DOT/FAA/CT-86/340-1

Proceedings and Minutes of the National Interagency Coordination Group Meeting

National Atmospheric Electricity Hazards Protection Plan for Aircraft

February 11-12, 1986

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

March 1986

Proceedings

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The meeting was held at the Atlantis Casino Hotel, Atlantic City, New Jersey

16. Abstract

This publication is a composite of the minutes and presentations given at the annual National Interagency Coordination Group on Lightning and Static Electricity meeting held in Atlantic City, New Jersey, on February 11-12, 1986. Mr. Michael S. Glynn of the Federal Aviation Administration Technical Center, Atlantic City Airport, New Jersey, 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	18. Distribution Statement
Lightning Characterization Rate-of-Rise Electromagnetic Compatibility	This document will have limited distribution which will include members of the National Interagency Coordination Group and guest speaker only.

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Unclassified	Unclassified		

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*Due to a limitation on time and the fact the material was partially covered by preceeding presentations, these two enclosures were not presented but included for future reference.

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(continued)

EXECUTIVE SUMMARY

The annual meeting of the National Interagency Coordinating Group (NICG) sponsored by the Federal Aviation Administration (FAA) Technical Center was held in the Atlantis Hotel/Casino, Atlantic City, New Jersey, on February 11, 1986. In addition, on February 12, 1986, the final planning meeting for the 1986 NICG Conference to be held in Dayton, Ohio, in June was held. Both meetings were chaired by Mr. Michael S. Glynn, FAA Technical Center.

The primary purpose of the NICG annual meeting was to provide a forum for all members to brief the status of ongoing projects and those anticipated new requirements of the near future. Such a forum allows for the timely transfer of information and, in many cases, precludes duplication of effort.

Business

Mr. Mike Glynn opened the meeting by reading the minutes of the January 1985 meeting. No additions, deletions, or corrections being required, the minutes were filed.

Old Business -- None.

New Business --

- Packets for all members were distributed which contained an Atlantic City Flyer magazine, a hotel/casino directory, and a copy of deleted names from the NICG master mailing list.
- An artist drawing of the proposed 1986 NICG conference pin was presented to the group. Having no negative comments, an order was placed with the manufacturer.
- Several administrative comments were made which only referred to the accommodations while staying in Atlantic City.
- All presenters were requested to provide the secretary with a copy of their presentation so they could be included in the published minutes. All but two were immediately available.

Discussion

Larry Walko gave a brief update on the status of the 1986 conference. To date, 59 abstracts had been submitted and accepted for the conference. The current plan is for two parallel sessions Tuesday through Thursday. Authors kits are prepared and will be sent out shortly. On February 12, 1986, final details of the conference will be addressed by the conference committee.

Mike Glynn mentioned that the current plans are to skip 1987, and the 1988 conference would be held in Boulder, Colorado, in June. Don MacGorman, National Oceanic and Atmospheric Administration (NOAA), National Severe Storms Laboratory (NSSL), will chair the conference.

Dr. Lothar Ruhnke noted that the Dayton conference was written up in the January newsletter of the International Commission on Atmospheric Electricity. He further noted that the newsletter publicized the VIII International Conference on Atmospheric Electricity to be held in Uppsala, Sweden, on June 13-16, 1988. This may require some coordination/thought as to the timing of an NICG conference in 1988.

With no further discussion, the meeting continued with the formal prepared briefings by each member.

NICG

AGENDA

2-11-86

0900	Call to Order	Glynn
0910	Welcome	Reed
0915	Administration	Glynn
0930	Overview Flight Safety Research Atmospheric - Electrical	Glynn Lawrence
1000	Activities of the Atmospheric Electricity Group (USAF)	Walko
1030	Lightning Characteristics and Effects	Pitts
1100	Categories of Lightning Strikes to Aeroplanes	Mazur
1130	LUNCH	
1300	Advanced Development Program Update	Walko
1330	Army Aviation R&D Activities	Albright
1400	Absolute Aircraft Electrical Fields from Aircraft	Anderson
1430	N49 - Convair 580 Future Requirements	Glynn

1986 NICG UPDATE

FAA
FLIGHT SAFETY RESEARCH
ATMOSPHERIC - ELECTRICAL

MICHAEL S. GLYNN
FAA TECHNICAL CENTER

NICG BRIEFINGS

NASA DIRECT STRIKE ANALYSIS

ADVANCED DEVELOPMENT UPDATE

FLIGHT SAFETY RESEARCH BRANCH

MISSION STATEMENT

Provides Engineering and Scientific Leadership to Plan, Develop, Implement, and Manage Complex/Sophisticated Research Efforts in Atmospheric Hazards and Advanced Technology as Related to the Airworthiness, Certification, and Operational Safety of Civil Fixed/Rotary Wing Aircraft.

LOW ALTITUDE

DIRECT STRIKE

LIGHTNING CHARACTERICATION

PROGRAM

DIRECT STRIKE LIGHTNING

84

FLORIDA
RESULTS
REPORT

85

FLORIDA
NASA WALLOPS
RESULTS
REPORT

86

PATUXENT RIVER
NASA WALLOPS

FUTURE

NATIONAL RESOURCE
NSSL
NRL
NASA

GEOGRAPHIC STUDY

CRMI

PURPOSE - CENTRALIZED DATA BASE

APPROACH - PROJECT PLAN
IDENTIFY ALL DATA BASES
COMPUTERIZE
ANALYZE

RESULTS - PROJECTED
VALIDATION OF MODELS

LIGHTNING HAZARDS HISTORICAL STUDY

LTI, RFP

PURPOSE - GATHER DATA
COMMERCIAL TRANSPORTS

APPROACH - CARRIERS
LOCAL
REGIONAL
WORLDWIDE

RESULTS - IDENTIFY TRANSPORT HAZARDS
851 THRU '84

LIGHTNING STRIKE/STATIC DISCHARGE INCIDENT REPORT

INSTRUCTIONS

The purpose of this report is to gather data relating lightning strikes or static discharges to aircraft type and flying conditions. This data will be used in support of research efforts leading to the development of lightning protection systems.

Please complete and file this report immediately following your flight, providing as much of the requested data as you can.

PART I - TO BE COMPLETED BY THE FLIGHT CREW.

PART II - TO BE COMPLETED BY THE GROUND CREW.

PART I (TO BE COMPLETED BY FLIGHT CREW):

Operational Conditions at Time of Strike

- Flight No. ________ Date ________ Time of Strike ________ Aircraft type ________
- Route ________ To ________ DME Reading ________ Miles from ________
- Altitude ________ Ft.; Air Speed ________ Kts.;
- Condition: Approach ____ Climb ____ Level Flight ____ Other ________
- Area Weather:

Cloud Type	% Cover	Ceiling (ft.)	Tops at (ft.)	SAT (°C)
________	________	________	________	________

- At time of strike aircraft was: Above Clouds ____ Within Clouds ____ Below Ceiling ____,
- Experiencing: None ____ Light ____ Mod. ____ Heavy ____ Turbulence
- Experiencing Precipitation in Form of: Rain ____ Sleet ____ Hail ____ Snow ____ None ____
- Were There Lightning Flashes in Vicinity Before ____ After ____ Strike?
- Were You Aware of Electrical Activity (Static) Before ____ After ____ Strike?
- Was St. Elmo's Fire Visible Before Strike? Yes ____ No ____

Experienced: (Check Which)

	Interference	Outage
Compass	1 __ 2 __	1 __ 2 __
Weather Radar	1 __ 2 __	1 __ 2 __
VOR Receiver	1 __ 2 __	1 __ 2 __
ILS G/S	1 __ 2 __	1 __ 2 __
LF ADF	1 __ 2 __	1 __ 2 __
INS	1 __ 2 __ 3 __	1 __ 2 __ 3 __
Radio Alt.	1 __ 2 __	1 __ 2 __
CAS	1 __	1 __
VHF COMM	1 __ 2 __ 3 __	1 __ 2 __ 3 __
HF COMM	1 __ 2 __	1 __ 2 __
Autopilot	1 __ 2 __	1 __ 2 __
Other	1 __ 2 __	1 __ 2 __

Any Effects on: (Check Which)

AC Power System	________
DC Power System	________
Flight Controls	________
Engine Flameout	________

Any Effects on Personnel, such as:

Flash Blindness	________
Electric Shock	________
	________
	________

Additional Comments (Further Description of Effects Checked Above Such as Error Codes, Etc.) ________

____

____

PART I Completed By ________

PLEASE TURN TO REVERSE SIDE FOR PART II, TO BE COMPLETED BY GROUND CREW

NVL FORM L38P-1

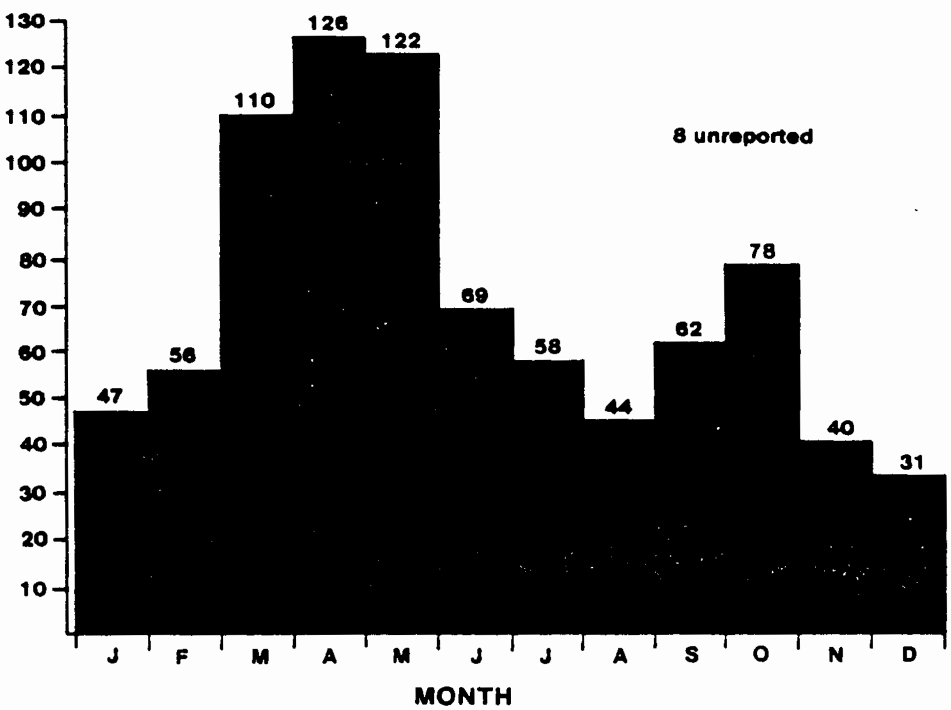
LOW ALTITUDE

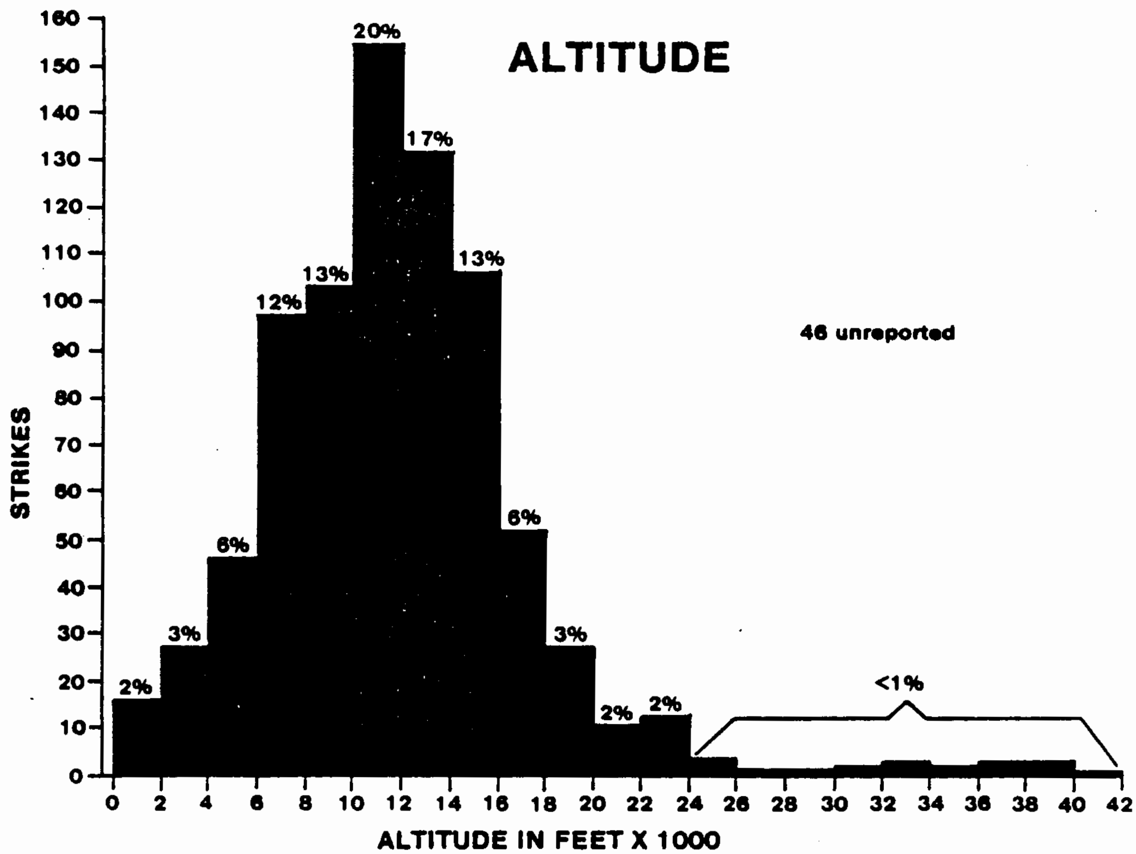
DIRECT STRIKE

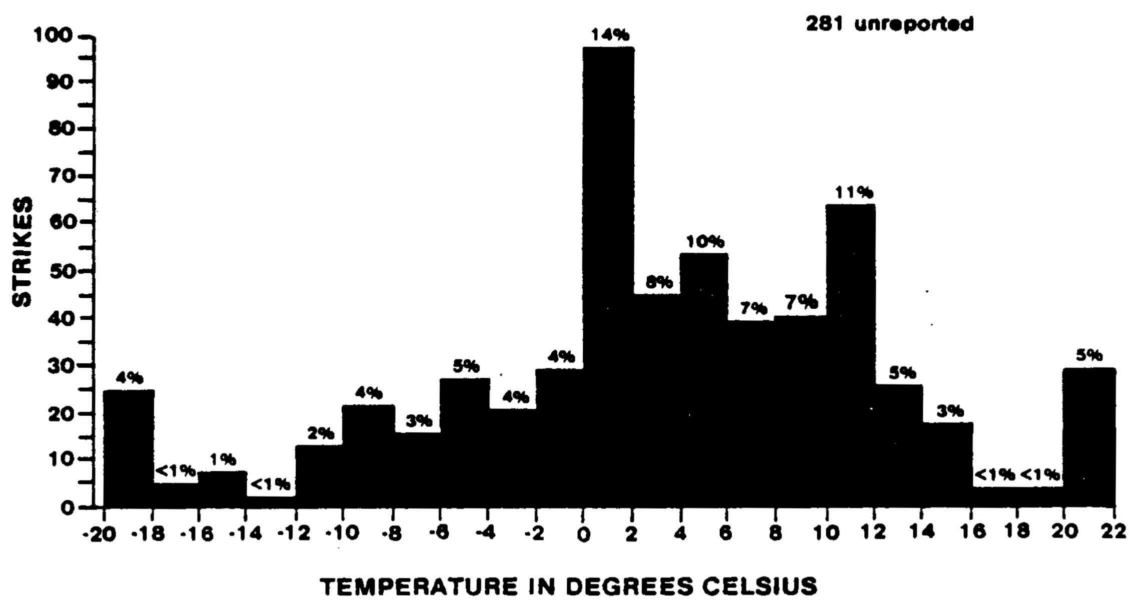
LIGHTNING CHARACTERICATION

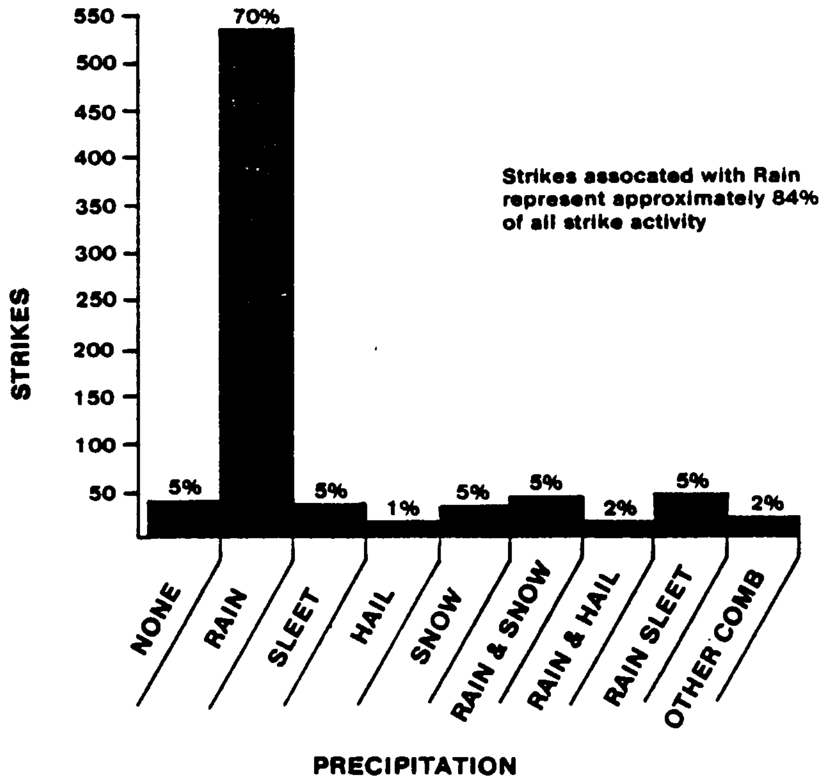
PROGRAM

STRIKES PER MONTH

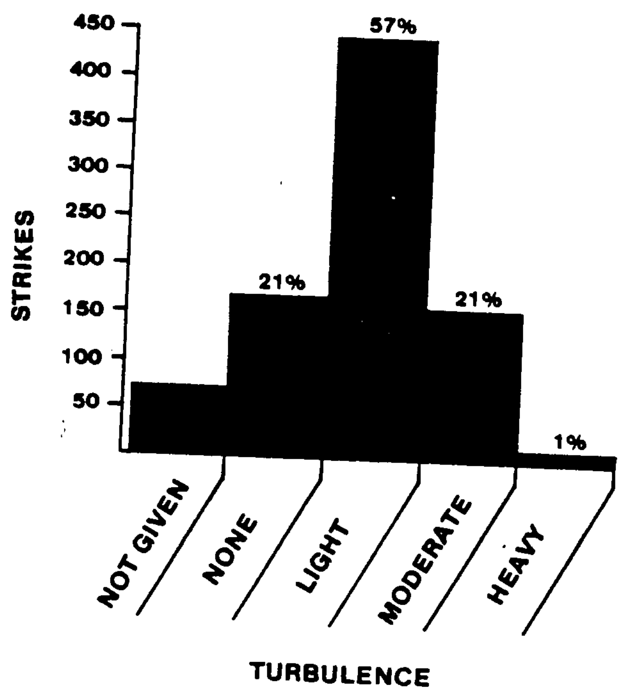


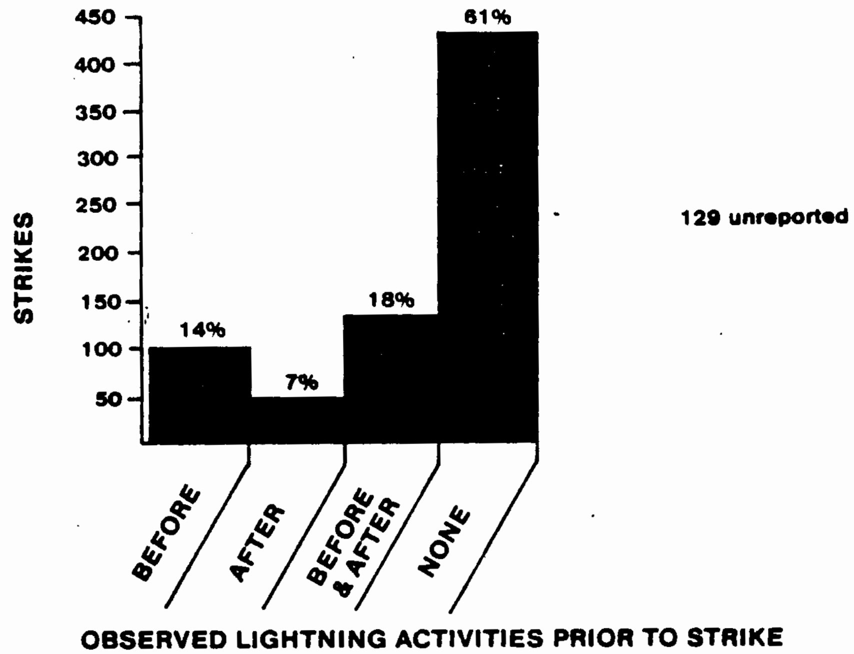

ALTITUDE
46 unreported
STRIKES
ALTITUDE IN FEET X 1000
20%
17%
13%
13%
12%
6%
6%
3%
3%
2%
2%
2%
<1%

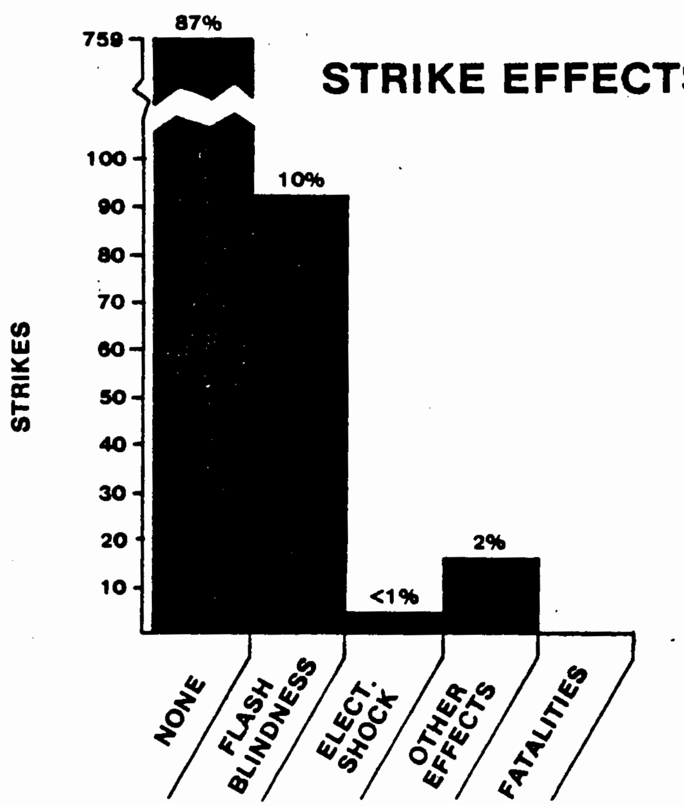

281 unreported
STRIKES
TEMPERATURE IN DEGREES CELSIUS
14%
11%
10%
8%
7%
7%
5%
5%
5%
4%
4%
4%
4%
3%
3%
2%
1%
<1%
<1%
<1%
<1%

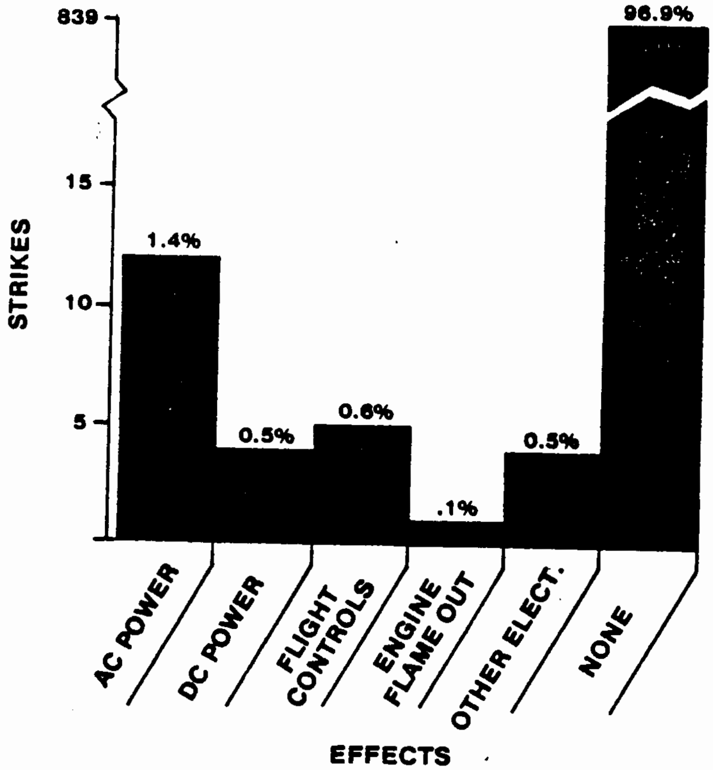


TURBULENCE NOTED

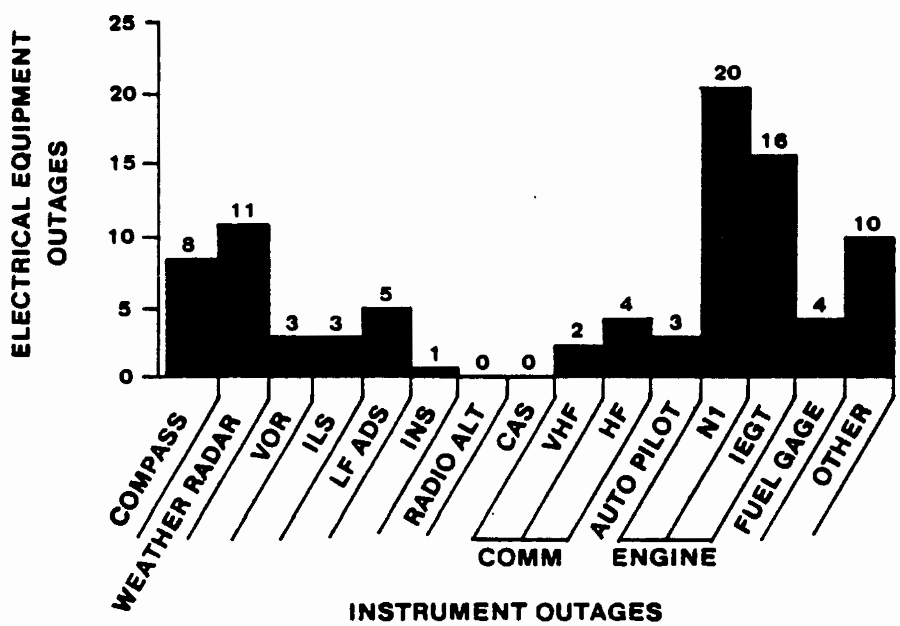



450
400
350
300
250
200
150
100
50
STRIKES
14%
7%
18%
61%
129 unreported
BEFORE
AFTER
BEFORE & AFTER
NONE
OBSERVED LIGHTNING ACTIVITIES PRIOR TO STRIKE

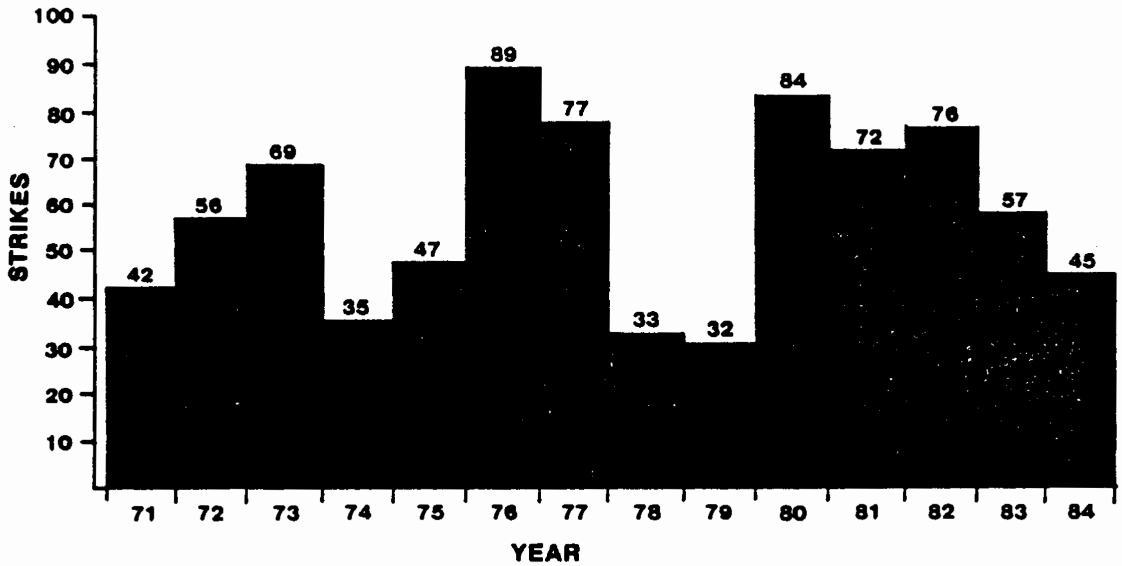

STRIKE EFFECTS TO CREW
759
100
90
80
70
60
50
40
30
20
10
STRIKES
87%
10%
<1%
2%
NONE
FLASH BLINDNESS
ELECT. SHOCK
OTHER EFFECTS
FATALITIES



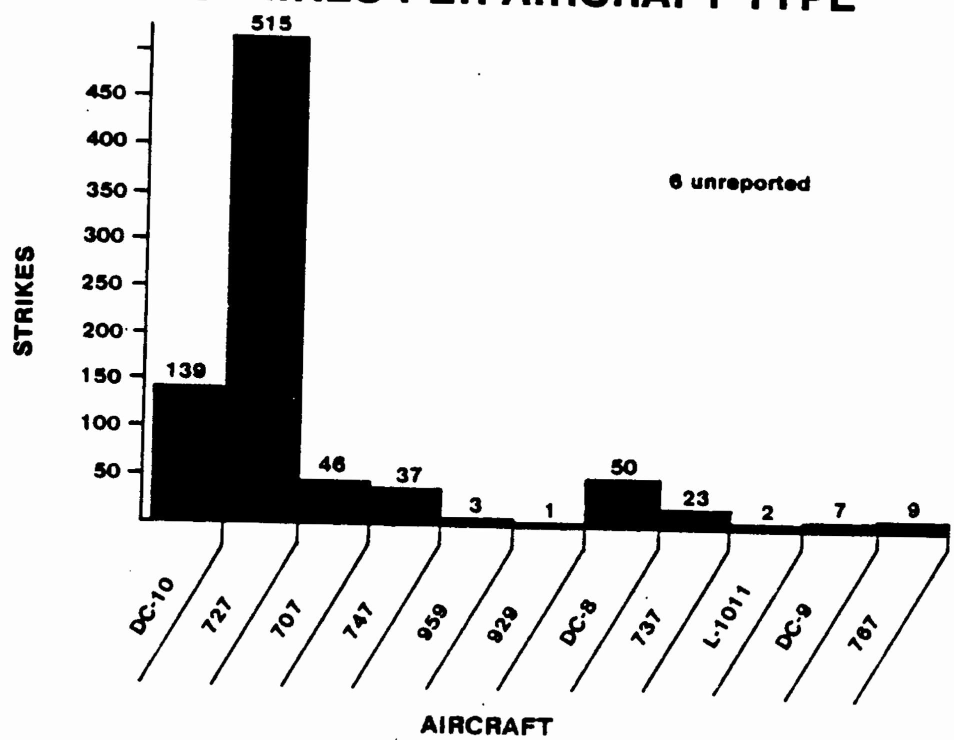
ELECTRONIC EQUIPMENT INPACT DUE TO LIGHTNING STRIKES



STRIKES PER YEAR



STRIKES PER AIRCRAFT TYPE



DIRECT STRIKE LIGHTNING

NASA, FAA

PURPOSE - DATA BASE - HIGH ALTITUDE
DIRECT & INDIRECT STRIKES
CLOUD TO CLOUD
INTRA CLOUD

APPROACH - F106
FULLY INSTRUMENTED

RESULTS - 690 STRIKES

SOFTWARE

CRMI - BATTELLE, LOCKHEED
BOEING, KENDALL

SOFTWARE RELIABILITY ASSESSMENT

SOFTWARE SYSTEM ERROR DETECTION/CORRECTION

SOFTWARE MONITOR/REDUNDANCY

DIGITAL SYSTEM BUS INTEGRITY

INDIRECT STRIKE LIGHTNING HAZARDS DEFINITION

USAF, BMAC

PURPOSE - STUDY EMI & DEVELOP PROTECTION
DEVELOP
PROTECTION MEASURES
DESIGN CRITERIA
SPECIFICATION GUIDELINES

APPROACH - FABRICATE TEST BED
TEST DESIGN AND CRITERIA

RESULTS - HANDBOOK
DESIGN
TESTING

<u>LIGHTNING SIMULATION TEST TECHNIQUES</u>

<u>COMPOSITE MATERIALS ELECTRICAL PROPERTIES</u>

<u>LIGHTNING PROTECTION HANDBOOK</u>

<u>DAVID LAWRENCE</u>

<u>FAA TECHNICAL CENTER</u>

LIGHTNING PROTECTION HANDBOOK UPDATE

* Original published in 1977 as NASA!s RP 1008, "Lightning Protection of Aircraf

* Update obviously needed to bring together in a single reference volume the important information that has been developed since 1977.

* Considered to be an FAA responsibility, ~~xx~~ despite NASA's original sponsorship The book is to be prepared as a handbook to assist designers, manufacturers, certification engineers and operators by supplying practical and technical in formation for the lightning protection of all aircraft (f/w & r/w).

* Bulk of the work involved will be (obviously) concerned with the proxtection of composite airframe components, digital avionics - autopilots, AFCS, engine montrols etc.

* Proposed work is intended to develop a readily useable reference volume, reflecting the most recent practical knowledge of the lightning phenomenon itself, its effects on all types of airframe and aircraft equipment, and the practical means by which all concerned can protect them.

* Present publication deals with the material under these general headings:

The lightning phenomenon - how and where it occurs

How aircraft become involved with lightning

Conditiond under which aircraft are struck

Summary of direct and indirect effects

Protection of aircraft against direct effects

The mechanisms of indirect effects, analytical methods, testing and protection against indirect.

It is anticipated that the new handbook will follow the same general format, with greatly expanded sections on advanced airframes/structural materials, digital avionics.

* It is expected to let a contract forx this work late this summer, with a draft final report due ten months after date of award of contract.

DETERMINATION OF THE ELECTRIAL PROPERTIES OF GROUNDING, BONDING AND FASTENING TECHNIQUES FOR COMPOSITE MATERIALS.

* Work under this contract was performed to:

a) Evaluate grounding, bonding and fastening electrical properties for metal, metal honeycomb and advanced composite materials

b) Select candidate bonding and grounding systems for modelling test and evaluation.

c) Perform and analyse further selected test techniques.

d) Provide recommendations based on the analysis.

The final document is to be in handbook format, providing design requirements and guidelines..

* The problems of non-metallic primary structure, the use of bonding to join metal components (instead of rivetting same) include the much reduced electric conductivity and shielding.

* The report provides technical data on bonding and grounding reqirements for composite materials and recommendations for bonding and grounding specification applicable to advanced technology aircraft.

* There are three main sections to the report:

I) Extensive background information, discussion of direct and indirect effects of lightning on advanced airframes and avionics, and how these differ from the effects on conventional airframes.

II) Test methods evaluation - test methods were identified for determining the the electrical properties of structural elements and assemblies appropriate for lightning, static electrification and RF environments, specifically for:

a) Bulk material properties
b) Coating properties
c) Joint characterisation
d) Bonding ditto
e) Grounding ditto

The methods were evaluated for their application to the bonding/grounding tests needed to characterise advanced technology aircraft structural matdrials. Evaluation considered:

a) Accuracy of the data.
b) Validity of extrapolation of data to lightning threat magnitudes.
c) Do the methods yield basic data applicable to full-scale structures?
d) Is data obtained on threshold current and breakdown voltage?
e) Is the data to be used to set safety margins against sparking?

* Existing material was surveyed and quoted, and an extensive bibliography provided.

* Test data is required to determine allowable current levels that samples can stand without sparking.

  Data is required on current distribution through the complete vehicle.

* The approach to assessing a design for lightning protection is spelled out, indicating where tests on coupons and sub-assemblies will suffice, and where complete vehicle testing is desirable.

* Experimental test methods, their merits and their deficiencies are discussed at length.

III) Analytical models.

Five analytical models for determining the resistance of metal fasteners in composite panels are discussed. The first was the resistance sheet analog meth the other methods were strictly mathematical. The methods were tested on numbe of samples, and results presented for comparison.

* Spark threshold models are discussed at length.

* Composite damage models - radius of damage, action integral.

* Voltage breakdown of subelements.

* Draft final report has been reviewed.

EVALUATION OF LIGHTNING SIMULATION TEST TECHNIQUES.

* Required to address the problem of lightning protection verification for design and certification purposes - particullarly advanced materials and electronics technology. Previous methods pertaining to all-metal aircraft/ analog electronics of no help.

* Simulated lightning tests are required on the new airframes/equipment to verify the adequacy of the protection measures. Full-threat tests on a complete airframe not possible because of storage capacity requirements and inability to achieve the maximum rate of rise of current - assuming that agreement on this is ever reached.

* As a result of the limitations indicated, the task is acccomplished by attacking singly the salient features that comprise a lightning strike, instead of covering them all at one time. Different, achievable methods are appropriate - each one designed to handle a single feature.

* Several techniques have emerged for ~~xxxxxxx~~ complete vehicle lightning tests. Four in common use are:

  a) Swept frequency contimuous wave

  b) Fast rise time low level pulse

  c) Full threat fast rise time pulse (?)

  d) Shock excitation pulse.

* Evaluation of a technique must include evaluation of the analytical models and computations to check and validate the test data. For some methods, analytical procedures permit extrapolation of test data to the other (more severe) environments, and give guidance for design modifications.

* FAA is looking for validation criteria to assure that lightning protection measures in advanced technology aircraft are adequate. This is far from simple each test method used requires a different level of analytical detail in the extrapolation of the measured data.

* Specific objectives of the test progam are to

  a) Develop comparitive data on the effectiveness of the four commonly used lightning simulation test methods

  b) Define the analytical requirements to extrapolate the ~~xxx~~ results of the tests to severe lightning environments.

* The investigation will use a specially designed and fabricated test bed, dimensionally and electrically representative of a general aviatioh heavy single engine airplane (Bellanca). It consists of the fuselage, a single wing, vertical tail, an engine block (which is simply plywood faced with aluminum sheet), and a test stand. The test bed contains several built-in systems that electrically represent elements of:

  Fuel system - electrical
  Fuel system - mechanical
  Engine controls
  Autopilot
  Electrical power system

  Simulated lightning induces voltages and currents in the above systems. Responses are measured for use in defining/characterising response to the various simulated lightning environments. Other sensors measure sources of EM coupling into the test bed, and the IR drop in joints and sections of skin.

* The work is being done with the aid of facilities at WPAFB. The initial (swept CW) phase has been completed, and an interim report is in preparation.

* Completion scheduled for the Fall of 1987.

AIRCRAFT ELECTROSTATIC DISCHARGE STUDY

* Investigate precipitation-static interference to communications and navigation equipment, and upset of the associated computers.

* Technical approach to investigating/solving this problem

I) Computers

a) Study the susceptibility of computers to electric/magnetic fields and conducted interference.

b) From results of a), combined with existing theoretical analyses, recommendations/guidelines will be developed to reduce/prevent sub-systems upset.

II) Low-frequency navigation systems.

a) Study the effects of electrostatic charging and discharging on L-F navigation systems, such as OMEGA and LORAN _ specifically study the mechanisms of static electrification and how this in turn generates interference - and how it may be reduced

b) Passive and active discharge systems/special antenna systems.

III) Shock hazards from hovering helicopters

a) Problem of masking of the sensors by charged dust or snow

b) Develop methods of making field measurements in the presence of charged particle cloud

IV) Develop a full-scale model and demonstrate criteria required for the alleviation of discharge effects on composide airframes with 5th generation computers

V) Develop a full-scale model and demonstrate the feasibility of using active/passive systems and special antennas to alleviate the discharge problem.

VI) Develop a model and demonstrate the feasibility of an active discharge system capable reducing helicopter-to-ground potentials during low-level operations typical of air-sea rescue.

ACTIVITIES OF THE ATMOSPHERIC ELECTRICITY GROUP

USAF

LARRY WALKO

WRIGHT-PATTERSON AIR FORCE BASE, OHIO

AIR FORCE WRIGHT AERONAUTICAL LABORATORIES


AFWAL

FY86 IN-HOUSE WORK UNIT SYNOPSIS

WORK UNIT NO.: 24020223

WORK UNIT TITLE: Atmospheric Electricity Hazards Assessment for Aircraft

PRINCIPLE INVESTIGATOR: Lawrence C. Walko

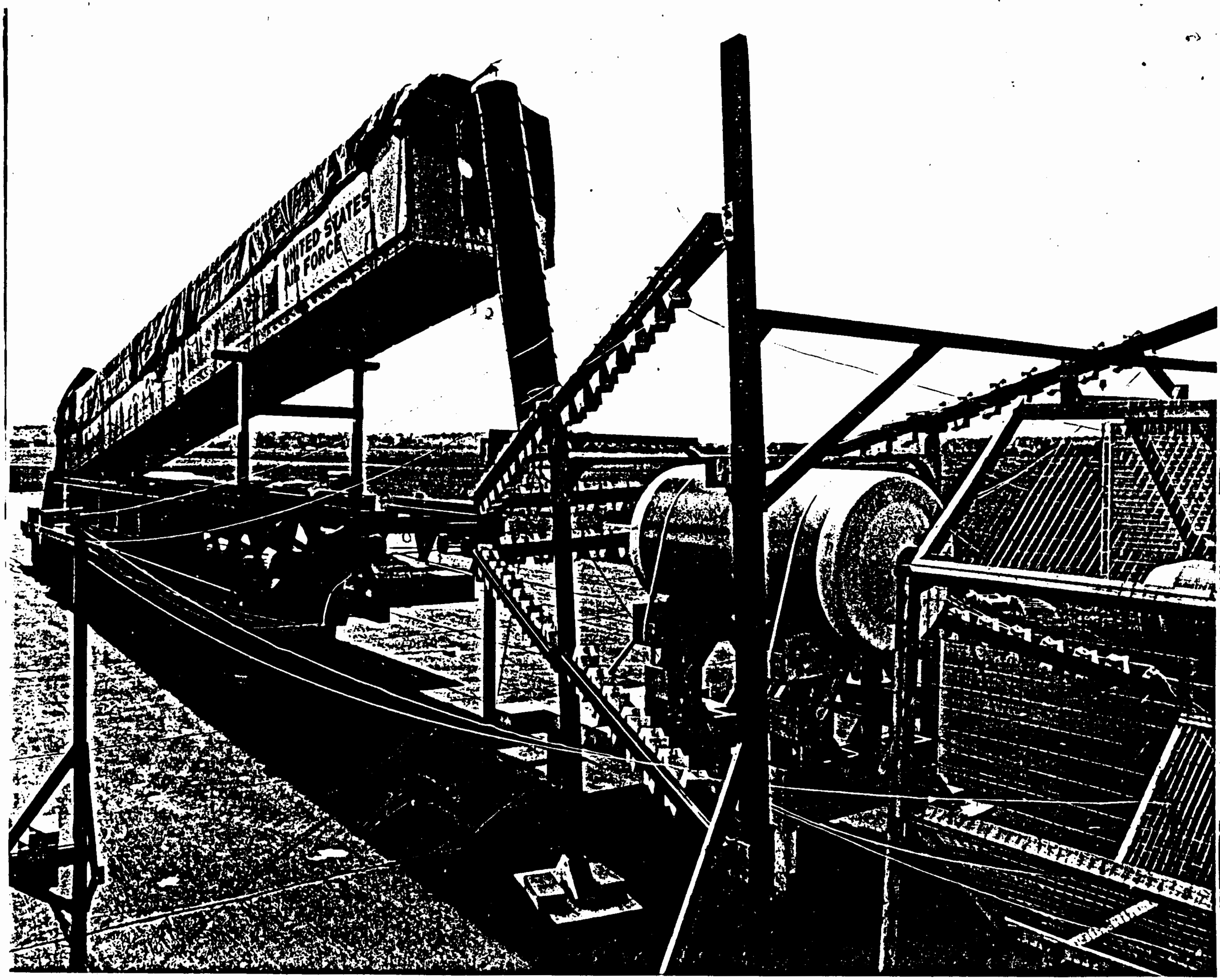
SUBTASK I: Assessment Methodology

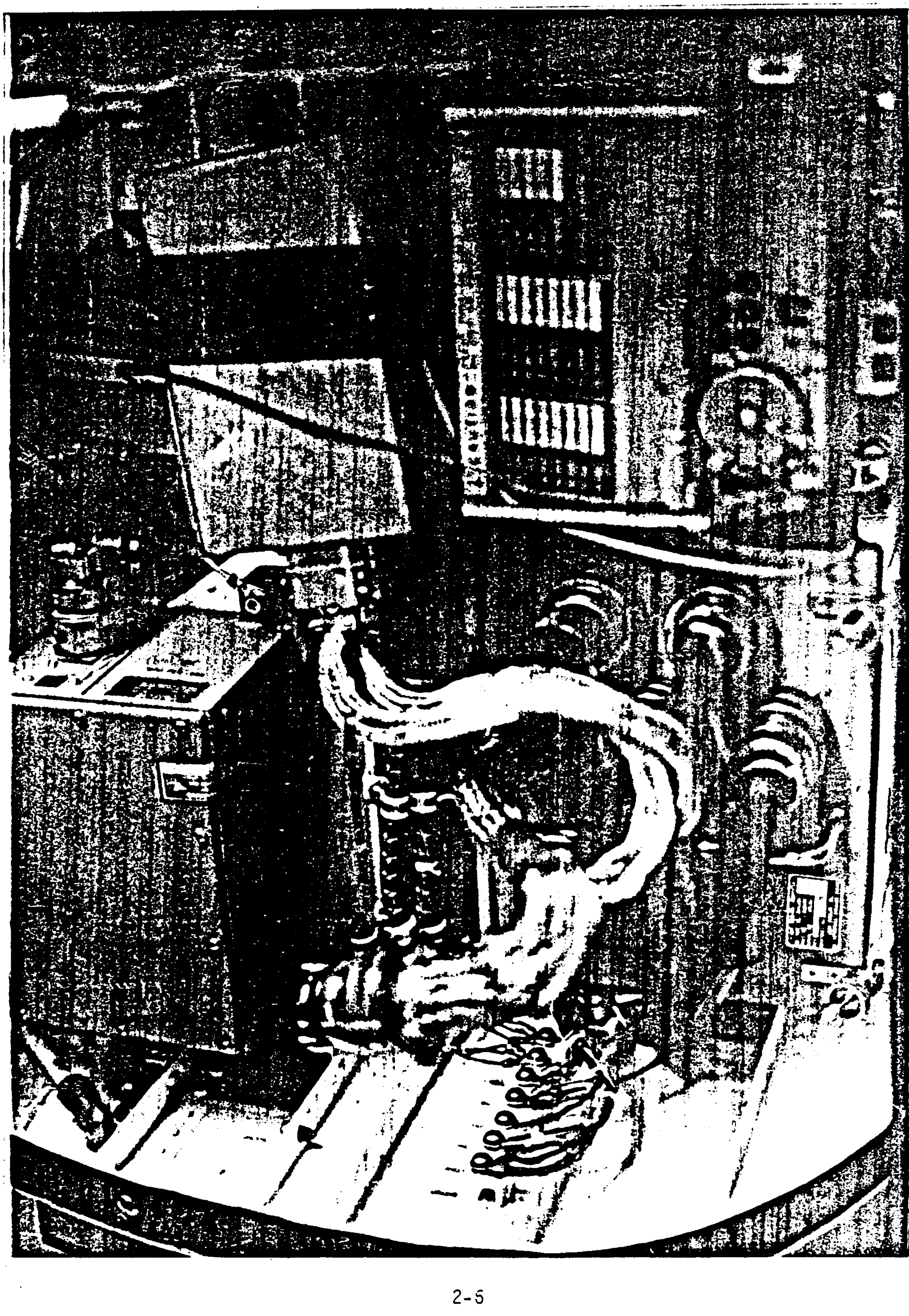
LEAD ENGINEER: 1Lt James L. Hebert

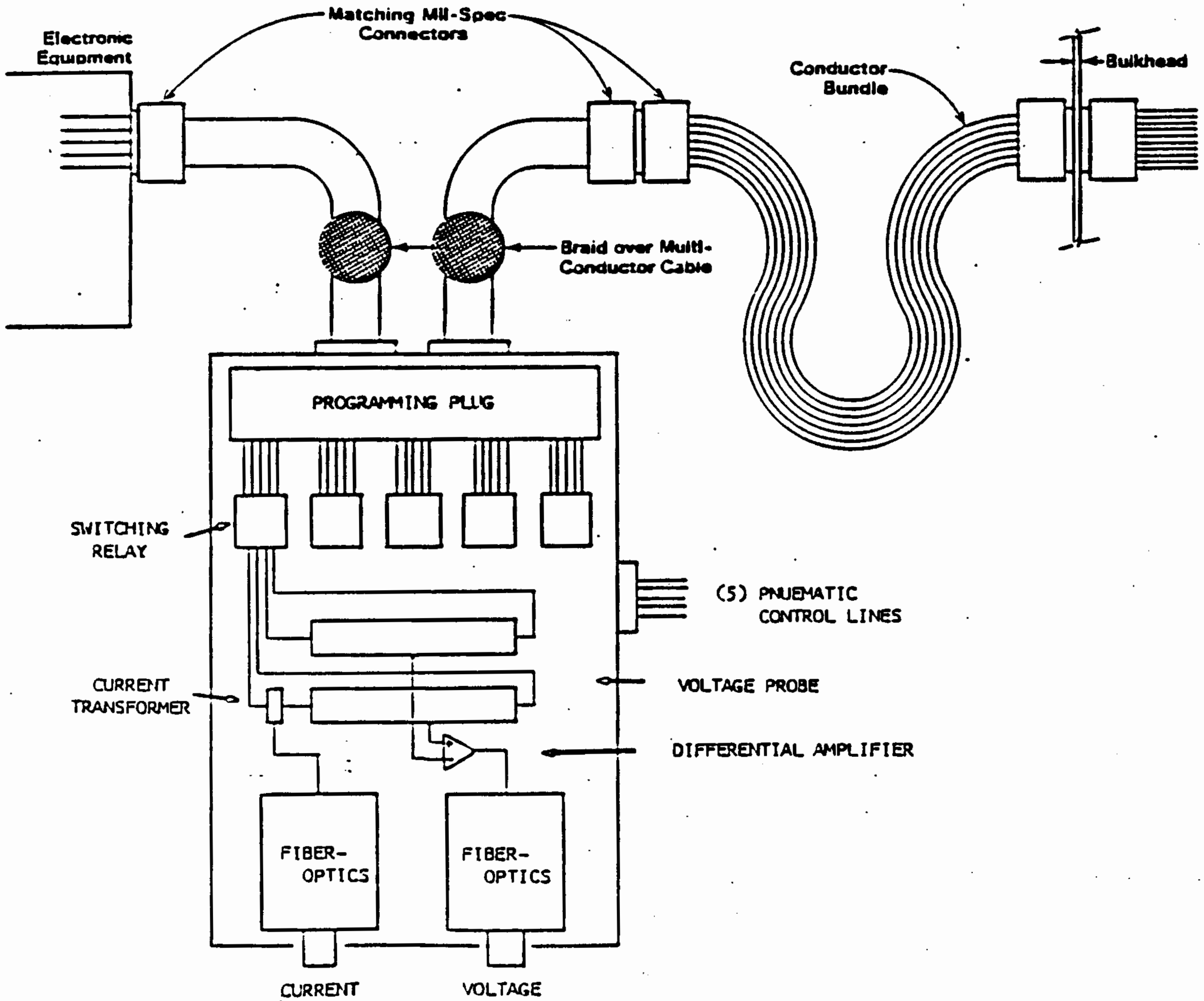
OBJECTIVE: Develop techniques and procedures that accurately assess the impact of natural Atmospheric Hazards to Aircraft.

