Recent Data from the Airlines Lightning Strike Reporting Project

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In 1971, General Electric Company and five United States commercial airlines initiated a project to obtain data on lightning strikes to transport-category aircraft. The purpose of the project was to obtain information on the conditions under which aircraft are most likely to receive lightning strikes in flight, and document the effects of these strikes on the aircraft. For this purpose, the airlines were provided with questionnaire-type reporting forms for use by pilots and maintenance personnel in documenting lightning strike events and effects on the aircraft. The motivation for the project stemmed from a need to obtain a better understanding of the conditions under which aircraft are struck, the places on the aircraft where strikes are most likely, and the effect of these strikes on the airframe as well as onboard electrical and avionic systems. Initial results from the project were published by General Electric in 1974. At that time, a total of 214 strike reports had been received. The data were found useful by lightning protection designers for new aircraft. For example, the strike reports helped clarify the locations of lightning strike zones on transport-category aircraft, and alerted designers to potential lightning-induced voltage problems. Strike reports continued to be received by General Electric, but no further data summaries were published; therefore, in 1977, the project was taken over by Lightning Technologies Inc. By early 1984, nearly 800 lightning strike reports had been accumulated and Lightning Technologies Inc. invited the Federal Aviation Administration Technical Center to participate in the project by computerizing each of the strike reports and processing the data. With the data in computer memory, it would be possible to provide correlation among various reported conditions and effects. This paper presents a summary of the strike data obtained through January 1984.

Introduction

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The motivation for the project stemmed from a need to obtain a better understanding of the aircraft-lightning interaction, conditions under which aircraft are struck, places on the aircraft (i.e., zones) where strikes are most likely, and effects of these strikes on the airframe and onboard electrical and avionics systems. These data are very important to designers of new generation aircraft which incorporate increasing amounts of composite materials in the airframe and solid-state avionics which are inherently more vulnerable to lightning-induced effects.

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The program began with five participating airlines (American, Braniff, Continental, Eastern, and United); however, economic factors have made it necessary for Braniff, Continental, and Eastern to cease participation. Thus, for the past five years, data have been furnished by United and American only. These airlines, however, provide a large geographic database.

Reporting of Data

One side of the questionnaire requests data on the synoptic weather conditions prevalent at the time and location of the strike, any effects on cockpit electrical and avionics equipment, and effects on the crew (such as electric shock or flash blindness). These data were provided by the flight crew. The reverse side of the questionnaire requests data on the physical marks or damage to the aircraft's external surfaces, e.g., the location and size of burn marks and melted holes. This information helps to establish the places where the lightning flashes entered and exited the aircraft, and thus is important in establishing lightning strike "zones." This information normally cannot be provided by the flight crew, who have neither the time nor equipment to perform a thorough inspection of the aircraft following a strike. Instead, it is to be provided by the airline personnel responsible for maintaining the aircraft. Unfortunately, unless the lightning strike has caused some noticeable physical damage to the aircraft (e.g., a hole in the

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radome) it is not required to be "written up" by the maintenance personnel. Also, the need for quick "turn-around" of the aircraft provides little time for additional inspections. Therefore, in many cases the physical damage and strike location information have not been reported, or are incomplete.

It must be noted that these reports are not part of the airline required post-flight reports. In most of the cases, the reports were prepared by the pilots in domiciles sometime after the flight. Report forms were then accumulated by a cognizant individual within each airline and periodically forwarded to Lightning Technologies Inc.

Aircraft Types

This paper covers lightning strike information from 10 different transport-type aircraft from the aforementioned air-carriers. The aircraft types include Boeing B707, B727, B737, B747, and very recently B757 and B767. Also included were Douglas' DC-8, DC-9, and DC-10, and Lockheed's L1011 aircraft.

Reduction of Data

Aircraft flight conditions and synoptic weather as reported by the flight crews had been correlated as a percentage of the total number of strikes reported. Included are altitude, temperature, month in which the strike occurred, degree of precipitation (rain, snow, hail), extent of the turbulence (light, moderate, heavy), electrical activity before and after the strike, and flight conditions (climb, level, flight, descent, or approach). Histograms representative of the lightning strike information for each condition are presented in Figs. 1-13. No attempt has been made to cross-correlate two or more parameters, although this capability exists now that the data are stored in computer memory.

