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ACTIVATION OF THE NAVY'S INDIRECT EFFECTS LIGHTNING SIMULATION LABORATORY

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ABSTRACT

The Naval Air Test Center is currently the Navy's lead laboratory for electromagnetic effects testing. As part of this charter, it has been performing lightning effects testing on Navy aircraft in support of specification compliance since 1973. This paper presents an overview of lightning test and evaluation efforts at the Naval Air Test Center, both past and present, as well as its plans for the future. The array of simulation capabilities presently operational are described, and a high-level look is given to the test methodology now being used.

The principal discussion of this paper centers on the results from the recent air-launched ordnance test and the testing of the Navy's A-6E all-weather attack aircraft. Particular attention is paid to the Naval Air Test Center's test approach, including details about coaxial return construction, aircraft preparation, and the test waveforms and data acquisition systems that were used.

1. INTRODUCTION

Electromagnetic effects testing for the Navy is the responsibility of the Naval Air Test Center's Electromagnetic Systems Department. The Navy's lightning simulation facility operated from 1973 through early 1986. In 1986, the old simulation equipment was dismantled due to equipment degradation and the concerns of the Occupational Safety and Health Administration about the insulation oil contained in the storage capacitors.

Almost immediately, the Naval Air Test Center began acquiring equipment to assume its role in the testing of naval aircraft. Studies were then conducted to evaluate the Navy's needs and to determine the equipment necessary to perform the testing required for qualifying Navy aircraft to operate in the lightning environment. It was determined that the primary thrust should initially be concentrated on full-scale testing for the indirect effects of lightning on aircraft and systems.

Equipment presently on hand at the Naval Air Test Center is described in table I. The Naval Air Test Center's in-house expertise provides the ability to construct simulators as required for testing in any of the disciplines.

SYSTEM	TYPE	OUTPUT	STATUS
LIGHTNING			
NAILS	SEVERE THREAT	UP TO 200 kA	DEPLOYED
NAPLES	PORTABLE MODERATE THREAT	UP TO 100 kA	DEPLOYED
LOW-LEVEL			
LLCW	LIGHTNING	UP TO 20 A, 10 kHz-10 MHz	UNDER DEVELOPMENT
DIRECT-DRIVE			
LIGHTNING	CIRCUIT/CABLE DIRECT-INJECT	MIL-STD-461 UP TO 50 A @ 100 kW	INITIAL PLANNING

Table 1. Major Lightning Simulators

2. TEST METHODOLOGY

The primary goals of electromagnetic transients testing at the Naval Air Test Center are to determine specification compliance and to quantify system survivability/vulnerability. Our mission is to provide cost-effective and timely test and evaluation services.

The Naval Air Test Center has developed a standardized, modular approach for all plans, procedures, and reports. Any of these can be modified to accommodate a user's requirement.

As shown in table 1, the Naval Air Test Center has the simulators required for producing the waveforms for full-scale aircraft testing. Aircraft can be qualified either by full-threat testing or testing at a lower level. In addition, the Naval Air Test Center can extrapolate cable responses and perform current injection direct-drive testing at the threat level to determine the survivability/vulnerability of aircraft. Through cable injection, the aircraft can be tested to a moderate level without subjecting it to the unnecessary stresses of repeated injection of high currents into the airframe. This alternative provides the user with a non-destructive way to test to levels that are not obtainable or that are sometimes recommended for full-scale aircraft due to the unique construction of the airframe.

3. TEST WAVEFORMS AND SIMULATION

The Naval Air Test Center performs testing tailored to military standards and contractual requirements. Early on in the procurement cycle, the test waveforms are decided and agreed to by both the aircraft manufacturer and the Navy. The Navy can produce either the high threat severe waveform or waveforms of lower energy content to acquire large amounts of data without applying undo stresses to an operational aircraft.

During our recent testing on an air-launched torpedo and the composite-wing A-6E aircraft, a damped sinewave was used that met the amplitude and rate-of-rise requirements. Figures 1 and 2 identify the typical waveform injected into these test objects. The simulator used for testing (photo 1 and figure 3) is a modular generator with gas-operated switches. The simulator is portable, and each of its three stages can be operated separately or stacked for various loads and current requirements. Each stage can contain up to four parallel capacitors. Because each three-stage module is insulated with gas, the simulator has a low-inductance construction. The simulator can be triggered either electrically or by dumping the pressure on the first spark gap to cascade the Marx stack.