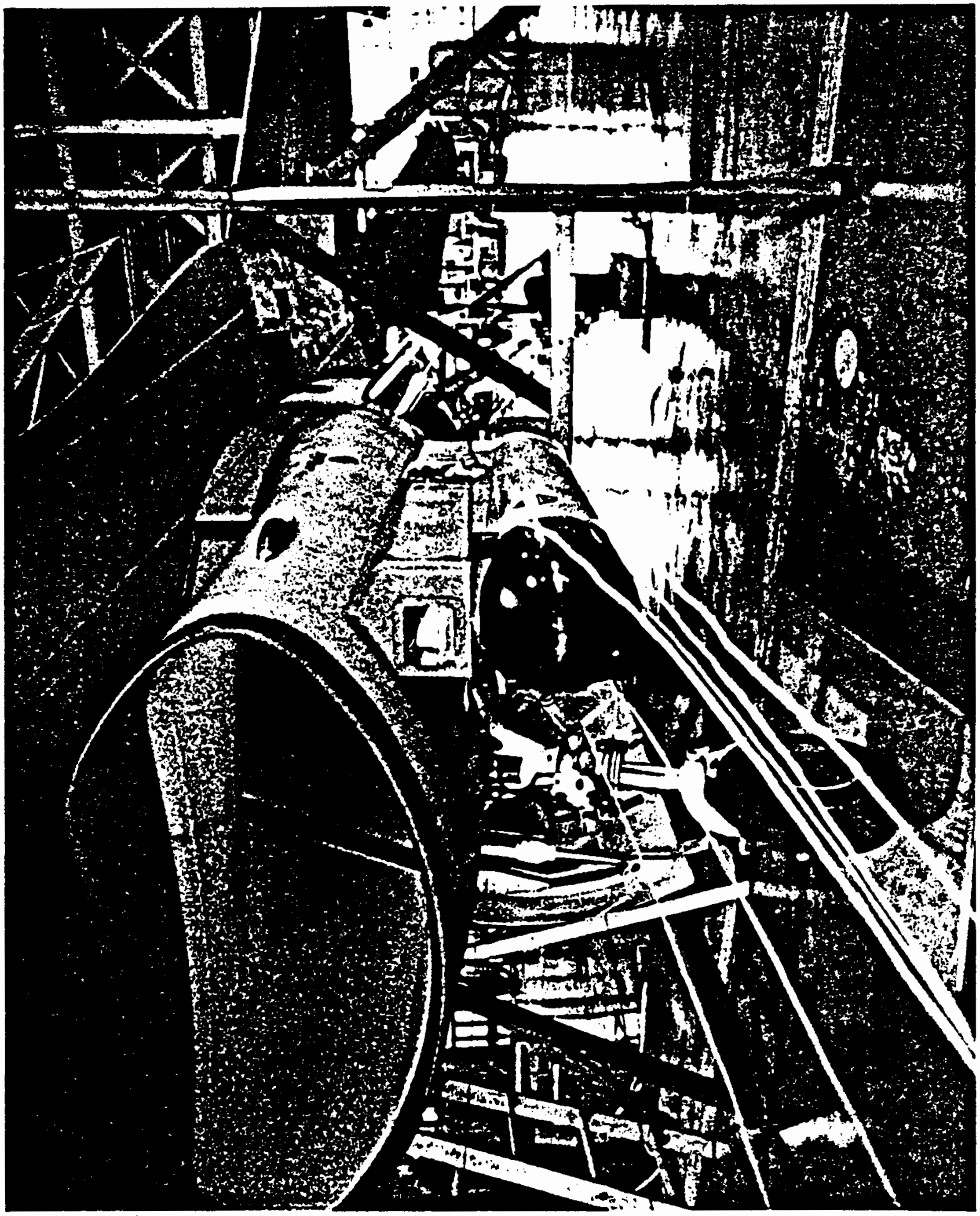
EXPECTED RESULTS: (1) Construct operational fast risetime/high current lightning simulation system. (2) Development and validation of simulation test and analytical techniques.

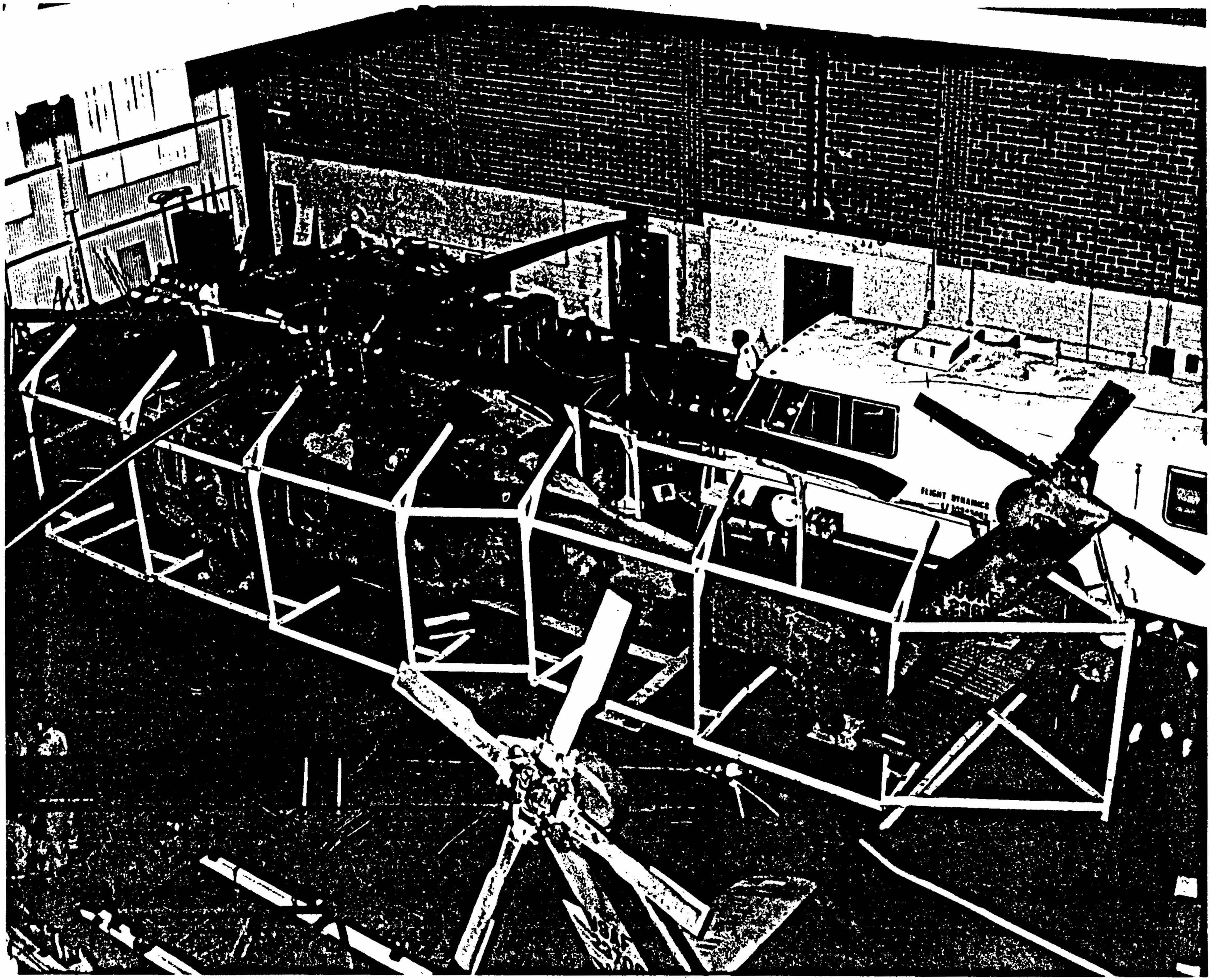
END PRODUCT AND DATA: Technical Reports, September 1986


UNITED STATES
AIR FORCE




Matching Mil-Spec Connectors
Electronic Equipment
Conductor Bundle
Bulkhead
Braid over Multi-Conductor Cable
PROGRAMMING PLUG
SWITCHING RELAY
(5) PNUEMATIC CONTROL LINES
CURRENT TRANSFORMER
VOLTAGE PROBE
DIFFERENTIAL AMPLIFIER
FIBER-OPTICS
FIBER-OPTICS
CURRENT
VOLTAGE

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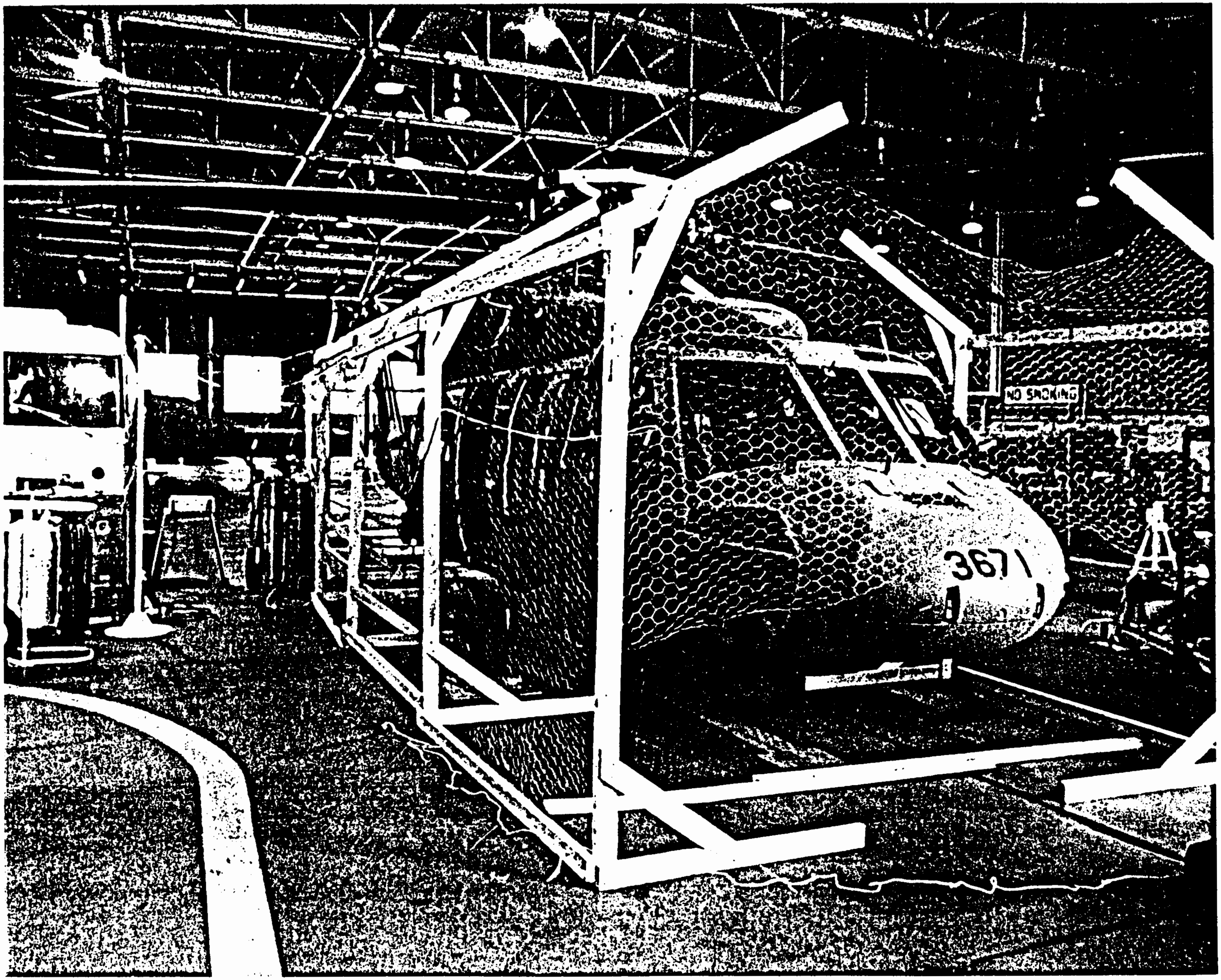
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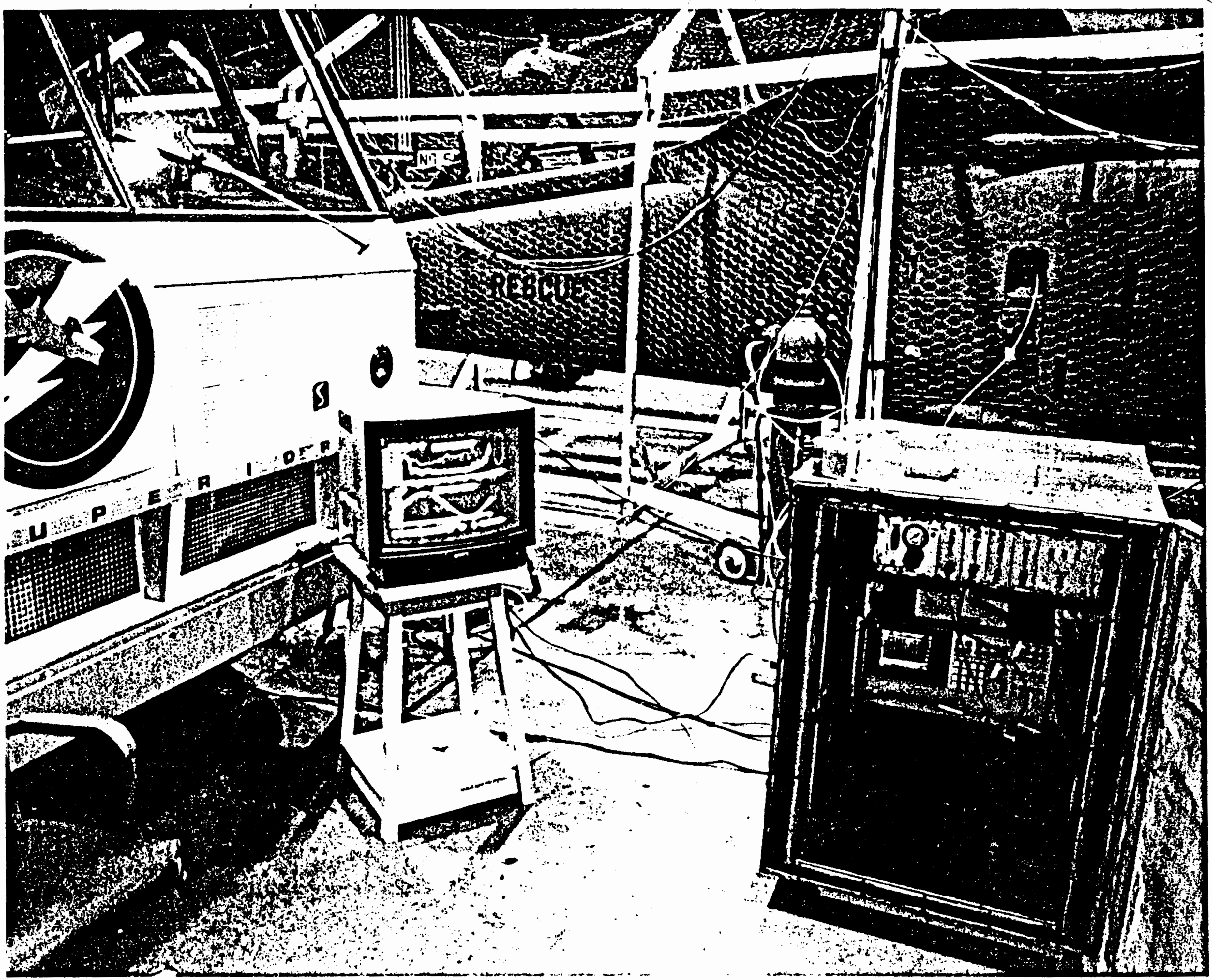
3671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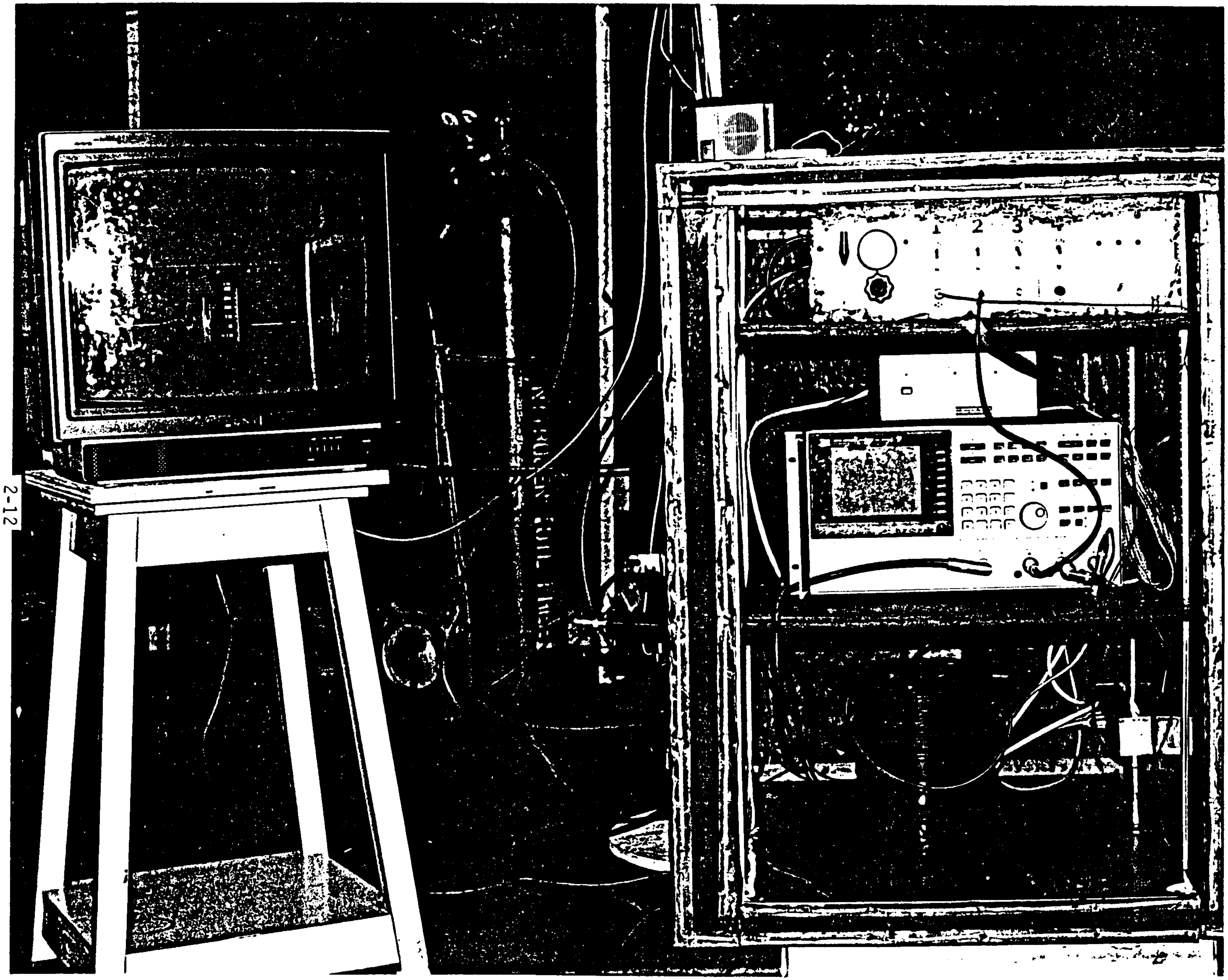
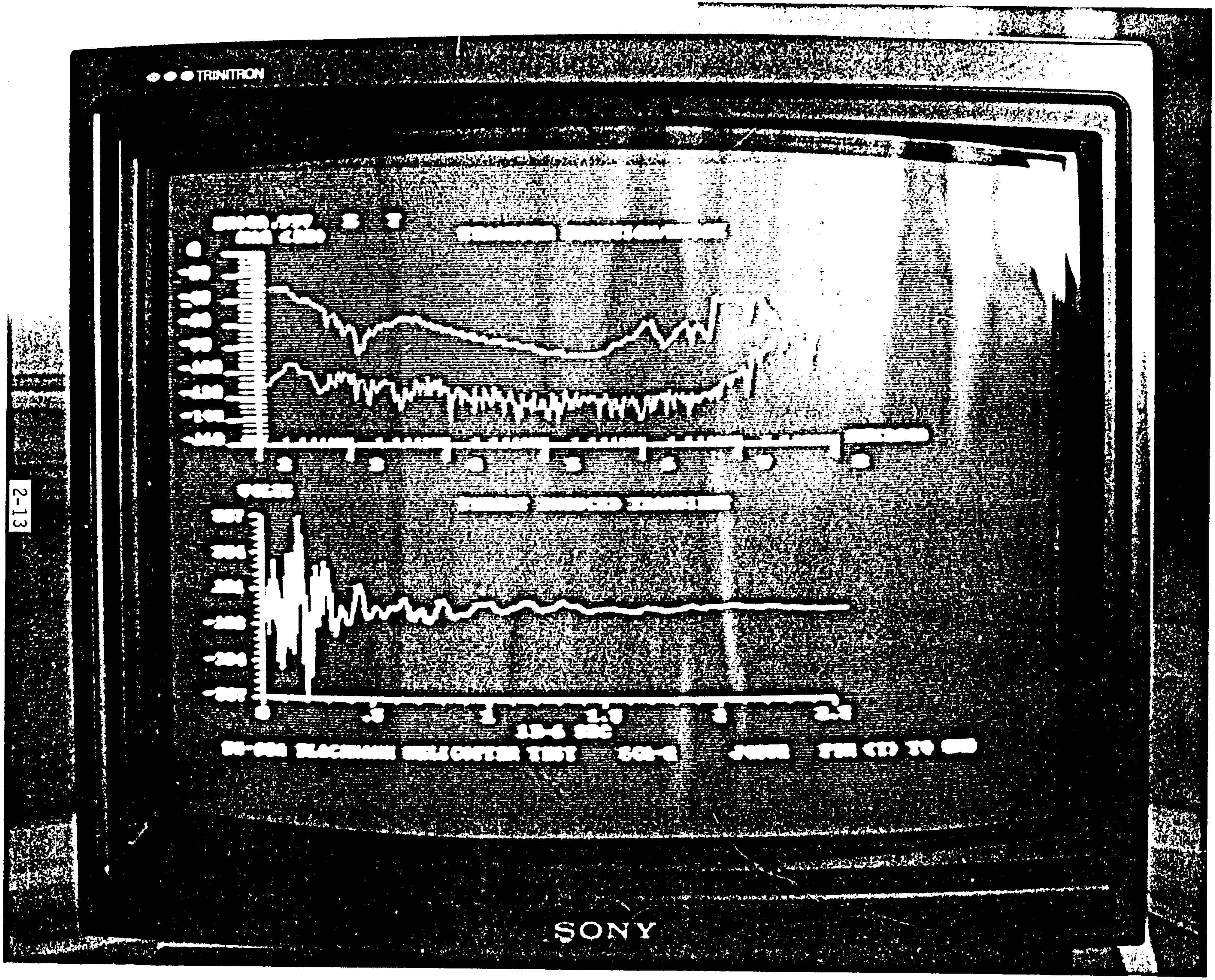
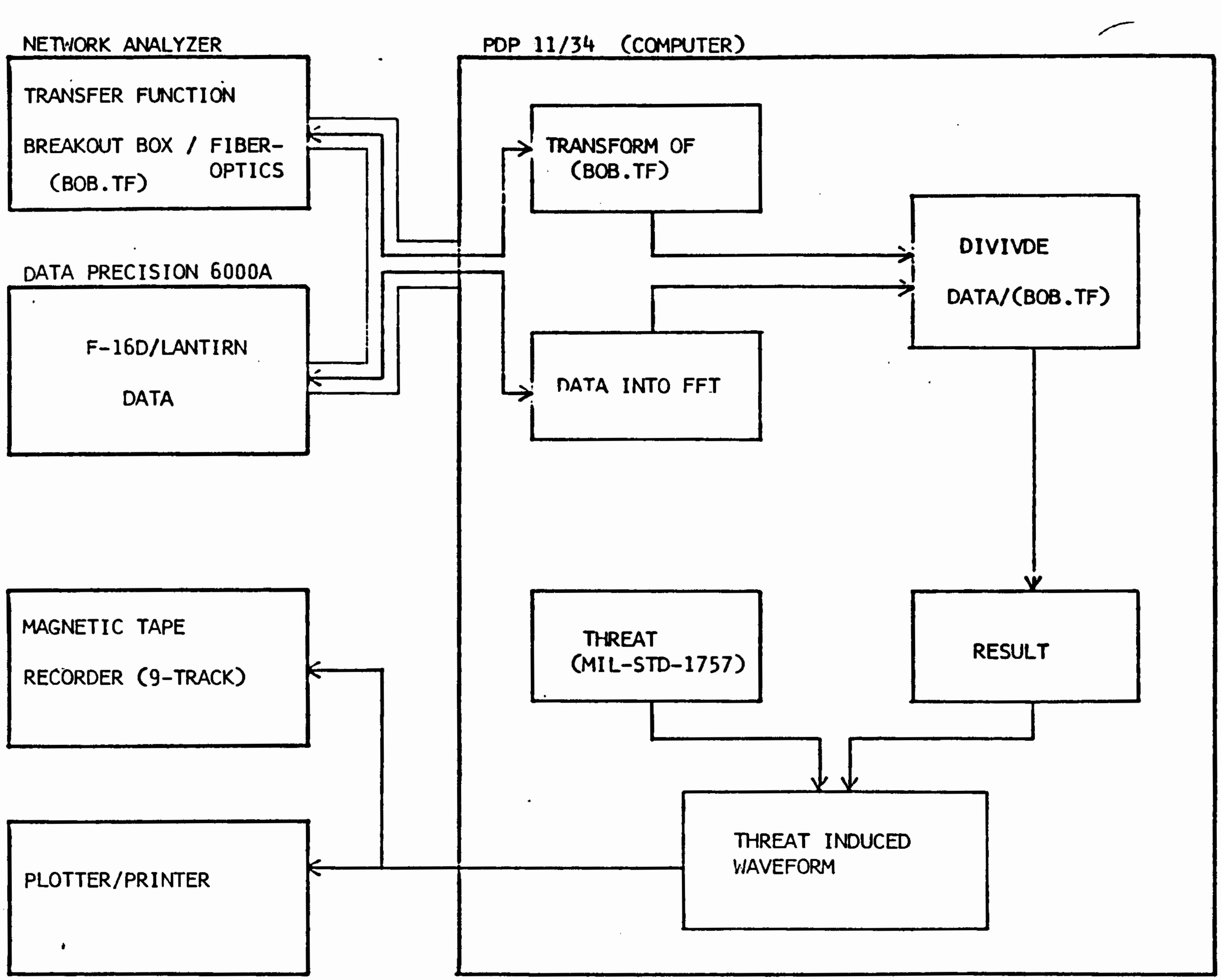



TRINITRON
SONY


NETWORK ANALYZER
TRANSFER FUNCTION
BREAKOUT BOX / FIBER-OPTICS
(BOB.TF)
DATA PRECISION 6000A
F-16D/LANTIRN
DATA
MAGNETIC TAPE
RECORDER (9-TRACK)
PLOTTER/PRINTER
PDP 11/34 (COMPUTER)
TRANSFORM OF
(BOB.TF)
DIVIVDE
DATA/(BOB.TF)
DATA INTO FFT
THREAT
(MIL-STD-1757)
RESULT
THREAT INDUCED
WAVEFORM

W.U. 24020223
Subtask I: Assessment Methodology
FY 86 Tasks

Facility Enhancement

1. Completion of construction of portable 4 MV Marx generator.

2. Completion of computer control for SFCW.

3. Integration of state-of-the-art data acquisition system (CV-580) into AEH test facility.

Research and Development

1. Qualification Test Research using various lightning simulators

   a. All-metal LSO

   b. All-metal LSO with graphite composite panels

   c. Metal LSO with graphite composite section.

2. Electromagnetic (EM) Analysis

   a. Continued implementation of the GEMACS and T3DFD EM Codes

   b. Develop circuit analysis program for response predictions for LRU's down to pin level.

3. Validation

   a. After development of the EM codes, all research testing will be preceded by EM analysis and the testing used to validate, and improve the analytical techniques.

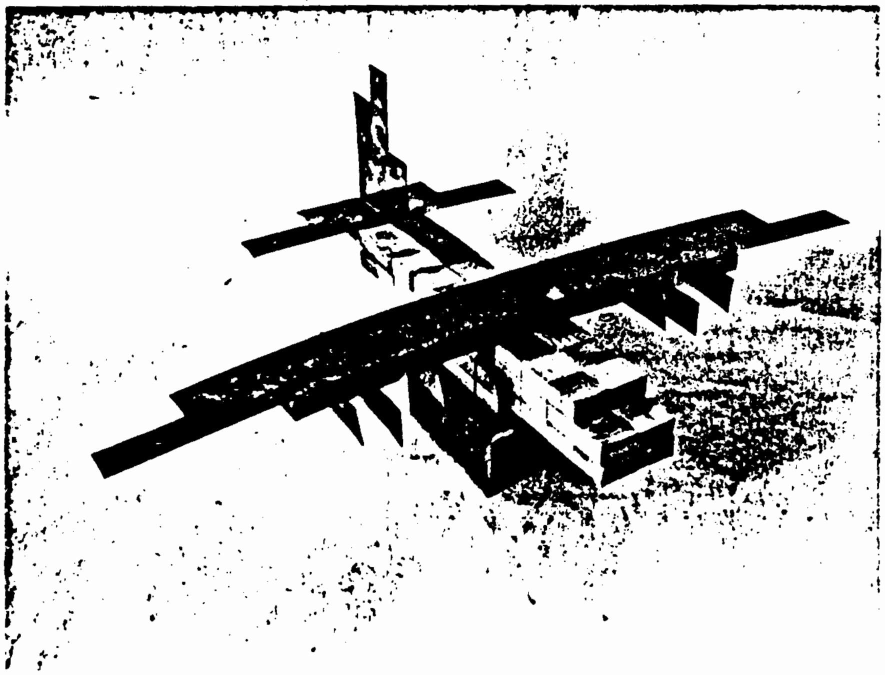


Figure 4.9. Actual Model of 3DFD C-130

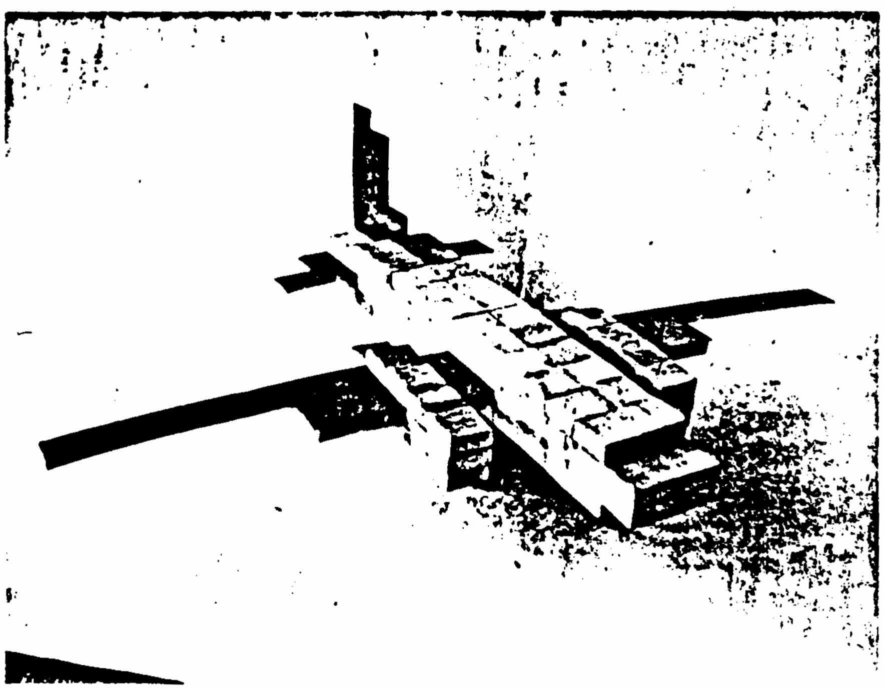
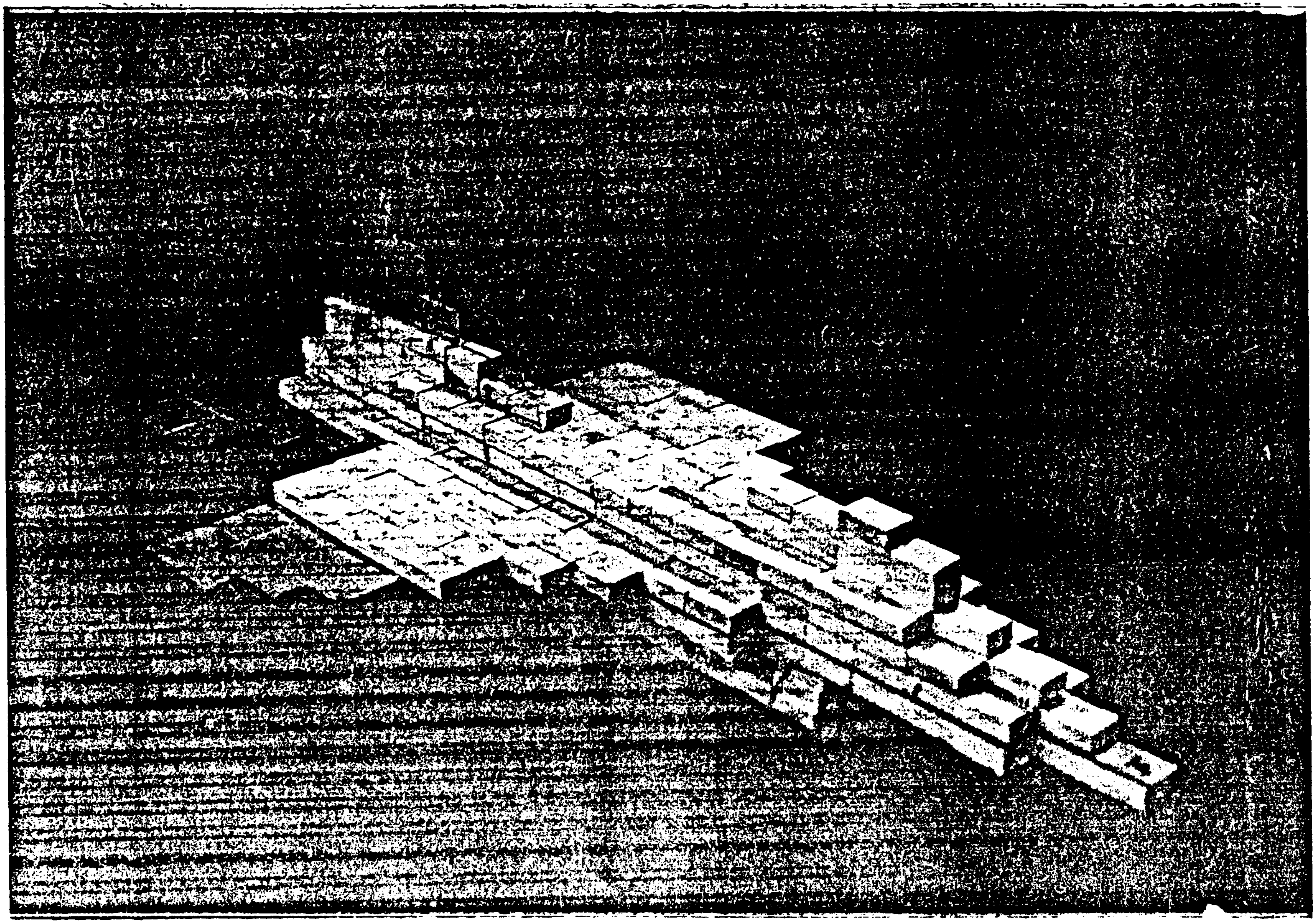


Figure 4.10. Actual Model of 3DFD CV-580



FY86 IN-HOUSE WORK UNIT SYNOPSIS

WORK UNIT NO.: 24020243

WORK UNIT TITLE: Lightning/EMP Measurement Program

PRINCIPAL INVESTIGATOR: Lawrence C. Walko

OBJECTIVE: Assess the characteristics and impact of lightning direct strikes and simulated nuclear electromagnetic pulse (NEMP) on a common test vehicle.

EXPECTED RESULTS: (1) Expand the limited existing data base on lightning direct strike characteristics. (2) Commonalities and differences in lightning and NEMP can be identified.

END PRODUCT AND DATE: Technical Report, September 1986

LIGHTNING/EMP MEASUREMENT PROGRAM

RATIONALE:

- SEVEN USAF AIRCRAFT LOST IN PAST THIRTEEN YEARS DUE TO CONFIRMED LIGHTNING STRIKES.
- EXISTING LIGHTNING STRIKE DATA COLLECTED MOSTLY AT ALTITUDES ABOVE 25,000 FEET AND DON'T CONTAIN CLOUD TO GROUND ATTACHMENTS TO AIRCRAFT.
- PRESENT CRITERIA FOR PROTECTION OF AIRCRAFT AND FOR LIGHTNING/EMP COMPARISONS BASED UPON GROUND BASED MEASUREMENTS AND NOT UPON ACTUAL AIRBORNE MEASUREMENTS.

LIGHTNING/EMP MEASUREMENT PROGRAM

APPROACH:

— CONDUCT A TWO-YEAR FLIGHT TEST PROGRAM IN AN INSTRUMENTED CV-580 AIRCRAFT TO OBTAIN AIRBORNE LIGHTNING MEASUREMENTS (JUNE - AUGUST 1984,1985).

— SUBJECT THE SAME AIRCRAFT TO SIMULATED NEMP TESTING AT THE PATUXENT RIVER NAVAL FACILITIES (NOVEMBER OR DECEMBER 1985).

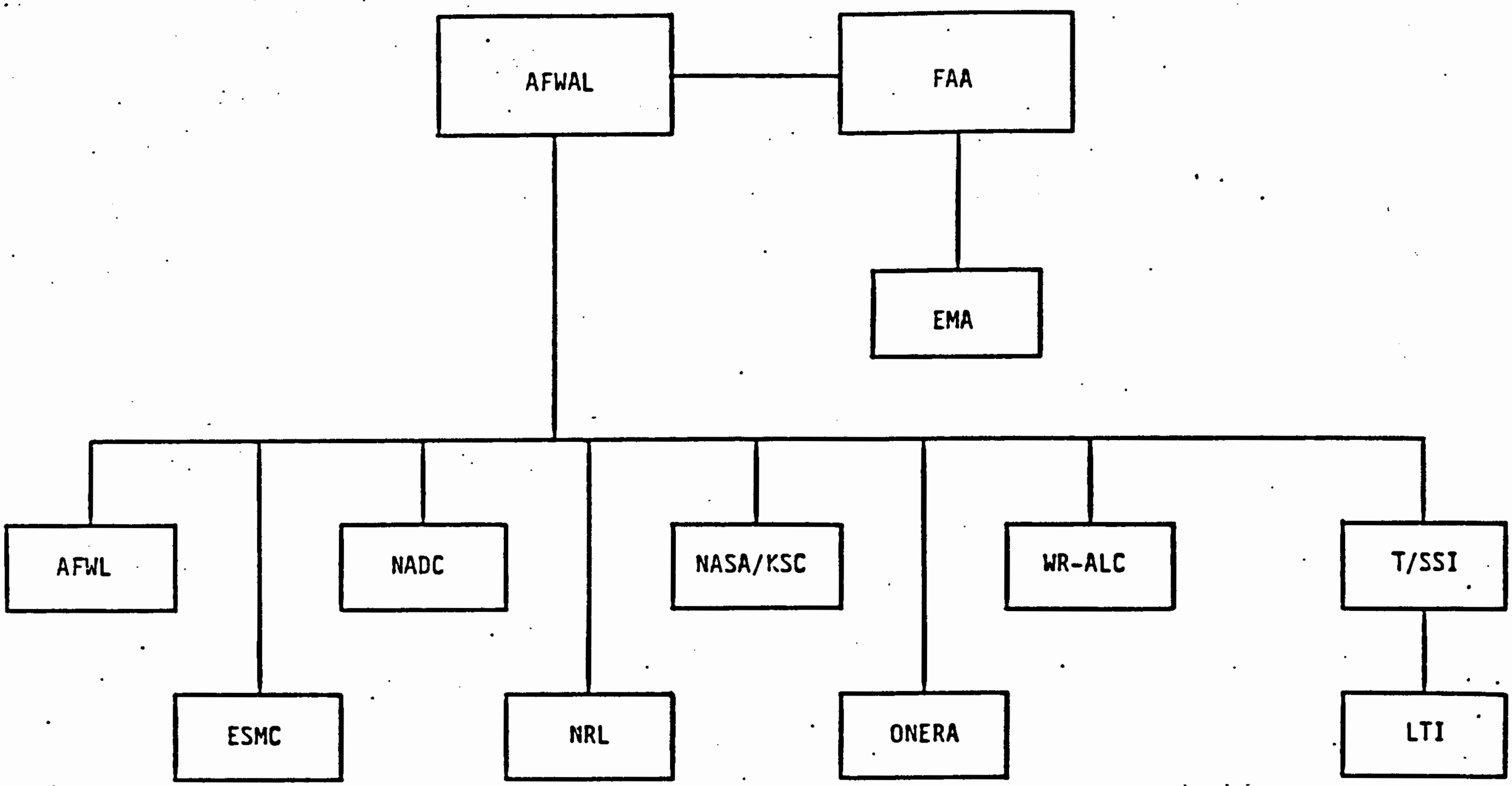
— COMPARE RESULTS WITH SMALL-SCALE COMPUTER MODEL DEVELOPED FOR THE AF WEAPONS LAB BY THE UNIVERSITY OF MICHIGAN.

LIGHTNING/EMP MEASUREMENT PROGRAM

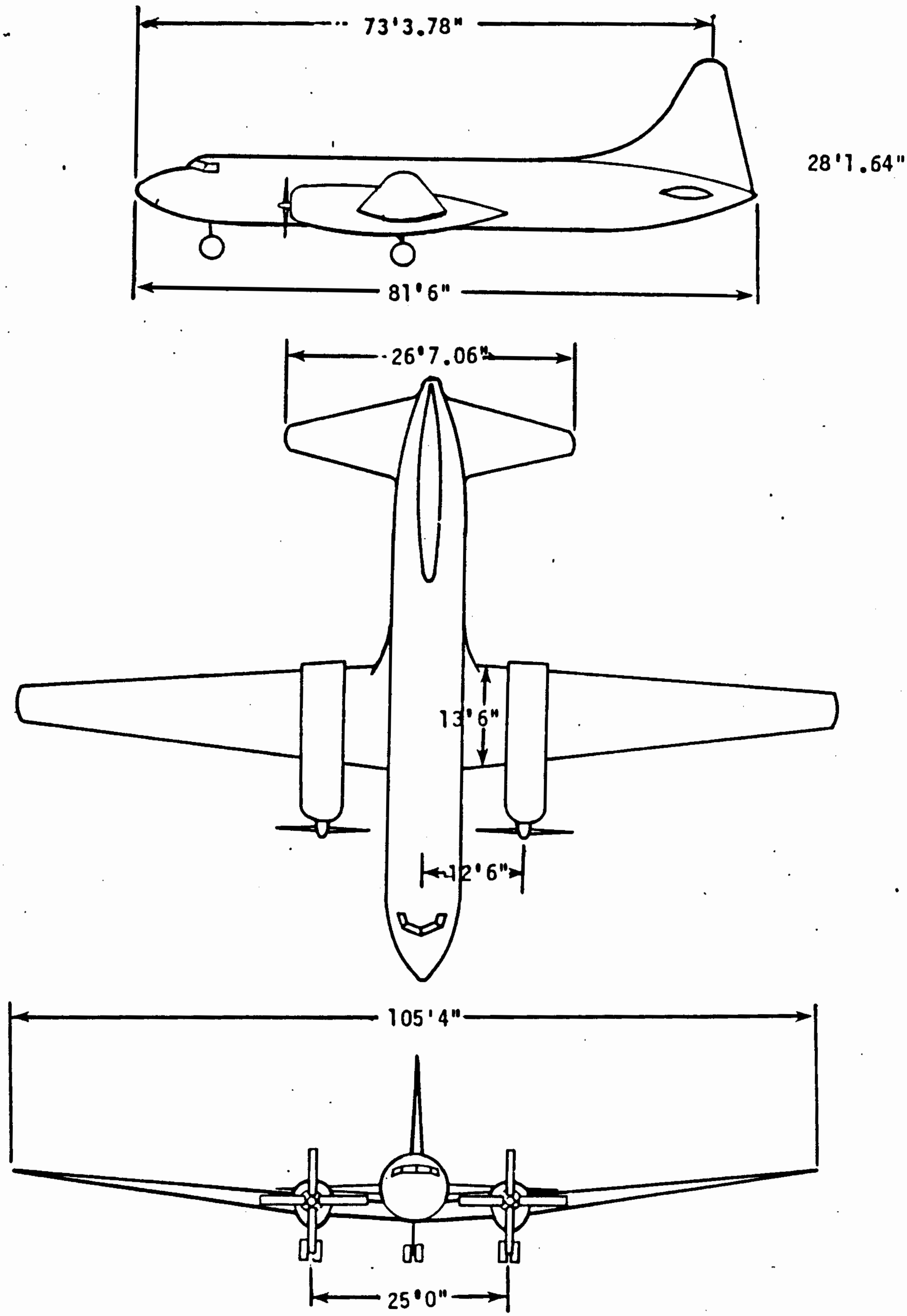
PRIMARY GOAL:

DETERMINE HARDENING LEVELS FOR ADEQUATE PROTECTION OF AIRCRAFT SYSTEMS IN ORDER TO PROVIDE TECHNOLOGY TO INCREASE SURVIVABILITY AND SAFETY WHILE REDUCING VULNERABILITY TO PRESENT AND FUTURE AEROSPACE VEHICLES.