Strike by Month

Figure 1 lists the lightning strikes by month and shows that the highest incident rates occur during the spring (March, April, and May). This has been contrary to previously

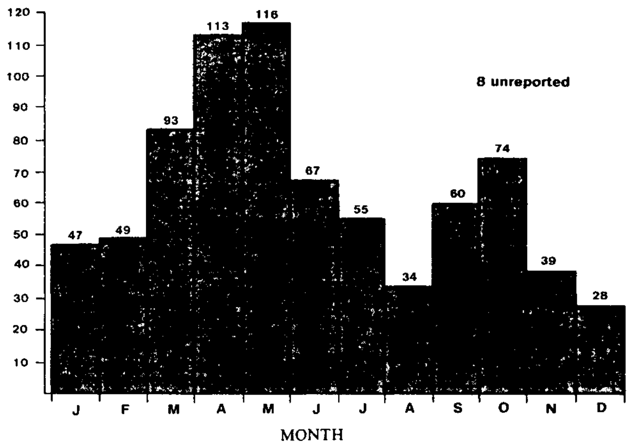

Fig. 1 Strikes per month.

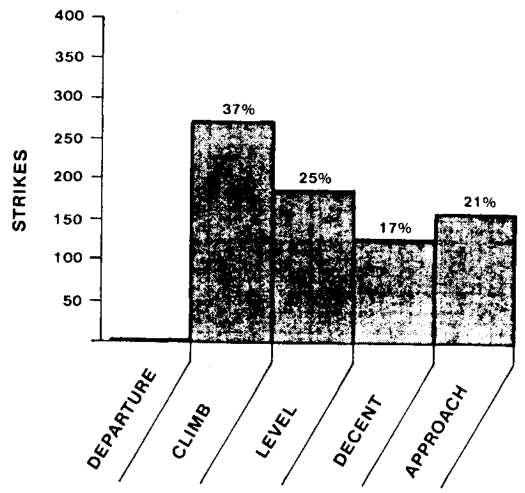

Fig. 2 Aircraft attitude.

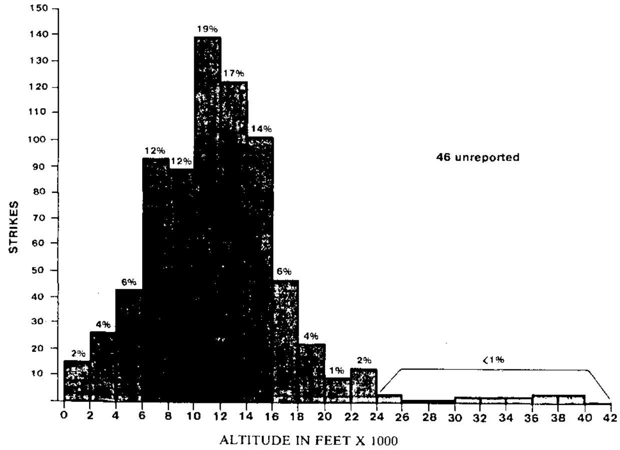

Fig. 3 Aircraft altitude.

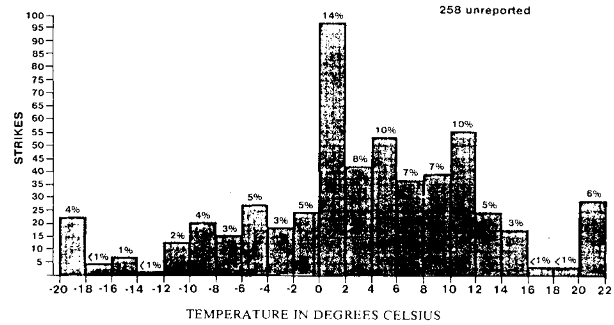

Fig. 4 Temperature, °C.

