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Milestones in Airborne Astronomy: From the 1920's to the Present

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ABSTRACT

The use of airplanes for astronomical observations began in the 1920's. From then until the early 1960's, almost all of the observations made from aircraft were for the purpose of viewing solar eclipses. Due to advances in technology and increasing interest in infrared astronomy, the use of airplanes for astronomy expanded during the 1960's to include planetary observations and a wide range of other studies. This paper describes some of the major milestones of airborne astronomy, from the1920's to the present.

INTRODUCTION

The history of airborne astronomy goes back to the early days of aviation itself, with the first airborne observations made from biplanes during the 1920's and 1930's. Until the 1960's, airborne astronomy was predominantly undertaken for the purpose of observing solar eclipses. The aircraft's mobility allowed cloud-free observing most of the time, placement of the instrumentation at the exact geographic location desired, and increased the time spent in totality, as the aircraft could stay within the shadow much longer than a ground-based observer. A turning point was reached during the mid-1960's when the invention of new infrared sensors caused infrared astronomy to flourish. Also, the importance of ascending to high altitudes into regions of cold, dry atmosphere was realized. These events, coupled with the increasing availability of jet aircraft during the 1950's and more sophisticated telescope technologies, led to the rapid extension of airborne astronomy into areas other than eclipse studies, and was the beginning of airborne astronomy as we know it today.

Countless astronomy flights have been carried out more or less continuously from the 1920's, for research and enjoyment, by scientists and non-scientists alike. The April 1979 issue of Life magazine[1], for example, states that there were at least 1,000 planes in the air for the eclipse of February 26, 1979. This paper describes some of the important milestones in airborne astronomy - a detailed history of airborne astronomy is beyond its scope.

THE ECLIPSE OF SEPTEMBER 10, 1923: ASTRONOMY FROM BIPLANES

One of the first airborne astronomy attempts was undertaken by the US Navy, for the solar eclipse of September 10, 1923. [2] This was an extensive effort involving sixteen Navy planes, including an F5-L "flying boat" biplane. Although records of all the aircraft involved are not available, the fleet most likely also included one or more DeHaviland DH-4B biplanes. The primary objective of the expedition was to determine the centerline of the eclipse from the air. On the morning of September 10, the aircraft took off and were positioned along the expected path of totality, at altitudes ranging from 5,500 - 16,500 feet. Some useful visual observations were made by the flyers, and thirty photographs were exposed, but none of the photographs successfully recorded the eclipse. Although the expedition could be considered a failure in some ways, it was successful in attracting the attention of the press and the general public, and in generating popular support for airborne science. Newspaper accounts credited the Navy with coming to the rescue of astronomers!

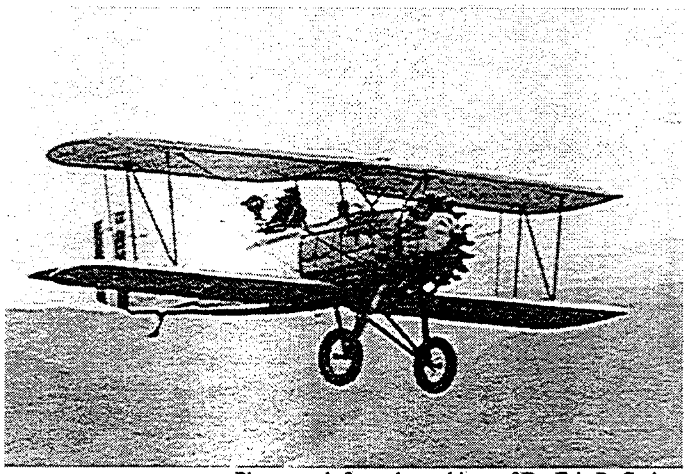
It is notable that one of the pilots involved in the 1923 eclipse endeavor was Captain Albert W. Stevens of the Army Air Corps, an accomplished aerial photographer who is considered by some to be the father of airborne astronomy. This was his first airborne solar eclipse flight. He went on to participate in the Honey Lake and National Geographic Society airborne eclipse expeditions described below, as well as many other missions from aircraft and balloons. In the 1920's Captain Stevens set altitude records from airplanes, recording the temperatures at the boundary of the stratosphere during those flights, and during the 1930's was one of the "aeronauts" to ascend in balloons during the "race to the stratosphere" .[3]

1930: THE HONEY LAKE EXPEDITION

For the eclipse of April 28, 1930, the Naval Observatory organized an expedition to Honey Lake, California.[2]This eclipse had a particularly short period of totality - only 1.5

seconds - and a narrow ground shadow. Because of these constraints, not many astronomers made plans to observe the event. However, it offered a good opportunity to observe the exact centerline of the eclipse, needed to make corrections to the lunar almanac, and was tailor-made to exploit the advantages of observing from aircraft.

Two naval aircraft, a Sikorsky PS-3, and a Vought O2U-1, were secured for the expedition. The Sikorsky was used to transport people and equipment to Honey Lake. The Vought O2U-1 was equipped with an Akeley motion picture camera for recording the eclipse shadow on film.



Photograph from the archives of Dr. Eric R. Craine

Figure 1. The O2U-1 flying over Honey Lake.

The expedition was a success. The ground observers, through breaks in the clouds, recorded film that showed that the ground station was within the shadow. The film obtained from the Vought O2U-1 recorded the approach of the shadow and was used to verify the correctness of the predicted path.

Photograph from the archives of Dr. Eric R. Craine

Figure 2: Chief photographer (left) and pilot on the O2U-1 aircraft used during the Honey Lake eclipse mission. Akeley motion picture camera is in the background.

1932: THE NATIONAL GEOGRAPHIC SOCIETY / ARMY AIR CORPS - ECLIPSE PHOTOGRAPHY FROM THE AIR

Building on the experience of the 1923 eclipse and the Honey Lake expedition, Albert Stevens undertook his third airborne eclipse expedition in 1932.[4] This expedition was a joint effort of the Army Air Corps and the National Geographic Society. The National Geographic Society had a ground party in place to study the eclipse, and was interested in recording the position of the shadow as it moved across the earth, which was best done from high altitude.

