NASA TECHNICAL MEMORANDUM

NASA TM X-62,436

(NASA-TM-X-62436) AVIATION'S ROLE IN EARTH RESOURCES SURVEYS (NASA) 33 p HC $3.75 CSCL 08G

N75-26481

Unclas

G3/43 27317

NASA TM X-62,436

AVIATIONS'S ROLE IN EARTH RESOURCES SURVEYS

C.A. Syvertson and
Donald R. Mulholland

Ames Research Center
Moffett Field, Calif., 94035

August 1972

1. Report No.
TM X-62,436

2. Government Accession No.

3. Recipient's Catalog No.

4. Title and Subtitle
AVIATION'S ROLE IN EARTH RESOURCES SURVEYS

5. Report Date

6. Performing Organization Code

7. Author(s)
C.A. Syvertson and Donald R. Mulholland

8. Performing Organization Report No.
A-6081

10. Work Unit No.

9. Performing Organization Name and Address
Ames Research Center
Moffett Field, Calif., 94035

11. Contract or Grant No.

13. Type of Report and Period Covered
Technical Memorandum

12. Sponsoring Agency Name and Address
National Aeronautics and Space Administration
Washington, D.C., 20546

14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The new family of satellites designed to make a wide variety of Earth Observations has stimulated renewed interest in the use of aircraft as platforms for similar and complementary Earth Resources Surveys. Aircraft have been used for survey purposes for many years. The oil and mining industries have made extensive use of aircraft in the search for new oil and ore deposits. Less well known are the uses made by the federal, state, and local governments who each year photograph over 20 percent of the land in the United States. The surveys cover the areas of forestry, agriculture, hydrology, oceanography, geology, and geography. These various uses provide missions for approximately 300 aircraft.

In the future, the use of aircraft for Earth Resources Surveys will be greater than at present and the variety and numbers of aircraft will also grow. If we take a broad definition of Earth Resources Surveys, then the types of aircraft involved include light general aviation aircraft, special purpose military aircraft, and heavy four-engine transport type aircraft.

At the present time, 275 companies are engaged in aerial surveys but less than 50 of these are equipped for nonphotographic remote sensing. New sensor technology growing from and stimulated by the space program has made it possible to obtain vastly improved data. For example, on the Earth Resources Technology Satellite, use is made of three spectral bands and a multispectral scanner. The three spectral bands in the green, red, and infrared pass through a return beam vidicon and are reproduced on the ground on black and white film. Two high-altitude survey aircraft at the Ames Research Center have been equipped with cameras filtered to match the ERTS spectral bands and have obtained photography of selected test sites for ERTS so that investigators were able to become acquainted with the type of data which will be available from the ERTS satellite recently launched from the west coast. Aircraft flights are now being synchronized with satellite observations to provide correlated data. The pre-ERTS aircraft data as well as the underflight data, are being distributed to the Department of Interior, Department of Agriculture, Corps of Engineers, Department of Commerce (NOAA), the Navy, and to a large number of individual ERTS investigators. Photographs are shown to illustrate preliminary results from several of the test sites.

17. Key Words (Suggested by Author(s))
Remote sensing aircraft
Earth Resources Surveys
Aerial photography

18. Distribution Statement
Unclassified - Unlimited

STAR Category - 42

19. Security Classif. (of this report)
Unclassified

20. Security Classif. (of this page)
Unclassified

21. No. of Pages
33

22. Price*
$3.75

*For sale by the National Technical Information Service, Springfield, Virginia 22151

AVIATION'S ROLE IN EARTH RESOURCES SURVEYS

C. A. Syvertson[1] and Donald R. Mulholland[2]

Summary

The new family of satellites designed to make a wide variety of Earth Observations has stimulated renewed interest in the use of aircraft as platforms for similar and complementary Earth Resources Surveys. Aircraft have been used for survey purposes for many years. The oil and mining industries have made extensive use of aircraft in the search for new oil and ore deposits. Less well known are the uses made by the federal, state, and local governments who each year photograph over 20 percent of the land in the United States. The surveys cover the areas of forestry, agriculture, hydrology, oceanography, geology, and geography. These various uses provide missions for approximately 300 aircraft.

In the future, the use of aircraft for Earth Resources Surveys will be greater than at present and the variety and numbers of aircraft will also grow. If we take a broad definition of Earth Resources Surveys, then the types of aircraft involved include light general aviation aircraft, special purpose military aircraft, and heavy four-engine transport type aircraft.

At the present time, 275 companies are engaged in aerial surveys but less than 50 of these are equipped for nonphotographic remote sensing. New sensor technology growing from and stimulated by the space program has made it possible to obtain vastly improved data. For example, on the Earth Resources Technology Satellite, use is made of three spectral bands and a

[1] Deputy Director, Ames Research Center, NASA, Moffett Field, Calif., 94035.

[2] Chief, Airborne Science Office, Ames Research Center, NASA, Moffett Field, Calif., 94035.

multispectral scanner. The three spectral bands in the green, red, and infrared pass through a return beam vidicon and are reproduced on the ground on black and white film. Two high-altitude survey aircraft at the Ames Research Center have been equipped with cameras filtered to match the ERTS spectral bands and have obtained photography of selected test sites for ERTS so that investigators were able to become acquainted with the type of data which will be available from the ERTS satellite recently launched from the west coast. Aircraft flights are now being synchronized with satellite observations to provide correlated data. The pre-ERTS aircraft data as well as the underflight data, are being distributed to the Department of Interior, Department of Agriculture, Corps of Engineers, Department of Commerce (NOAA), the Navy, and to a large number of individual ERTS investigators. Photographs are shown to illustrate preliminary results from several of the test sites.

Introduction

One of the very first practical uses of aircraft was for military reconnaissance. From this beginning in the earliest days of aviation, the use of aircraft for earth observations has grown to the present widespread and varied applications. The extensive use made of aircraft by the oil and mining industries in the search of new oil and ore deposits is reasonably well known. Less well known are the uses made by the federal, state, and local governments who each year photograph over 20 percent of the land in the United States. The surveys cover the areas of forestry, agriculture, hydrology, oceanography, geology, and geography. Remote sensing from aircraft can, for example, provide information on timber growth, inventory, and stress (i.e., infestations). Aerial photography permits agricultural crop inventory and classification, the study of temporal changes in crop phenology, and the determination of irrigation and harvest patterns. Water-shed management and treatment proposals for the abatement of accelerated erosion and the improvement of water quality are now feasible through use of aerial surveys. Remote sensing techniques are presently being used to study the relationship between water surface chlorophyll concentration and water temperature for marine food resource predictions. Geological investigations indicate that ore bodies are associated with intersections of major structural trends. The locations and orientations of fractures and other relevant structures can be determined by aerial surveys.

Detailed photographic surveys of large areas with calibrated cameras are now being made with high-altitude aircraft for the preparation of very accurate (orthophotoquad) maps.

As indicated above, the users are varied and their data requirements are both varied and extensive. Widest use is made of simple photographic information, but there is growing use of more sophisticated techniques and sensors. Infrared photography is perhaps the next most common in application after simple photography in the visible spectrum. In addition, there are presently in use a variety of infrared and microwave radiometers. Microwave radiometers in the wavelength range from less than a centimeter to almost a meter are currently being used to measure brightness temperature of sea water and ice and in the determination of moisture content of soils and snow. Active microwave (radar) is being used on aircraft to map (through cloud undercast) otherwise inaccessible areas, as well as to determine the thickness of glacier and sea ice. Photopolarimeters are used for measurement of visible polarization of reflected sunlight for soil moisture determination and infrared thermal imagers are used for obtaining surface temperature maps. Other instruments such as magnetometers and air samplers are also employed.

