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FIRST ANNUAL WORKSHOP ON AVIATION RELATED ELECTRICITY HAZARDS ASSOCIATED WITH ATMOSPHERIC PHENOMENA AND AIRCRAFT GENERATED INPUTS FEBRUARY 26-27, 1980

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PROCEEDINGS

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On May 25, 1980 the National Aviation Facilities Experimental Center (NAFEC) referred to in the report changed its name to the FAA Technical Center, and all ANA symbols are now ACT.

16. Abstract

This workshop was to bring together the various elements of the agency to engage in discussions to identify aviation related electricity hazards associated with both atmospheric phenomena and aircraft generated inputs, and determine a prioritize specific FAA problem area and/or requirements that need to be addressed. This information is vital in the development of the agency's posture and requirements in this important technology area.

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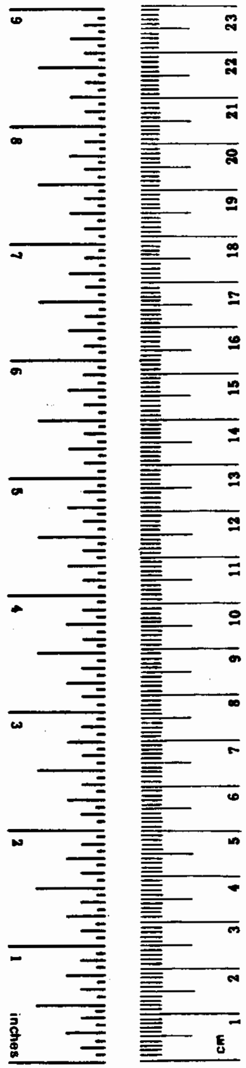
METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

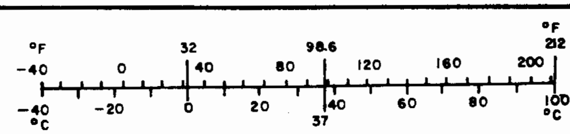
Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



EXECUTIVE SUMMARY

Introduction

The First Annual Federal Aviation Administration (FAA) Workshop on Aviation Related Electricity Hazards Associated with Atmospheric Phenomena and Aircraft Generated Inputs was held at the National Aviation Facilities Experimental Center (NAFEC) on February 26-27, 1980. The meeting was sponsored by the Operations Branch, ANA-340, Aircraft Safety Development Division, ANA-300.

The purpose of this workshop was to bring together the various elements of the agency to engage in discussions to identify aviation related electricity hazards associated with both atmospheric phenomena and aircraft generated inputs, and to determine and prioritize specific FAA problem areas and/or requirements that need to be addressed. This information and material is vital to the development of the agency's posture and requirements at the forthcoming National Atmospheric Electricity Hazards Protection (NAEHP) Program meeting scheduled at NAFEC on May 28-29, 1980. The attendees will include representatives from the US Air Force (USAF), National Aeronautics and Space Administration (NASA), FAA, US Navy (USN), US Army (USA), US Coast Guard (USCG), and National Oceanic and Atmospheric Administration (NOAA).

It should be recognized that extensive work is currently being accomplished (or is projected for initiation in the near future) in this technology area. The subject of aviation related electricity hazards associated with atmospheric phenomena has been, and continues to be, a topic of vital interest to the FAA and other organizations and agencies such as NASA, the Department of Defense (DOD), industry, and universities.

During the FAA workshop, discussions in this technology field appeared to concentrate on two principal broad topics; namely:

- Dissemination of available information.
- Current needs and/or identified problem areas.

The items listed below denote the areas of current interest to the FAA in this technology field. They provide the agency with an updated and near-term focus on those activities that are of primary concern to the Regions, headquarters, and other elements of the FAA. The listing is not intended to reveal the specific level of activity, priority interest of effort, or monies obligated by all agencies in each research area. The above areas of discussion will be among the first items of business for the NAEHP and its working/planning committees.

The following listed discussion topics were developed at NAFEC by the FAA workshop members:

Discussion Topics

Dissemination of Available Information

- The need was expressed for an agency clearing-house to condense information and data into a useful form for better and more rapid utilization by both the Regions and headquarters personnel.

- The requirement was noted for full agency representation and participation on the soon-to-be formed NAEHP Interagency Coordinating Group.

- Establish international coordination and promote information exchange to stay abreast of the North Atlantic Treaty Organization (NATO) Air Electrical Working Panel (AEWP) activities.

- Establish agency representation and full participation on the Society of Automotive Engineers (SAE) Lightning Committee (SAE-AE-4L).

- Publish and circulate, on a regular basis, an FAA newsletter on this technology area. Condense the material into easy-to-read form that incorporates the following features:

  - A procedure for exchange of information between the various elements of the FAA.

  - Provide a bibliography/abstract of work in the lightning research area that includes both completed and in-progress research efforts.

  - Identify the research organization and technical representative with appropriate telephone numbers and address (if possible).

- Establish a positive tracking system for obtaining aircraft lightning strike information. Review and scrutinize existing aircraft lightning strike data for validity, since present statistics seem suspect.

Current Needs and/or Identified Problem Areas

- Review and determine the present status and adequacy of recommended operational procedures (by both the agency and the aircraft operators) related to direct lightning strikes. Establish the currency, uniformity, and applicability of current operational procedures for present and future aircraft given the available research results and information.

- Utilizing all available lightning technology testing techniques, determine what level of unit (complete aircraft/system/subsystem/component/subcomponent, etc.) need be tested to adequately determine the effects of a direct lightning strike, and evaluate the electromagnetic compatibility (EMC) of the entire system.

- Determine whether or not, or to what extent, model-scale lightning data can be correlated with full-scale lightning data. Establish the validity of the data as influenced by scale-factor and model construction fidelity. Evaluate the possibility of data utilization for analytical modeling purposes.

- Need for protection/"hardening" criteria and techniques.

  - Requirement to determine the compatibility of the requirements specified by the Radio Technical Commission for Aeronautics (RTCA) and the SAE Lightning Committee related to hardening information. Analyze and combine the appropriate material with the existing and projected research results of NASA, FAA, DOD, and other agencies.

  - Resolve issue of whether redundancy is or is not a hardening technique, and determine if criteria can be established for substituting "redundancy" for "hardening."

- Update and modify lightning protection/hardening criteria and procedures for advanced, new technology, control and avionics systems on derivative and new generation aircraft.

- Resolve electricity hazards issues on the use of "composites" in aircraft primary structures. Determine the impact on protection/ hardening requirements, techniques, and procedures for direct-strike lightning and swept-stroke attachment phenomena on composite type primary aircraft surfaces, nacelles, and fuselages. Study the effect on passenger/crew protection for the "all-composite fuselage."

- Utilizing all available lightning technology testing techniques, determine what level of unit (complete aircraft, major surface, nacelle, panel/subpanel, etc.) need be tested and hardening reqirements and the specific component.

- Determine and resolve the issues related to atmospheric lightning phenomena causing jet engine flameouts due to "swept-stroke shock," "pressure wave" effects, etc.

- Establish the impact and influence of aircraft electrical power system generated (electromagnetic interference (EMI)) effects including all transient phenomena, power interrupts, etc. Obtain aircraft electrical power system "signatures" on existing derivative and new generation aircraft to ensure that adequate protection/ hardening criteria are provided for aircraft generated EMI efects and electrical power system anomalies.

A more detailed listing of topics is contained in the body of this document.

OPENING REMARKS

Thomas J. O'Brien
Deputy Director
NAFEC

On behalf of the workshop's organizing committee and NAFEC, welcome to the FAA's First Annual Workshop on Atmospheric Electricity Hazards. I sincerely hope that this meeting will set a precedent and become an annual event.

We are here to determine how NAFEC can best involve itself in the new NAEHP Program. I became involved in lightning associated research following the crash of a Boeing 707 near Elkton, Maryland, in December 1963. This accident triggered investigations into the direct effects associated with a lightning strike, and included everything from model test to the feasibility of installing an inerting system in the fuel tanks. Also, the feasibility of utilizing an explosion suppression system was evaluated.

With the rapid application of digital computer technology to controls application, lightning is a real threat. The adverse effect of lightning on these systems must be controlled to permit utilization of digital control systems where thousands of signals per second are being sent from the computer to various control systems on small wires throughout the aircraft.

The engine technology has been pushed to its limits, so the airframe designers are looking into composite structures for weight reduction with added strength. At this time, much research is required to determine the effects of a lightning strike on this composite material. Researchers have a good understanding of the lightning effects on aluminum and titanium.

It is a very interesting field in which to get, and a good time to get into it. This could provide the opportunity to get ahead of some of the problems, but in doing so, we need to determine what information we need, what the testing procedures are, and what the certification criteria will be. I hope you will have a very productive time while you are here.

"JB" McCollough
Chief, Operations Branch, ANA-340

In keeping with the format of the agenda, this workshop was called for the purpose of providing an FAA forum to define agency problems associated with EMC as related to advanced systems such as digital flight controls and avionics. The forum is important from two standpoints:

- Definition of our research requirements.
- Determination of our role in the NAEHP Program.

As stated in his letter to you, the Director of NAFEC strongly supports the participation of the FAA in this important technology area and the national activities. The efforts are of priority interest to the agency because of the serious safety implications and the potential to provide essential, timely information on atmospheric hazards and EMC as related to current and future aircraft.

