IN FLIGHT:
THE STORY OF LOS ALAMOS ECLIPSE MISSIONS

by Barb Mulkin

Los Alamos can claim an extensive and quite unique history of solar eclipse studies, but little known is that the capability arose from resources made available during the uneasy period climaxed by the signing of the 1963 Atmospheric Test Ban Treaty.

Made cautious by an era of broken nuclear test agreements, Congress required four safeguards before ratifying the Treaty: establishment of an aggressive underground testing program, improvement of our monitoring capability vis-á-vis Sino-Soviet nuclear activity, continuation of progress in America's nuclear technology, and "maintenance of the facilities and resources necessary to institute promptly nuclear tests in the atmosphere should they be deemed essential to our national security or should the Treaty or any of its terms be abrogated by the Soviet Union."

So was born the Test Readiness Program and with it the acquisition by the Atomic Energy Commission of a joint interest in three Air Force NC-135s to be used as flying laboratories by the nation's weapons research facilities of Los Alamos, Sandia, and Lawrence Livermore.

According to the AEC's 1964 annual report to Congress, weapons test diagnostics from airborne platforms had proved so successful in the latter part of Operation Dominic (the last American atmospheric test series in 1962) that extensive ground installations such as those at Christmas Island and Eniwetok were unnecessary. The point was also made, perhaps, that some things can be done more thoroughly from the air. In any event, Air Force crews began flying readiness missions in the modified NC-135 jets with scientific contingents drawn from the weapons labs. For a while, B-52 bombers simulated weapons drops above the Pacific so scientists could hone their data-gathering skills, and the 135s came to be viewed as the mainstays of the Test Readiness Program's diagnostics effort.

However, the rather bland simulation exercises added little joie de vivre to the scientific flight crews. The researchers, quick to see the potential of the aircraft for a different kind of scientific mission, petitioned the AEC for permission to gather data on cosmic rays, electrical and magnetic fields in the ionosphere, and the frequent solar eclipses studied almost exclusively, until then, from the ground. They argued that such missions could replace the simulation exercises without interfering with the readiness status required by the Treaty.

High-flying, long-range jet aircraft, the scientists claimed, could be used as observation stations for extraterrestrial phenomena and would have a tremendous advantage over ground facilities. Jet aircraft capability would place researchers above the clouds that often negate ground observation, and above 80 per cent of the earth's atmosphere, whose dust and water vapor scatters light and degrades data. For instance, they contended, meaningful measurements of the solar corona, which are impossible from the ground because of water vapor that blocks the infrared end of the solar spectrum, could be made from the aircraft.

The obvious advantages of a fast-flying plane in tracking a solar eclipse were presented to the AEC as making it possible to extend the length of totality by typically 50 per cent over a fixed ground location.

Scientific arguments were sufficiently persuasive that the AEC gave its permission for the program within a program that continued, albeit catch-as-catch-can, until 1975.

The first airborne solar eclipse mission in 1965 was to take Laboratory researchers to Pago Pago in American Samoa. Led by astrophysicist Art Cox, the scientists were confronted by several obstacles, for the planes were already fully equipped laboratories and solar observation equipment had to be phased in smoothly, so as not to interfere with the aircraft's primary mission. Cox's crew designed optical instrumentation, provided stabilized instrument platforms that reduced image motion blur, fitted their instruments into the cramped space available, arranged for the fuselage of the plane to be modified at Kirtland Air Force Base in Albuquerque to allow special instruments to be mounted, and plotted a course that would place them at that time and point in three-dimensional space where a few precious minutes of totality could be mined for information.

Pago Pago followed months of frantic preparation and it was a tour de force. The mission was notable for many things, not the least of which was the debut of an ingenious multiple-use telescope dubbed the "Rube Goldberg" for its unusual configuration that was reminiscent of the zany cartoon contraptions by that name. The Rube was much modified for later missions and has long been recognized as the workhorse of the airborne eclipse effort.

