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EXPERIMENTS ON VISUAL ACUITY AND THE VISIBILITY OF MARKINGS ON THE GROUND IN LONG-DURATION EARTH-ORBITAL SPACE FLIGHT

by S. Q. Duntley, R. W. Austin,
J. L. Harris, and J. H. Taylor

Prepared by
UNIVERSITY OF CALIFORNIA
San Diego, Calif.
for Manned Spacecraft Center

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PREFACE

This is the final report by the Visibility Laboratory of the visual acuity experiments conducted during the Gemini program. It sets forth in greater detail than has been done heretofore all aspects of the investigation, including the events in Project Mercury which led to the experiment, the evolution of the experimental design, the preparatory experiments, the equipments constructed, the training of flight crews and teams of experimenters, the selection of ground sites, their preparation and operation, the inflight experiments on Gemini V and Gemini VII, the resulting data and their interpretation, the conclusions and their meaning in terms of the Apollo mission and other future spaceflights, as well as certain suggestions for future inflight tests of human visual capabilities in space. Earlier summary reports containing brief descriptions of the experiments, the results obtained, and their interpretation have been made from time to time. The principal one of these documents has been included in this report as Appendix A to provide a concise description for readers who do not wish to peruse the lengthy account which this report provides.

Most of the historical facts concerning the Gemini Visual Acuity Experiments are set forth in the first section of the report, entitled "Introduction," but occasional mention of historical matters is made throughout the body of the report. It should be noted that the experiment was proposed independently by the Visibility Laboratory and by the NASA Manned Spacecraft Center. Immediate interest resulted on the part of the United States Navy, who agreed to share the financial cost with NASA.

The Gemini Visual Acuity Experiment was designated as NASA Project R131 when it was formally established by the Inflight Sciences Branch of the NASA Office of Space Sciences and Applications, Dr. Jocelyn Gill, Chief. Funds from the Office of Manned Spaceflight were transmitted via the Bureau of Ships, U. S. Navy. The subsequent decision by NASA to conduct the experiment on both of the two long-duration Gemini spaceflights caused the initial scope of the experiment to be expanded. When this decision and changes in the orbits, launch times and launch azimuths, etc., caused the program to grow in cost well beyond the initial estimates, additional NASA funding was supplied by the Bioastronautics Branch of the NASA Office of Advanced Research and Technology and by the Environmental Physiology Branch of the NASA Manned Spacecraft Center. Until the end of fiscal year 1965, all funding for the experiment whether from NASA or the Navy, was channeled through the Navy Bureau of Ships contract NObs-84075 with the University of California. Funding for the Visibility Laboratory's participation in the experiment for fiscal year 1966, and beyond was supplied by NASA through a direct contract NAS-9-5095 between the Manned Spacecraft Center and the University. Funding for the construction of the ground site near Laredo, Texas was provided by the U. S. Navy Bureau of Weapons. The actual engineering and supervision of the construction of the site in Texas was performed by the Gulf Division of the U. S. Navy Bureau of Yards and Docks, New Orleans. The design and construction of the Australian site was performed by the American Projects Division of the Australian Ministry of Supply using funds supplied by NASA.

The formal designation of the experiments used by NASA was S-8/D-13, and this is the title by which the study is identified in many official documents. It should be made clear here, that this designation *does not* mean that the two experiments in the study were sponsored separately by NASA and the Department of Defense. Rather, it means that the study, in all its phases, was supported under the joint aegis of DOD and NASA. The roll of each agency in the study will become clear in the sections of this report which follow.

Dr. Wayne C. Hall. of the U. S. Naval Research Laboratory, took an active part in the initial discussions of the Gemini visual acuity experiment. Commander N. J. Stevenson, Code RTAD, of the Bureau of Naval Weapons, initiated the Navy participation in the work. Later, he was replaced by Lt. Cdr. J. H. Alvis who attended many of the initial meetings. Lt. Cdr. Harold Hilz, also of the Bureau of Naval Weapons, became the Navy representative in residence at the Manned Spacecraft Center throughout the Gemini V and Gemini VII flights. He was also a member of the site selection team which visited Australia to make arrangements with the Australian Ministry of Supply for the construction of the ground markings at Woodley Station near the NASA tracking station at Carnarvon, Australia. The site survey party also included Capt. Robert D. Mercer, USAF, of the Manned Spacecraft Center, and Dr. John H. Taylor, of the Visibility Laboratory. Lt. Cdr. H. Hilz also acted on behalf of the Bureau of Naval Weapons throughout the construction of the ground site on the Gates Ranch near Laredo, Texas by the Bureau of Yards and Docks, U. S. Navy through a contract with the H. B. Zachary Co.