This is especially true when one considers the utilization of advanced integrated type digital concepts, new design avionics, structures, and systems. I am convinced that an investment in time and planning effort now will provide greater payoffs in the near-term for this activity in the areas of:

- Data acquisition and dissemination of knowledge.
- Certification procedures and techniques.
- Criteria information and guidelines.

Lastly, participation in a national program provides the agency with a greater opportunity to discuss its priority needs and integrate its research efforts, where appropriate, with NASA and DOD activities.

J. J. Traybar
Program Manager, Advanced Integrated
Flight Systems
Operations Branch, ANA-340

I would like to make a few brief remarks on the agenda, and then list some statements on the general technology areas, discuss certain points of this meeting, as well as offer a brief introduction into the Advanced Integrated Flight Systems (AIFS) Program and ongoing project work in this area.

The general technology areas of vital importance are:

- Indirect Effects: Loss of control systems and air/ground avionics, disablements, or "scrambling" of digital air/ground systems, etc.
- Direct Effects: Damage to aircraft wing tips, structures, composite surfaces, and ground systems.
- External Phenomena: Lightning, P-static, static discharge, etc.
- Internal Phenomena: Induced effects, aircraft electric power interrupts/transients, "spikes & noise," etc.

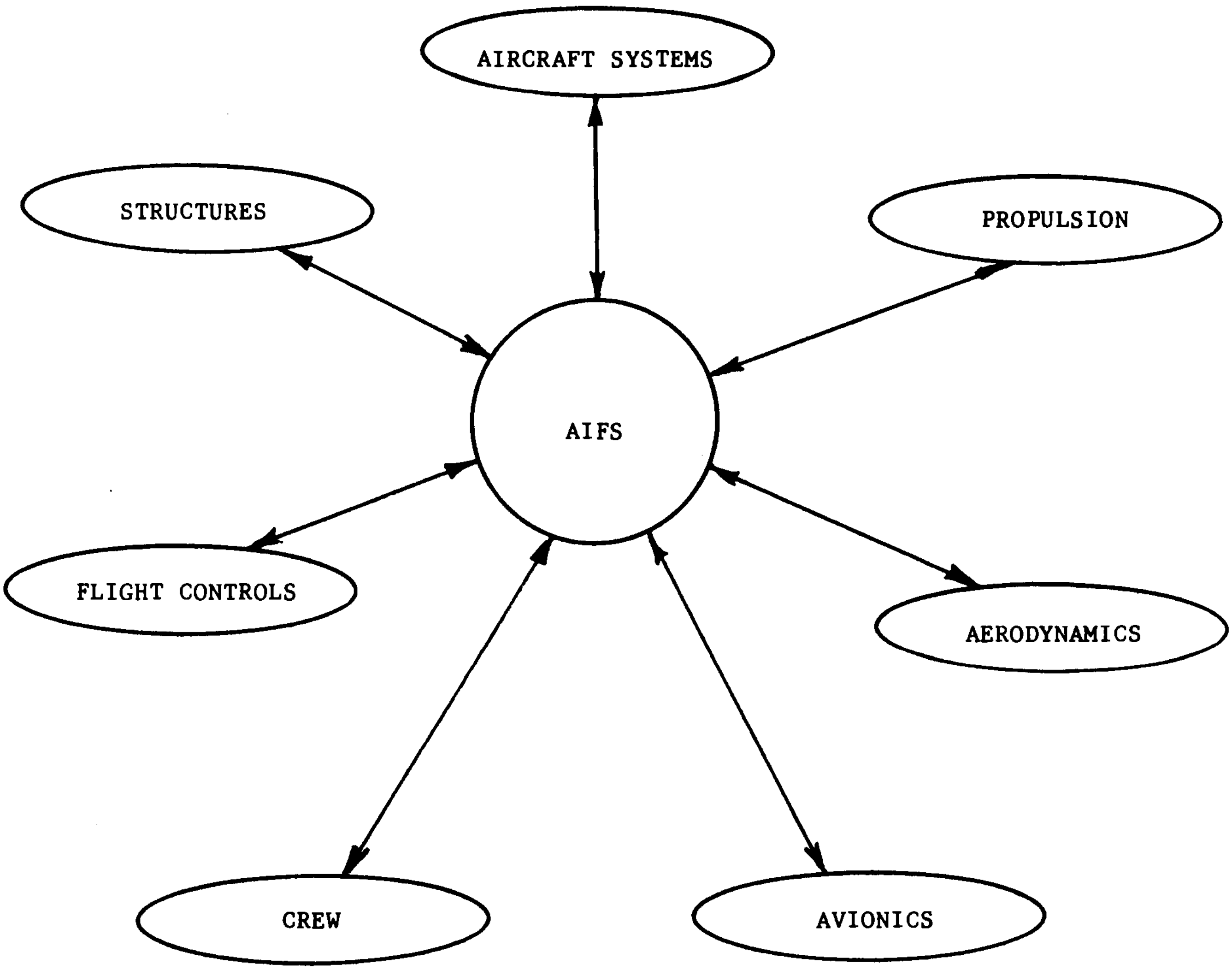
Recently, a terminal configured vehicle (TCV) aircraft (NASA-TCV) was struck by lightning. The aircraft was being flown from the rear cockpit. Although this aircraft has many digital systems, the flight continued, and the only adverse effect noted was a ripple through the cathode ray tube (CRT) displays. Post-flight inspection revealed the loss of an antenna on the lower fuselage due to burning through of the mounting structure.

In addition to the previously discussed technological areas, the following subjects are of concern to the agency:

- Testing and certification procedures and criteria.
- Protection and "hardening" guidelines and criteria.
- Lightning detection and warning devices for aircraft/systems.
- Qualification testing considerations.

The agency is concerned with aircraft operations in a lightning environment, and the Associate Administrator for Engineering and Development (AED-1) recently designated ANA-340 as the focal point for research in this area, and implemented the activity as part of the AIFS technology effort. The following figure shows the project areas of the AIFS program:

ADVANCED INTEGRATED FLIGHT SYSTEMS
(AIFS)
PROGRAM



The AIFS Program objectives are the following:

- Evaluate and assess advancing technology for impact on the FAA.
- Acquire needed data base.
- Support the development of certification procedures.
- Transfer information to flight standards.

The AIFS Program Plan is currently being updated. I am the new AIFS Program Manager, and will be the chairman of the AIFS Planning Group when it is reactivated. In the areas of concern here, airworthiness problems always list effects of EMI and lightning as shown:

AIRWORTHINESS PROBLEMS

- Failure Modes
- Software Validation
- Effects of EMI and Lightning
- Performance/Flight Margins

The current ongoing AIFS projects being conducted by joint FAA/NASA interagency agreements (IA) are:

- Simulation Methods for Digital Systems
  - Predict reliability and failure effects, flight software validation.
  - Real-time systems/mission simulation and research experimentation.
- Lightning Study Flight Tests
  - Obtain in-flight "direct-strike" data.
  - Determine effects of EMI transients on systems.
- Hardware/Software Functional Assessment Concepts
  - Assess functional operation of advanced computer concepts.
  - Develop diagnostic emulation concepts for analysis of system design.

John E. Reed
Systems Branch, AWS-130
Office of Airworthiness

The key to the NAEHP Program occurred at a NATO conference in Paris, France, a couple of years ago. The United States (US) was presenting its research programs, from the phenomena of lightning, ground and airborne protection, through qualification testing for direct/indirect effects. Representatives from the academic centers, aviation community, industry, and Government were involved in the presentations. Although much research has been conducted in air-to-ground strikes, little information has been collected on air-to-air strikes.

The airborne people were becoming quite concerned; i. e., everyone from NATO to our own military people, in how to protect aircraft in a lightning environment. It also became apparent that most of the Government organizations individually did not have sufficient funds to conduct a comprehensive test program. Therefore, it appeared that a combined team effort would be required to facilitate utilization of available funds for a test program.

It was decided that, in the near future, we must get together to develop a national program for the protection of ourselves, and to present a unified front to Congress during the budgetary process. To initiate the program, the FAA was not in a position to make a large contribution very rapidly. Although the agency did not have funds available, it was able to respond by furnishing expertise. NASA could also make a large contribution, as they had ongoing programs (the Space Shuttle, the Digital F-8 program at the NASA-Dryden Flight Research Center, lightning research at the NASA-Langley Research Center, and propulsion at the NASA-Lewis Research Center). The USAF had a large program, but no excess monies. The USN also had a large ongoing program without any additional money.

It was decided that we must consolidate our expertise, funds, and facilities. The initial meeting was held at Front Royal, Virginia, on August 22, 1979, with participants from NASA, USN, USAF, and the FAA in attendance. This planning meeting delineated the scope of program, and created a joint agency national program to more efficiently utilize available national resources to produce reliable protection criteria and guidelines for both military and civil aircraft. Agency focal points and areas of responsibility were established.

To assure that the agencies interface with industry in this critical area, workshops are annually held (Meteorological and Environmental Inputs to Aviation Systems, Symposium on Lightning Technology, etc.) to bring together various disciplines of the civil and military aviation communities with meteorologists, atmospheric scientists, and engineers in round table discussions to foster education and disseminate knowledge in the area of natural environmental inputs required for aeronautical operations.

The importance of this national organization cannot be over emphasized, and to ensure that the agency fulfills its obligations, your cooperation is required. Inputs from the field and headquarters are essential to the program. This information should be forwarded to "JB" McCollough for collection, evaulation, and dissemination.