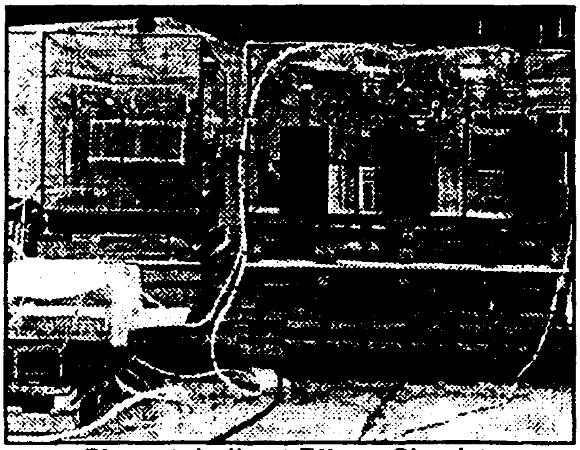

Photo 1. Indirect Effects Simulator

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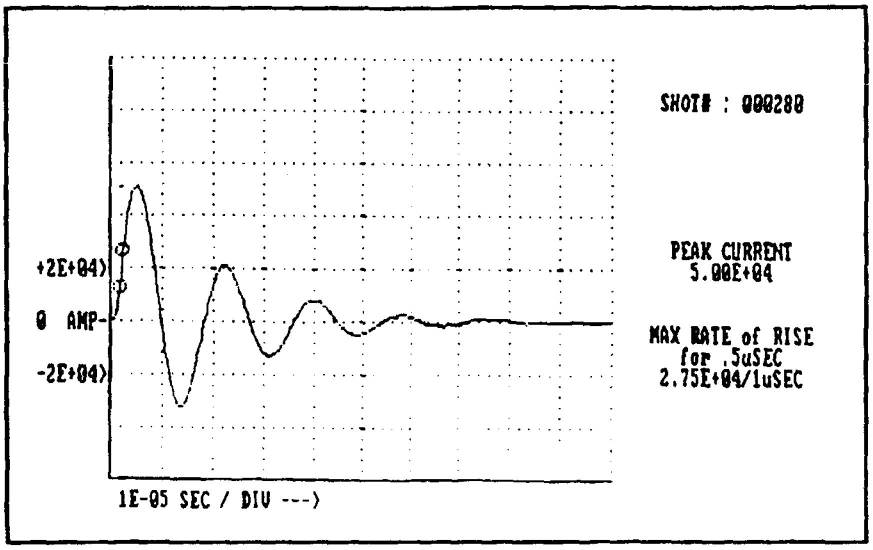

