING RESULTS WITH SIMULTANIOUS CURRENT AND FIELD LEVELS OBTAINED AT KSC USING ROCKET TRIGGERED LIGHTNING. RESULTS TO BE SHARED WITH ALL PARTICIPANTS

4

KSC SHUTTLE OPERATIONS

KSC NEEDS

NAME: W. JAFFERIS
ORG: SO
DATE: 1/17/85

REDUCED STS SCHEDULE & OPERATION LOST TIME

- O PROVIDE LIGHTNING PROTECTION FOR CRITICAL WORK AREAS
  - O ROCKET TRIGGERED LIGHTNING WILL VERIFY VARIOUS DESIGNS
- O IMPROVE ADVERSE WEATHER WARNING RELIABILITY (LIGHTNING WITH 5 MILES)
  - O EXPANDED MESO NETWORK WILL IMPROVE SHORT TERM FORECAST (30 MIN.)
  - O (L.P.) X (F.C.R.)= COST AVOIDANCE

KSC SHUTTLE OPERATIONS

KSC NEEDS

NAME: W. JAFFERIS
ORG: SO
DATE: 1/17/85

RENEWED AWARENESS TO LIGHTNING RELATED PROBLEMS OCCURRED BECAUSE OF THE NEAR DISASTER OF APOLLO 12; DAMAGE TO SPACECRAFT & GSE; LOST TIME DUE TO RETEST AND UNNECESSARY WORK STOPPAGE DURING APOLLO AND SKYLAB PROGRAMS AND SCHEDULE SENSITIVITY OF ASTP. THRU A LESSON LEARN TECHNIQUE, THE FOLLOWING IMPROVEMENTS WERE INITIATED BY OPERATIONS:

- O REVIEWED AND VERIFIED CX39 AREA LIGHTNING PROTECTION SYS (ALPS)
- O ELIMINATED "TOWER CLEAR" REQMT DURING ADVERSE WEATHER (LW5M)
- O IMPROVED LIGHTNING MEASURING SYS (LIVIS, CWLIS, OPTIC-OTV)
- O IMPROVED STS ALPS; CAT WIRE, EXTERNAL CABLE ROUTING (TSM) DAMAGE SUSCEPTIBILITY ANALYSIS (KSC-JSC)
- O EXTENSION OF ALPS TO SCHEDULE SENSITIVE AREAS (SCAPE, HYPER-FARMS, PRSD . . .)

KSC SHUTTLE OPERATIONS

KSC NEEDS

NAME: W. JAFFERIS
ORG: SO
DATE: 1/17/85

FURTHER IMPROVEMENTS ARE REQUIRED BECAUSE OF THE ACCELERATED LAUNCH RATE AND NEW LANDING REQUIREMENTS FOR THE STS VEHICLES (TILE, ELECTRONICS)

- O FURTHER EXTENSION OF ALPS FOR SAFETY
  - PERSONNEL (LIGHTNING VOLTAGES & CURRENTS)
  - SENSITIVE FLIGHT HW & GSE, ORDNANCE (ELECTRIC & MAGNETIC FIELDS)
  - SRB DISASSEMBLY & RECOVERY, CRYO LH & LO STORAGE, ESA-60A AND DELTA SPIN
- O IMPROVED WEATHER FORECASTING
  - LONG-TERM 1-3 DAYS (SCHEDULING)
  - SHORT-TERM 30 MIN (WORK FLOW), 2 HOURS (LANDING & CRYO LOADING)