Designed by a group headed by Don Liebenberg that included Ken Williamson, Bill Ogle, Walt Wolff, and Paul Rudnick of Los Alamos and Mert Rob-

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Art Cox: "The pilot chose an emergency option called full military-rated thrust to zoom to more than 40,000 feet. . . when we landed, he wouldn't let me see the fuel gauge". . . Pago Pago '65

ertson and Melvin Mattison of Sandia, the Rube made five important measurements through its 80-inch focal length lens. Detailed photometry of the coronal continuum and six emission lines was obtained, as well as interferometric observations of the shape of two iron emission lines and a photospheric absorption line. In addition, the Rube yielded information on the interferometer fringe pattern of the green iron emission line to 1.7 solar radii. While the data made the crew jubilant, it was only a beginning, as the cadre of astronomy buffs planned for more airborne missions that in February, 1980, would total seven.

Pago Pago 1965 is remembered by those who flew for more than good data and a successful mission; there were lighter moments that have entered the folklore of the tightly knit group of solar eclipse veterans. For instance, Bill Regan, who retired from Laboratory service last year and has flown on six of the seven missions, recalls that on the Pago Pago expedition he was forced to shoot his pictures, as the aircraft nosed into totality, from the only space available—the forward latrine.

Our Bill Ogle, the AEC representative for the mission, is remembered for the aplomb he displayed when he rose to respond to the greeting of a Samoan chief at a party thrown for the crew. Ogle lost his lava lava, the native skirt donned for the occasion, and was thereafter known to the natives as a "smart palangi" for having had the forethought to have donned a pair of underpants.

A few hairy moments during the eclipse flight are also recalled, for the scientists were forced to "go to war." At the plane's planned altitude, just before totality, they found they had to contend with high cirrus clouds that would wipe out any hope of gathering high-quality data. The flight crew chose an emergency option called "full military-rated thrust" to zoom to more than 40,000 feet—an option exercised generally only in wartime and then for just a few minutes because of the increased use of fuel and the possibility of burning up an engine. The ploy worked, but Art Cox remembers that pilot Jim Wells refused to let him see the fuel gauge when the party landed at Samoa.

Veterans now, the Laboratory team began planning for the 1966 eclipse off the coast of Brazil, when no less than five aircraft were to be involved in a coordinated effort to wrest the sun's secrets while its brilliance was diluted by the moon's shadow.

The Los Alamos NC-135 flew first, followed by a Sandia plane, the Lawrence Radiation Lab's aircraft, NASA's Convair 990, and the Air Force Cambridge Research Laboratory's craft.

The original plan called for the three leading planes to maintain a ground speed of 450 knots along the path of totality, but a crosswise 150-knot jet stream necessitated a change in speed and made it extremely difficult to navigate accurately. However, Bob Brownlee reported that Los Alamos managed 160 seconds of total eclipse observation with instruments installed for backward-look angles. Three optical systems were used on the mission: a coronal camera with a 4-inch aperture and 36-inch focal length pointing directly at the sun to avoid the polarization effect mirrors would have introduced in feeding a fixed telescope; a second instrument with eight parallel telescopes to record the corona in the light of five spectral emission lines and three nearby continuum regions; and the Rube, tracking on three axes to provide a steady rotation-corrected image.

An innovative feature on this mission was the hydraulic tracking system used for several of the telescopes; it was quicker and more powerful than the electric motors used on the first eclipse flight, and the accuracy of 1 minute of arc was improved to 10 seconds of arc.

The presence of five aircraft and simultaneous rocket experiments on this mission gave pause to the veterans who flew off the coast of Brazil; they remember being tempted to watch the sky for payloads heading in their direction!

At the official welcoming ceremony, bemedalled and bemused South American officials greeted the rumpled eclipsers as they deplaned, headed by Bill Ogle, resplendent in a pair of bib overalls.

Electing to use some vacation on the way home, two intrepid souls ventured onto a boat crossing the famed Lake Titicaca that bisects the Andes between Peru and Bolivia. An attempt to pay for a boat ticket with Bolivian currency failed; Peruvian coins were needed; the Peruvians took travelers' checks, however. At least, they took them long enough to admire them politely, having no idea they could be exchanged for money.