Scientific liason with the Inflight Experiments Branch of the Office of Manned Spaceflight was provided throughout the experiments by Dr. Jocelyn Gill and by Dr. Siegfried Gerathewohl. Both were at the Mission Control Center during parts of Gemini V and Gemini VII. Dr. Gerathewohl visited the ground site near Laredo, Texas and on several occasions during Gemini V and Gemini VII participated in flights of the Air Force C-130 aircraft used by the Visibility Laboratory. Mr. William Allen of the Bioastronautics Branch of the NASA Office of Advanced Research and Technology took an important technical and administrative part in the program.

Technical liason on behalf of the NASA Manned Spacecraft Center was provided by the Center Investigator, Dr. John Billingham. He was also the technical monitor for contract NAS-9-5095 until his transfer to the NASA Ames Research Center during the Gemini V mission. He was replaced by Dr. Robert L. Jones, of the Manned Spacecraft Center. From the outset Dr. Billingham took a major and vital part in developing the experiment, in coordinating the worldwide preparations, in arranging for the necessary facilities and services at the Mission Control Center, and in the management of the program for NASA. His successor, Dr. Jones, ably continued all of these roles in the final stages of the Gemini V mission, throughout Gemini VII and during most of the postflight period. During the latter part of 1967, Dr. L. R. Loper became the contract monitor. He represented the Manned Spacecraft Center during the terminal phase of the work, including the preparation of this report.

The U. S. Air Force also participated in the Gemini Visual Acuity Experiment through the Air Force Cambridge Research Center. That Center permitted a C-130 aircraft assigned to the Visibility Laboratory to be used in visual training flights for the Gemini V crew over the Laredo markings and for monitoring the atmosphere and the appearance of the ground site throughout the Gemini V and VII space flights.

Many individuals within the Visibility Laboratory contributed to the Gemini visual acuity experiments. The Director of the Visibility Laboratory, Dr. Seibert Q. Duntley, was the official investigator. Equally major parts were taken by three other members of the academic staff of the Laboratory: Research Engineer, Roswell W. Austin, Research Psychologist, John H. Taylor, and Research Engineer, James L. Harris, Sr. All four were deeply involved throughout the program and the various sections of the report which follows this preface was written by them, as shown by the initials following the section headings in the Table of Contents.

It is indeed difficult to recognize adequately the very important contributions which the many other engineering and shop personnel in the Visibility Laboratory made to the program.

Mr. Robert L. Stapleford assisted Dr. Taylor in the many supporting psychophysical experiments which were part of the program. He also was in residence at the Manned Spacecraft Center for a considerable period during which he conducted the training of the astronauts in the visual acuity experiment and measured their visual thresholds in the training van. He also assisted the principal investigator, Dr. Duntley, at the Mission Control Center throughout Gemini V and Gemini VII.

The Engineering Branch of the Visibility Laboratory, headed by Mr. Theodore J. Petzold, designed and produced the inflight equipments and the specialized devices used to monitor the atmosphere and the ground markings. The design, calibration and flight qualification of the inflight equipments was performed by engineers T. J. Petzold, R. W. Loudermilk, J. J. Lones, H. H. Smith and B. J. Ruff, ably assisted by mechanical designer J. J. Edwards and optical technician D. M. Webb.

Mr. John C. Brown, Principal Photographer in the Visibility Laboratory, made the microscopic test objects used in the inflight vision tester and prepared many specialized displays for astronaut training and supporting research experiments. The inflight photometer, the inflight vision tester, the contrast reduction meters and other specialized equipments used at the ground sites were fabricated in the Visibility Laboratory shops headed by Alden D.J. Hooten. The electronics shops of the Visibility Laboratory headed by engineer George Tate constructed the electrical components of the inflight equipments and the apparatus used at the ground stations, and performed the many electrical and photometric calibrations required in these equipments. It is a matter of great pride to the Visibility Laboratory that the equipments built by the Laboratory operated without any form of malfunction throughout the Gemini visual acuity experiments.