The many instruments in the arsenal have widely varying capabilities in terms of range and resolution. Sometimes observations must be made or samples taken close to the ground, and in other cases, coverage and field-of-view requirements necessitate very high altitude flight. Many different types of aircraft are used as instrument platforms. Most common are general aviation aircraft, but also found are helicopters, special purpose military aircraft, and even large, four-engined jet transports. Data from the FAA show that last year some 230 aircraft were used for aerial surveys and another 31 for patrolling. At the NASA Ames Research Center, we use general aviation, high-altitude research, and four-engine jet-transport aircraft.

With the variety of sensors and aircraft used, some of the results that can be obtained are remarkable. For example, detailed information is becoming available on land use, soil surface temperatures and water content, ocean chlorophyll content, pollution sources, and so forth. In the paper that follows, we will examine the present and potential users of earth survey information, their data and instrumentation requirements, the types of aircraft used and the numbers involved, and finally, also examine a few samples of the data presently becoming available.

Users

One of the best ways to assess the role of aviation in earth resources survey is to examine the list of present and potential future users of the information that can be obtained with various types of survey aircraft. The list of users is indeed extensive. Some measure of the extent of interest in survey data can be obtained from the roster of experimenters that propose to use data from the Earth Resources Technology Satellite launched this past July from Vandenberg Air Force Base. These experimenters numbered over 300. They come from nearly all of the 50 states and over 30 foreign nations. They represent a variety of scientific disciplines including geology, meteorology, agriculture, hydrology, forestry, cartography, oceanography, and land planning. In this brief paper, we can not hope to examine all of the interests and needs of all of the users of information from earth resources surveys. We will try to develop some perspective, however, by using some of the interests of one state as an example. The state we have selected is California. We made this choice for several reasons. First, the interests in California are varied; second, they are reasonably well recognized and developed; finally, and equally important, we are somewhat more familiar with these interests since the NASA Ames Research Center is located in California and we have worked with various state organizations in connection with several of their evolving programs. We will therefore explore some of the interests of a few appropriate organizations in California.

Division of Mines and Geology. As noted earlier, the search for new oil and mineral resources has been one of the well established users of aircraft for earth resources surveys. It is somewhat surprising then that the results of these surveys are not especially thorough in terms of either the completeness or the detail of available data. For example, a magnetic map of the complete State of California is not available. Virtually all of the data on hand are from scaler magnetometers; that is, only the magnitude of the magnetic field is known and not its direction. The Division of Mines and Geology would like to develop a complete magnetic map of the state based on data from three axis magnetometers. This map would facilitate the identification and location of magnetic anomalies, throughout the state. It is apparent that similar maps would be of interest in almost every state.

Another unrelated interest of this Division is the identification of potential landslides. Through the years, landslides have often caused extensive damage in California and, of course, in other states as well. Identification of potential landslides is of interest to urban planners, to land developers, and to highway departments and the Corps of Engineers as well as others having an interest when it comes to the siting of dams.

Most landslides are caused by an accumulation of water. Ground water seeps into the earth until it encounters a layer of impervious rock; then it flows laterally and can accumulate in certain areas until in effect, it lubricates some of the sublayers of soil and rock. The result is a landslide.

The accumulation of water in a potential landslide area can assist in identifying a potential problem. Some of the water evaporates and in the process slightly cools the surface. Temperature depressions of a few tenths of a degree result. Ground surface temperatures can be determined by sensitive measurements of the earth's IR spectra in the 8 to 14 micron range. Based on this identification process, measurements from aircraft with appropriate thermal IR instrumentation can be very valuable in the future in avoiding major damage from landslides.

Department of Water Resources. The need to identify available water resources has always been an important problem in the Western United States and it is of growing importance elsewhere in the nation. Surveys are needed therefore to locate and map the entire inventory of water sources. There is an equally important need to identify accurately the demand for water. Both of these needs can be largely satisfied with systematic high quality aerial photography. Additional useful data are also being obtained using color IR photography.

In California as well as in some other states, the annual snow pack is an all-valuable water resource. The need to measure this resource precisely is very important because of the well known problem of controlling efficiently the discharge from the system of dams used to store the runoff from the snow pack.

Aircraft have been and can be used in a number of ways to survey the snow pack. One new way that is being explored is to use a microwave signal swept from 10^6 to 10^9 Hz By examining the reflected signal, the effective depth of penetration into the snow surface can be determined. The variation of this effective depth with frequency is dependent on the water content of the snow. It may be possible, therefore, to obtain important information about snow depth and water content using aircraft equipped with appropriate micro wave instrumentation.

Air Resources Board. Clearly the atmosphere is one of the earth's resources and it is one part of our environment about which there is growing concern. One of the primary problem areas is the Los Angeles basin. The Statewide Air Pollution Research Center of the University of California, Riverside, and the NASA Ames Research Center are engaged in a joint research program involving the use of aircraft to study photochemical air pollution. We will describe some of the early results from this program later in this paper.

One of the problems facing the Air Resources Board is to establish the background level of natural pollution. Without an accurate picture of "baseline" natural pollution it is difficult to establish precisely the effects of man-made pollution sources. Among the sources considered to be natural are brush and forest fires.

In addition to the problem of establishing background levels, other sources must be identified and inventoried. Yet another problem facing the Board is the requirement to analyze the need for the burning of agricultural debris. For many crops, a large amount of debris is accumulated after harvesting and this debris is normally disposed of by burning. The essential problem is to burn the debris before the backlog is too large and at a time when the conditions are favorable to dispersal of the products of combustion. The specific needs are to know how much debris is piled up, what other pollution sources will be important at the time of burning, and what the atmospheric conditions will be. Data obtained with aircraft can contribute to the analysis of all three parts of the problem.

Department of Public Health. Many of the problems of interest to the Department of Public Health are related to those of interest to the Air Resources Board. For example, this department is concerned with an overview of solid waste disposal and with sources of stream pollution. The requirements for mosquito abatement districts must be established. In a broader sense, many diseases spread in geographical patterns that are associated with a variety of factors such as prevailing winds, breeding sites, and so forth. There is a need to identify potential disease vector sources.

One of the rather unique problems of concern to the Department of Public Health is combating the so-called "red tide" that poisons shellfish. It is believed that there are precursors to the microorganisms that cause the red tide. If a way can be found to identify and detect these precursors, then the possibility exists that countermeasures may be taken. Aerial detection of the red tide precursors would therefore be of considerable value to this department.

Department of Navigation and Ocean Development. One of the growing issues in California is control of the development of coastal areas. In the process of resolving this issue, accurate knowledge is needed of the present use of coastal lands. Aerial surveys provide the most efficient way to obtain an up-to-date inventory of coastal land use. Not only is the type of use important (e.g., urban development, farming, etc.) but knowledge is also desired of the type of vegetation growing in each area.

Department of Public Works. One of the concerns of this department is the selection of routes for future highways. It is important therefore to identify geological hazards such as landslides and earthquake faults. We have already discussed the problem of identifying potential landslide areas. Faults are relatively easily identified from the air through standard photography. Even small faults can be readily seen when lighting is from a low angle such as for the periods immediately after sunrise and immediately before sunset. Almost every casual observer who has flown between Los Angeles and San Francisco has been able to discern the famous San Andreas fault as well as several others. Experienced observers can easily locate faults of concern in highway construction.

Once highway construction is underway, aerial reconnaisance can be used to determine work progress and to observe construction details. One technique presently being considered is the use of IR photography to determine areas where newly poured concrete is unsatisfactory. It is believed that minute differences in surface temperatures can be used to define those areas where new concrete has deficient characteristics. This problem has been of continued concern to both the Department of Public Works and the highway construction industry.