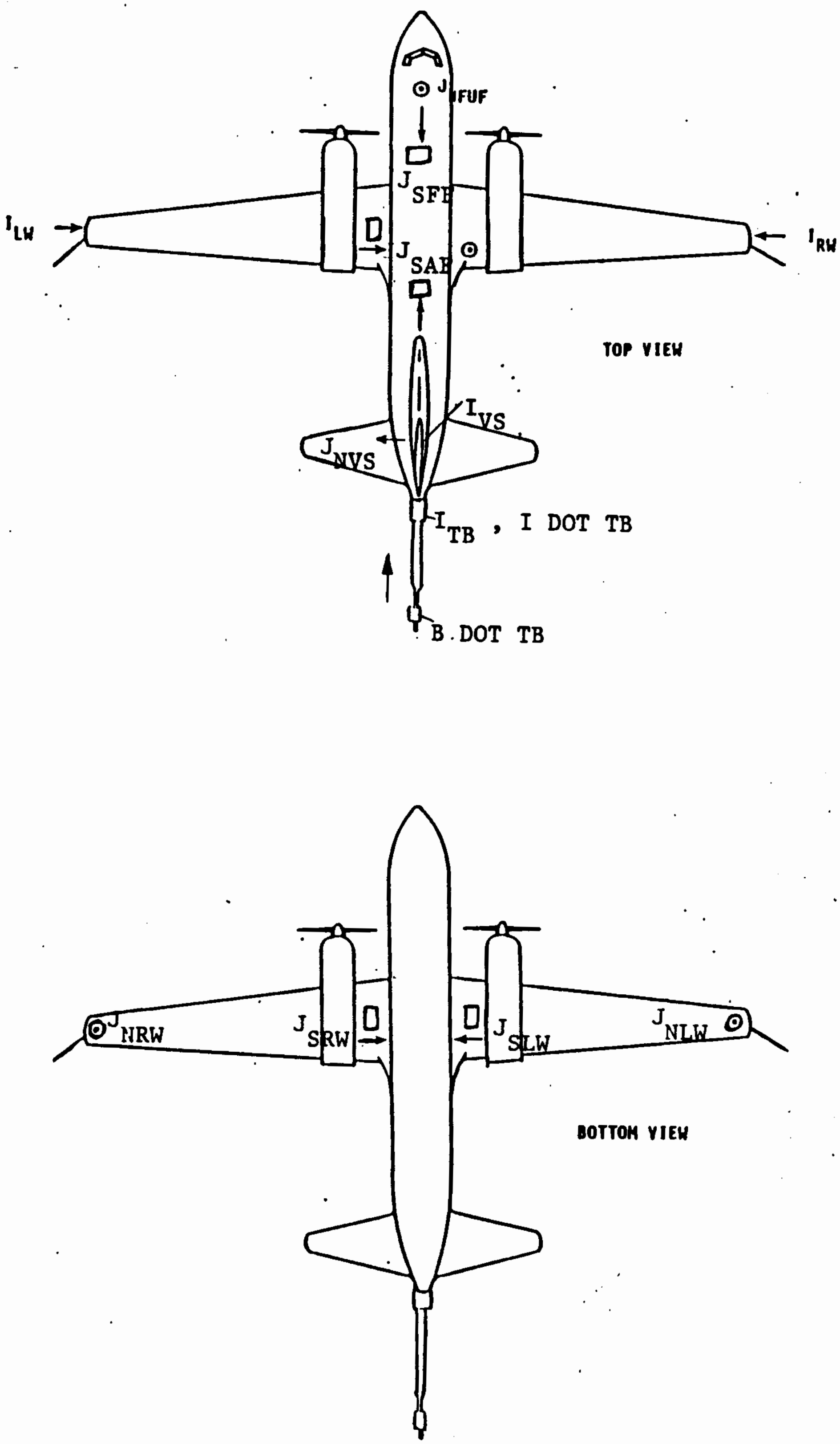
ORGANIZATIONAL BLOCK DIAGRAM



AFWAL	- Air Force Wright Aeronautical Laboratories
AFWL	- Air Force Weapons Laboratory
EMA	- Electromagnetic Applications
ESMC	- Eastern Space and Missle Center
FAA	- Federal Aviation Administration
LTI	- Lightning Technologies, Inc.
NADC	- Naval Air Development Center
NASA/KSC	- National Aeronautics and Space Administration/ Kennedy Space Center
NRL	- Naval Research Laboratory
ONERA	- Office National d'Etudes et de Recherches Aerospatiales
T/SSI	- Technology/Scientific Services Inc.
WR-ALC	- Warner Robins Air Logistics Center



THREE VIEW DRAWINGS OF CV-580 AIRCRAFT
AND OVERALL DIMENSIONS



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

CV-580 EXTERNAL SENSORS

J_{NFUF} -- DISPLACEMENT CURRENT, FORWARD UPPER FUSELAGE

J_{NLW} -- DISPLACEMENT CURRENT, LEFT WING

J_{NRW} -- DISPLACEMENT CURRENT, RIGHT WING

J_{NVS} -- DISPLACEMENT CURRENT, VERTICAL STABILIZER

J_{SFF} -- SURFACE CURRENT RATE OF CHANGE, FORWARD FUSELAGE

J_{SAF} -- SURFACE CURRENT RATE OF CHANGE, AFT FUSELAGE

J_{SLW} -- SURFACE CURRENT RATE OF CHANGE, LEFT WING

J_{SRW} -- SURFACE CURRENT RATE OF CHANGE, RIGHT WING

I_{LW} -- CURRENT, LEFT WING

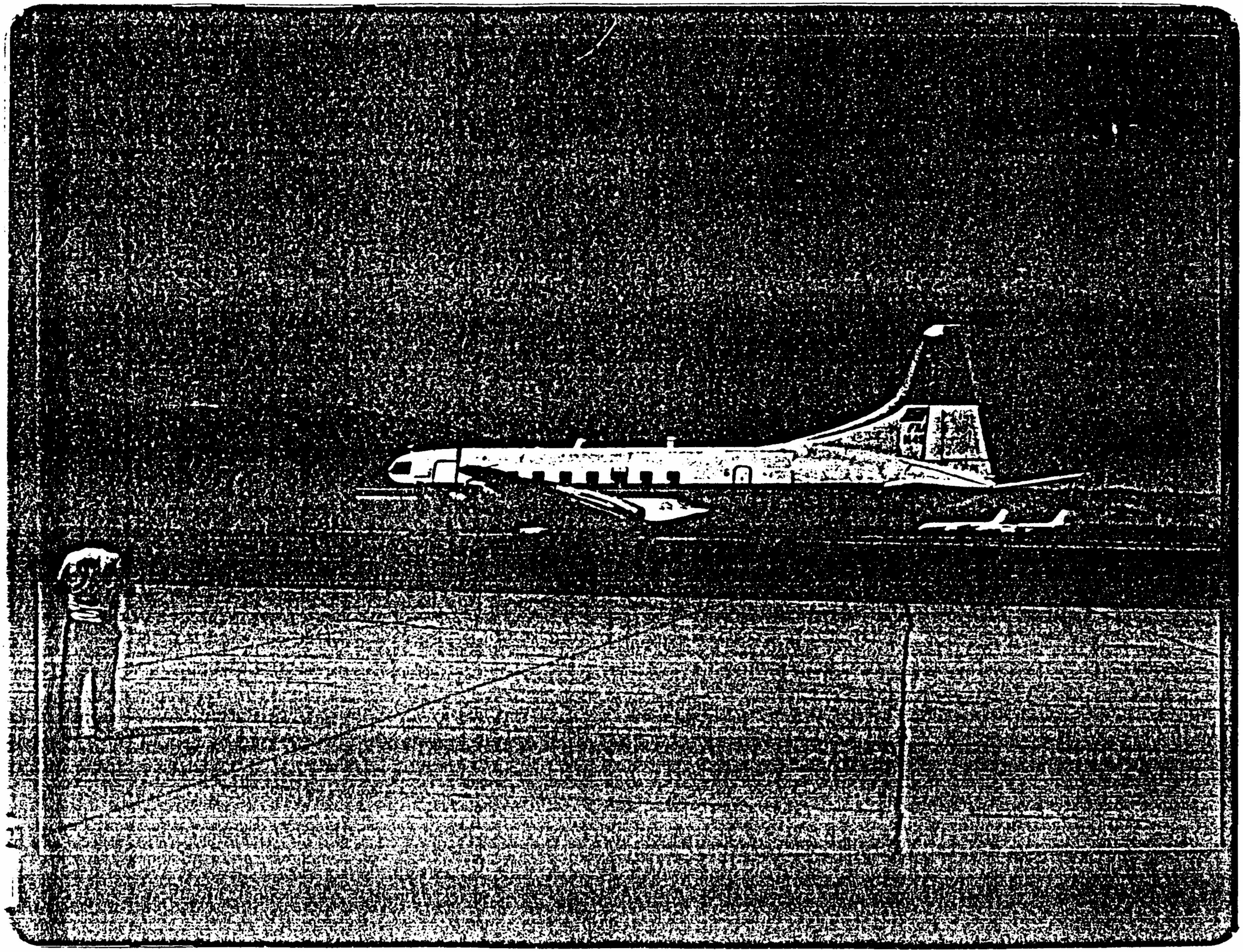
I_{RW} -- CURRENT, RIGHT WING

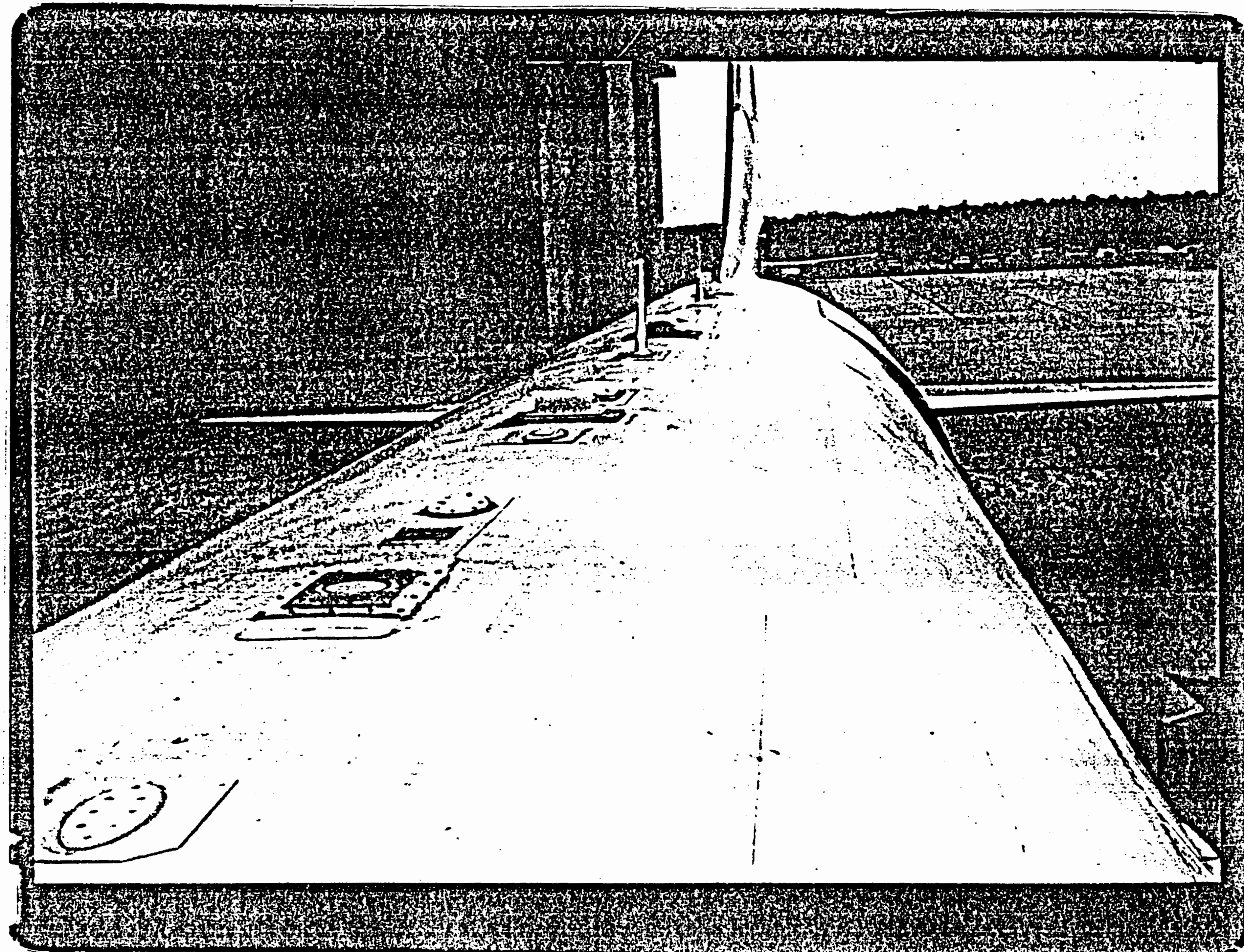
I_{VS} -- CURRENT, VERTICAL STABILIZER

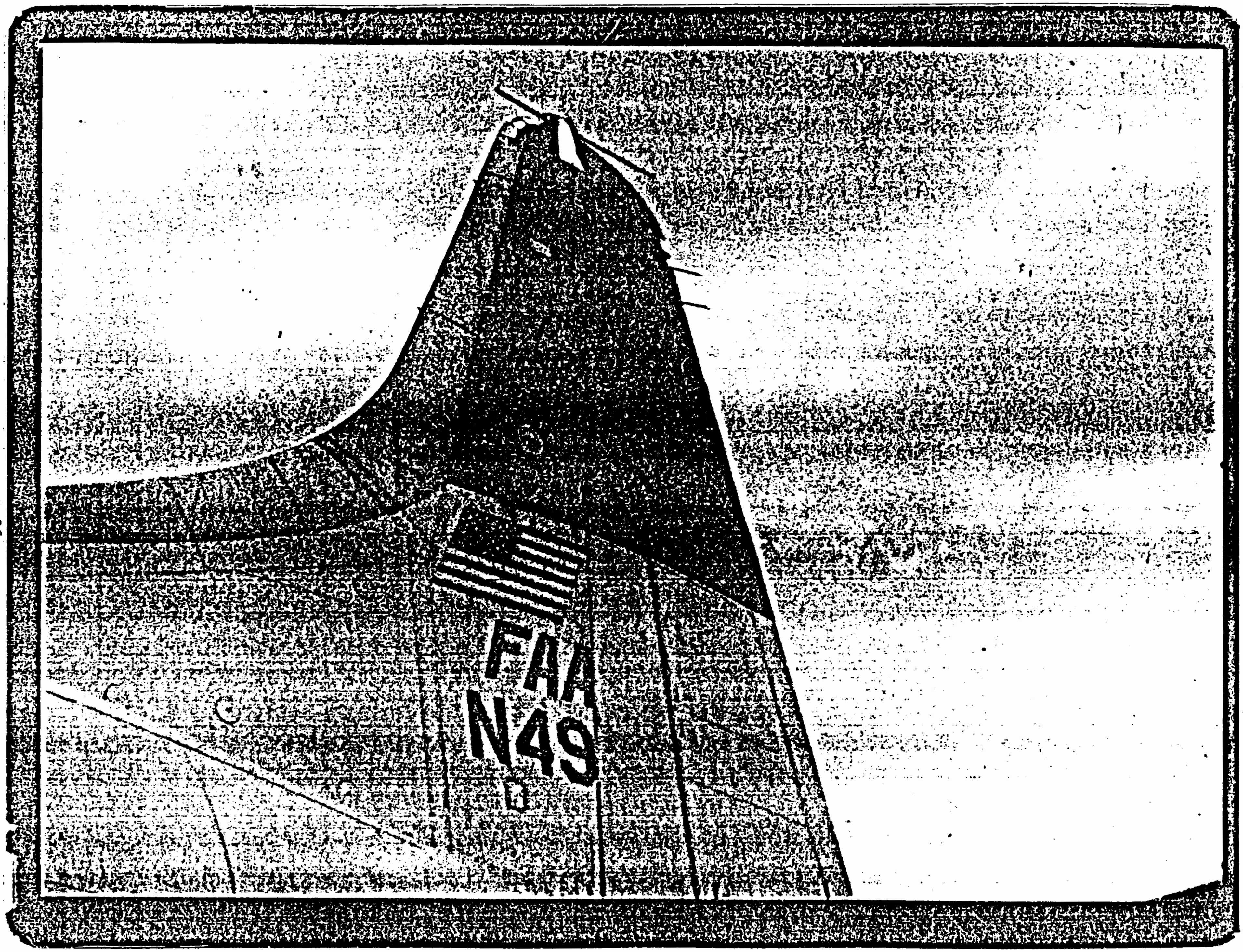
I_{TB} -- CURRENT, TAIL BOOM

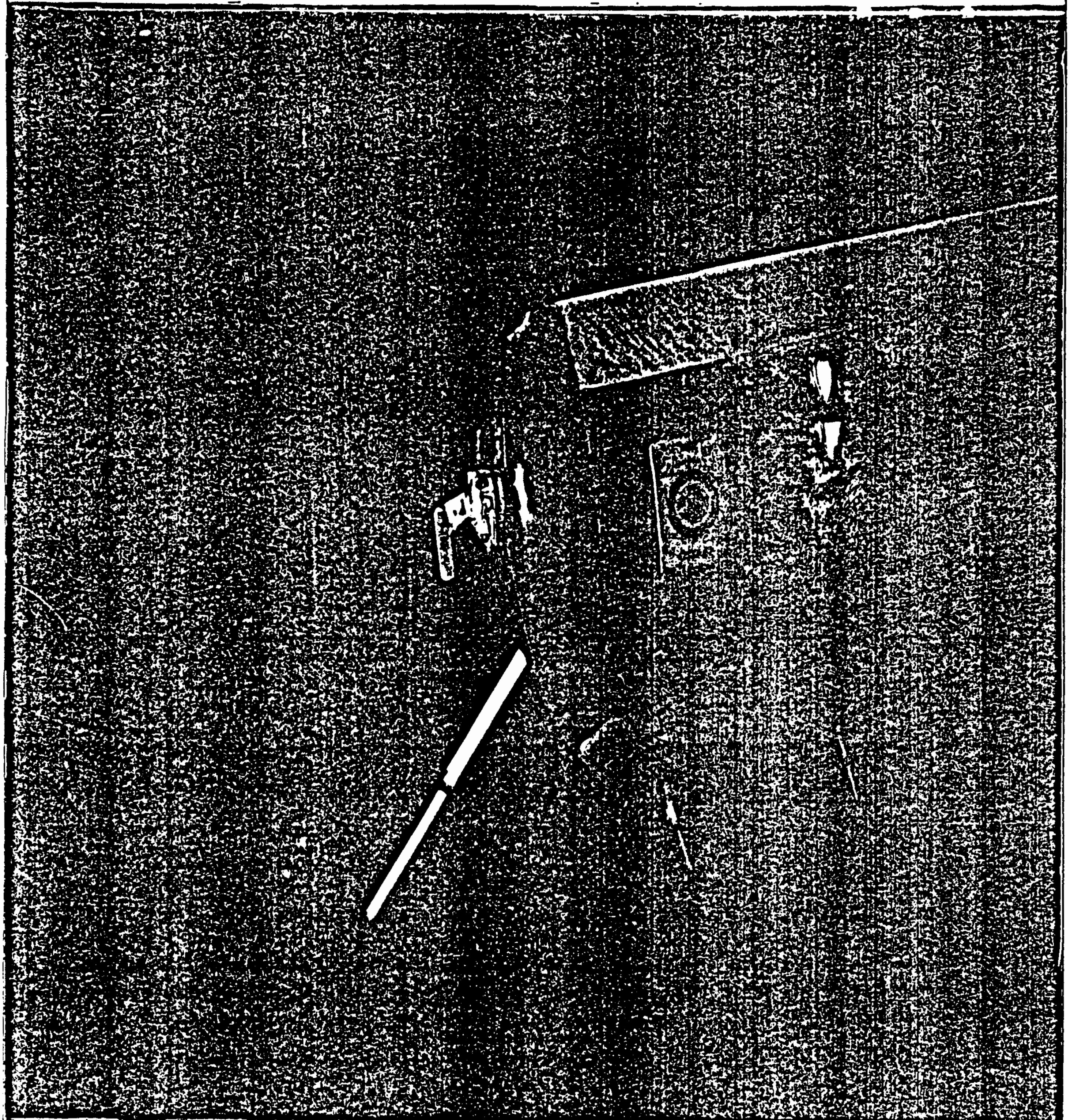
I DOT TB -- CURRENT RATE OF CHANGE, TAIL BOOM

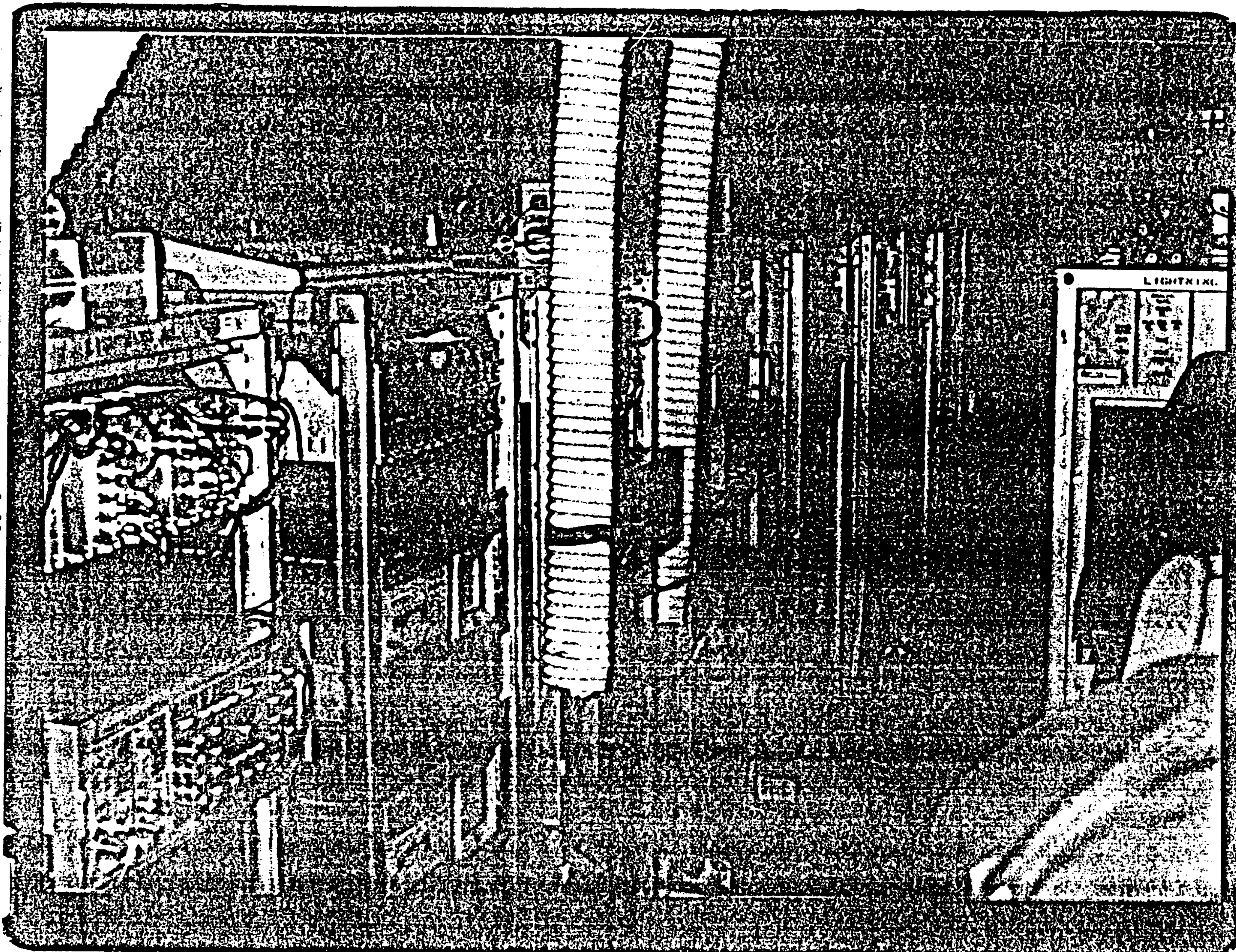
B DOT TB -- MAGNETIC FIELD RATE OF CHANGE, TAIL BOOM






FAA
N49





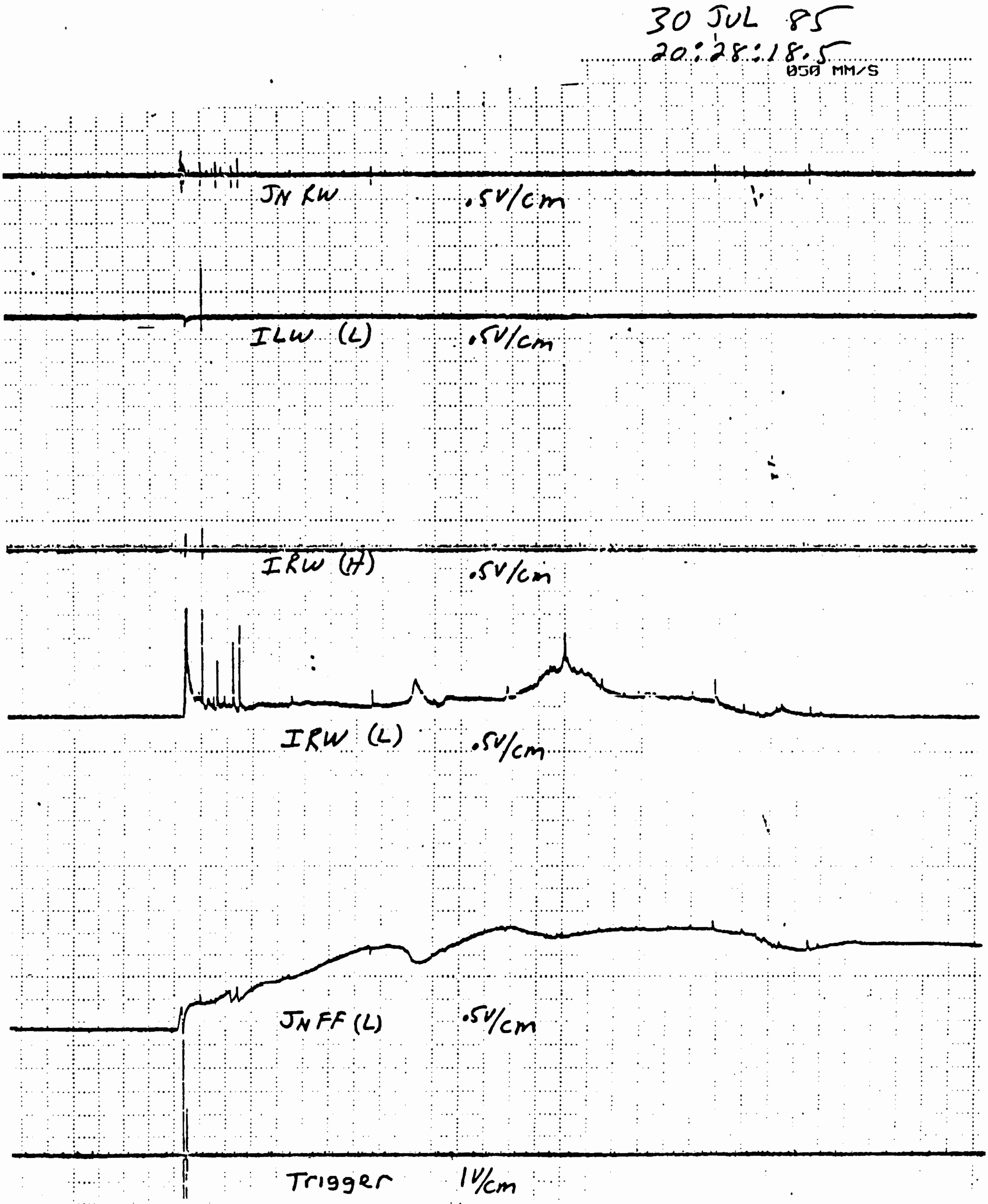
DATE TIME	13 July 84 20:46:23	6 Aug 84 21:44:05	7 Aug 84 21:41:58	7 Aug 84 21:43:26	17 Aug 84 21:36:01	20 Aug 84 17:37:41	5 Sep 84 21:53:05
SENSOR	CURRENT LEVELS IN AMPERES						
JSFF	128	NR	168	136	2864(s)	1265	208
JSAF	386	213(s)	724	235	1902	591	630
JSLW	42	250(s)	Noise	NA	724	309	1073
JSRW	47	453(s)	Noise	341	711	290	1111
I LW	Noise	Noise	Noise	Noise	Noise	Noise	Noise
I RW	Noise	Noise	Noise	797	Noise	Noise	1600

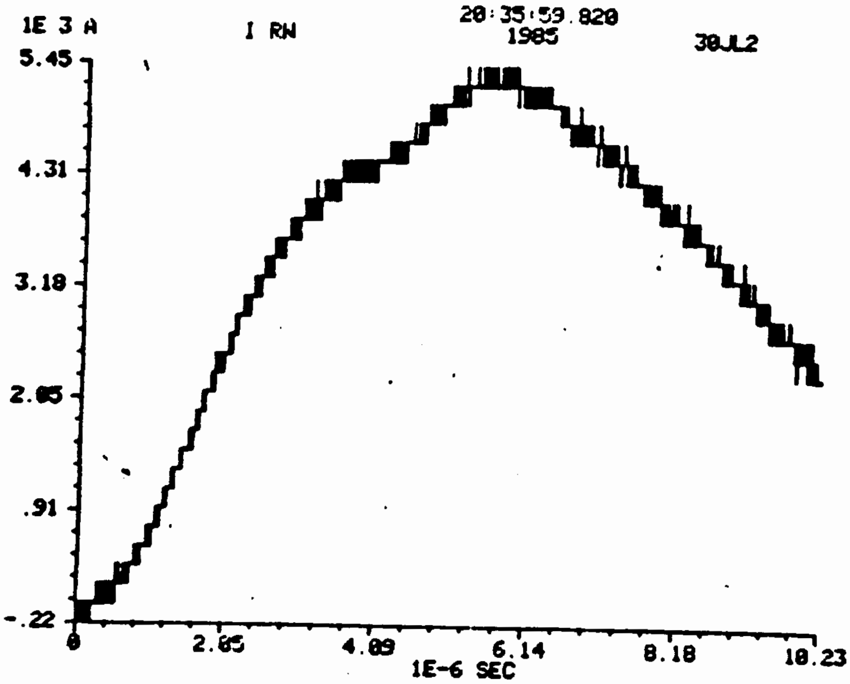
FLIGHT PARAMETERS

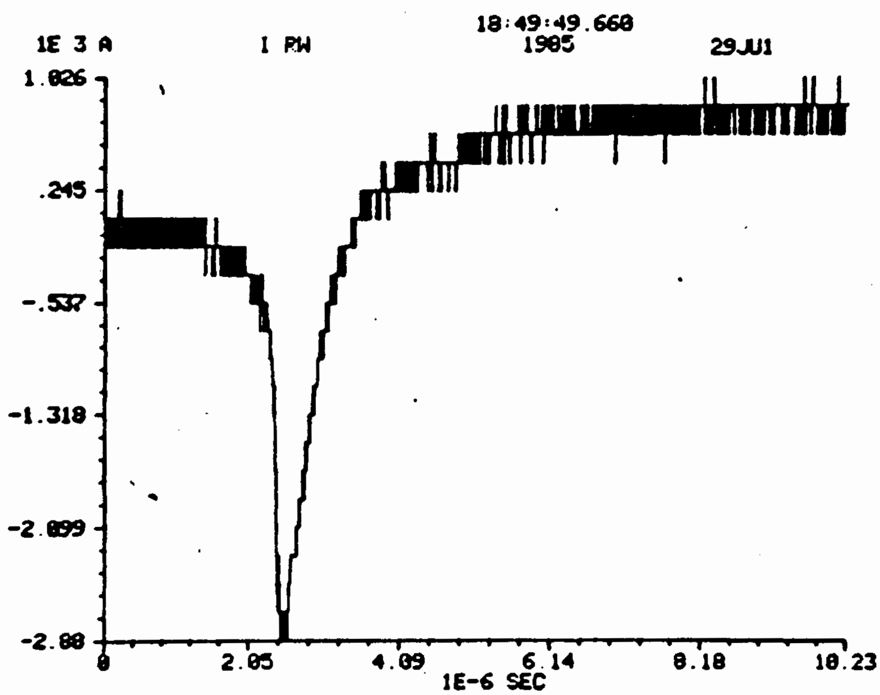
Altitude (PT)	14000	14000	18000	18000	4000	2000	18000
OAT (°F)	26°F	NR	21°F	20°F	NR	62°F	24°F
Turbulence	LT	LT	LT	LT	MD	MD	MD
Clouds	Y	Y	Y	Y	Y	Y	Y

NR = Not Recorded
S = Saturated

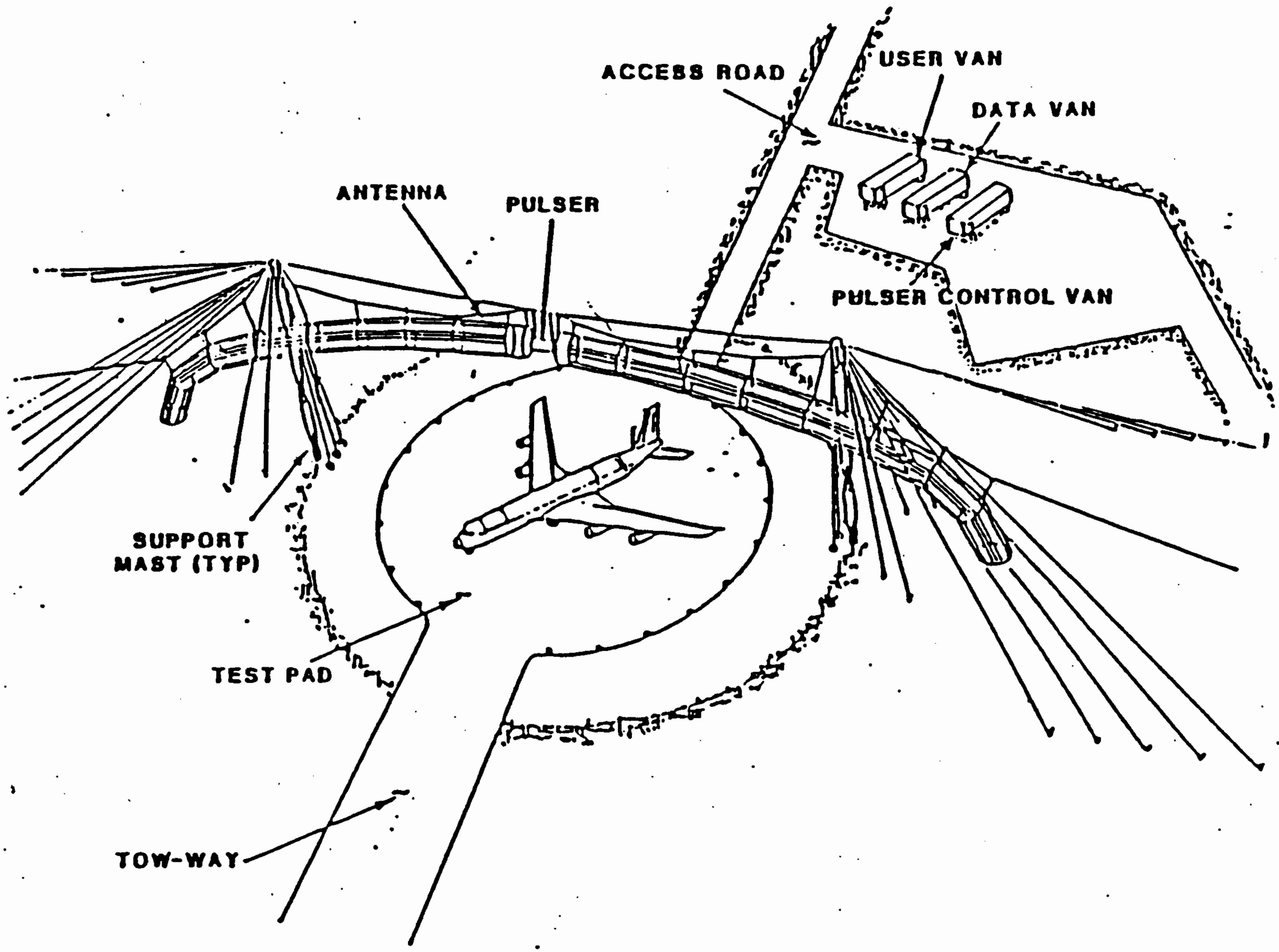
TYPICAL FUSELAGE AND WING CURRENT LEVELS
ON THE C-580 AIRCRAFT
DURING THE 1984 TEST PROGRAM