The path of totality for this eclipse was over Maine, New Hampshire and Canada. Captain Stevens took off from North Conway, New Hampshire on eclipse day, with three cameras on board: a long focal-length camera for photographing the corona, and a medium focal-length camera and a short focal-length camera for photographing the shadow. In addition, an electroscope was onboard for the measurement of cosmic rays.

The eclipse photography was carried out at an altitude of 27,000 ft. In those days, flying at such a high altitude was a challenge in itself. Captain Stevens was in the back of the airplane manipulating the cameras, and communicated with the pilot by short shrieks, or "yips". Two yips meant turn right. More double yips meant keep turning right, one yip meant turn left, and so forth. The plane was open cockpit, and keeping warm was a major problem. The aviators bundled up, head-to-toe, in layers of wool, down, and leather clothing, but still reported problems with the cold, particularly frozen fingers and toes. The crew used oxygen, but Captain Stevens reported that nevertheless, it was easy to become disoriented in flight, and to help remind himself of crucial procedures, wrote instructions in large letters on tape attached to the apparatus.

Captain Stevens, by quick sequential manipulation of the three cameras onboard, captured a series of excellent photos of the moon's shadow as it approached, and during totality obtained a photograph of the solar corona using an infrared filter. These photos were published in National Geographic Magazine's November 1932 issue.

The National Geographic article, written by Captain Stevens, describes in detail the difficulties encountered during this flight, including a tangling of his oxygen hose with the camera, a loss of engine power caused by the snagging of the pilot's glove on the throttle and ensuing dive to recover control, and the numbing of his hands as they struggled to operate the cameras in the bitter cold.

1945: ROYAL CANADIAN AIR FORCE "OPERATION ECLIPSE"

For the eclipse of July 9, 1945, the Royal Canadian Air Force (RCAF) carried out observations from four aircraft: a Spitfire, a Mitchell, and two Ansons.[5] This effort was part of a series of ionospheric observations sponsored by the Canadian Radio Wave Propagation Committee. Although the focus of this expedition was not strictly on astronomy, it's included in this paper because it is a good illustration of the technology that was in use during the 1940's, which had improved very much since the 1932 eclipse observations described above.

Three of the aircraft involved in the RCAF operation were outfitted with a total of seven standard cameras, of the type commonly used at that time for aerial photography. The second Anson carried a motion picture camera. Spectrographic and polarization measurements were made, as well as visual and infrared photographs of the solar corona and prominences.

There are several notable differences between this effort and the expeditions described above. The altitude of the aircraft ranged between 17,000 ft and 34,000 ft. The cameras were mounted behind special plate glass windows, and all except one were adjusted to automatically take exposures, once started. Three of the aircraft were kept on the proper heading using a modification to the pilot's gun sight; the pilot kept the sun centered on the sighting rings, which kept the cameras pointing at the sun. The spectra obtained during the mission may be the first ever taken from an aircraft.

1948: THE NATIONAL GEOGRAPHIC SOCIETY'S "OPERATION ECLIPSE"

For the annular solar eclipse of May 8, 1948, the National Geographic Society organized an expedition unprecedented in size.[6] Observers were stationed on the ground in Burma, Siam, China, southern Korea, Japan, and the Aleutian Islands. Two B-29 aircraft were also stationed in the Aleutians, as a backup to the ground observers, because of the high probability of bad weather.

As it turned out, bad weather interfered with most of the ground observations, a major disappointment, especially for an operation of its size. However, observers aboard the B-29's, ascending to 27,000 ft and 29,000 ft, were successful in obtaining photographs during totality.

These observations were made in spite of a risky situation that developed in flight, as the optical-glass domes that housed the cameras began to crack. Both aircraft experienced the trouble, the loud groaning sounds as the glass cracked causing considerable tension amongst the observers. Luckily, the domes held, and both aircraft landed safely, having successfully recorded the eclipse. The National Geographic article about this event reports on the "triumphant crews" landing at Amchitka after the eclipse mission.

The ultimate purpose of the National Geographic Operation Eclipse was to make measurements that could be used to determine more accurately the relative locations of points on the earth's surface. Again, the focus was not on astronomy. However, it was an important milestone in the history of airborne eclipse observations, because the success of the airborne observations stood out in such contrast to the largely unsuccessful ground operations. The story of Operation Eclipse is written up in a 47-page article in the March, 1949 edition of National Geographic magazine. The author offered two conclusions, one of which was that the use of aircraft for astronomical observations held great promise, as a kind of "eclipse insurance" for future expeditions. The importance of airborne observations was again shown, with high public visibility.

OPEN-DOOR OBSERVATIONS DURING THE ECLIPSE OF JUNE 30, 1954

The eclipse of June 30, 1954 was observed from the open door of a special Lincoln aircraft flying at an altitude of 30,000 ft.[7] Photographs obtained in flight were used to derive coronal brightness and polarization, along with sky brightness and polarization, and their variation with altitude. Details of the operation are only briefly described in a lengthy article by D.E. Blackwell, published in Monthly notices of the Royal Astronomical Society in 1955. The author makes the assertion that airborne astronomy observations should be made from an open port in the aircraft, not through an aircraft window. Regarding observation of the 1954 eclipse, the author notes that "it was found most convenient to fold the aircraft door back and to mount the camera in the open doorway in such a way that it could be guided in altitude and azimuth". Although the aircraft was capable of flight up to 43,000 ft., the observing altitude was limited to 30,000 ft., to give "the best compromise between sky darkening on the one hand, and aircraft stability and observer alertness on the other hand."

EARLY 1960'S: EVENTS COINCIDE TO CREATE A MAJOR TURNING POINT IN THE HISTORY OF AIRBORNE ASTRONOMY

A remarkable series of events during the early 1960's led to a rapid increase of activity in airborne astronomy. In 1963, the first major eclipse mission aboard a jet aircraft was successfully carried out. Sponsored by the National Geographic Society and Douglas Aircraft Company, this mission proved the feasibility and usefulness of observations from jet aircraft.

Also during the early sixties, Frank Low was performing pivotal experiments that would expand the window for infrared observations, up to 1000 microns. The invention of the Gallium-doped Germanium bolometer detector by Low in 1961[8], and his efforts in performing observations using open-port instruments on aircraft, were vitally important in furthering the development of airborne astronomy.