Much the same technique can be used to identify those areas where existing highways have begun to deteriorate and where preventive maintenance is required. Again the basic principle is that differences in surface or undersurface characteristics will result in small differences in surface temperature that can be identified by IR photography or by other IR sensing technique. Aerial surveys would be used to obtain the IR data.

Water Resources Control Board. We have already briefly discussed the problem of water pollution in describing the interests of the Department of Public Health. The Water Resources Control Board has similar interests in identifying water pollution and the pollution sources. Pollution is often manifest by changes in biological activity in the water, either an excessive increase in algae or in severe cases by poisoning of many types of plant and animal life. Many types of plant life absorb light in a particular part of the spectra. By examining the absorption spectra, the presence or the absence of plant life can be determined. We will speak more of this problem in a later section on the Fishing Industry.

Department of Agriculture. One of the largest potential users of aerial surveys is the Department of Agriculture and the related industry. The needs are quite varied. Many of them are associated with identification of land use. First, the interest is in the type of land use – metropolitan/urban, cultivated, range, or forest. Next, the interest is in the type of crop – field, tree, vine, or livestock pasture. Next, the interest is in the species of crop and in the percent of area covered by this crop. From information such as this, it is possible to forecast accurately potential crop yields. Crop forecasts are not always well received. As most people know, agriculture is a highly competitive industry and not without its gambles. In the grape growing industry, for example, a grower's financial success is dependent on how well he makes his decision to devote his crop to fresh grapes, wine production, and raisins. A few years ago detailed aerial surveys were used to determine very accurately the magnitud of the grape crop. Apparently, this knowledge was especially valuable to buyers and to some extent reduced the growers' ability to bargain for better prices. The results of the survey proved to be so accurate that the surveys have never been made since. It is apparent that for aerial surveys as for many other parts of aviation, not all of the problems are technical.

At this point, it is appropriate to diverge briefly from considering users only in the State of California. The U.S. Department of Agriculture is perhaps the largest user of aerial surveys in the country. Each year about 20 percent of the area of the country is surveyed from the air. One of the major uses is to determine the areas devoted to various crops. Many individual crop subsidies are determined by the amount of land devoted to that crop. Aerial surveys provide the required data and basis of control.

Fishing Industry. One of the industries important to California and to any coastal region is fishing. The ocean, as a source of food for the world, is becoming more and more important. One of the problems is to locate accurately and rapidly schools of fish of interest to commercial fisherman. Most people know that larger fish feed on smaller fish, perhaps through several cycles, and that small fish feed on plankton. Phyto-plankton (plantlike) are one of the primary food sources in the ocean. In the process of forming chlorophyl, phyto-plankton absorbs energy from the sun at 452 nm (4520Å). By observing the absorption spectra at this band, the presence of the plankton can be detected and, thus, schools of fish can be located. This identification system has been tested in several regions of the Pacific and Atlantic Oceans. During a recent airborne expedition near the Canary Islands, the scientists involved observed a good correlation between their chlorophyl readings and the concentrations of native fishing boats. This correlation suggests several things; one being that some fisherman will do all right even without advanced technology. However, aerial sensing techniques can cover large areas more quickly than boats and may thus prove aid to the fishing industry in identifying new or changing areas representing fertile fishing fields.

While the foregoing discussion concentrated mainly on the users in a single state, it is apparent that there are many agencies, many industries, and many technical and scientific disciplines that can make use of survey data obtained with aircraft. With the breadth of the constituency established, we will next examine some of the sensing and observing techniques of interest.

Sensors

The sensors used in aerial earth surveys are as varied as the users. Many of the instrument techniques employed by users with special needs were discussed in the previous section. A partial list of sensors used for earth observations in Ames Research Center aircraft include still and motion picture photography, infrared photography, television systems, microwave radiometers, laser systems, side-looking radar protilometers, air sampling devices, and magnetometers. In some sophisticated investigations, several instruments are coupled electronically. Devices with both fixed and scanning viewing systems are used. The coupled instruments include scanning spectrometers, multichannel differential radiometers, infrared images, laser geodolites, and dual-channel differential television systems. Because of the variety of techniques used, it is difficult to categorize them completely and accurately. For this reason, we will describe only a few of the more common types.

Standard Photography. Aerial photography is the earliest technique used and it is still the most common. Aerial survey cameras are highly developed and largely "off-the-shelf" items. Cameras accommodate film sizes from 70 mm up to about 9 by 18 in. High resolution can be obtained as we will attempt to demonstrate in a later section when some sample results are described. In larger aircraft where an independent observer may be carried, television is also being used. For some types of surveys, "real-time" viewing of results is important and permanent records can also be otained on magnetic tape.

IR Photography. With either photographic or television observations, the equipment is often fitted with selective filters to make observations in particular parts of the spectrum. Color infrared photography is becoming particularly useful for many applications and such imagery can be obtained either by direct use of color IR film or by a technique called reconstituted or false color IR. With this technique three black and white films are exposed simultaneously and individually to exactly the same scene while using appropriate filters to the green, red, and IR wave lengths. Each film is useful by itself; in addition, however, in ground laboratories the film can be projected back through green, blue, and red filters respectively, to make a reconstituted IR color photograph. The resulting photograph is not only striking but permits very detailed analysis. In this process healthy vegetation containing much chlorophyl appears bright red; unhealthy growth appears faded pink or white, bare soil appears blue-grey, and water appears almost black. A variety of radiometers and thermal imagers are also used to make observations in the longer wavelength thermal IR spectral region. Some of these techniques were referred to in the earlier discussion of the problem of locating potential landslides.

Microwave. In another part of the spectrum, increasing use is being made of microwave radiometers. By the use of instruments for various selected wave lengths, brightness temperatures and moisture content can be obtained for soil, snow, and various regions of the atmosphere. Ice studies have been made using a variety of microwave sensors on our CV 990 aircraft operating over lakes and artic oceans. These studies lead to the ability to estimate ice thickness remotely and to distinguish remotely newly formed ice from old year ice (or so-called ice islands). Ice fissures or so-called plenums can also be identified.

Air Sampling. With the increasing interest in air pollution, more and more use is being made of air sampling. The techniques are relatively straightforward. Pitot tubes are used to collect the samples. Both gases and particulates can be studied. For some air contaminants, such as ozone and most oxidants, analyses can be performed in flight. For the analyses of more complicated chemicals, such as hydrocarbons, and of particulates samples must be returned to ground-based laboratories where a variety of techniques such as gas chromatography and micro photography can be employed.

Magnetometers. The use of magnetometers in aerial surveys is historically second only to photography. Oil and mining interests have long used airborne instruments to identify local anomalies in the magnetic field as evidence for locating mineral deposits. Some refinements in the techniques are currently being explored as a result of the technology developed for scientific instruments used in the space program. Many, many spacecraft – from the Apollo lunar rover to the Pioneer X presently on its way to Jupiter – have carried magnetometers of one type or another. Many of these space-borne magnetometers have been designed for three-axis measurements and this feature is now being investigated in aerial surveys. By use of the vector properties in addition to the scalar properties of magnetic fields, studies one being made not only of local geological conditions but also of large scale phenomena such as earthquake fissures and large mass movements including continental drift. These and other types of instruments are carried on a variety of airborne platforms as will be discussed in the next section.

Remote Sensing Aircraft

The operational requirements associated with various aerial surveys result in the use of many different types of aircraft. Some surveys may cover only a very small region such as an individual lake or valley while others may cover an entire state or nation. Sensors have varying fields of view and resolution. Depending on the application, a light general aviation aircraft or a large jet transport may be the more appropriate platform.

Some feeling for the variety of aircraft involved can be developed by using as examples the aircraft we have used in our several programs at the Ames Research Center. For air sampling work in the Los Angeles basin, we have used the Cessna 401 shown in Fig. 1. It is especially well suited for this type of work and carries a scientific instrumentation payload of 400 to 500 lb. It normally operates at altitudes under 20,000 ft.