Visibility calculation specialists Jacqueline I. Gordon, Peggy V. Church, and Donna M. Resch developed new techniques of data collection and reduction. Meteorologist Catharine Fean Edgerton participated in the reduction of meteorological data, some of which was collected during a preliminary site survey by laboratory assistant C. F. Pinkham. Research Engineer Almerian R. Boileau, and members of his group operated the scientific equipments in the C-130 aircraft throughout the visual acuity experiments. Dr. J. H. Taylor, with engineer R. W. Johnson and technician K. W. McMasters manned the ground site in Australia during Gemini V. Research Engineer R. W. Austin, engineers G. H. Tate, T. J. Petzold (Gemini V) and R. W. Johnson (Gemini VII) and technician G. F. Simas manned the ground site in Texas. Engineers T. J. Petzold and R. W. Loudermilk performed prelaunch tests of the inflight vision tester and the inflight photometer at Cape Kennedy. Nearly all of the remaining staff of the Visibility Laboratory contributed to the experiments throughout the several years during which the work was in progress.

1. Introduction

1. INTRODUCTION

When Apollo astronauts have landed on the moon and returned safely to earth their mission will have entailed many critical seeing tasks. Even if no emergency procedures are invoked at any stage of the voyage, unimpaired visual performance will have been necessary. If equipment malfunctions develop, vision must provide the backup system in some very critical instances. For example, if the returning Apollo spacecraft is required to orbit the earth and perform a successful re-entry into the atmosphere without the benefit of communication from the ground, the crew must rely on visual landmarks on the surface of the earth to identify their orbit and establish their re-entry pattern. This critical visual task would occur at the end of a 14-day mission. If, after this long-duration spaceflight, their visual capabilities have changed in some unsuspected way, disaster might result.

The Mercury and Gemini series of manned earth orbital spaceflights were designed to generate the capabilities and assurances needed for the Apollo mission. The Gemini program included, therefore, two long-duration flights primarily to ascertain whether human performance became impaired. This report describes visibility experiments performed by the crews of Gemini V, which orbited the earth for more than seven days, and Gemini VII, which was in space for the full 14-day duration. These experiments tested the visual acuity of all four astronauts before, during, and after their spaceflights and found that their visual acuity did not change. The experiments also established quantitatively man's limiting capability to discriminate small white rectangular objects on the ground and demonstrated that this limiting performance was precisely as predicted on the basis of preflight visual thresholds measured in the laboratory when combined with the measured optical properties of the rectangles, their background, their lighting, the atmosphere, and the spacecraft window. Thus, the same visibility calculation techniques which have been developed and used in the past to forecast the visual acuity of aviators can be used equally well to make reliable predictions of what can be seen in space. Based upon these results Project Apollo can proceed with confidence that the visual performance of the astronauts will be as expected throughout each of the missions and that no deterioration of their visual acuity will take place.

Interest in what could be seen from space has been evident throughout all of the manned orbital flights, beginning with the exclamation, "What a beautiful sight!" by Astronaut Alan Shepard and including particularly the comprehensive sighting reports by Astronaut Gordon Cooper on the last of the Mercury flights. During certain of the 22 orbits Major Cooper reported having seen objects on the surface of the earth which must necessarily have subtended very small visual angles from the capsule altitude. There was an immediate and vociferous reaction on the part of the scientific and lay communities. Opinions ran the gamut from flat denial, to the possibility of Cooper's sightings being genuine, to acceptance of his reports being based upon one or another "explanatory" principle. These included such things as hallucination, magnification due to the atmosphere, and a postulated improvement in visual acuity due to weightlessness. Most of these hypothetical effects can be dismissed or shown to be insignificant; for example, the "magnification" due to the whole atmosphere has the effect of raising the object about eight feet, an insignificant amount compared with an orbital altitude of nearly one hundred miles.

In September of 1963 the Visibility Laboratory was asked by Dr. Robert B. Voas, then of the Manned Spacecraft Center at Houston, to investigate the situation in terms of visual and atmospheric optical considerations in the hope of settling the controversy. The results of the subsequent analysis of Major Cooper's reported sightings were contained in a letter from Dr. S. Q. Duntley, Director of the Visibility Laboratory, to Dr. Voas and eventually formed the basis for a NASA press release. Further, it led to plans for a controlled experiment, also independently suggested by Dr. John Billingham of the Manned Spacecraft Center, which resulted in the visibility experiments in the Gemini V and the Gemini VII missions, which form the subject of this report.