The 1963 signing of the Atmospheric Test Ban Treaty, which banned the testing of nuclear weapons in the atmosphere, prompted scientists from the Los Alamos Scientific Laboratory to propose an alternate use of three NC-135 test readiness aircraft. They suggested that the aircraft, originally intended for use as airborne laboratories kept in readiness should nuclear testing again become necessary, be used for solar eclipse observations. Their proposal was approved, and the three aircraft were made available for a highly successful series of solar eclipse missions, carried out from 1965 to 1980. Each of the events described above is written up in more detail in sections below.

And finally, the period from January 1, 1964, to December 31, 1965 was designated the International Quiet Solar Year (IQSY), the predicted minimum for solar activity. During the IQSY, scientists all over the world participated in coordinated measurements of solar phenomena.

Perhaps as a consequence of all of the above events and circumstances, no fewer than four 4-engine jet aircraft were deployed to the South Pacific for the solar eclipse of May 30, 1965: two Atomic Energy Commission (AEC) NC-135's were stationed in Samoa, and the newly-acquired NASA CV-990 and an Air Force KC-135 were stationed in Hawaii.[9] For the eclipse of November 1966, the third AEC aircraft was deployed, and all five aircraft participated in a massive coordinated effort, which also included simultaneous rocket experiments.[10]

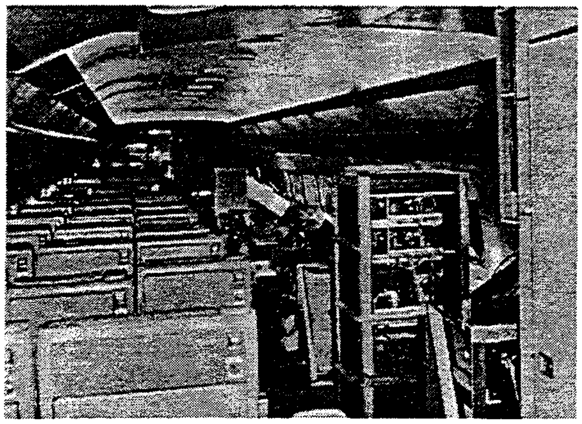
1963: NATIONAL GEOGRAPHIC SOCIETY - DOUGLAS AIRCRAFT COMPANY ECLIPSE EXPEDITION

The National Geographic Society (NGS) and Douglas Aircraft Company collaborated to organize a major airborne expedition for the July 20, 1963 eclipse[11]. Fifty-five scientists operated 25 scientific experiments on a DC-8 aircraft, which had been leased from Delta Airlines for the event. This was an international mission, involving a dozen organizations in addition to the NGS and Douglas Aircraft company.

The project was called APEQS - Aerial Photography of the Eclipse of the Quiet Sun. All seats on the right side of the aircraft, and four rows on the left, were removed to make room for science instruments. Among these was a 700 lb spectrograph to be used for recording a spectrum of a narrow band of the sun's corona. The spectrograph was mounted on a 6-inch telescope that received light from a gyro-stabilized heliostat tracking mirror. This kept the image of the sun stable to an accuracy of 1 arc minute.

The DC-8, flying at 525 miles per hour in the direction of the shadow's movement over the earth, at an altitude of 40,500 ft, stretched the time of totality to 142 seconds, compared to 100 seconds seen by observers on the ground. Among the many observations made were infrared measurements of the sun's upper atmosphere.

Although not all the observers met their goals for the flight, overall it was a highly successful mission. This was a significant milestone in the history of airborne astronomy, demonstrating clearly the potential of using jet aircraft for airborne astronomy. The aircraft proved a stable platform for science instruments and could fly fast at high altitudes.



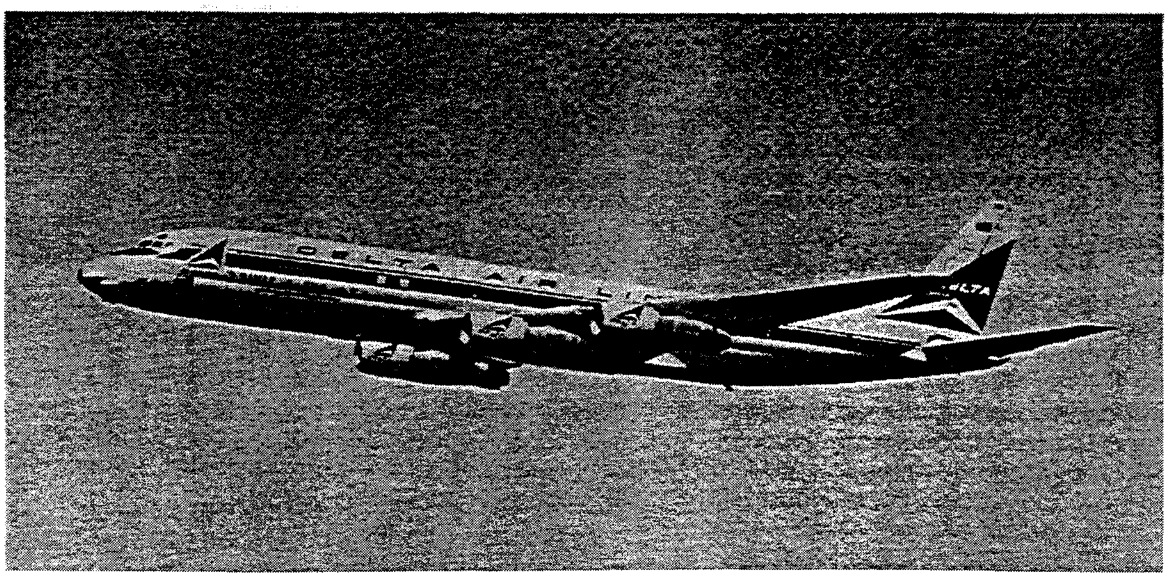
Douglas Aircraft Photo

Figure 3. Interior of the APEQS DC-8, showing instrumentation installed along the right side.