For our programs to study such things as ocean plankton, arctic ice, soil moisture, sea roughness and wind conditions, meteorological studies, atmospheric characteristics, and other such phenomena, we have employed a highly instrumented Convair 990. This aircraft is shown in flight over San Francisco's Golden Gate Bridge in Fig. 2. Specially installed observation windows used for some of the instrumentation can be seen above the normal aircraft windows.

In addition, special downward looking windows and cavities for microwave and radar antennas have been built into the aircraft. A view of the interior of this aircraft can be seen in Fig. 3. On a normal expedition, this aircraft will carry 12 to 15 experimenters and their instrumentation. The scientific payload is of the order of 10,000 lb. As can be seen in Fig. 3, most of the instruments are modified standard laboratory equipment. The main requirement imposed on an experiment is based on safety. The airborne equipment must be mounted to withstand loads of −9 to +15 g's axial, +7 to −2 g's vertically, and ±1.5 g's lateral. Since the experimenter accompanies the instrument, he can maintain surveillance of the data being obtained and he can effect equipment maintenance and minor repairs in flight. For these several reasons, the equipment is relatively inexpensive, especially by some standards. For longer expeditions to remote areas, ground personnel are also carried for a total flight complement of about 40. This aircraft is truly an airborne laboratory that operates at altitudes up to about 45,000 ft.

As a precursor to the Earth Resources Technology Satellite, we have used the high-altitude Earth Resources Survey aircraft. One of these aircraft is shown in Fig. 4. These aircraft are operated up to 65,000 ft altitude and normally carry a battery of up to five cameras. A variety of photographic imagery, including the reconstituted color IR technique discussed earlier, has been obtained from these aircraft. Individuals can obtain results from the Department of the Interior. The aircraft carries only the pilot as crew, thus the remote sensors must be automated.

From the Manned Spacecraft Center in Houston, the NASA also operates a variety of Earth Resources Survey aircraft.

Throughout NASA, therefore, the number of aircraft involved is relatively small, about 10 in total. As the foregoing descriptions indicate, most of these are specially adapted military or transport aircraft. Most of the aircraft used for aerial surveys in this country are general aviation types and some helicopters. FAA records show that for the end of 1971, 230 aircraft were used for aerial surveys and another 31 for patrolling. Thus the total number of aircraft involved is not large, especially when compared to the more than 2000 commercial transports and more than 100,000 general aviation aircraft registered in this country. In addition, of the 275 companies engaged in aerial surveys, less than 50 are equipped for nonphotographic remote sensing.

The subjects of potential users, sensors, and survey aircraft have now been discussed briefly and as a final subject we will examine samples of the data presently being obtained from aircraft in earth survey work.

Sample Results

The wide variety of users, sensors, and aircraft involved in earth resources surveys result in an even wider variety of data being available. As noted earlier, the Earth Resources Technology Satellite will provide data for approximately 300 experimenters. The number of scientists, agencies, and industrial concerns involved in aerial surveys is even greater. It is not possible, therefore, to do justice in any comprehensive way to the scope of information that is becoming available. Rather than try, we will examine only a few selected samples.

We will examine typical results from air pollution studies in the Los Angeles basin. The Cessna 401 was flown in a series of patterns over the Los Angeles area. These patterns included linear and saw-tooth ground tracks, spiral ascents and descents, and even touch-and-goes to obtain data down to ground level. The collected data were reduced and analyzed and pollution profiles were developed from the results. One profile for ozone is shown in Fig. 5. On the sample day, measurable ozone concentrations extended to 3000 ft altitude and the highest concentration was about .25 parts per million. In addition to providing basic information on pollution distribution, the profiles are also useful for guiding analytical studies of pollution movement and dissipation. Equipment to measure atmospheric pollution is being developed on the Ames Convair 990 for certification and installation on commercial Boeing 747 operated by the airlines. The equipment will be used to get world-wide statistical measurements of air pollution. Devices for high altitude measurements are also being developed on the CV 990 for later use on the Earth Resources Survey aircraft. These devices will be used to obtain large scale upper level pollution measurements. From both sets of measurements, it is hoped that a better understanding of pollution problems will evolve.

Other types of pollution are threatening Lake Tahoe. For example, sedimentation is being deposited along some areas of the shore. Sedimentation plumes are readily visible in photographs taken from high altitude. One of these photographs is shown in Fig. 6. From photographs such as this, it is possible to develop relief models of the deposited material. One of these models is shown in Fig. 7. These data are being used by geologists and hydrologists studying the Tahoe sediment problem.

Black and white prints of IR photographs taken of part of the agricultural area around Stockton, California, are shown in Fig. 8. (Color photographs are available showing more contrast.) These photographs were taken one month apart and the platform was again an aircraft flying at about 65,000 ft. The IR photographs show the differences between healthy crops, harvested areas, and newly cultivated areas. The differences in the distributions between the two dates are also apparent. Photographs such as these are very valuable for estimating the status and probable yield of many crops. They are also useful in the early identification of crop diseases, drought damage, etc.

Recent examples of aerial photography used for disaster assessment are shown in Figs. 9 and 10. Figure 9 shows a mosaic of the flooded area caused by a break in the dike near Isleton, California. The Corps of Engineers along with representatives of the State of California found these photographs and others taken at various stages of flooding to be useful in damage assessment. Other similar photos have been obtained of recently flooded areas in the Eastern United States.

A mosaic of the forest fire area near Big Sur, California, is shown in Fig. 10. High resolution black and white pictures were made available quickly to fire line crews. Aircraft flight altitude was selected so that photo scales matched those of maps used by fire crews. With this easy comparison and high resolution, crews could quickly identify fire activity in remote canyons. Access trails not shown on maps could also be identified. With magnification, bulldozers and even individual firefighters could be seen. Infrared images obtained simultaneously permitted hotspots (potential rekindling sources) to be located that could not be easily located from the ground. From the IR pictures, the type of foliage in front of the fire could be appraised. With this information and wind inputs, the firefighters used computerized techniques to assess the future dangers from the fire and to plan counter actions effectively.

As a final sample of aerial survey data, we have selected an aerial photograph covering virtually the entire city of San Francisco. This photograph is shown in Fig. 11. Clearly visible in the photograph are the Golden Gate Bridge, all of the city streets and freeways, park areas, docks, and even ships in the bay. While this particular photograph is indeed spectacular, the combination of coverage and detail possible in modern aerial surveys provides results such as this one extremely valuable in urban planning and land use studies. There is a program underway to photograph the entire state of Arizona with the kind of detail shown in Fig. 11.

Concluding Remarks

The foregoing discussion covers only a very few examples of the earth survey data that can be obtained using modern sensors mounted on appropriate aircraft. The needs for this and similar information are extensive and growing and there is a variety of interested users of survey results. Existing and possible users cover the fields of agriculture, forestry, oceanography, hydrology, geology, and geography. In view of this demand, there is a large potential for aviation to make a major contribution to improving the environment, to conserving natural resources, and to economic growth.

The sensors required for aviation to make these contributions are evolving rapidly, in part, from well-established aerial reconnaissance technology, and in part, from technology developed for the space program. The number of aircraft used for surveys in the United States is relatively small; on the order of a few hundred. Most of these are used for standard aerial photography. Since a wide variety of reliable aircraft are available and since their combined operating envelopes appear to cover the needs of the survey programs, a significant market for new type aircraft is not envisaged. Rather, adaptations of existing general aviation, commercial, and military aircraft appear to satisfy survey needs.

Bibliography

Proceedings of the First Symposium on Remote Sensing of Environment, 13–15 February 1962, Institute of Science and Technology, The University of Michigan.