The first step by the Visibility Laboratory was to get as much information as possible about the objects which Major Cooper reported, the manner in which they were illuminated, and the backgrounds against which they were seen. For this purpose, representatives of the Laboratory went to Houston where they were able to secure transcripts of the taped in-flight verbal reports, get the detailed orbital information regarding the areas in chich the sightings were made, read the post-flight pilot's report, and talk with Major Cooper at some length about his experiences. It must be noted that Gordon Cooper is a remarkably careful observer; he is meticulous in differentiating fact from inference. Not only does he have excellent visual acuity as measured clinically, but he has had a tremendous amount of experience in the sighting of angularly small distant objects. From his Wisconsin boyhood hunting days through his Air Force test pilot work in high-altitude jet aircraft, he emerges as a genuine specialist in the sorts of observations which he later reported from orbit. The results of the studies made from the information obtained by the Visibility Laboratory at the Manned Spacecraft Center and from other sources were set forth in the aforementioned letter, which bore the date of 28 September 1963. It stated in part:

"Since the return of Mrs. Gordon and Dr. Taylor from their visit to the Manned Spaceflight Center last week and their interesting conversation with Major Cooper concerning the objects he reported seeing during his spaceflight, we have made four calculations of seeing probabilities for circumstances intended to be similar to four of those under which he reported seeing roads, vehicles, buildings, and smoke. The purpose of this letter is to report the result of these calculations.

"It must be emphasized that the visibility calculations described in this letter do not constitute proof that Major Cooper actually saw what he reported. They do, however, show that such sightings are not impossible by an observer at orbital altitude if his visual capabilities are like those which we believe Major Cooper possesses, and if the atmospheric conditions and target properties are like those we have assumed in making the calculations.

"It would require a very much longer letter than I have time to write today to spell out in detail all of the thinking and data compilation which has gone into the four calculations this letter describes. It is important to note, however, that the inputs to the calculations are measured data. Nowhere have mathematical models or theoretical relations been used. Thus, all of the information concerning the targets and the backgrounds are derived from optical measurements of real objects out-of-doors under real lighting conditions. We believe the terrain and background data to be similar to that in which the targets Major Cooper reported were situated. The atmospheric contrast attenuation values used in the calculations were measured by our instrumented aircraft during the clearest weather conditions under which we have flown research flights. Presumably the atmospheric clarity that prevailed when Major Cooper made his observations was at least as good as during our flights. In any event, the atmospheric conditions assumed in these calculations are not hypothetical but existed and were measured under actual flight conditions by the techniques I have described in Ref. 1.

"No data are available to us about the penalty on Major Cooper's ability to see objects on the ground which may have been imposed by the window of the spacecraft. The transmission of the window as ordinarily measured or computed does not enter into the problem, since a minor amount of light loss will have no deleterious effect. Light *scattered* by the window can, however, lower the apparent contrast of earth objects importantly. No data on this contrast loss are available here, but we have assumed that Major Cooper minimized the effect by orienting the spacecraft so that the window was downward and, therefore, not exposed to direct sunlight. No allowance for loss of contrast due to the window has been included in our calculations.

"The visual data used in these calculations are laboratory studies of unrestricted binocular vision at daytime adaptation levels 2, 3, 4 and include the performance of a large number of normal observers. In using these data, allowance has been made for our belief that the visual capabilities of Major Cooper correspond with performance substantially better than the mean of good observers. We recognize that his lifelong training in seeing distant objects out-of-doors, his unusually extensive experience in visual observation from the air, particularly from high altitudes, and his demonstrated 20/12 visual acuity as measured clinically, indicate that he is more capable of making the type of visual sightings he reported than is the average normal observer.

"The four hypothetical situations which have been explored by visibility calculations will be discussed in the following paragraphs as Examples I, II, III, and IV. Attached to this letter is a table summarizing the four examples.