Figure 1. Input Waveform

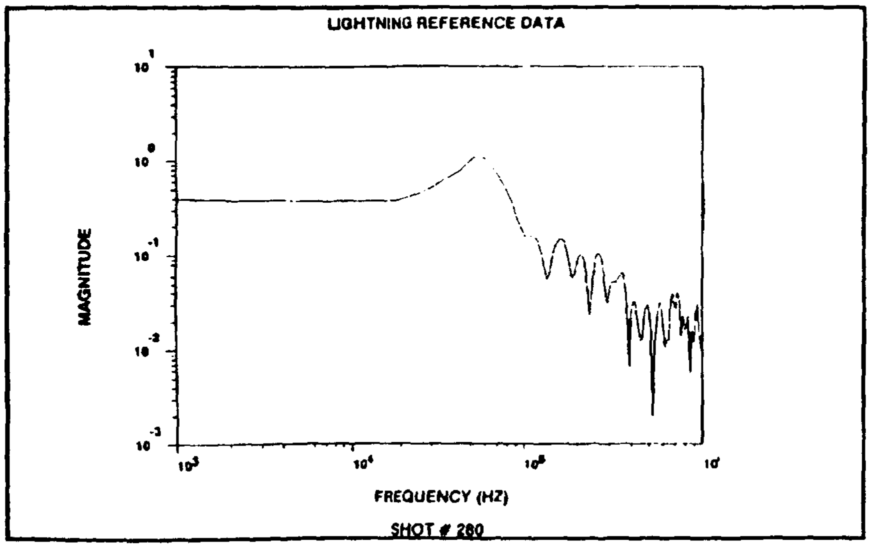

Figure 2. Frequency Spectrum of Input Waveform

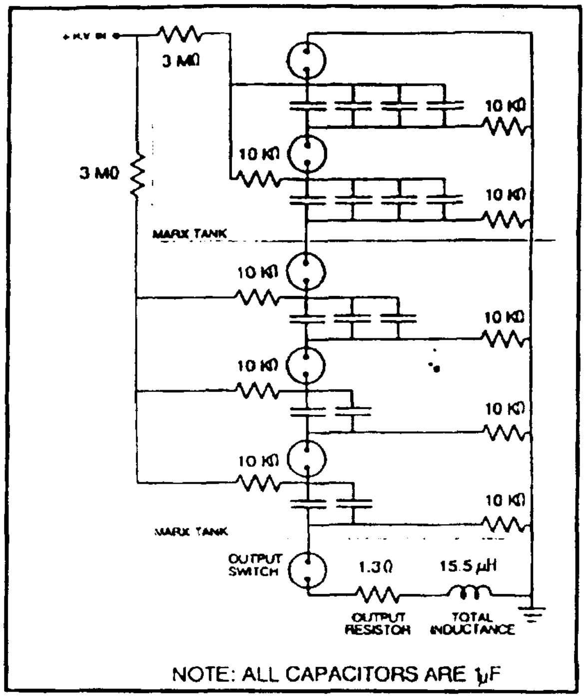

Figure 3. Indirect Effects Simulator

To gain a high level of confidence in the aircraft and systems during the composite-wing A-6E test, the Naval Air Test Center employed its Current Injection Direct-Drive System (figure 4) to increase the amplitudes at the cable level and performed this test with systems operating.

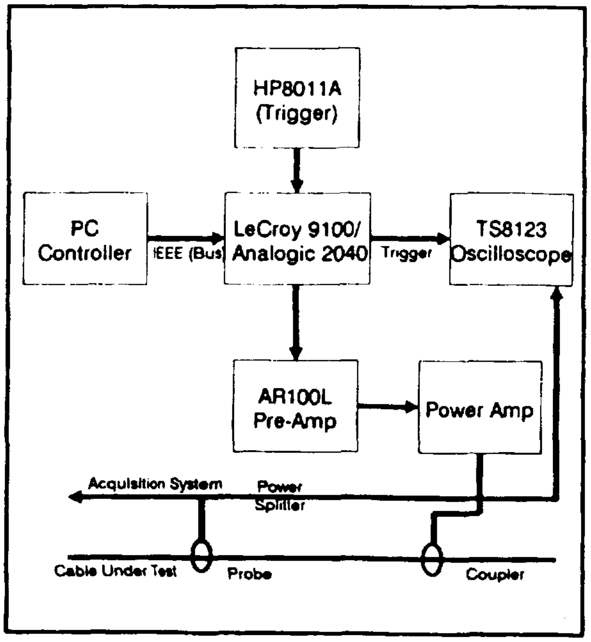

Figure 4. Current Injection Direct-Drive System

4. DATA ACQUISITION SYSTEM

The portable data acquisition system (PDAS) is the primary system for lightning and direct-drive testing.

The data acquisition concept permits high-volume data throughout and immediate processing. All data are automatically maintained in a database. Data gathered from the simulators during testing are downloaded to a central laboratory (see figure 5).