Proceedings of the Second Symposium on Remote Sensing of Environment, 15–17 October 1962, Institute of Science and Technology, The University of Michigan.

Proceedings of the Third Symposium on Remote Sensing of Environment, 14–16 October 1964, Institute of Science and Technology, The University of Michigan.

Proceedings of the Fourth Symposium on Remote Sensing of Environment, 12–14 April 1966, Institute of Science and Technology, The University of Michigan.

Proceedings of the Fifth Symposium on Remote Sensing of Environment, 16–18 April 1968, Institute of Science and Technology, The University of Michigan.

Proceedings of the Sixth Symposium on Remote Sensing of Environment, October 1969, Institute of Science and Technology, The University of Michigan.

Proceedings of the Seventh Symposium on Remote Sensing of Environment, May 1971, Institute of Science and Technology, The University of Michigan.

Selected Papers on Remote Sensing of Environment, *Amer. Soc. of Photogrammetrist*, Willow Run Laboratories, Institute of Science and Technology, University of Michigan, July 1966.

First Annual Earth Resources Aircraft Program Status Review, 16–18 September 1968, Manned Spacecraft Center, Houston (3 volumes).

Second Annual Earth Resources Aircraft Program Status Review, 16–18 September 1969, Manned Spacecraft Center, Houston (3 volumes).

Earth Survey Bibliography: "A KWIC Index of Remote Sensing Information," William I. Thompson, September 1970, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass.

NASA SP 275, "Monitoring Earth Resources from Aircraft and Spacecraft, R. Colwell, University of California, 1971.

Remote Sensing of Earth Resources, A Compilation of Papers Prepared for the *13th Meeting of the Panel on Science and Technology*, Committee on Science and Astronautics, U.S. House of Representatives, U.S. G.P.O. 1972.

Figure Captions

Fig. 1. Cessna 1 used for air sampling

Fig. 2. Convair 990 used in Earth Observations Program at NASA Ames Research Center

Fig. 3. Interior of Convair 990 showing typical installation of scientific equipment

Fig. 4. Earth Resources Survey aircraft

Fig. 5. Ozone profiles in Los Angeles Basin based on data obtained with Cessna 401

Fig. 6. Sedimentation plume in Lake Tahoe observed from high altitude

Fig. 7. Sedimentation plume profiles based on aircraft observations

Fig. 8. Black and white prints of IR photographs of Stockton, California, and surrounding agriculture region

(a) October 19, 1971

(b) November 19, 1971

Fig. 9. Flood damage around Isleton, California

Fig. 10. Aerial reconnaissance of forest fire at Big Sur, California

Fig. 11. San Francisco, California, as observed from an Aircraft at 65,000 ft

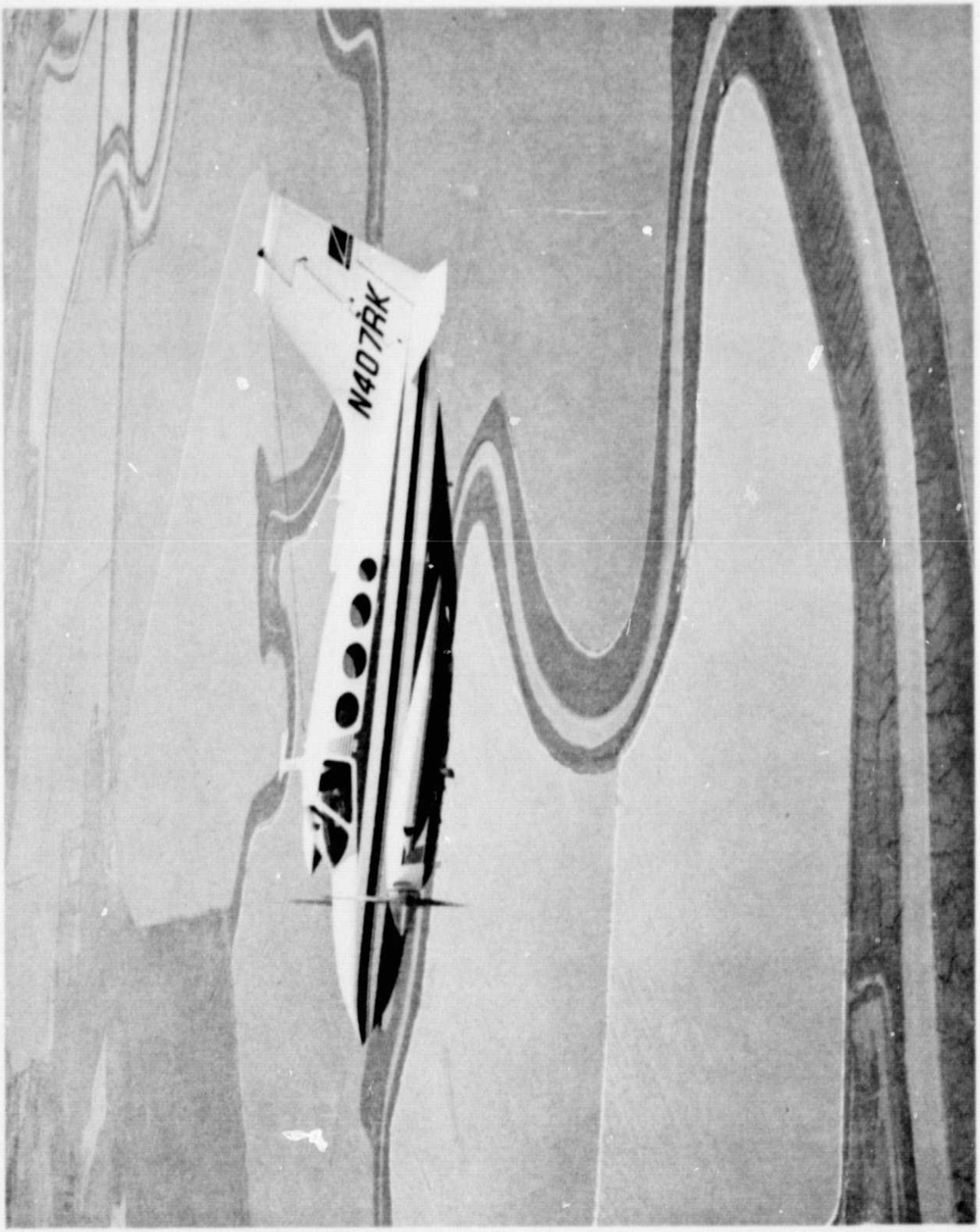

Figure 1.