Nickolus O. Rasch
Project Manager
Operations Branch, ANA-340

This presentation will be divided into three separate parts: The first will be a brief dissertation on the physics of lightning; the second will cover the NASA direct strike program; and the third and final part will cover the pending IA between the Air Force Flight Dynamics Laboratory (AFFDL) and the FAA for the Atmospheric Electricity Hazards Protection (AEHP) of Advanced Technology Aircraft Program.

The purpose of this presentation is to illustrate the basic physics of lightning. Although lightning can be very enhancing and frightening, it can also be very dangerous to aircraft flying near or through a thunderstorm cell. The agency must strive for flight safety in this environment.

The first slide is a schematic diagram of a typical lightning cloud-to-ground flash. The flash as seen by the human eye is shown in Figure 1(a). Figure 1(b) is a schematic diagram showing the sequence of the lightning flash. This shows that a stepped leader takes approximately 10 milliseconds as it forms an ionized path from the cloud to the earth. The positive return stroke (luminous segment of lightning stroke) then continues up this ionized path to the negatively charged lower extremity of the cloud (approximately 40 microseconds). After approximately an additional 40 milliseconds, a dart leader (reionization of the path) is completed, and a second return stroke is observed. This procedure continues until conditions are electrically stabilized (a minimum of two strokes or a maximum of up to 20 return strokes). The first return stroke has the maximum of up to 200 thousand amps with subsequent strokes being reduced in amperage.

An aircraft encounters three different types of lightning as shown in Figure 2. The first is the cloud-to-ground and is the most important to the agency as it represents a realistic environmental flight condition encountered when aircraft are landed in a thunderstorm. The second is a cloud-to-cloud strike, while the third is an intracloud strike. These two represent the majority of the lightning activity, but have resulted in less aircraft strikes as the aircraft are usually vectored around thunderstorm activity.

Figure 3 shows the physics of a thunderstorm cell. The lower portion of the cell will be discharging moisture (rain) towards the earth, and due to a reduced pressure, precipitation will also be directed upward through a low pressure channel. As the moisture proceeds upward, it freezes and continues upward until the low pressure area is equal to the gravitational attraction. As the moisture (rain, hail) proceeds upward, it becomes ionized causing a static charge being put on the cloud. When the charge exceeds the capacity of the environmental conditions, a lightning strike occurs. The lightning strike temporarily reduces the charge on the cloud to a relative stable condition. This condition is repeated with lightning flashes occurring up to 4 times per minute.

The bar charts on the right hand side of Figure 3 show the reported lightning strikes to aircraft at various altitudes. Very few strikes occur at cruise altitude as the aircraft are vectored around the thunderstorms. The majority of strikes are experienced below 15,000 feet altitude as the aircraft approaches for a landing.

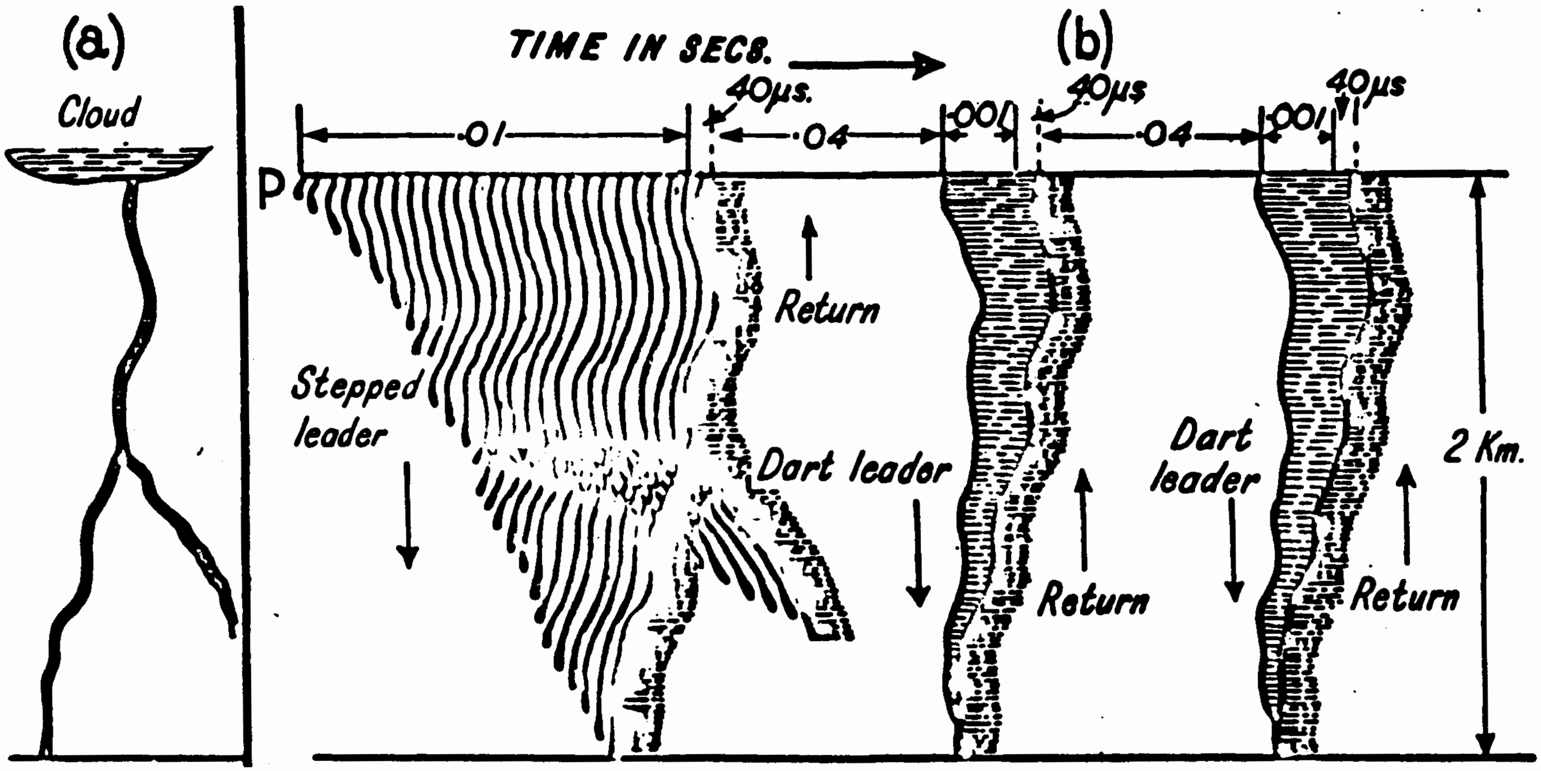
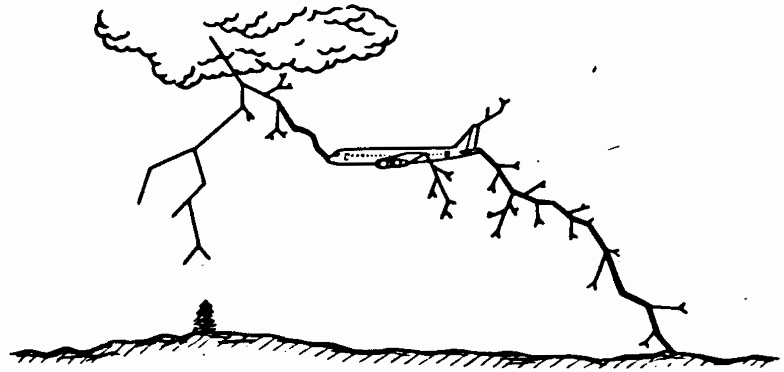
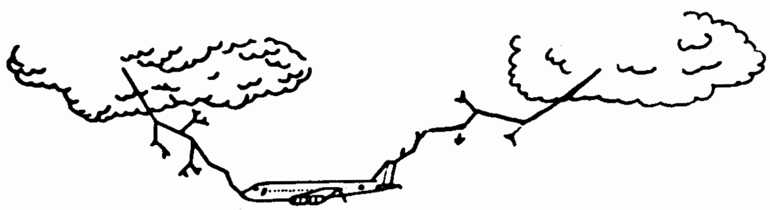