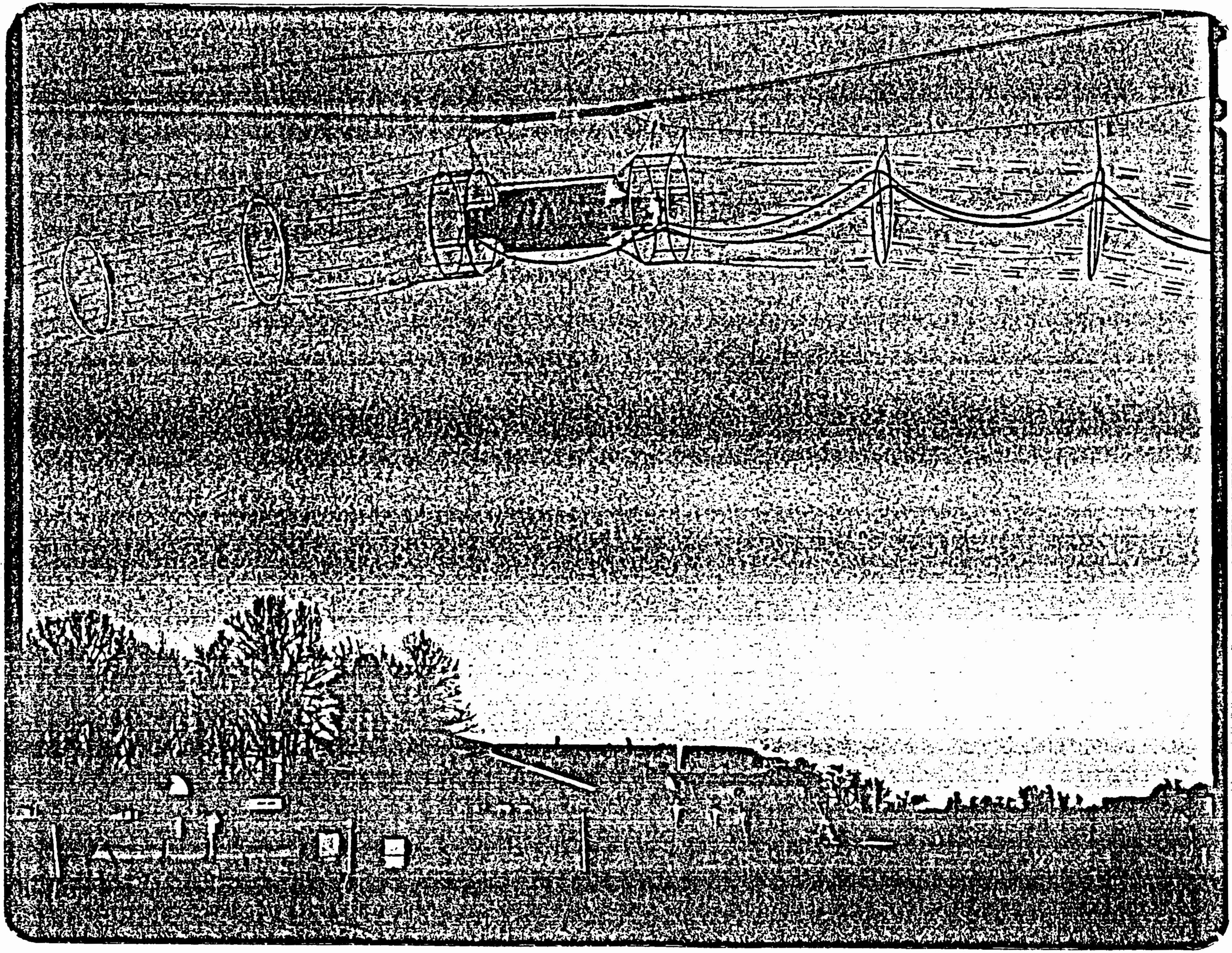

30 JUL 85
20:28:18.5
050 MM/S
JN RW .5V/cm
ILW (L) .5V/cm
IRW (H) .5V/cm
IRW (L) .5V/cm
JNFF (L) .5V/cm
Trigger 1V/cm

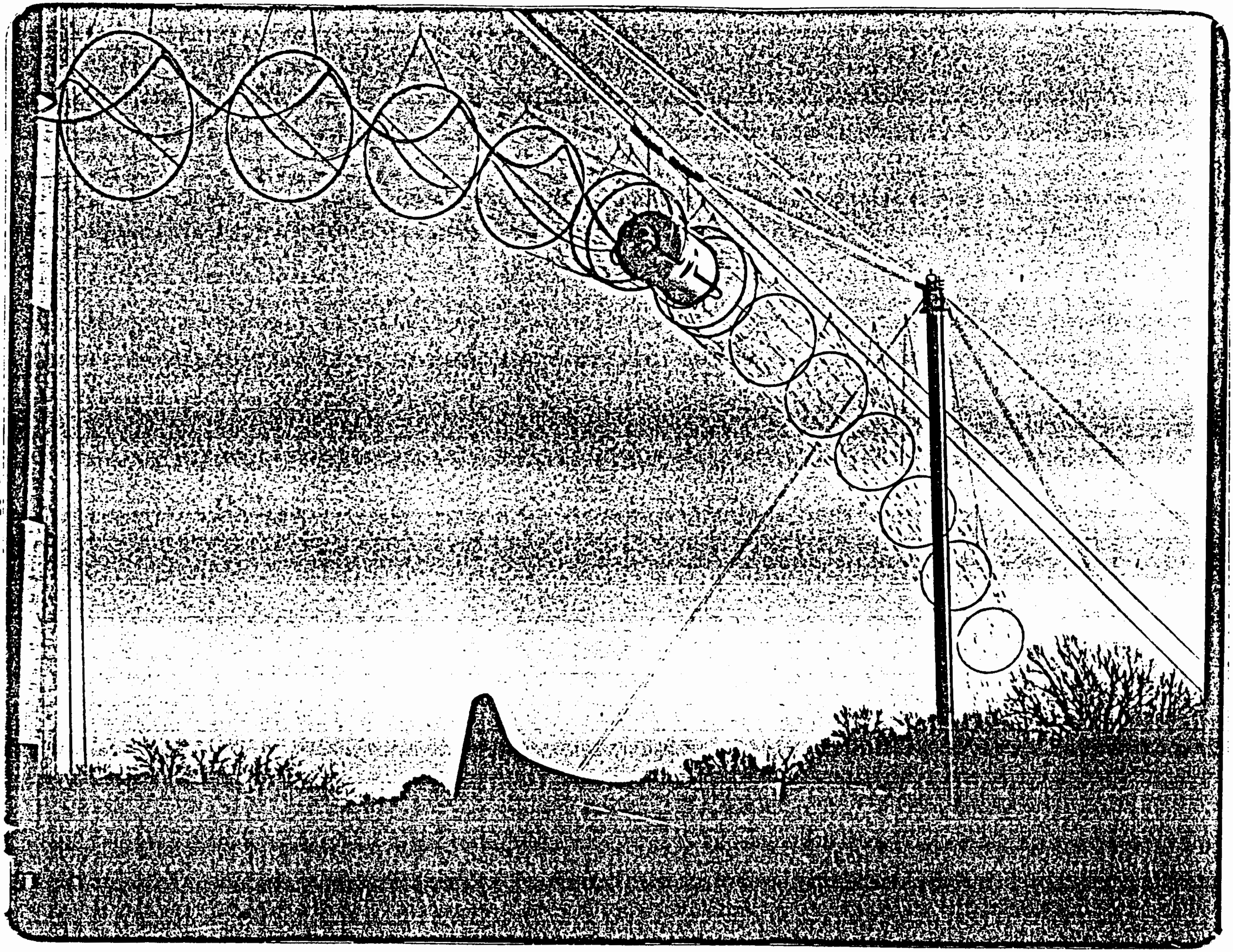

1E 3 A
I RN
20:35:59.820
1985
30JL2
5.45
4.31
3.18
2.05
.91
-.22
0
2.05
4.09
6.14
8.18
10.23
1E-6 SEC

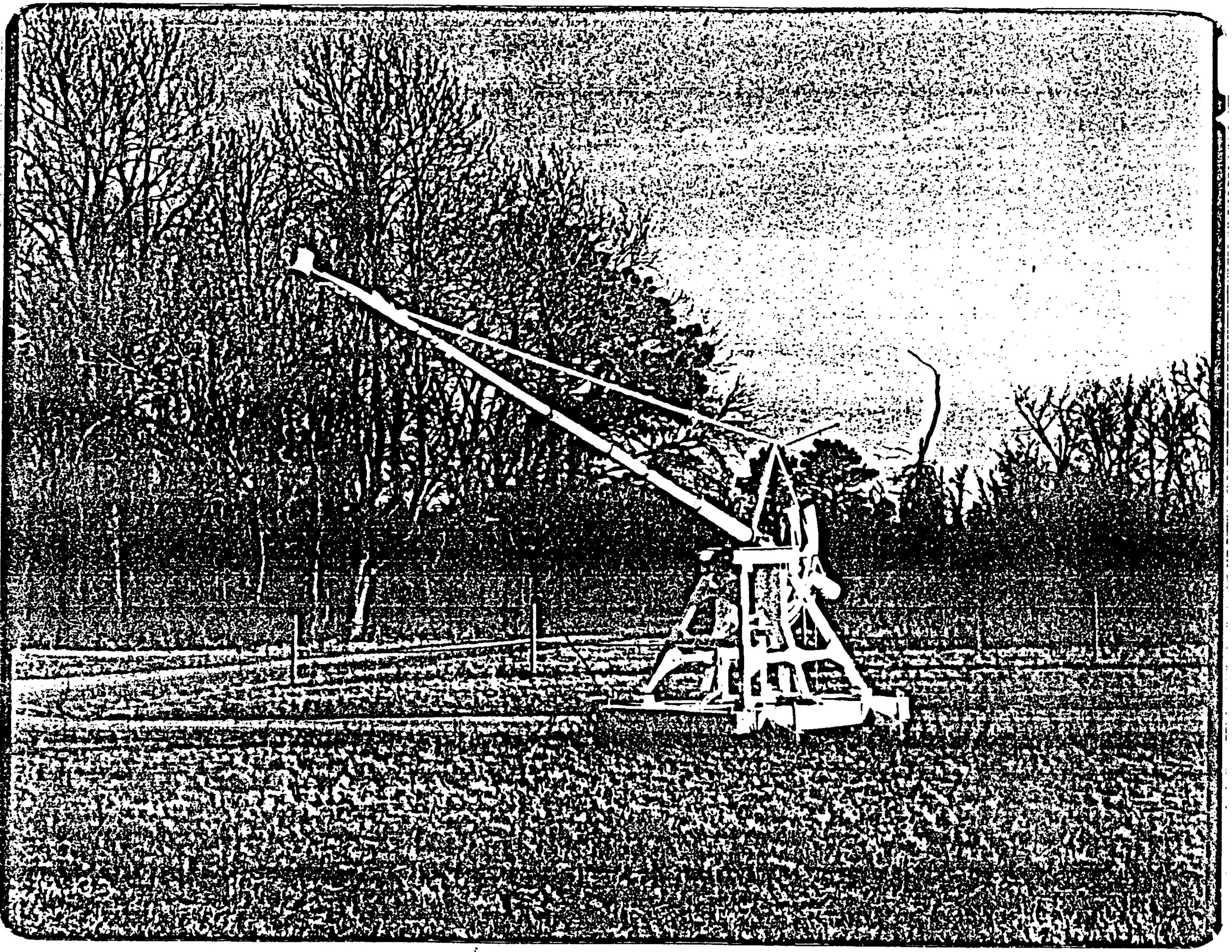

1E 3 A
I PW
18:49:49.660
1985
29JU1
1.026
.245
-.537
-1.318
-2.099
-2.88
0
2.05
4.09
6.14
8.18
10.23
1E-6 SEC

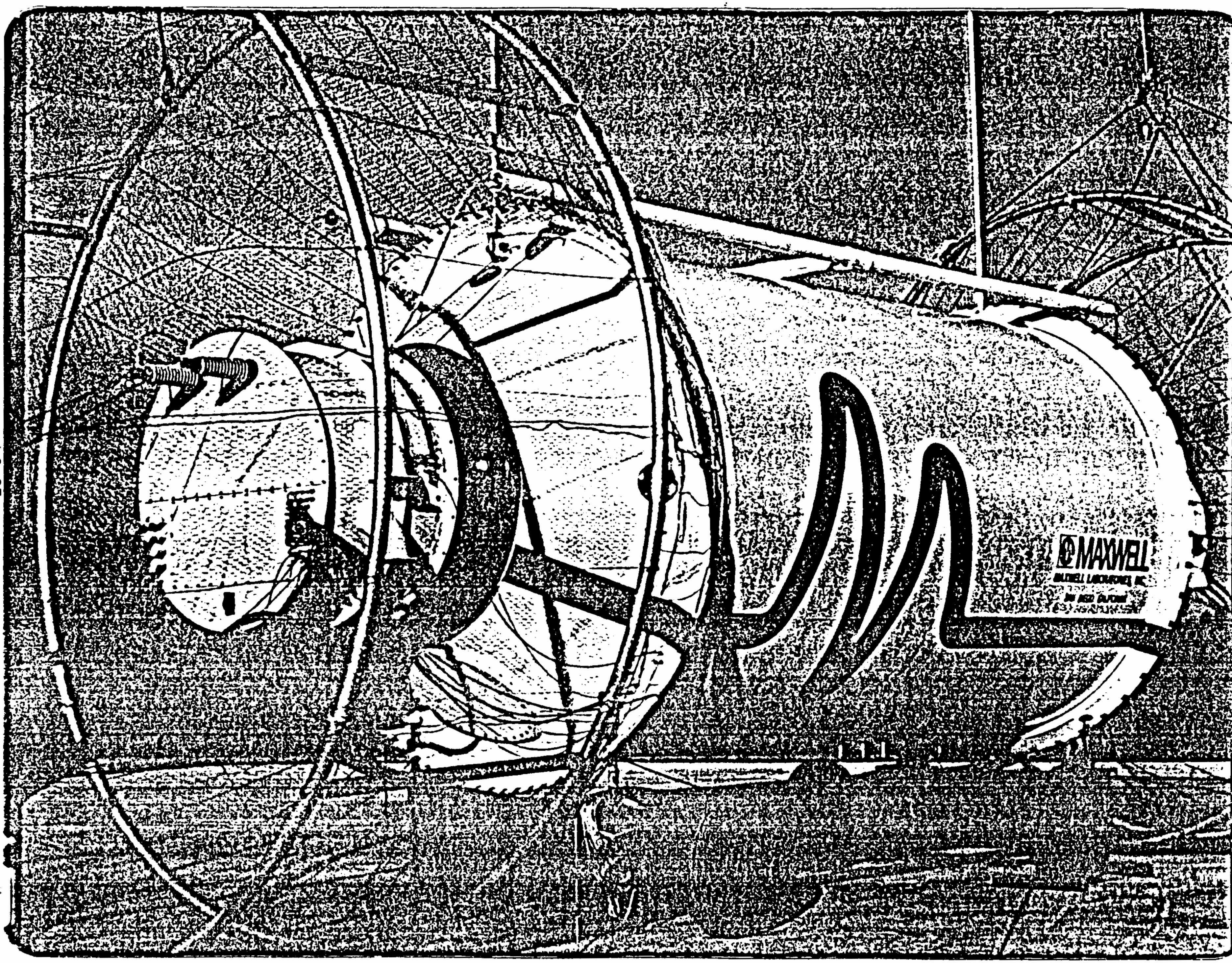
TES TEST FACILITY










MAXWELL

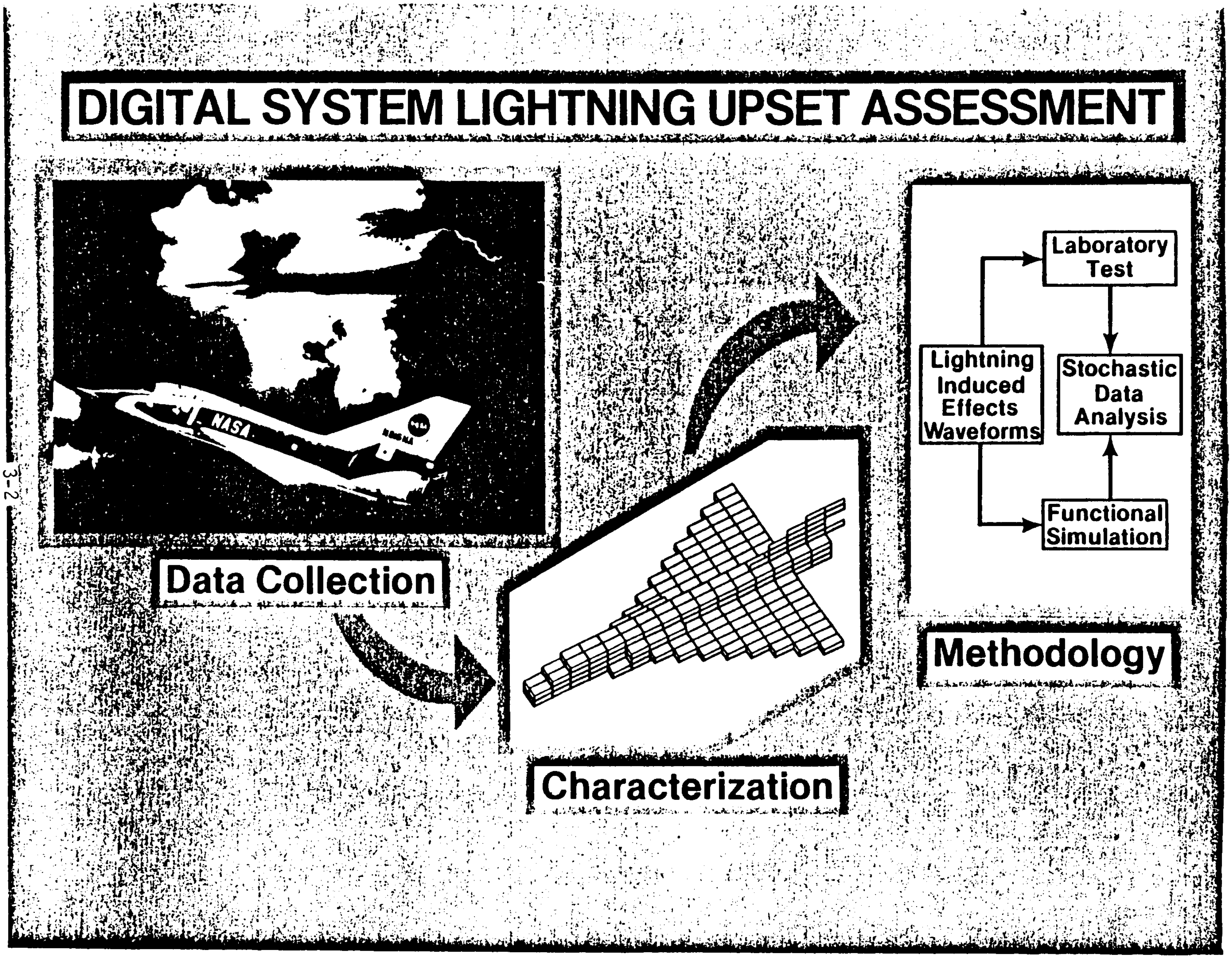
LIGHTNING/EMP MEASUREMENT PROGRAM
DEVELOPMENTS SINCE LAST PROGRESS REVIEW

- SIMULATED NEMP TESTS COMPLETED (5 - 10 JAN 86)
- AFWAL INSTALLED INSTRUMENTATION REMOVED FROM AIRCRAFT (15 - 16 JAN 86)
- J. PATRICK MOREAU (ONERA) WILL VISIT FIESL AND MAJ RUSTAN TO COPY ANALOG DATA AND ASSIST IN DATA ANALYSIS (27 JAN - 10 FEB 86)
- DETAILED ANALYSIS OF LIGHTNING AND SIMULATED NEMP DATA SHOULD BEGIN IN FEB 86

LIGHTNING CHARACTERIZATION AND EFFECTS

Felix L. Pitts

NASA Langley Research Center



DIGITAL SYSTEM LIGHTNING UPSET ASSESSMENT
NASA
Data Collection
Characterization
Laboratory Test
Lightning Induced Effects Waveforms
Stochastic Data Analysis
Functional Simulation
Methodology

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

505-66-21-04 LIGHTNING EFFECTS ON DIGITAL ELECTRONICS

FY 85 ACCOMPLISHMENTS

o ACQUIRED 41 STRIKES TO F-106 BETWEEN 15,000 AND 20,000 FEET

o DEVELOPED STATISTICAL ANALYSIS TECHNIQUE FOR PEAK RECORDER DATA
  - PROVIDED PRIMARY DATA FOR NEW LIGHTNING TEST CRITERIA TO FAA AND SAE-AE4L LIGHTNING COMMITTEE

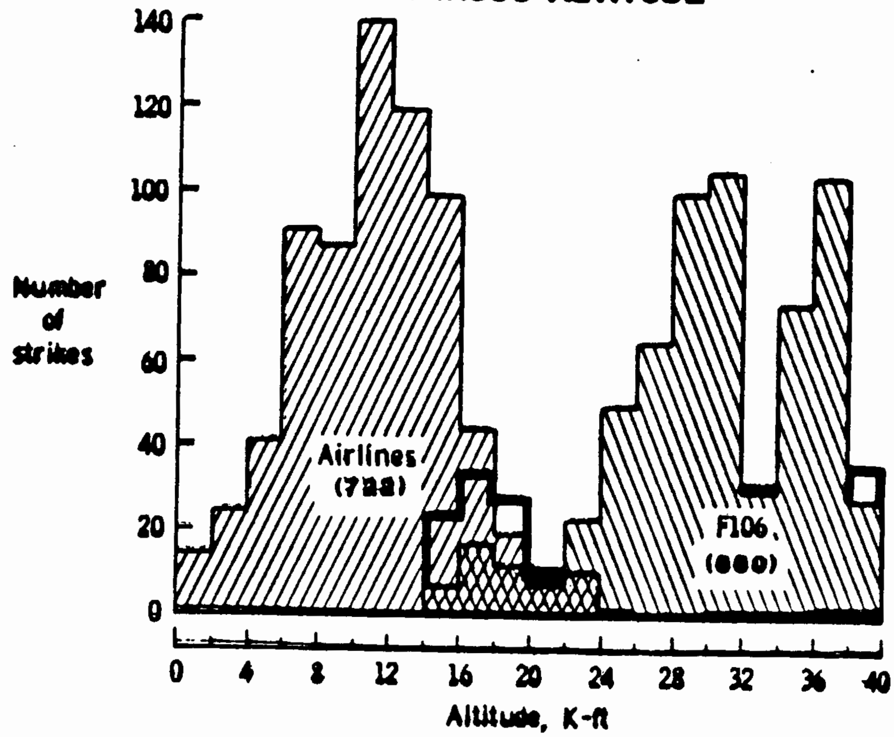
o DEVELOPED NEW WIDE BANDWIDTH ELECTRIC FIELD MEASURING SYSTEM FOR TRIGGERED LIGHTNING STUDY

o INITIATED CONTRACT NAS1-18115 WITH HAMILTON STANDARD FOR ENGINE CONTROLLER SYSTEM FOR USE IN UPSET ASSESSMENT
  - ARRANGEMENT FOR PORTABLE UNIVERSAL PULSER FROM AIR FORCE WEAPONS LAB
  - CONSULTATION WITH VPI ON GSP MODEL

o COMPLETING WORK UNDER THREE UNIVERSITY GRANTS

o EXTENDED CONTRACT WITH EMA FOR F-106 DATA INTERPRETATION

STRIKES VERSUS ALTITUDE



TOTAL DATA BASE THROUGH 1985

o 690 STRIKES
  - 53 IN 1986

o 671 STRIKES/2674 TRANSIENT WAVEFORMS

	$\dot{B}_L$	D_F	$\dot{D}_F$	I_B	$\dot{I}_B$	$\dot{D}_T$	$\dot{D}_T$	$\dot{D}_{WL}$	D_{WR}	$\dot{D}_{WR}$	B_{WL}	$\dot{B}_{WL}$	$\dot{B}_{WR}$	I_{VF}	INT. RESP.
o 1982 AND PRIOR	46		93	27	8										
o 1983	166		218	17	56	23	56	24	15		16	34	48	39	29
o 1984	119	117	106	120	126		125	106		91		43	37	120	150
o 1985	27		41	3	38		40			44		41	40	14	115
o TOTAL WAVE-FORMS	358	117	466	167	228	23	221	129	15	135	16	118	125	173	294
o PEAK VALUES (STRIKES)			62 (399)	2 (13)	60 (418)										6 (49)

DISTRIBUTION OF PEAK RATE OF CHANGE OF ELECTRIC FLUX DENSITY

(D-DOT SENSOR UNDER FUSELAGE 6 FEET FORWARD OF NOSE GEAR STRUT)

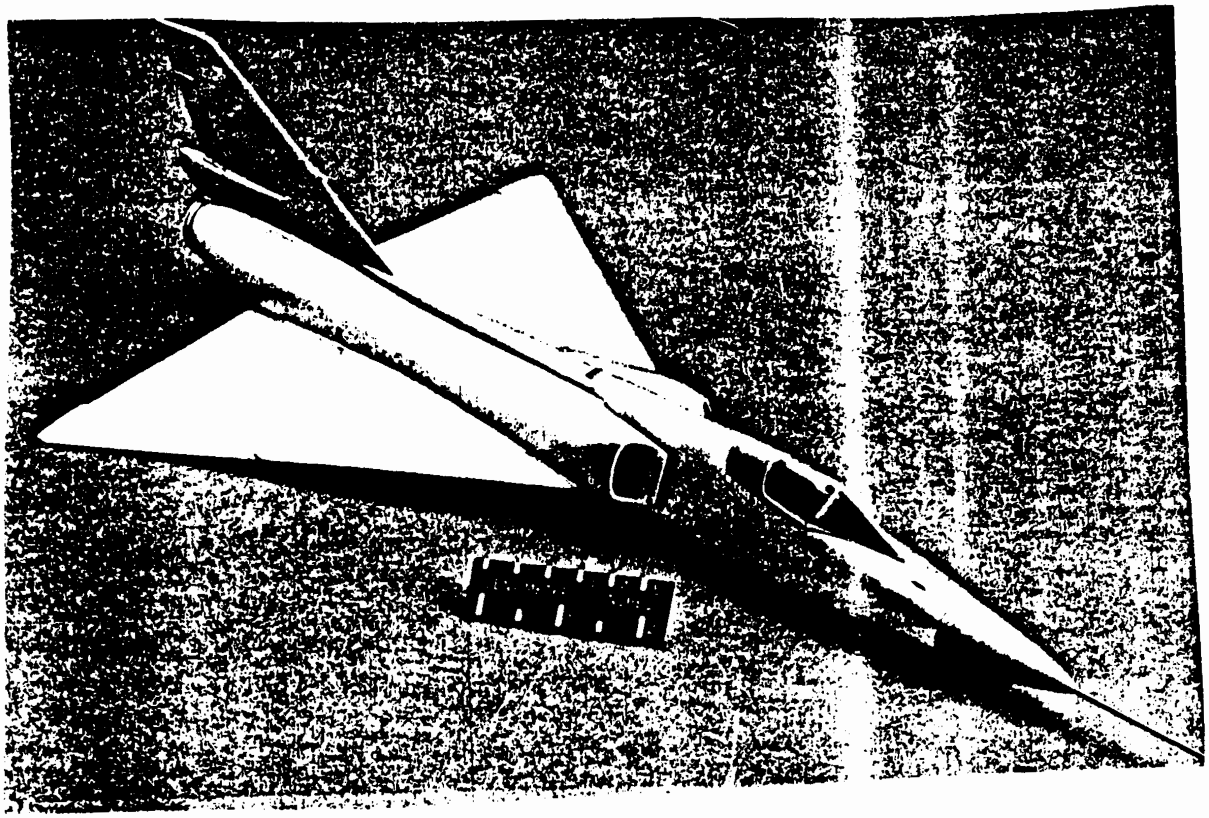
INTERVAL AMPERE PER SQUARE METER	#FLIGHTS	#STRIKES	MAXIMUM LIKELIHOOD ESTIMATE	CUMULATIVE PERCENTAGE
[0,6)	1	1	.098	9.8
[6,12)	3	5	.197	29.5
[12,18)	10	27	.314	60.9
[18,24)	4	8	.070	67.9
[24,30)	13	47	.162	84.1
[30,36)	6	43	.048	88.9
[36,42)	9	66	.051	94.0
[42,48)	5	26	.023	96.3
[>48	11*	177	.037	100

*NOTE: SIX FLIGHTS WITH 81 STRIKES HAD STRIKES EXCEEDING THE INITIAL FULL SCALE RANGE OF 48 A/M^2, AFTER SCALE CHANGE TO 97 A/M^2 THERE WAS A FLIGHT WITH A READING OF 75 A/M^2 COVERING 5 STRIKES AND A FLIGHT WITH A READING OF 78 A/M^2 COVERING 6 STRIKES AND THERE WERE 3 FLIGHTS WITH READINGS EXCEEDING 97 A/M^2

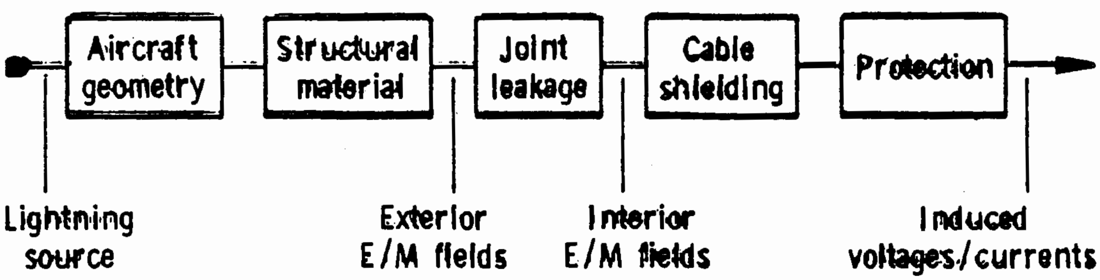
NASA LANGLEY F-106

DISTRIBUTION OF PEAK BOOM CURRENT RATE-OF-CHANGE

INTERVAL KILOAMPERE PER MICROSECOND	#FLIGHTS	#STRIKES	MAXIMUM LIKELIHOOD ESTIMATE	CUMULATIVE PERCENTAGE %
[0,25)	27	125	0.8762	87.62
[25,50)	13	120	0.0749	95.11
[50,75)	5	21	0.0188	96.99
[75,100)	4	47	0.0135	98.34
[100,125)	3	50	0.0088	99.22
[125,150)	1	20	0.0027	99.49
[150,175)	1	3	0.0026	99.76
[175,200)	1	9	0.0025	100.0



LIGHTNING EFFECTS ON AIRCRAFT DIGITAL ELECTRONICS



Data analysis objective

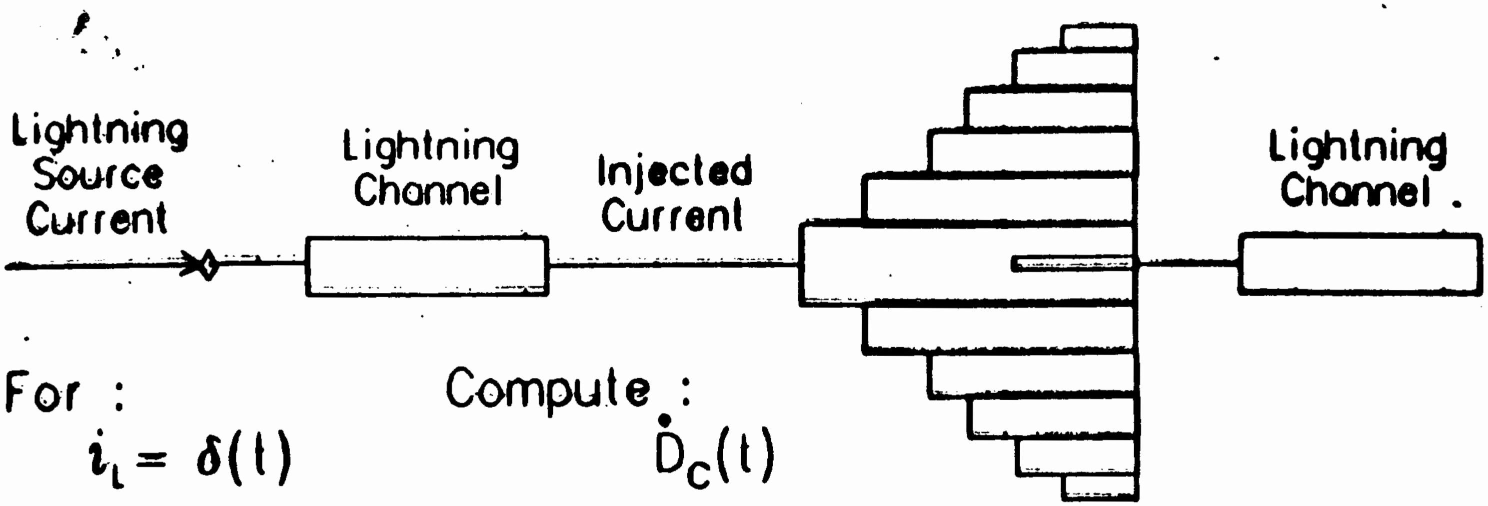
Methodology to predict transients in generic composite aircraft systems for use in upset assessment studies

F-106 DATA INTERPRETATION

ACCOMPLISHMENTS DURING 1984-85

- Extrapolation of F106 data to other aircraft of different shapes and sizes.
- First analytical/numerical determination of self-consistent aircraft response with six simultaneous sensor measurements
- Determination of lightning channel effects on aircraft response
- Ongoing parameter study of F106 nonlinear responses has been extended to nonprincipal field orientation angles. This has shown that even small differences in orientation can significantly alter responses.
- The nonlinear response of the F106 to a high current (200 kA) lightning strike has been calculated
- Thunderstorm particle environment has been determined and field enhancement factors calculated for typical ice crystals
- Subgrid development has been completed and the subgrid applied to calculate better field enhancement factors on the F106
- An improved two dimensional air breakdown model has been developed which includes the effects of electron temperature and molecular vibrational energy states
- 1983 measured data has been classified into categories having similar response characteristics

LINEAR DATA INTERPRETATION METHODOLOGY -
Current Injection Approach

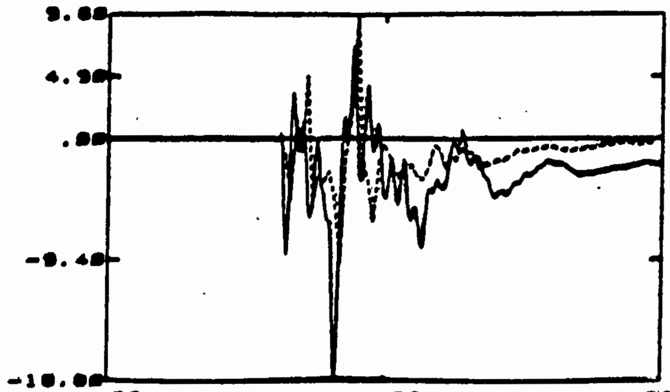


Develop Transfer Function Relating Sensor Response to Source Current

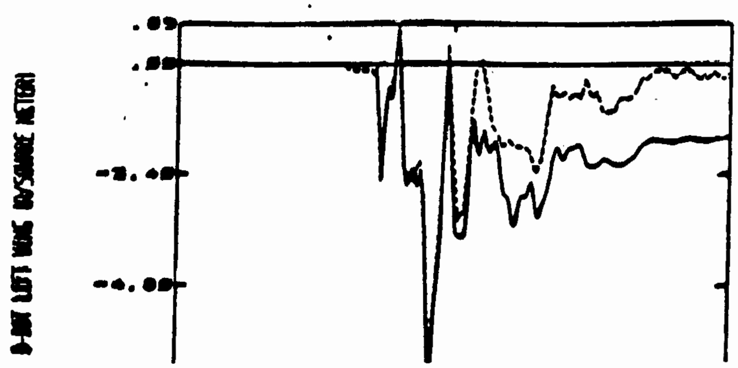
$$G(s) = \frac{\mathcal{L}[\dot{D}_C(t)]}{\mathcal{L}[\delta(t)]}$$

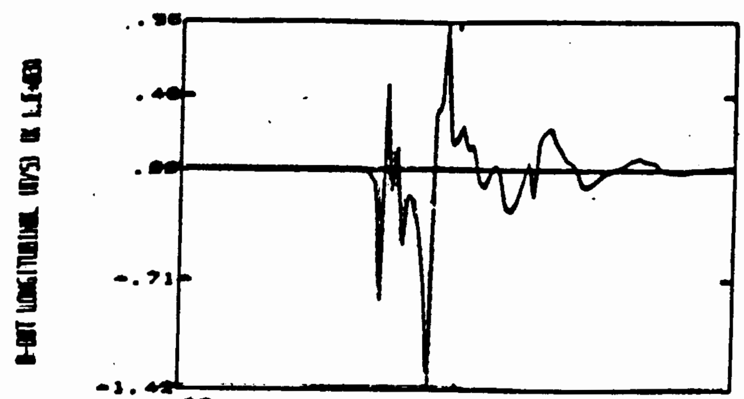
Then use $G(s)$ along with $\mathcal{L}[\dot{D}_F(t)]$ to compute Lightning Source Current

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

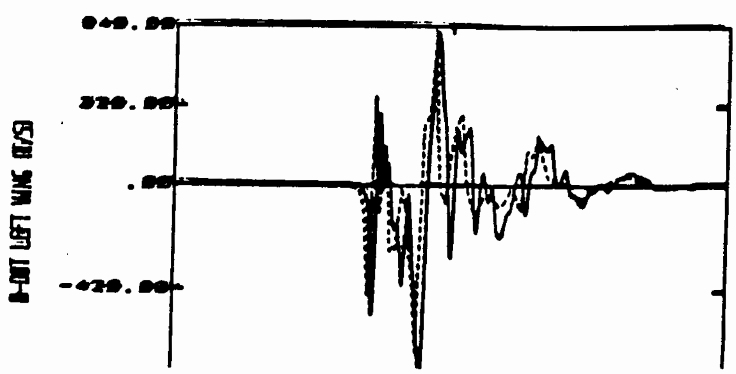

9.80
4.90
.00
-9.40
-18.80
D-DOT FORWARD (A/SQUARE METER)
.00
.50
1.00
TIME (SEC) (X 1.E-06)

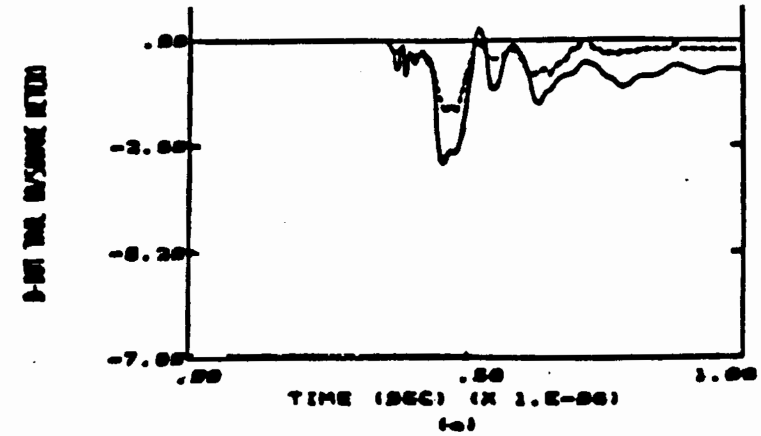
(c)

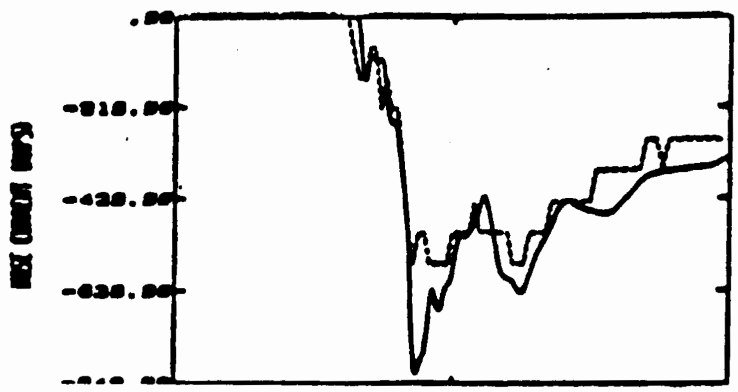

.00
-2.40
-4.80
D-DOT LEFT WING (A/SQUARE METER)


.40
.00
-.71
-1.42
D-DOT LONGITUDINAL (A/S) (X 1.E+03)
.00
.50
1.00
TIME (SEC) (X 1.E-06)

(e)


640.00
320.00
.00
-420.00
D-DOT LEFT WING (A/S)

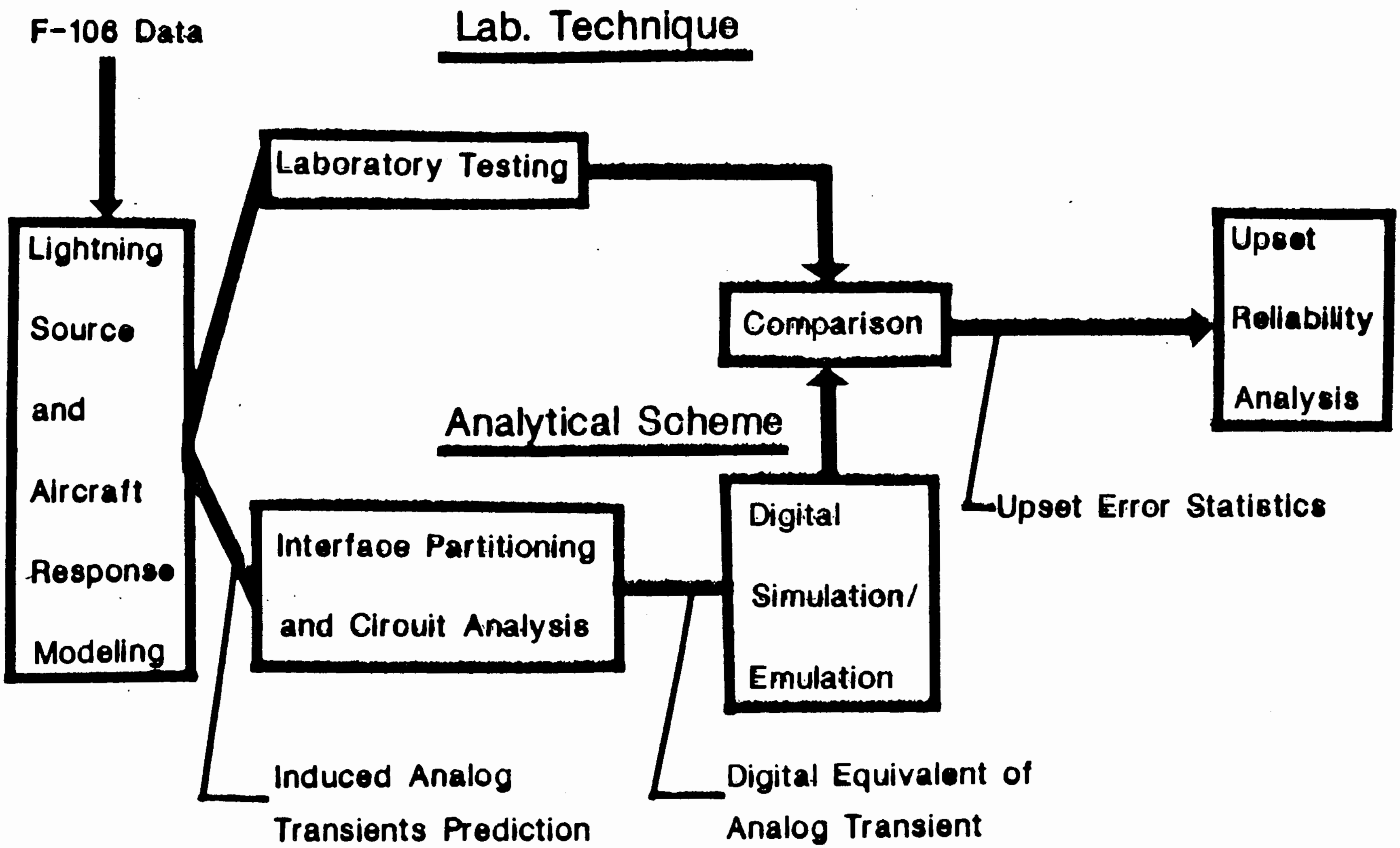




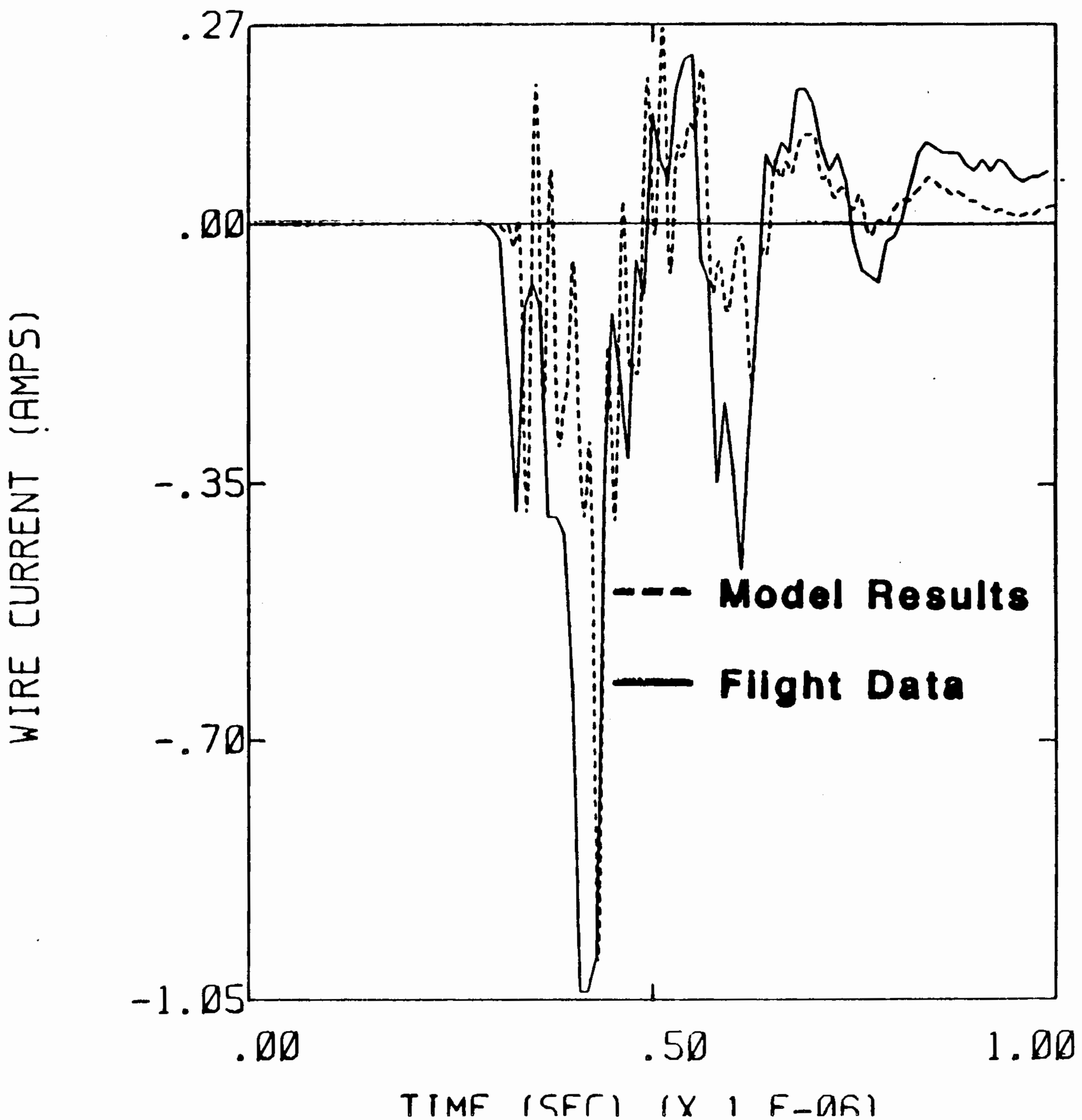
UPSET RESEARCH OBJECTIVE

- Develop an assessment methodology for evaluating the susceptibility of digital systems to upset caused by electrical transients
    - Analytical scheme
        - applicable at the design phase
    - Laboratory test technique
        - Generate guidelines/criteria for testing (presently nonexistent)
        - Verify analytical approach

DIGITAL SYSTEM UPSET RESEARCH METHODOLOGY



INTERNAL COUPLING MODEL AND FLIGHT RESULTS COMPARISON



ELECTRONIC ENGINE CONTROLLER UPSET ASSESSMENT

- Based on Large Transport Controllers
- Two Phase Effort with Hamilton-Standard/Pratt-Whitney

  - Phase 1 "Pseudo Controller"

    Simplex Version of EEC 104 (Used on 757)

    Simulated Static Interfaces

    Hardware to be delivered 2/86

    Random Analog Transient Injection and Analytical Simulation and Analyses 3-86 through 7-86

  - Phase 2 "In-Service Controller"

    Dual Channel EEC 104

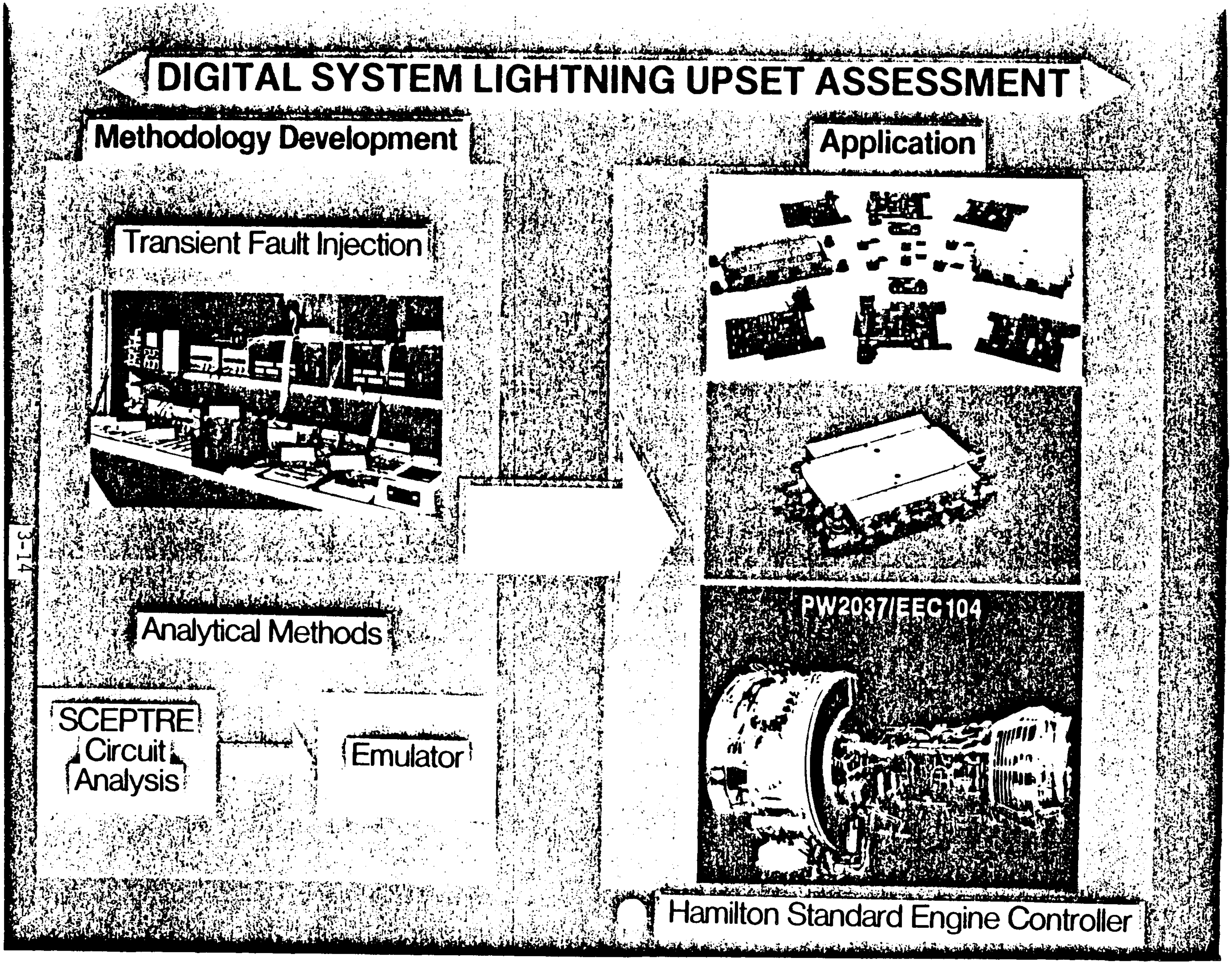
    Closed Loop Engine Simulation Planned in AIRLAB

    Tests and Analysis Begin 3-87

UPSET SUMMARY AND PLANS

- Viable laboratory test technique
- First generation analytical methodology
- Utilize pseudo controller in methodology development
  - Contract NAS-18115 with Hamilton Standard
  - Based on EEC 104 and EEC 131 controllers
  - Customized for LaRC test technique
  - Simulated interfaces
- Future application to state-of-the-art controller
  - Dynamic engine simulation in AIRLAB
  - AIRLAB test control and instrumentation

NASA
L-85-11,159



505-66-21-04 LIGHTNING EFFECTS ON DIGITAL ELECTRONICS

FY 86 PLANS

- O CONTINUE F-106 LOW ALTITUDE STRIKE TESTS
- O CONTINUE CONTRACT WITH ELECTRO MAGNETIC APPLICATIONS FOR ANALYSIS OF F-106 DATA
- O EXTEND CONTRACT WITH HAMILTON STANDARD FOR UPSET ASSESSMENT OF IN-SERVICE EEC 104 ENGINE CONTROLLER
- O UPSET ASSESSMENT OF HYBRID EEC OBTAINED UNDER CONTRACT
  - PERFORM LABORATORY UPSET TESTS
  - DEVELOP MODEL FOR ANALYTICAL UPSET TESTS
- O DEVELOP ADVOCACY FOR SINGLE EVENT UPSET EXPERIMENT FOR SPACE STATION

CATEGORIES OF LIGHTNING STRIKES TO AEROPLANES

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NORMAN, OKLAHOMA

On Types of Lightning Strikes to the F-106 Airplane

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This note discusses results of utilization of transient light sensors and video cameras on board an instrumented airplane for investigation of the attachment pattern of lightning strike to the airplane and physical processes of strike initiation and development. Information obtained from light sensors and TV camera(s), although limited by sensor placement and viewing angles, provides both valuable additions to data obtained by other instrumentation and unique data not otherwise available.

Processes involved in lightning strike initiation

Comparison of analog (frequency band 400 Hz - 100 kHz) records of the light detector with those of currents flowing through the airplane and local electric field derivatives revealed correspondence of luminosity pulses to those of current and E-field derivatives (Fig. 1,2). This coincidence is observed during the initial period of channel attachment to the airplane.

The characteristics of current pulses are as follows: 1) maximum frequency up to 6.0 x 10^3 pulses per second, and 2) pulse duration of a few tens of microseconds. The continuous current (duration of tens of ms) through the same sensors, which is recorded at the frequency band 0-400 Hz, occurs usually a few milliseconds after the initial current pulses (Figs. 3 and 4). The parameters of current pulses and field changes during the initial period of the strike to the airplane, together with the presence of continuous current, make it very similar to "initial" and "very active" parts of intracloud discharge (Kitagawa and Brook, 1960). The initial and very active phases are associated with the initial breakdown streamer processes and with continuous unidirectional streamer progression.

The ability to identify the breakdown process in the record of the electric field derivative can be used to determine the type of strike initiation, triggered flash, intercepted naturally occurring flash, or flash initiated in the close vicinity to the airplane (a few hundred meters) most probably as a result of the airplane presence. The absense of pulses in the record of the local E-field derivative prior to the attachment, i.e., current pulses, is a definite sign of triggering of the flash (e.g., flash illustrated by Fig. 1). On the other hand, if the record of the E-field derivative has pulses prior to occurrence of current pulses, this indicates the initiation of discharge away from the airplane. The lightning strike with records shown in Fig. 2 started about 1.4 ms before attachment, i.e., about 200 m away from the airplane (if propagation is along a straight line). The criterion for separation of the naturally occurring flashes can be the time (range) between initiation (breakdown) and attachment.

Processes of lightning strike development

Video images of lightning obtained with TV camera(s) on board sometimes are sufficient to determine (describe) the stages of an attachment process. These images are also of significant help in interpreting records of electromagnetic parameters of the strike. From comparison of simultaneous development of the radar echo and visual images of lightning channels, we have become confident in determining 1) the direction of lightning channel motion and 2) the total duration of channel attachment to the airplane from analysis of lightning radar echo signals. The continuous luminosity in visual images of lightning indicates the presence of continuous current in the channel. The histogram of continuous current duration measured with time resolution of 33 ms is shown in Fig. 5. The sudden change in luminosity observed in many strikes indicates a surge of current in a channel. There were 66% of the strikes at low altitudes and 82% of the strikes at high altitudes with more than one surge of luminosity during the attachment, with or without discontinuity of channel luminosity (Fig. 6). The time intervals between sequential surges of current in the lightning strike channel (Fig. 7) are similar to those between sequential return strokes in cloud-to-ground flashes. What we observed as surges of luminosity could be an indication of a multistroke feature in intracloud discharges; all direct strikes to the airplane essentially are intracloud flashes.

However, an additional correlation analysis of the time variation of electromagnetic parameters associated with strike and channel luminosity is needed to test this hypothesis.

Reference

N. Kitagawa and M. Brown, A comparison of intracloud and cloud-to-ground lightning discharges, J. Geophys. Res., 65, 1189-1201, 1960.

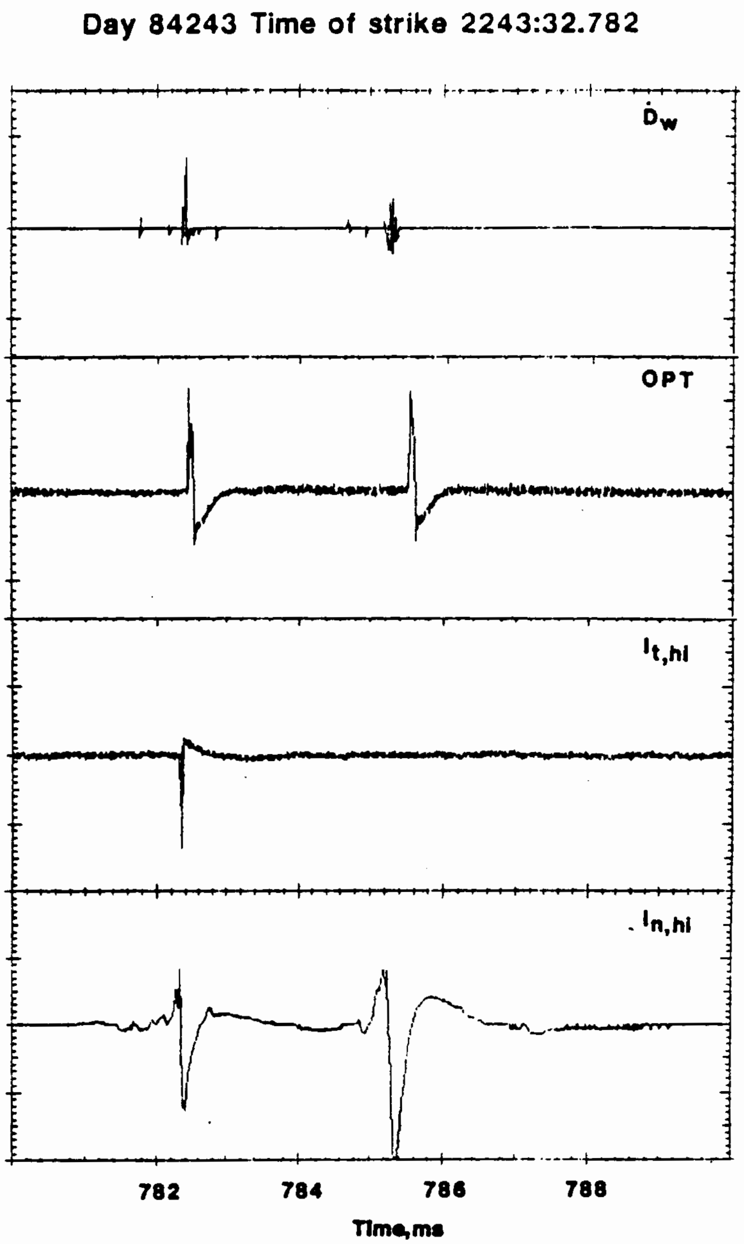


Fig. 1 Strike on 84243, 2243:32.782 UT. Simultaneous records of the E-field derivative on the wing (D'_w), transient light detector (OPT), currents flowing through the nose boom (I_n,h_i) and the tail fin cap (I_t,h_i) at the initial period of attachment. Records are made on the direct channel with frequency band 400 Hz - 100 kHz.