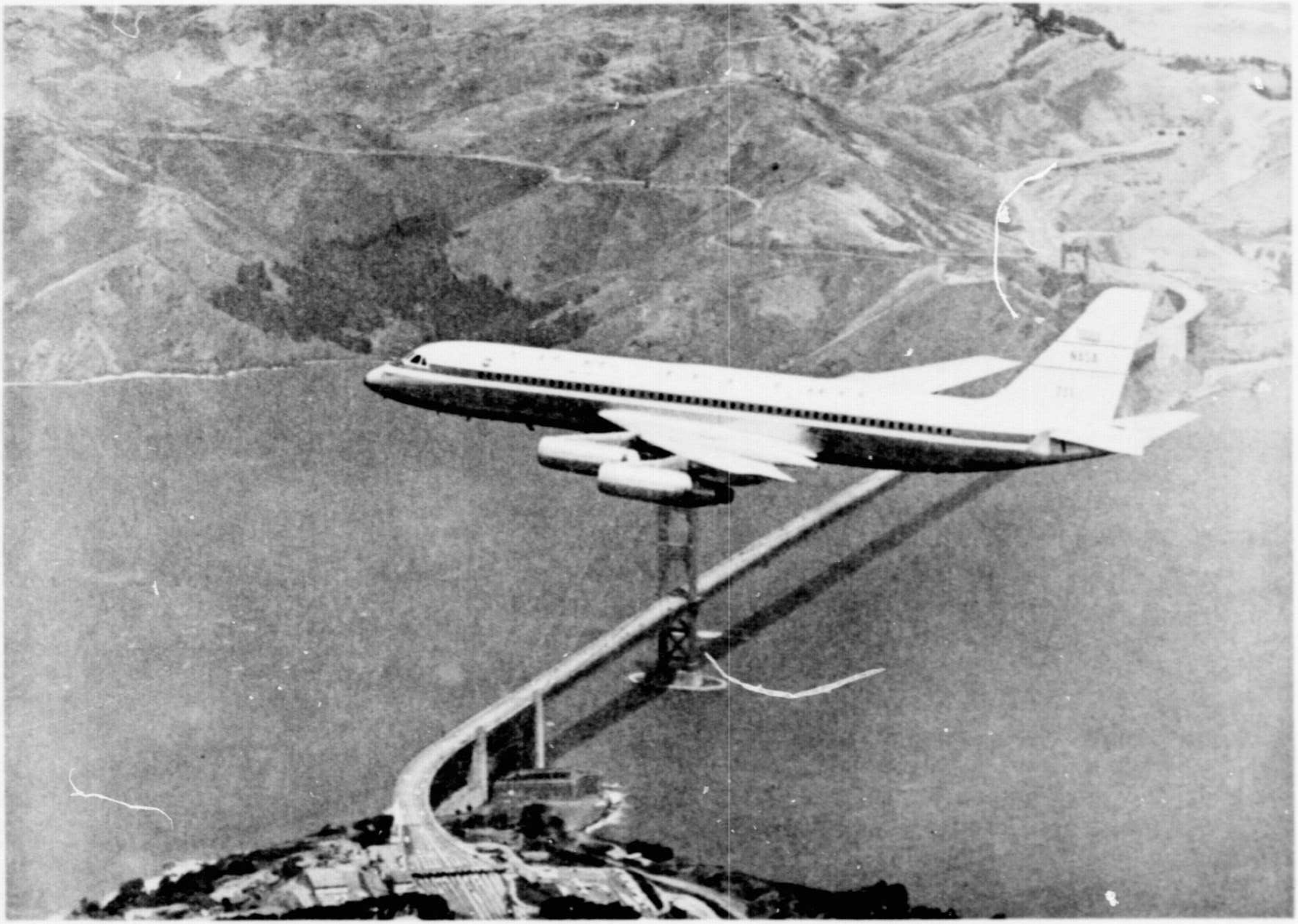

Figure 2.

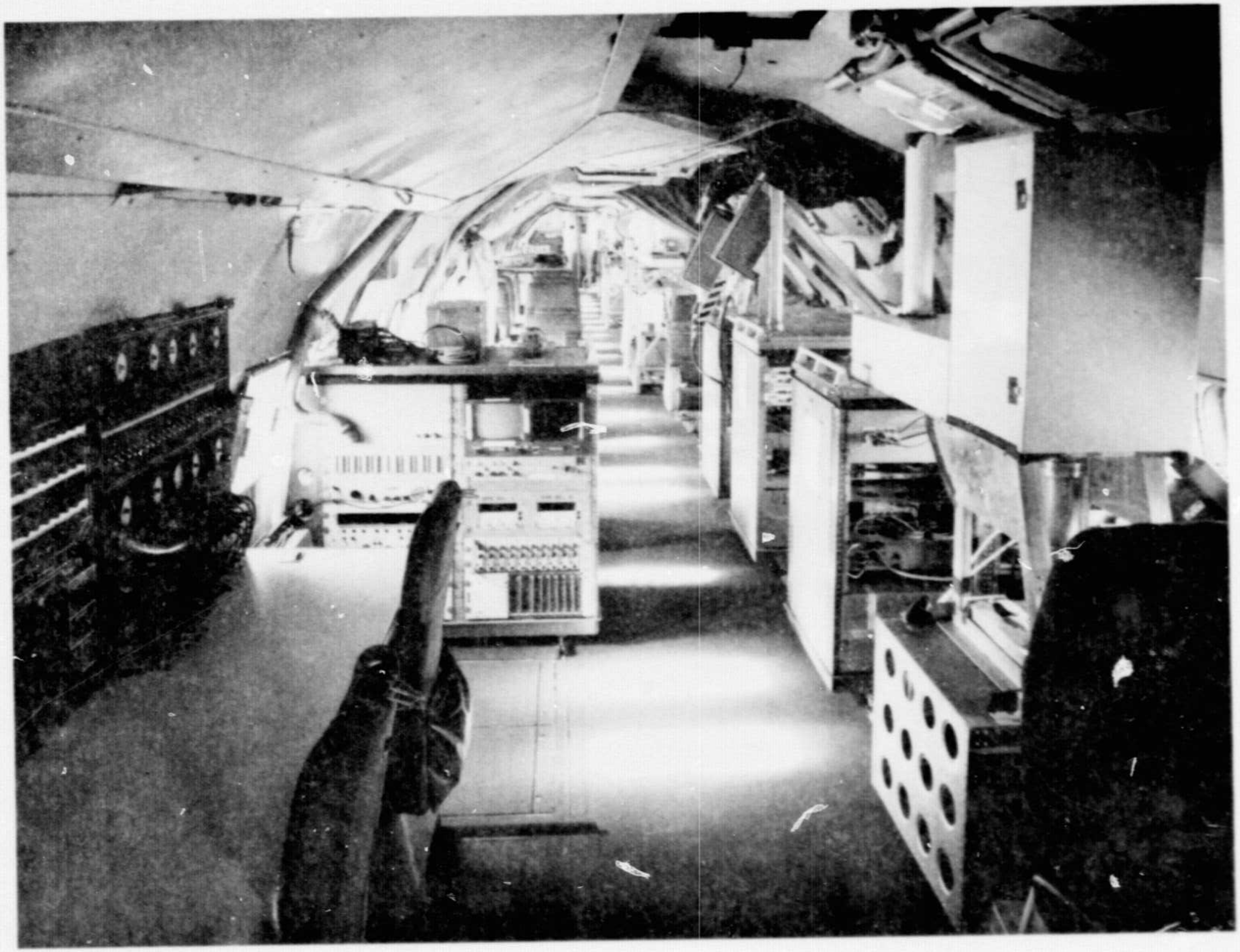

Figure 3.

Figure 4.