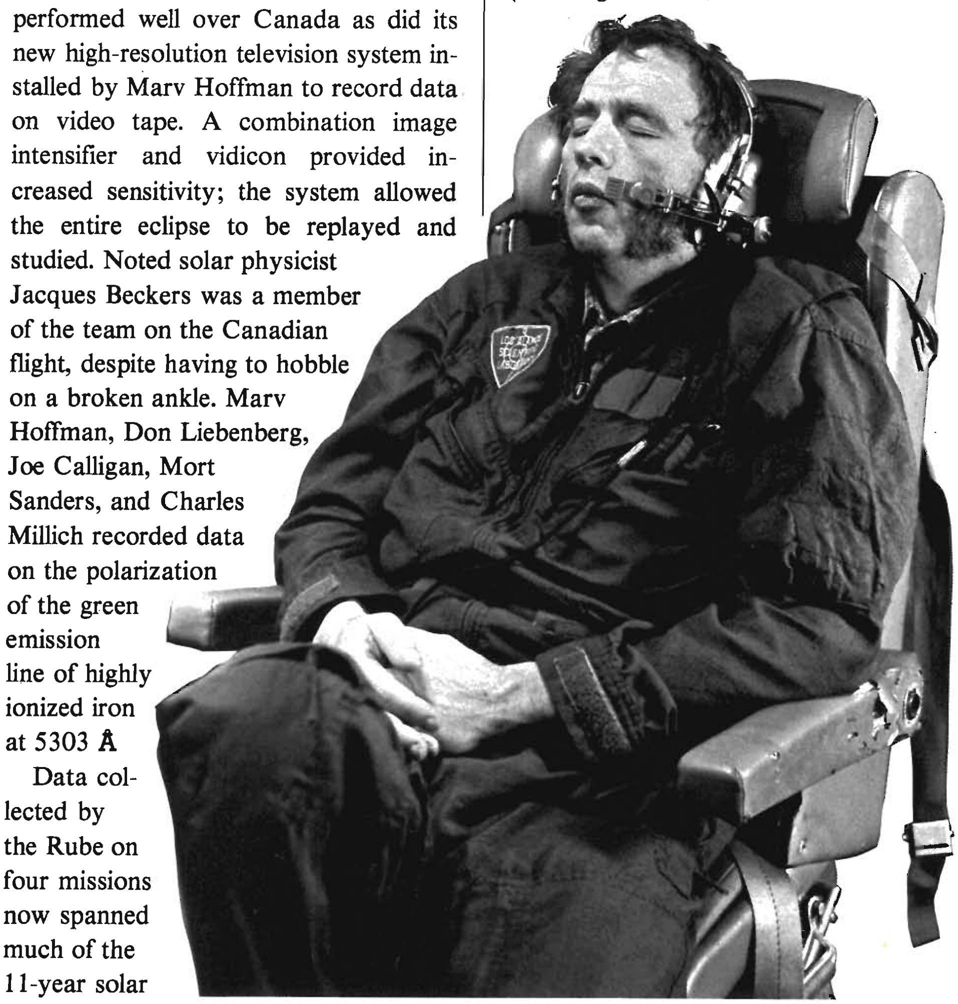
Before the 1970 eclipse, heavy rain in San Antonio, Texas, jeopardized experiments before takeoff, but subsided in time for windows to be cleaned; the Rube recorded data out to two solar radii; streamers to 10 solar radii were photographed and one streamer, dominant in the northwest quadrant, was photographed out to 13 solar radii.

At the traditional open house for the San Antonio press hosted aboard the aircraft before the mission, reporters edged gingerly around the mounds of equipment. One timid neophyte of the printed word stopped before the Rube and asked for an interview with "Dr. Goldberg."