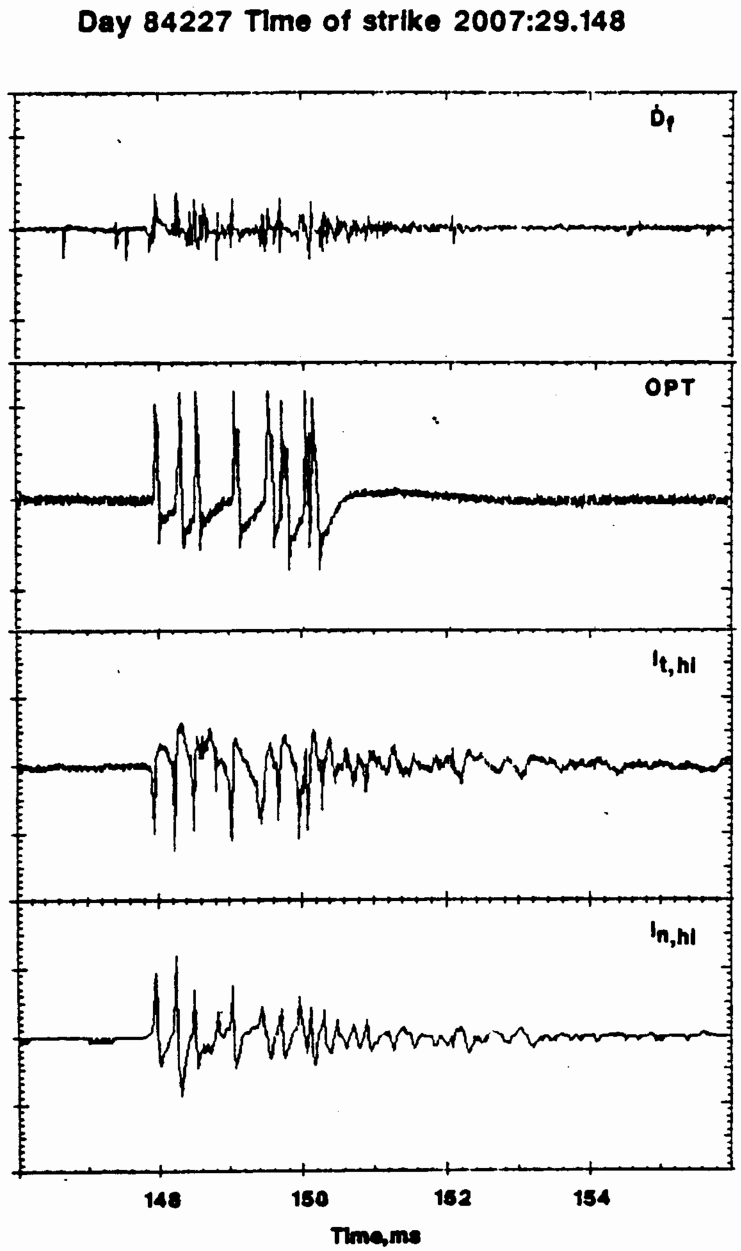


Fig. 2 Strike on 84227, 2007:29.148 UT. See comments to Fig. 1, except $\dot{D}_f$, which is the E-field derivative on the forward section of the fuselage.

84227 1948:35 UT

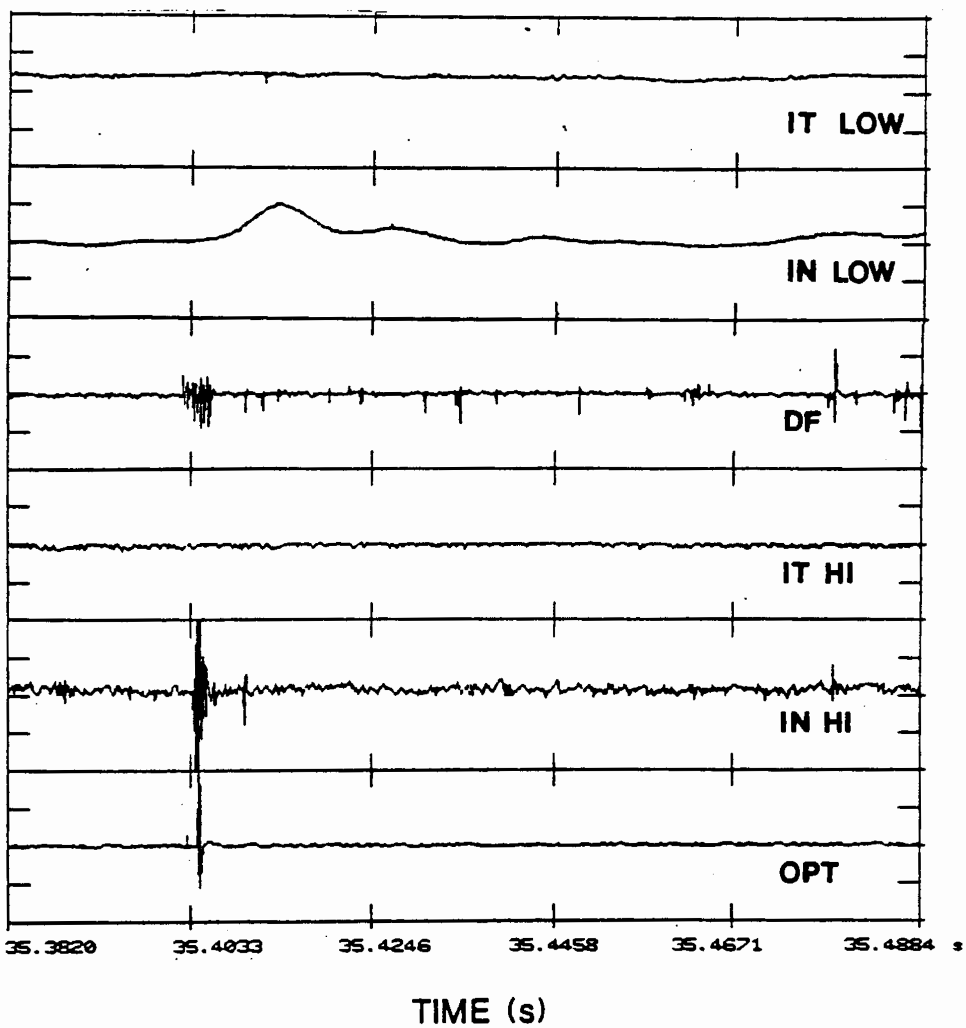


Fig. 3 Strike 84227, 1948:35 UT. Simultaneous records of the currents flowing through the nose boom (IN_{low}) and tail fin cap(IT_{low}) made on FM channel with frequency band 0 - 400 Hz, and records on direct channel of currents at the nose boom (IN_{hi}), the tail fin cap (IT_{hi}), transient light sensor (OPT) and E-field derivative (DF).

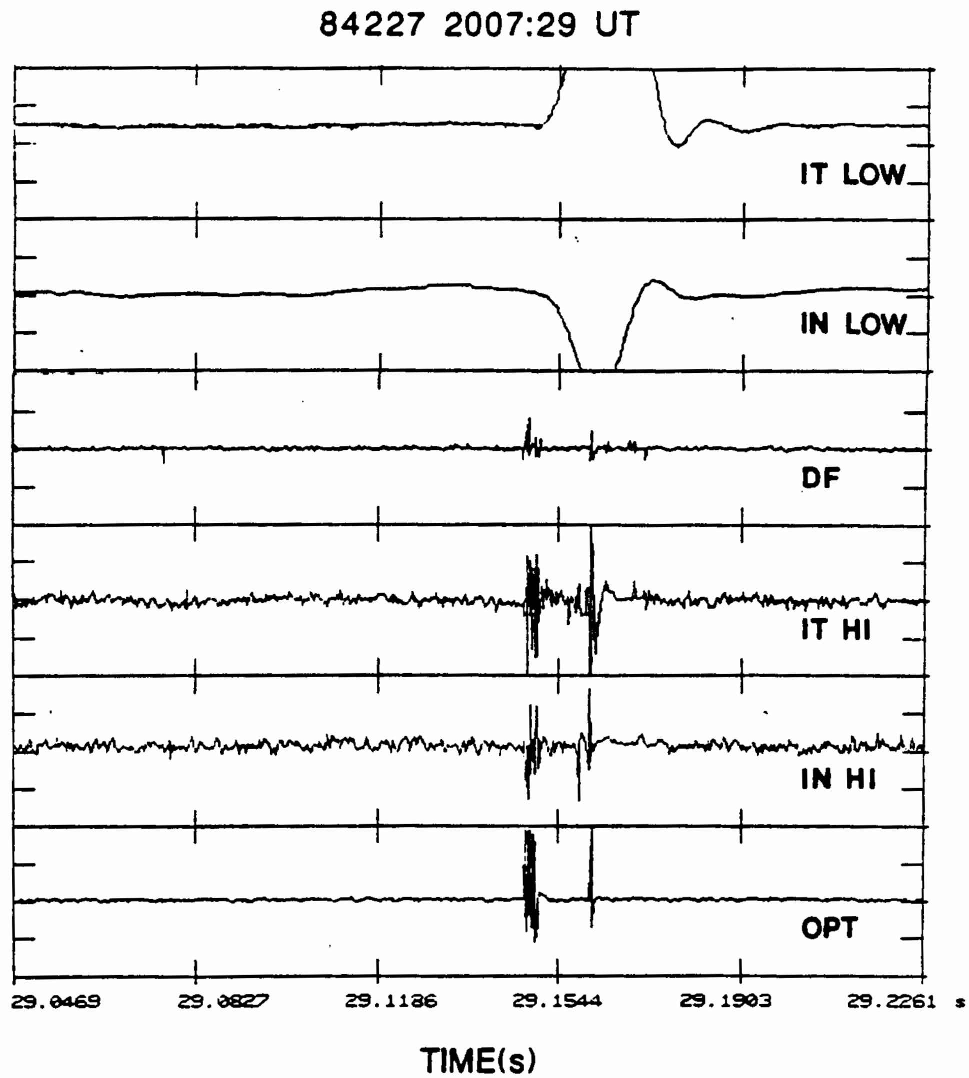


Fig. 4 Strike 84227, 2007:29 UT. Comments are the same as for Fig. 3.

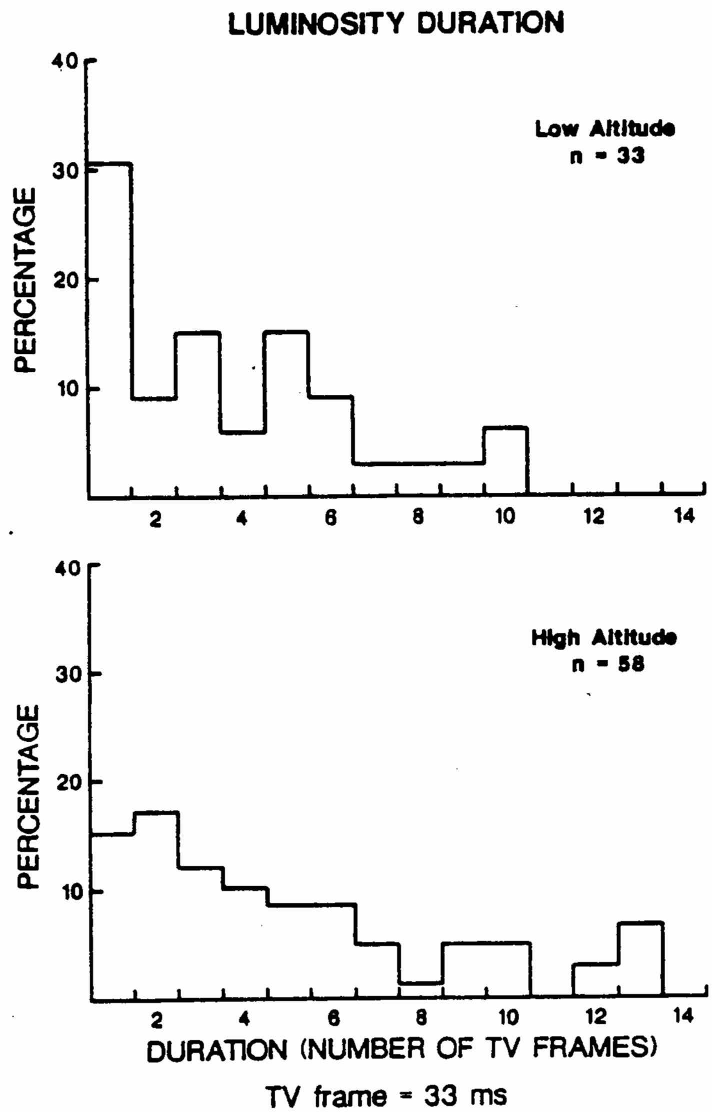


Fig. 5 Luminosity duration measured from the video images of lightning channel mode with TV camera on board. This parameter indicates the presence of continuous current that maintains the channel ionization and therefore its luminosity.

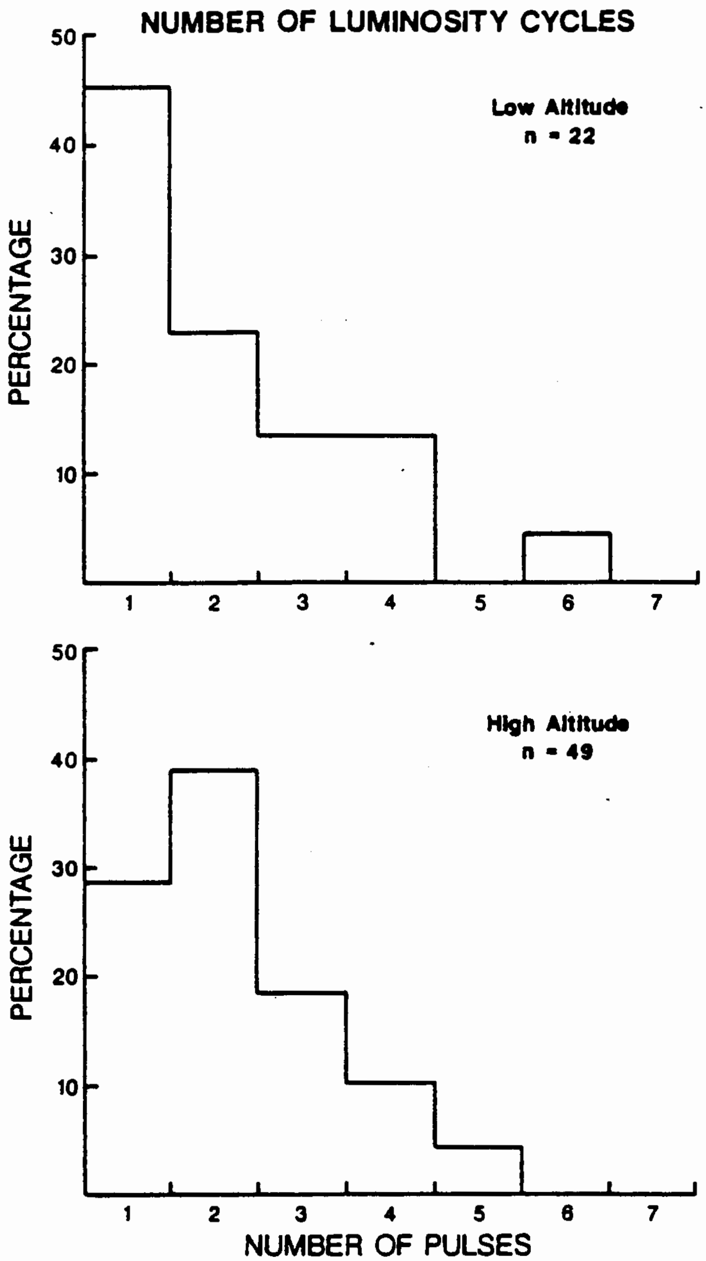


Fig. 6 Number of luminosity cycles obtained from the visual observations of lightning channel with the TV camera on board.

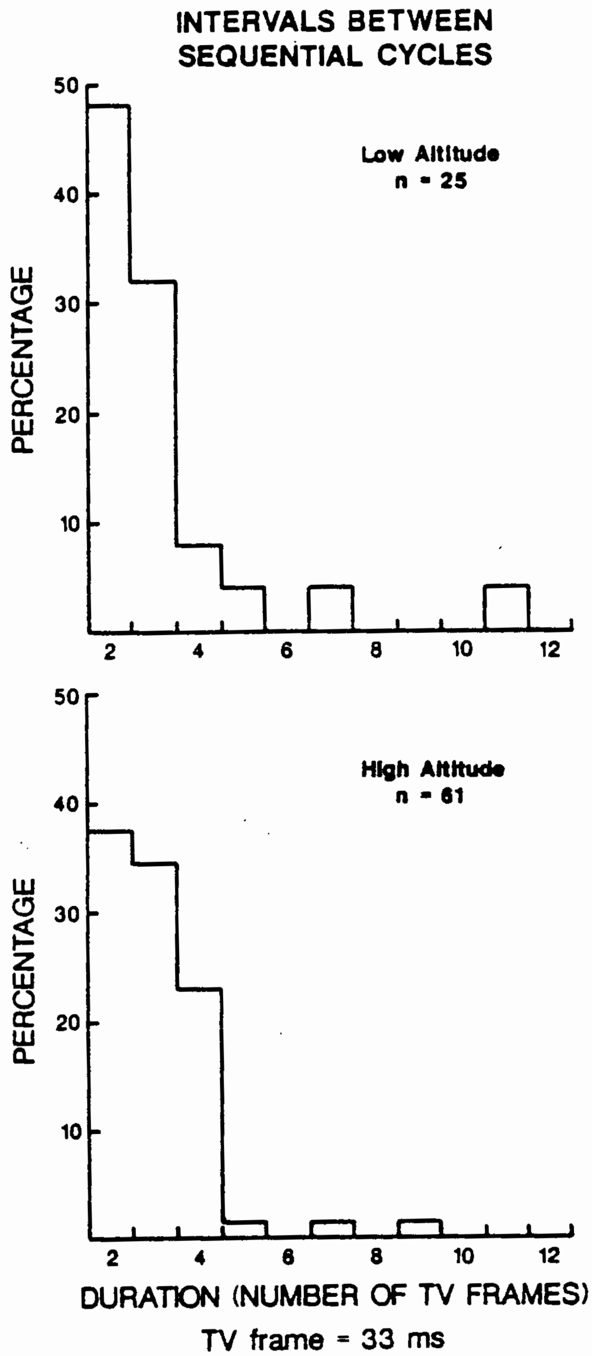


Fig. 7. Intervals between sequential cycles of luminosity in the attached lightning channel calculated between beginnings of the cycles.

Atmospheric Electricity Hazards Protection

(AEHP)

Of Advanced Aircraft

Contract F33615-82-C-3406

Program Management		Technical Management
AFWAL FIEA	Rudy Beavin	Captain M. Patricia Hebert
Boeing	Stan Schneider	David B. Walen


STATIC
STREAMERS

Boeing

Atmospheric Electricity

AEHP

Hazards Protection

Advanced Development Program

Atmospheric Electricity Hazards Protection (AEHP) Program

Objective:

Develop and demonstrate optimal protection measures, design criteria, guides and specifications to assure necessary reliability of advanced aircraft electronic equipment in the natural atmospheric electricity environment

Scope:

This effort is part of a national atmospheric electricity hazards protection (AEHP) program, and is a coordinated joint undertaking of USAF, USA, USN, DNA, FAA, and NASA

Phase I: Protection requirements and design - complete

- Hardening criteria
- Test bed evaluation

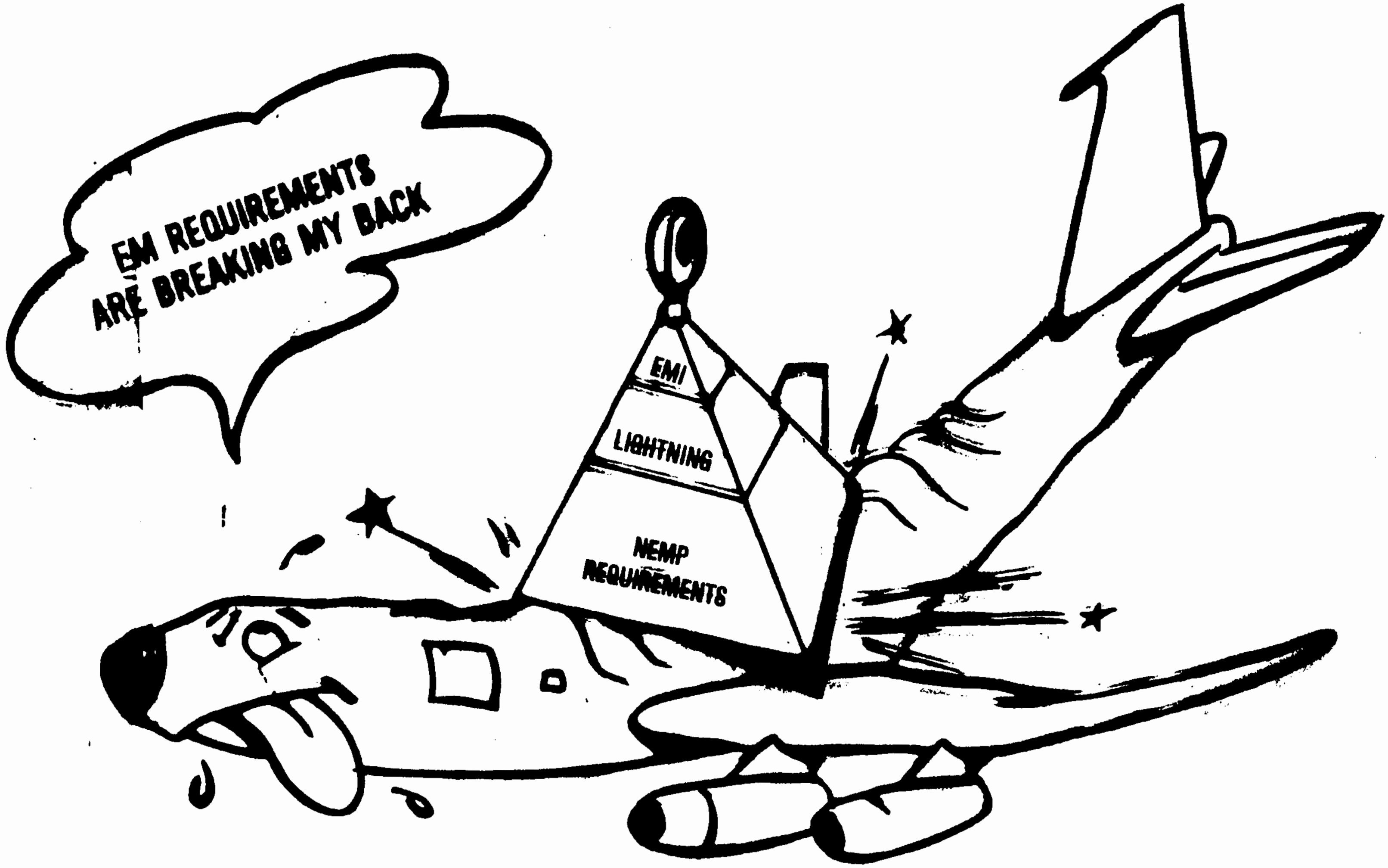
Phase II: Protection validation - in progress

- Final design criteria
- Design guides and specifications
- Qualification test procedures

WEAPON SYSTEM PROGRAM OFFICE VIEW

Atmospheric Electricity AEHP Hazards Protection

Advanced Development Program



Boeing
Atmospheric Electricity
AEHP
Hazards Protection
Advanced Development Program

Phase I
Preliminary Analysis and Protection Design

TASK II

STRUCTURAL INTERACTION
- Structural trends
- Current flow and field penetration code

TASK I

THREAT ENVIRONMENT
- Lightning model
- AEHP, EMI, and EMP environment comparison
- Parametric threat levels
- Natural lightning environment

TASK III

ELECTRONIC SUSCEPTIBILITY
- Component and subsystem susceptibility
- System trends

TASK IV

VULNERABILITY ASSESSMENT
- Vulnerability analysis
- Transient response measurement
- Pretest Prediction
- Subsystem sensitivity
- Test technique evaluation
- EMI/EMP response comparison

TASK V

PROTECTION EFFECTIVENESS
- Threat exposure
- Protection evaluation
  - Circuit hardening
  - Wires and cables
  - Subsystem equipment protection
  - Vehicle hardening
- Tradeoff evaluation
  - Cost
  - Reliability
  - Power
  - Weight
  - Maintenance
- Supplementary threat evaluation
  - NEMP/EMI
  - Inflight emitters and shipboard environment
- Balanced protection specification

TASK VI

INTERIM DESIGN CRITERIA
- AEHP design criteria
- Equipment design requirements
- Installation design requirements

TASK VII

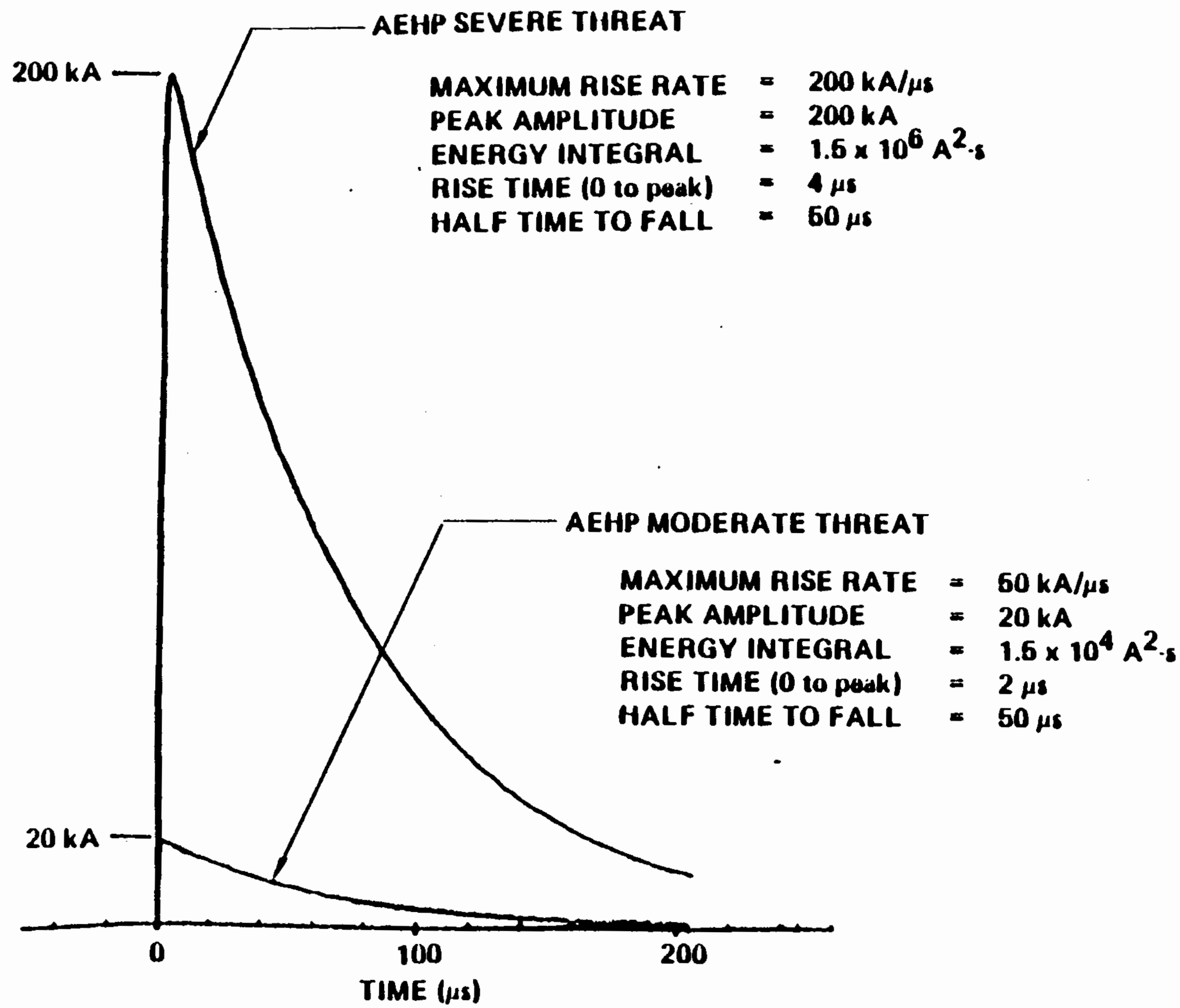
PHASE II DEFINITION AND APPROVAL
- Test bed identification
- Test bed protection specification
- Protection schedule
- Phase II decision

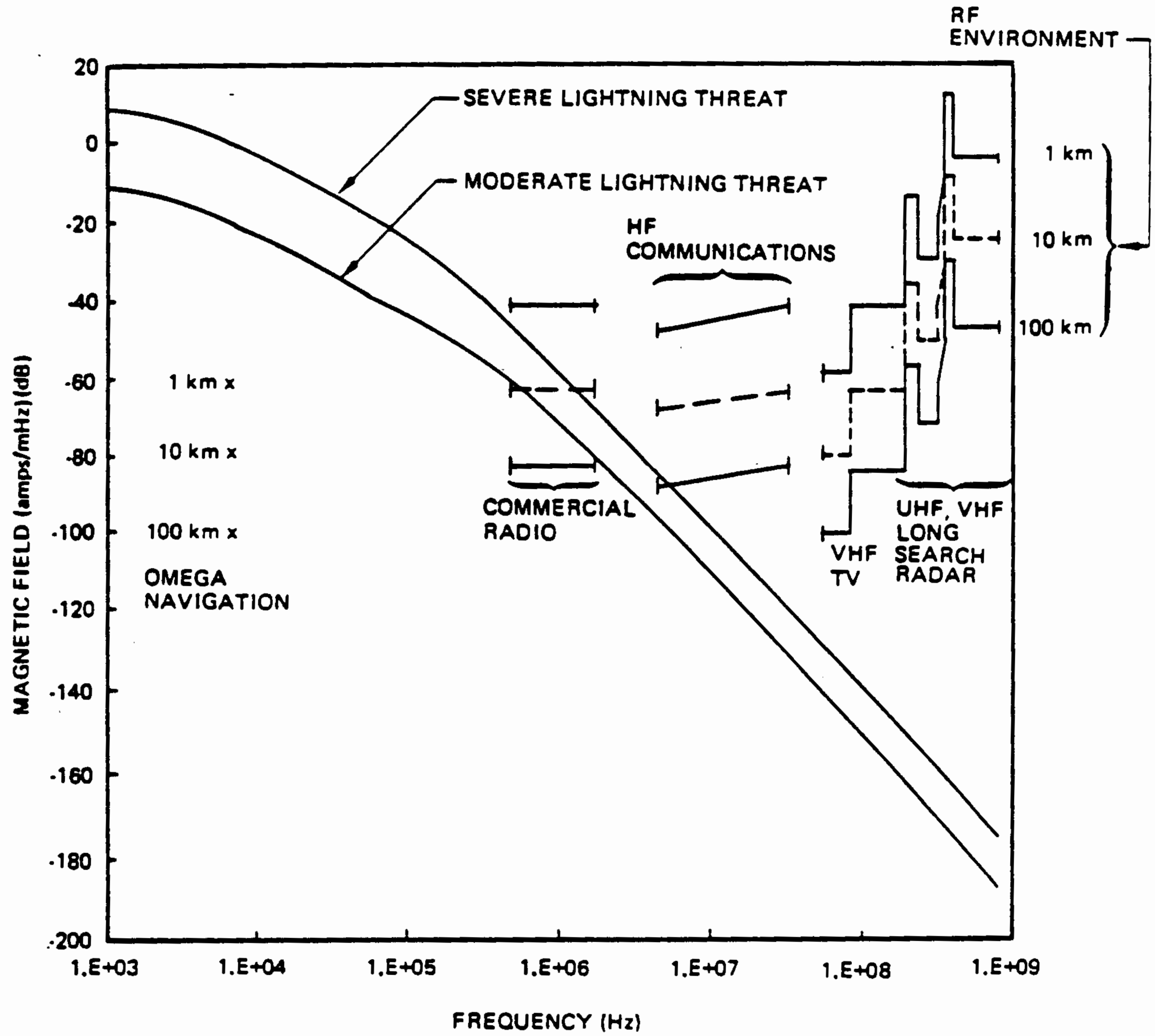
TASK VIII

PHASE I FINAL REPORT

TO PHASE II

Single Lightning Stroke Threat

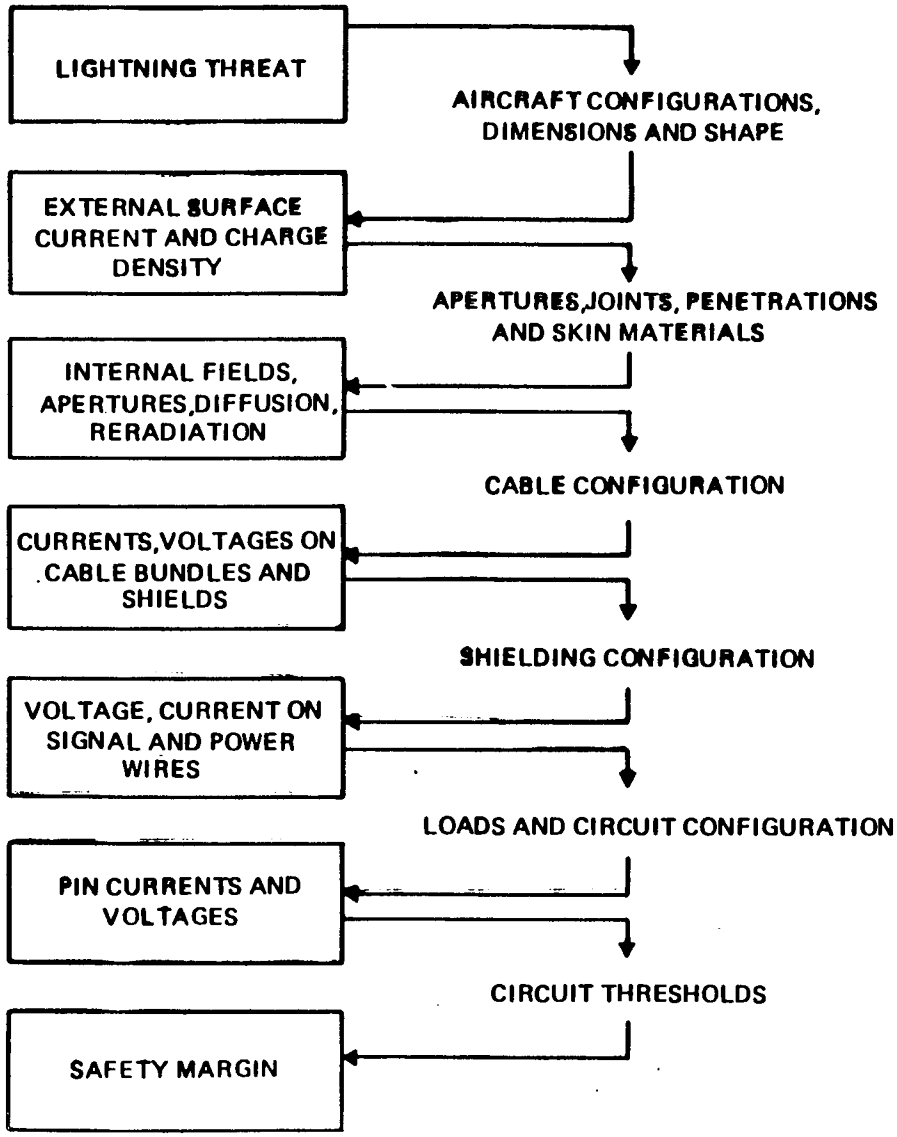


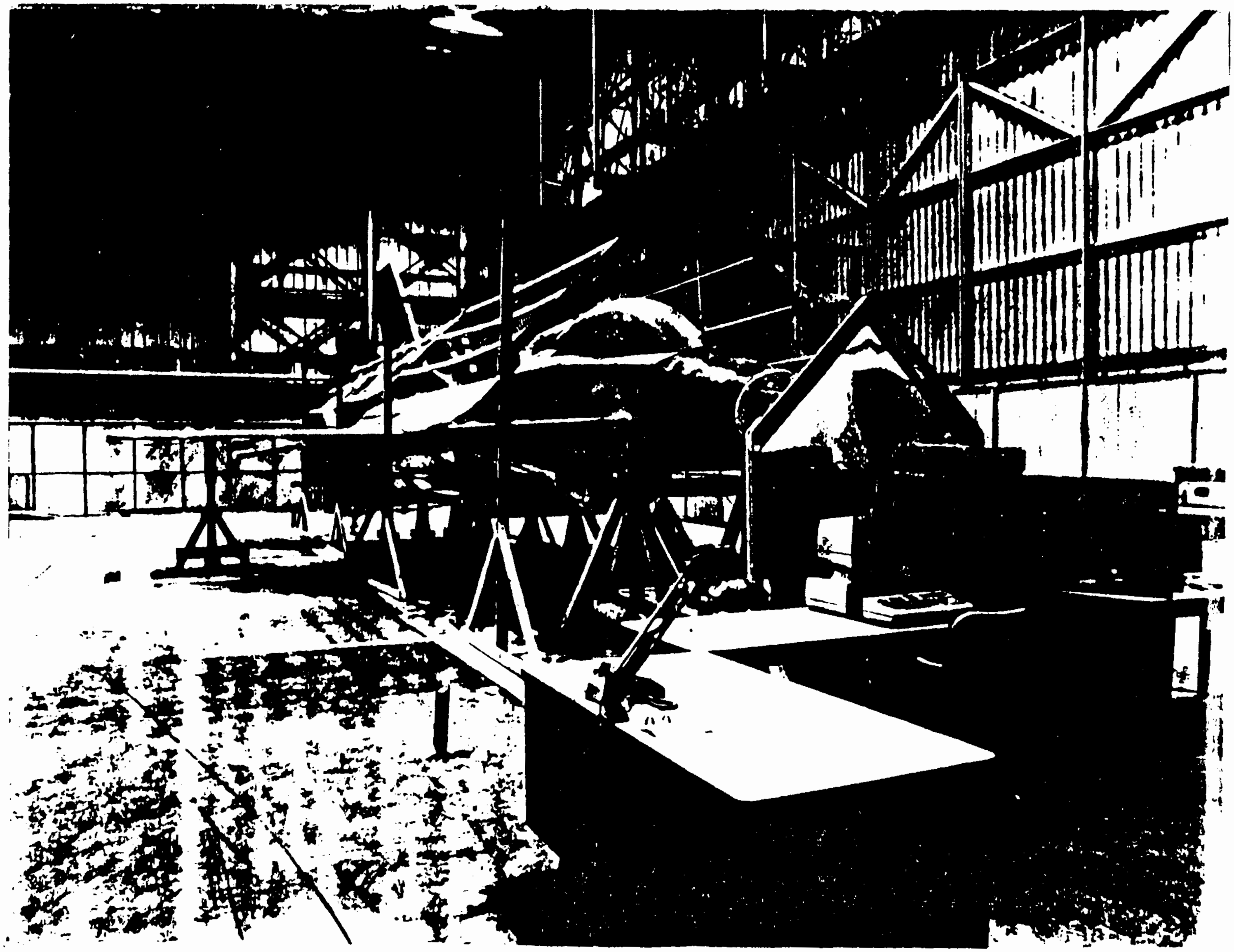


Attached Lightning Versus EMI Environment

- Deny high currents to aircraft interior, advanced structure, and fuel
- Trade structures, interface and subsystem hardening for best protection
  - Integrate lightning, EMI/EMC, NEMP protection methods
- Emphasize systems affecting safety and mission
  - Flight control
  - Engine control
  - Electrical power
  - Stores management
  - Fuel systems
  - Advanced structure
- Use ground simulation tests and analytic tools for protection evaluation
  - Employ best available lightning characterization
  - Bound key parameters to define safety margins
- Provide practical protection guidelines for generic aircraft employing microelectronic subsystems and advanced composite structures

AEH Protection Assessment Methodology





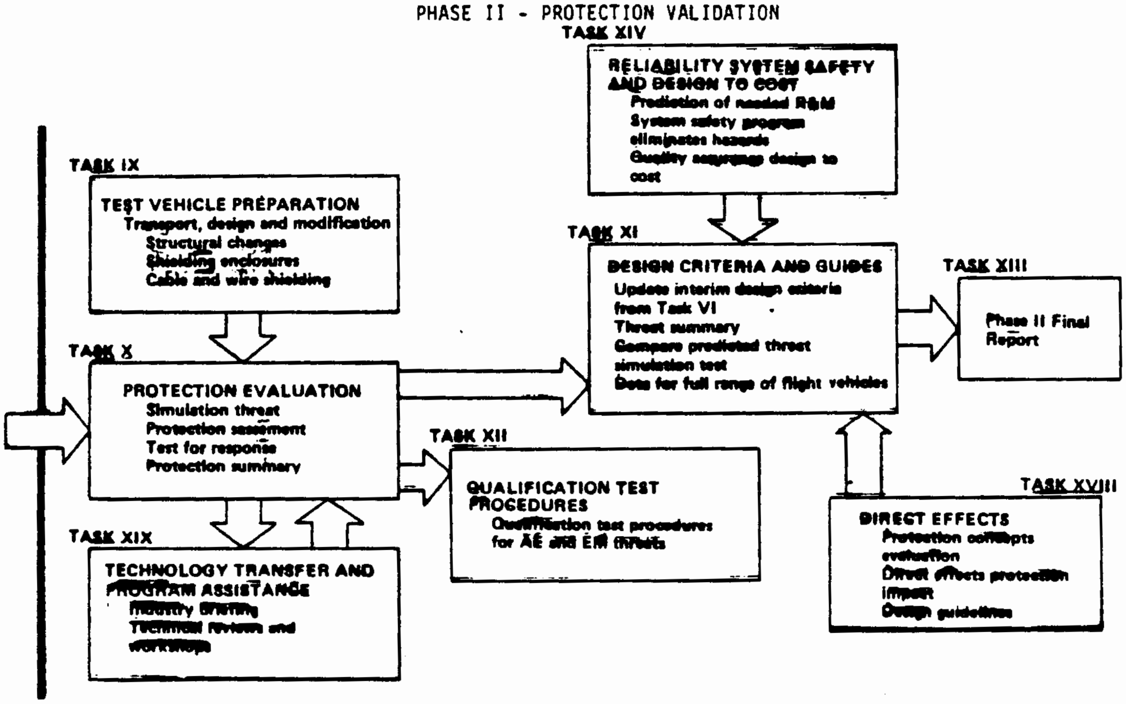
AEHP
TECHNOLOGY TRANSITION

- PHASE I TECHNICAL REPORTS
- MILITARY / U.S. AGENCIES COORDINATION
- ANNUAL GOVT / INDUSTRY TECHNOLOGY EXCHANGE MEETING
- QUARTERLY PROGRAM REVIEW
- ASD / ENAS PARTICIPATION
- TAD 1987 - INDIRECT EFFECT AEHP
  - THREAT / TEST DATA BASES
  - QUALIFICATION TEST / PROTECTION ASSURANCE PROCEDURES
  - FINAL DESIGN CRITERIA
- TAD 1988 - COMPLEMENTARY AEHP
  - DIRECT EFFECT PROTECTION
  - COMPOSITE A/C DEMONSTRATION

PHASE II

- DEMONSTRATION OF PHASE I DEVELOPMENTS
  - FULL SCALE TEST
  - PREDICTION CORRELATION
  - SAFETY MARGIN FOR MODERATE THREAT
  - A METHOD VERIFIED TO SEVERE THREAT
  - SPEC / STANDARD DEVELOPMENT
- ENHANCEMENTS
  - DIRECT EFFECTS FOR COMPREHENSIVE AEHP
  - COMPOSITE VEHICLE DEMONSTRATION

PHASE II - PROTECTION VALIDATION



AEHP ADP Objectives

- Design guidelines
- Simple analysis tools/techniques
- Integrated specifications
- Simple/useable qualification tests and procedures
- Surveillance and maintenance techniques

Atmospheric Electricity Hazards Protection

Tested

- ALCM – 200,000 amperes
- F-16 composite forebody – 20,000 amperes
- F-14 modified with composites/avionics – 200,000 amperes

1986 test

- ACAP composite helicopter – 200,000 amperes

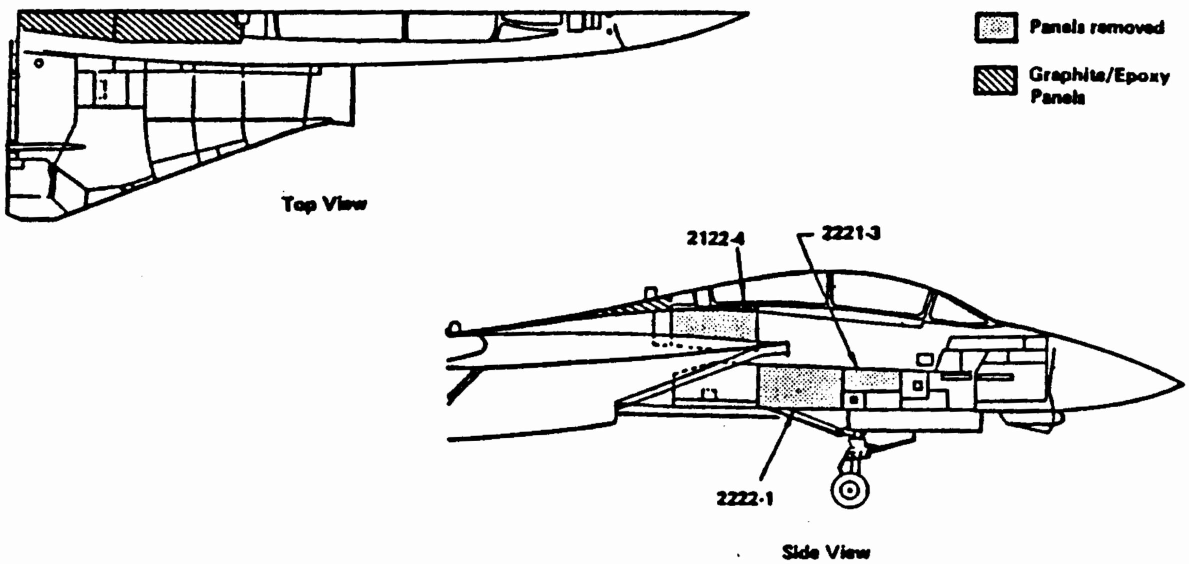
Benefits

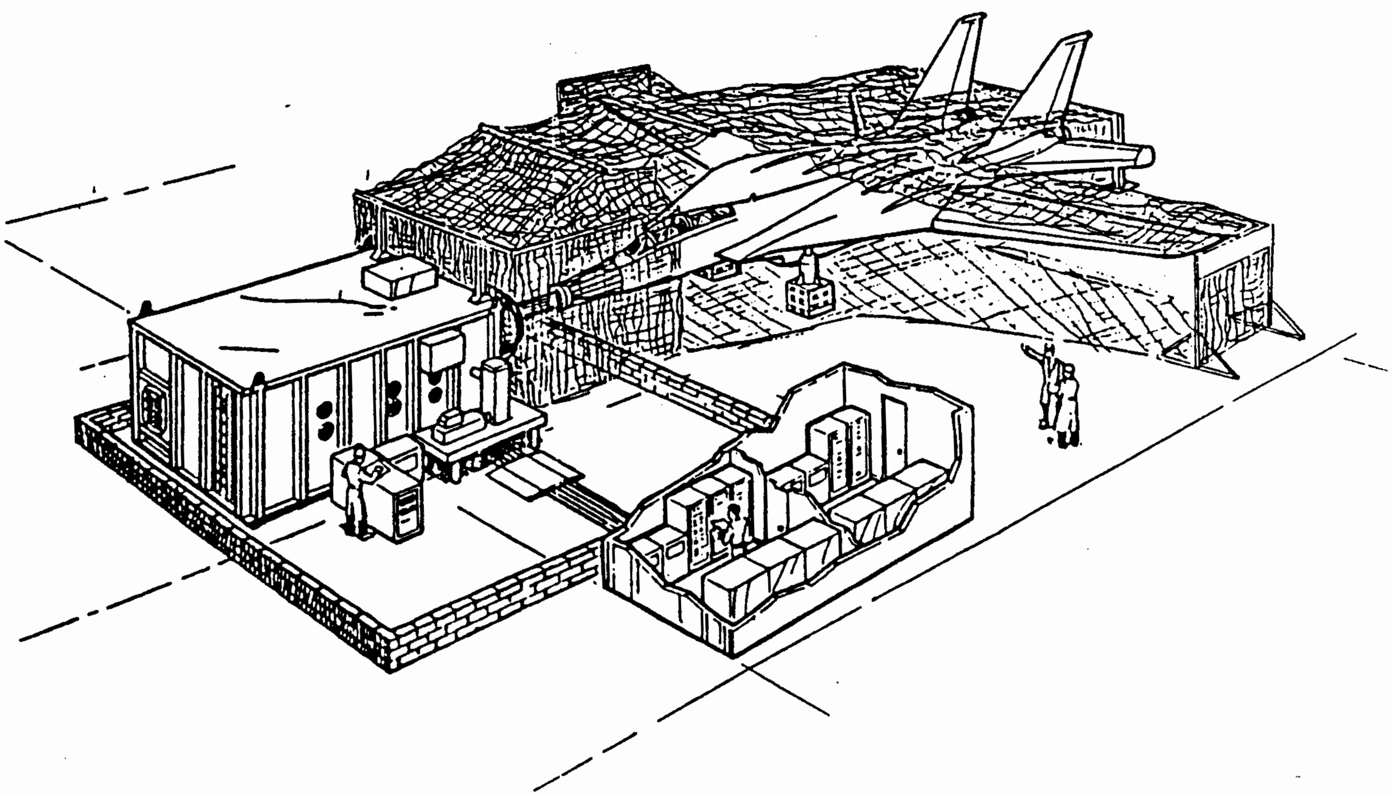
- Lightning protection guides for composite/digital aircraft
  - Design
  - Verification
  - Coupling analysis
- Advantages of composites and flight/mission critical electronics not compromised