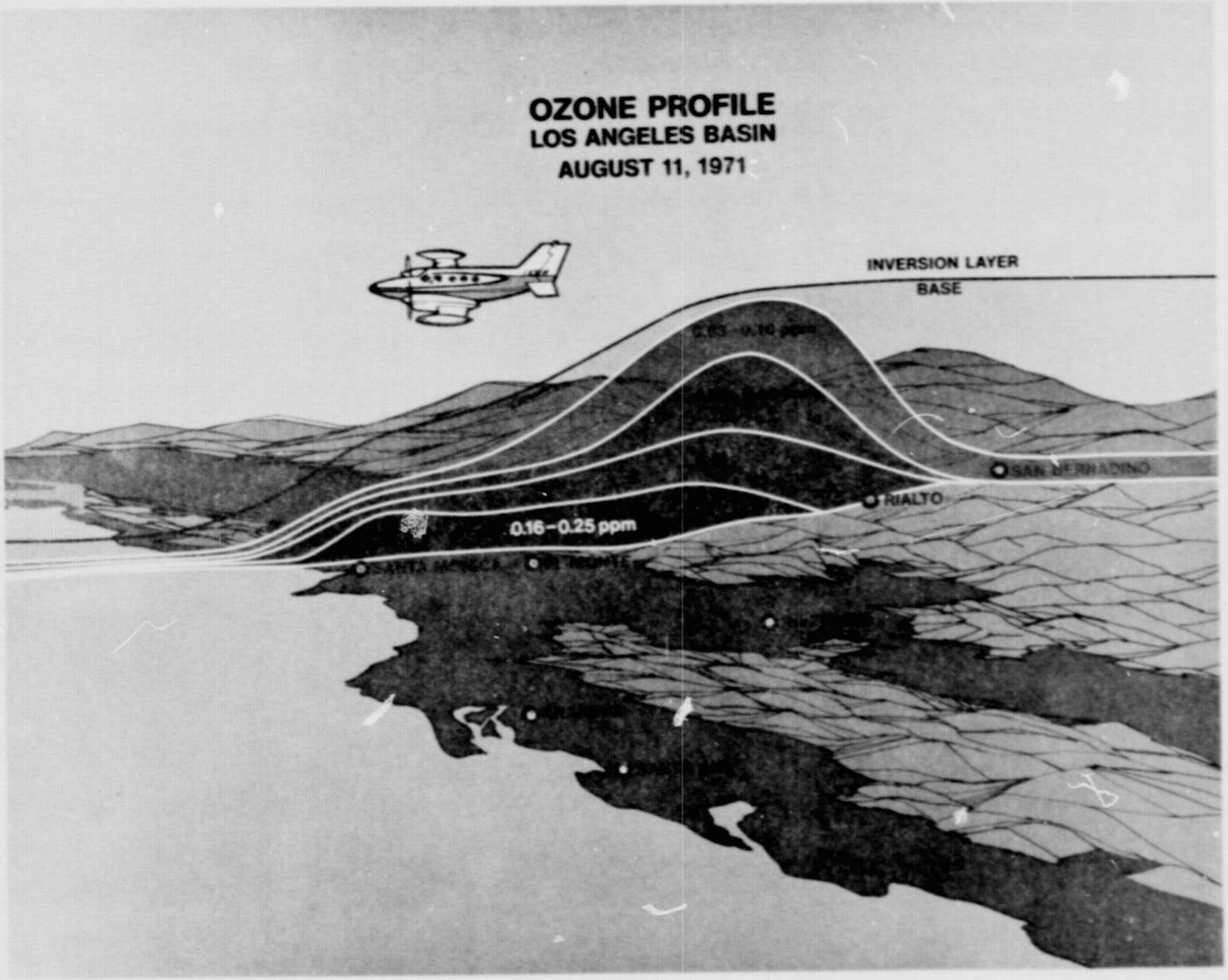
OZONE PROFILE
LOS ANGELES BASIN
AUGUST 11, 1971
INVERSION LAYER
BASE
0.16–0.25 ppm
RIALTO
SAN BERNADINO

Figure 5.

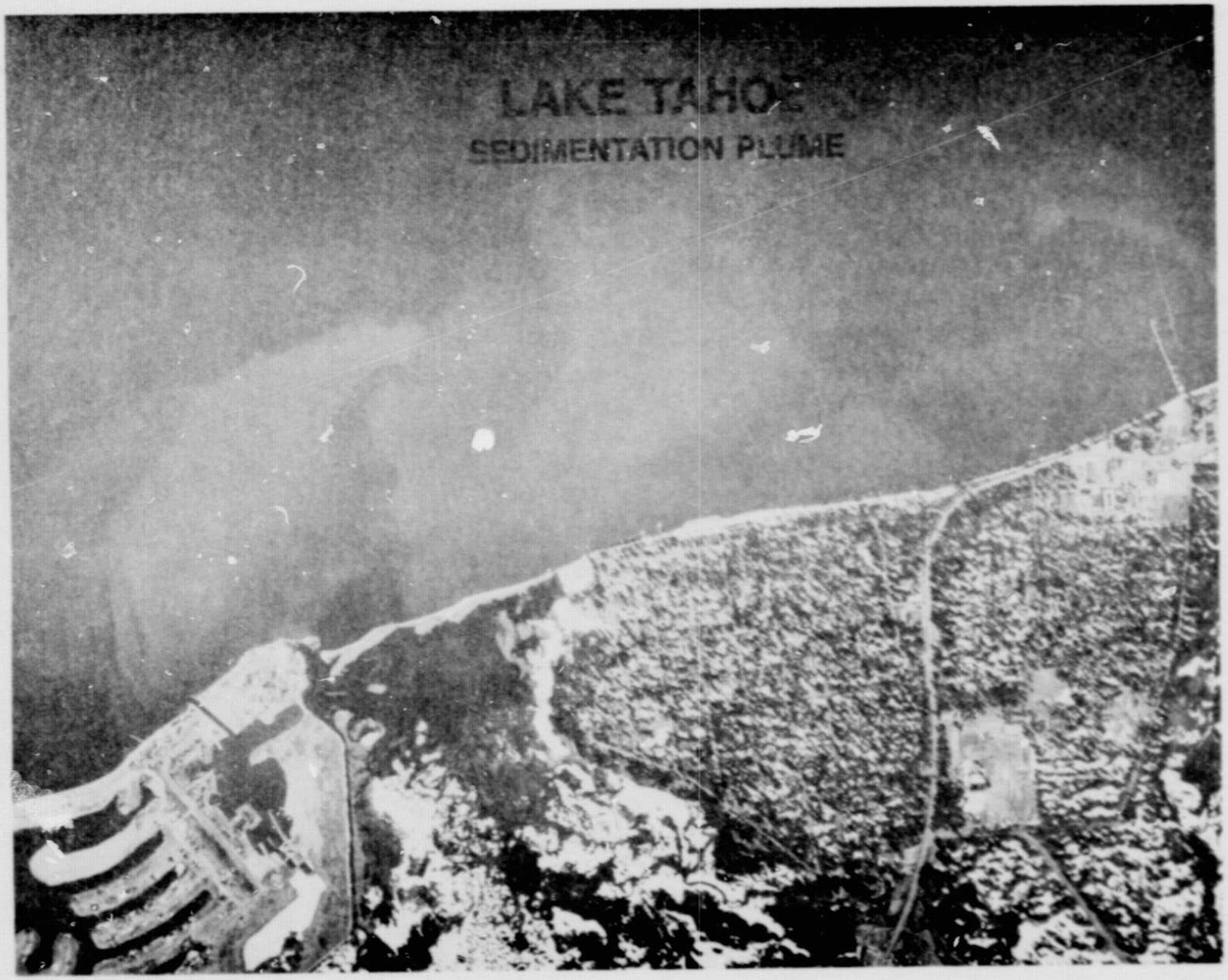

Figure 6.