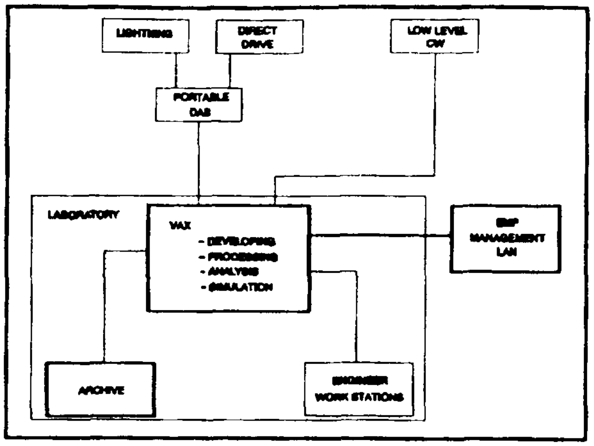

Figure 5. The Instrumentation Suite

There, all data are maintained in a database and ultimately combined with other electromagnetic transient data for the user. Also avaiable are data presentation capabilities, such as histograms, bar charts, and comparison tables. These data are provided daily in hard copy form, along with other logs and records, as part of the final report. When testing is completed, the users can be provided with the data on a database and with most of the software necessary to continue offsite analysis. Most aspects of data acquisition are standardized and segmented. All data acquisition plans, procedures, and reports are predefined and structured to allow the user to outline and adequately scope his test. This system furnishes the user with high flexibility in cost-effective, efficient test environment.

The PDAS was used during recent testing, which is discussed in this paper. Figure 6 offers a brief block diagram overviewing the PDAS. In addition, sample outputs are shown in figures 7 and 8. Data from this test were acquired on test points from EG&G 91550-2 or Prodyn I-125-2C probes. Surface current measurements were made using MGL-5 probes.