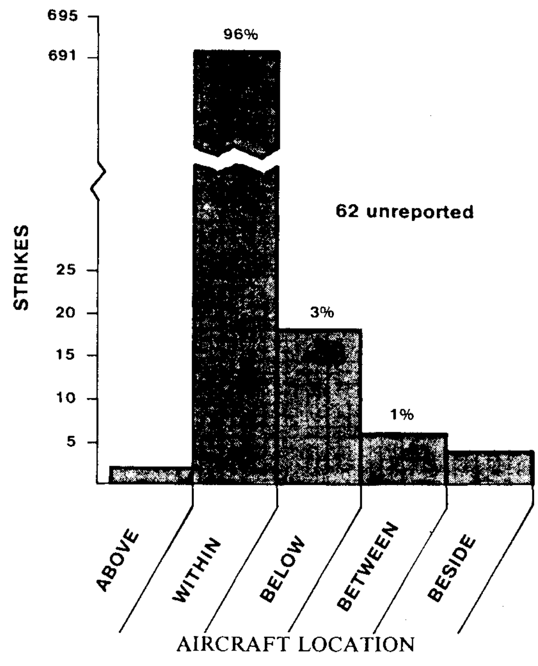

Fig. 5 Aircraft cloud reference.

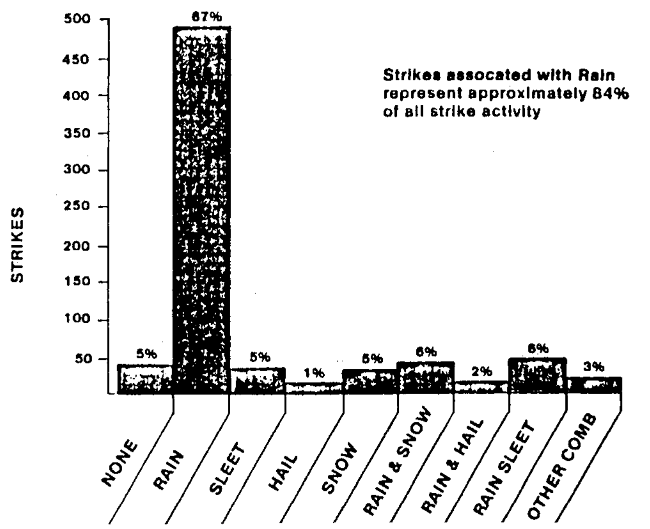

Fig. 6 Precipitation.

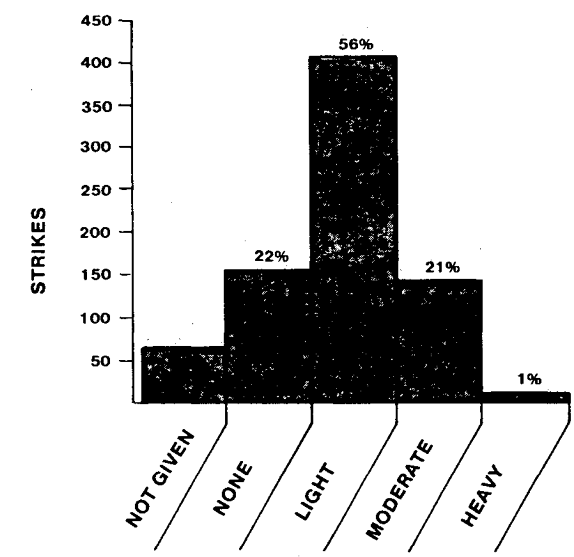

Fig. 7 Turbulence noted.

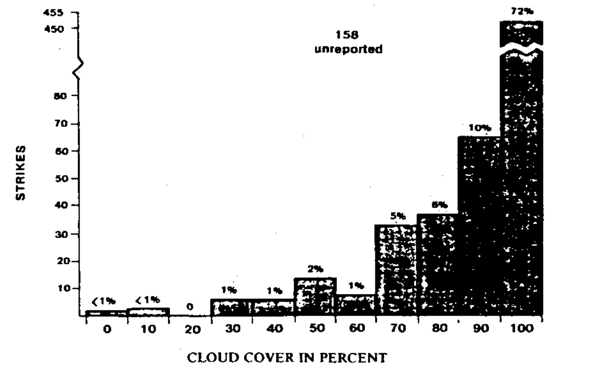

Fig. 8 Cloud cover.