1

KSC SHUTTLE OPERATIONS

KSC NEEDS

NAME: W. JAFFERIS
ORG: SO
DATE: 1/17/85

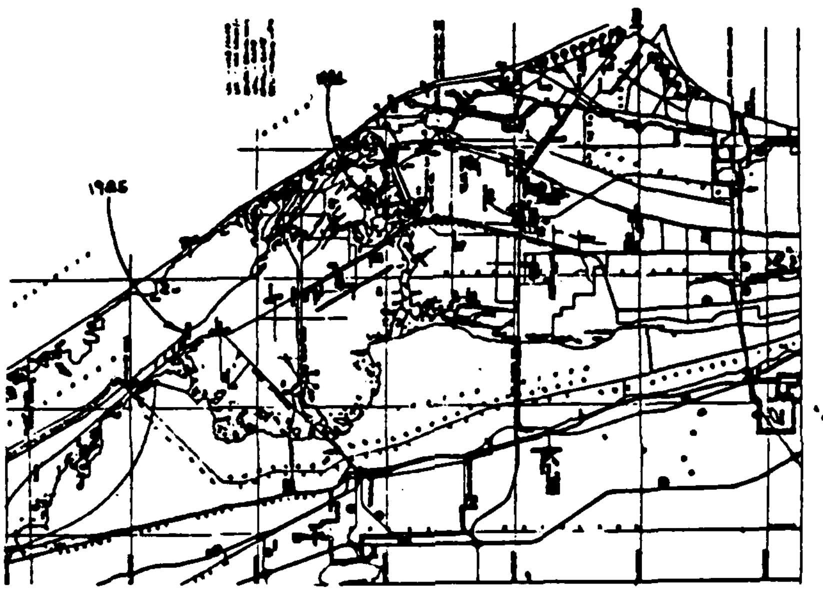
- O AREA LIGHTNING PROTECTION SYS (ALPS) DESIGN, TO:
  - O REDUCE MAGNETIC & ELECTRIC INDUCED FIELD LEVELS TO PREVENT DAMAGE TO FLIGHT HW & GSE & REDUCE ORDNANCE HAZARD
- O BENEFITS
  - O ECONOMICAL SOURCE OF NATURAL LIGHTNING TO:
    - o VERIFY DESIGN OF GRD & A/B LIGHTNING PROTECTION SYSTEM AND DEMONSTRATE EFFECTIVENESS
    - o VERIFY LIGHTNING LOCATION SYSTEMS
    - o FORECASTING OF THUNDERSTORMS
- O REQUIRES
  - O ELECTRIC & MAGNETIC FIELD MEASUREMENTS INSIDE & OUTSIDE PROTECTED AREA
  - O TYPICAL ORDNANCE CIRCUITS WITH INITIATORS CONNECTED COULD BE PLACED INSIDE/OUTSIDE PROTECTED AREAS TO DEMONSTRATE EFFECTIVENESS
  - O COORELATION OF OPERATIONAL LIGHTNING MEASUREMENTS WITH A/B GROUND DATA DURING NATURAL & TRIGGERED LIGHTNING EVENTS

2

KSC SHUTTLE OPERATIONS

KENNEDY SPACE CENTER
ROCKET TRIGGERED LIGHTNING PROGRAM (RTLP)

NAME: W. JAFFERIS
ORG: SO
DATE: 1/17/85



9

KSC SHUTTLE OPERATIONS

RESEARCH SCIENTIST INTEREST

NAME: W. JAFFERIS
ORG: SO
DATE: 15 JANUARY 1985

o UNIVERSITY OF FLORIDA - KSC AND NSF FUNDED
  - HORIZONTAL AND VERTICAL ELECTRIC FIELDS
  - LIGHTNING CURRENT CHARACTERISTICS & GEOMETRIC SHAPE

o UNIVERSITY OF ARIZONA - KSC & NSF FUNDED
  - MAXWELL CURRENTS, ELECTRIC AND MAGNETIC FIELDS
  - THUNDERSTORM CHARACTERISTICS, LIGHTNING & CHARGE LOCATIONS
  - SUPPORT FOR NOAA-ERL WIND DIV. STUDY TO IMPROVE SHORT TERM FORECASTING

o STATE UNIVERSITY OF NEW YORK AT ALBANY (SUNYA) NSF FUNDED
  - LIGHTNING CURRENT CHARACTERISTIC - VELOCITY OF RETURN STROKE USING STREAK CAMERA TECHNIQUE