"There are many bases for reporting the results of any visibility calculation. The one we have chosen for the purpose of this letter is particularly appropriate for the case under discussion, wherein the objects are seen at or near the limits of visual performance. Under such conditions an observer may fixate on an area containing the object without seeing it on each and every glance. The probability of discriminating the object is a well-known function of apparent target contrast. Thus, under threshold conditions and over a comparatively narrow range of about 6 to 1 in target contrast or target area, there is a steady rise of detection possibility. We have chosen to report our results in terms of this probability. Thus, a supra-threshold object would be reported as having a probability of being seen greater than 0.99, whereas an object reported as having a probability of less than 0.01 is virtually certain to go undetected. These probabilities refer to the threshold of confident seeing; they are not to be confused with liminal thresholds often reported in laboratory work where, under forced-choice conditions, the phenomenon of perception without awareness may enter in. The probabilities reported here relate to the threshold of confidence at which an observer will report having seen the object. It must be emphasized also that probabilities discussed in this letter do not relate to matters of visual search. We are talking only of the probabilities that an observer who fixates accurately upon an area containing a target will see that target. This, we believe, is the proper datum in this instance because, in each case, some highly visible mark, such as a road, aided Major Cooper in finding the object he reported.

"*Example I.* Major Cooper reported that he saw a dust cloud presumably caused by a vehicle traveling on a dirt road paralleling the U.S.-Mexican border in the desert near El Centro, California. His observation was from an orbital altitude of 86 nautical miles. He stated that conditions at the surface of the earth appeared to be windless, that the dust cloud seemed to be caused by a vehicle traveling from west to east, and that he could discern a light dot at the eastern end of the dust cloud.

"Inquiry of the U.S. Border Patrol indicates that there is indeed a one-track dirt road which parallels the U.S.-Mexican border and which is used almost exclusively by Border Patrol vehicles. A somewhat similar road also parallels the border on the Mexican side but our Border Patrol says that vehicles seldom appear on the Mexican road. The U.S. Border Patrol uses a specially built vehicle called the International Scout. This is similar in size and general characteristics to the familiar jeep but it is covered by a white metal top. Dimensions of this vehicle furnished by the U.S. Border Patrol have been used in our calculations. We have not sent a field expedition to this border road but we have inquired about the region from the San Diego Museum of Natural History and we have from that source data on the nature of the soil and vegetation cover in that region. It is quite similar to other desert locations which our field expeditions have measured and we believe that our data are representative of the area near the border.

"As indicated by the attached table, an observer like Major Cooper at orbital altitude should have had little difficulty in seeing the road itself. Thus, if it is assumed that the road is 8 feet in width and optically infinite in length (in the sense that making it longer would not have influenced its visual detectability) and if the road surface, the background terrain, and the prevailing atmospheric contrast transmittance are as given in the attached table, then the probability of confident detection by an orbital observer is predicted to be 0.84. At this high probability, it is likely that an observer like Major Cooper would see the road.

Example:

					Target		Reflectance			
Example	Location	Alt. (ft.)	Orbit Alt. (NM)	Target	Width (ft.)	Length (ft.)	Target	Background Terrain	Contrast Transmittance	Probability of Seeing
I	El Centro	0	86	Dirt Road	8	∞	0.23	0.18	0.77	0.84
				Vehicle*	5.7	12.9	0.92	0.18	0.77	< .01
				Vehicle* plus cloud				0.18	0.77	>0.84
II	Tibet	16 000	86	Dirt Road	8	∞	0.18	0.07	0.66	>0.99
				2.5 Ton Truck	8.2	21.5	0.60	0.07	0.66	0.50
III	Tibet	16 000	86	Side of House	Equivalent of projected area 138 sq. ft.		0.80	0.07	0.66	0.50
				Smoke	2	∞	0.125	0.07	0.66	0.50
IV	Probably China	Uncertain; (between 0-16 000)	86	Train Track	8	∞	0.06	0.09	0.70	0.90
				Smoke	2	∞	0.33	0.09	0.70	>0.99

* International Scout

"If the white Border Patrol vehicle (the International Scout) was standing motionless on the road, the probability of its being seen from orbital altitude has been computed to be less than 1 percent. It is extremely unlikely, therefore, that an observer like Major Cooper would have reported seeing the motionless vehicle. With the International Scout in motion, however, a cloud of dust is produced which, in view of the windless condition, has been assumed to hang near the road behind the moving vehicle. This dense cloud of dust composed of road material is believed to have reflectance similar to that of the road itself. At the time of Major Cooper's observation, the shadow of the vehicle moving eastward along the road would fall directly behind it and would have been obscured by the dust cloud. This is a favorable circumstance since otherwise the shadow would tend to cancel part of the optical signal produced by the white vehicle. Calculation shows that the vehicle plus the dust cloud behind it is more visible than the road itself; that is to say, more than 0.84. It is possible, moreover, that the appearance of the dust cloud (because of dust concentration plus the presence of the vehicle) would create the impression of having a lighter tip at its eastern end. There is reason to believe, therefore, that the presence of a moving Border Patrol vehicle on the dirt road near El Centro, California, could have been seen from orbital altitude under the atmospheric and lighting conditions which we believe to have prevailed at the time of Major Cooper's observation.