FIGURE 1. SCHEMATIC DIAGRAM OF TYPICAL SEQUENCE OF LIGHTNING EVENTS



CLOUD TO GROUND RETURN STROKE



CLOUD TO CLOUD RETURN STROKE

INTRA CLOUD RETURN STROKE

FIGURE 2. THREE TYPES OF LIGHTNING

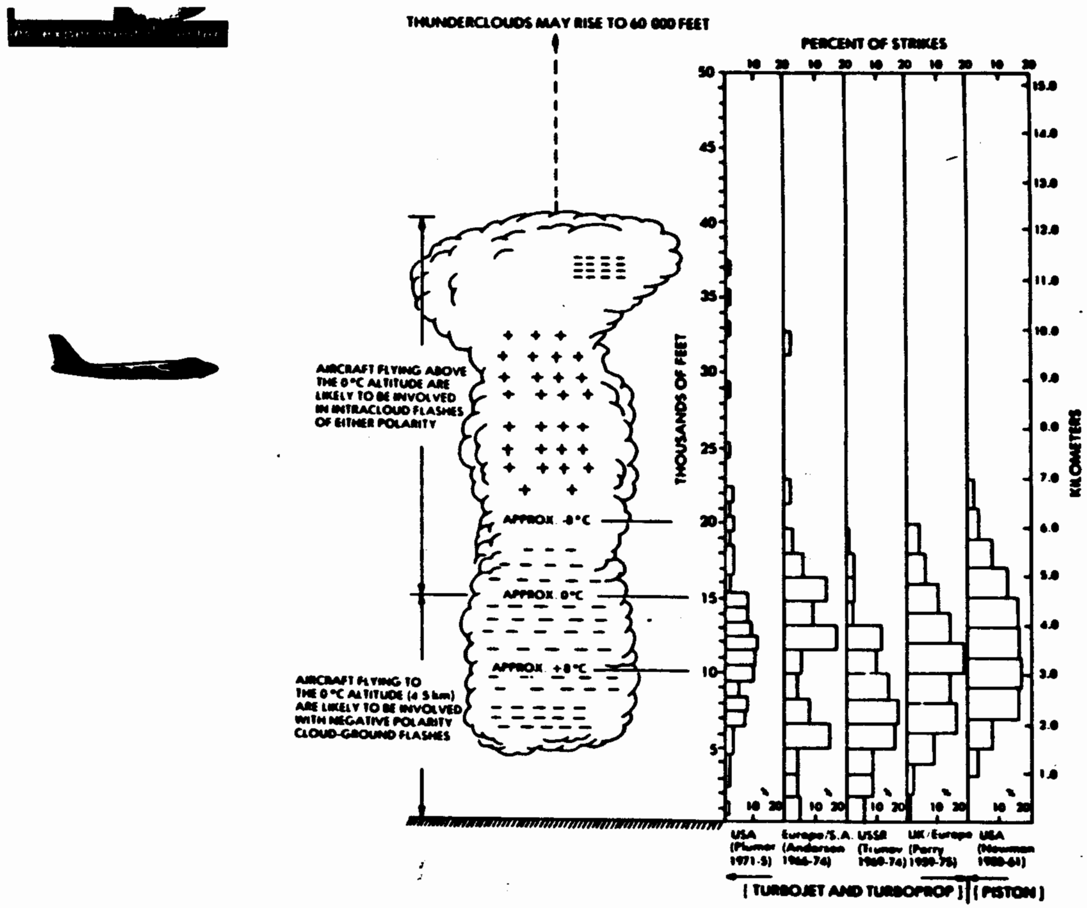


FIGURE 3. AIRCRAFT LIGHTNING STRIKE INCIDENTS VS ALTITUDE

The physics of lightning are as shown:

- Types — Cloud-Cloud, Cloud-Ground, Positive, Negative
- Voltage — 30-100 million volts
- Current — 20-200 thousand amps
- Power — 10^{13} watts
- Energy — 5×10^{8} joules (200 pounds of TNT)/stroke
- Extent — 3 to 30 km/stroke
- Duration — Flash (1 to 20 strokes); Stroke (up to 100 microseconds)

To determine the impact of lightning on aircraft, a sampling period of 4 years was analyzed (1971 to 1974). The reported lightning information on commercial aircraft was as follows:

- 216 Strikes:
  - 78 Reported no effects
  - 32 Reported random damage
  - 40 Reported interference or damage to avionics
  - 27 Reported static discharge damage
  - 6 Reported an "AC" generator tripped off the line
  - Flash blindness and/or loud bangs were reported by aircrews in most cases
  - 6 Reported lightning arrester damage
  - 27 Reported damage to metallic structure

Flash blindness can be a very dangerous condition during final approach as the pilot can become disoriented and lose control of the aircraft. The USAF recently reported a case similar to this where the pilot became disoriented and caused the aircraft to crash with several fatalities.

Strike attachment zones have been determined in model testing and are shown in Figure 4. The initial attach point is shown in Zone 1A, and represents the point where there is a high probability of lightning initially striking the aircraft. Zone 2A is called the sweep stroke zone and is shown as the area where there is a high probability of the strokes sweeping aft on the aircraft. This is the result of the aircraft moving through the ionized lightning channel. Zone 1B is an initial attachment point with a high probability of flash hang-on, where Zone 2B is a sweep stroke zone with a high probability of flash hang-on (such as trailing edges). Similar model tests are utilized to determine the zones for various aircraft designs.

The airframe, electronic control, and avionic system encounter effects from both direct and indirect lightning strikes. Historically, aircraft designers and operators were mainly concerned with the direct strike, but with the advent of microelectronic digital control and avionic systems being incorporated in present and new generation aircraft, the indirect effects are of equal concern. Listed are the effects of both indirect and direct lightning strikes on an aircraft.

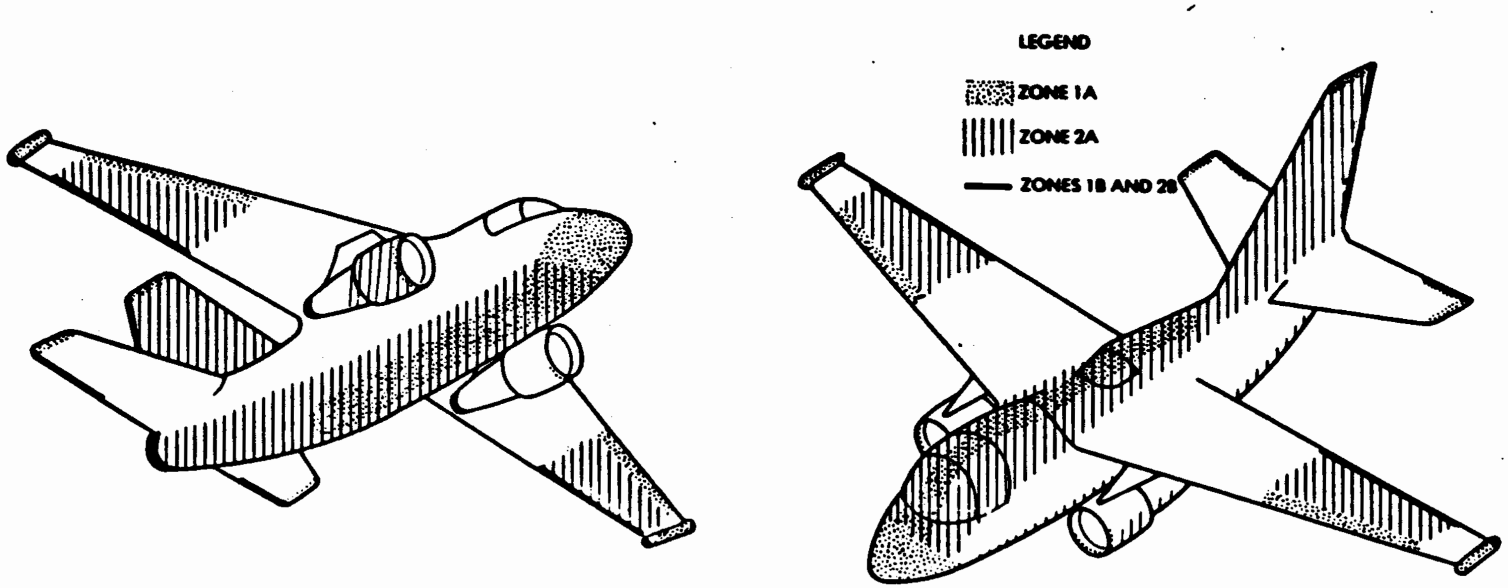


FIGURE 4. LIGHTNING — STRIKE ATTACHMENT ZONES (MODEL TESTS)

- Indirect
  - Failures (damage of electronic and electrical components)
  - Upset (unacceptable transient condition or condition wherein system no longer performs intended function until reset, etc.)
- Direct
  - Same as Indirect
  - Physical damage from blasting and heating

These conditions are compounded by the fact that airframe manufacturers are using composite material for strength and weight reduction. The use of composite material greatly reduces the faraday shielding effect presently provided with aluminum skin.

With all this in mind, the agency became alarmed as new generation aircraft were being developed with microelectronic digital control and avionic systems (which historically are more susceptible to upset or damage) being incorporated and reducing the electromagnetic protection by utilizing composite materials. This problem was also of prime concern with both the USAF and NASA.

An investigation of the situation revealed the following:

- Lightning channel not clearly defined:
  - No unified electromagnetic radiation model.
- Past activities concentrated on ground-based return stroke measurements:
  - Mostly structural damage testing.
  - Little concern for induced effects (analog electronics - not flight critical).
- 70-80 Percent of lightning occurrences are cloud flashes:
  - Return stroke characteristics vary with altitude.
- Induced effects testing rudimentary:
  - Cannot extrapolate measurements based on simulated tests (low-level return strokes).
  - SAE-AE-4L Committee now only addressing induced effects testing.

- Fundamental problem:

  - Inadequate information upon which to base lightning hazard program.

With this in mind, the FAA joined NASA in a research program to define the lightning channel and induced lightning effects. In 1977, the initial IA was written with NASA performing the research and the FAA providing partial funding of the program. The initial testing was accomplished using an instrumented Lear jet during the Thunderstorm Research International Program (TRIP) of 1976 and 1977.

This was an inflight survey of thunderstorm activity in support of Kennedy Space Center launches and correlations of airborne lightning data with ground-based data. The correlated data was then utilized to conduct simulated lightning ground tests. The Lear jet was not configured to directly penetrate the storm cells but only fly in areas adjacent to the storms. This program provided additional information into design requirements for sensors and recording equipment for future airborne lightning investigations.

The second program was the Rough Rider lightning experiment using an RF-4C type aircraft heavily instrumented for lightning research. The primary objective of this program was to obtain information for time-correlation of prestrike radiation with lightning attachment. The approach was to record selected spectral components of incident radiation and increases of onset currents.

This program was also designed to have the aircraft fly near a thunderstorm cell but not penetrate the storm. Although the aircraft was flown as scheduled, eight direct lightning strikes were reported. The data has not been released for review as of this date.