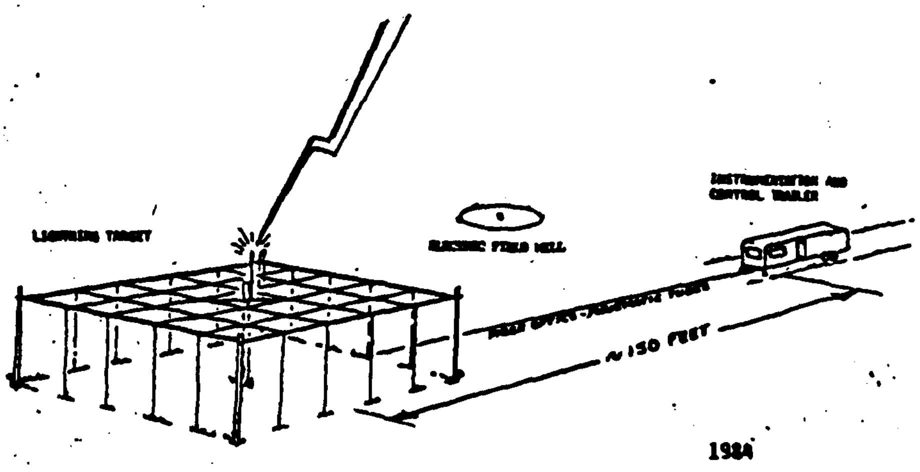
10

KSC SHUTTLE OPERATIONS	RESEARCH SCIENTIST INTEREST (CONTINUED)	NAME: W. JAFFERIS ORG. SO DATE: 15 JANUARY 1985

- o NAVAL RESEARCH LABORATORY - NAVY
  - A/B ELECTRIC FIELD MILL
  - ELECTRIC AND MAGNETIC FIELDS (UHF)
- o AIR FORCE WRIGHT AERONAUTICAL LABORATORY & FAA - SELF FUNDED
  - A/B GROUND ELECTRIC & MAGNETIC FIELDS
  - DIRECT AND INDIRECT LIGHTNING CURRENT CHARACTERISTICS
    CLOUD TO GROUND AND INTERCLOUD LIGHTNING
  - THUNDERSTORM TURBULENCE
  - OPTICAL RECORDING
- o ONERA, CENG AND CNET
  - A/B AND GROUND ELECTRIC AND MAGNETIC FIELDS
  - LIGHTNING CURRENT CHARACTERISTICS -
    NATURAL AND TRIGGERED LIGHTNING

11

KSC SHUTTLE OPERATIONS	1984 RTLS	NAME: W. JAFFERIS ORG. SO DATE: 1/17/85



1984
TRIGGERED LIGHTNING SITE
(CONVERTER COMPRESSOR FACILITY)

12

KSC SHUTTLE OPERATIONS	1984 RTLP RESULTS	NAME: W. JAFFERIS ORG: SO DATE: 15 JANUARY 1985

- o AIRBORNE, FAA, NAVY, AND ONERA
  - DURATION 11 JUNE THRU 19 SEPTEMBER
  - 27 MISSIONS FLOWN
  - 21 NATURAL LIGHTNING EVENTS
  - 6 NEAR-BY TRIGGERED LIGHTNING EVENTS
  - SUBSTANTIAL A/B & GROUND DATA COLLECTED - ANALYSIS UNDERWAY
  - SLIGHT A/C DAMAGE WITH SOME DOWN TIME
- o GROUND - RTLP
  - DURATION 11 JULY THRU 28 AUGUST
  - 4 STORM DAYS
  - 8 TRIGGERED EVENTS

    4 TRIGGERS RESULTED IN NATURAL-LIKE RETURN STROKES, PEAK CURRENT - 43KA
  - SUBSTANTIAL GROUND BASE DATA COLLECTED - ANALYSIS UNDERWAY
- o CLEAN UP
  - STOWAGE OF 23 ROCKETS AND LAUNCHING EQUIPMENT
  - PRELIMINARY PLANNING FOR RTLP 85 STARTED

13

KSC SHUTTLE OPERATIONS	1984 RTLP RESULTS (CONTINUED)	NAME: W. JAFFERIS ORG: SO DATE: 15 JANUARY 1985

KSC ACCOMPLISHMENTS

- o SAFE OPERATIONS AND PROCEDURES

  NO STS INTERFERENCE
- o WITH ESMC VECTOR CONTROLLER DEMONSTRATED ABILITY TO ROCKET TRIGGERED LIGHTNING ON TIME. (PLANE OVER TARGET, ROCKET AT ALTITUDE RELATIVE TO ELECTRIC FIELD)
- o WITH ESMC/WE PROVIDED TIMELY WEATHER FORECAST AND OBSERVATIONS