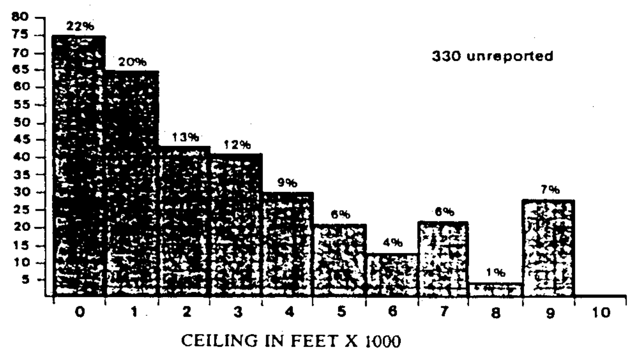

Fig. 9 Ceiling.

reported data which indicated the highest incident period was during the summer (June, July, and August). December continues to display the lowest reported rate.

Operational and Synoptic Weather Conditions

Aircraft operational and synoptic weather conditions prevailing at the time of the strike have been categorized under the headings of aircraft attitude, altitude, outside air temperature, location weather, and electrical activities. For ease in analyzing the data, histograms were developed and are presented in Figs. 1-12.

Aircraft Attitude (Fig. 2)

The highest percentage of aircraft lightning strikes occurred when climbing (37%); with 21% of the strikes reported during approach.

Aircraft Altitude (Fig. 3)

Transport-type aircraft fly at barometric altitude with the altimeter set at 29.92. This references the aircraft altitude to mean sea level (MSL). The data indicated that 36% of the aircraft were struck at altitudes below 10,000 ft MSL, and 87% of the strikes are reported at altitudes of 16,000 ft MSL or less. A smaller number of lightning strikes were reported at altitudes up to 40,000 ft MSL.

The fact that most strikes occurred when the aircraft was at altitudes of 16,000 ft or less should not be taken as an indication that lightning is less prevalent at higher altitudes. On the contrary, it is well known that thunderclouds may extend up to 60,000 ft and lightning flashes occur throughout them. Also, the NASA F106B storm hazards research aircraft has encountered frequent lightning strikes on cloud penetrations above 20,000 ft. Photographs of cloud tops at night from satellites, high-flying aircraft,[2] and the Space Shuttle have shown indications of frequent lightning activity. The reason that commercial aircraft do not encounter many lightning strikes at the higher altitudes is because of thunderstorm avoidance procedures.

Outside Air Temperature (Fig. 4)

Previous reports indicated that most of the lightning strikes occurred at or near the freezing level, 0°C±5°C. The data clearly show that 72% of the air transport lightning strikes occurred at 0-22°C. Sixty-seven percent of the report contained outside air temperature information.

Cloud Reference (Fig. 5)

A total of 92% of the reports described the aircraft location with reference to clouds. Of those reported, 96% were within a cloud, with only 3% reported below the clouds.

Precipitation (Fig. 6)

Within the 92% reporting precipitation, 81% percent were associated with rain when struck with lightning. Further breakdown is as follows: 67% with rain only, 6% rain and snow, 2% rain and hail, and 6% rain and sleet.

Turbulence (Fig. 7)

A total of 78% of the reports indicated turbulence ranging from light to heavy.

Cloud Cover (Figs. 8-10)

The reported lightning strike incidents appear to be related directly to percent of cloud cover. As the amount of cloud cover increased, the lightning strikes reported increased. This is clearly shown in Fig. 8. Figure 9 shows that as the ceiling increases, the potential for a strike diminishes. No strikes were reported with a ceiling greater than 11,000 ft above ground level. The reports showed that most of the strikes occurred when the cloud tops were reported to be at approximately 15,000 ft.

The cloud data confirmed that aircraft lightning strikes occur either while the airplane is flying through a cloud or relatively close to one. There were no reports of strikes while aircraft were flying "in the clear" at great distances from clouds, or reports of "bolts from the blue." It has sometimes been suggested that clear air may become sufficiently electrified to produce lightning flashes; however, there is no such evidence in this database.

Electrical Activity (Figs. 11 and 12)

The results show that only 40% of the pilots observed lightning activity either before, before and after, or after receiving a lightning strike (Fig. 11). Fifty percent did not observe any "P" static effects either before or after the strike (Fig. 12), and only 24% reported observing St. Elmo's Fire. St. Elmo's Fire is most readily detected during periods of reduced light and might not be detected in bright sunlight or active lightning conditions.

