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THUNDERSTORM HAZARDS FLIGHT RESEARCH -

STORM HAZARDS '80 OVERVIEW

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SUMMARY

The National Aeronautics and Space Administration's Langley Research Center is conducting a flight research project to improve the state of the art of severe storm hazard prediction, detection, avoidance, and design of aircraft for those hazards which cannot reasonably be avoided. The hazards considered are lightning, turbulence, windshear, precipitation type (rain or hail), and precipitation rates. A highly instrumented NASA F-106B aircraft is being used in conjunction with various ground based radars and lightning measurement systems to collect data during thunderstorm penetration flights. Primary emphasis is being placed on lightning research, and the F-106B has been modified to withstand direct lightning strikes.

During 1980, flight operations were conducted in Oklahoma, working with the National Oceanic and Atmospheric Administration's National Severe Storms Laboratory (NSSL) at Norman, Oklahoma and in Virginia, working with the Wallops Flight Center. There were 69 thunderstorm penetrations made, resulting in 10 direct lightning strikes to the aircraft.

This paper will deal with the modifications to the F-106B aircraft, the various flight experiments, research instrumentation, the operational aspects, some of the preliminary results from the Storm Hazards '80 program, and plans for future tests.

INTRODUCTION

The NASA thunderstorm hazards research program originated in 1977 as a result of a concern expressed by a National Transportation Safety Board (NTSB) review, calling for "more sophisticated measurements of thunderstorm hazards." There was also a request from the Airline Pilots Association (ALPA) for "realistic policies for flight operations in severe storm areas." Additionally, there has been a need in the aviation and scientific communities to better understand the effects of lightning on the design and operation of aircraft at flight altitudes by sensing and recording the electromagnetic characteristics of direct lightning strikes to an instrumented aircraft. Flight tests are also needed to confirm laboratory and analytical results that have indicated the lightning process may cause the production of nitrous oxide gas (N_2O) and

X-ray fluxes. Most of the current knowledge of the characteristics of lightning and its effects has been accumulated from instrumentation on earthbound structures to measure the electric currents in cloud-to-ground strikes, and from electromagnetic radiation measured at some distance from cloud-to-ground or cloud-to-cloud lightning. This continuing program is one of the few ever conducted to gather direct lightning strike data on an aircraft at normal flight altitudes. The results of the 1978 and 1979 work are reported in References 1 and 2.

TEST AIRCRAFT AND MODIFICATIONS

The F-106B (Fig. 1) is well suited for thunderstorm research. In addition to its typical all-weather fighter aircraft characteristics, it has a cockpit for two crewmembers and a large internal weapons bay to house the research instrumentation systems. Also, the canopy design provides metal structure above the crew to minimize the possibility of canopy puncture or electric shocks to the crew from lightning. The J-75 engine has proven to be reasonably resistant to flameouts due to ingestion of large amounts of precipitation, and the F-106 has shown itself to be relatively free from lightning strike damage, as compared with other aircraft in the United States Air Force (USAF) inventory. Additional reasons for choosing the F-106B are provided in References 2 and 3.

The entire MA-1 aircraft and weapons control system was removed from the NASA F-106B, and all new flight instruments and avionics were installed including:

1. VHF and UHF communications radios.

2. Flight director system, receiving signals from TACAN, Instrument Landing System (ILS), and Inertial Navigation System (INS) as selected.

3. Separate indicator for displaying VOR/ILS information.

4. A color digital weather radar.

5. An airborne lightning locator.

6. Distance measurement equipment (DME).

7. A standby attitude indicator (one that will operate for 10 minutes after complete power failure).

8. A standby transponder.

9. A secondary pitot-static system with separate airspeed and altitude indicators.

10. An angle-of-attack indicating system.

The front and rear instrument panels are shown in Figures 2 and 3.

The control panels for all of the research instrumentation and data systems are located in the aft cockpit (Figs. 4 and 5), however, a single master switch is installed in the front cockpit to provide the pilot the capability of eliminating electrical power to all of the research data systems in case of an emergency. Rather than relocate circuit breakers for remotely located flight critical electrical circuits, parallelled circuit breakers are installed in the aft cockpit. These circuit breakers are flown in the open position and could be closed in the event a lightning strike causes one of the remote circuit breakers to open. This safety feature has not been used to date. Another safety precaution is the use of JP-5 or Jet A fuel because the vapor from this fuel is too lean to be ignited at the altitudes where lightning strikes are prevalent, as compared with the more volatile JP-4. External drop fuel tanks are not used because they might provide additional unwanted lightning strike attachment points. Other lightning protection features and modifications are described in Reference 2.

A contract was awarded to Lightning Technologies, Inc., to study the storm hazards aircraft and mission from all aspects (hardware, sofeware, procedures, and techniques) and make recommendations to insure maximum flight safety relative to lightning hazards (Ref. 3). The U.S. Air force Rough Rider personnel, who had been making thunderstorm penetration flights for 20 years, were also consulted to take advantage of their experience in operating procedures and in hardening aircraft for thunderstorm penetration flights. After all aircraft and data systems were prepared, Lightning Technologies, Inc., conducted a series of simulated lightning strike tests to obtain additional assurance that the aircraft was adequately protected. Figure 6 shows the F-106B in the simulated lightning test rig. Electrical currents up to 29,500 amps were applied to the aircraft's noseboom and wingtips with the aircraft manned, engine running, and all normal avionics and research instrumentation systems operating. The simulated lightning tests showed that the on-board systems were protected and afforded an opportunity to verify the operation of the on-board lightning sensors and recording systems.

FLIGHT EXPERIMENTS AND INSTRUMENTATION

Figure 7 shows the location of the sensors and other equipment associated with the various experiments.

Direct-strike lightning measurement experiment (DLite).- The instrumentation concept consists of seven sensors mounted at strategic points on the aircraft's surface that detect the electromagnetic properties during lightning strikes and a recording system especially shielded and isolated in a lightning instrumentation enclosure located in the weapons bay of the aircraft. All components are tied together by shielded cables and fiber optic links. The DLite control panel is shown in Figure 4, and the recording system is shown in Figure 8.

There are three types of sensors, having frequency responses from 300 Hz to 50 MHz. The four D-Dot sensors are flat brass-plate dipole antennas that

respond to the time rate of change of the electric flux density. The two multigap loop (B-Dot) sensors measure the time rate of change of the magnetic flux density of circumferential fields about the airframe locations. The total attachment current rate-of-change is measured by the single inductive current sensor (I-Dot) mounted on the noseboom, inside the radome.

The recording instrumentation (Fig. 8) in the shielded enclosure includes a wideband (6 MHz) video recorder for overall lightning strike phenomena and two transient waveform recorders modified to capture 1.3 milliseconds of data at a 10-nanosecond resolution. The outputs of both transient recorders are recorded on a single 14-track analog recorder.

Data collected by this experiment will be of great importance to the design of lightning protection for advanced solid-state microelectronics that are expected to perform an increasing amount of flight-critical functions in aircraft of the future. Also, it is hoped that the present aircraft lightning protection for airframes and structures can be improved by better understanding the lightning attachment phenomenon and strike intensities.

Lightning X-ray detecting experiment.- This experiment is furnished by the University of Washington and is designed to determine whether lightning produces X-rays, which, in turn, could have an effect on aircraft equipment and passengers. The X-ray detector experiment measures the X-ray flux and energy spectrum within certain ranges from nearby strikes as well as direct strikes to the aircraft. This experiment is activated just prior to engine start before each flight by a manual switch located at the X-ray sensor (Fig. 7).