"*Example II.* Major Cooper reported the presence of a dust cloud, presumably caused by a large vehicle traveling east on an east-west dirt road on a high Tibetan plain. The direction of the dust cloud indicated a surface wind from the south. He observed a light spot at the intersection of the dust cloud and the road. This he interpreted to be the vehicle. The altitude of this region is approximately 16 000 feet above sea level, and this fact contributed to the atmospheric clarity which probably prevailed. We have endeavored to obtain information concerning the probable nature of the dirt road and the terrain in its vicinity, and we have selected from our files of data on terrain and road surfaces the values which have gone into the calculations reported in the attached table. Under the conditions we have assumed, the road should be easily visible with a probability of confident seeing in excess of 0.99. If the vehicle was the size of a 2.5 ton truck having a light-colored top, its probability of being seen is 0.50. We believe, therefore, that there is a significant probability that Major Cooper correctly reported the presence of this moving vehicle during his pass over Tibet.

"*Example III.* Major Cooper reported that, in the vicinity of Tibetan roads, he saw what he believed to be buildings with smoke issuing from them. Photographs of Tibetan structures taken from the National Geographic magazine lead us to believe that these may have been large, multi-family dwellings having dark-colored roofs but white sides. The lighting which prevailed at the time of Major Cooper's observations was such that the sides of the houses should have been brightly lit and these areas should have formed high contrast with the terrain. Using terrain reflectance data which we believe to be applicable to Tibet, we have found that if a brightly lighted building-side had a projected area of 138 square feet in the direction in which Major Cooper was looking, it would have produced an optical signal capable of being visually detected with a confident probability of 0.50. It is likely that the building walls in question had a larger subtended area in the direction of the path of sight than 138 square feet and the probability of seeing increases rapidly with the projected area of the target under these circumstances. For example, a wall having twice the area we assumed, that is, 276 square feet, would produce an optical signal capable of being seen from orbital altitude with a probability greater than 0.90.

"In the case of the smoke which Major Cooper reported coming from these buildings, it was stated that ground wind carried the smoke horizontally across the countryside. We have endeavored to ascertain the nature of the fuel (probably Yak dung) and the method of combustion used to produce the smoke and, if our information is correct, a long streak of the grey smoke thus produced would have been seen with a probability of 0.50 if it were only 2 feet in width. A wider streak of smoke would have produced a higher probability of being seen.

"*Example IV.* Major Cooper reported seeing a train track, which was probably in western China. He observed an interruption in the track with a trail of white smoke issuing from its northeastern end; this he interpreted to be a train. He stated that the train track was darker than the terrain and, according to values which typify the conditions we believe to have prevailed, the long

> dark streak across the countryside should have been visually detectable with a probability of 0.90. Under the same conditions, the streak of white smoke should have been even more visible.
>
> "In conclusion, let me emphasize again that the calculations reported in this letter are based upon assumptions concerning the target, the background, and the atmospheric conditions which we believe to have prevailed on the occasions when Major Cooper reported seeing the four objects discussed above. There is no way of proving that these conditions did, in fact, prevail but it can be stated that if they did exist, then the visual sightings of these objects by an astronaut as visually capable as Major Cooper from an orbital altitude of 86 nautical miles have a finite probability."

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3. S. Q. Duntley, "Visibility Studies and Some Applications in the Field of Camouflage," Summary Tech. Rept. of Division 16, NDRC (Columbia University Press, New York, 1946), Vol. 2.
4. H. R. Blackwell, "Contrast Thresholds of the Human Eye," J. Opt. Soc. Am. **36**, 624 (1946).