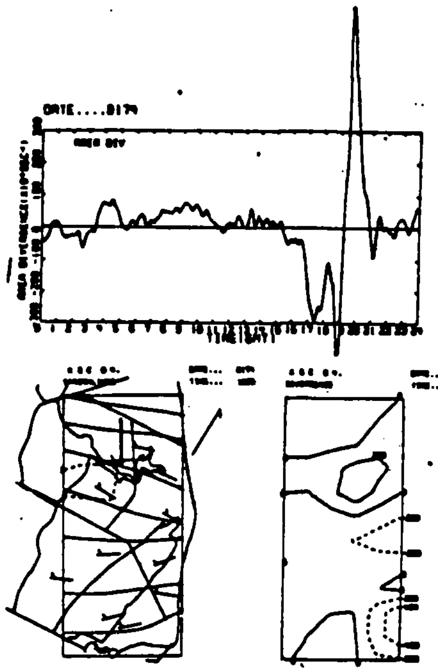
  COLLECTED UNIQUE SET OF WIND, LIGHTNING & METEOROLOGICAL DATA FOR NOAA-ERL WIND DIVERGENCE STUDY AND OTHER INTERESTED RESEARCHERS
- o DEMONSTRATED LIGHTNING PROTECTION SYSTEM TECHNIQUES

  BONDING, GROUNDING AND SHIELDING - LITTLE EFFECTS IF ANY TO CONTROL/INSTRUMENT VAN WITH LIGHTNING WITHIN 150 FEET

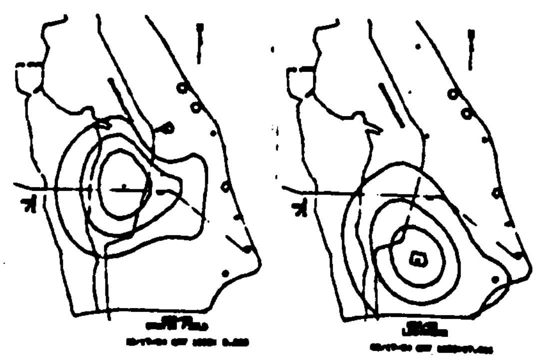
  - o PUBLIC AWARENESS OF WHAT IS BEING DONE TO PROTECT STS ELEMENTS

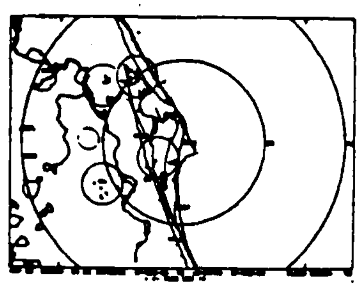
14

KSC SHUTTLE OPERATIONS	1984 RTLP RESULTS (CONTINUED)	NAME: W. JAFFERIS ORG: SO DATE: 15 JANUARY 1985



KSC SHUTTLE OPERATIONS	1984 RTLP RESULTS (CONTINUED)	NAME: W. JAFFERIS ORG: SO DATE: 15 JANUARY 1985

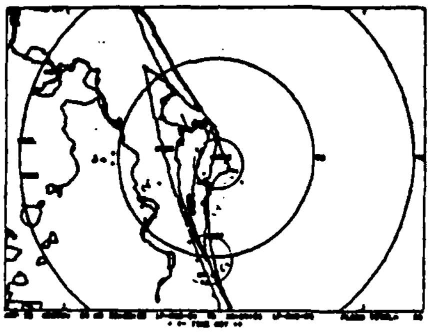


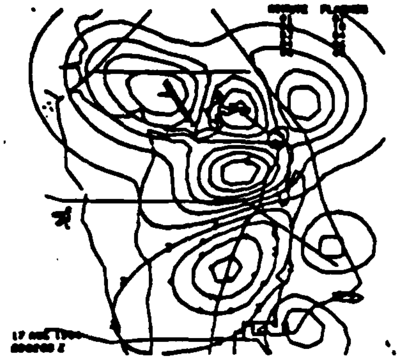


KSC SHUTTLE OPERATIONS

1984 RTLP RESULTS (CONTINUED)

NAME: W. JAFFERIS
ORG: SO
DATE: 15 JANUARY 1985





KSC SHUTTLE OPERATIONS

1985 ROCKET TRIGGERED LIGHTNING PROGRAM

NAME: W. JAFFERIS
ORG: SO
DATE: 15 JANUARY 1985

MANPOWER:

- o CENG - FRENCH LAUNCH CREW (2)/EQUIPMENT
- o KSC/SM - (1) SUPPORT, (1) OPS, (1) PROJECT MANAGER
- o CONTRACTOR - INSTRUMENTATION/COMM & PLANNING TIC