Atmospheric chemistry experiment (ACE).- This experiment is designed to determine whether the lightning process produces environmentally significant gases, specifically, whether the levels of nitrous oxide (N_2O) and carbon monoxide (CO) are being increased by lightning as indicated by laboratory tests. Nitrous oxide (N_2O) is considered to be instrumental in the depletion of the earth's ozone layer, which filters potentially harmful solar ultraviolet radiation.

The ACE sampling system consists of 24 stainless steel collecting bottles, an air pump and associated plumbing located in the missile bay compartment and a control panel in the aft cockpit. The control panel is shown in Figure 5. As lightning is observed during a thunderstorm penetration, individual bottles are opened and closed remotely from the control panel to collect the air samples.

Lightning optical signature experiment. This experiment is furnished by the NSSL and is designed to record amplitude and frequency of the visible light waveforms generated by lightning inside storms to compare with measurements from the ground. These waveforms will be used to provide fundamental information on optical transients from lightning and to aid in the design of a satellite package for observation of lightning from space. The sensor is located on top of the fuselage aft of the cockpit (Fig. 7).

Composite materials experiment.- This experiment is to determine the physical damage effects of direct lightning strikes to reinforced composite

aircraft skins, and to evaluate the effectiveness of several protection measures. More and more composite components are being used in new aircraft designs because of their high strength and light weight, compared with aluminum; however, these new materials have been shown to be vulnerable to damage from lightning strikes in laboratory tests. Serious damage to all metal aircraft has been rare because conventional aluminum structures are excellent electrical conductors. Graphite-reinforced plastics, however, are approximately 500 times more resistive and will therefore absorb much more energy from a lightning strike, necessitating, in most cases, that protective measures be applied. Langley researchers hope to validate the use of flame-sprayed aluminum and aluminized glass weaves as a means of providing this protection.

Lightning strike patterns.- Lightning strike zones have been determined and categorized by laboratory tests and in-flight experiences (Ref. 4). Manufacturers have used this information to design the skin thickness of wing panels that cover wing fuel cells. The results of this experiment will improve the understanding of lightning attachment processes so that zones may be determined with greater confidence and help validate laboratory tests with actual lightning strike data at normal flight altitudes. These strike patterns are being determined by carefully documenting each swept stroke attachment point on the aircraft surface after each lightning strike.

Turbulence measurements.- The objective is to determine the intensity, frequency content, and spatial location of atmospheric turbulence associated with severe storms by means of in-flight measurements during aircraft penetrations of severe storms. These measurements are correlated with other turbulence intensity measurements obtained from ground-based Doppler weather radars, and with measurements of the other storm hazards such as wind, lightning, and precipitation. The aircraft instrumentation system (AIS) measures and records the aircraft motion, flight parameters and location (through the INS) for the turbulence and wind measurement experiments. Figure 5 shows the AIS and INS control panels in the right side panel of the aft cockpit.

Wind measurements.- The objective of this experiment is to determine the horizontal and vertical components of the mean wind field of intense storms by means of aircraft measurements at places and times coincident with ground-based Doppler radar observations, and to make detailed correlations of the aircraft measurements and Doppler radar measurements.

OPERATIONAL PROCEDURES

The NSSL has been conducting the "Rough Rider" thunderstorm research program for many years, with the United States Air Force (USAF) providing the primary penetration support aircraft. In 1980, the USAF dropped its support, and the NASA began its thunderstorm research program by working with the NSSL in Oklahoma and supplying the penetration aircraft. It was to NASA's advantage to base its initial thunderstorm penetration work on the experience and expertise of the NSSL, with their dual Doppler radar capability. During

the many years of operations, the "Rough Rider" program personnel learned many valuable lessons that could be passed directly to the NASA team. These lessons became operating rules for thunderstorm penetration procedures and techniques. All flights were limited to daytime because of the potential lightning flash blindness problem. The initial flights were made by two research test pilots to build experience and confidence in the aircraft, equipment, and the mission. Storms of intensity levels over 50 dBZ were avoided because hail was likely to exist in such storms. Relatively mild storms were investigated first, and finally, storms up to 50 dBZ were penetrated with coordination from the NSSL. The airborne weather radar was calibrated with the ground-based Doppler radar so that the pilots could compare intensity level presentations. Later, as experience and confidence were gained the test pilot in the aft seat was replaced with a flight test engineer to allow the flight test engineer the opportunity to observe the actual conditions inside a thunderstorm.

The NASA project control was located in the NSSL control room where a radar controller provided direction to the F-106 pilot based on project control's decisions for making the thunderstorm penetration. This controller, who was on loan from the FAA and a qualified Air Traffic Controller, also provided positive separation for the F-106 from other aircraft traffic in the area. When a storm of proper intensity and characteristics was observed on radar to move close to or develop within a 100 n. mi. radius of NSSL, project control would alert the F-106B crew to prepare for a launch. The 100 n. mi. radius was established early in the program to be the limit for radio communications and was reasonable for the limited fuel load carried by the NASA F-106B. The flight crew would then get a complete weather picture, including the storm's direction of movement, strength, tops and general weather forecast. An IFR flight plan was filed directly to a point close to the storm, usually defined by a distance and radial from the Oklahoma City VORTAC. A block altitude clearance was requested to include 2 to 3 thousand feet above and below the assigned penetration altitude to allow for deviations caused by the strong up and down drafts commonly encountered in thunderstorms.

After becoming airborne and climbing to the intended penetration altitude (usually the freezing level where lightning most often occurs) the normal FAA Air Traffic Controller would turn control of the aircraft over to the NSSL radar controller. The NSSL controller then vectored the aircraft to a position so that the penetration could be made into the area of the thunderstorm to be investigated. The emergency escape heading out of the storm was established by project control and transmitted to the pilot prior to the penetration. The emergency escape heading was determined so that the aircraft could escape the storm as quickly as possible in case hail or other unexpected storm hazards were encountered. In some cases, the escape heading might require a 90^{o} hard break turn; in others, it was the penetration heading directly through the storm. As the penetration heading was established, the crew was able to see the storm cell visually if the aircraft was in the clear. The airborne lightning locator showed the presence of lightning, and the intensity of the storm as seen on the airborne weather radar was compared with the ground-based radar. If the intensity level showed red (50 dBZ or higher), the penetration was not attempted because of the likelihood of encountering

hail. The ground-based Doppler radar also confirmed that the turbulence levels were satisfactory for penetration (less than 10 meters per second). Preparation was made for penetration in the aircraft by securing all loose items, locking the shoulder harnesses, retracting the anticollision lights and turning on all research instrumentation data systems. The pilot set the power and airspeed prior to storm entry and maintained a constant pitch attitude during the penetration, accepting the altitude excursions. This procedure was not only the best technique for aircraft control, but provided a more accurate measurement of the turbulence recorded by the onboard data system. The target airspeed for all storm penetrations was 300 knots indicated airspeed (KIAS).

Inside the storm cell, the crew described the conditions as they occurred by radio to project control. This information was also recorded on tape aboard the aircraft for later data correlation. Depending upon the conditions encountered during a penetration, the test pilot could elect to discontinue the mission and return to base to have the aircraft inspected for damage. In any case, an extensive inspection was accomplished after each flight during which a lightning strike occurred or heavy rain, turbulence, or hail was encountered.

After the aircraft and research team returned to NASA Langley, the Virginia operations commenced with the NASA Wallops Flight Center supplying the ground-based support. Since the Wallops radar operators were not trained ATC controllers, more of the overall decisions relative to flight safety were made by the pilot. Coordination with the normal FAA Air Traffic Control also had to be handled by the pilot.