The APEQS scientific director and author of the National Geographic magazine article describing the event wrote of the "far-reaching conclusions that can already be drawn... that point to a new era in astronomical observation." A quote from one of the scientists onboard the mission ends the article. He said, "In such an observatory, astronomers could conveniently conduct many valuable experiments...in addition to those concerning eclipses of the sun."

Coincidentally, the scientific director of the Douglas/ NGS eclipse expedition was Wolfgang B. Klemperer, an aeronautical engineer who helped design the National Geographic - U.S. Army Air Corps stratospheric balloons in 1934-35. Albert Stevens, mentioned earlier in this paper as the pilot who flew on the earliest airborne eclipse expeditions, flew on the stratosphere balloon flights in 1934 and 1935.

Klemperer's assistant at the control desk of the DC-8 during the 1963 eclipse flight was Robert Cameron of Douglas Aircraft. Dr. Michel Bader of Ames Research Center directed one of the science teams aboard the aircraft. Bader and Cameron (who later went to work for NASA) became key participants in the start-up of NASA's airborne science program.



Douglas Aircraft Photo

Figure 4. DC-8 aircraft leased from Delta Airlines for the National Geographic Society - Douglas Aircraft APEQS solar eclipse mission in 1963

1965: THE BEGINNINGS OF NASA'S AIRBORNE ASTRONOMY PROGRAM ABOARD THE CV990 GALILEO OBSERVATORY

From their experiences on the historic National Geographic - Douglas Aircraft expedition in 1963, scientists at NASA Ames were convinced of the potential for the use of high-flying jet aircraft for astronomy. Through the efforts of team leader Michel Bader, a Convair 990 aircraft was purchased by NASA in 1964 for use as an airborne science platform. Thirteen apertures capable of holding optical-quality glass were installed along the upper left side of the fuselage. Its first mission was the solar eclipse of May 30, 1965.

From the beginning, the NASA airborne science program was open to scientists from around the country and the world. Setting the stage for this, the 1965 mission included scientists from the US, Switzerland, the Netherlands, Italy, and Belgium. Professor Guglielmo Righini from Italy was onboard the eclipse flight. During totality, he looked out at the eclipse and spotted the brighter moons of Jupiter, the first objects seen by Galileo with his telescope. Dr. Righini immediately suggested that the CV990 be given the name "Galileo"[13]. His suggestion was quickly approved by NASA. The CV-990 was operated from 1965 to 1973, when tragically the aircraft and everyone onboard were lost in a mid-air collision while attempting to land at Moffett Field, CA. NASA replaced the Galileo with another CV-990, called Galileo II, which was used very little for airborne astronomy, as, by then, the Learjet and the Kuiper Airborne Observatory were in operation.

The Galileo I was used for astronomical observations during the late 1960's and early 1970's. The major Galileo I airborne astronomy missions are summarized inTable 1.

Table 1. NASA CV-990 Galileo I astronomy missions

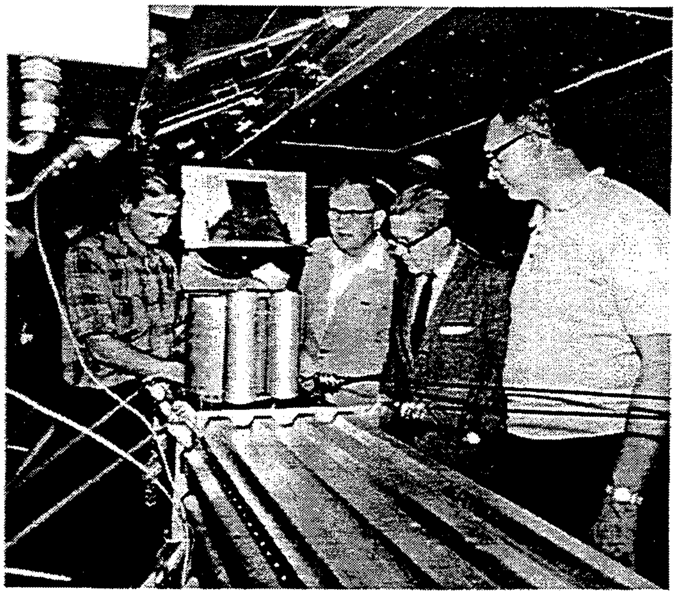
Year	Galileo I Mission
5/65	Solar eclipse
10/65	Comet Ikeya-Seki
10/66	Solar eclipse
1967 to 1969	IR solar and planetary observations
8/67 & 10/67	Solar constant studies
8/71	Mars opposition expedition
10/72	Giacobinid meteor shower expedition
1972	Solar eclipse

One of the scientists who flew on the CV-990 Galileo I was Gerard P. Kuiper, Director of the Lunar and Planetary Lab at the University of Arizona, who was interested in obtaining near-infrared spectra of bright planets, free of contamination from the Earth's atmosphere. Flying on the CV-990, using a telescope with a gyro-stabilized heliostat to achieve accurate pointing and guiding, Dr. Kuiper obtained a remarkable set of near-infrared spectra of Venus, showing that the clouds of Venus were not made of water, as had been widely believed. During another mission in 1971, Dr. Kuiper's team, and another group from Cornell University made observations of Mars during opposition.

Figure 5. NASA CV-990 - Galileo I: Observation windows can be seen along the upper left side of the fuselage, as well as special ports in the passenger windows.

NASA photo

Figure 6. Robert Cameron and Earl Petersen on NASA's Galileo I, with a Questar telescope and gyro-stabilized heliostat used during the Comet Ikeya-Seki mission in 1965.



NASA photo

Figure 7. Gerard P. Kuiper (second from left) onboard NASA's CV-990 Galileo observatory. With Dr. Kuiper are (left to right) Dale Cruikshank, Ferdinand DeWiess, and Godfrey Sill.

1965 TO 1980: AIRBORNE OBSERVATIONS WITH ATOMIC ENERGY COMMISSION NC-135 AIRCRAFT

An interesting chapter in the history of airborne astronomy concerns the use of three NC-135 aircraft operated by the Atomic Energy Commission for solar eclipse observations.