Time of the Year

As expected, many of the strike reports occurred during the spring and early summer months when thunderstorm conditions are most prevalent in the United States; however, a significant number of strikes also occurred during the winter months of December and January when thunderstorms are not as frequent. Some of these latter strikes occurred when the aircraft were flying in snow, indicating that snowstorms may become highly electrified and produce lightning. One reason for the comparatively high incidence of lightning encounters during winter months may be that avoidance is more difficult because the conditions which produce lightning in winter storms are not as well defined or understood as those associated with summer thunderstorms. It is comparatively easy for an aircraft to identify and avoid a well-defined summer thunderstorm comprised of cumulonimbus clouds which contain heavy rain and reach very high altitudes. On the other hand, winter storms are associated more often with nimbostratus clouds which extend over wide areas and do not have intense rain cores easily detectable by weather radar.

Relationship of Strikes to Number of Flight Hours

The aircraft's number of flight hours involved in this project were not available; therefore, correlations could not be made between the strikes and the aircraft's total number of flight hours. Airline maintenance reports involving lightning damage seem to indicate that a typical aircraft is struck approximately once every 2500 flight hours, although public statistics of this nature are rare.

Effects of the Strike

The reported effects of the lightning strike were tabulated under the following headings: attachment points, interference/outage, effects on personnel, and electrical/electronic damage.

Attachment Points

The exact locations of lightning attachment points are generally uncovered during the post-lightning strike ground inspection. Due to the size of transport-type aircraft and the

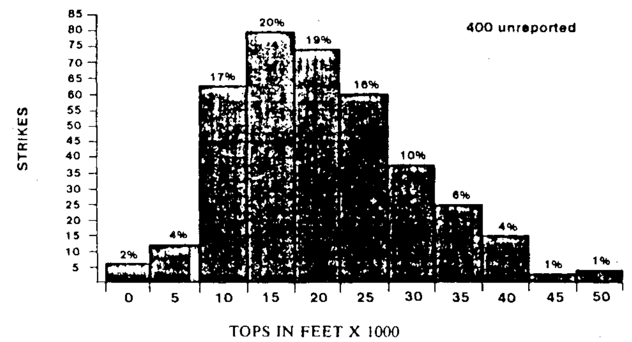

Fig. 10 Cloud tops.

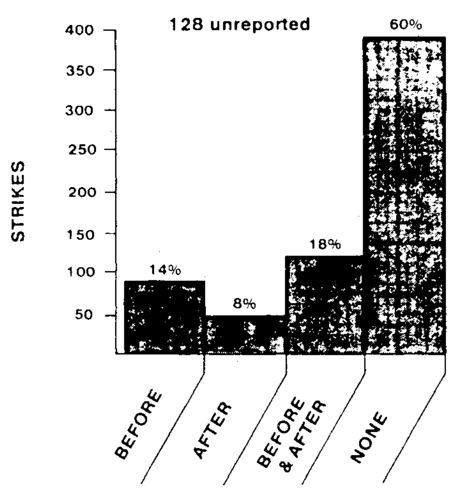

Fig. 11 Observed lightning activities prior to strike.

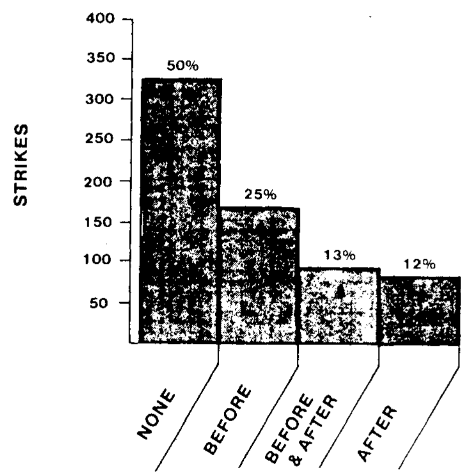

Fig. 12 Observed "P" static.

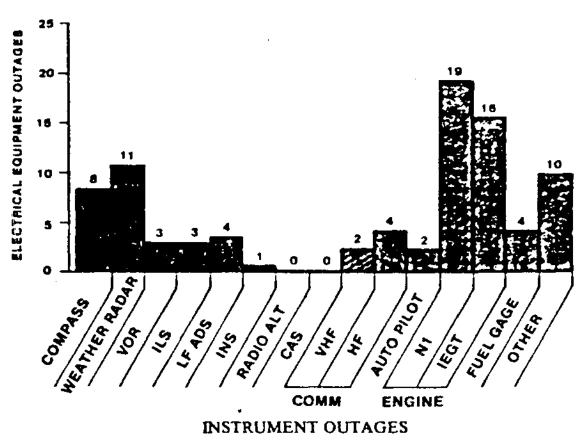

Fig. 13 Electronic equipment impact due to lightning strikes.