RESULTS AND DISCUSSION

General.- There were 69 thunderstorm penetrations made during the 1980 program, resulting in 10 direct lightning strikes to the aircraft. The initial attachment point for all 10 strikes was the nose of the aircraft, and eight strikes exited the wingtips, and two exited the vertical tail, aft and below the fin cap. All 10 lightning strikes were considered to be of mild intensity, resulting in only superficial damage to the external surface. Strike attachment points looked like small burn marks; however, the exit points on the tips of the wings and vertical tail showed more erosion, since all of the current must leave the aircraft at one or two exit points. The exit damage to the left wingtip is shown in Figure 9. There were no problems encountered with the aircraft electrical or avionics systems, and the research instrumentation systems performed as designed. After one flight in very heavy rain and turbulence in Oklahoma (no lightning strikes), the inspection revealed that both rotating beacons had been broken, some rivet heads and metal skin edges exposed directly to the wind stream had been peeled back, a crack had developed in the canopy frame, and several small leaks developed in the hydraulic systems' plumbing. Also, the fiberglass radome, which was original equipment on the airplane (23 years old), showed signs of considerable stress and erosion and had to be replaced. The normal acceleration extremes recorded during this flight were approximately 2 g positive and .5 g negative, resulting from the heavy turbulence. On another flight in Virginia,

hail was encountered briefly, resulting in an emergency exit of the storm cell. Only superficial damage was incurred.

As an electrically active storm was entered, many close lightning discharges were usually observed prior to a direct strike to the aircraft. In some cases, a bolt of lightning could be seen arcing toward the nose, followed by a flash sweeping by one or both sides of the aircraft. In other cases, only a flash was observed very near the aircraft. In the latter cases, the research instrumentation equipment had to be checked to be sure that the aircraft had actually been struck, but when the bolt was seen curving toward the nose and flashing by, it could reasonably be assumed that the aircraft had been struck. The visual phenomena was sometimes accompanied by a noise similar to the crack of a gunshot. These noises varied; however, in some cases there was no sound at all. The crew did not experience any electrical shocks, nor was there a problem with flash blindness. After experiencing several strikes, the crew found the possibility of future strikes to be more exciting than frightening.

Direct-strike lightning experiment (DLite).- Interpretation and analysis of the lightning strike data is still in progress; however, Figure 10 shows representative data recorded concurrently from the D-Dot and B-Dot sensors during a single lightning strike to the aircraft. The symbols used on the lightning data figures are as follows:

D-Dot - Amperes per square meter (A/m^2)
B-Dot - Tesla per second (T/s)

Preliminary interpretation of the data in general indicates that significant electric flux density changes (D-Dot) accompany relatively mild intensity lightning strikes; whereas, the magnetic measurement (B-Dot) was low. The magnetic measurement had been expected to be higher to reflect the electromagnetic wave relationship found in free space. The characteristics of the D-Dot waveforms varied with the different lightning encounters; some with fast rising, mostly unipolar waveforms of either polarity and others with slower rising, bipolar waveforms.

Table I summarizes the maximum peak-to-peak D-Dot, B-Dot, and I-Dot values recorded for 9 out of the 10 lightning strikes along with the approximate duration of activity adjacent to the peaks. Multiple entries in the rows of Table I indicate data that were recorded simultaneously. Additional data can be found in Reference 5.

Detection of X-rays experiment.- This experiment confirmed the theory that lightning discharges X-ray fluxes. Although the results are preliminary, one strike generated 7 - 8 times the normal level of energetic electron activity associated with X-rays. In Figure 11, the top two data clips illustrate the activity of one X-ray energy level (12 thousand electron volts, keV) recorded in clear air with no nearby lightning. The error bars shown indicate the range wherein 99 percent of the clear air data fall. Also, it is noted that the error bar range varies with altitude. The remaining two data clips illustrate how this X-ray energy level was increased by nearby lightning activity. Additional analysis of the X-ray data is in progress (Ref. 6).

The atmospheric chemistry experiment (ACE).- Table II shows the preliminary nitrous oxide (N_2O) results from the ACE experiment during the 1980 Storm Hazards program. Analysis of these results indicates that N_2O levels were increased more than 10 percent above the clear air levels for 36 out of 107 samples obtained in thunderstorms. (The background level of N_2O based on analysis of samples obtained during clear air flights was found to be 308 parts per billion (ppb), with a sample variability of less than 8 percent.) The mean of these 36 samples gives an N_2O level of 376 parts per billion (or 22 percent above the clear air level). One thunderstorm air sample had an N_2O level approaching 500 ppb, an increase of 60 percent above the background level. These measurements indicated a very non-homogeneous distribution of N_2O within the thundercell. These results, which constitute the first direct measurements of the production of a trace gas by lightning, qualitatively confirm earlier laboratory measurements and theoretical calculations (Ref. 7). N_2O is also produced biogenetically by soil bacteria and diffuses up to the stratosphere along with the N_2O from world-wide lightning activity. It is estimated that about 70 percent of the total stratospheric destruction of ozone (O_3) is the result of the N_2O being produced by these two methods.

Composite material experiment.- The standard F-106 fiberglass fin cap was coated with molten aluminum using the flame spraying technique to a thickness of 4 - 5 mils in an attempt to protect it from lightning strike damage. There were no lightning strikes with initial attachment points directly to the vertical fin, although two strikes did exit the vertical fin, below the fin cap. The fin cap withstood the type of lightning strikes to the aircraft that occurred with only minor damage to the aluminum coating. It is therefore concluded that the protective technique was at least successful for indirect strikes.

Lightning strike patterns determination.- This program is providing an excellent opportunity for a thorough study of aircraft lightning attachment mechanisms and the resulting lightning strike zones. This is being accomplished by careful inspection and identification of lightning attachment points and swept stroke paths following each strike, together with pilot observations of each event. The result is the most thorough documentation of lightning attachment phenomenon ever conducted on a single type of aircraft.

Figure 12 shows an example of the strike pattern results from two lightning strikes that occurred on one flight. The flash swept aft across the top of the center of the left wing during one strike and beneath the center of the right wing during the other strike. In the past, most designers have considered mid-wing areas to be a region of very low probability of direct or swept lightning strikes, yet strike patterns like this occurred in three out of 10 strikes-a rather high percentage. These results thus indicate that greater attention should be given to design of protection for the surfaces of integral wing fuel tanks, at least in swept-wing aircraft. Additional information of this nature will become available as more strikes are recorded in the future.

Other experiments.- Interpretation and analyses of the data generated from the following experiments are pending.

1. Lightning optical signature

2. Turbulence and windshear

FUTURE PLANS

New research experiment.- An experiment contributed by the Boeing Commercial Airplane Company, called Lightning Data-Logger, will be added. This experiment will measure the total current of a lightning strike by obtaining waveforms of currents conducted by the airframe and will have the capability to count and record the total number of lightning strikes occurring on each flight. Other objectives are:

1. To determine whether pronounced airframe resonances appear in the current waveforms.

2. To verify the long-term reliability of the fiber optics system under sustained exposure to the airplane operating environment.

Instrumentation additions.- A video tape camera will be installed in a compartment in the weapons bay along with remote radar and lightning locator indicators to record the simultaneous displays of each storm. From these films, a comparison can be made between the two types of airborne storm hazard display devices as well as a comparison of the airborne displays with those of ground-based radars and lightning locating equipment.

There will be an acoustic microphone installed to record the thunder or noise associated with each lightning bolt, and two movie cameras will be installed to attempt to photograph the lightning strike phenomenon as it occurs.