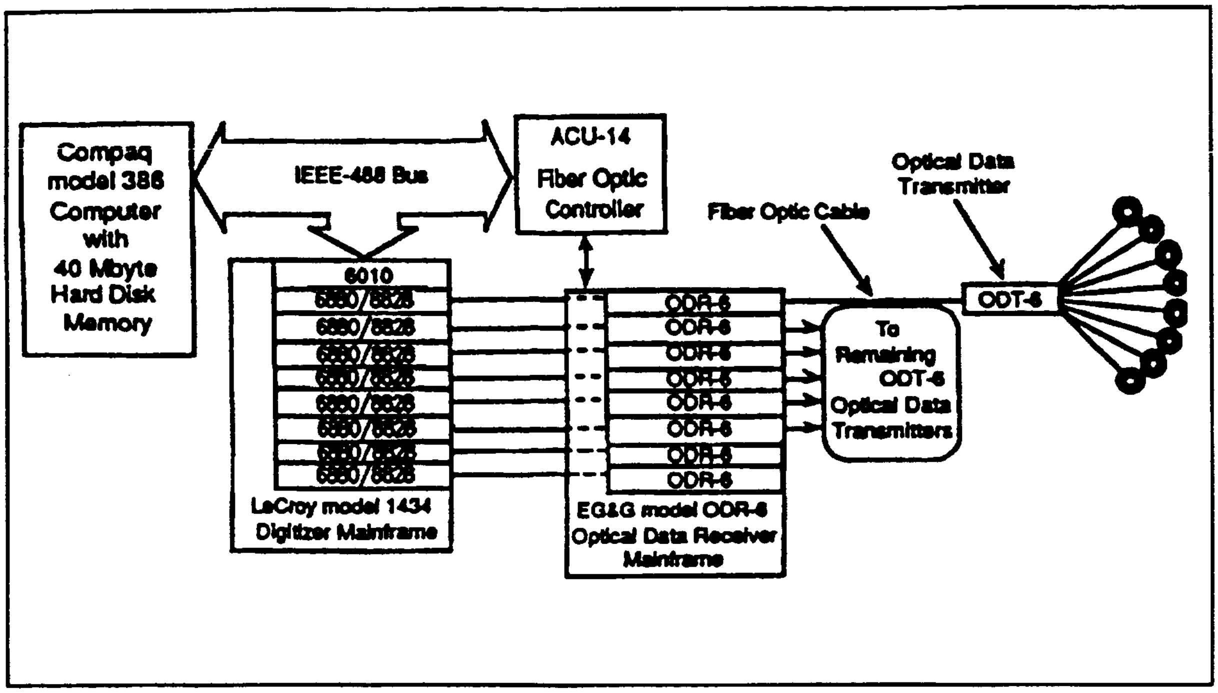

Figure 6. The Portable Data Acquisition System

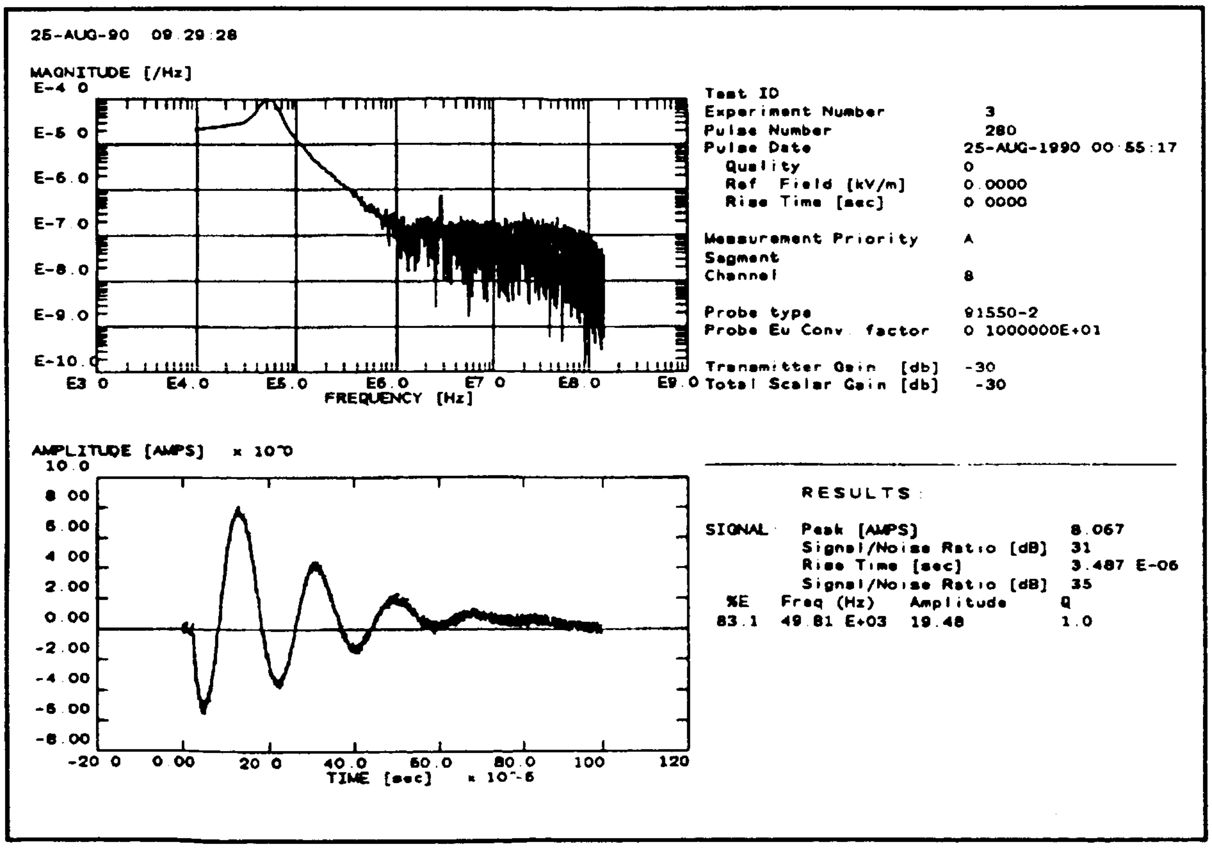

Figure 7. Sample Data Output

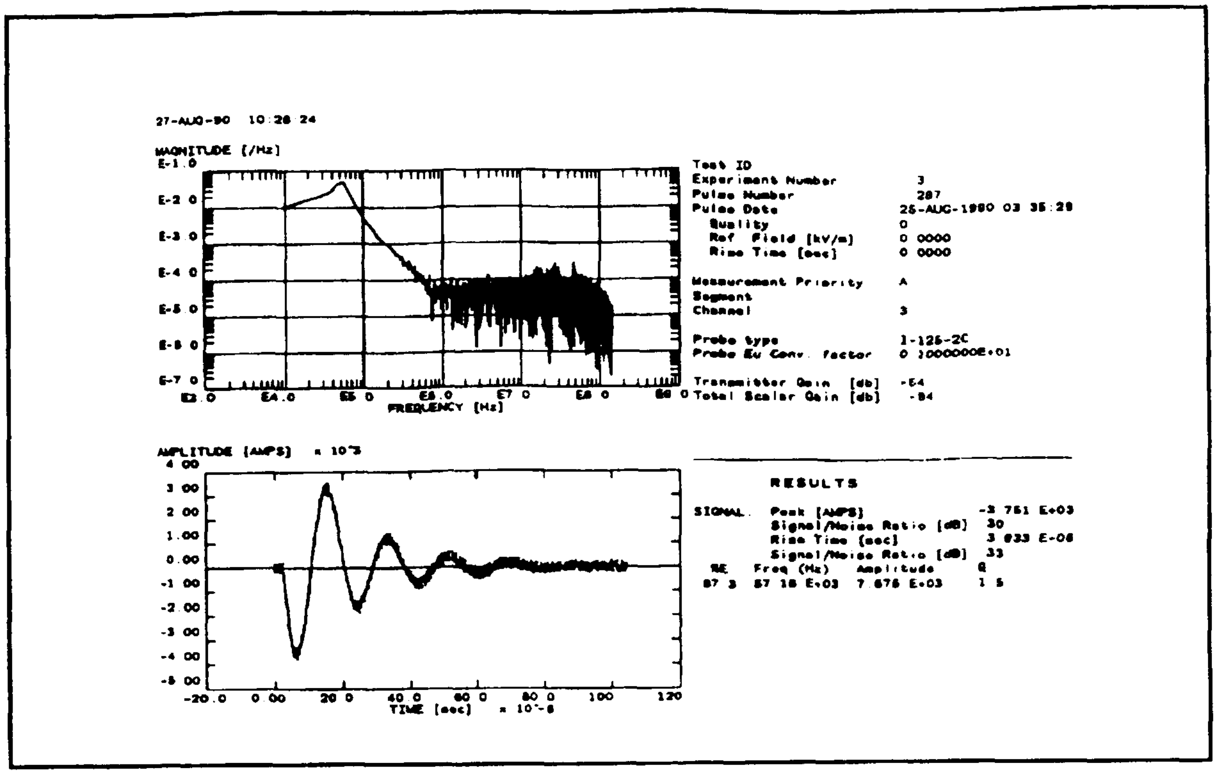

Figure 8. Sample Report

5. PREPARATION OF TEST FIXTURE

For the composite-wing A-6E test in summer of 1990, the aircraft was positioned within a coaxial return test fixture (figure 9). The aircraft was first hoisted onto isolation pads (photo 2). The second step of preparing the aircraft for test was to build a mechanically strong wooden frame around the aircraft to provide support and an adjustable coaxial return grid (see photo 3). The coaxial return consisted of 12 copper tubes, each one-quarter inch in diameter. Copper tubes were run both parallel and perpendicular to the aircraft. Tubing was soldered