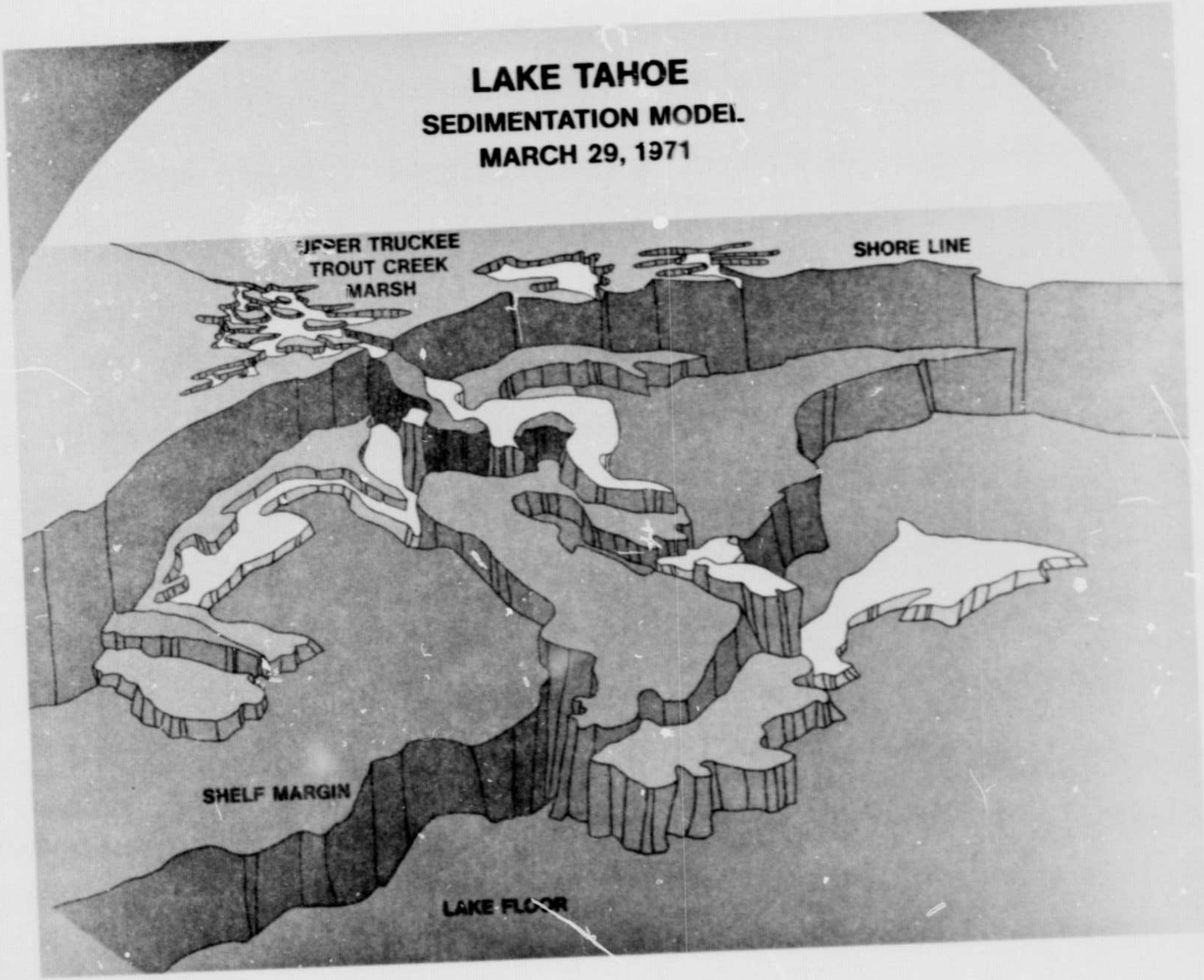
LAKE TAHOE
SEDIMENTATION MODEL
MARCH 29, 1971
UPPER TRUCKEE
TROUT CREEK
MARSH
SHORE LINE
SHELF MARGIN
LAKE FLOOR

Figure 7.

Figure 8(a).

Figure 8(b).

DELTA REGION – NO. CALIFORNIA
FLOOD ASSESSMENT PHOTOMOSAIC

DATE • 6/21/72 • 20 48 GMT
FLIGHT ALTITUDE – 45,000'
HR-732 CAMERA (24-INCH FOCAL LENGTH)
FILM TYPE – 3400

NASA AMES RESEARCH CENTER
AIRBORNE SCIENCE OFFICE

Figure 9.

MOLERA — BIG SUR FIRE

AUGUST 4, 1972

ALTITUDE: 27000 MSL

EARTH RESOURCES AIRCRAFT PROJECT

AIRBORNE SCIENCE OFFICE

NASA AMES RESEARCH CENTER
MOFFETT FIELD, CALIFORNIA

A - POINT OF ORIGIN
B - MAJOR HOT SPOT
C - FIRE RETARDANT
CHEMICAL DROP

Figure 10.

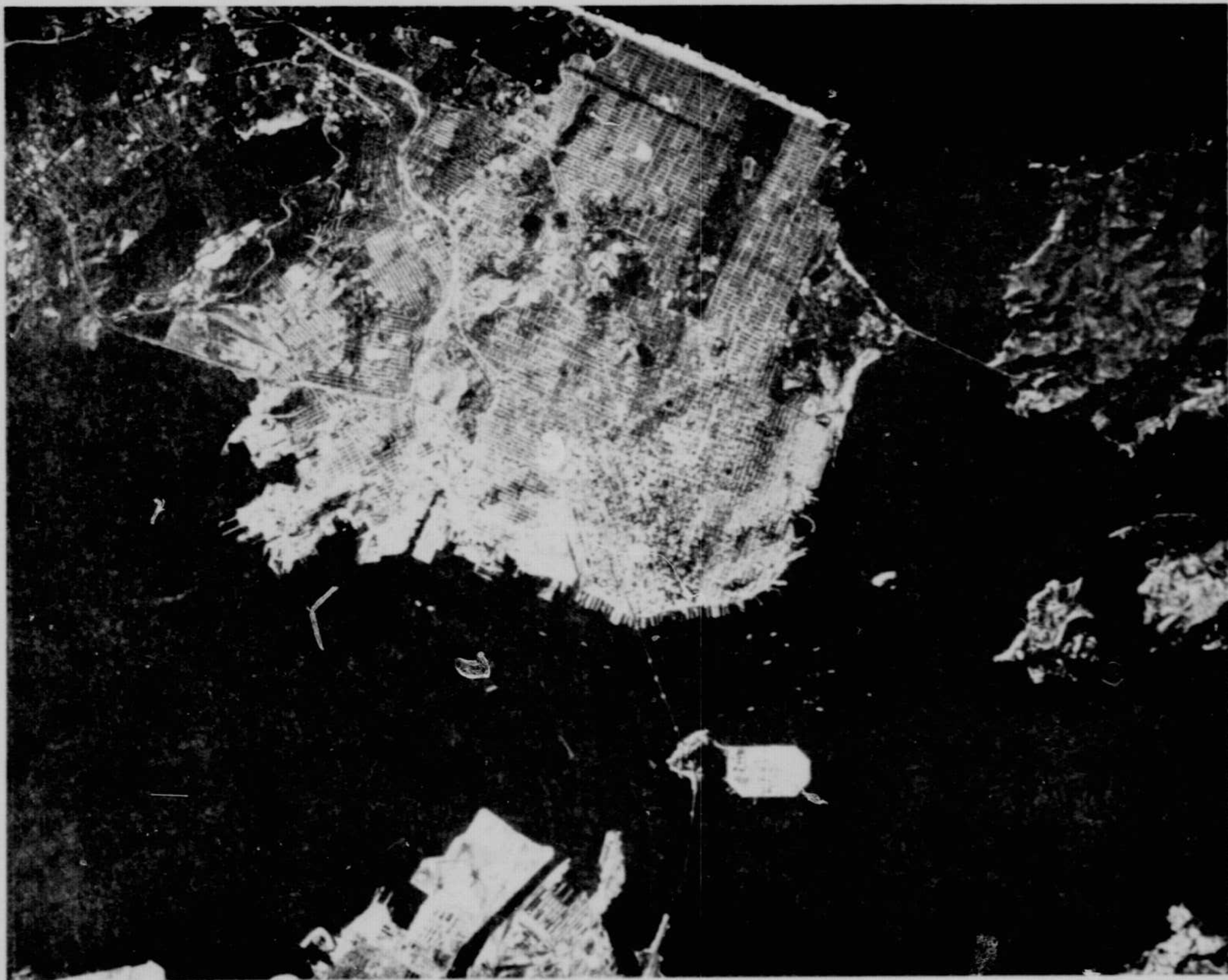

Figure 11.