Additional instrumentation containing three field mills will be installed. This instrumentation consists of an electronic package containing signal conditioning networks and signal outputs which can be recorded, and a display and control panel for the aft cockpit. The field mill is a flat plate antenna that is alternately shielded and exposed to an impinging electrical field which generates a current proportional to the changing field volts per meter (V/m). Shielding is accomplished with a segmented disc which is electrically grounded and rotated by an electric motor, thereby deriving the name "mill." This field mill installation will document the horizontal and vertical components of the quasi-static electrical field or total charge on the aircraft for each lightning strike to the aircraft. The cockpit display of the electric field parameters will provide the F-106B crew information to maneuver the aircraft to regions of maximum field intensity to improve the chance of receiving a direct lightning strike. Two more B-Dot sensors will be mounted-one under each wing to sense wingtip to wingtip magnetic flux density. Also, a current sensor, I, will be installed in the radome to additionally measure the total current of each lightning strike to the nose. Finally, an unshielded, grounded wire will be installed in the leading edge of the left wing for measuring the induced voltages caused by lightning.

For 1981 the composite materials experiment will include evaluating the effects of lightning on two different composite vertical tail fin caps-one made of Kevlar and graphite epoxy for another. The core material for both fin caps will be epoxy honeycomb.

Instrumentation Modification.- Changes to the direct strike lightning experiment (DLite) will include increasing the airborne fast waveform instrumentation capability to 12 channels and the analog recorder bandwidth to 15 MHz.

Aircraft modification.- One change will be made to the aircraft that was a result of the 1980 program. Because of the swept stroke attachment points across the mid-span of the wings where the fuel cells are located, the paint will be removed to greatly reduce the dwell time of each attachment, and consequently, the possibility of a burn-through. Reference 8 provides detailed information on ways to reduce lightning arc dwell time.

1981 operations.- The 1981 thunderstorm hazards program will begin April 1, in Oklahoma with the coordinated effort between NASA and NSSL. The research team will return to Virginia about May 1 and commence operations with NASA Wallops for the remainder of the thunderstorm season. During May and June there will be ground-based Doppler radar support at Wallops for a cooperative effort with the USAF Geophysics Laboratory (Hanscom Air Force Base, Massachusetts). For a brief phase of the program, a NASA Shorts Sky Van aircraft will participate with an airborne Doppler radar. This airborne radar will attempt to get Doppler radar characterization of the thunderstorm winds and turbulence at the same time, location and altitude of the F-106B penetration.

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TABLE I

SUMMARY OF MAXIMUM DLITE VALUES RECORDED

DURING NINE DIRECT LIGHTNING STRIKES

FLIGHT	D-Dot		B-Dot		I-Dot*	
	Max p-p A/m^2	Duration μs	Max p-p T/s	Duration μs	Max p-p $x10^9$ A/s	Duration μs
80-018	22	4.2				
80-019	30.5	0.25				
	15.5	2.0				
80-036	19	1.6	980	4.0		
80-038			675	1.3	0.72	1.8
	17.5	2.8	**		0.37	2.0
			240	0.3	0.43	2.5
	19	2.5	1160	1.8	0.54	4.0
	26	2.7	980	0.9	0.57	2.2

* Recorder has step response limitation of 100 ns.
** Memory read-out in process from previous strike.

TABLE II

ATMOSPHERIC CHEMISTRY EXPERIMENT (ACE)

PRELIMINARY NITROUS OXIDE (N_2O) RESULTS

FLIGHT NO.	DATE	CONDITIONS	NO. SAMPLES	NO. SAMPLES WITH $N_2O \geq 339$ PPB*
80-07	6/30/80	CLEAR AIR	3	0
08	6/30/80	STORM	2	0
09	6/4/80	STORM	8	1 (356)
12	6/8/80	STORM	13	7 (349, 349, 356, 375, 381, 394, 394)
15	6/12/80	STORM	4	0
17	6/16/80	STORM	20	11 (347, 355, 355, 363, 374, 377, 382, 398, 404, 436, 436)
18	6/17/80	STORM (FIRST DIRECT STRIKE)	5	0
19	6/17/80	STORM (TWO DIRECT STRIKES)	8	0
23	7/22/80	STORM	12	8 (340, 341, 356, 367, 375, 412, 453, 490)
29	8/12/80	STORM (DIRECT STRIKE	18	1 (357)
30	8/15/80	STORM	5	0
36	9/1/80	STORM (DIRECT STRIKE)	7	5 (340, 351, 352 369, 376)
38	9/3/80	STORM (FIVE DIRECT STRIKES)	5	3 (344, 347, 396)
39	9/10/80	STORM	6	3 (339, 339, 339)

* 339 PPB represents a value 10 percent higher than the N_2O level in clear air of 308 PPB

NASA
L-79-7207

Figure 1.- NASA F-106B research aircraft.

NASA
L-80-3582

Figure 2.- NASA F-106B foward flight instrument panel.

Figure 3.- NASA F-106B aft flight instrument panel.