Progress in sun missions continued with the interception of the 1972 eclipse by flying astronomers at 39,000 feet northwest of Canada's Hudson Bay. The Rube, which had delivered coronal light to interferometers on three missions, performed well over Canada as did its new high-resolution television system installed by Marv Hoffman to record data on video tape. A combination image intensifier and vidicon provided increased sensitivity; the system allowed the entire eclipse to be replayed and studied. Noted solar physicist Jacques Beckers was a member of the team on the Canadian flight, despite having to hobble on a broken ankle. Marv Hoffman, Don Liebenberg, Joe Calligan, Mort Sanders, and Charles Millich recorded data on the polarization of the green emission line of highly ionized iron at 5303 Å

Data collected by the Rube on four missions now spanned much of the 11-year solar cycle from minimum activity (1965) to near maximum (1970), and a comparison of temperatures, as the data were reduced, indicated that average coronal temperature varies little over the solar cycle and is more dependent on activity on the surface of the sun.

The grueling aftermath of the 1973 eclipse is evident in sleeping Art Cox. (Bill Regan Photo)



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Don Liebenberg: The moon appeared to work as a slow camera shutter, slicing off only a tiny piece of the atmosphere each second. . . from the SST we managed an incredible 74 minutes of totality. . . Africa '73

The Laboratory eclipse experts scrambled next for the 1973 mission, which came to be called "the frosting on the cake." Liebenberg boarded the SST prototype—the French-British Concorde—to monitor the 20th century's 50th eclipse, which occurred over Africa. Racing at nearly 1300 miles per hour (Mach 2), Liebenberg, Kitt Peak's Don Hall, and others from Britain and France managed man's longest look at a total eclipse—an incredible 74 minutes of totality.

Liebenberg recalls looking with awe at the shadow of the moon racing across the Sahara Desert. The flying altitude of the SST was so high that by Air Force definition it was in space, and the curvature of the earth was clear against a purple sky, as the plane raced to intercept the elliptic cone of the eclipse shadow. The precise flight plans were drawn using a computer code developed by Art Cox, a code so accurate that the plane arrived at its destination within one second of the predicted time! As the mission proceeded, those on the 135 watched in disbelief as the SST streaked by and above at 55,000 feet.

Liebenberg's emission line experiments were coordinated with work being done on the slower NC-135, and were designed to probe the transition region between the inner and outer parts of the sun's chromosphere, about which little was known. Hoffman, in the slower subsonic plane, had almost 13 minutes of observation time, little by comparison with the SST's 74 minutes, but still the longest time for airborne eclipse observa-

It was hot and humid at the Tafuna Airport just before the 1965 mission. Charlie Hyder went native in a Samoan lava lava; the rest opted for more conservative attire. From left are Carl Young, Harold Staake, Don Liebenberg, Paul Rudnick, Ken Williamson, and Jerg Jergensen. (Bill Regan Photo)

The radially graded filter experiment produced magnificent pictures in 1973 for the three-man team of (from left) Sid Stone, Darrell Call, and Bill Regan, and a stunning photo of a coronal bubble in 1980. (Bill Regan Photo)

Design genius Bobby Strait (left), Joe Montoya, and Charles Keller study the coronal camera used on the expedition out of Madrid, Spain, in 1973. (Bill Regan Photo)

tion from a subsonic aircraft then and now, and he used the time to measure the polarization of the red, green, and yellow emission lines in the corona.

With the added time gained by the Concorde's keeping pace with the moon's shadow, Liebenberg triumphantly noted the onset and departure of totality as the speed of the plane made the moon appear to work as a slow camera shutter, slicing off only a tiny piece of the sun's atmosphere each second. For the first time, pulsations in light intensity, presumably due to traveling waves, were observed in the corona.

Aboard the 135, Sid Stone, a veteran of 1965, joined Bill Regan and Darrell Call in mounting a radially graded filter experiment that succeeded in recording on one photograph intensities ranging over a factor of 10,000, from the glaring base of the inner corona to the faint emanations from the outer corona at 10 solar radii.

The coordinated experiments of 1973 yielded such a wealth of information that the shipboard 1977 eclipse event was a profound disappointment. Los Alamos had tremendous cooperation from the crew of the vessel on which they set up shop off the coast of Mexico, but Murphy's Law struck with a vengeance: high clouds obscured much of the eclipse and failure of a power cord, dislodged by a stranger who opened a door near the experiment, put an end to the effort.