The Manned Spacecraft Center also requested the Visibility Laboratory to provide some explanatory comments concerning the term "visual acuity". These comments were provided by Research Psychologist John H. Taylor, Ph.D., and were as follows:

> "The term 'visual acuity' is used to describe a variety of discriminations of which an observer is capable. In all cases it refers to the detection of a spatial difference or discontinuity and the subject is tested to find the smallest such difference he can detect. This value, generally expressed in terms of the subtended angle of the spatial element or its reciprocal, is taken as a measure of the visual acuity. A wide variety of test objects has been used in the investigation of this function, and the numerical results are widely disparate and depend upon the nature of the visual task involved. Simplest of these tests involve the detection of presence of an object, such as a point or a line, and are referred to as tests of the 'minimum visible.' Somewhat more complicated are those test objects which contain some spatial discontinuity within themselves, such as a pair of small targets or a broken ring, in which the 'twoness' of the points or the location of the gap must be discriminated, and which are referred to as measures of the 'minimum separable.' Still other tests involve higher-order discriminations, such as form recognition. These tests, of which the ordinary clinical wall chart of Snellen, requiring the recognition of letters, is typical, are called measures of the 'minimum cognizable.'
>
> "It is evident that the last-named measures of acuity are most often used in medical practice, and that the numerical values resulting from such tests are most familiar to the majority of the population. Since the Snellen charts are based upon the notion that one minute of arc is required for the perception of form (based upon a statement of Hook, quoted by Robert Smith in 1738), it is firmly implanted in the popular mind that one minute of arc angle

represents the value of best acuity. After all, is it not often said that 20/20 scored on the Snellen test (from the line on which the letter stroke width subtends one minute of arc) means 'perfect vision'? Major Cooper's Snellen acuity happens to be 20/12, or 0.60 minutes, although it will be indicated below that this value is merely suggestive of his superior vision and does not represent a limiting value of visual resolution.

"Measures of acuity other than the conventional clinical wall charts yield quite different values, and generally speaking the simpler the test the more acute vision becomes. Only two studies will be cited, although there are dozens in the experimental literature, and these have been chosen because the test objects are more closely analogous to the real objects sighted during the MA-9 flight.

"Let us begin by summarizing the data of Hecht and Mintz[1], who determined the minimum angular diameter required for a long wire to be seen against a uniformly luminous background. The subtended angle of the wire, which was seen as a dark silhouette (Contrast = -1.0), was found to decrease with increasing field luminance, reaching its limiting asymptote at 0.007 arc minutes. These data were taken from a single observer (Hecht), aged 45 years, and it is probable that Major Cooper, similarly tested, would better this result by a palpable factor. While the terrain backgrounds against which roads, rivers, and railroad tracks were seen were probably not as uniformly bright as those used in the experiments, still these data are most closely applicable to the visibility of such earth features.

"One variety of visual acuity comes from tests in which the observer is required to detect the presence of a discontinuity in an extended line. This measure, called *vernier acuity* from its resemblance to the visual task required in the reading of vernier instrument scales, is analogous to the situation in which an extended line is suddenly displaced by some small angular amount. A hypothetical example might be the case where a truck and its shadow combine to produce a pair of such apparent displacements. Experiments by Berry[2] have shown vernier acuity values in the range of one second of arc, or about 0.017 arc minutes.

"Both of the studies referred to concerned targets of essentially -1.0 contrast, the lower limit for targets darker than their backgrounds. Targets which are darker than their terrain backgrounds may approach this value, but owing to contrast losses suffered on account of the presence of the atmosphere, will always be of lesser contrast and concomitantly reduced discriminability. The quantitative features of this situation may be calculated, and this is done in order to arrive at visibility estimates. When targets are brighter than their effective backgrounds, however, no upper limit on contrast is imposed, and it is common to see angularly tiny objects (such as stars, distant lights, sun glints and the like) provided only that sufficient light from these objects reaches the eye. The light-colored vehicles reported by Major Cooper may be a case in point.

"A final point should be made in regard to the use of laboratory data in predicting the performance of an observer in a real-life situation. By and large, the numerical results of these experiments are estimates based upon large numbers of observations, and almost always refer to that value of angle which is necessary for discrimination to be successful one-half of the time. There are statistical considerations which make this a desired value which need not be gone into here. It must be emphasized, however, that the numbers so derived represent only a single point on a continuum; that there are larger visual angles which result in certainty of seeing and lower ones which yield lesser probability of seeing. For example, much smaller targets than indicated will be seen, albeit less frequently. This fact, together with the likelihood that Major Cooper, as hinted above, is a superior observer and the unquestionable fact that he is highly experienced in high altitude observation make it very probable that estimates based upon laboratory data may be conservative indeed."