NASA
L-79-6308

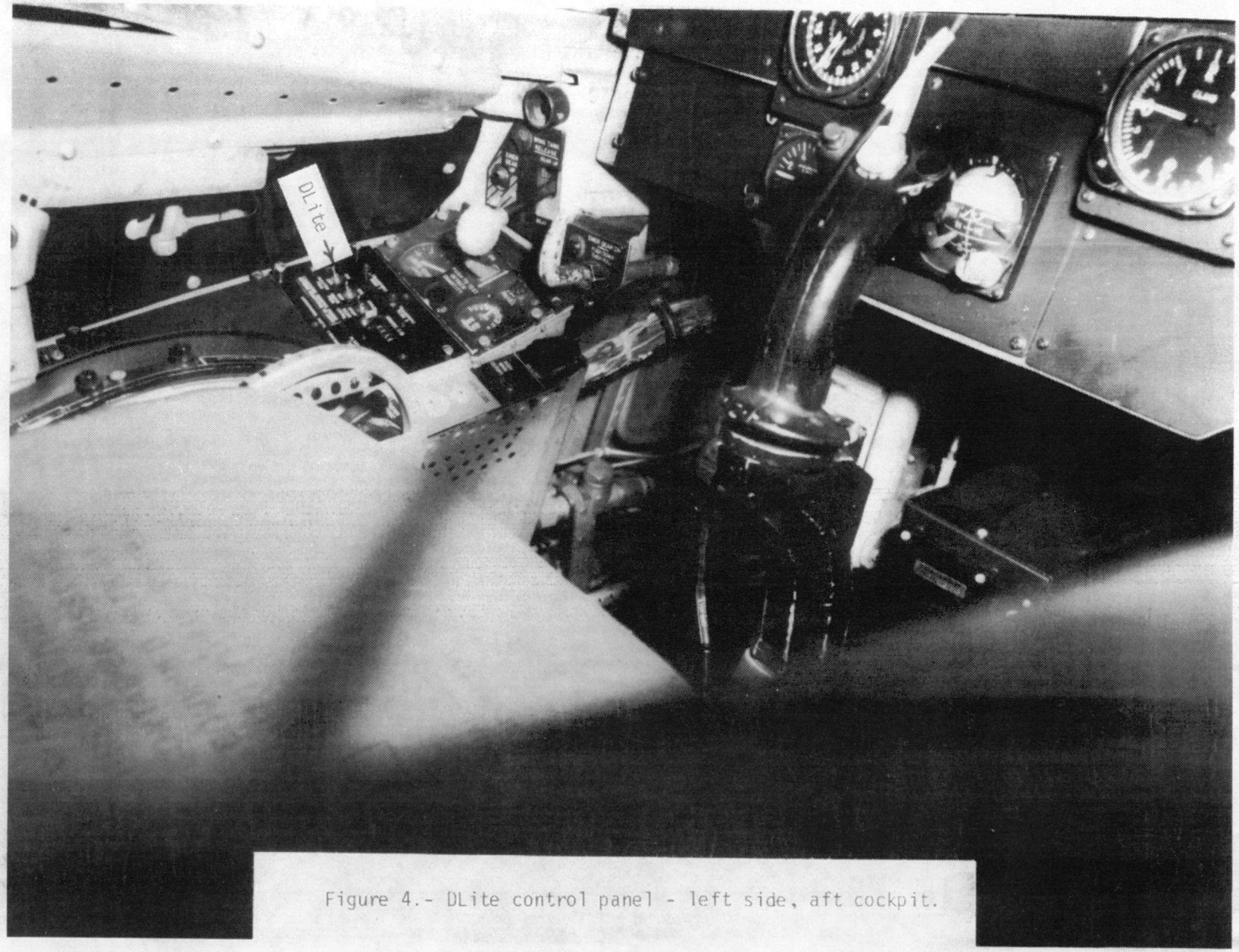

Figure 4.- DLite control panel - left side, aft cockpit.

NASA
L-80-3584

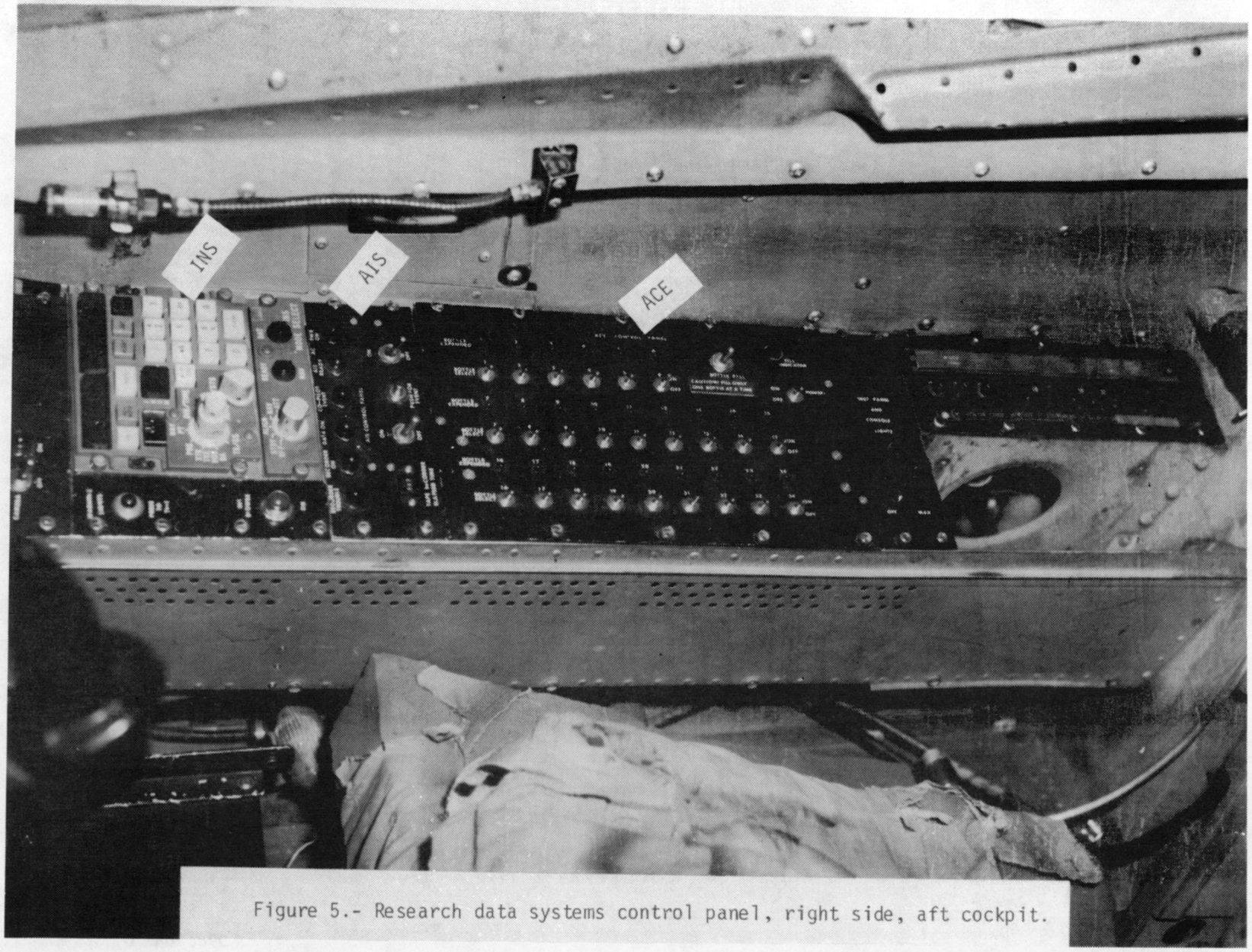

Figure 5.- Research data systems control panel, right side, aft cockpit.

NASA
L-80-2966

Figure 6.- F-106B aircraft in simulated lightning test rig.

Figure 7.- Location of sensors and equipment on the NASA F-106B.