together, creating a 1-meter-square grid. Nylon ropes were used to control the 1-meter spacing from the aircraft skin. Use of the 1-meter grid and 1-meter spacing from the skin permitted easy access to equipment bays for changing instrumentation during the test. The calculated impedance of this 1-meter spacing ranged from 41.6 to 65.8 ohms. During testing of one configuration, the spacing from the aircraft skin was decreased to one-half meter, for an impedance range of 24.3 to 41.6 ohms.

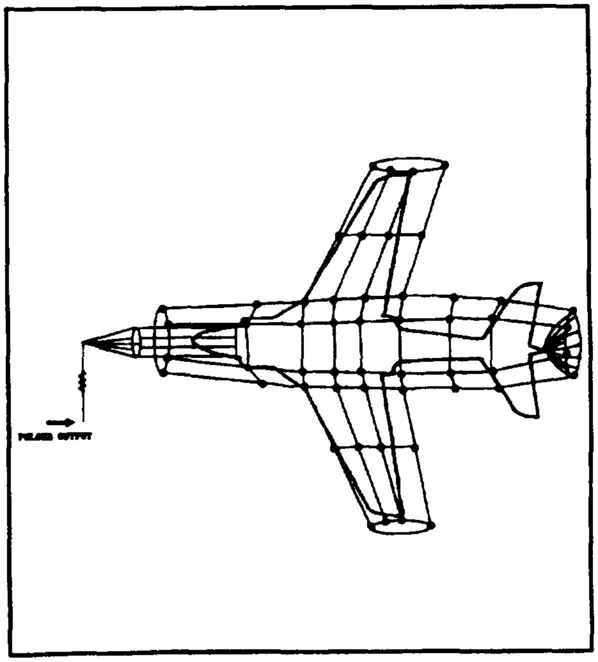

Figure 9. Coaxial Return Test Fixture

The construction of coaxial returns varies, depending on the size and shape of the test object. For smaller test objects, such as air-launched ordnance or missiles, styrofoam spacers are used to support the wire grid in place of wooden framework.