SUPPORT MANPOWER

- o SITE PREPARATION (WILDLIFE REFUGE BUILDING #5 (F5-2151)
- o POWER
- o TIMING
- o TELEPHONE
- o MISCELLANEOUS

TIME PERIOD:

60 DAYS (JUNE, JULY, AUGUST)

KSC SHUTTLE OPERATIONS

1985 ROCKET TRIGGERED LIGHTNING PROGRAM

(CONTINUED)

NAME: W. JAFFERIS
ORG: SO
DATE: 15 JANUARY 1985

FUNDS - FRENCH ONLY: $100K

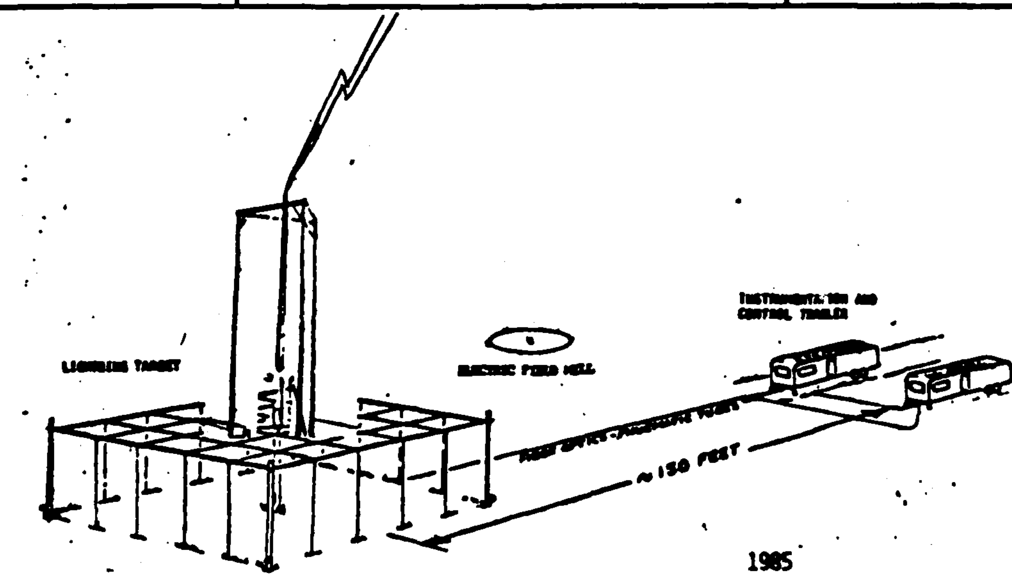
- ADDITIONAL ROCKETS (72) AND FRENCH CREW (2 OR 3).
- INSTRUMENTATION AND COMM
- KSC SUPPORT $30+K

TIC	15 K
EGG	10 K
SIMULATOR	5 K
SPC	?

KSC SHUTTLE OPERATIONS

1985 ROCKET TRIGGERED LIGHTNING PROGRAM

NAME: W. JAFFERIS
ORG: SO
DATE: 1/17/85

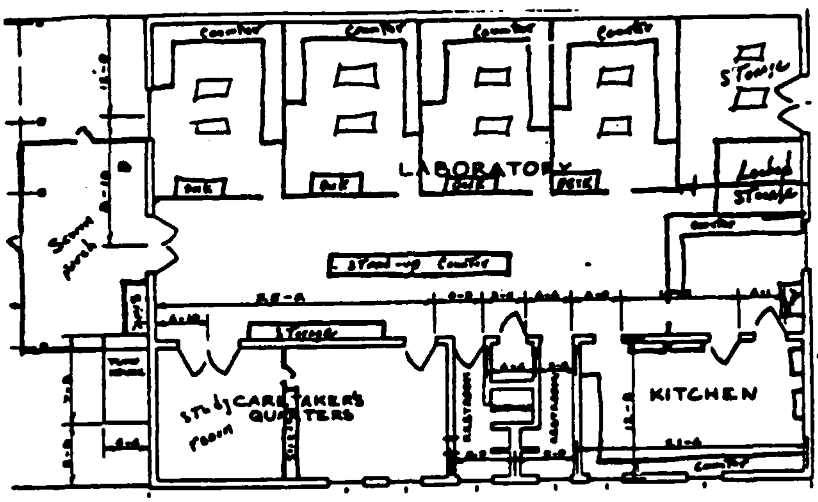


1985
TRIGGERED LIGHTNING SITE
WILDLIFE REFUGE BUILDING #5 (F5-2151)

KSC SHUTTLE OPERATIONS

1985 ROCKET TRIGGERED LIGHTNING PROGRAM (CONTINUED)

NAME: W. JAFFERIS
ORG: SO
DATE: 15 JANUARY 1985



WILDLIFE REFUGE BUILDING #5 (F5-2151)