A quick and dirty mission was mounted in 1979. Los Alamos eclipsers heard that the USAF 4950th Test Wing was considering a request from a major television network to cover the mission in a 135 (now used primarily by the Air Force Weapons Laboratory) so that the eclipse could be filmed live. Superb ob-

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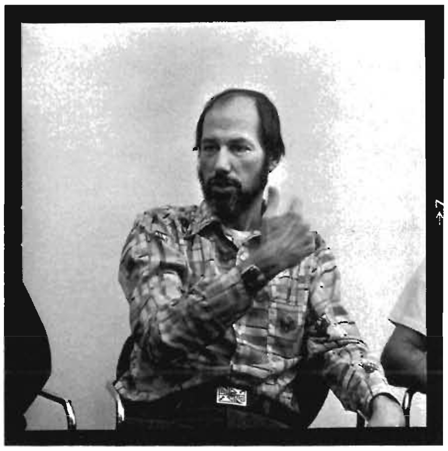


Charles Keller: We mounted a quick and dirty mission. . . for the first time in 16 years of eclipse observation continuous intensity data out to 20 solar radii were collected. . . North Dakota '79

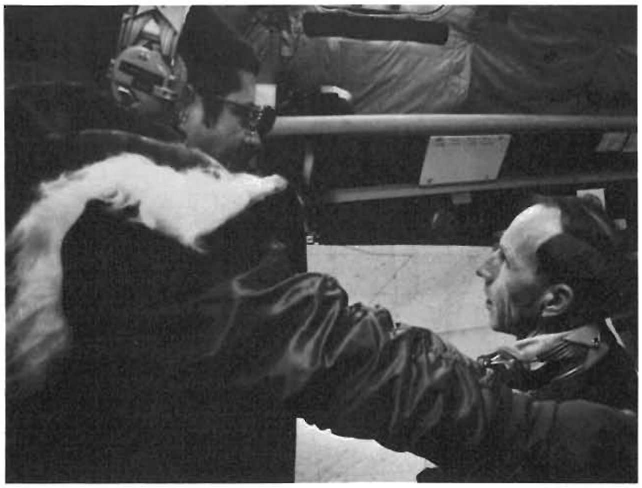
servation possibilities at 37,000 feet above North Dakota and a relatively short flight, plus renewed interest by both the Air Force and the Laboratory resulted in a fruitful mission, although the live TV coverage had to be scrubbed and delayed footage substituted. The flight was also an excellent training opportunity for the 1980 eclipse over Africa. Senior scientist Charles Keller produced some remarkable image-enhanced photographs out to 12 solar radii. For the first time in 16 years of eclipse observation, continuous intensity data out to 20 solar radii were collected. For such a crash effort—only five weeks' preparation—it was a good mission. It also aroused more public interest than any eclipse in recent years, perhaps because much of North America was in on the act.

By contrast, hundreds more man hours were devoted to preparing for the 1980 eclipse, which climaxed on February 16. The Los Alamos contingent flew to Spain on the first leg, and the time was used by Brook Sandford to test an onboard microcomputer designed to interface with his ingenious new experiment to make direct measurements of electron temperatures in the solar corona—the first experiment of its kind. The computer's magnetic disk appeared to function well, but during the flight to Nairobi, the jumping off point for the mission, it began recording intermittently. A back-up unit was installed while the plane was on the ground at the Jomo Kenyatta Airport, and it too functioned well, until a Kenyan ground crew member inadvertently pulled the plug to the power source on the aircraft and destroyed the disk. Sandford and the rest of the crew worked feverishly the night before the eclipse to get the experiments in order. The original disk was put back into the system; it worked, but failed as totality approached, a victim of the stress of turbulent air travel. Sandford glumly watched what appeared to be good data flickering across his screen, and was unable to record the information for later analysis.