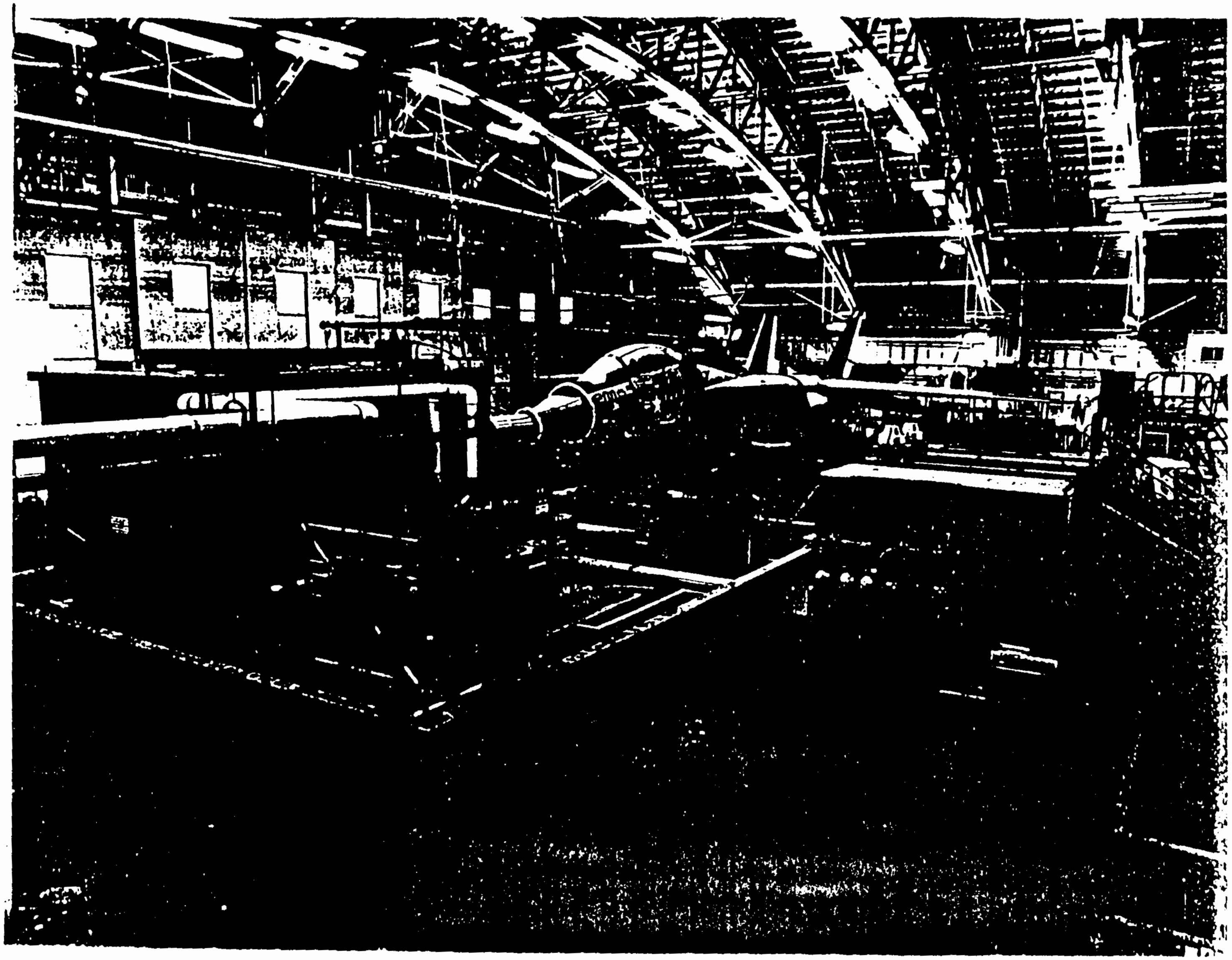
AEHP F-14A Tests

- Turtle deck and over wing fairings replaced with graphite/epoxy panels
- Forward side panels removed to simulate kevlar and fiberglass
- Installed ALCM avionic suite and avionic suite using advanced airborne computer
- Injected currents nose-to-tail and nose-to-wingtip
  - Swept CW (2 amps)
  - 20 KA pulse
  - 200 KA pulse
- Protection included LRU hardness, wire braid on cables and placement of wires away from apertures

F-14A Panel Modification







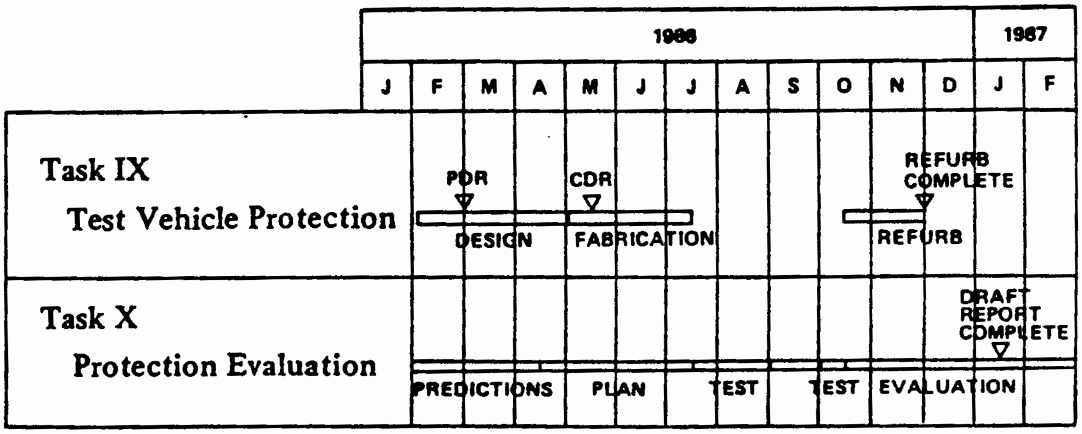
AEHP F-14A Results

- Transformed swept frequency results from 3 to 27 percent higher than results measured with moderate level pulse tests
- Extropolated moderate level pulse test results from 35% lower to 32% higher than high level pulse test results
- Tests showed avionics safety margins of 5 to 24 dB
- 200 KA simulator very reliable and repeatable

ACAP Tests

- Bell tool proof article
- Bell will modify test bed
  - Drive train
  - Landing gear
  - Wire screen repair
  - Engine mockup
  - Tail rotor and hub
- Boeing install Army avionic suite and ALCM avionic suite
- Tests at Seattle
  - Swept CW
  - 20 KA pulse
  - 200 KA pulse

AEHP, ACAP Task IX and X Schedule



AEHP Accomplishments

- Lightning threat data recorded on NASA F106
- AEHP design methodology developed
- Innovative protection concepts developed
  - Composite F-16
  - ALCM
  - F-14A
- Standardized test techniques
- Aircraft protection design criteria
- Simulator developed

AEHP Program Future Plans

- Perform lightning tests and analyses on Bell all-composite helicopter (January 1986 to February 1987)
- Perform lightning simulator modifications for aircraft structural damage tests (January 1986 to May 1986)
- Update lightning protection design guidelines and test procedures (September 1986)
- Propose additional tests and anlyses on graphite/epoxy airplane (1987-1988)
- Document direct effects data deficiences
  - LTI and McDonnell subs to Boeing
- Modify 200KA simulator for small specimen direct effects testing
  - Maxwell subcontractor to Boeing

AEHP Deliverable Documents

TITLE	AVAILABLE
Atmospheric Electricity Hazards Protection Concepts	Now
Atmospheric Electricity Hazards Balanced Protection Schemes	Now
Atmospheric Electricity Hazards Threat Environment Definition	Now
Atmospheric Electricity Hazards Design Criteria for Air Vehicles	Mid CY 1987

INDUSTRY WIDE BRIEFINGS

May 1983 Seattle, Washington

May 1984 Seattle, Washington

August 1985 Dayton, Ohio

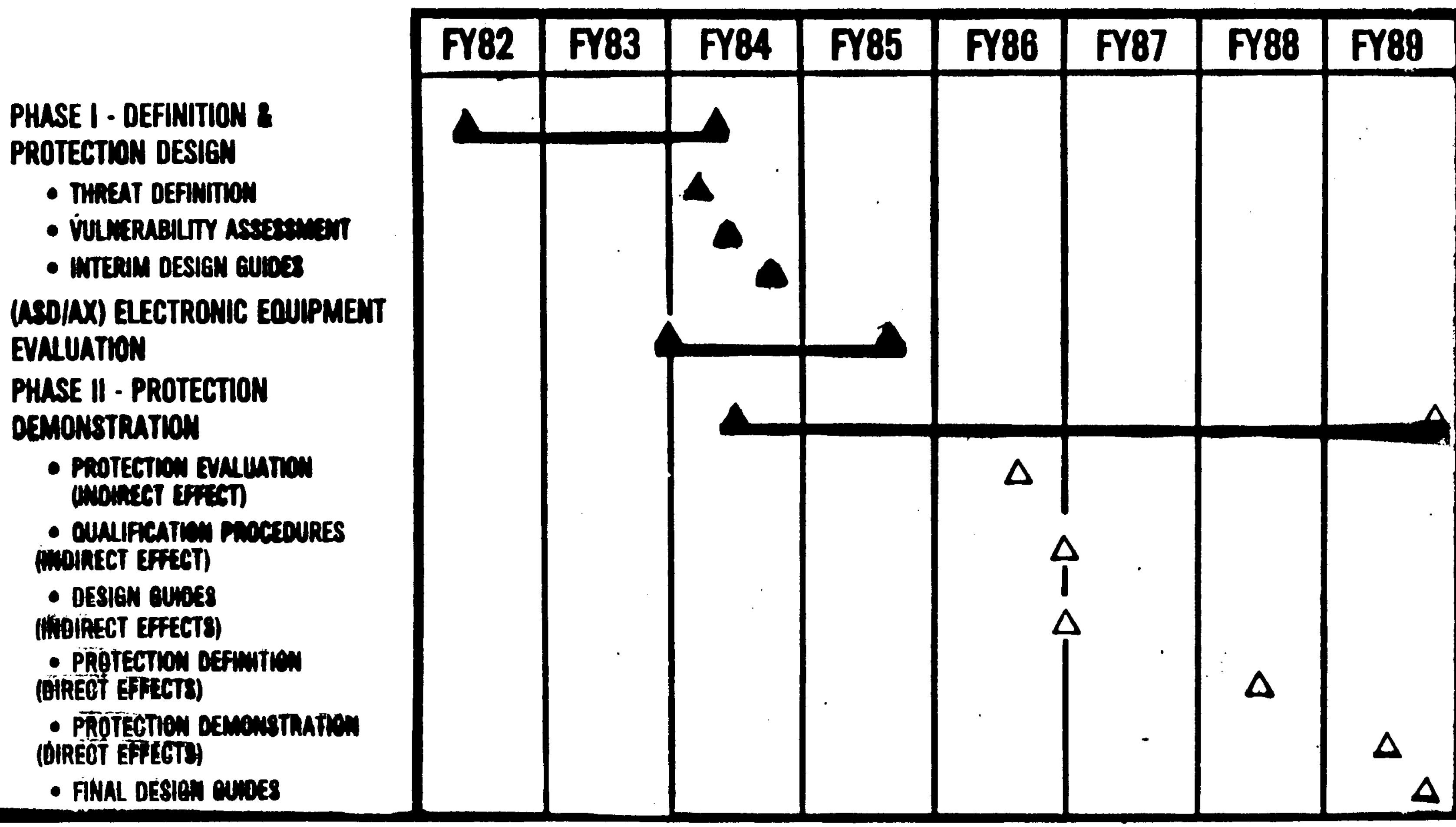
June 1986 TBD

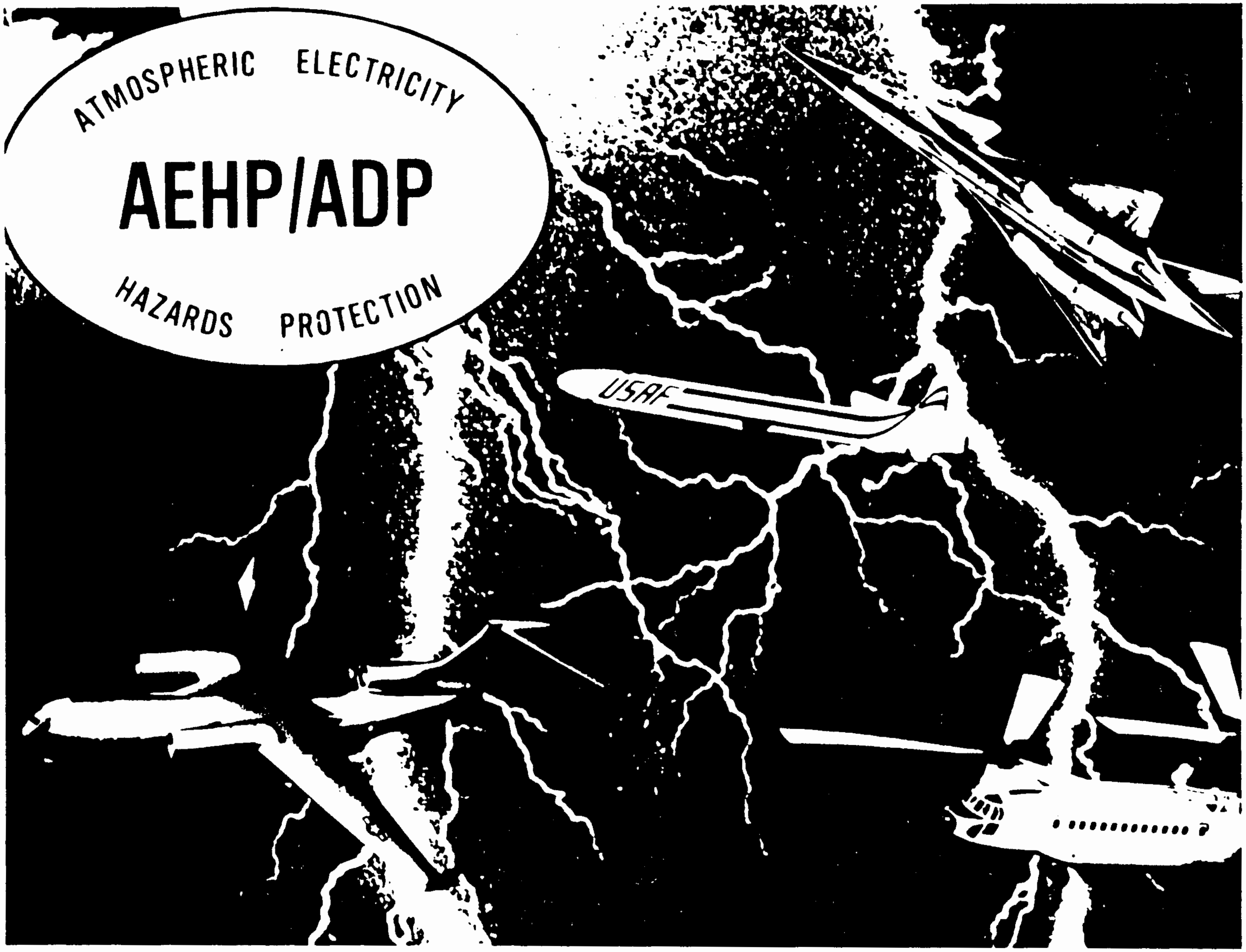
TBD 1987 TBD

AEHP ADVANCED TECHNOLOGY DEVELOPMENT

Atmospheric Electricity AEHP Hazards Protection

Advanced Development Program




ATMOSPHERIC ELECTRICITY
AEHP/ADP
HAZARDS PROTECTION
USAF

RECENT/CURRENT/FUTURE
ACTIVITIES
FOR
LIGHTNING/STATIC ELECTRICITY
PROTECTION
OF
U.S. ARMY AIRCRAFT

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11 February 1986

1. OVERVIEW: In today's presentation, I'll give you a brief rundown of the U.S. Army's activities in lightning testing for the Advanced Composite Airframe Program (ACAP) in regard to support of the Air Force's Airborne Electrical Hazards Protection (AEHP) Advanced Development Program (ADP) and the Army Aviation Applied Technology Directorate's (Fort Eustis) funded effort. After that, I'll say a few words about recent testing of the UH-60A (BLACK HAWK) helicopter for both nuclear EMP (NEMP) and swept CW (lightning) testing. This will be followed by a discussion of the HQ Army Material Command's apparent blossoming interest in lightning and electrostatic discharge hazards as they affect all Army commodities. Finally, I'll touch briefly on an aeronautical design standard for lightning protection requirements, field inquiries regarding residual magnetism on aviation components, and Army aviation interest in ESD protection work being conducted by the Naval Research Laboratory.

2. ACAP ACTIVITIES:

a. The first vuegraph summarizes characteristics of the ACAP as they pertain to this discussion.

b. The next three vuegraphs show pictures of the Sikorsky Tool Proof Article (TPA), the Bell Helicopter TPA and an overview of types of materials used in the construction of their respective airframes.

c. In this presentation, I'm primarily reporting on activities of the following elements of the U.S. Army Aviation Systems Command (AVSCOM):

(1) Aviation Applied Technology Directorate (Fort Eustis, VA) of the Aviation Research and Technology Activity (Moffet Field, CA).

(2) Avionics Research and Development Activity (Fort Monmouth, NJ).

d. The ACAP program is primarily managed at Fort Eustis with avionics support provided by Fort Monmouth. AVSCOM is currently not much in the loop.

e. The next three vuegraphs summarize current activities and plans both within the Army and in support of the Air Force's AEHP ADP. AVRADA is currently recommending the following Army avionics to be considered in these tests: the AN/ARC-115 (VHF-AM) and AN/ARC-116 (UHF) radio sets, the AN/ASN-137 doppler navigation system, a C-6533 intercom set, an Automatic Target Handoff System (ATHS), an Integrated Avionics Control System (IACS) display, and a CCU bus controller. This is a mix of older and newer technology. I don't know what avionics is planned by Boeing or the Air Force. As far as I know, Boeing will add any wiring, instrumentation, and selected avionics to the BHT modified TPA.

3. UH-60A (BLACK HAWK) Activities: Results of NEMP testing of the UH-60A at Kirtland Air Force Base, Albuquerque, NM, were recently briefed at AVSCOM. These tests were conducted by TRW and funded by the Defense Nuclear Agency (DNA). Results are documented in a Secret report. The Air Force looked into the details of this test in preparation for low level swept CW tests of the UH-60A for lightning interest; and the results of both are expected to eventually be compared. The swept CW tests were conducted at Eglin AFB using

portable test equipment. The BLACK HAWK that was struck by lightning over Germany is still in repair at Scott AFB. I visited the aircraft twice last year and both times took pictures of rotor blades, rotor head bearing surfaces, and any other burn marks I could find. I understand that just about every component of the drive train (including the engine) had residual magnetism and these were to be replaced per maintenance manual guidelines. A number of rotor head linkages had burn marks on metal bearing surfaces and these were removed; but they were not available when I was there. I'll keep on this with a special interest in electrical/electronic components being replaced.

4. AMC/LABCOM: In mid 1985 the U.S. Army Laboratory Command (LABCOM) was assigned Army Material Command (AMC)-wide responsibility for organizing and coordinating efforts to solve electrostatic discharge (ESD) problems. An ESD conference was held at LABCOM on 19-20 Sep 85 to discuss problems, solutions, and activities at the various Commands in this area. Many of the topics appeared to be centered on the logistics aspects of ESD regarding handling and packaging problems on piece parts. Representatives of the aviation, missile and test commands added the operational system aspects; e.g., in regard to aircraft and missiles. Since then, the commanding general of AMC has added the subject of lightning as a result of several lightning strikes to ammunition igloos. The next conference will also be at LABCOM (26-27 Mar 86) and will primarily address lightning. The various commands have been asked to send selected information to LABCOM for a LABCOM data base as well as dissemination among interested parties. My recent submittals to LABCOM included NICG and SAE activities and copies of previous presentations to annual NICG meetings such as this. I don't know where this exercise is going. There may eventually be funding made available to do some work. In any event, at least the various Army Commands will better communicate with one another as we do here at the NICG. Incidentally, I'm the AVSCOM ESD and lightning point of contact for this activity.

5. Other Activities:

a. ADS-28: We at AVSCOM are currently engaged in writing a request for proposal (RPF) for the next generation of light helicopters (LHX). Since the military standard on lightning protection requirements is not yet released, an aeronautical design standard was developed based on a recent draft of the basic military standard.

b. Residual Magnetism: Occasionally we get phone calls or written communications regarding use of a magnetometer to trace the path of lightning current of lightning-struck aircraft in order to locate damaged parts. In general, magnetized parts must be replaced or, at least, demagnetized. Recently, some field personnel have been using the magnetometer on aircraft even though there had been no record of a lightning strike. It appears that some aircraft parts become magnetized just from normal flights. There was even one instance of a magnetized wire cutter that caused a considerable error in the onboard magnetic compass. As a result of these inquiries, additional instructions for replacement criteria have been developed for inclusion in technical manuals.

c. ESD Shock Hazards: As a result of a recent liaison activities report to HQ AMC regarding Naval Research Laboratory (NRL) work for control of the ESD shock hazard associated with helicopter sling-load operations, AVSCOM was requested to investigate this work and to provide recommendations on incorporting this technology on current and future Army helicopters. I contacted NRL and got the details of what they have been doing:

(1) They recently completed ESD measurements on a CH-53E. The test report reconfirms an old problem and recommends addition of series resistances in hoist cables to limit current when grounded.

(2) Two hoist configurations are addressed: a single-point pendant and a utility hoist.

(3) Change involves replacing the ground strap of the pendant and the steel cable of the hoist with distributed ten megohm resistances to limit current to a safe level to protect ground personnel from serious shocks in the event proper grounding procedures are not followed.

(4) NRL plans to test a modifed pendant in late spring of this year. The modification of the hoist is not as far along: i.e., it is only at the specification stage.

(5) I recommended we track this effort and survey our own needs in this area for possible consideration.

d. Other: During a recent conversation with Dr. Nanevicz of Stanford Research Institute, he voiced an interest in revisiting use of an active discharger for hovering situations where dust cloud (and subsequent recirculation currents) do not occur: e.g., over water.

ALL COMPOSITE AIRCRAFT PROGRAM (ACAP)

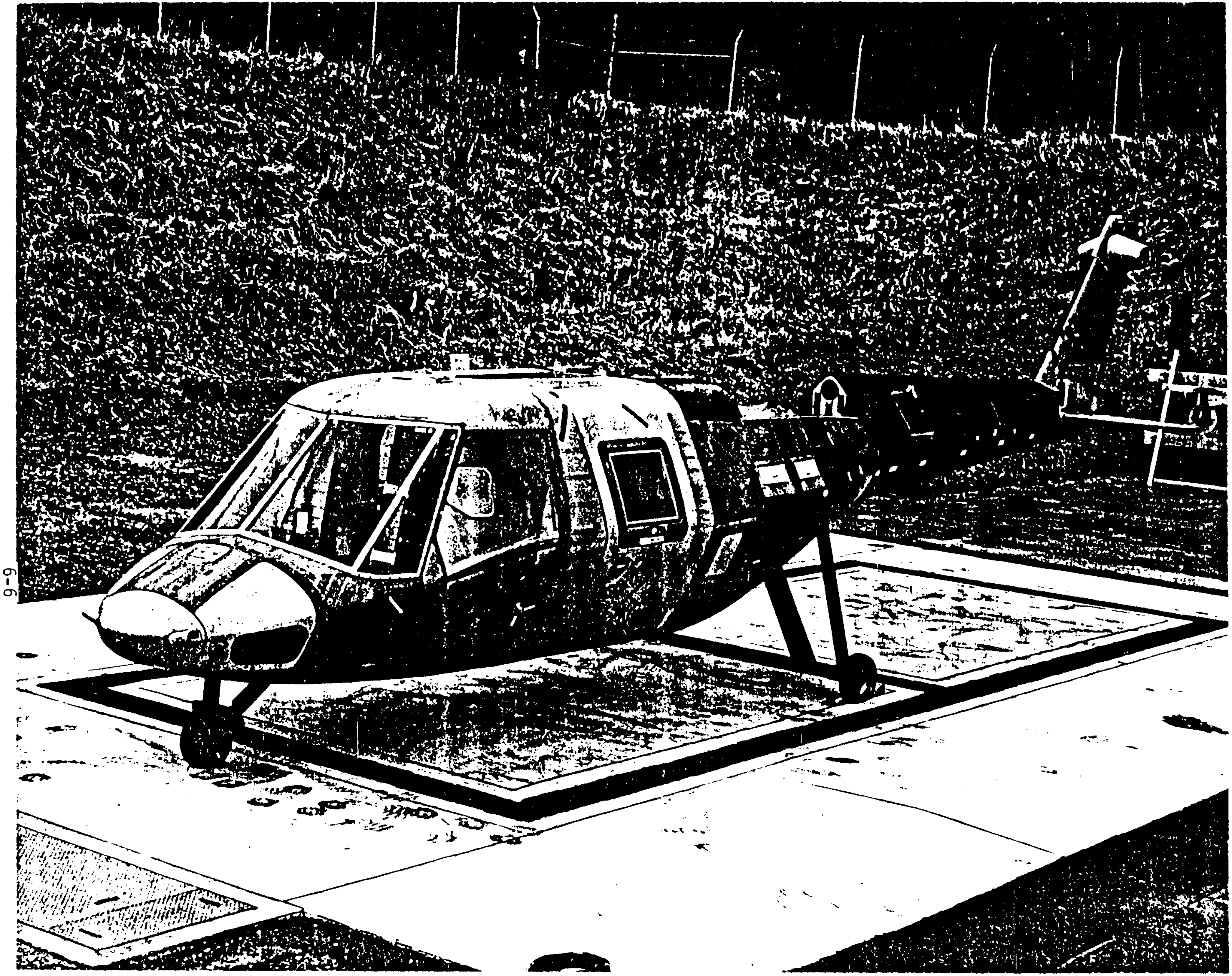
OBJECTIVE---TO PROVIDE TECHNOLOGY BASE FOR ENGINEERING DEVELOPMENT OF COMPOSITE AIRFRAMES

CONTRACTORS---SIKORSKY AIRCRAFT AND BELL HELICOPTER TEXTRON (BHT)

TEST HARDWARE---1 EACH FLIGHT TEST ARTICLE (FTV)
1 EACH TOOL PROOF ARTICLE (TPA)
1 EACH STATIC TEST ARTICLE (STA)

METALIZATION---ALL NONCONDUCTIVE WXPOSED COMPOSITE SURFACES HAVE ALUMINUM WIRE MESH. COMPOSITE JOINTS ARE METALIZED (SIK--FOIL; BHT--WIRE MESH). ALL FTVs, TPAs AND STAs HAVE SAME DEGREE OF METALIZATION, EXCEPT SIKORSKY TPA HAS NO METALIZATION.

<u>NOTE</u>-----THE ONLY DELIVERABLES TO THE GOVERNMENT ARE THE AIRFRAMES.

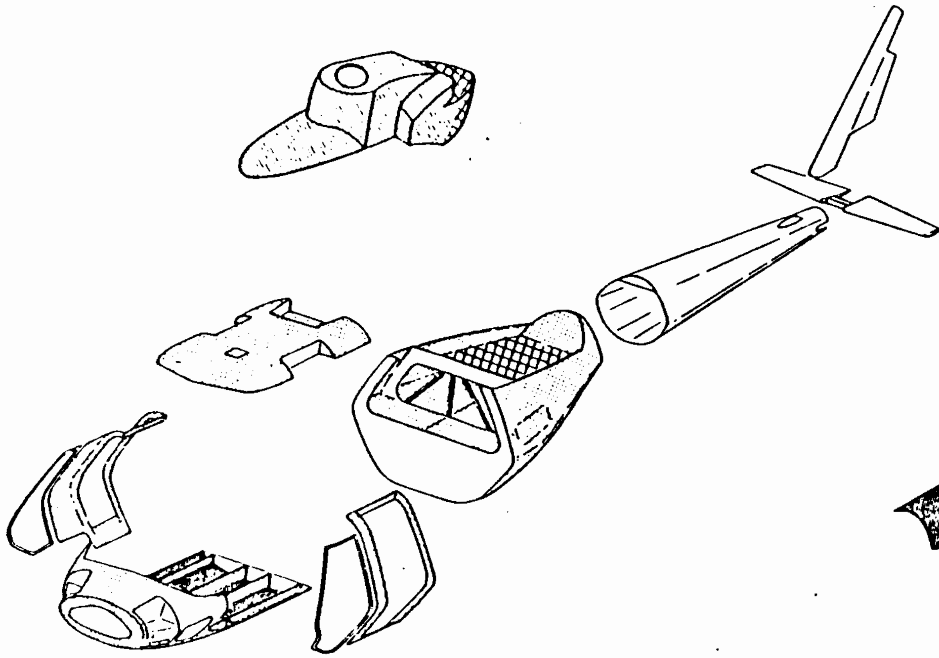


SIKORSKY TOOL PROOF ARTICLE

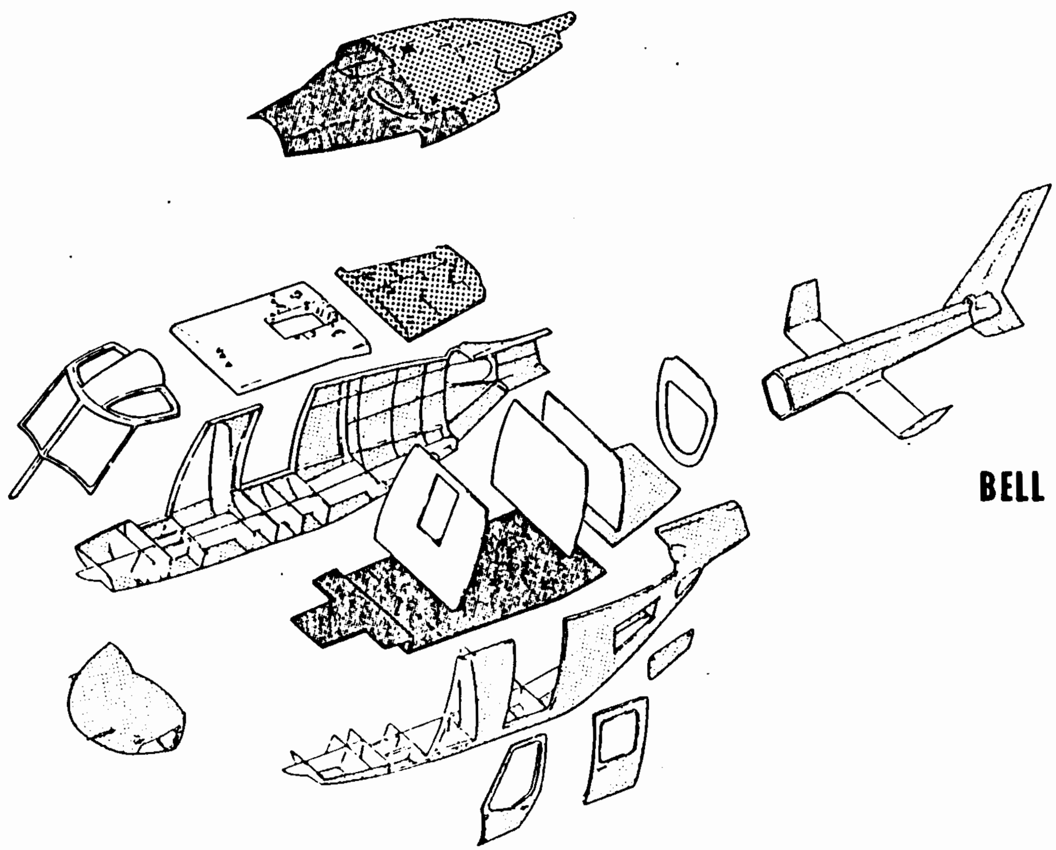
BELL TOOL PROOF ARTICLE

ADVANCED COMPOSITE AIRFRAME PROGRAM

- GRAPHITE/EPOXY
- KEVLAR/EPOXY
- FIBERGLASS/EPOXY
- METAL
- KEVLAR/THERMOPLASTIC
- FIBERGLASS/POLYIMIDE



SIKORSKY



BELL

- REDUCED WEIGHT AND COST
- EASE OF MAINTENANCE
- DAMAGE TOLERANT
- REDUCED RADAR CROSS SECTION

CURRENT ACAP LIGHTNING TEST PROGRAM

SUPPORT TO AEHP ADP

ARMY TO FURNISH BHT TPA.

BHT SUBCONTRACT TO THE AIRFORCE/BOEING TO ADD DRIVE TRAINS, DUMMY GEARBOXES/ TRANSMISSIONS/ENGINES, (NO ROTOR BLADES), ADD ELECTRICAL MODS BASED ON FTV EXPERIENCE, CHECK ELECTRICAL BONDING PATHS AND MAKE MODS WHERE NECESSARY (MAR-JUN 86)

SHIP MODIFIED TPA TO BOEING (JUN 86)

ARMY AVRADA RECOMMENDING SELECTED ARMY AVIONICS FOR INSTALLATION. AIR FORCE PROVIDE ALSO.

LIGHTNING TEST WINDOW AT BOEING (JUL-AUG 86)

NO TEST PLAN YET

STATUS OF BOX HARDENING? WHO WILL CHECK? CHECK BEFORE LIGHTNING TEST?

ARMY TEST PROGRAM

BOTH SIKORSKY AND BELL HAVE ALREADY DONE PANEL AND COMPONENT TESTING

SIKORSKY STA AND BHT TPA WILL BOTH BE LIGHTNING TESTED FOR STRUCTURAL INTEGRITY ONLY. CONTRACTS HAVE BEEN LET BY ARMY AS PART OF ACAP MILITARIZATION TEST AND EVALUATION.

INCORPORATE SAME STRUCTURAL/ELECTRICAL BONDING MODS AS DISCUSSED UNDER SUPPORT TO AEHPADP.

HIGH VOLTAGE ATTACHMENT TEST FOLLOWED BY LOW LEVEL CURRENT (20KA) FOLLOWED BY HIGH LEVEL CURRENT (200KA).

WILL DRIVE CURRENTS OVER LONGEST ELECTRICAL PATHS; I.E.,
- MAIN ROROR HUB TO TAIL GEAR (BHT)
- MAIN ROTOR HUB TO NOSE GEAR (SIK)
- TAIL ROTOR HUB/VERTICAL FIN TO MAIN LANDING GEAR (SIK AND BHT)

WHEN AND WHERE
- SIKORSKY(AUG 86) AT MCDONNELL DOUGLAS (?)
- BHT (MAR87 OR EARLIER) AT BOEING SEATTLE

FOLLOW-ON TESTING

AIR FORCE INTERESTED IN LOW LEVEL EMP TESTING AT PAX RIVER

ARMY INTERESTED IN HIGH ELECTROMAGNETIC FIELD TESTING AT DAHLGREN

NO LIGHTNING EMP TESTING CURRENTLY PLANNED

OTHER ACTIVITIES

LHX RFP

DEVELOPED AN AERONAUTICAL DESIGH STANDARD (ADS) ADS-28 BASED ON CURRENT DRAFT OF AIR FORCE MIL-STD-XXXX FOR USE IN CITING LIGHTNING PROTECTION DESIGN REQUIREMENTS. ADS HAS BEEN SENT TO OTHER GOVERNMENT SERVICES AND INDUSTRY FOR COMMENT.

FIELD INQUIRIES RE RESIDUAL MAGNETISM

SHOULD COMPONENTS BE REPLACED EVEN IF NO RECORD OF A LIGHTNING STRIKE?

WHAT PASS-FAIL CRITERIA SHOULD WE USE FOR MEASURED LEVELS OF MAGNETISM?

NRL ESD HAZARD PROTECTION

APPLICABILITY TO ARMY AIRCRAFT.

ABSOLUTE MEASUREMENTS OF ELECTRICAL FIELDS IN A LIGHTNING ENVIRONMENT

ROBERT V. ANDERSON

NAVAL RESEARCH LABORATORY

ABSOLUTE MEASUREMENTS OF ELECTRIC FIELDS IN A LIGHTNING ENVIRONMENT

R. V. Anderson
Naval Research Laboratory
Washington DC 20375

I. FIELD METER DESIGN CONSIDERATIONS

A. Offset fields due to Volta potentials limit ultimate sensitivity.
   1. Extensive laboratory tests at NRL indicate that 304 stainless steel is the best material.
      a. Stainless and rhodium plate had comparably low values of Volta potential and variability.
      b. Rhodium plating did not weather well.
      c. Gold, aluminum, Iridite (TM), and chromium were inferior.
   2. Inter-electrode spacings of at least 5 mm reduced Volta effects without materially affecting sensitivity.

B. Mechanical characteristics are strongly influenced by the specifics of the aircraft to be used.
   1. 3 inches was the greatest possible diameter for wing-tip mounts.
   2. 8000 rpm, 400 Hz synchronous motors were used.
      a. 400 Hz power was available.
      b. Motor dimensions were commensurate with the 3" limit.
      c. 8000 rpm and 2-bladed design yield a signal frequency of 266.7 Hz, which is nearly optimum for noise rejection.

C. Rotor grounding can often be a source of noise.
   1. The rotation is synchronous with the data signal.
   2. The rotor must be insulated from the motor shaft.
   3. Grounding is accomplished with silver graphite brushes and a coin silver slip ring.

D. Phase reference is provided by a magnetic rotor on the motor shaft and a stationary pickup coil.

E. The head design must facilitate cleaning and repair.

F. Anti-microphonic coaxial cable (RG-149/U) must be used to connect head and amplifier.

G. The amplifiers incorporate decades of practical experience in field meter amplifier practice.
   1. Protective diodes are used at the input to guard the pre-amplifier module.
   2. A voltage gain of 100 is provided in an isolated preamplifier module.
      a. The amplifier is actually configured as a current sensor.
      b. The module is totally shielded.
      c. The RG-149/U coaxial cable terminates on this module.
      d. Power leads are heavily decoupled.
   3. Low-pass filters are placed in both signal and reference paths.
      a. They are frequency insensitive.
      b. They are designed for excellent power frequency rejection.
      c. They provide pure sinusoidal signals.
      d. Attenuation is > 60 dB at 400 Hz and above.

4. Range changing is accomplished by gain switching.
   a. 10000:1 variation is provided in 5 decade steps.
   b. The feedback configuration of the two main gain stages is altered to achieve these values.
5. A phase sensitive demodulator provides polarity information.
   a. A half-lattice phase shifter is placed in the reference channel to facilitate adjustment
   b. The synchronous demodulator provides a significant improvement in signal to noise ratio.
   c. A commercial solid state module serves as the demodulator.
   d. The rectifier is followed by a smoothing filter with cut-offs for both lightning and calibration use.
6. Provision is made to apply a DC "bucking" voltage to the insulated stator electrode.
   a. Bucking is applied through the coaxial cable.
   b. This provides an artificial field for gain calibration.
   c. In the measurement of fair weather fields, this capability is essential for the removal of self-charge fields.
   d. Voltages from 0 to ±120 volts are available.

II. AIRCRAFT INSTALLATION

A. The field meters are located as optimally as possible.
   1. Wing tips provide symmetry and enhancement.
      a. Separation of self-charge field is facilitated.
      b. Enhancement facilitates measurements of fair weather field.
   2. The belly locations were chosen within the limits of practicality.
      a. A centerline location assures insensitivity to Ey.
      b. Fore to aft separation was maximized.
      c. Nearby protuberances were avoided as much as possible.
      d. Upward facing installations were avoided because of water impaction and collection.

B. The aircraft charge was found to be orders of magnitude larger than experienced with reciprocating engine aircraft.
   1. This required operation at low sensitivities to avoid saturation.
   2. Self charge was reduced by the installation of many discharge wicks to the ailerons made of 0.010" diameter stainless wire.

III. DERIVATION OF AIRCRAFT ENHANCEMENT FACTORS

A. The sensitivity matrix is given by:

$$Ep = p_x\, Ex + p_y\, Ey + p_z\, Ez + p_q\, Q$$

$$Es = s_x\, Ex + s_y\, Ey + s_z\, Ez + s_q\, Q$$

$$Ef = f_x\, Ex + f_y\, Ey + f_z\, Ez + f_q\, Q$$

$$Et = t_x\, Ex + t_y\, Ey + t_z\, Ez + t_q\, Q$$

B. From symmetry we may write:

$$Ep = p_x\ Ex + p_y\ Ey + p_z\ Ez + p_q\ Q$$

$$Es = p_x\ Ex - p_y\ Ey + p_z\ Ez + p_q\ Q$$

$$Ef = f_x\ Ex + f_z\ Ez + f_q\ Q$$

$$Et = t_x\ Ex + t_z\ Ez + t_q\ Q$$

C. For convenience we define (and record):

$$Y = (Ep - Es)/2 = p_y\ Ey$$

$$Q' = (Ep + Es)/2 = p_x\ Ex + p_z\ Ez + p_q\ Q$$

D. The coefficients are divided into absolute values and ratios.
  1. The set of Q coefficients is independant of the others.
  2. Therefore, there are two absolute values to be determined.
     a. p_y is an obvious candidate for external fields.
     b. Arbitrarily choose p_q for self charge.
  3. There are then 8 ratios to be determined.
     a. Six for the external field.
     b. Two for self charge.

E. The ratios of external field enhancement are determined by measurements in maneuvers.
  1. The fair weather field is used for these measurements.
     a. It can be stable with time.
     b. It is usually horizontally homogeneous.
     c. Fair weather values are near the sensitivity limit of the measurement system.
  2. The ratios p_y/f_z and p_y/t_z are determined by precision rolls.
     a. The fair weather field vector is vertical.
     b. The change in Y from 45° left to 45° right determines Ez to within a constant.
     c. The change in Ef and Et between the 45° bank condition and level flight is also proportional to Ez.
  3. The ratios p_y/f_x and p_y/t_x are derived from a climb and dive maneuver.
     a. The variation of Ez with altitude must be considered.
     b. Constant engine power is maintained throughout.
     c. Climb at 15° until near stall; then dive at a 15° slope.
     d. Repeat this as often as possible.
     e. Ez as determined on 45° rolls before and after the climb and dive is used in the computation.
     f. The change in Ef and Et from +15° to -15° is proportional to Ez.
  4. The change in Q' between a 45° roll and level flight is used to evaluate p_y/p_z.
  5. Similarly, the change in Q' between climb and dive is used to determine p_y/p_x.

6. The ratios p_q/f_q and p_q/t_q are measured in three ways.
    a. Experimental after the fact removal of correlations between Q' recordings and those of Ef and Et give values for these ratios.
    b. In flight changes in engine power modify Q. The resultant steps in recorded values will also provide these ratios.
    c. Observation of static readings (against a "zero" value) in level fair weather flight will also yield these ratios since the high self charge produces the only field of significance.

IV. ERROR ANALYSIS

A. Plane charge variations can mask the desired measurement.
B. Instrument noise can also mask data.
C. Exhaust puffs apparently introduce variability into the readings of the tail meter.
D. Variations in the fair weather field can vitiate the results.
    1. There can be horizontal inhomogeneities in the field.
    2. The field may vary with time.
E. Inaccuracies in the maneuvers have an adverse impact.
F. Weather perturbations such as clouds produce error.

V. DETERMINATION OF ABSOLUTE COEFFICIENTS

A. The p_v value may be based on the known value of ionospheric potential.
    1. Vertical profiles of Ez integrate to a potential value.
        a. Such integration is a well proven technique.
        b. Extrapolation from aircraft ceiling to ionospheric altitude is a stable, well-proven operation.
    2. The value of the ionospheric potential is well known.
        a. It has been accurately measured.
        b. These measurements have been repeated over several decades.
        c. The diurnal variation of Vi is also well known.
B. The external field may be determined by another (previously calibrated) aircraft.
    1. Measurements of the fair weather vertical component are the only possible ones.
    2. There is total dependence on the accuracy of the calibration of the other aircraft.
C. The ultimate calibration is based on comparison with measurements made on the ground.
    1. Proper allowance must be made for vertical variation of field.
    2. The aircraft system must be sensitive enough for measurement of fair weather fields on the belly meters.
    3. It has been observed that zero drifts on the belly meters will vitiate the measurement unless an in-flight calibration scheme is implemented.
    4. Consequently, this technique could not be employed.

D. Flight through an artificial field of sufficient magnitude could be used for calibration.
   1. The spatial extent and homogeneity required would be difficult to obtain.
   2. The virtual impossibility of maneuvering in such a facility requires that a full three dimensional field is needed.
   3. This is not practical within realistic manpower and budget constraints.

VI. CALIBRATION RESULTS

A. Initial values of the coefficients are:

$$p_x = 2.50 \pm 1.6 \quad p_y = 16.8 \quad p_z = 0.40 \pm .8 \quad p_q = p_q$$

$$s_x = 2.50 \pm 1.6 \quad s_y = -16.8 \quad s_z = 0.40 \pm .8 \quad s_q = p_q$$

$$f_x = 1.08 \pm .16 \quad f_z = -1.74 \pm .34 \quad f_q = 0.175\ p_q$$

$$t_x = -.85 \pm .15 \quad t_z = -1.14 \pm .42 \quad t_q = 0.231\ p_q$$

   1. The value of p_q is available based on measurements made in January 1986, but the analysis is not complete.
   2. The p_y is based on the profiles of july 9 and August 12. Two profiles made in 1984 give corroborative values, but no error is indicated pending analysis of other data. An uncertainty of 10% is reasonable.
   3. Indicated errors are based on observed variations. The charge coefficients are accurate to about 10%.
   4. Analysis of recordings of pitch and roll angles indicate a significant improvement is available in the values of p_x and p_z.