KSC SHUTTLE OPERATIONS

1985 ROCKET TRIGGERED LIGHTNING PROGRAM (CONTINUED)

NAME: W. JAFFERIS
ORG: SO
DATE: 15 JANUARY 1985

RECOMMENDATION

- APPROVE THE EXTENDED PROGRAM AND GIVE GO AHEAD TO AMEND EXISTING MOU FOR CD SIGNATURE
- CONSIDER 1985 RTLP AS ONE SMALL STEP TOWARD THE FOUNDATION OF A PERMANENT KSC ATMOSPHERIC RESEARCH FACILITY
- SUPPORT PLANNING/FUNDING FOR KNOWN RESEARCH INTEREST. CONSIDER SPONSORING INTERAGENCY BRIEFING OF 17 AUGUST 1984 DATA RTLP - SHORT TERM FORECASTING

NOTICE OF MEETING

SIXTH ANNUAL MEETING OF THE NICG OF THE NATIONAL
ATMOSPHERIC ELECTRICITY HAZARDS PROTECTION PROGRAM

DEPARTMENT OF THE ARMY
HEADQUARTERS, US ARMY AVIATION SYSTEMS COMMAND
4300 GOODFELLOW BOULEVARD, ST. LOUIS, MO. 63120-1798

REPLY TO
ATTENTION OF

AMSAV-ES

28 DEC 1984

SUBJECT: Sixth Meeting of the National Interagency Coordination Group of the National Atmospheric Electricity Hazarus Protection Program

SEE DISTRIBUTION

1. The subject meeting is to be held in St. Louis, MO, on 28-29 Jan 85. The meeting will be held at the Ramada Inn (near the airport), 9636 Natural Bridge Road, and will commence at 1230 hours on 28 Jan.

2. In addition, a special briefing will be presented on Wednesday, 30 Jan, regarding results of the C-580 flight test program to date. A tentative agenda is provided in Encl 1. The undersigned, who is with the US Army Aviation Systems Command (AVSCOM), will preside as chairman for this session.

3. One of the primary purposes of this meeting is to discuss each agency's programs, projects, and concerns. Historically, these meetings have been very productive in the transfer of information which has resulted in multi-agency collective research efforts. With the continued restrain of resources (both manpower and money), it is imperative that the agencies continue to coalesce their research activities. This year's meeting format will be slightly different from that of previous years in that the first day will address each agency's past year's activities, followed by future plans and issues on the second day.

4. A block of rooms has been set aside for our committee at the above Ramada Inn; however, each committee member is expected to make his own motel arrangements. You are requested to make motel reservations through the AVSCOM Protocol Office, commercial 314-263-1046 or AUTOVON 693-1046. Additional information such as directions and arrangements for special audio/visual equipment should also be made with the Protocol Office.

5. If you need any additional information or encounter any difficulties in which we could be of help, please contact the undersigned at commerical 314-263-1695 or AUTOVON 693-1695. Incidentally, the phone number of the Ramada Inn is 314-426-4700.

AMSAV-ES
SUBJECT: Sixth Meeting of the National Interagency Coordination Group of the National Atmospheric Electricity Hazards Protection Program

6. For those NICG committee members who are also members of SAE subcommittee on lightning, the next AE4L meeting will be at McDonnell Douglas, also in St. Louis, MO, near the airport, on 31 Jan and 1 Feb 85. A separate letter of invitation with details will be forthcoming from that organization.

7. In an effort to expedite publication of the minutes, you are requested to supply a reproducible copy of your presentation to the secretariat at the completion of the session.