Difficulty with the mirror tracking system in the airplane caused Bill Regan and Carl Lilliequist's radially graded filter experiment not be be centered precisely on the sun. The experiment failed to record the entire corona, but it did produce a marvellous photograph of a hydrodynamic eruption from the sun's surface that formed a huge bubble in the corona.

There were other successes, too. Liebenberg and an interdivisional team, which included Ed Brown, Pete Murray, Mort Sanders, and Bob Kennedy, successfully captured very-high-resolution data on emission lines of highly ionized iron and calcium. Bob Brownlee and Paul Mutschlecner and Kitt Peak Observatory's Don Hall, veteran of the SST 1973 mission, recorded excellent data on the thermal properties of dust in the F corona. Bobby Strait, Charles Keller, and Joe Montoya fielded the photographic polarimetry experiment, first flown in 1970 and designed to determine electron densities in the corona. They captured the first detailed and complete record of a hydrodynamic solar eruption from the base of the corona out to 7 solar radii—a phenomenon seen previously by satellite, but only down to 1.5 solar radii.

Failure and success are common in eclipse study, and there are other commonalties. There is the indescribable feel-



Above, Practice flight arrangements are discussed before the 1980 mission by USAF Maj. Mike Bartlett and the Laboratory's Bill Roach. (Johnnie Martinez Photo)

Above, plotting a course for home after the 1980 eclipse mission are, from left, Bob Jeffries, Charles Keller, Brook Sandford, Paul Mutschlecner, Joe Montoya, and Carl Lilliequist. (Johnnie Martinez Photo)

Four members of the 1965 American Samoa flight (left to right) Ken Williamson, Bill Ogle, Don Liebenberg, Walt Wolff, and the Rube Goldberg. (Bill Regan Photo)

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Bill Regan: The light was so eerie. . . like a mercury vapor lamp on a dark night. . . Lilliequist was on his back, still struggling to center the disc as totality approached. . . Africa '80

ing of being so close to the awesome display, untroubled by weather or other interference, as the plane begins the race-track orbits designed to place it in the path of totality. Typically, three to seven orbits are flown after first contact, when the moon's shadow touches the disc of the sun and the plane turns eastward to the path of the shadow's center line.

In 1980, at least, the frantic preparations continued up to and into totality, as Carl Lilliequist struggled beneath his equipment trying to center a 2.54-mm disc on a second 2.54-mm image, and was only partly successful. Sandford mourned the loss of his data, and in every section of the noisy, chilly, padded interior of the plane, teams conversed tersely on closed-circuit intercom systems linked only to each other and to a frequency used by the flight crew to relay directions in case of emergency.

As the shadow deepened, the chill spread, and the light became ominous, a blue-tinged glow like a mercury vapor lamp on a very dark night. The General Dynamic Company's crew struggled with the obstreperous tracking system up to and beyond totality. Bob Jeffries, watching a video screen monitor for the master tracker, cried "Lock it in, that's it!" The moment had arrived. Months of gut-wrenching effort, the tension, the successes, and the failures were all forgotten in the ensuing minutes, as each team worked in the eerie twilight. For just a few moments, as the light returned, there was silence, broken only by the overwhelming noise of the less than luxuriously appointed aircraft. Then the analysis began.