B. Matrix inversion gives:

$$Ex = 0.030\ Ep + 0.030\ Es + 0.366\ Ef - 0.537\ Et$$

$$Ey = 0.030\ Ep - 0.030\ Es$$

$$Ez = 0.059\ Ep + 0.059\ Es - 0.422\ Ef - 0.191\ Et$$

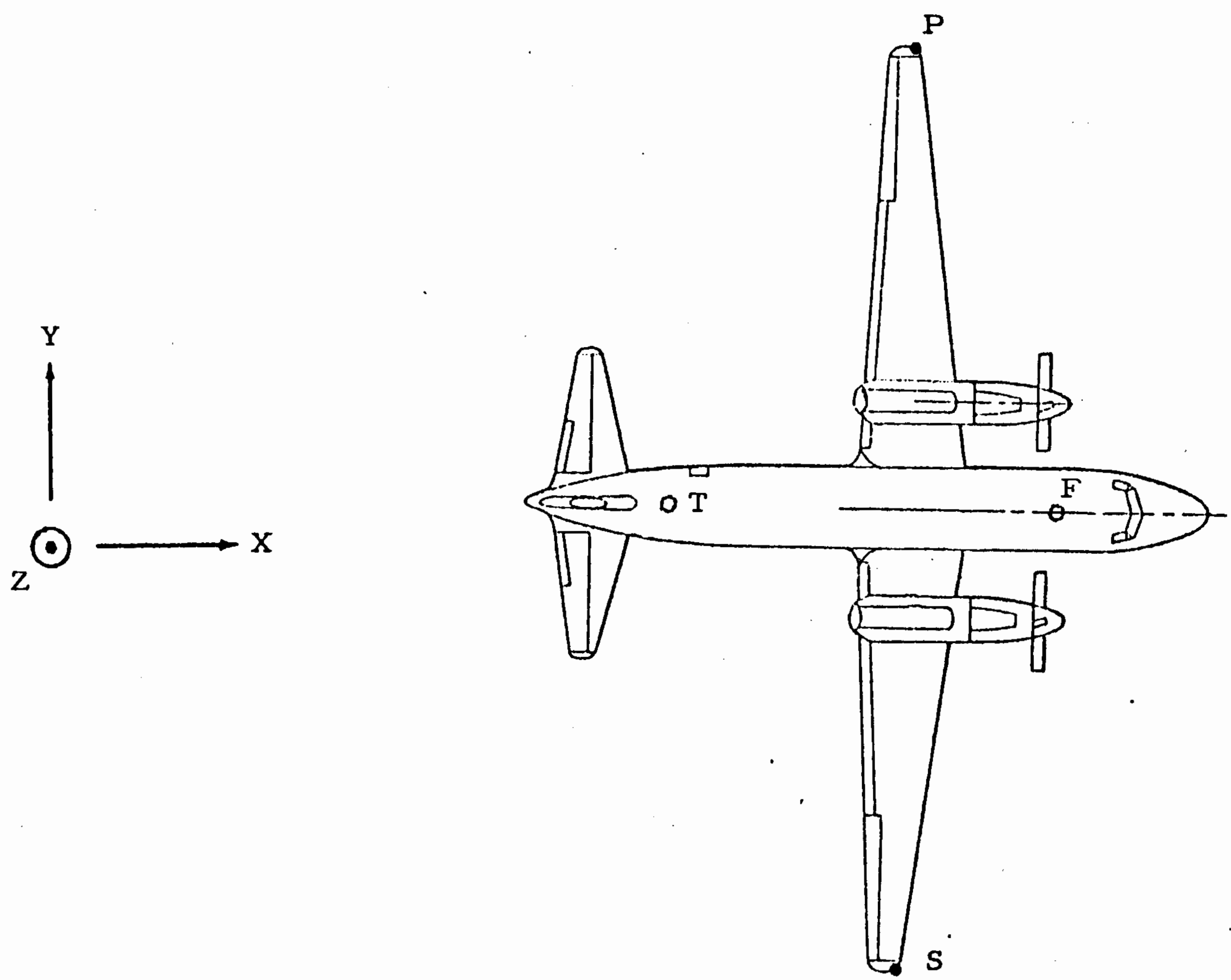
$$V' = 0.070\ Ep + 0.070\ Es - 0.130\ Ef + 0.248\ Et$$

VII. RESULTS

A. A typical strike is shown as recorded.

B. The vector field components for this strike are shown in the final figure.

AIRCRAFT INSTRUMENTATION



December 2, 1985

AIRCRAFT FIELDS IN MANEUVERS

(Fair weather: $\underline{E} = \hat{k} E_z$)

E_j = Field in absolute coordinates

$\mathcal{E}_j$ = Field in aircraft coordinates

ROLL

$$\mathcal{E}_x = 0$$
$$\mathcal{E}_y = E_z \sin\theta$$
$$\mathcal{E}_z = E_z \cos\theta$$

CLIMB

$$\mathcal{E}_x = E_z \sin\phi$$
$$\mathcal{E}_y = 0$$
$$\mathcal{E}_z = E_z \cos\phi$$

DIVE

$$\mathcal{E}_x = -E_z \sin\phi$$
$$\mathcal{E}_y = 0$$
$$\mathcal{E}_z = E_z \cos\phi$$

MATRIX EQUATIONS (Definitions)

$$E_p = p_x E_x + p_y E_y + p_z E_z + p_v V'$$

$$E_s = p_x E_x - p_y E_y + p_z E_z + p_v V'$$

$$E_f = f_x E_x + f_z E_z + f_v V'$$

$$E_t = t_x E_x + t_z E_z + t_v V'$$

Symmetry Assumptions:

Wingtips symmetrical

$$S_x = P_x$$

$$S_y = -P_y$$

$$S_z = P_z$$

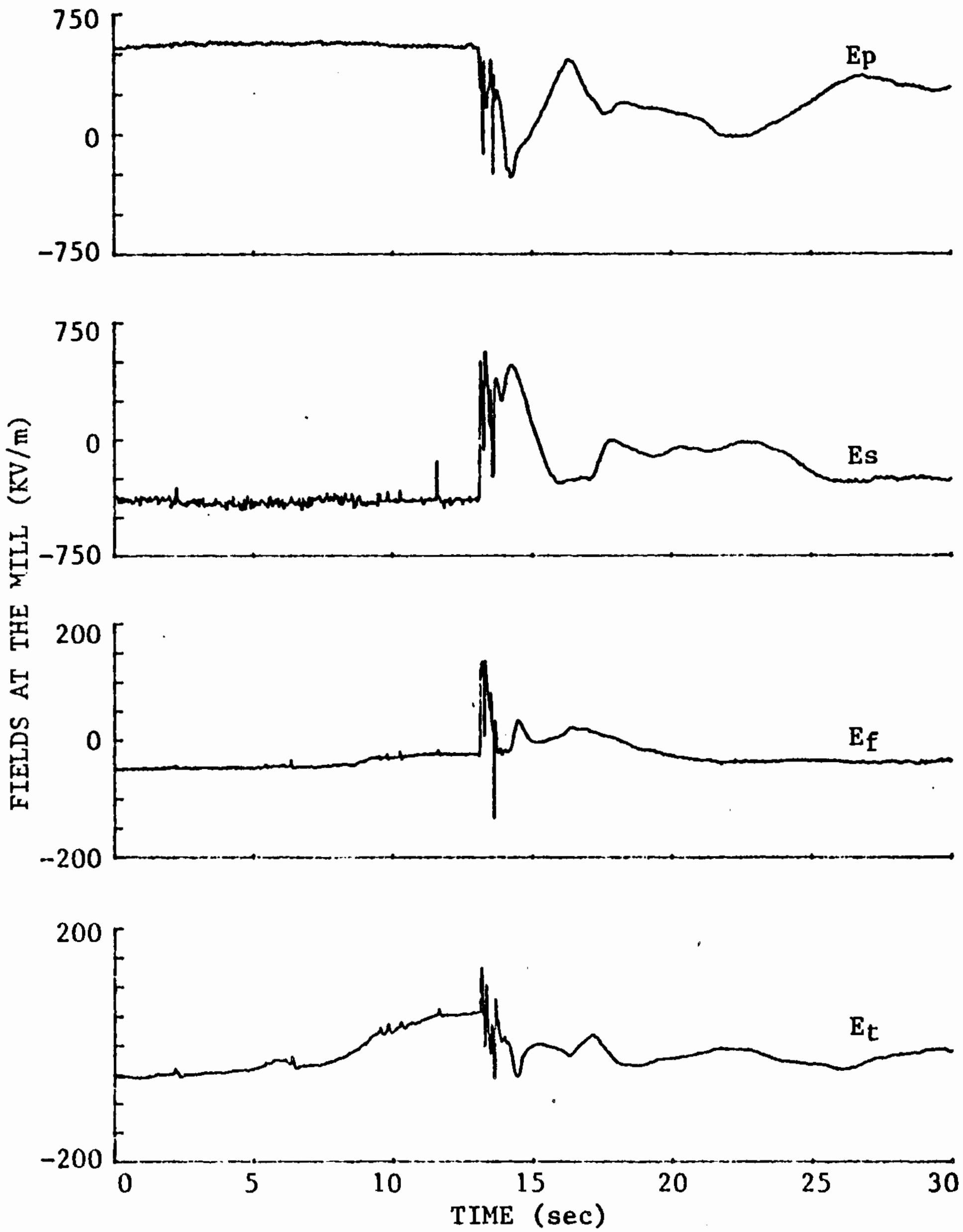
$$S_v = P_v$$

Belly mills on centerline

$$f_y = 0$$

$$t_y = 0$$

FLASH 26 JULY 2351 Z



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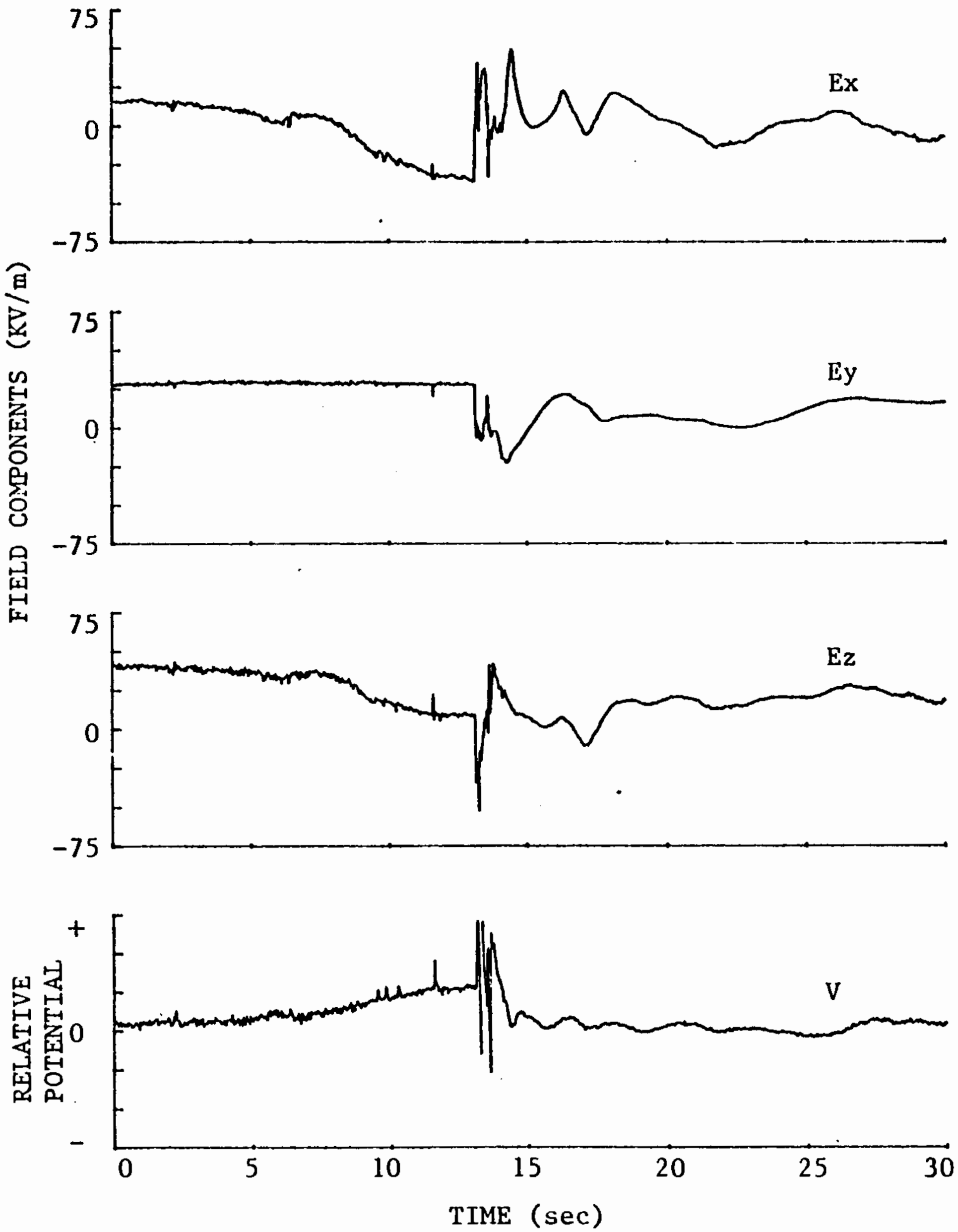
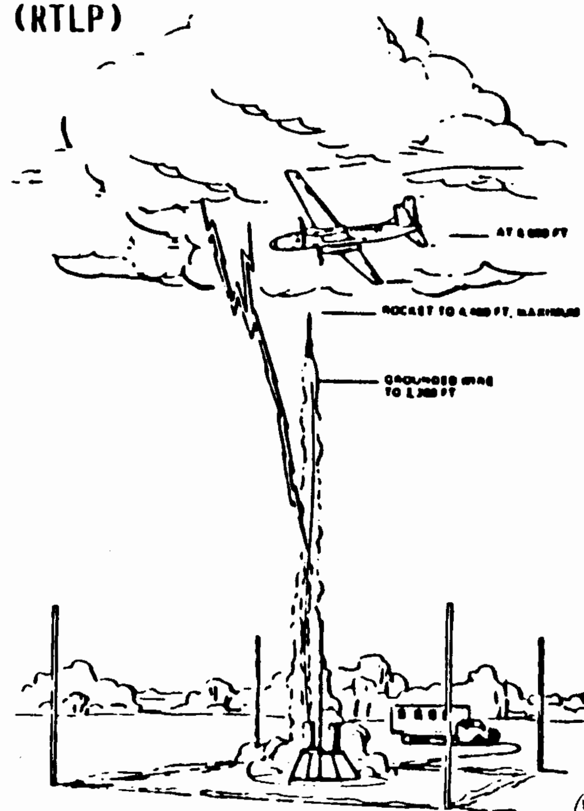


KENNEDY SPACE CENTER

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 FORM 4-184 (5/79)

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

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

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/EQUIPMENTS
- 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.)K= 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 . . .)

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KSC FORM 4-184 (5/79)

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)

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

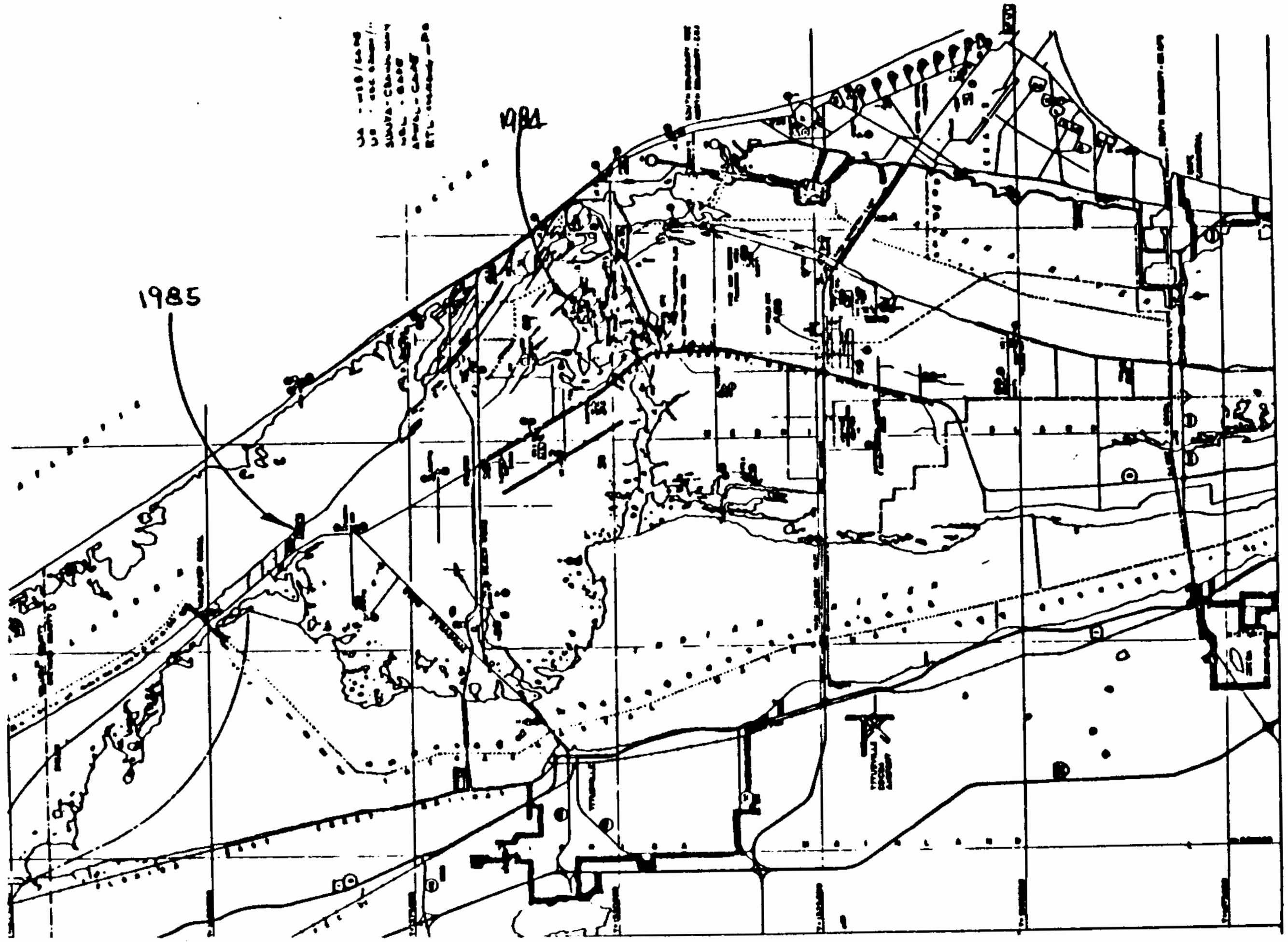
- O AREA LIGHTNING PROTECTION SYS (ALPS) DESIGN, TO:
  - O REDUCE MAGNETIC & ELECTRIC INDUCED FIELD LEVELS TO PREVENT DAMAGE TO FLIGHT HW & GSE & REDUCE ORDNANCE HAZARD
- O BENEFITS
  - O ECONOMICAL SOURCE OF NATURAL LIGHTNING TO:
    - o VERIFY DESIGN OF GRD & A/B LIGHTNING PROTECTION SYSTEM AND DEMONSTRATE 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

KSC FORM 4-184 (5/79)

KSC SHUTTLE OPERATIONS

KENNEDY SPACE CENTER
ROCKET TRIGGERED LIGHTNING PROGRAM (RTLP)

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



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

- UNIVERSITY OF FLORIDA - KSC AND NSF FUNDED
  - HORIZONTAL AND VERTICAL ELECTRIC FIELDS
  - LIGHTNING CURRENT CHARACTERISTICS & GEOMETRIC SHAPE
- 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
- STATE UNIVERSITY OF NEW YORK AT ALBANY (SUNYA) NSF FUNDED
  - LIGHTNING CURRENT CHARACTERISTIC - VELOCITY OF RETURN STROKE USING STREAK CAMERA TECHNIQUE

KSC SHUTTLE OPERATIONS

RESEARCH SCIENTIST INTEREST (CONTINUED)

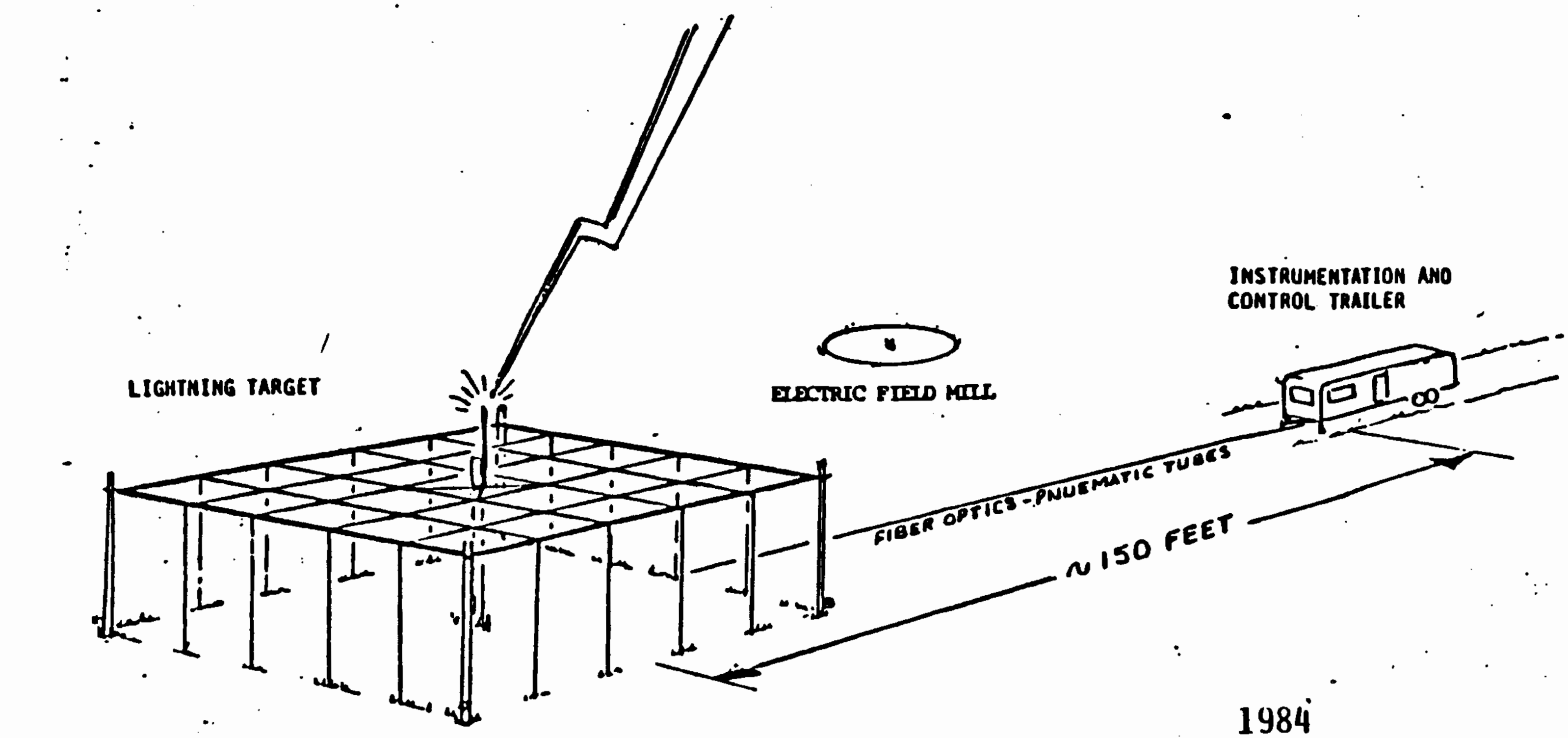
NAME: H. JAFFERIS

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

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



1984
TRIGGERED LIGHTNING SITE
(CONVERTER COMPRESSOR FACILITY)

KSC FORM 4-184 (5/79)

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

KSC SHUTTLE OPERATIONS

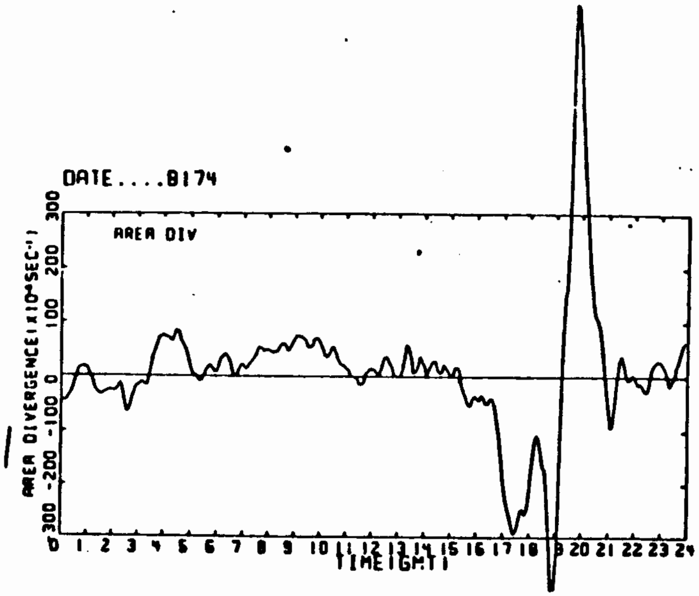
1984 RTLP RESULTS (CONTINUED)

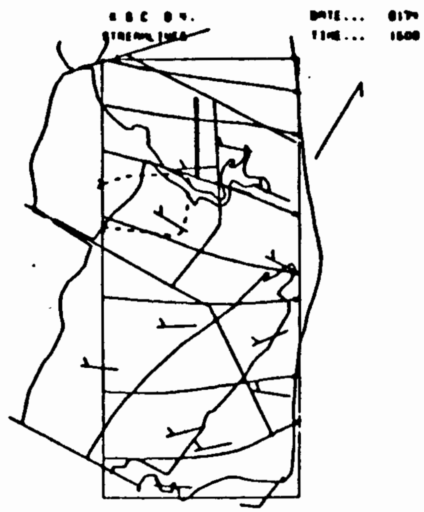
NAME: W. JAFFERIS
ORG: SO
DATE: 15 JANUARY 1985

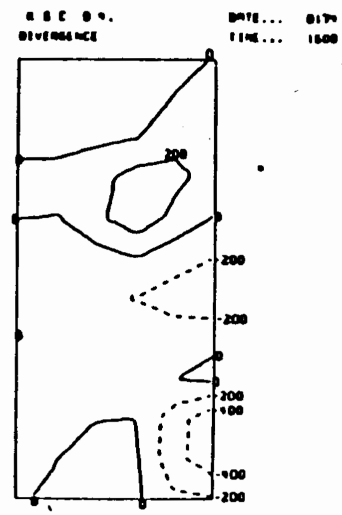
KSC ACCOMPLISHMENTS

- 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

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







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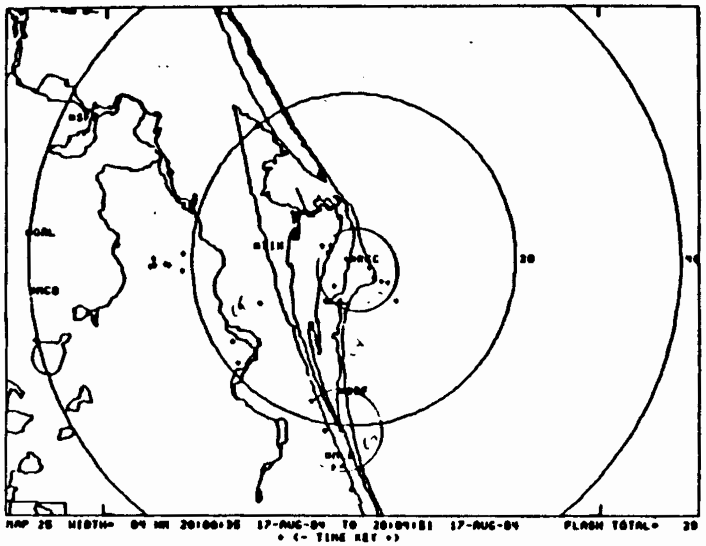

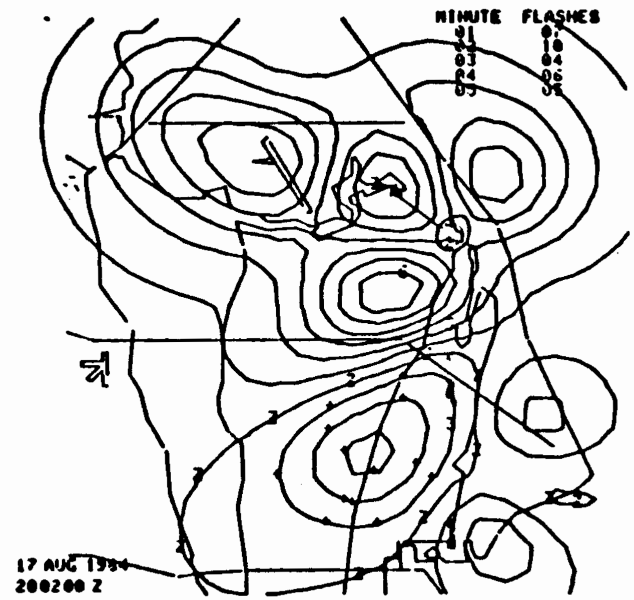

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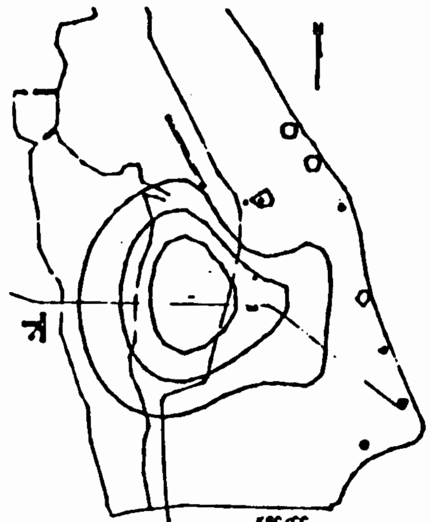

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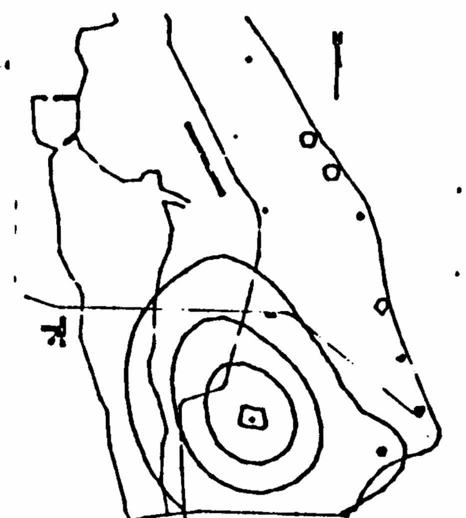

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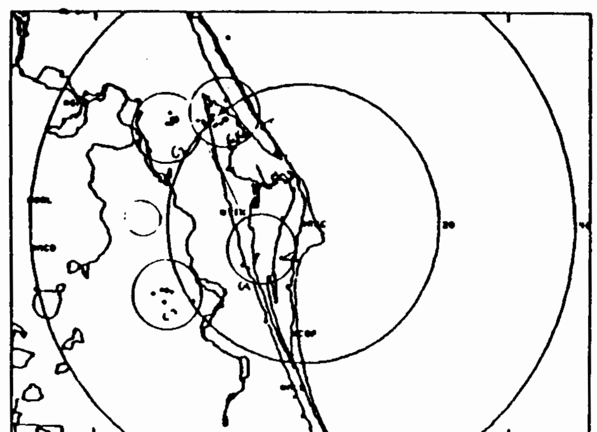

KSC SHUTTLE OPERATIONS

ATMOSPHERIC SCIENCE FIELD LAB
ROCKET TRIGGERED LIGHTNING PROGRAM
1986 AND SUBS PLANNING

NAME: W. JAFFERIS
ORG: SO
DATE: 8/7/85

O 1985 RTLP KSC GOALS

- O RENEWAL OF AFWAL/KSC MEMORANDUM OF UNDERSTANDING
- O SMALL STEP TOWARD A PERMANENT FIELD LABORATORY
- O IMPROVED WEATHER FORECASTING/LIGHTNING AND ELECTRIC FIELD SENSORS
- O TECHNOLOGY TRANSFER
  - LIGHTNING PROTECTION AND MEASURING
  - LIGHTNING HAZARD DETECTION AND WARNING
  - RESEARCH SUPPORT FACILITY

KSC SHUTTLE OPERATIONS	ATMOSPHERIC SCIENCE FIELD LAB ROCKET TRIGGERED LIGHTNING PROGRAM 1986 AND SUBS PLANNING	NAME: W. JAFFERIS ORG: SO DATE: 8/7/85

0 1985 RTLP RESULTS TO DATE

- 0 AIRBORNE
  - 17 MISSIONS FLOWN
    - 4 CALIBRATION FLIGHTS
    - 27 STRIKES
- 0 GROUND
  - ~~76~~ 13 STORM DAYS
  - ~~18 1/2~~ 34 LIGHTNING TRIGGERS
- 0 TOURS
  - FAA, LAWRENCE LIVERMORE LAB, SANDIA LAB, REPORTERS AND NEWSCASTERS
- 0 TALKS
  - PRESENTATION TO FLORIDA POWER AND LIGHT CO. SAFETY GROUP

KSC SHUTTLE OPERATIONS	ATMOSPHERIC SCIENCE FIELD LAB ROCKET TRIGGERED LIGHTNING PROGRAM 1986 AND SUBS PLANNING	NAME: W. JAFFERIS ORG: SO DATE: 8/7/85

1986 RTLP KSC GOALS

0 TRIGGERED LIGHTNING - SUMMER/WINTER -

0 ELECTRIC FIELD, MAXWELL CURRENT SENSORS, AND RAIN BUCKET EXPANSION INTO KSC/AF EXPANDED MESONETWORK

0 INTERFEROMETER AND TOA LIGHTNING LOCATING SYSTEMS DEPLOYMENT

0 EXPANSION OF ASFL ROLE - L.P.I. & SANDIA LAB USES FOR RTL

0 ~~CONTINUATION OF FAA C-580 FLIGHTS~~ AFWAL L80

0 EXPANSION OF OVERHEAD POWER LINES AND TELEPHONE BURIED LINE TRANSIENT RECORDING SYSTEM

0.

SUMMER 86 RTLP - 2 SITES LAND, WATER

KSC
SHUTTLE
OPERATIONS

ATMOSPHERIC SCIENCE FIELD LAB
ROCKET TRIGGERED LIGHTNING PROGRAM
1986 AND SUBS PLANNING

NAME: W. JAFFERIS
ORG: SO
DATE: 8/7/85

1986 KSC SUPPORT

- O BUILDING F5-2151
  - A/C, POWER, COMMUNICATION
  - METEOROLIGICAL DISPLAY AND RECORDING
  - DATA DISPLAY AND QUICK ANALYSIS
- O INSTRUMENTATION VANS
  - QRV
  - IRON MAIDEN
  - MARV
- O EARLY SCHEDULING AND PLANNING SUPPORT

KSC SHUTTLE OPERATIONS

ATMOSPHERIC SCIENCE FIELD LAB

ROCKET TRIGGERED LIGHTNING PROGRAM

1986 AND SUBS PLANNING

NAME: W. JAFFERIS

ORG: SO

DATE: 8/7/85

LONG RANGE PLANNING

- O PARTICIPANTS
  - NASA, FAA, AIR FORCE, NAVY, FRENCH, & UNIVERSITIES
- O GOALS
  - MEASURE NATURAL LIGHTNING CURRENT CHARACTERISTICS FROM GROUND REMOTE STATIONS
  - PERMANENT KSC/UNIVERSITY FACILITY TO STUDY ATMOSHPERIC PHENOMENA
  - CATALYST FOR:

    IMPROVING NATURAL LIGHTNING PHENOMENON UNDERSTANDING RELATIVE TO LIGHTNING PROTECTION OF AEROSPACE AND GROUND FACILITIES AND OF FORECASTING OF METEORLOGICAL EVENTS

FEASIBILITY STUDY

FOR

ATMOSPHERIC SCIENCES FIELD LABORATORY
(LIGHTNING PROTECTION PROVING GROUND)

AT

NASA
JOHN F. KENNEDY SPACE CENTER

BY

J.S. NOBLE
J.A. PLUMER

P.O. CC 38416B
LTI PROJECT NO. 344
DATA BOOK 31

DECEMBER 1985

LIGHTNING TECHNOLOGIES, INC.
10 DOWNING PARKWAY
PITTSFIELD, MASSACHUSETTS 01201

TABLE OF CONTENTS

1.0 Introduction

This report presents the results of a study of the feasibility of establishing an atmospheric science field laboratory (ASFL) at NASA John F. Kennedy Space Center (KSC) for the purpose of furthering the understanding of natural lightning phenomena and evaluating its' effects on ground-based systems and structures. The ASFL would take advantage of the comparatively high incidence of natural lightning activity in the KSC area coupled with the established capability at KSC to trigger cloud-to-earth lightning strikes by rocket-borne wires. It would provide a unique opportunity to study the effects of natural lightning on systems and structures, and evaluate the adequacy of various protective measures.

Such a facility would be especially desirable for evaluation of effects/protection of electrical or electronic systems comprised of distributed components interconnected with overhead or buried cables. These systems, which include a wide variety of automated control and monitoring systems in use throughout many industries, are among those most susceptible to damage or upset by lightning. Lightning effects on these systems are also among the most difficult to simulate in lightning laboratories because coupling results from electric and magnetic fields and earth voltage differences distributed over large distances. A "proving ground" where systems and facilities could be set up in a life-like setting and exposed to natural lightning would allow more realistic studies of lightning effects and development of improved protection measures. Such measures could then be incorporated in large numbers of "production" systems with a higher probability of success than heretofore possible.

The feasibility study for the ASFL began with a review of lightning triggering experiments conducted at KSC in the Rocket Triggering Lightning Program (RTLP) in 1984 and 1985 plus other triggered lightning experiments carried out in France and the United States. This was followed by a visit to KSC and inspection of the 1985 RTLP site and other alternative locations at KSC. The inspection was augmented by review of various site plans and drawings provided by KSC.

Next, the types of systems and structures whose protection design would benefit most from exposure to natural lightning were identified. These include electrical or electronic systems comprised of multiple components interconnected by overhead or buried cables or telecommunications lines; structures fabricated of new technology materials, exposed personal handling and transportation facilities, and other installations too large or extensive to enable evaluation in one of the existing simulated lightning laboratories. Designers, manufacturers and operators of these facilities or systems would utilize the ASFL to evaluate natural lightning effects or verify protection adequacy.

Additional users of the ASFL would include government agencies and other groups concerned with development of new regulations and standards defining the lightning environment and protection requirements which various systems must meet; as well as researchers studing as yet poorly understood electrical and physical characteristics of natural lightning.

The feasibility study concluded with conceptual design of a proposed ASFL site plan and preliminary estimate of the costs of necessary site improvements and installation of utilities. Results of each aspect of the study are described in sections 3.0 through 9.0 of this report and illustrated on Lightning Technologies, Inc., drawing no. 344-85-1 sheets 1 through 3 which are referenced herein.

2.0 Background

The Kennedy Space Center is located in an area of the highest frequency of thunderstorms and lightning activity in the United States. Outdoor operations at KSC involve space vehicles, servicing towers, explosives, antennae, fuel storage, distribution facilities, aerial/buried cabling which connects widely distributed sensitive electronic and mechanical equipment; all subject to exacting and critical schedules. These conditions have made lightning a serious hazard to successful launch operations. For this reason KSC has conducted extensive studies of lightning phenomena, its characteristics and effects, and methods of protection against it; as well as methods to locate and forecast thunderstorms and lightning. For the past several years KSC has hosted a number of scientists during the summer months for studies of lightning and thunderstorm phenomena, and has established an ongoing program with the Eastern Space Missile Center (ESMC) weather group to improve the forecasting of thunderstorms and other weather phenomena.

This involvement with semi-tropical severe weather has resulted in recognition of KSC as a center of research into lightning and other severe weather occurrences as well as an awareness of the need for additional knowledge to overcome the potential problems posed by the increased frequency of future shuttle launch and landing operations.

Notwithstanding these developments, lightning interractions with other aerospace and industrial systems and facilities have become increasingly troublesome. Computers which interface with remotely located sensors or control units are frequently vulnerable to surges induced in interconnecting cables or telecommunication lines, for example. In many cases, this results in shutdowns of manufacturing operations, information systems, environmental control systems, burgler and fire alarms and other facilities that affect the daily lives of large numbers of people.

Whereas lightning protection features have already been incorporated in many aerospace electronic systems from which a high degree of reliability is demanded, this technology has not yet been integrated into the design of most industrial and consumer electronic systems. Design engineers are not generally familiar with the ways in which lightning interacts with these systems, nor with protection methods. Government and industry standards-writing organizations pertaining to industrial and consumer electronics have only recently begun to address the need to incorporate adequate protection into this class of electronics.

Even when protection has been attempted, difficulties have existed in assessing the magnitudes of lightning-induced transients that occur within large-scale interconnected systems due to the widespread nature of some installations and the impossibility of testing them in lightning simulation laboratories. Similar problems have also prevented verification of protection adequacy by laboratory tests; yet verification of protection effectiveness is often necessary before the financial resources necessary for installation of protection measures in a large number of products or systems will become available. The uncertainty surrounding protection methodology and lack of confidence in its results has often resulted in nothing being attempted.

A similar situation exists regarding protection of new, high technology materials and structures. Architectural styles have precluded installation of the familiar "lightning rods" atop roofs and parapets, as such protrusions are now considered unsightly. As a result, other means of protection must be provided, and sometimes integrated directly into the structural materials or facades so as not to be architecturally displeasing. Existing lightning protection standards address only traditional structures and protection methods; new "high tech" buildings and materials are not addressed. Again, designers are generally unaware of the potential problems and protection approaches, so protection is either omitted or inadequately applied.

In contrast to these situations, the public (i.e. owners, operators or users of systems and facilities) has become increasingly aware that lightning phenomena and protection technology are no longer the "black magic" once associated with this environment, and that lightning strikes are an expected ingredient of the environment nearly everything is exposed to. Thus, designers and owners are increasingly being held responsible for providing adequate lightning protection; and being forced to compensate for losses or injuries arising from inadequate designs.

These developments have led NASA to consider ways to transition some of the lightning protection technology developed in support of the KSC launch operations to industrial, commercial and "public" applications. Three broad categories for technology transfer have been identified, as follows:

1. Thunderstorm and Weather location and Forecasting
2. Lightning phenomenology (i.e. the electrical and physical characteristics of lightning)
3. Lightning protection development and verification

The Atmospheric Sciences Field Laboratory described in this report would address the third opportunity, by establishment of a lightning protection "proving ground", taking advantage of the plentiful supply of natural lightning strikes that occur in the KSC area coupled with triggering of additional strikes at more desirable locations and times. Methods previously developed by KSC and visiting scientists in 1984 and 1985 would be used. An established triggered lightning facility, staffed by a core of KSC specialists in triggering and instrumentation and available to users from outside industry, other agencies and research laboratories would offer a unique opportunity to transfer lightning protection and verification technolgy to a wide range of industries and applications.

3.0 Purpose

The purpose of establishing a facility such as the RTLP/ASFL facility is to provide a "proving ground" for conducting full scale lightning testing. The facility should provide an environment in which a variety of structural and electrical systems can be erected, maintained, supervised, monitored and evaluated under real life/time lightning conditions. The "proving ground" concept would enable those organizations concerned with lightning effects to their systems or structures to test their system(s) under full scale conditions. Such a "proving ground" could provide data helpful in determining the susceptibility/vulnerability of an unprotected system thus leading to effective design of the protection required. In addition, "protected" systems could be evaluated for their response to natural lightning effects and, thereby prove the value of the protection measures. At the same time that such technological studies are being performed, independent basic technical data may be obtained on such lightning related parameters as earth voltages and magnetic fields. These characteristics may then be compiled and disseminated to those scientific organizations which conduct research on natural lightning, its phenomena and effects.

Already rocket triggered lightning programs have been used to test and evaluate lightning locating systems[1]. These lightning location and protection (LLP) systems are being designed and utilized for such purposes as early detection of lightning caused forest fires, interruptions to power networks, monitoring thunderstorms and issuing warnings of impending lightning hazards as well as relationships between lightning and convective storms [2]. Since the first rocket and wire triggering technique was used by Newman, et al. at sea in 1967, much has been done to improve and utilize the operation. Rocket triggered lightning experiments have been conducted in France and Japan as well as in the United States at different locations. There is extensive potential with triggered lightning experiments in scientific and technical research. A partial list of the studies which can be conducted through triggered lightning experiments includes "(1) measurement of lightning current, (2) measurement of electric and magnetic fields with several types of sensors situated at various distances, (3) wide-band electromagnetic radiation spectroscopy, (4) electromagnetic interferometry at 33 MHz, (5) effects of lightning strokes

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[1] Meier, Michael W. and Jafferis, William, "Locating Rocket Triggered Lightning Using the LLP Lightning Locating System at the NASA Kennedy Space Center," 1984.

[2] Lopez, Raul E. and Holle, Ronald L., "Diurnal and Spatial Variability of Lightning Activity in Central Florida During the Summer", NOAA Tech. Memo ERL ESG-13, March 1985.

on the equipment enclosed in a metal cylinder simulating the body of an aircraft, (6) radar observations, (7) correlated observations with an aircraft and with instrumented balloons, (8) acoustic measurements for three-dimensional thunder source localizations, (9) optical spectroscopy, (10) leader and return stroke velocity measurement, and (11) photography with still, movie, streak, and video cameras." [3]

It can be seen then, that there is a potential market for a facility which can provide the physical environment in which to evaluate the performance of systems and structures with natural lightning. This concept of a "proving ground", integrated with a scientific research laboratory and accessible to a wide variety of users will improve public safety through increased knowledge of the lightning environment as it effects systems and structures. Thus a permanent RTLP/ASFL facility should attract widespread attention, use and support from various sectors of government and industry.

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[3] Hubert, P., Laroche, P., Eybert-Berard, A., and Barret, L., "Triggered Lightning in New Mexico", Journal of Geophys. Res., Vol. 89, No. D2, pp 2511, April 20, 1984.

4.0 Potential Users

Those organizations concerned with lightning effects for whatever reason would be the "users" of the facility. They would use the proving ground to satisfy a need for evaluation, testing, gathering information and so on. Such users may include any government, agency, company, or university with a system, structure or component which is susceptible to hazardous lightning effects and requires evaluation, either pre- or post-design. Such a user problem might include a need to verify adequacy of a protection modification before proceeding with a costly recall and modification program. Another user might be a government agency desiring to establish and verify minimum lightning protection design criteria for an industry standard.

The following is a general representation of some of those potential users who might be interested in participating in the RTLP/ASFL program based upon their involvement in the effects of lightning and some examples of their related areas of concern:

A. Power/Utility Companies: Gas, Electric

1. Fuels handling/storage: coal, oil, gas, nuclear
   a. ship-to-shore handling
   b. overland conveying
   c. storage tanks, stockpiles

2. Generation Facilities
   a. automated equipment
   b. elevated structures attract lightning: smoke-stacks, towers

3. Transmission
   a. overhead lines including towers, transmitters, antennas
   b. underground lines

4. Switching and Utilization Equipment

B. Communications Industry

1. Transmission
   a. overhead and underground lines
   b. transmitter, receivers

2. Switching and Processing Facilities

3. Utilization Equipment
   a. telephones, television equipment, radio, computers, fire alarm signal devices, security systems

4. Central Computer Facilities

C. Transportation

1. Rail: tracks, switching, signaling
2. Air: runway lighting, weather monitoring, control towers
3. Roadways: signal controls, lighting, toll booths, weigh stations
4. Water: vessels, dock operations, lighthouses

D. Military

1. Ordnance: depots, handling
2. Testing
3. Communications including security
4. Defense: air, water, land vehicles

E. Industry

1. Mining, oil and gas, drilling on-and-off shore
2. Refineries, chemical plants, processing plants: volatile materials
3. Fuels handling and storage
4. Agriculture: open field activities, grain storage

F. Recreation

1. Crowds of people - sports arenas, stadiums, galleries
2. Open area, outdoor activities: golf, boating playing field sports, mountaineering

G. Science/Technology

1. Weather forecasting, monitoring
2. New materials - testing (aviation industry)
3. Lightning protection: methods, materials, direct and indirect effects
4. Testing laboratories/services: Underwriters Laboratories, universities

H. Government

1. Specification writing: lightning withstand levels, tolerances
2. Municipal facilities: communication, security
3. Testing associated with litigation

As an example of a sample experiment by a potential user in Japan, studies have been conducted using rocket triggering lightning in order to empirically determine the final striking distance of a lightning flash to an object, such as a power transmission line. [4] This is the type of experiment which could be

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[4] Horii, K. and H. Sakurano, "Observation of Final Jump of the Discharge in the Experiment of Artifically Triggered Lightning", November 27, 1984.

executed at the RTLP/ ASFL facility to determine the shielding effect of a grounded conductor for the protection of power lines or other structures. The information gained would benefit the hundreds of power companies with millions of miles of transmission lines acrross this country.

It is expected that the users of the facility would contribute financially to its support and operation. In some cases, a number of users would team-up together to devise tests which would be mutally beneficial, thus sharing the costs. The implications for financial benefits compared to the costs of the experiments are significant. With some "seed" money for initial construction and start-up, it would not be long before such a facility would become self-supporting through a users' fee program and in turn expand and develop.

5.0 Methods

Since the primary objective of the facility is to provide natural lightning in a laboratory type environment, an important consideration in its effectiveness is the source of lightning. As a full scale "proving ground" and research facility, there are three methods by which lightning may be provided for testing and data gathering:

a. Natural (randomly occurring) lightning

b. Triggered lightning directed at a specific test setup within one of the proving ground sites.

c. Nearby lightning effects created by triggering to a site remote from a test setup.