NASA
L-79-5627

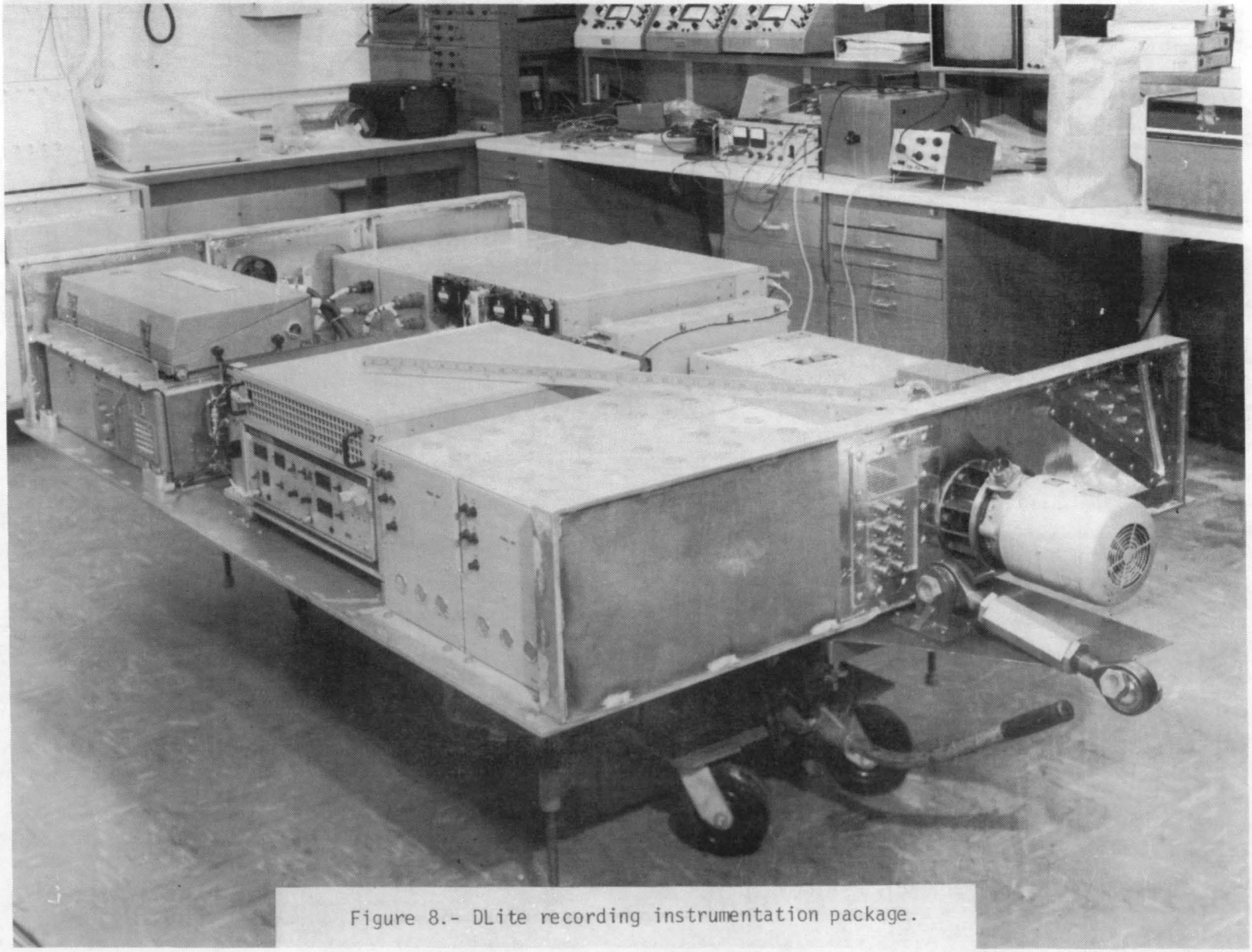

Figure 8.- DLite recording instrumentation package.

NASA
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