Before ratifying the 1963 Nuclear Test Ban treaty, which prohibited nuclear tests in the atmosphere, outer space and underwater, Congress required that certain safeguards be put in place. One of these was that the U.S. should maintain the ability to resume nuclear tests quickly if necessary, or should there be any abrogation of the treaty. To satisfy at least part of this requirement, the Atomic Energy Commission obtained joint interest in three NC-135's maintained by the Air Force, and modified them for use as flying laboratories.[14] To keep the aircraft crews active and capable of fast deployment, the AEC performed exercises using simulations instead of real weapons tests.

The aircraft were made available to the Los Alamos Scientific Laboratory (LASL, later to become Los Alamos National Laboratory), the Sandia Laboratory, and the Lawrence Livermore Laboratory. These three laboratories were each assigned one of the NC-135's, although they were available to the other labs and used interchangeably, as programmatic and science needs dictated. The individual histories of each of these aircraft, and their use by each of the laboratories, is beyond the scope of this paper. Included here is a summary of the Los Alamos Scientific Laboratory's use of the NC-135's for a series of eclipse missions.

The same year the treaty was signed, two scientists from LASL traveled to Northern Canada for the eclipse of July 20, 1963. Frustrated by clouds which obscured their view of the eclipse and swarms of stinging mosquitoes, and aware of the success of the NGS/Douglas Aircraft mission, they proposed that the AEC NC-135's be used for airborne observations during the May 1965 eclipse.[15,16] There was much popular support amongst the scientists at LASL for this proposal, as they were not finding the simulation exercises particularly satisfying. The proposal was accepted, and the series of eclipse flights was born.

The aircraft were already equipped with the best communications equipment available, and windows for various types of observations; they were well-suited for airborne eclipse studies. In May of 1965, two of the three AEC NC-135's were deployed to American Samoa for solar eclipse observations by LASL and the Sandia Laboratory. The first LASL mission was led by astrophysicist Arthur Cox; in preparation for the mission, Cox and his fellow scientists worked feverishly to install special equipment for solar observations, including stabilized platforms for the instrumentation. The mission was a success, and LASL scientists went on to carry out six more eclipse expeditions, in 1966, 1970, 1972, 1973, 1979, and 1980.[17]

One of many notable aspects of the first LASL eclipse mission was the first airborne use of a 10-inch diameter, 80-inch focal length refracting telescope called the "Rube Goldberg", after the popular cartoon contraptions of that name. Designed by a group led by Donald Liebenberg of LASL, the "Rube" was modified extensively over the years to incorporate new ideas and technologies, and was considered the workhorse of the LASL eclipse missions.[18]

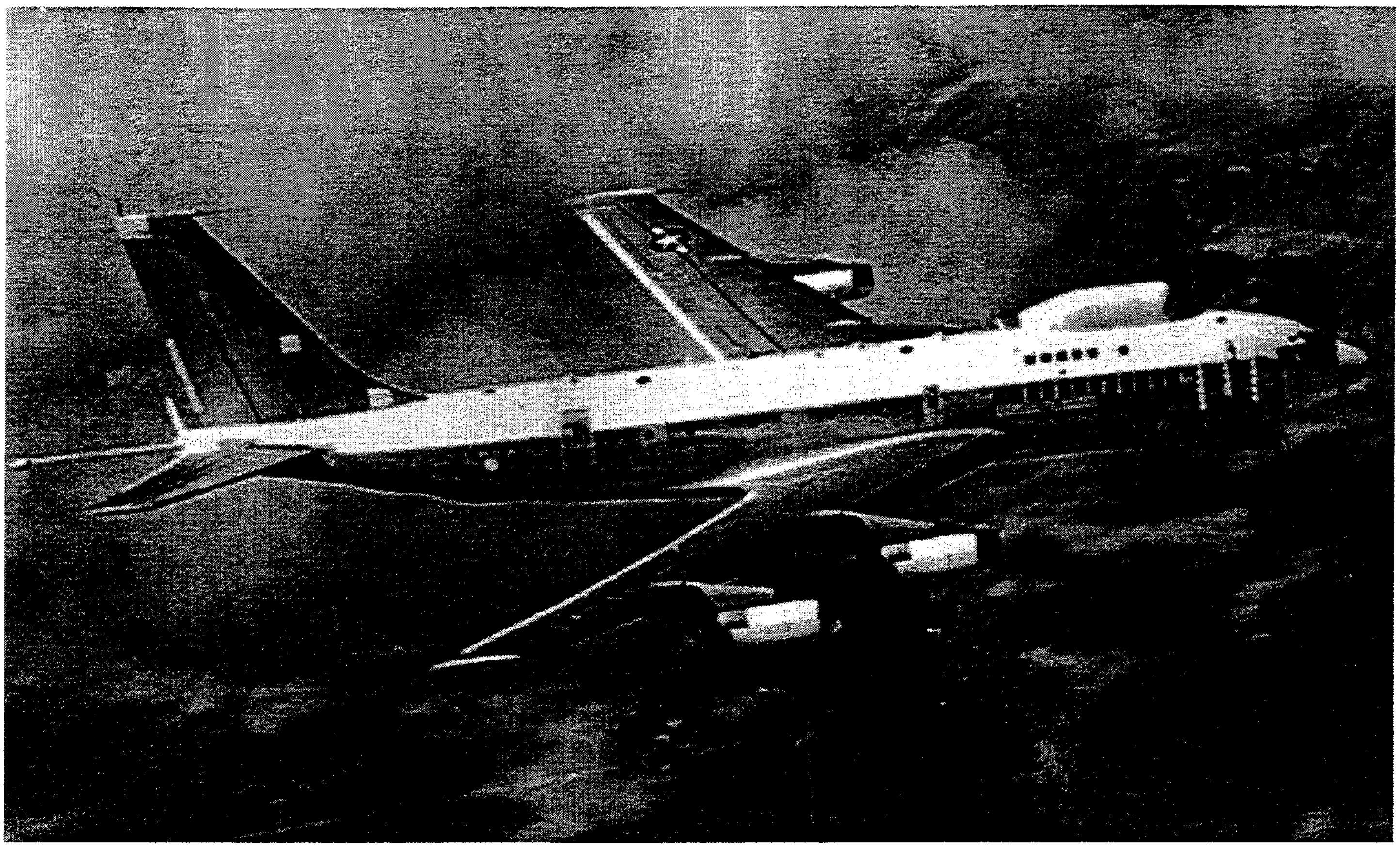


Photo from the archives of William Regan

Figure 8: AEC NC-135 used by Los Alamos National Laboratory for eclipse missions from 1965 to 1980.