8. I am looking forward to your attendance at the meeting.

DAVID L. ALBRIGHT
Chairman

DISTRIBUTION:

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Avionics Research and Develop Activity
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Commander Max Bellune
OP NAV-551
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Wright-Patterson AFB, OH 45433

Mr. M. Glynn
FAA Technical Center
ACT-340
Atlantic City Airport, NJ 08405

AMSAV-ES
SUBJECT: Sixth Meeting of the National Interagency Coordination Group of the National Atmospheric Electricity Hazards Protection Program

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Atlantic City Airport, NJ 08405

Dr. David Rust
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Dr. Donald R. MacGorman
NOAA
National Severe Storms Lab
1313 Halley Circle
Norman, OK 73069

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AFWAL/FIEA
WPAFB
Dayton, OH 45433

Mr. John P. O'Neill
AFWL/NTCA
Kirtland AFB
Albuquerque, NM 87117

Mr. William Walker
NADC
Code 20P3
Warminster, PA 18974

Mr. Norm Crabill
Code 130
NASA-Langley Research Center
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Dr. J. Birken
NAVAIR
Comm Naval Air Sys Cmd
Washington, DC 20361

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Mr. David Holmes
Chief, Sounding Sys Branch, OA/W522
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Mr. Jack Lippert
AFWAL/FIEA
Air Force Wright Aeronautical Lab
Wright-Patterson AFB, OH 45433

Mr. Larry Walko
AFWAL/FIESL
WPAFB
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Major Pete Rustin
AFWAL/FIESL
WPAFB
Dayton, OH 45433

Mr. J. Corbin
ASD/ENACE
WPAFB
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Mr. Bruce Fisher
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Mr. Felix Pitts
Code 130
NASA-Langley Research Center
Hampton, VA 23665

Mr. Jim Foster
Code 9482
Naval Air Engineering Center
Lakehurst, NJ 08733

Mr. D. Suiter
NASA
Johnson Space Center (Code MD-3)
Houston, TX 77058

Dr. L. Ruhnke
Naval Research Lab
Code 4110
Washington, DC 20375

NICG MEETING, 28-29 JANUARY 1985

TENTATIVE AGENDA

28 January 1985 (Monday)

1230 Hours	Welcome
1245 Hours	Review of Minutes from Previous Meeting (NOAA, Norman, OK, 27-28 Mar 84)
	Replacement for Secretariat
1330 Hours	Overview of National Severe Storm Laboratory (NSSL) Activity - A Progress Review (Dr. D. MacGorman, NSSL, NOAA, Norman, OK)
1400 Hours	Air Force Wright Aeronautical Laboratory (AFWAL) Activity for the Past Year (Mr. L. Walko, Atmospheric Electricity Hazards Group, WPAFB, Dayton, OH)
1430 Hours	Atmospheric Electrical Hazards Protection (AEHP) Advanced Development Program (ADP) Overview (Mr. R. Beavin, Flight Dynamics Laboratory, WPAFB, Dayton, OH)
1500 Hours	Break
1515 Hours	Lightning Protection Standard for Military Aircraft - An Overview (Dr. J. Corbin, Aeronautical System Division, WPAFB Dayton, OH)
1545 Hours	US Army Program for Protection of Aircraft Against Natural EM Hazards - A Progress Review (Mr. D. Albright, AVSCOM, St. Louis, MO)
1615 Hours	Design Guide for Lightning Protection of Advanced Fuel Systems - A Progress Review (Mr. W. Walker, Naval Air Development Center, Warminster, PA)
1645 Hours	Navy Basic Research Program on Lightning - An Overview (Dr. L. Ruhnke, Naval Research Laboratory, Washington, DC)
1715 Hours	FAA R&D Technical Center Accomplishments (Dr. T. Carro, FAA Technical Center, Atlantic City, NJ)
1745 Hours	Naval Air Systems Command Activities - A Progress Review (Mr. J. Birken, NAVAIRSYSCOM, Washington, DC)
1815 Hours	Adjourn