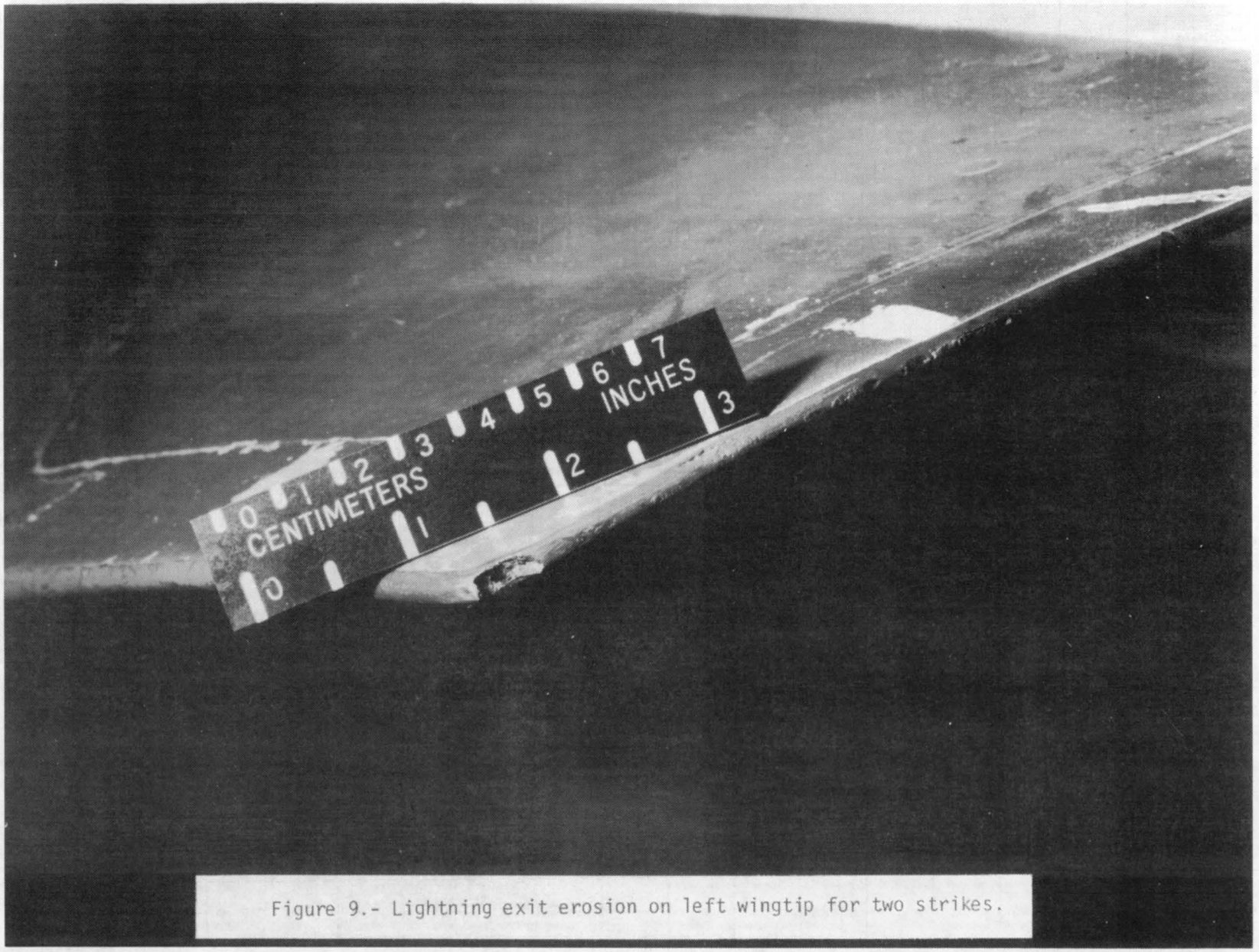
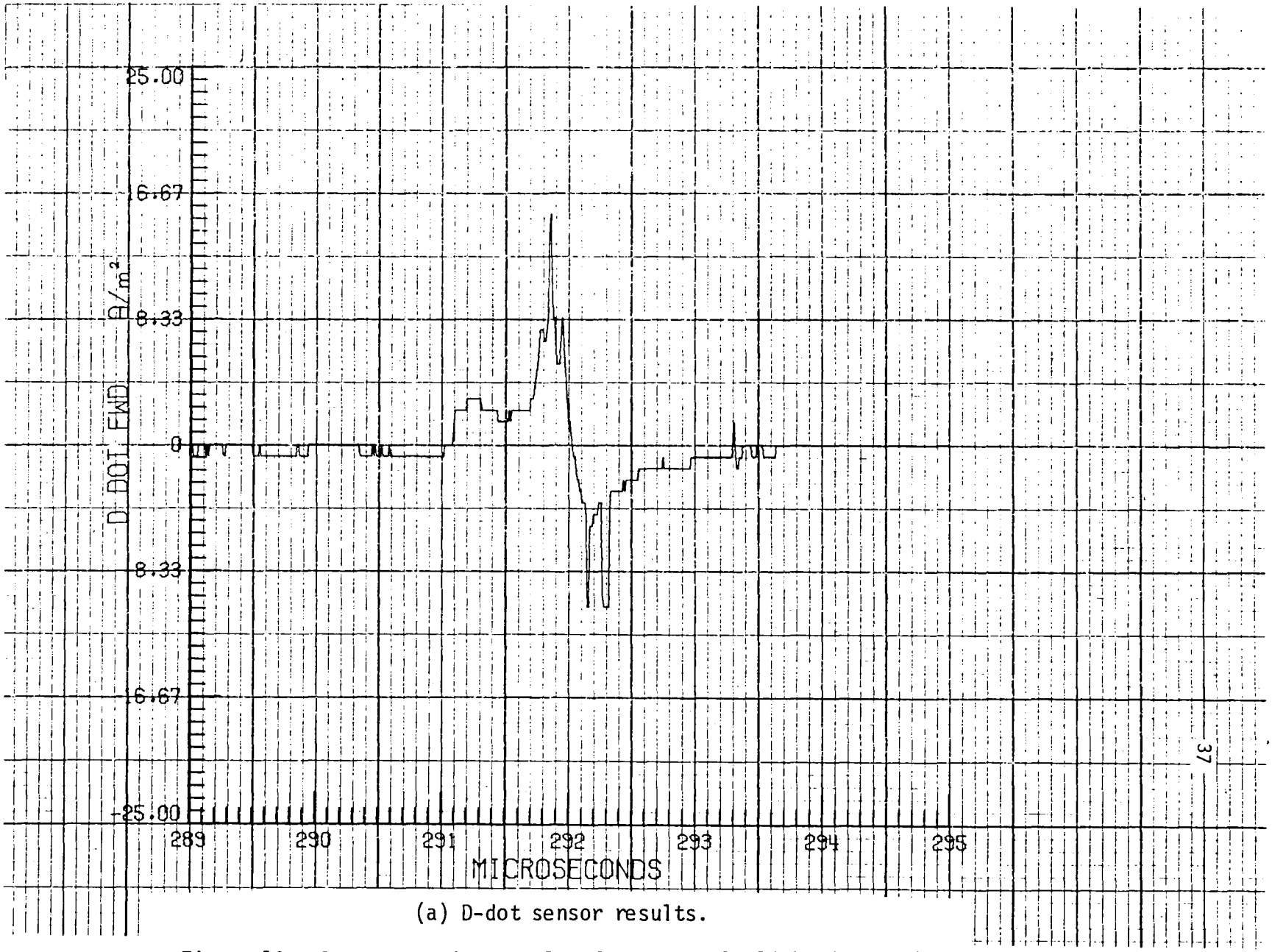
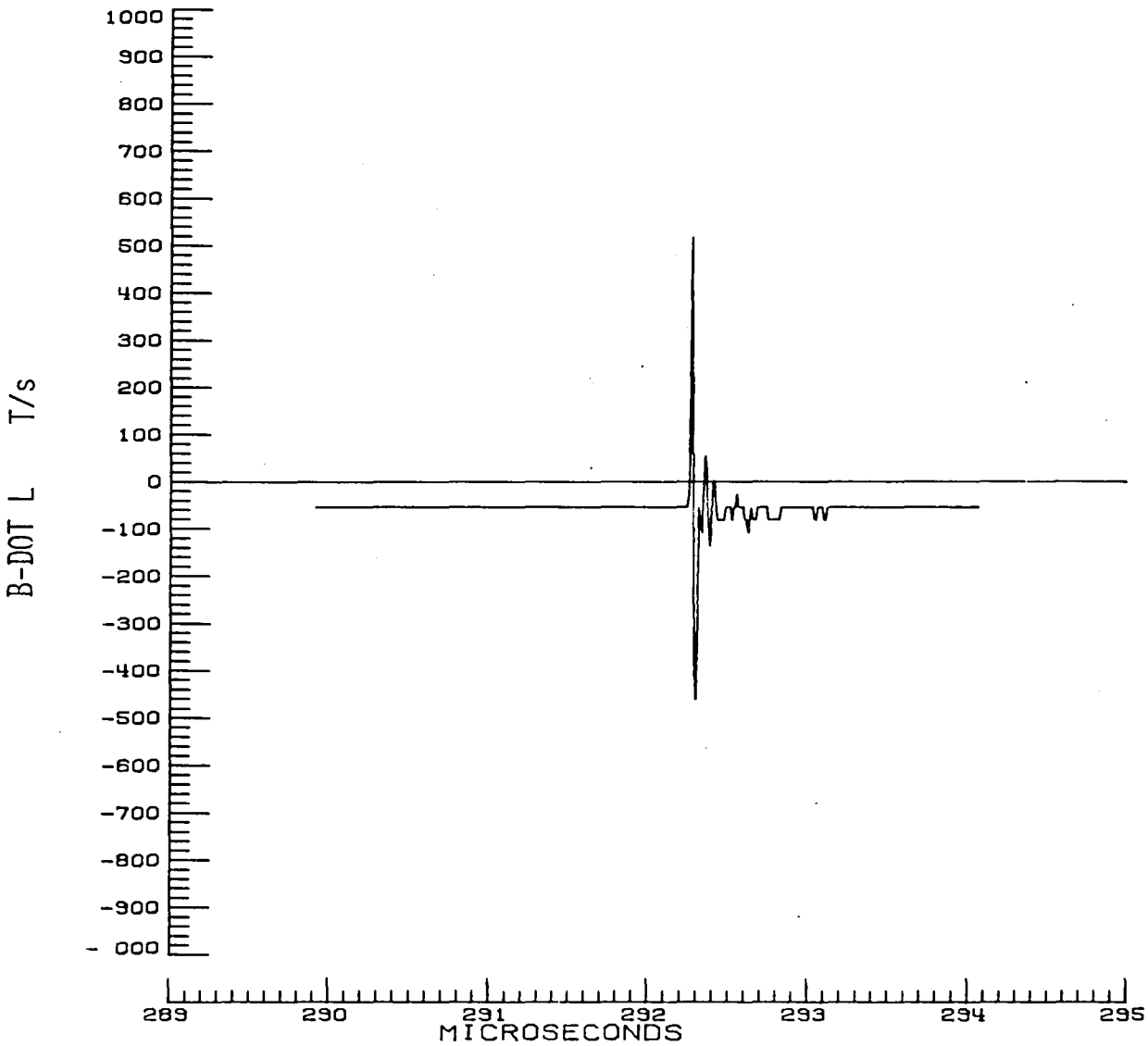