The NASA-Langley Research Center has instrumented and modified an F-106 type aircraft. This aircraft is scheduled to be flown into a thunderstorm cell and take a direct lightning strike. The special sensors were develohed during the Nuclear Electricity Hazards Protection Program and the recording instrumentation developed by the NASA-Langley Research Center. The NASA-Langley Research Center schedule for FY-80 is as follows:

- Host 1980 FAA/NASA/Florida Institute of Technology (FIT) Lightning Technology Symposium, April 22-24

- Direct Strike Data (Instrumented F-106 Aircraft)

  - NASA-Langley Research Center severe storm program flight at the National Severe Storm Laboratory (NSSL), May 1-30.

  - Severe storm program flight at NASA-Langley Research Center, June 1 to August 30

- Modeling

  - Continue analytical modeling at the Goddard Space Flight Center.

The SAE-AE-4L subcommittee has recommended the lightning model shown in Figure 5 be accepted. The model has generally been accepted, as much discussion has been encountered over the leading edge slope which is considered to be in error. The latest thinking is that the leading edge goes from zero to a maximum in approximately 200 nanaseconds. The data from the F-106 direct strike program should aid in identifying a lightning model.

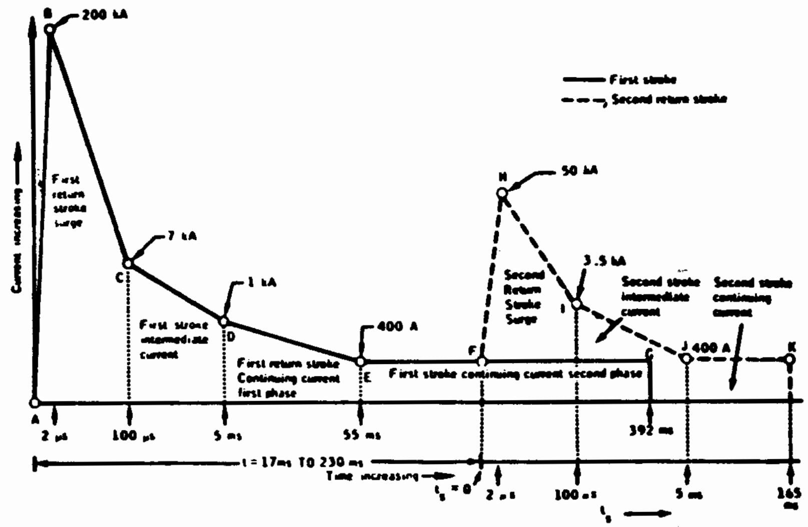


FIGURE 5. DIAGRAMMATIC REPRESENTATION OF LIGHTNING MODEL

The importance of this model cannot be overemphasized as it will represent the inputs for all simulation and model testing. At the present time, there are many ongoing projects concerning atmospheric hazards for the aircraft and avionic population. A few of the projects in which the agency is directly interested in are as shown:

USAF - AFFDL:	Lightning Hazard Definition (Lt. Baum)
	Lightning Simulation Testing (Dr. Corbin)
	Induced Effects Modeling (Dr. Corbin)
	Protection - Hardening (Major Corn)
USN - NAV - AIR:	Induced Effects Modeling (Drs. Berkin/Bechtold)
	Composite/Shielding Development
NASA:	Johnson Space Center - Rockwell - Shuttle Protection (Mr. Suiter)
	Goddard Space Flight Center - Lightning Modeling (Dr. LeVine)
	Kennedy Space Center - LDAR (Mr. Lennon)
NOAA:	Lightning Range (Dr. Taylor)
SAE-AE-4L:	Qualification Testing (Direct/Indirect Effects) (Messrs. Plumer and Robb)
	Induced Effects Test Procedures (Mr. Hess)
UNIVERSITIES:	Lightning Phenomenology (Dr. Uman, Dr. Krider, etc.)
BOEING:	Lightning Simulation Testing (Mr. Schneider)
	Induced Effects Modeling (Dr. Straw)
McDONNELL-DOUGLAS:	Lightning Analysis, Model and Simulation Testing (Mr. Clifford)

The USN (Dr. Berkin) has instrumented an F-18 which has been modified with additional composite material to aid in determining the hardening criteria necessary for composite structures. This program also will require the aircraft to be flown into a thunderstorm and experience direct lightining strikes.

The final part of this presentation will discuss the IA between the AFFDL and the FAA for AEHP of Advanced Technology Aircraft Program.

The USAF and FAA have mutual interests in the technology area of atmospheric electricity hazards related to systems and structures on current and new generation aircraft. The AFFDL has a long standing concern in this technology as exemplified by the efforts detailed in the USAF Technology Program Plan entitled, "Atmospheric Electricity Hazards Protection (AEHP) of Advanced Technology Aircraft." The AEHP advanced development technology program delineates its goals, methodology, and payoff as follows:

GOAL - Optimal protection criteria for electrical/electronic subsystems in advanced aircraft structures.

APPROACH - Two-phase contracted demonstration program joint effort with NASA, USN, USAF, FAA.

PAYOFF - Safe economical, designed-in protection assured by up-to-date design guides, military specifications (MILSPECS), certification tests.

To accomplish the program, the AFFDL personnel reviewed the area responsibilities and activities to define the optimum AEHP program. The responsibilities and activities are shown:

- Air Force Systems Center focal point laboratory for lightning/static electricity protection research since 1975.
- Directed to:
  - Develop overview and roadmap plan (1976)
  - Carry out programs to:
    - Define the lightning threat
    - Develop protection techniques
    - Demonstrate protection effectiveness
- Comprehensive AEHP Program:
  - Lightning characterization
  - Assessment methodology:
    - Simulation testing (high voltage generators, instrumentation, test techniques)
    - Analytic modeling (adapt nuclear electromagnetic pulses (NEMP) models)
  - Advanced development demonstration program (planned)

In the review, the systems susceptible to atmospheric electricity hazards were determined. Commercial aircraft experience the same susceptibility to atmospheric electricity hazards as military, with the exception of external stores. This is shown in Figure 6. A review of the lightning strike damage to USAF aircraft during a 10-year period from 1969 to 1979 is as shown:

- 773 documented USAF lightning strikes in 10-year period from 1969 to 1979.
- 7 confirmed (2 other likely) aircraft losses are lightning related.
- 150 serious mishaps due to lightning:
  - Pilot disorientation
  - Instrument failure (F-101, F-106)
  - Flight control failure (F-111F)
  - Fuel tank
  - Fuel tank explosion (C-130E)
  - Dual engine flameout (F-4)
  - Failure of unprotected, nonmetallic rotor blades (HH-43)

To reinforce the severity of the threat to USAF aircraft, Figure 7 shows graphically the probability of lightning strikes per flight hour from 1969 through 1976. The decline from 1974 through 1976 is a result of reduced flying in adverse thunderstorm conditions. The projection is that the curve will increase rapidly as the USAF goes to all-weather flight operations.

The increased threat to new generation aircraft from atmospheric electricity is shown in the following three items which affect both military and civil type aircraft:

- Advanced aircraft microelectronics are inherently more susceptible to lightning and static electricity effects.
- Advanced structures provide less electrical protection.
- Increasingly critical applications and all-weather requirements are planned.

It was also noticed that the present MILSPECS, standards, and guides were inadequate.

The AFFDL protection philosophy for the program is to deny high currents into the interior of the aircraft. To accomplish this, the following ground rules are being adhered to in order to maximize the scope of the program and minimize the expenditures:

- Trade structures, interface, and subsystem hardening for best systems level mix:
  - Selectively integrate lightning, EMI/EMC, NEMP, protection methods.