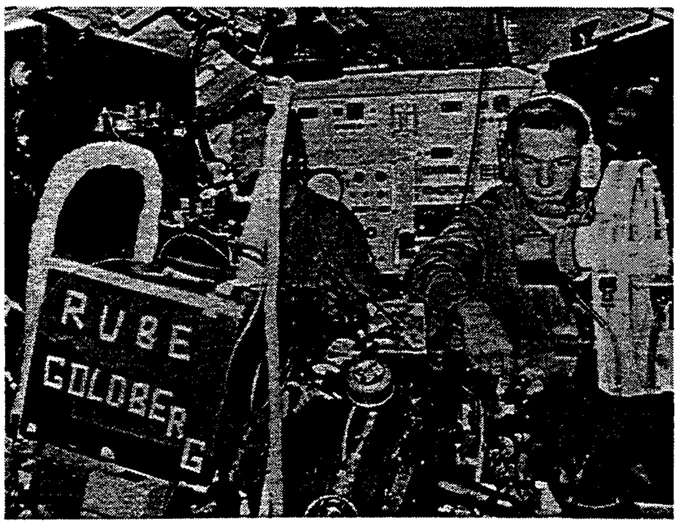


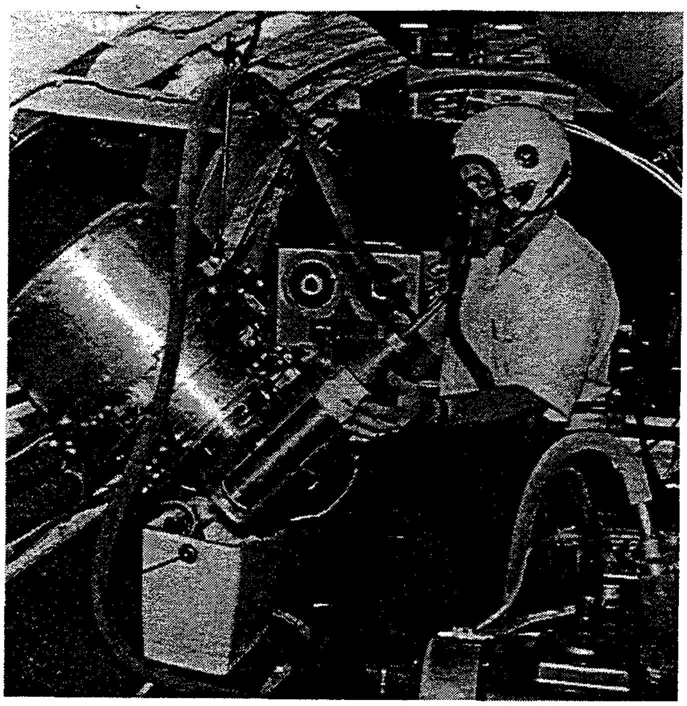
Figure 9: The Rube Goldberg telescope used during eclipse missions aboard the AEC NC-135 aircraft.

1968: NASA'S LEARJET OBSERVATORY TAKES TO THE SKIES

Encouraged by the infrared observations made on NASA's CV-990 aircraft, scientists at NASA Ames began planning for a larger telescope that could be installed in an open port configuration. The 1-inch thick quartz windows on the CV-990 only allowed transmission of infrared radiation out to about 5 microns; in addition, the 12-inch windows restricted the size of the telescopes used.

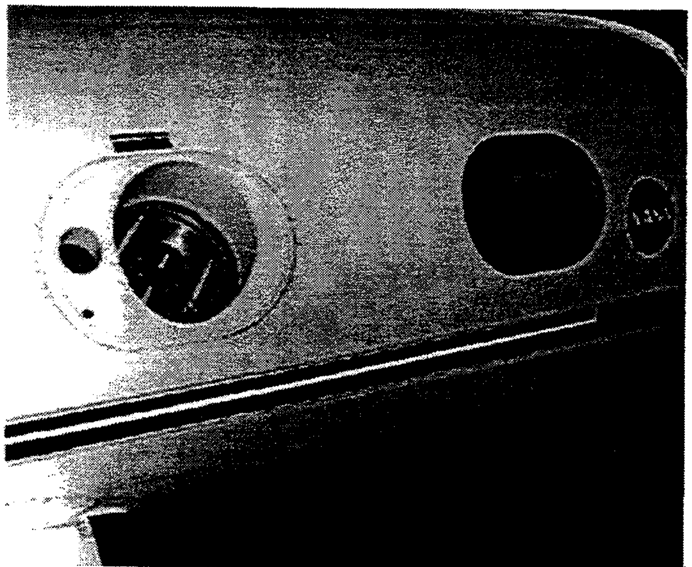
During 1966 and 1967, Frank Low and his colleague Carl Gillespie started experimenting with a 2-inch telescope aboard a U.S. Navy Douglas A3-B bomber.[19] A series of 14 research flights were performed, using a helium-cooled Germanium bolometer mounted on a ball-and-socket fixture in a canopy of the aircraft. Flying at altitudes from 40,000 to 44,000 ft, the first far-infrared airborne observations were made, recording the solar brightness temperature at a wavelength of 1mm. Just after the solar measurements were made, the A3-B and its crew were lost on a transcontinental flight.

In 1966, recognizing the need for an open-port airborne telescope for far-infrared observations, Frank Low, at the suggestion of Gerard P. Kuiper, approached Michel Bader at Ames Research Center, and the decision was made to submit a proposal for installing an open-port telescope on a NASA Ames Learjet. The proposal was accepted, a 12-inch open-port reflecting telescope was designed and installed in a passenger window location, and the first astronomical observations aboard the Learjet took place in October, 1968. During the pioneering early flights of the Learjet observatory, major obstacles were overcome, including researching and solving the problems associated with an open-port airborne telescope, and the invention of the first chopping secondary mirror for subtracting of sky brightness from the signal.