Figure 9.- Lightning exit erosion on left wingtip for two strikes.



(a) D-dot sensor results.

Figure 10.- Representative results from a single lightning strike.



(b) B-dot sensor results.

Figure 10. Concluded.

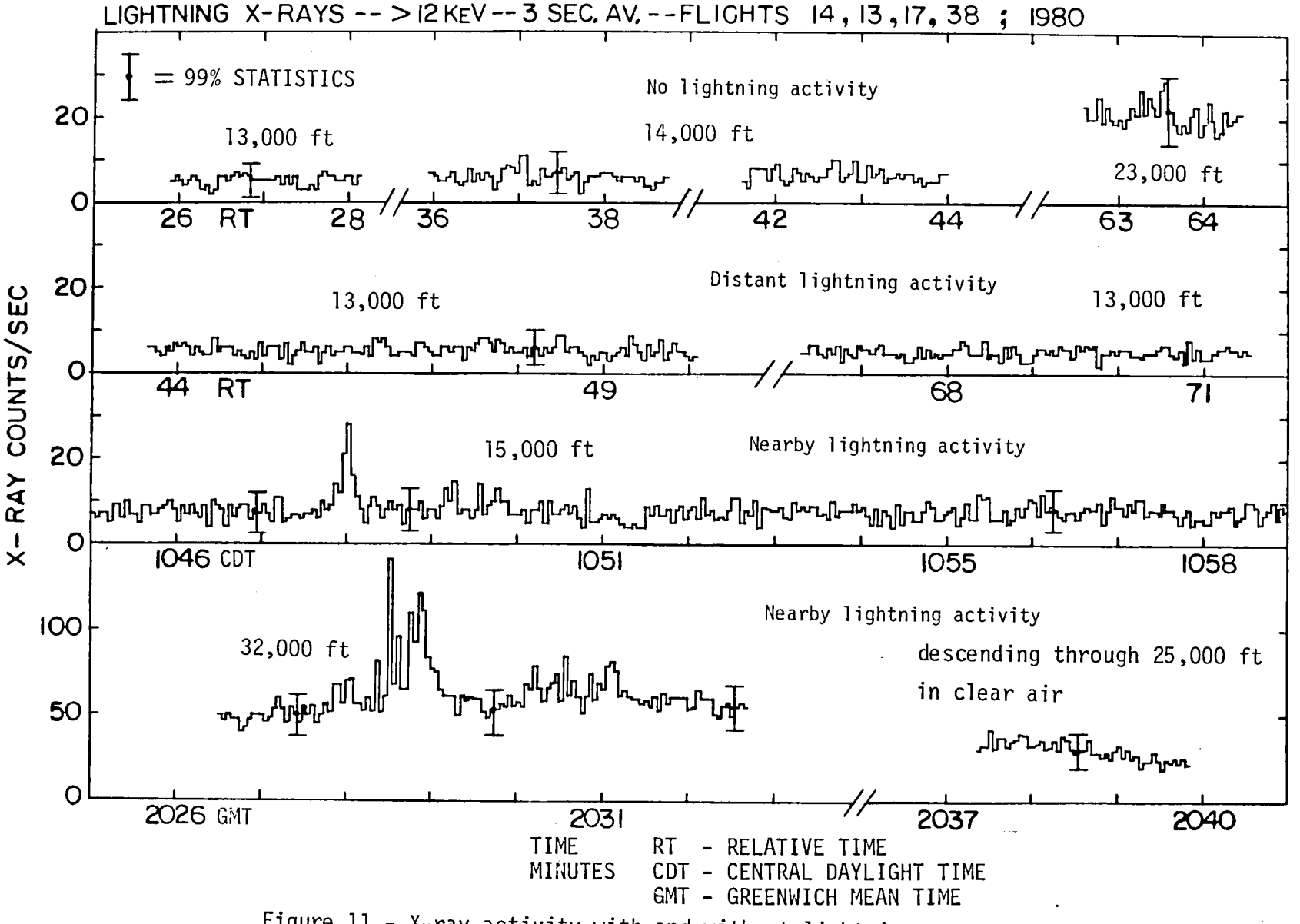


Figure 11.- X-ray activity with and without lightning.

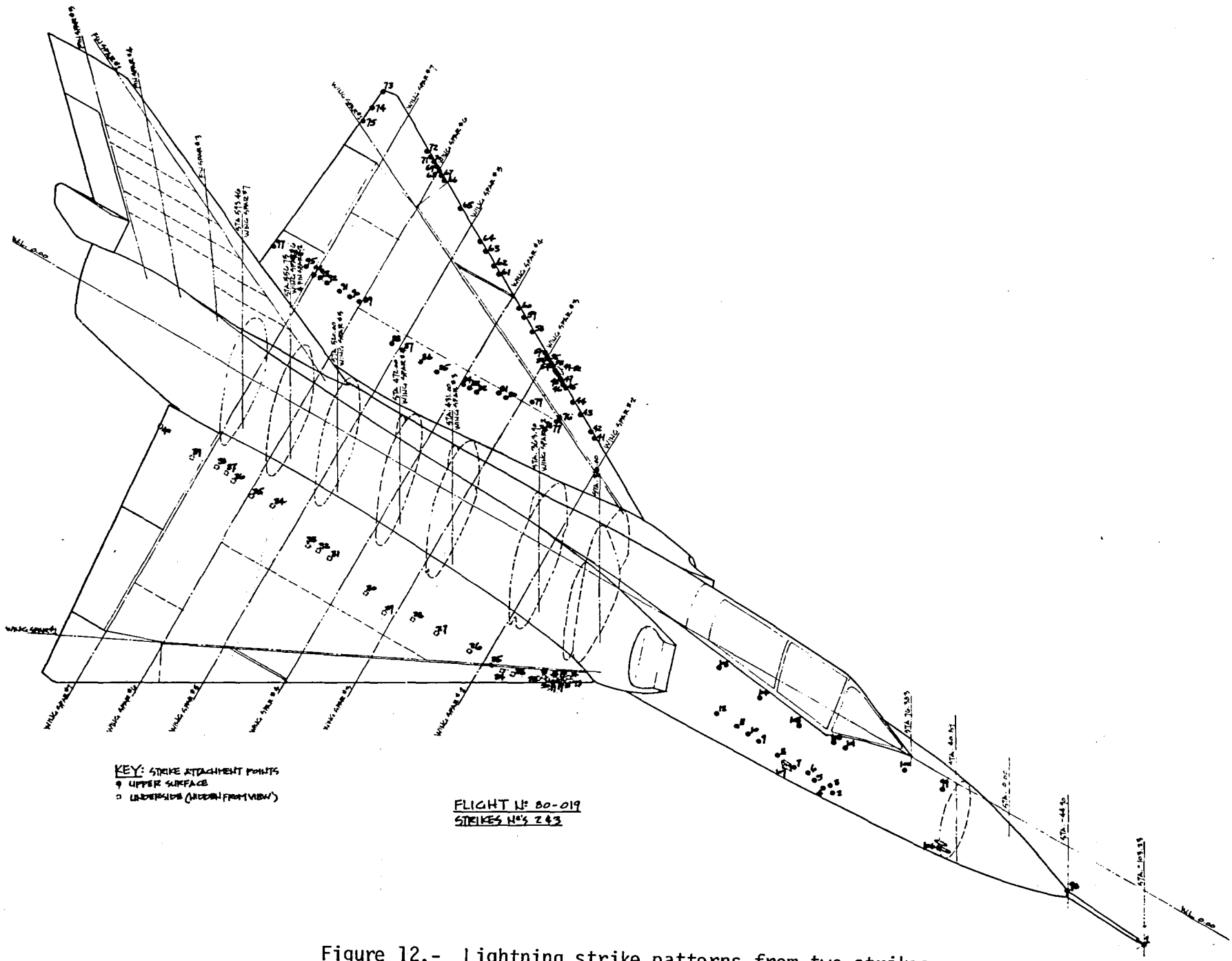


Figure 12.- Lightning strike patterns from two strikes.

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15. Supplementary Notes

16. Abstract

The National Aeronautics and Space Administration's Langley Research Center has been conducting a flight research project to further the knowledge of the effects of some of the thunderstorm hazards to the design and operation of aircraft. A highly instrumented NASA F-106B aircraft has been used in conjunction with various ground based radars and lightning measurement systems to collect data during thunderstorm penetration flights. Primary emphasis has been placed on lightning research, although turbulence and windshear are also being studied. The NASA F-106B aircraft has been modified for the storm hazards mission and to withstand direct lightning strikes.

During 1980, flight operations were conducted in Oklahoma, working with the National Oceanic and Atmospheric Administration's National Severe Storms Laboratory (NSSL) at Norman, Oklahoma and in Virginia, working with Wallops Flight Center. There were 69 thunderstorm penetration made, resulting in 10 direct lightning strikes to the aircraft. There were no problems encountered with any of the aircraft's systems as a result of the lightning strikes, and the research instrumentation systems performed as designed. Electromagnetic characteristics of nine strikes were recorded, and the results of other experiments confirm the theory that X-ray radiation and nitrous oxide gas (N_2O) are being produced by processes associated directly with thunderstorm electric fields and lightning discharges. A better understanding of aircraft lightning attachment mechanisms and strike zones is being accomplished by careful inspection, identification, and documentation of lightning attachment points and swept stroke paths following each strike to the aircraft.

This continuing thunderstorm flight research program is one of the few ever conducted to gather direct lightning strike data on an aircraft at normal flight altitudes.

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