Constructing the coaxial return as a solid grid greatly facilitated changing from one test configuration to another, e.g., changing from nose-to-tail to wing-to-wing configuration. Very little test time was lost when relocating the simulator to vary the entry and exit points for injected current.

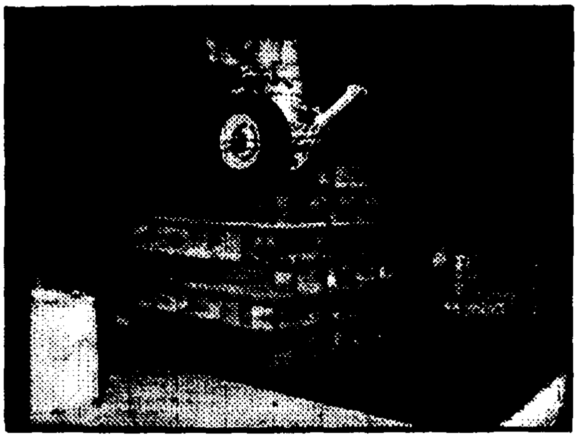

Photo 2. Isolation Pads

6. AIR-LAUNCHED ORDNANCE TEST

The Naval Air Test Center supported the Naval Surface Warfare Center in fall of 1989 by performing lightning and ESD tests on an air-launched torpedo. The test required 25 kV ESD, 300 kV ESD, and up to 50 KA injected current. ESD was injected in various test points. Lightning was injected into the major current paths that would exist if the torpedo or its host aircraft were hit by lightning. Due to the nature of the test object, there were no current probes mounted into the torpedo. After each amplitude, a functional checkout was performed to determine failures.

In response to numerous safety concerns, the test torpedo was mounted on a moveable stand, and the coaxial return was built around and supported by the test object itself. To remove the test object from the test area, as in cases of emergency, it would have been necessary only to release two bolts and tow the test object to a safe area.

This experience thoroughly exercised the Naval Air Test Center's procedures for conducting a potentially hazardous test, while causing little impact on other electromagnetic testing being performed within the shielded hangar.