29 January 1985 (Tuesday)

0800 Hours	Summary of NASA LaRC Lightning Characterization and Effects (Mr. F. Pitts, NASA-Langley Research Center, Hampton, VA)
0830 Hours	Update of Lightning Simulation Facilities Survey (Mr. L. Walko)
0900 Hours	Update of the ICOLSE Conference in Paris, Jun 85 (Mr. L. Walko)
0915 Hours	All Composite Aircraft Program (ACAP) - A Lightning/Avionics/ Electromagnetic Assessment (Mr. T. Mazza, AVSCOM Applied Technology Laboratory, Ft Eustis, VA)
0945 Hours	Break
1000 Hours	FAA R&D Technical Center Planned Future Activity (Dr. T. Carro)
1030 Hours	Navy Issues on Lightning Research (Dr. L. Ruhnke)
1100 Hours	NAVAIRSYSCOM Future Activities (Mr. J. Birken)
1130 Hours	US Army Programs for Protection of Aircraft Against Natural Electromagnetic Hazards - Future Activities and Needs (Mr. D. Albright)
1200 Hours	Lunch
1300 Hours	AFWAL Future Activities (Mr. L. Walko)
1330 Hours	AEHP ADP Demonstration Planning and Workshop Plan (Mr. R. Beavin)
1400 Hours	Future Concerns (Dr. J. Corbin)
1420 Hours	Spring Operations and Analysis (Dr. D. MacGorman)
1430 Hours	Break
1500 Hours	General Issues, Discussions, Closing Remarks
	Publication of Minutes
	Previous Action Items:
	Mr. L. Walko - National lightning Test Facility
	Dr. D. MacGorman - Review Questionnaires
	Next NICG Meeting (FAA)
1600 Hours	Status Review of 1986 Conference, Dayton, OH (Mr. L. Walko)
1800 Hours	Adjourn

ATTENDANCE (NICG)

NICG Meeting
St. Louis, MO
28-29 January 1985

Name	Affiliation	Phone
David L. Albright	U.S. Army-AVSCOM	AV 693-1695 (314) 263-1695
Lawrence C. Walko	U.S. Air Force AFSAL/FIESL	AV 787-7718 (513) 257-7718
Nickolus O. Rasch	FAA/APM-700	(202) 426-1410
Felix L. Pitts	NASA-LARC	(804) 865-3681
Bob Von Husen	Federal Aviation Admininstration Aircraft Safety Program (APM-713) 800 Independence Ave, S.W. Washington, DC 20591	(202) 426-3593
David G. Snedaker	Test Dept. Code 9452, N.A.E.C. Lakehurst, NJ 08733	(201) 323-7636
Robert V. Anderson	NRL/4115 Washington, DC 20375	(202) 767-3350
Vid L. Buggs	US Army Applied Technology Lab.	AV 927-3302 (804) 878-302
Vlad Mazur	NSSL/NOAA	(405) 360-3620
Lothar Ruhnke	NRL/Navy Washington, DC 20375	(202) 767-2951
J. Birken	NASAIR Air	(202) 692-7803
Rudy C. Beavin	AFWAL/FIEA	(513) 255-2527
Mike Glynn	FAA Technical Center	(609) 484-4138

ATTENDANCE (CV-580)

CV-580 Direct Strike Lightning
Meeting - 30 January 1985

Name	Affiliation	Phone
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Lothar Ruhnke	NRL	(202) 767-2951
Rod Perala	EMA/DENVER	(303) 989-2744
Martin Unam	Univ. of Florida	(904) 392-0940
R. V. Anderson	NRC-4115	(202) 767-3350
Bill Jafferis	KSC-Shuttle Operations	(305) 867-2437
David G. Snedaker	NAEC Test Dept. Lakehurst, NJ	(201) 323-7636
Lowell E. Earl	AFISC/SESO Norton AFB, CA	(714) 382-4703
Stan Schneider	MS 33-03 The Boeing Co. Seattle, Washington	(206) 241-4417
Haold Shonyo	Boeing Vertol, Philadelphia MS P32-33	(215) 522-3027
Edward Schulte	McDonnell Aircraft, St. Louis, MO	(314) 234-9080
Robert C. Twdmey	Douglas Aircraft Company Long Beach, CA	(213) 593-1069
Bob Van Husen	FAA/APM-713	(202) 426-3593
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Pete Rustan	AFWAL/FIESL WPAFB, OH	(513) 257-7469
Nick Rasch	FAA/APM-700	(202) 426-1410
Larry Walko	AFWAL/Fiesl WPAFB, OH	(513) 257-7718
Gus Weinstock	MIAIR	(314) 233-4343
Cliff Skouby	MCAIR	(314) 233-4341
Rick Goodwin	MCAIR	(314) 233-2993

END

DTIC

7-86