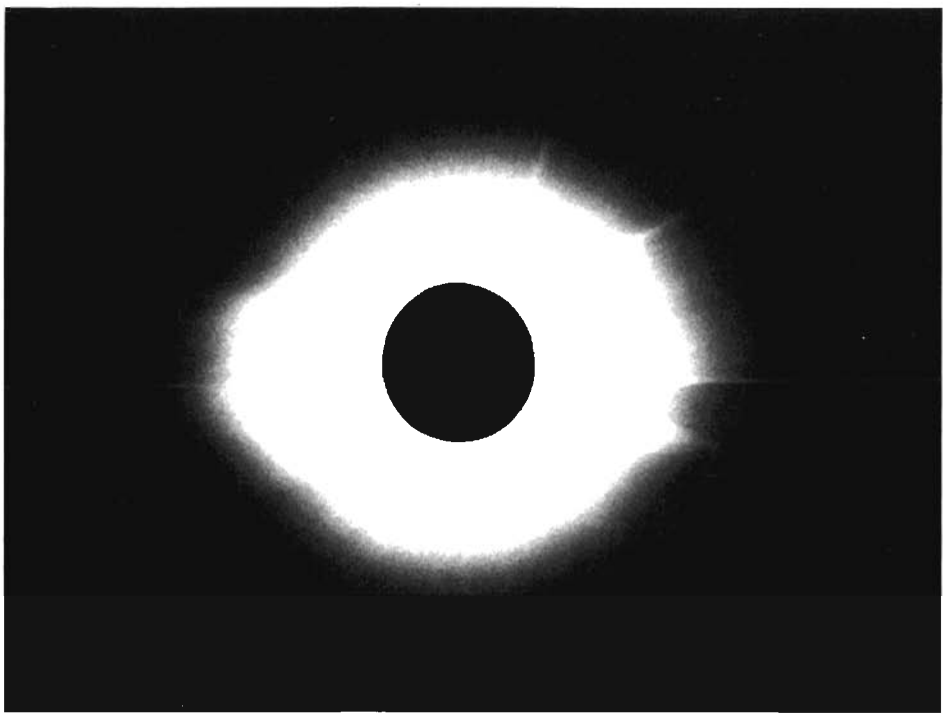
So exciting is the field of astrophysics that the media coverage tends to make the missions sound like fun and games, and the considerable ingenuity and months of hard work are frequently overlooked. Nevertheless, the increasing sophistication of both equipment design and diagnostic techniques has improved the accuracy of coronal data and added to the slim store of knowledge of the star on which our existence depends.

For instance, Art Cox, working with Don Eilers, put together the computer code for predicting aircraft interception of solar eclipses, and the model has been used by all other aerial observers. Ralph Partridge designed and has continually improved photo tracking systems that permit experiments to lock on to the eclipsed sun and hold it centered with a maximum error of six arc seconds—this is the equivalent of holding perfect aim with a rifle for five minutes on a penny-sized target a mile away.

Special lens systems have been produced by Berlyn Brixner using a lens design computer code. Stabilized platforms and servo systems—major contributions—have come from Joe Perry, Ed Brown, and Bobby Strait. Strait, called the magician for his expertise in designing and adapting equipment for aerial eclipse study, is deemed essential to the success Los Alamos has enjoyed. Strait's idea for individual tracking systems that could make future missions even more successful is something that might apply to the eclipse over Indonesia in 1983.

Cox, Brownlee, Keller, Roach, Sandford, Regan, Carl Lyon who smoothed the logistic progress of several trips and handled communications—the list goes on. The veteran Liebenberg, who has covered 11 mission since 1954, including at least one on his own time and at his own expense, has logged more totality observance than anyone in history—117 minutes and 11 seconds, and as Keller *et al.* are fond of pointing out, "sometimes Liebenberg even remembers to put film in the camera, remove the lens cap, and refrain from jiggling the equipment at the wrong moment. . ."

That pretty much sums up the spirit of the flying eclipse corps at Los Alamos: slightly irreverent and doggedly determined. The word most often used by those who know is—dedicated ■



Scientific Collaborators
on Los Alamos Airborne
Eclipse Missions

1965 Charles L. Hyder, University of California
1970 Merton M. Robertson, Sandia Laboratories
1972 Jacques M. Beckers, Sacramento Peak Observatory
Apostolos Frangos, Scientific Group for Space Research, Greece
1973 Jacques M. Beckers, Sacramento Peak Observatory
Warren N. Arnquist, University of California, Los Angeles
Alberto Righini, Arcetri Astrophysical Observatory, Italy
Manuel Lopez Arroyo, Madrid Observatory, Spain
Ervin C. Woodward, Lawrence Livermore Laboratory
Robert E. Donaldson, Lawrence Livermore Laboratory
Jose L. M. Cortez, Lawrence Livermore Laboratory
1979 R. Kent Honeycutt, Indiana University
1980 Donald L. Hall, Kitt Peak National Observatory
R. Kent Honeycutt, Indiana University