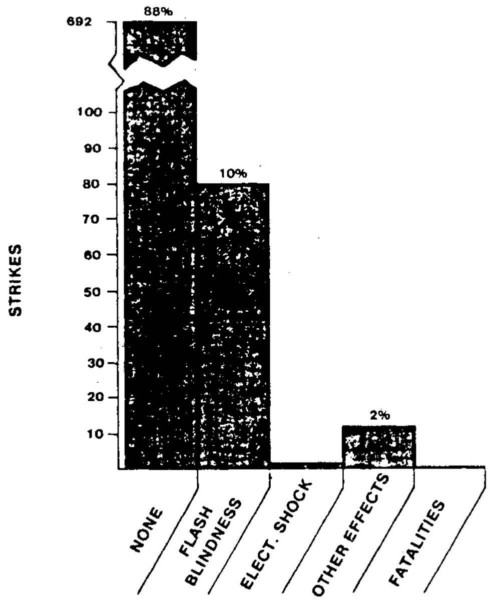

Fig. 14 Strike effects to crew.

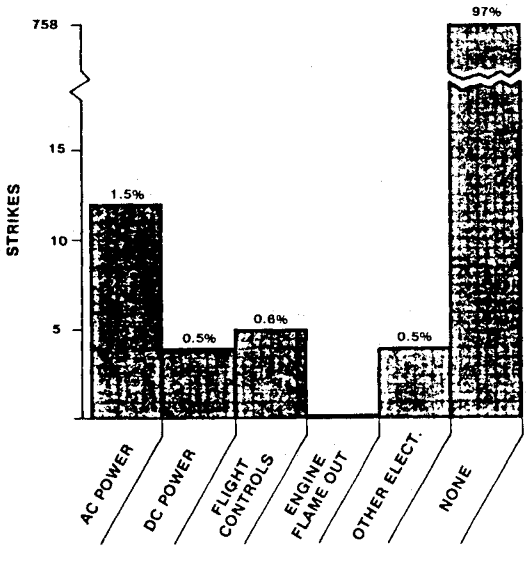

Fig. 15 Electrical/electronic effects.

complexity of locating the exact attachment points, the attachment points are often not located and reported.

This was evident in analyzing the data, since a total of 672 did not indicate the attachment points. Of the total 253 attachment points recorded, 29% were to the nose of the aircraft, with approximately 50% reported to the fuselage at some point. The remainder of the attachments was divided equally between the wings and tail.

Interference/Outage (Fig. 13)

Of the total 783 reports, 87 reported outages. These outages required ground crew maintenance (either repair or replacement). The navigation systems had 30 instrument outages with only six communication systems impacted. Engine instruments had a total of 39 outages.

Effects on Personnel (Fig. 14)

Ninety-one reports stated effects on crew members. Of those reported, 80 consisted of momentary flash blindness with only one report of electrical shock to personnel.

Electrical/Electronic Damage (Fig. 15)

From the 783 reports, only 3.1% (25 reports) stated any impact to the electrical/electronic systems. No engine flameouts were reported.

Summary and Conclusions

All metal transport-type aircraft will not generally sustain significant structural damage when struck by lightning, but may encounter interference or outage of navigation, communication, or engine instruments. The reports indicated that temporary flash blindness has been the major problem for personnel.

The potential atmospheric electrical hazard to aircraft will challenge the designers of future generation aircraft employing advanced technology, structural materials, and critical microelectronic digital flight control systems. These designs will require close coordination between the designers, manufacturers, and FAA certification specialists to ensure that aircraft are capable of sustaining a direct lightning strike without damage to the aircraft, electronic systems, passengers, or crew.

References

[1]"Data from the Airlines Lightning Strike Reporting Project," General Electric Co., Rept. GPR-75-004, March 1975.

[2]Technical paper or report by NASA Manned Space Flight Center, Huntsville, Ala. on U-2 photographs.