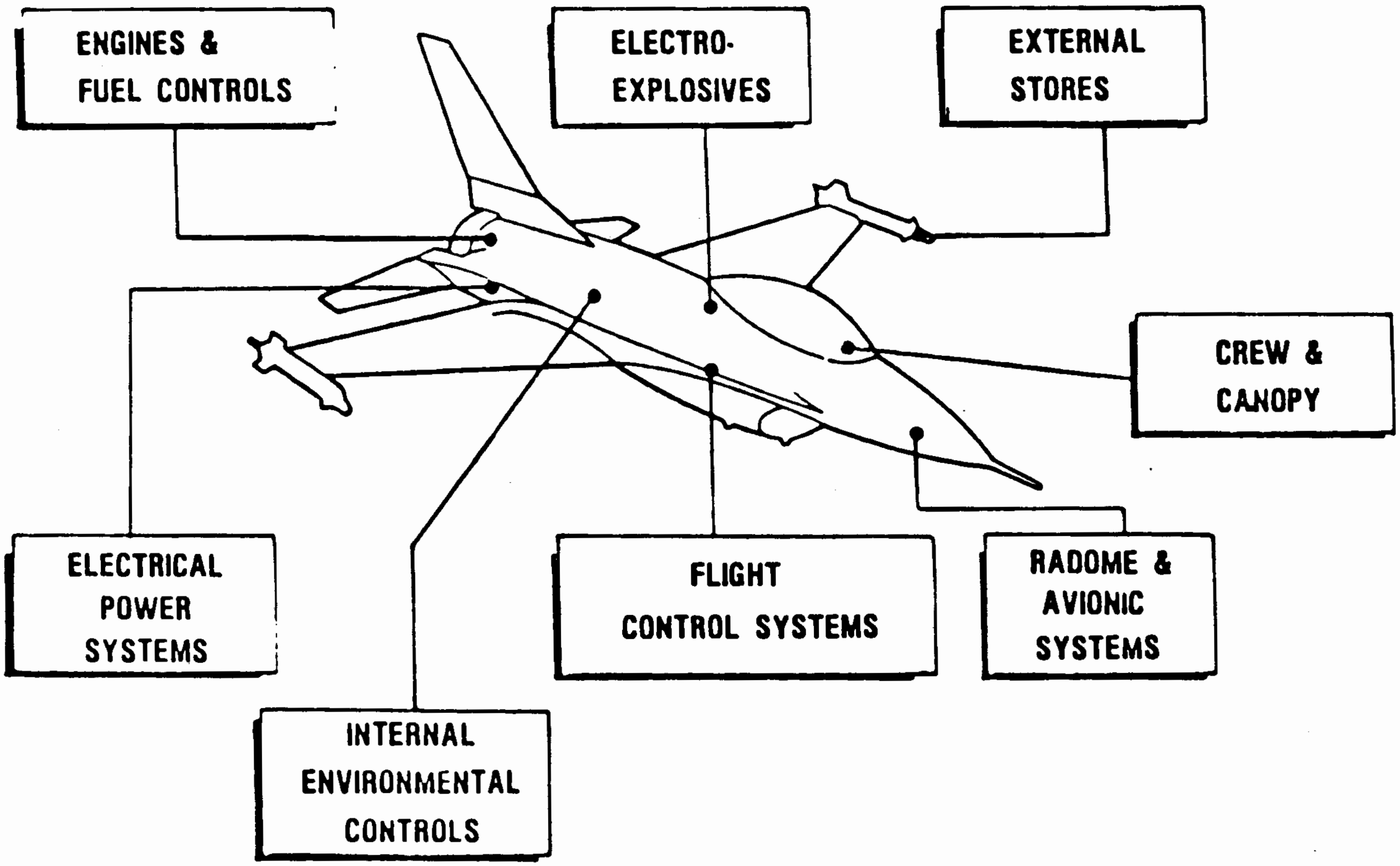
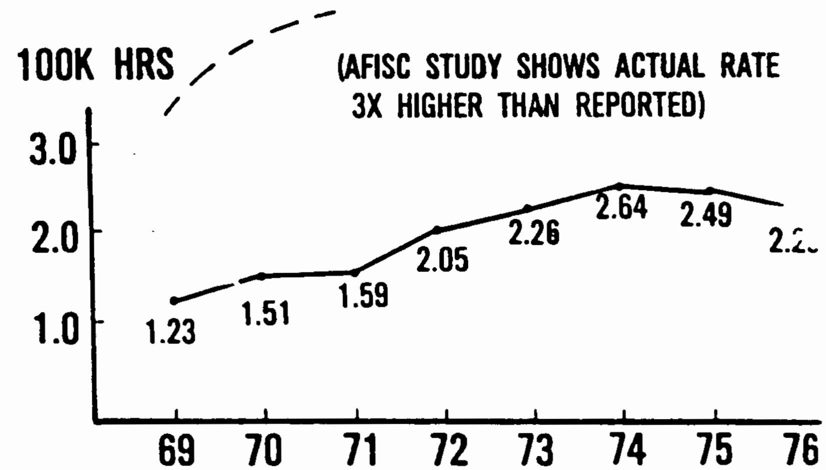


FIGURE 6. SYSTEMS SUSCEPTIBLE TO ATMOSPHERIC ELECTRICITY HAZARDS



- STRIKE RATE REPORTED
  (3 YR SMOOTHED AVG)

- TEN YEAR HISTORY OF INCIDENTS:
  CATASTROPHIC -9, MAJOR -7, MINOR -153

- COST OVER LAST FIVE YEARS EXCEEDS $21,000,000

- 1978: F-111F LOST 29 MAR 78, LAKENHEATH, UK; 2 FATALITIES
  C-130E LOST 30 NOV 78, CHARLESTON, SC; 6 FATALITIES

FIGURE 7. USAF LIGHTNING STRIKE EXPERIENCE

- Concentrate on critical electrical and microelectronic control systems affecting safety and mission:

  - Flight control

  - Engine control

  - Stores management

  - Electrical power systems

  Use ground simulation tests and analytic tools for hardness evaluation:

  - Employ best existing lightning characterization

  - Bound key parameters to define safety margins

  Produce practical protection guidelines and specifications for generic aircraft employing microelectronic subsystems and advanced composite structures.

The schedule for the program is shown in Figure 8.

Mr. Hugh Waterman asked about the general aviation dual engine flameout problem encountered with the shock wave from lightning strikes, as it was noted that the AFFDL program did not address this problem. This problem will be investigated and incorporated into the program, if possible; if it is not feasible to incorporate the investigation into this project, then NAFEC will determine what alternatives are available to ensure the problem is satisfactorily resolved.