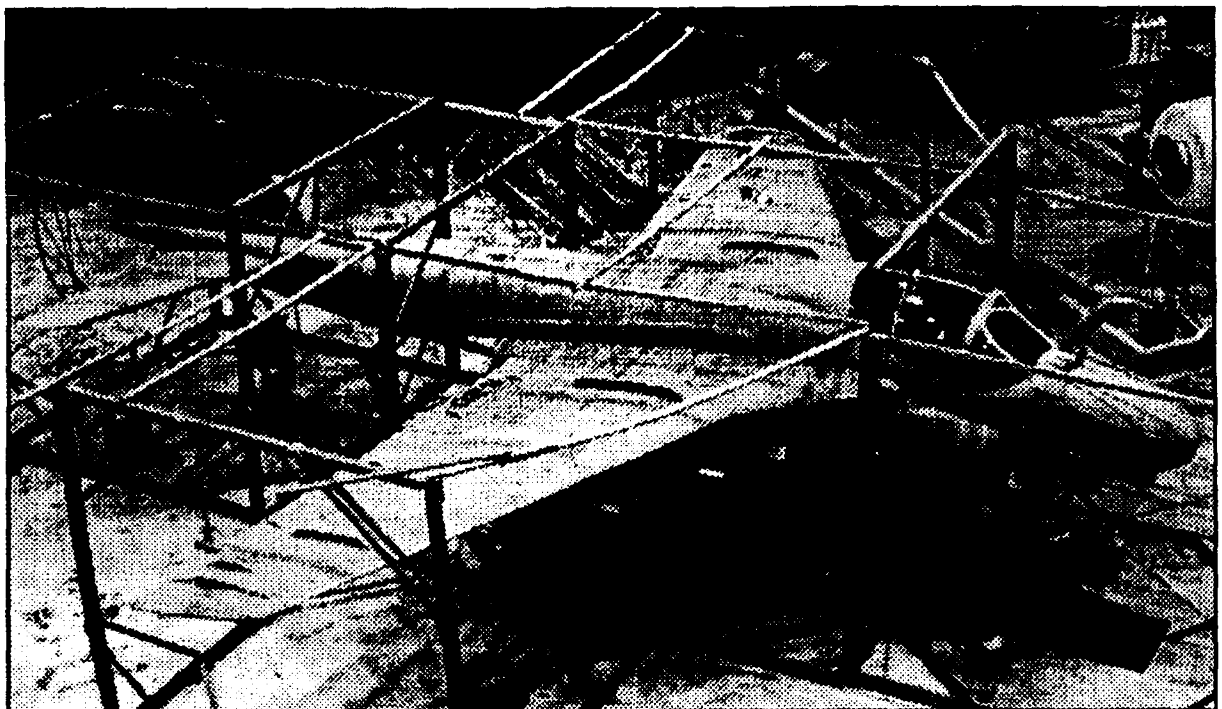

Photo 3. Test Setup

7. COMPOSITE-WING A-6E TEST

During August and September of 1990, indirect effects lightning testing on the Navy's newly rewinged A-6E was performed. The new wing was constructed of graphite, titanium, and aluminum. Testing was required to assure the Navy that the new wing would not seriously degrade the inherent lightning protection offered by the old metal wing. Previous direct effects testing was performed by the new wing's manufacturer.

No lightning indirect effects testing was ever performed on the *metal* wing A-6E, although a substantial HEMP database had been developed on both the metal wing and the composite wing. This database proved invaluable in the development of the test points for the lightning test. The list of test points was narrowed to a minimum of 104 points. By acquiring data on these points, susceptibility of the safety-of-flight and mission essential equipment could be determined.

The test approach was to exercise all of the major current paths by injecting current from nose to tail, nose to wing, wing to wing, and wing to tail. A minimum of two current amplitudes was planned for each test configuration to aid in the extrapolation of data to the full-threat environment. Table II shows the allocation of test points and amplitudes. Table III presents the various experiments by aircraft location.

During this test, a total of 442 acceptable data responses on 104 test points was added to the A-6E database.

Of these 104 test points, the Naval Air Test Center used direct-drive test techniques to further drive 43 of the acquired responses to the full-threat level.

By using a moderate current followed by direct-drive testing, the Naval Air Test Center could evaluate the survivability of the A-6E with a high degree of confidence.

Table II. Allocation of Test Points and Amplitudes

Experiment ID Number	Configuration	Amplitude (in kA)	Number of Test Points	Number of Test Shots
1	Nose-to-Tail	20	104	95
2	Nose-to-Wing	35	71	51
3	Wing-to-Wing	50	53	26
4	Wing-to-Tail	50	53	26
5	Canceled	–	–	–
6	Wing-to-Wing (modified coaxial return)	50-72	22	20
10	Direct-Drive	N/A	43	43

Table III. Experiments by Aircraft Location

Aircraft Location	Experiment				
	1	2	3	4	6
Radome (RADOME)	X	X	–	–	–
Cockpit (CKPT)	X	X	–	–	–
Forward Fuselage (FWD)	X	X	–	–	–
Mid Fuselage (MID)	X	X	X	X	X
Main Wheelwell (MWWELL)	X	X	X	X	X
Aft Bay (AFTBAY)	X	–	–	X	–
Left Wing (LWING)	–	X	X	X	X

8. CONCLUSIONS

The Naval Air Test Center has a prominent role in the DoD as a Major Range Test Facility Base. It is the primary research, development, test, and evaluation laboratory for DoD aircraft. As such, it offers its users the highly sophisticated resources necessary to ensure specification compliance and mission survivability of aircraft systems in a lightning environment. And as plans for continued development of the facility's capabilities are implemented, the Naval Air Test Center will offer an even broader spectrum of services to support users.

9. ACKNOWLEDGMENTS

The Navy expresses its appreciation for the excellent support received from its contractual team: Ktech for its operation and maintenance of simulators and facilities, BDM for its operation and maintenance of the instrumentation, and UIE for its test engineering technical support.