One or more of the methods may be suitable to a particular user's objectives.

Natural lightning provides the spontaneity of nature. It is useful to those concerned with collecting data relative to naturally occurring lightning, its formation, characteristics and effects. At the Kennedy Space Center, natural lightning flashes to ground may be expected to occur at a rate of eight per kM^2 per year as shown in Appendix I. Naturally occurring lightning, however, is sporadic in its occurrence and therefore may not be reliably available for conducting certain tests. In other words, after a test structure (or system) has been set up, at a proving ground site, the user would want to be able to have lightning strike at or near the site at predictable times or frequencies of occurrence. This would not be possible; however, naturally occurring lightning would be useful to those observing the meteorological effects which surround the occurrence of a lightning strike and would provide data for those users who maintain test sites over long periods of time. For instance, various lightning grounding techniques such as Ufer grounds, might be installed around the facility and left in place for months or years in order to evaluate long term effects of changing moisture, ground water level and concrete ageing conditions on the electrical resistances of these grounds. These installations might be monitored to record their resistances as well as related parameters such as earth voltages developed during lightning strikes occurring in the vicinity.

It is anticipated that many of the tests to be conducted would involve evaluation of a manufactured component or system. For these "proving ground" type experiments, a lightning flash must be produced at a given time as if in a laboratory. For this purpose, a rocket launching system would be utilized to trigger a lightning strike from a thundercloud formation above. Obviously, the timing of the experiment(s) would be subject to weather conditions which favor the formation of a thundercloud. The advantage provided by the location of the facility at the Kennedy Space Center is the high isokeraunic level of the area which assures as high a frequency of thunderstorm activity, approximately ninety days per year, as is available in the United States and most of the world (see Appendix I).

The triggered lightning could provide effects via two methods. The first method involves the rocket being connected to one end of a free-spinning bobbin of wire. The test object is located on or near the launch pad at the earth end of the wire.

As the rocket rises above the earth, the wire unwinds, trailing the rocket. The lightning flash triggered by the rocket is attracted to the wire and follows it to the test object. Examples demonstrating this type of test arrangement are given in section 7.0. This type of test provides a direct strike attachment to the test object for observation and evaluation of direct strike effects. Measurements of relevant system performance parameters may be made before, during and after the strike for evaluation of strike effects.

The second method by which rocket triggered lightning may provide data for a user's test is via a "nearby strike. This is possible by locating the tested system or structure at a site other than the one from which the rocket is launched. When the lightning strikes the nearby rocket launch pad, it produces magnetic fields, earth voltages, etc. at the test site. The importance of evaluating nearby lightning strike effects may exceed the need for direct strike data since systems often experience the indirect effects of nearby strikes far more frequently than they are exposed to direct strikes. For example, a central computer located within a building which is interconnected to other buildings at remote locations may experience surge voltages caused by earth voltage rises associated with cloud-to-earth lightning strikes within a radius of one or two kilometers.

Some skepticism has surrounded the use of triggered lightning and its value as a representative sample of a typical natural lightning event. One objection was that "...triggered lightning was supposed to have rather poor characteristics because it extracts electricity from a cloud before it reaches the unstable, highly electrified state leading to a natural flash. [5] Hubert continues, "...it is true that triggered lightning is generally not as powerful as the stronger flashes of natural lightning. However, its characteristics are sufficient to make possible meaningful tests of experiments,..." as explained in his paper. Another difference which has been noted is the absence of a first return stroke in a triggered flash. The first return stroke of natural lightning usually has a higher peak current than the subsequent strokes. For triggered lightning, the ionized path left by the trailing wire creates conditions similar to a subsequent stroke. However, the values of the wide spread of currents reported for natural strokes have been compared to the representative currents measured for triggered strokes indicating that the differences may not be important. [6] In addition, in support of using triggered lightning for conducting tests, Richmond offers the following conclusions,

> "CONCLUSIONS
>
> BECAUSE OF THE WIDE VARIANCE in the characteristics of the first return stroke in natural flashes, the lack of this stroke in triggered lightning should not detract from the suitability of combining data from triggered lightning with natural lightning data. The other characteristics of natural flashes, such as current level and number of strokes, are well represented by the flashes triggered during this experiment. This apparent similarity of triggered lightning to natural flashes is especially important because of the growing conviction that aircraft that are struck by lightning may, in fact, be triggering the flash, as suggested by D. W. Clifford and H. W. Kasemir (18). Triggered lightning, therefore, offers a method of obtaining "controlled" data about lightning phenomena and may be a potential procedure for "severe threat" testing of aerospace vehicles and systems."

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[5] Hubert, P., "Triggered Lightning in France and New Mexico", Endeavour, New Series, Vol. 3, No. 2, 1984

[6] Richmond, Richard D., "Rocket Triggered Lightning: A Comparison with Natural Flashes" (1984).

Therefore, with the relatively high level of availability of naturally occurring lightning augmented by the possibility of triggering strikes to or near the proving ground sites, there exist ample opportunities for conducting full scale evaluations of lightning effects and protection adequacy on a wide variety of systems and structures.

6.0 Site Selection Criteria

NASA - John F. Kennedy Space Center is located in a geographical region where thunderstorms and lightning strikes are a common occurrence. This environment, combined with the presence of on-site engineering personnel who have become skilled in lightning phenomenology and protection design necessary to support the space launch programs present a unique opportunity to establish a lightning research and proving ground. Toward this end, an inspection was made of various sites at NASA-KSC where such a facility might be established. Criteria to be considered in selecting an appropriate site for the RTLP/ASFL facility include the following:

A. Accessibility

1. Nearby primary vehicular service for:
   Staff/residents
   Users
   Shipping/receiving materials:
   truck (air, water, rail)

2. Restricted from access by casual sightseers, passersby i.e. limited access provides security.

B. Utilities Available

1. Electric power: 120/240 volts AC, single phase and three phase
2. Potable water
3. Sewage disposal
4. Communications: telephone,(including computer-compatible) teletype, radio.

C. Buildable Site

1. Relatively level
2. Soil structure to support construction (i.e. not marshland)

D. Space

1. Large enough for present needs and future expansion

E. Remotenesss from other activites for safety; such as:

1. Inhabited areas
2. Fuel/munitions storage
3. Routine daily operations
4. Recreational areas (e.g. beaches)
5. Swampland (mosquitos)

Results of the inspection and a description of proposed sites at NASA-KSC for the RTLP/ASFL facility are presented in Section 7.0.

7.0 Description of Proposed Facility

The most desirable location for the RTLP/ASFL facility, based on the criteria of Section 6.0, was determined to the area north of and including the 1985 RTLP site, as shown in Lightning Technologies, Inc. drawing No. 344-85-1, sheet 1. This site is located adjacent to Kennedy Parkway North for vehicular access. The 1985 site includes a structure containing office and laboratory space which would eliminate the need to construct a new structure. The storage and living quarters required utilities are available. The site appears to be on stable, solid soil. The area could be developed for five or six test sites for present needs and expanded for the future. It is remote from the KSC launch operations and other activities. In addition, it is adjacent to a body of water, useful for evaluation of lightning effects on boats or other maritime facilities.

The proposed facility, in its function as a lightning protection proving ground, might include two types of test installations. The first would be those structures or systems erected by users interested in obtaining data over an extended period of time, such as three to six months or longer. For example, a section of an airport runway lighting system might be installed on Test Site "E" as shown on drawing 344-85-1 sheet 2. Lights could be installed, powered and controlled as if in actual service. Instrumentation could be connected to monitor the system for a length of time. During this period, nearby strikes would also contribute effects at irregular intervals during the duration of the test. The objective might be to establish a level of confidence in a specific protection design which is being considered for implementation into a manufacturer's runway lighting powr supply or electronic control network. It is a type of passive test. The lights would be operated and controlled in a normal fashion and be located in the center of the area with additional sites radiating outward. The sites might vary in size and design in order to accommodate many different test arrangements. Each site would be excavated and leveled. Then gravel would be brought in and compacted for a uniform surface on which to construct test set-ups. 120/240 volt AC power would be brought in to the central site underground as well as spare conduits for signal cables. From the center site, power and signal conduits would be run to each of the other sites underground to an electric handhole, then over to panels installed above ground. 120/240 volt AC power would be provided to each site but the signal conduits would be left empty for each user's own requirements. At the test site, each user would use the power supply but would provide their own hook-ups, site wiring, communications cabling, monitoring, instrumentation as well as the test set-up itself.

The test site nearest the waters edge might include a short pier which itself might be instrumented for data collection or would serve as connection to boats or other experiments conducted on (or underneath) the water. The pier might be constructed so that the mobile launcher could be positioned on the pier to trigger strikes directly to instrumented boats or rafts.

Examples of typical uses of the sites are depicted in Figures 7-1 and 7-2. Figure 7-1 shows the rocket triggering facility utilized to draw a lightning strike to small components that can be installed at or near the launchers. Alternately, the launcher can be drawing a strike to the launcher which has been placed a specific distance from a system being evaluated for the effects of a nearby strike.

Figure 7-2 shows the launches placed near a structure which is to receive direct strikes. In this case, the launcher would be installed on a flat-bed trailer which could be positioned adjacent to systems or structures under evaluation.

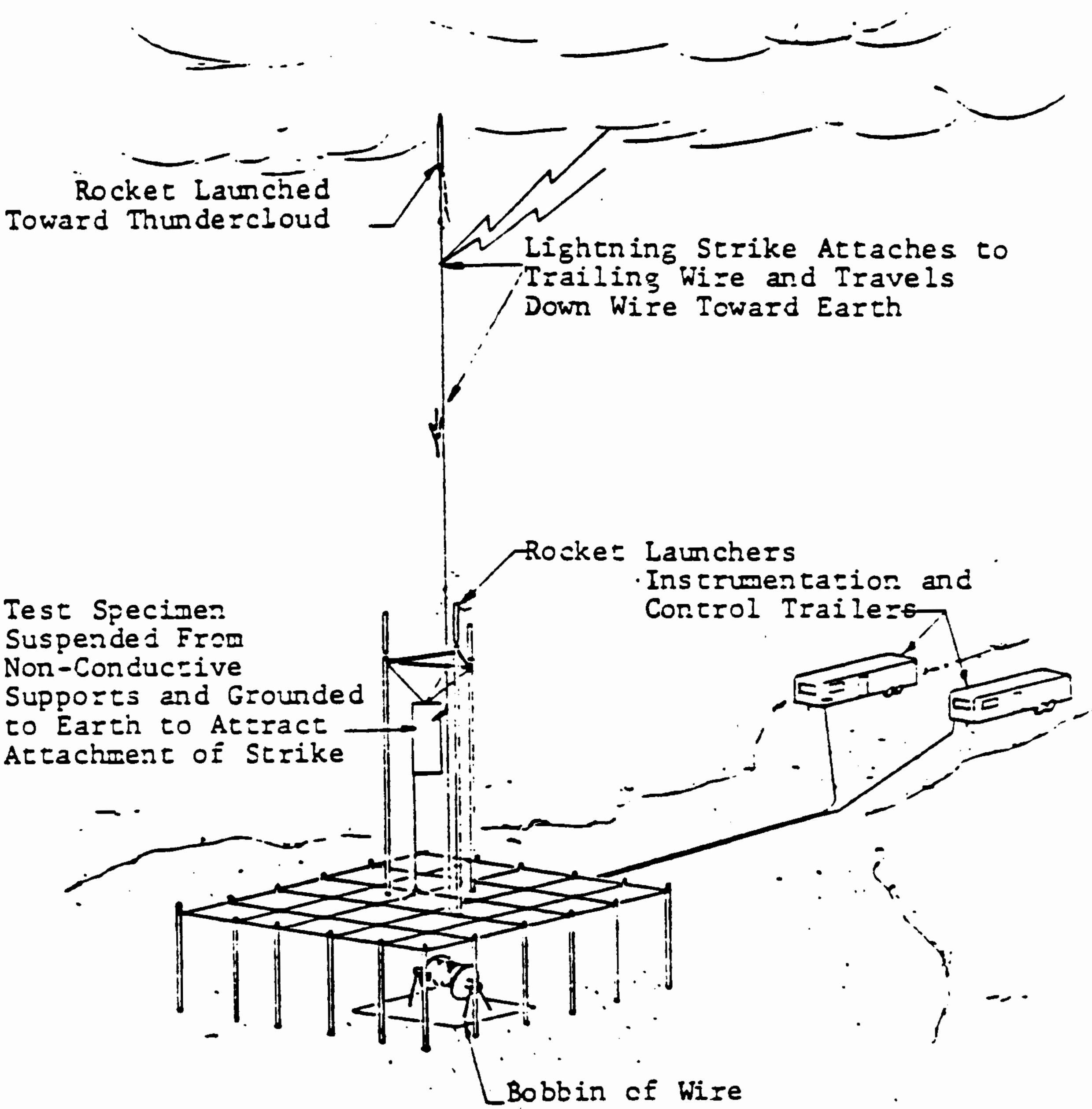


Figure 7-1 Small Components Installed on Launcher Rig as at 1985 Permanent Launch Pad

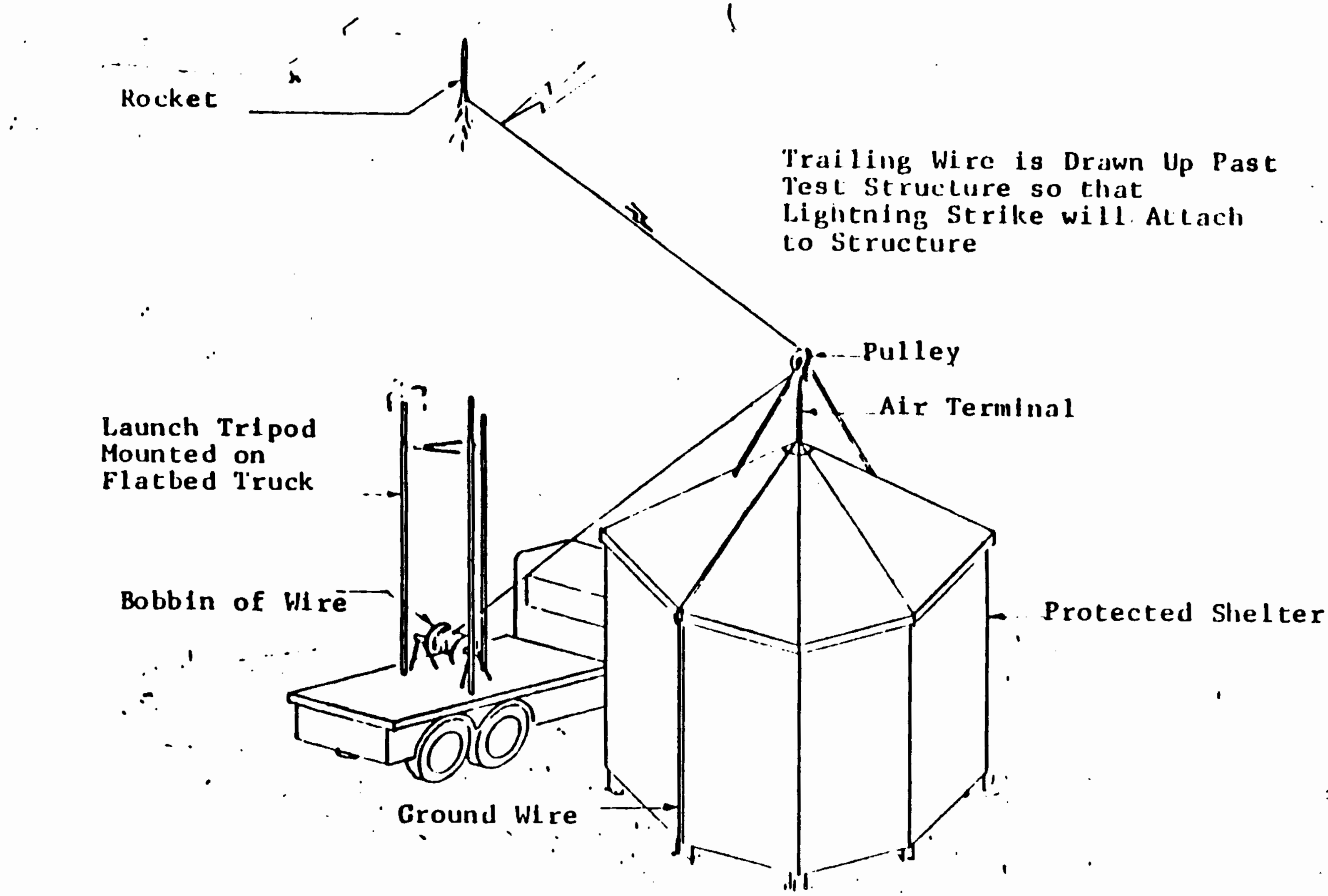


Figure 7-2 Mobile Launcher Brought to Large Scale Structures

8.0 Cost Estimate

The following is a general list of categories that would be included in final design and construction of the test sites described on drawing 344-85-1 sheet 1. Included are preliminary cost estimates of the costs associated with each category. These are the costs that would have to be provided by NASA (or other agencies that would own the facility) to make it ready for potential users, who would be required to pay specific project installation and operating costs.

	Category	Cost Estimate
1.	Engineering Design	$ 30,000
2.	Clearing of test sites and drives	60,000
3.	Grading, including gravel fill	150,000
4.	Installation of underground utilities and structures	30,000
5.	120/240 volt power to each site	50,000
6.	Construction of pier	20,000
7.	Additional lightning instrumentation	100,000
	Subtotal:	$ 440,000
8.	Contingency (25% of subtotal)	110,000
	Total estimated cost:	$ 550,000

It is assumed that the building at the 1985 site can be utilized as is; thus no estimate has been included for modifications or refurbishment of this building. Neither are cost estimates included for rocket launching apparatus or supplies; or for lightning effects data gathering instrumentation that is unique to specific tests, because this would be provided and retained by users.

9.0 Next Steps

If a decision is made to implement the facility, a number of steps must be accomplished leading to improvement of the sites and installation of necessary utilities. These steps are as follows:

1. Preliminary Investigations

As soon as a decision is made to proceed with establishment of the ASFL, it is recommended that a planning group be established with the purpose of setting forth the specific goals and timetable for the ASFL facility. In other words a master plan should be developed outlining the tasks to be accomplished within various time periods. For example, goals should be defined for the first year, the first five years and so on. It would be this group's role to:

A. Meet with prospective initial users

B. Ascertain user's needs, goals

C. Solicit suggestions and other inputs from users

D. Meet with KSC representatives

E. Prepare a program plan and schedule

F. Secure inital financing

2. Complete Program Definition

After the goals and desired schedule have been defined and a general plan has been established, it will be necessary to further define the requirements for the construction and operation of the facility. Items to be accomplished will include:

A. Determination of the number and sizes of test sites desired (initially and future expansion)

B. Determination of the extent of utilities to be provided

C. Outling of specific design requirements for each site, and access to, from and among sites

D. Establishment of construction and operational costs

E. Establishment of procedures and policies for collecting and disseminating information gathered: public vs. private

F. Definition of responsibilities of KSC, the ASFL and the user

G. Definition of operational policies

H. Preparation of draft agreements for use of facility

I. Determination of size and qualifications for permanent staff

3. Preliminary Engineering Design

It would be advisable that the original group be retained during this step in order to establish a design team which would then select an engineering firm to perform preliminary design work. The design team would be responsible for providing the program, overseeing the work of the engineering firm and reviewing the results. It would also be responsible for obtaining and allocating initial financing. Preliminary design work would include:

A. Site evaluations

B. Environmental impact

C. Cost feasibility (estimates, comparisons)

D. Soil borings, analysis

E. Drainage requirements

F. Preliminary utility designs

G. Site surveys

4. Construction Documents

Upon review and analysis of the preliminary design work, it should be possible to select a location for construction of the individual test sites and proceed with finalizing the design and construction documents. This step would include:

A. Preparation of construction plans and details

B. Preparation of construction specifications

C. Preparation of bidding documents

D. Advertising for contractors

E. Finalizing cost estimates

At the same time, the design team would be finalizing the designs for the additional lightning data instrumentation. Which would be kept separate, probably, from the general construction of the sites.

5. Implement Construction

Upon receipt of bids for construction, the engineering firm would recommend acceptance of a contractor and proceed with construction. The engineering firm would oversee construction through to completion. The design team would be responsible for installation of the lightning instrumentation including overseeing any subcontract work.

6. Operation

At this point, the facility would be ready for operation. A permanent staff would be assigned to the ASFL facility and be responsible for daily operations and maintenance.

APPENDIX I

Probability of Strike Occurrence

Thunderstorms and lightning flashes do not occur with uniform frequency throughout the world, but vary instead with the climate and topology of particular locations. The only parameter related to lightning incidence for which world-wide data accumulated over many years exists is the thunderstorm day. This data is accumulated by the World Meteorological Organization and is called the isokeraunic level. A thunderstorm day is defined as a 24-hour day on which thunder is heard. Thus, the parameter does not give information on the duration or intensity of the storm. For the United States, the isokeraunic level ranges between a low of 5 thunderstorm-days per year along the West Coast, to a high of 100 days' on which thunder is heard in central Florida. When used in the analysis that follows, this parameter is designated T_y.

Most observers agree that there are about 3 lightning flashes per minute in the average thunderstorm cell, and that a cell covers about 500 square kilometers of ground area for an average of between 1 and 3 hours. This works out to a flash density, τ_y, of between 0.3 and 1.0 flashes per square kilometer per thunderstorm day, as illustrated in Figure A-1. Actually, flash density τ_y is related more closely to the square of the isokeraunic level, as follows:

$$\tau_y = 0.02 T_y^{1.7} \text{ flashes/km}^2\text{/year} \qquad (1)$$

The flash density of equation (1) includes flashes between clouds and flashes to ground. Pierce [7] has noted that the percentage, P, of flashes to ground increases with geographical latitude and he has represented the latitudinal variation in equation (2):

$$P = 10\,[1+(\lambda/30)^2]\% \qquad (2)$$

where λ is the geographical latitude in degrees. For the U.S. the percentage of earth-bound flashes ranges between 20% (in the South) to 36% (in the North).

Equations (1) and (2) can be used to estimate the average number of times lightning may be expected to strike the ground within one square kilometer, based on the number of thunderstorm days per year and the geographical latitude of the location. The isokeraunic level of Kennedy Space Center is approximately 90 [8] and the latitude is 28.5°N. From equation (1),

---

[7] N. Cianos and E.T. Pierce, "A Ground Lightning Environment for Engineering Usage," Technical Report 1, August 1972 pp. 65,63.

[8] "World Distribution of Thunderstorm Days-Part I, WMO/OMN No. 21, TP 6, World Meteorological Organization, Geneva, Switzerland, 1953.

the flash density is:

$$\tau_y = 0.02 T_y^{1.7} \text{ flashes/km}^2\text{/year} \quad (3)$$

$$= 0.02(90)^{1.7}$$

$$= 42 \text{ flashes/km}^2\text{/year}$$

The percentage of these which reach earth at latitude 28.5°N is:

$$P = 10\ [1+(\lambda/30)^2]\% \quad (4)$$

$$= 10\ [1+(28.5/30)^2] = 19\%$$

Thus, the number of flashes reaching earth within each square kilometer in the vicinity of Kennedy Space Center is expected to be:

$$\text{Flashes to ground} = (0.19)\ (42)$$

$$= \underline{\underline{8 \text{ flashes/km}^2\text{/year}}}.$$

If, for discussion purposes, the RTLP/ASFL facility occupies an area of approximately 0.5 km², then the average number of flashes reaching the facility each year would be:

$$\text{Flashes to facility} = (8 \text{ flashes/km}^2\text{/year})(0.5 \text{ km}^2)$$

$$= \underline{\underline{4 \text{ flashes/year}}}$$

Of course, a much larger number of flashes will reach the earth each year within a radius of one kilometer of each site, as follows:

$$\text{Area within 1 Km of each site} = \pi(\text{km})^2 \quad (5)$$

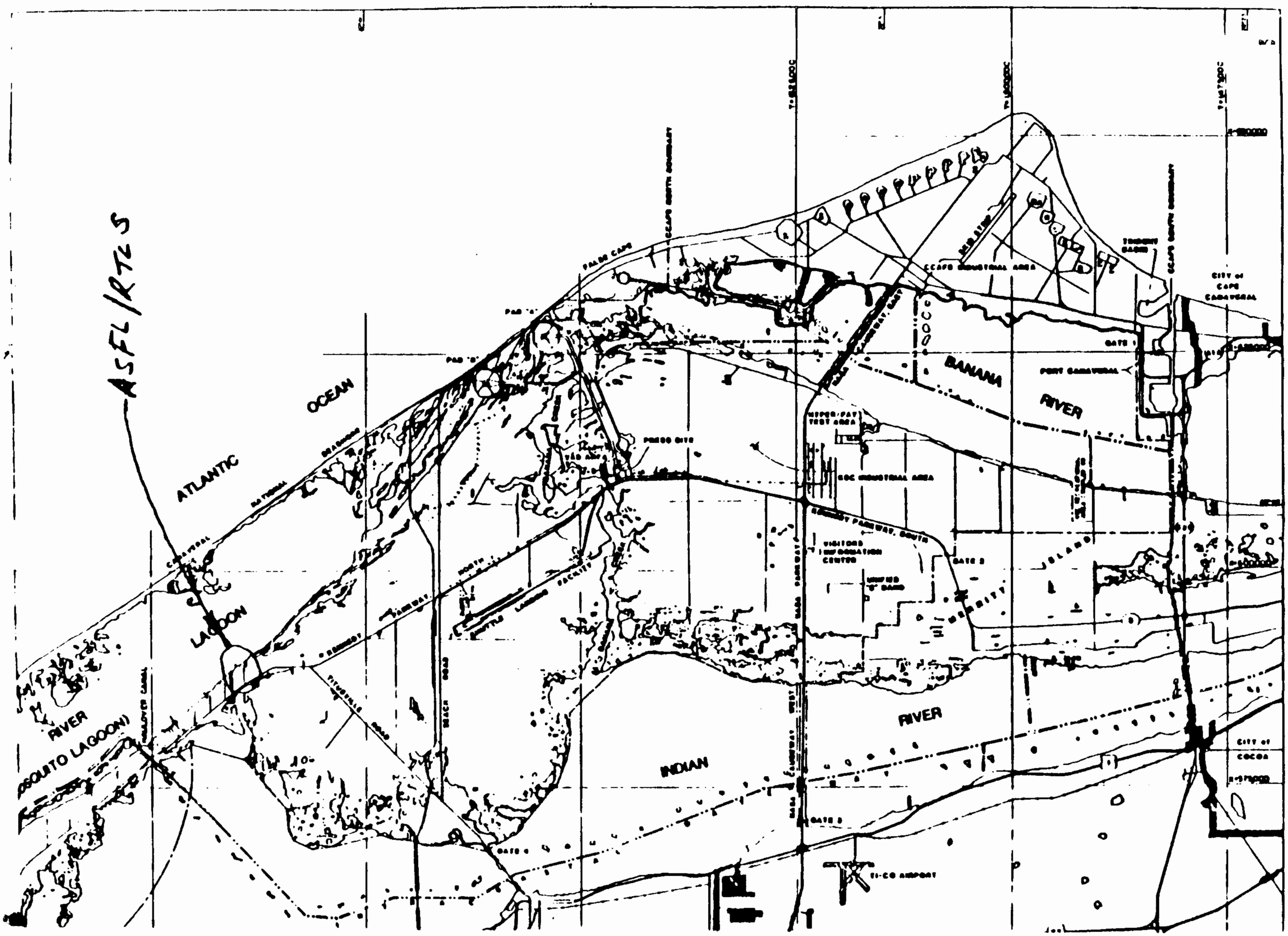
$$= 3.14 \text{ km}^2$$

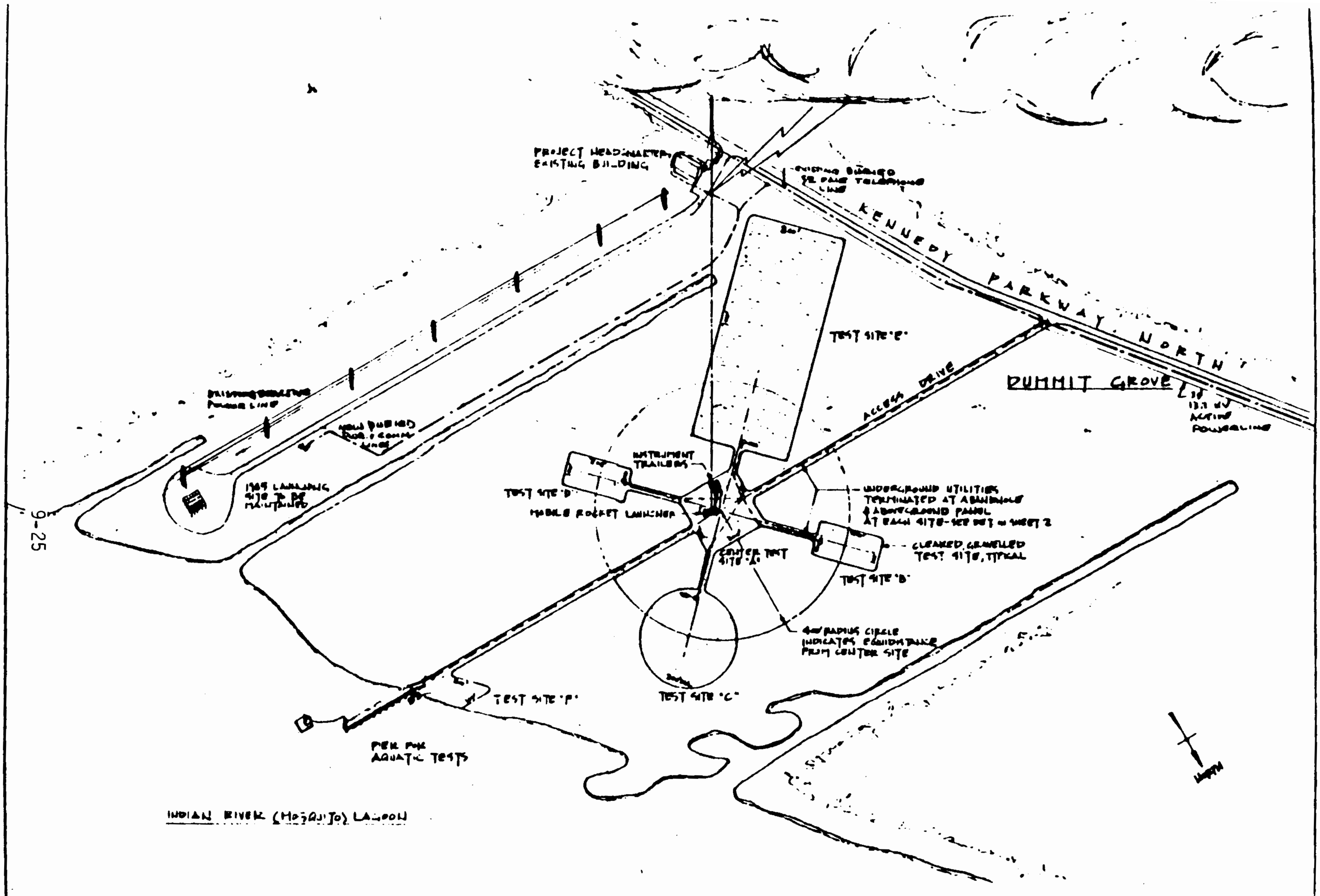
$$\text{Flashes to ground within this area} = (3.14 \text{ km}^2)(8 \text{ flashes/km}^2\text{/yr.})$$

$$= \underline{\underline{25 \text{ flashes/yr.}}}$$

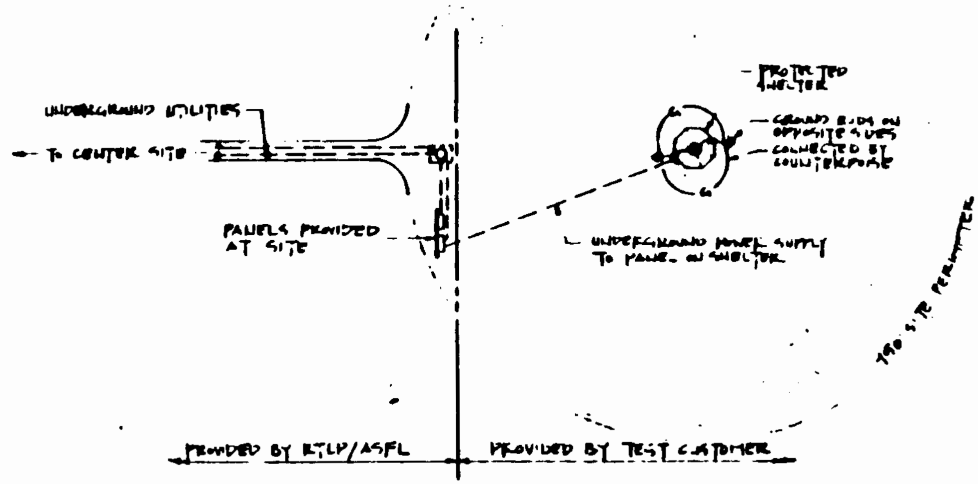
Since many electrical/electronic systems are known to be affected by the indirect effects of nearby lightning strikes, systems set up at a site for effects evaluation or protection verification will experience a significant amount of lightning activity even without triggering of dedicated strokes.

ASFL/RTCS

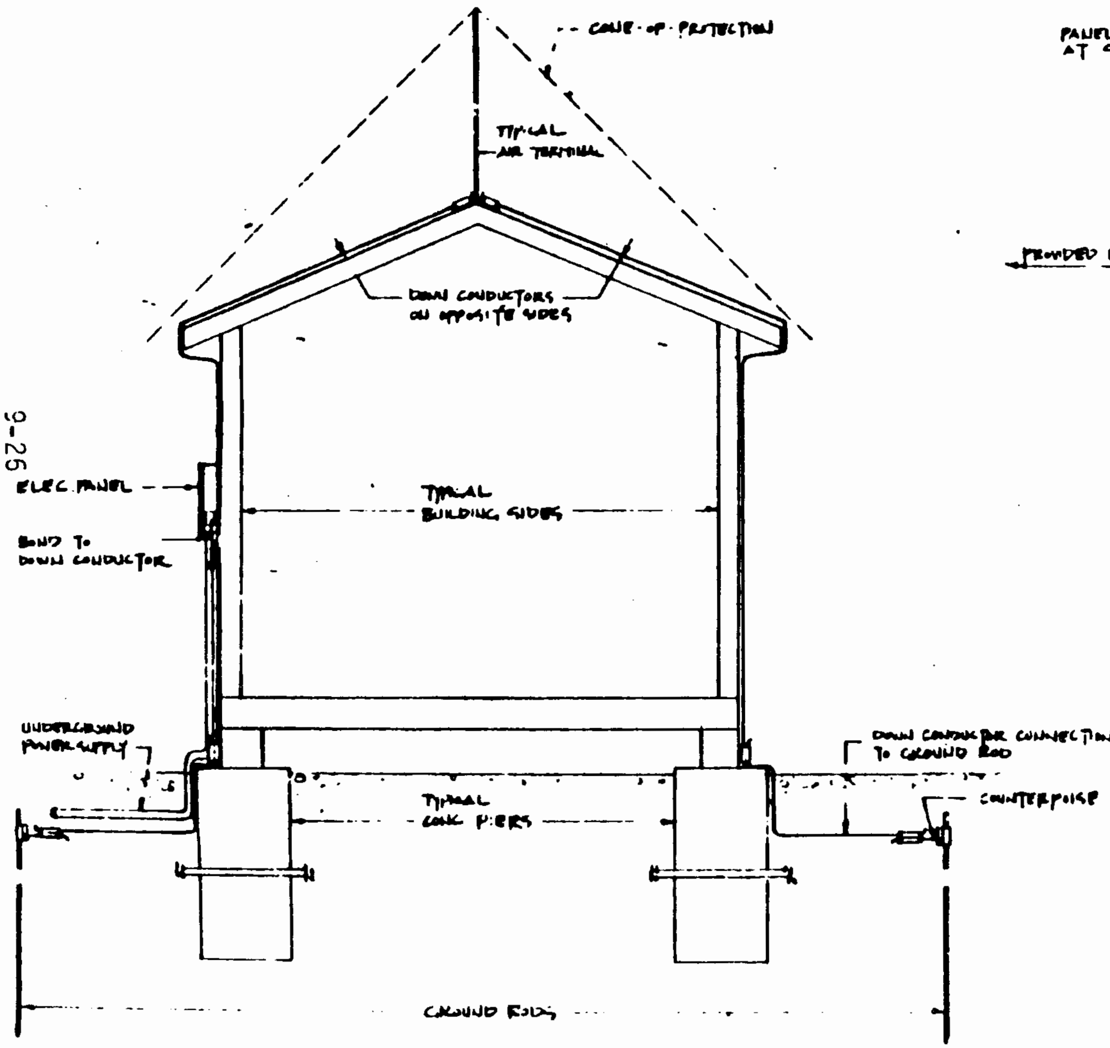

ATLANTIC
OCEAN
BANANA
RIVER
INDIAN
RIVER
LAGOON
RIVER
(MOSQUITO LAGOON)
CITY of CAPE CANAVERAL
PORT CANAVERAL
CCAFS INDUSTRIAL AREA
KSC INDUSTRIAL AREA
VISITORS INFORMATION CENTER
GATE 1
GATE 2
GATE 3
GATE 4
CITY of COCOA
TI-CO AIRPORT
TRIDENT BASIN



PROPOSED FACILITY LAYOUT			
RTLP/ASFL FACILITY PROPOSAL JOHN F KENNEDY SPACE CENTER, NASA KENNEDY SPACE CENTER, FLORIDA			
SCALE 1" = 200'	DATE 12-1- 85		
JAP	JN		
LIGHTNING TECHNOLOGIES, INC. 10 DOWNING PARKWAY PITTSFIELD MASSACHUSETTS			344-85-1



PLAN OF TEST SITE LAYOUT
1" = 50'



SECTION THRU PROTECTED SHELTER
NO SCALE

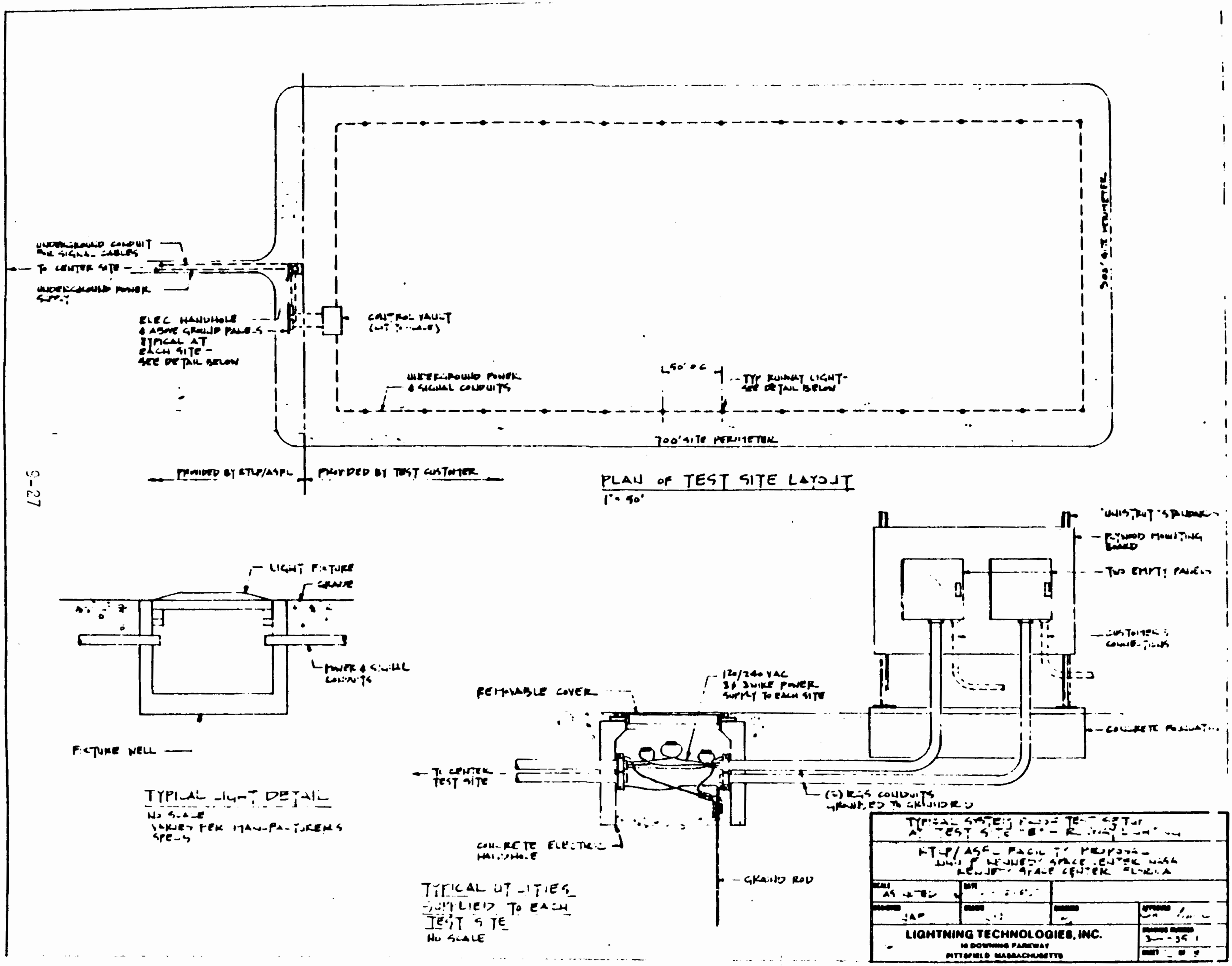
TYPICAL SYSTEM PROOF TEST SETUP AT TEST SITE "C" – PROTECTED 20.F SHELTER

RTLP/ASFL FACILITY PROPOSAL
JOHN F. KENNEDY SPACE CENTER, NASA
KENNEDY SPACE CENTER, FLORIDA

SCALE: AS NOTED

LIGHTNING TECHNOLOGIES, INC.
10 DOWNING PARKWAY
PITTSFIELD, MASSACHUSETTS

SHEET 3


UNDERGROUND CONDUIT FOR SIGNAL CABLES
TO CENTER SITE
UNDERGROUND POWER SUPPLY
ELEC HANDHOLE & ABOVE GROUND PANELS TYPICAL AT EACH SITE - SEE DETAIL BELOW
CONTROL VAULT (NOT TO SCALE)
UNDERGROUND POWER & SIGNAL CONDUITS
50' O.C.
TYP RUNWAY LIGHT- SEE DETAIL BELOW
700' SITE PERIMETER
300' SITE PERIMETER
PROVIDED BY ETLP/ASPL
PROVIDED BY TEST CUSTOMER
PLAN OF TEST SITE LAYOUT
1" = 50'
LIGHT FIXTURE
GRADE
POWER & SIGNAL CONDUITS
FIXTURE WELL
TYPICAL LIGHT DETAIL
NO SCALE
VARIES PER MANUFACTURERS SPECS
UNISTRUT STANCHIONS
PLYWOOD MOUNTING BOARD
TWO EMPTY PANELS
CUSTOMER'S CONNECTIONS
CONCRETE FOUNDATION
REMOVABLE COVER
120/240 VAC 3Ø 3WIRE POWER SUPPLY TO EACH SITE
TO CENTER TEST SITE
(2) RGS CONDUITS GROUNDED TO GROUND ROD
CONCRETE ELECTRIC HANDHOLE
GROUND ROD
TYPICAL UTILITIES SUPPLIED TO EACH TEST SITE
NO SCALE
KENNEDY SPACE CENTER FLORIDA
AS NOTED
LIGHTNING TECHNOLOGIES, INC.
10 DOWNING PARKWAY
PITTSFIELD MASSACHUSETTS

N-49 CONVAIR 580

FUTURE REQUIREMENTS

GENERAL DISCUSSION

Having presented the formal briefings by attending members, the session was opened to all for general comments pertaining to the future testbed requirements for atmospheric electrical data collection and, in particular, the future of N-49, the Federal Aviation Administration's (FAA) Convair 580, which has been used the past two seasons to collect direct strike lightning attachments.

Mike Glynn: Opened the general session by discussing the intent of the session, which was for all attendees to let it be known their needs for an airborne testbed. The dollars invested in the aircraft compared to the future operations cost were mentioned. The FAA is writing the United States Air Force (USAF) a letter requesting equipment and personnel support for at least 1986. A position paper supporting the continuation of the direct strike effort is being drafted by the FAA, and will contain the expressed needs of the FAA headquarters; FAA all directorate committee; Society of Automotive Engineers (SAE) 4L Committee; NSSL; NRL; EMA, Incorporated; and possibly others.

Tony Carro: The rate of rise and the peak current numbers are still a point of discussion, and there are no data to objectively determine these points with high confidence. We need this information for laboratory reproduction, and the number of strokes per event is still undetermined. Our immediate problem is 1986, and our long-term goal is the possibility of a national resource for atmospheric research.

John Reed: It is important to realize that the F-106 had a rough time getting 1986 approval, and we are having difficulties in laying out our 1986 coordinated plan. The FAA wrote letters supporting the National Aeronautics and Space Administration (NASA) storm hazard program of 1986, and we need written support for the Convair (CV) 580 program. We must take a strong position in the research and development (R&D) community, and attempt to capture a severe strike so we can determine the required testing to meet this threat. We need to extract the required data for the certification process and the writing of guidance material. With some national effort and coordination, the CV-580 could support the gale program and the genesis of storms program.

Bob VonHusen: The SAE threat level is less than what the FAA feels is required by about one-half. We need to verify what this threat should be. To date, we have promised management cloud-to-ground lightning data in quantities for statistical analysis; now they would like to see it. There are lots of severe damage being being witnessed, and we need to know the parameters causing it.

Felix Pitts: SAE is still working on the intensity and rate of rise. There are limited references to high fast data (200/2x10"). There is a German paper with some reference; believe John Robb has it.

Lothar Ruhnke: Looking at the F-106/CV-580/RTL, there are distinct differences when comparing amplitude, rates of rise, and percent of long continuous current. NAVAIR has some 6.1 and 6.3 effort, and there is a need for new definition. During a program review in November 1985, it was determined that more data was needed, but dollars are not there. Would appreciate any written support enumerating shortcomings in current data and available resources to secure needed data.

Larry Walko: Understands the need but supply of people and equipment limited, mostly dedicated to other projects. Need financial support to continue. Committed to other priority programs, but TSSI could possibly train personnel to run the systems. Believes letter okay but would suggest leaving it a little more open ended as to the requested support for 1986 and talk about transitioning to taking over the program.

Vlad Mazur: The advanced parameters of lightning to aircraft are void in the current data. Interested in direct strikes so we can make physical models of the aircraft and the environment, look at the differences in nature, and analyze the physical interaction. Need to complete the measurements and attempt to position two aircraft in the same electrical environment for comparison. In 1985, 10 of the 34 cloud-to-ground strikes were not associated with return strokes, and there were no huge currents. The airline data we have seen occurs in non-stormy areas, and triggered in these areas. What kind of creature is this and what will its effect to nonmetallic aircraft be? Russian data shows a higher incident of lightning strikes in winter months over coastal areas.

1986

International Aerospace and Ground Conference on Lightning and Static Electricity

June 24, 25, 26, 1986
Stouffers Dayton Plaza Hotel
Dayton, Ohio U.S.A.

In Response Reply To:

SUBJECT: Seventh Meeting of the National Interagency Coordinating Group (NICG) of the National Atmospheric Electricity Hazards Protection Program (AEHP)

FROM: Michael S. Glynn
Secretary, NICG

TO: See Distribution

Reference my call to the primary NICG members on December 19, 1985, this is the follow-up as promised and information letter to the entire NICG distribution list.

Having received concurrence from the Primary Committee members on their availability, the 7th NICG Meeting will be held at the Atlantic City Airport, New Jersey, on February 11-12, 1986. As of yet, firm reservations for meeting rooms and quarters have not been established, but within the next week, appropriate arrangements will be confirmed.

To assist in making finalized plans, it is requested that each individual on the distribution list provide the NICG Secretary with their intentions concerning the following information:

1. Name and number of individuals from your organization attending meeting and if billeting arrangements are desired.

2. Date and time of arrival and departure. Request, if possible, the entire days of February 11-12 be available for NICG business.

3. Title of subjects to be formally presented to the group and the time frame required.

4. Any special audio/visual aides required for presentations.

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5. Any recommended changes to the NICG distribution list which may assist in this coordination effort.

Any questions concerning the subject matter can be addressed directly to the secretary, Michael S. Glynn at (609) 484-4138 or FTS 482-4138.

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Atlantic City, New Jersey
February 11, 1986

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