NASA photo
Figure 10: Carl Gillespie with NASA's Learjet telescope.

Flying at 45,000 to 50,000 ft, and a cabin altitude of 18,000 to 25,000 ft, observers aboard the Learjet discovered a host of bright infrared sources; this work showed the usefulness of airborne infrared astronomy for planetary, stellar, and galactic studies. Discoveries during the early flights of the Learjet telescope include: the first measurement of the internal energies of Jupiter and Saturn, far-infrared observations of the great nebula in Orion, studies of star formation regions and the bright IR sources at the center of the Milky Way galaxy. Also, in the early 1970's, near-infrared spectroscopy by a NASA Ames team led by James Pollack and Edwin Erickson showed that the clouds of Venus are made from sulphuric acid droplets



NASA photo
Figure 11: NASA Learjet exterior, showing the telescope's open-port configuration.

Success on the Learjet encouraged scientists at NASA to continue with their plans, underway since late 1965, for building a much larger open-port telescope, which were eventually realized with the development of the Kuiper Airborne Observatory (KAO). The Learjet continued to fly astronomy missions long after the KAO was put into service in 1974. Between 1968 and 1984, over seventy papers were published in astronomy journals, using data obtained on the Learjet. The NASA Learjet is still available for astronomy missions today.

1973: 74 MINUTES OF TOTALITY ABOARD THE CONCORDE 001

On June 30, 1973, scientists aboard the British-French Concorde 001, traveling at nearly 1300 miles per hour at altitudes over 50,000 ft, experienced a record-breaking 74 minutes of totality. The aircraft, laden with scientific instruments and observers from France, England and the U.S., took off from Las Palmas in the Canary Islands and flew 1800 miles across Africa, intercepting the moon's shadow over Mauritania and landing in Chad, central Africa.

One of the scientists on the Concorde's historic flight was Donald Liebenberg, leader of the team that built the "Rube Goldberg" telescope, and veteran of LASL's NC-135 eclipse missions. For his flight on the Concorde, Liebenberg used a specially-designed 3-inch telescope, which looked out of the aircraft through one of five silica quartz windows installed in the Concorde's roof. Due to the speed of the aircraft, which was nearly as fast as the movement of the moon's shadow over the earth, observers on board were able to view the eclipse in slow motion. The moon moved across only 20 km of the sun's atmosphere per second, compared to 200-300 km per second for observers on the ground. This, for example, gave the airborne observers 50 seconds to view the 1000 km region of the sun's atmosphere, compared to only 3 seconds for ground-based observers. Another objective of the research, made possible by the long time spent in totality, was to look for oscillations in the sun's corona that occurred on a time scale of about five minutes. Compared to ground observers, who would see one pulsation, and Liebenberg's colleagues aboard the NC-135 who would see approximately two, the 74 minutes of totality aboard the Concorde would allow observation of 12 pulsations.

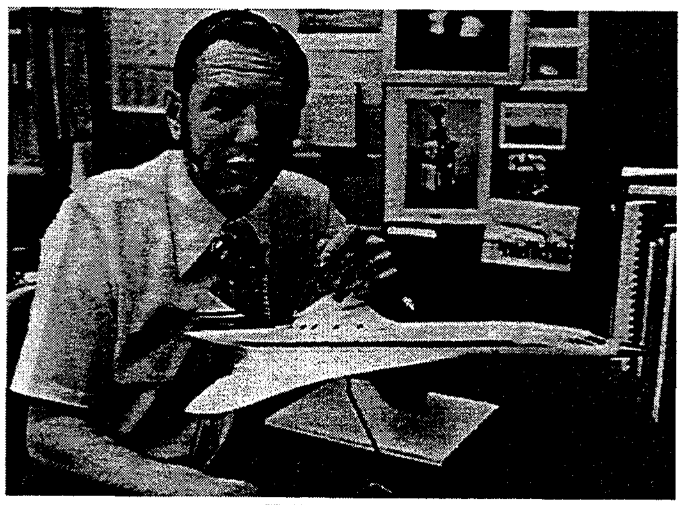


Photo from the archives of William Regan

Figure 12: Donald Liebenberg of LASL, showing the location of silica quartz windows on a model of the Concorde 001.

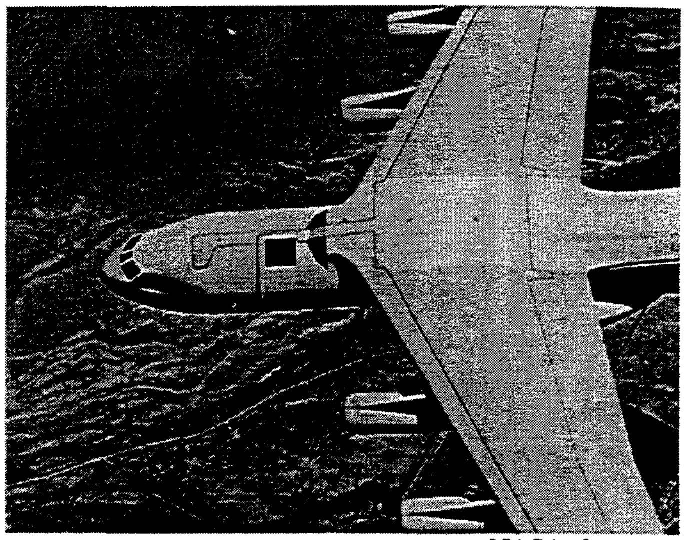
Photo from the archives of Dr. Donald H. Liebenberg

Figure 13: Donald Liebenberg of LASL, aboard the Concorde with instrumentation used in during the 1973 eclipse.

1974 TO 1995: NASA's KUIPER AIRBORNE OBSERVATORY

The next step in NASA's airborne astronomy program was the installation of a 36-inch open-port reflecting telescope onboard a Lockheed C-141 Starlifter. The project was approved by NASA in 1969, and the telescope design begun immediately. The original plan was to install the telescope on the CV-990 Galileo I observatory. It was later decided that the C-141 would be a more suitable platform; this change in plans also allowed the CV-990 to continue with important atmospheric and meteorological research already underway. The C-141 was purchased and delivered to NASA in early 1972; test flights began in April of 1973, and the first astronomical research flight was conducted in January of 1974. In May, 1975, the observatory was dedicated as the Gerard P. Kuiper Airborne Observatory (KAO), in honor of Dr. Kuiper's contributions to infrared and airborne astronomy.