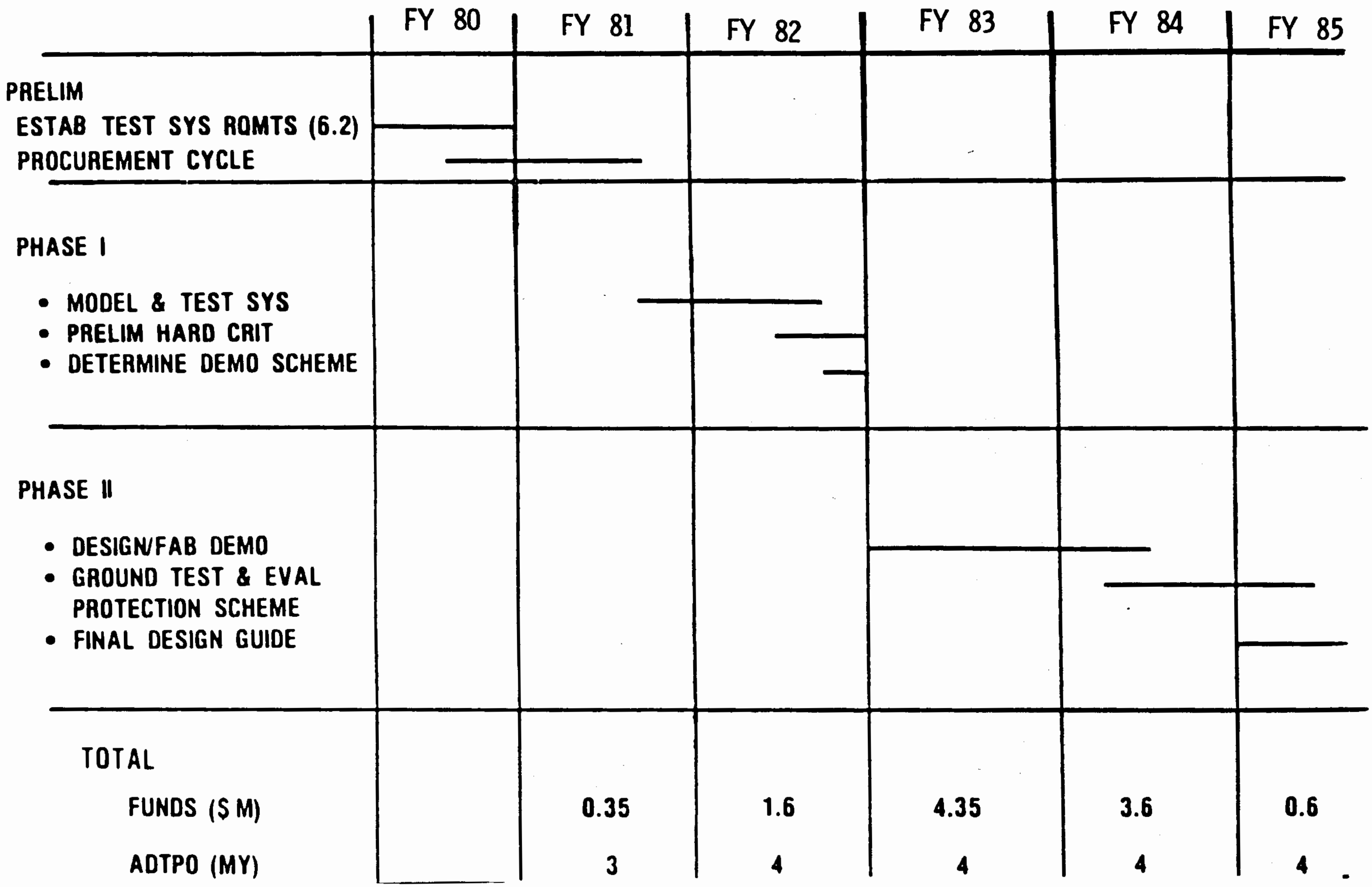


FIGURE 8. ADTP WORK SCHEDULE

William A. Larsen
Flight Simulation Branch, AEM-4
FAA-Ames Research Center

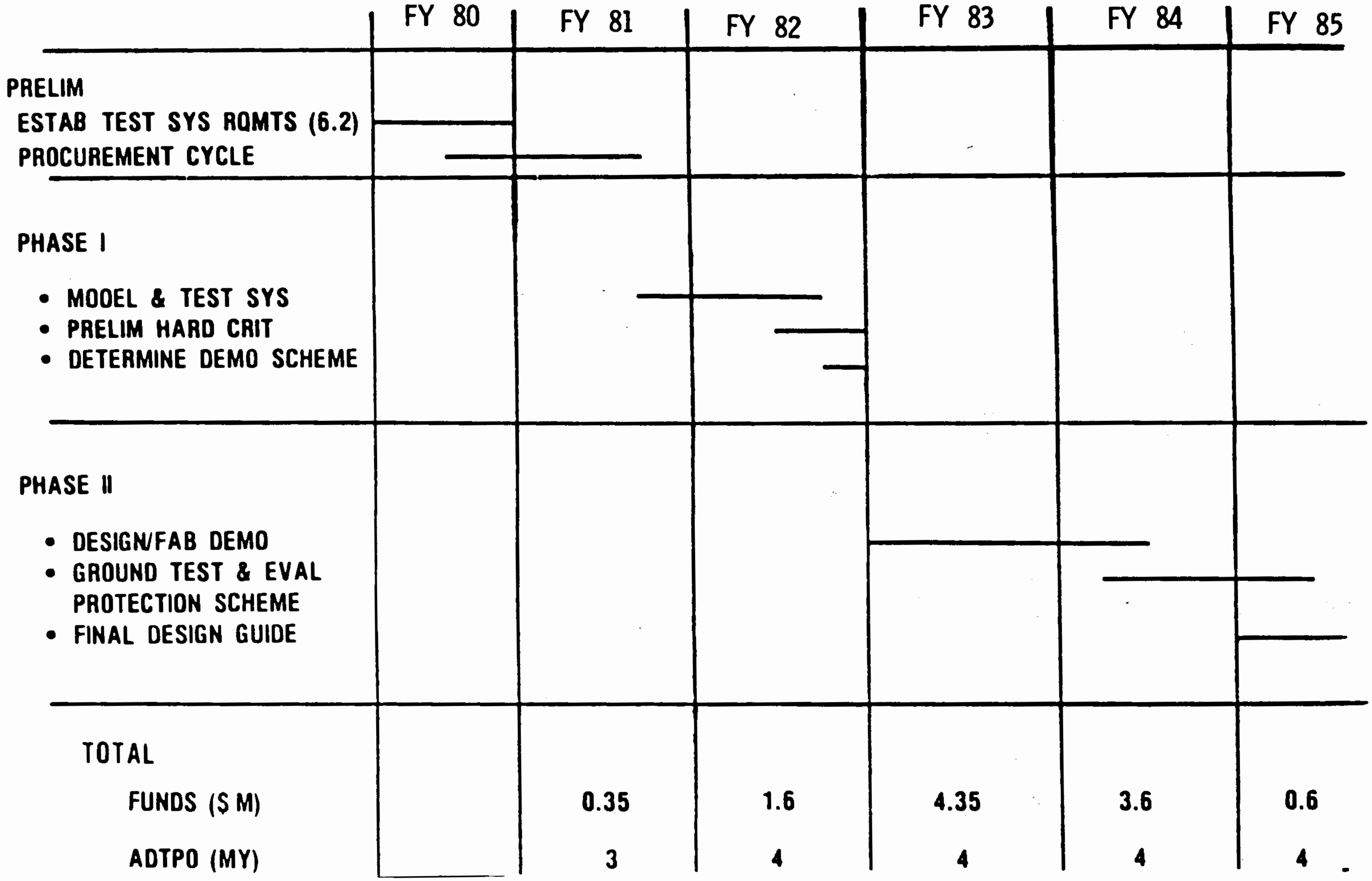
I would like to acquaint you with what we are doing and equipment available at the NASA-Ames Research Center. We now have a digital flight control system fabricated by Collins, Incorporated, which will be operational by September 30, 1980. This system has a mode to determine the reliability and failure mode of the various flight systems. The hardware/software will be supported by Collins, Incorporated; Lockheed Corporation; and other systems and software companies.

I want to discuss the use of the equipment as a test bed for our programs. The initial program has been configured as an L-1011-500 flight system. This test bed is constructed so that the central processing unit (CPU) can be monitored during the program to determine millisecond by millisecond what is happening to the control system. This system can be used as a tool to determine what effects lightning has on the aircraft itself. The lightning and internal EMI effects of the test aircraft can then be induced into this digital flight control system and the faults monitored in the CPU. This system will be available for use during the latter part of this year, and you are encouraged to use it for your programs.

The system incorporates the ability to analyze a control system processor with a failure at the chip level (designed by the Massachusetts Institute of Technology (MIT)).

We have a monitoring device to record the power system of an aircraft. This is very important as a typical sampling showed that, during one flight, electromagnetic pulses of 424 volts were observed; complete power dropouts were observed for microseconds. These anomalies were recorded 37 times during one single flight.

This test equipment can be flown on most aircraft to determine the electrical signature for use in the laboratory on the digital flight control system. The equipment is available for utilization by the FAA, and can be scheduled by a telephone call with formal paperwork follow-up. Presently, the program has sufficient funding; therefore, the FAA can run programs with full support at very little cost.



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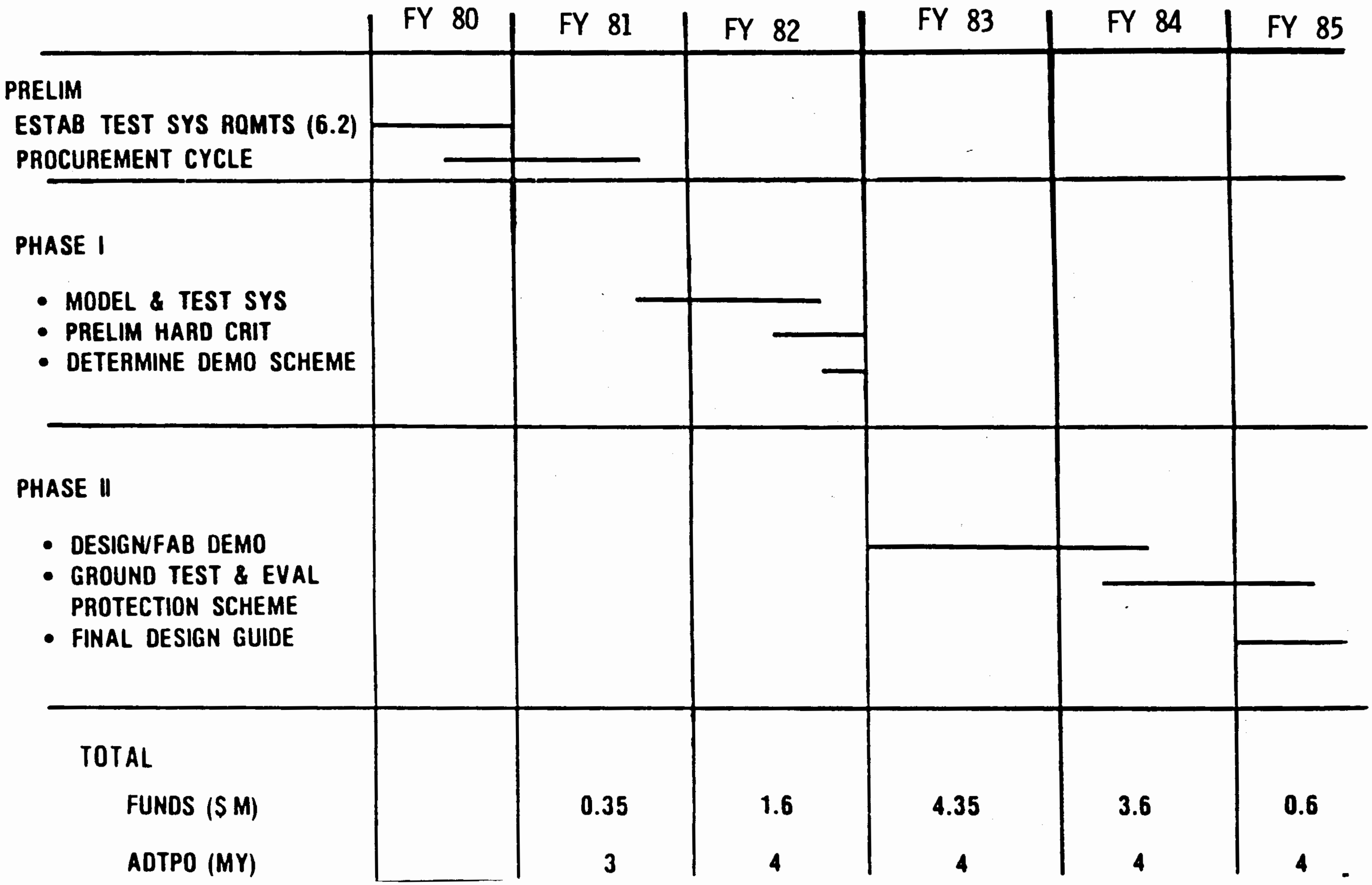

FIGURE 8. ADTP WORK SCHEDULE

18

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Tom Horeff
Chief, Propulsion Branch, AWS-140

Interest started with the Boeing 707 Elkton, Maryland, accident in 1963. The National Transportation Safety Board (NTSB) found the probable cause was lightning induced ignition in the fuel vent efflux. Following that accident, a very large lightning research and development (R&D) program was initiated which resulted in the publication of 12 reports which are shown in Appendix C.

An advisory Circular (AC) was published (AC 20-53) which we thought was the answer for fuel system resistance to lightning, but in 1976, an Iran Air Force Boeing 747 was struck with lightning near Madrid, Spain, with a fuel tank explosion. This indicated that the criteria we had in AC 20-53 had some serious gaps. Those gaps are what I would like to cover today. Our Branch is in the process of revising AC 20-53, utilizing the new SAE-AE-4L lightning model, and redefining the skin thickness for various strike zones.