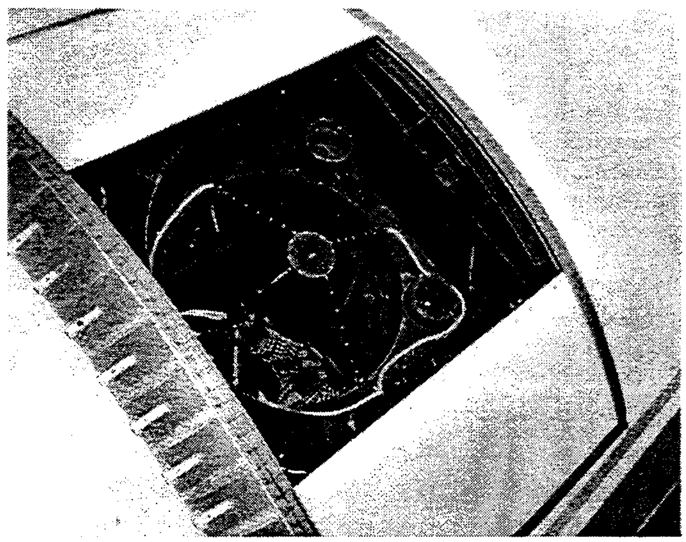
Although built using the experience gained on the CV-990 and Learjet observatories, there were critical differences in the design of the KAO that made it a far more versatile and efficient platform for astronomy. The most obvious difference is the size of the aircraft, and its telescope. The C-141 is a large, four-engine jet transport with a much larger capacity than the Learjet. Even with the installation of the three-times larger telescope in the forward section of the aircraft, and associated electronics racks and control consoles, the C-141 was capable of carrying approximately 20 scientists and telescope crew in its cabin. The Learjet only had space for two scientists. In addition, the typical KAO flight was 7.5 hours long, compared to a maxium of 2.5 hours on the Learjet.



NASA photo

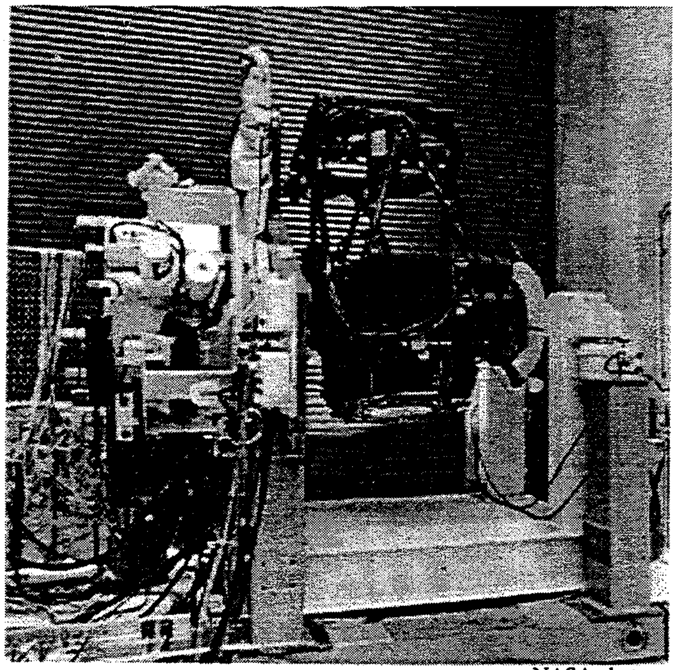
Figure 14: Kuiper Airborne Observatory in flight. The telescope cavity door, located forward of the wing, is open.

Another difference was in the unique telescope design. On the CV-990 and other airborne observatories prior to the KAO, gyro-controlled flat mirrors were often used to provide a steady image into the telescope. This allowed the positioning of long focal-length telescopes down the length of the aircraft. The KAO telescope was designed to balance on a 16-inch diameter spherical air bearing (believed to be the largest such airbearing in existence), and the entire telescope was gyro-stabilized. The air bearing was imbedded in a pressure bulkhead separating the open port from the crew cabin. The bent-Cassegrain Nasmyth configuration allowed light from the telescope to pass through the air bearing and be received by instruments in the cabin, making it unnecessary for those onboard to wear oxygen masks during entire observing missions.



NASA photo

Figure 15: Close-up of the KAO open port. This photograph was taken on the ground; a technician can be seen inside the telescope cavity.



NASA photo

Figure 16: KAO telescope at NASA Ames, before installation aboard the C-141.

From 1974 to 1995, the KAO flew an average of 70 research flights per year, from its home base at NASA Ames Research Center, and as science needs dictated, from remote locations around the world.

Scientific output from the KAO was prolific. Some examples of scientific findings based on KAO observations are: discovery of the rings around the planet Uranus; detection of water vapor in comets; discovery of Pluto's atmosphere; the composition, structure, and dynamics of Supernova 1987a; luminosity, dust, and gas distributions in the Galactic Center; emission by shocked gas components of the interstellar medium; and the structure of star-forming clouds. Other benefits from the KAO program, in addition to the contributions to science, were: the development of new instrument and other technologies, the training of young scientists, and - particularly in the last three years of KAO operations - an education program that included flight opportunities for schoolteachers.

The KAO was grounded in October 1995, after a long and productive lifetime, in order to allow work to begin on the Stratospheric Observatory For Infrared Astronomy (SOFIA). Decade reviews of NASA's airborne astronomy programs were given in symposia in 1984 and 1994.[21,22]

THE FUTURE OF NASA's AIRBORNE ASTRONOMY PROGRAM: SOFIA

NASA's next-generation airborne observatory is now under development. The Stratospheric Observatory For Infrared Astronomy (SOFIA), will be a Boeing 747SP modified to carry a 2.7 meter telescope. SOFIA is being jointly developed by NASA and the German Space Agency, DARA. Science flights will begin on SOFIA in the year 2001.

Figure 17: Photograph of SOFIA, now under development.

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