Listed are fuel tank incidents and accidents from 1976 to 1979:

FUEL TANK EXPLOSION INCIDENTS AND ACCIDENTS
CIVIL AND MILITARY TRANSPORT TYPE AIRCRAFT
1976 - 1979

DATE	AIRPLANE MODEL	LOCATION	OPERATIONAL MODE	PROBABLE CAUSE	FUEL
5/9/76	*B-747-131	Huete, Spain	Inflight	Lightning Strike - Fuel Transfer Valve	JP-4/Jet A
5/24/77	L-382B	Oakland, CA	Maint.	Internal Overtemp - Pump/Fill Valve	JP-4
12/11/77	DC-8-33	Lake City, FL	Maint.	Arcing-Boost Pump Connector	Jet A
9/22/78	P-3B	Brunswick, ME	Inflight	Short Circuit - Fuel Probe	JP-5/JP-4
11/29/78	C-130E	Cottageville, SC	Inflight	Lightning Strike	JP-4
4/6/79	KC-135Q	Sacramento, CA	Inflight	Lightning Strike	JP-4

*NOTE: A lightning strike on 3/22/78 to a B-747 using Jet A affected fuel transfer valve without causing an explosion.

The fuel in all of the accidents was either straight JP-4 or a mixture of JP-4 and JP-5. I cited the Boeing 747 was using a mixture of JP-4 and Jet A.

I would like to show a couple of films made by the Naval Air Systems Command in Washington, D. C. The first film talks about protecting fuel tanks against lightning while the second film shows lightning protection and research programs.

Mr. Charles Foster, Associate Administrator for Aviation Standards, feels this area of atmospheric hazards is of such importance that he is creating a position for a Research Specialist in icing/lightning. He expects to fill the position within the next year.

The one point of interest which has been reserved for this time is the subject of inflight flameouts related to lightning strikes. One operator utilizing Lear Falcon 5 aircraft has 29,000 flight hours and experienced 65 incidents causing inflight flameouts. Five of these flameouts have been associated to direct lightning strikes.

We are in the process of writing a new AC dealing with electrical components installed in the fuel tanks.

SUMMARY REPORT

Throughout the course of the workshop and especially during the closing session, the attendees engaged in extensive discussions on the general problem areas encountered in both the Regions and headquarters. The results of these discussions reflect current interest of the agency in the forthcoming NAEHP Program meeting scheduled for May 28-29, 1980. The regional personnel agreed that an investigation should be conducted to ensure that duplicate programs are not being funded by the agency. A concern was shown that the programs the agency is presently funding are long-term, and the regional offices are in need of guidance material which can be developed on a shorter-term basis.

The items that were adjudged as being of prime interest are as listed below:

I. INFORMATION REPORTING AND DISSEMINATION

A. Need an agency clearing-house to:

1. Establish international coordination (promote information exchange to stay abreast of the NATO Air Electrical Working Panel activities).

2. Condense information and data for use in Regions and headquarters.

3. Tailor and adapt information for use in the field.

4. Publish a newsletter of pertinent information and lightning research activities:

    a. Presented in condensed useful language.

    b. That facilitates information exchange throughout the agency.

    c. That provides a bibliography/abstract of work in progress and completed.

    d. That identifies responsible technical representatives.

B. Have an FAA representative actively involved on the SAE-AE-4L Committee and the NAEHP Committee.

C. Lightning strike reports:

1. Need an improved or totally new system.

2. Data statistics on reported lightning strikes are suspect.

II. NEEDS AND/OR IDENTIFIED PROBLEM AREAS

A. Problem definition:

1. What happens when a direct strike occurs?

2. Cockpit procedures after partial failure of flight controls and avionics systems.

B. System lightning test:

1. Can system be bench tested?
2. Can model-scale testing be correlated for full-scale aircraft and systems tests?

C. Protection/Hardening:

1. Is redundancy a hardening technique?
2. How much redundancy is required?
3. FAA use of techniques determined from RTCA and/or SAE?
4. What guidance can we provide now?

D. Composite material:

1. Lear Avia "all" composite material aircraft structure.
2. Engine nacelles and other primary structures.
3. Fuel system protection.
4. Passenger/crew protection for "all" composite fuselage.
5. Direct strike and "swept-stroke" damage information.
6. Testing of composite material:
   a. Determine if full vehicle, component, subcomponent, or only sample is required.

E. Engine flameouts:

1. Has any research been conducted to reduce the impact of lightning induced engine flameouts?
2. Apparently, both single and dual engine flameouts have been associated with lightning strikes; what, if anything, can be accomplished now to eliminate or mitigate this problem?

F. Need aircraft electrical power system signatures of existing and future aircraft:

1. What information is required for testing for electrical system induced effects on digital systems?
2. Can existing hardware/software simulation systems be utilized to enhance atmospheric hazards protection?

G. Aircraft manufacturing:

1. Need for management recognition of lightning protection requirements in the design process.

2. Need for EMC engineer to work with designers from initiation to completion of aircraft design.

3. Priority of lightning hazards and EMI/EMC considerations in aircraft design.

III. REGULATIONS AND STANDARDS

A. Standardization:

1. Lack of standardization in this technology.

2. Improved agreement/cooperation among Regions and headquarters.

3. Need lightning criteria.

4. Need acceptable lightning model.

5. Is B-727 direct strike test data applicable to DC-9 and other aircraft, etc.?

6. What is realistic criteria for sweep-stroke zones?

B. Regulations:

1. Are additional airworthiness standards and compliance procedures needed in order to provide guidance material to Regions and industry for lightning protection for aircraft and systems?

2. Do Federal Aviation Regulations (FAR) 23, 24, 25, 27, and 29 properly address lightning test procedures and criteria?

   a. Test at component level.

   b. Test at subsystem level.

   c. Test at system level.

   d. Test at aircraft level.

3. Does the FAR properly cover digital systems in the environment to which they are subject and in which they will be operated?

4. What information in support of guidance material can/should NAFEC provide at this time?

5. Is the RTCA DO-160 adequate (should it address the lightning environment)?

6. Do FARs 27 and 29 adequately cover lightning protection for helicopters?

7. Military has draft MILSPECS; will these be imposed on industry?

Two important questions which were posed and remained unanswered were:

1. Is there a lead Region for EMI/EMC in the FAA, and what advantages would this provide?

2. Is the agency presently providing sufficient funding on research in this technology area?

Additional questions which were not fully addressed at the meeting because of time considerations are as follows:

1. Can the application of airborne technology be enhanced by ground-based protection experience?

2. Solar flares/cosmic radiation, etc. - Do the associated magnetic fields or effects impact on airborne/ground systems?

3. Microwave radiation, etc., versus absorption of moisture on composite components.

4. Dissipation of P-static, corona, etc.

APPENDIX A

LIST OF ATTENDEES

Bob Stephens, Chief, ACE-210 Engineering and Manufacturing Branch	FTS 758-3446
Bradford Chin, AEA-213 Engineering and Manufacturing Branch	FTS 665-3372
Bill White, AEA-213 Engineering and Manufacturing Branch	FTS 665-3372
Bill Larsen, AEM-4 Flight Simulation Branch FAA-Ames Research Center	FTS 448-5049
Nelson Miller, ANA-4B Engineering Management Staff	FTS 346-2020
"JB" McCollough, Chief, ANA-340 Operations Branch	FTS 346-3313
Nick O. Rasch, ANA-340 Operations Branch	FTS 346-3740
Joe Traybar, ANA-340 Operations Branch	FTS 346-3064
Ron Vavruska, ANE-210 Engineering and Manufacturing Branch	FTS 836-1332
Kit Kaiser, ASO-210 Engineering and Manufacturing Branch	FTS 246-7428
Hugh Waterman, Chief, AWE-130 Systems and Equipment Branch	FTS 966-6393
Joe Sonderquist, AWS-120 Airframe Branch	FTS 426-8383
John Reed, AWS-130 Systems Branch	FTS 426-8395
Tom Horeff, Chief, AWS-140 Propulsion Branch	FTS 426-8200

APPENDIX B

LIST OF FAA REPORTS OF LIGHTNING STRIKES TO AIRCRAFT

1. "Report of Conference on Fire Safety Measures for Aircraft Fuel Systems," (AD 672036)

2. "Report of Second Conference on Fuel System Fire Safety," (AD 711059)

3. "Lightning Protection Measures for Aircraft Fuel Systems - Phase 1," ADS-17 (AD 603222)

4. "Lightning Protection Measures for Aircraft Fuel Systems - Phase II," ADS-18 (AD 603233)

5. "Electrical Behavior of an Airplane in a Thunderstorm," ADS-36 (AD 614914)

6. "Experimental Study of Triggered Natural Lightning Discharges," DS-67-3 (AD 661827)

7. "Investigation of Turbine Fuel Flammability within Aircraft Fuel Tanks," DS-67-7 (AD 669001)

8. "Airflow Velocity Effects on Lightning Ignition of Aircraft Fuel Vent Efflux," DS-67-9 (AD 660206)

9. "Measurements of Lightning Strikes to Aircraft," DS-68-1 (AD 669124)

10. "A Comparison of Natural Lightning and the Long Laboratory Spark with Application to Lightning Testing," DS-69-16 (AD 712308)

11. "Guidelines for Lightning Protection of General Aviation Aircraft," FAA-RD-73-98 (AD 778555)

12. "Lightning Effects on General Aviation Aircraft," FAA-RD-73-99 (AD 778852)

These reports are available from:

National Technical Information Service
5285 Port Royal Road
Springfield, Virginia 22151