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[1] S. Hecht and E. U. Mintz, "The Visibility of Single Lines at Various Illuminations and the Retinal Basis of Visual Resolution," J. Gen. Physiol., **22**, pp. 593-612(1939).

[2] R. N. Berry, "Quantitative Relations among Vernier, Read Depth, and Stereoscopic Depth Acuities," J. Exptl. Psychol., **38**, 708-721(1948).

1.1 The Gemini Visual Acuity Experiment

Despite the consensus of NASA medical scientists and physiologists that the visual acuity of astronauts in orbit would not be different from that measured under normal circumstances on earth, it was deemed necessary to test this null hypothesis carefully and fairly throughout the two long-duration missions in the Gemini series. This major experimental task was undertaken jointly by NASA and the United States Navy. The Visibility Laboratory designed, prepared and conducted the experiments under Navy and NASA contracts. The Navy independently arranged for the construction of the ground markings which were located in the Rio Grande Valley of Texas while NASA independently provided for the construction of an alternate set of ground markings that were constructed by the Australian Ministry of Supply near the NASA Tracking Station located at Carnarvon in western Australia. A succession of summary reports were produced soon after the Gemini V and Gemini VII missions, respectively, and were published by NASA, primarily in NASA Special Publication 121, February 1966, issued in connection with the Gemini Mid Program Conference, which was held at the Manned Spacecraft Center in Houston. The same material appeared subsequently as a Visibility Laboratory Report identified as Scripps Institution of Oceanography Reference 66-17, July 1966. That summary with minor updates and corrections appears as Appendix A near the end of this report for the convenience of those who may be interested. Indeed, it is recommended that those who wish to read a concise description of the experiments and the results they produced turn immediately to this appendix in lieu of the much more detailed account which is provided by the main body of this report.

1.2 Evolution of the Experiment

From the outset it was the basic plan that the program would be comprised of two parts: (1) vision tests prior to, during, and after the spaceflights in order to establish a preflight physiological baseline of visual performance and, subsequently, to monitor quantitatively any changes which might occur during flight; and (2) out-of-the-window sightings of prepared markings on the ground to ascertain man's limiting capability to discriminate small objects on the surface of the earth and to establish methods for making reliable predictions of these limiting capabilities under varying circumstances.

1.2.1 INFLIGHT VISION TESTS

Both aspects of the experiment required careful investigation and determination of the normal ground "baseline" visual capabilities of the astronauts to be involved in the experiment and a method of determining in flight what these same capabilities were. The test used on the ground had to be repeated in space with sufficient precision to detect changes from the preflight baseline. Ideally the same instrumentation should be used in the preflight, flight and postflight phases.

The concept of an instrument for testing vision which could be used by the astronauts to self-administer the same tests in these three phases evolved early in the design of the experiment. The details of what the instrument would measure and how it would perform these measurements were the subject of considerable study and compromise as the experiment progressed and as the pressures of time and the requirements for space-qualified instrumentation became known. Further compromise became necessary when it was decided to incorporate into the testing instrument the capability of performing measurements for a study of otolith function (medical experiment M-9). The resulting device was capable of measuring visual acuity as determined by orientation discrimination of small rectangular bars at the center of a large circular illuminated field. The tests were self-administered and could be self-scored in such terms that first order results could be transmitted to the ground. In this manner an inflight check could be maintained on the presence or absence of longitudinal variations from the astronaut's baseline visual performance. Complete analyses of the detailed records of usage of the instrument were performed after the recovery of the spacecraft.

1.2.2 OTHER VISUAL TESTS

There are, of course, several parameters of the visual process aside from acuity which are certain to be important in space operations, and which, therefore, it would have been desirable to study during the long-duration Gemini flights. Some of the more obviously interesting of these were considered for inclusion in the experiments, *viz*:

Color Vision

Of great importance in a number of tasks, especially those relating to lunar surface exploration (as in the evaluation of geological samples), observation of the surface of Earth, Moon, and planets from orbit, and the discrimination of color-coded information on displays and other spacecraft. Clearly, any disability of color vision which occurred during prolonged flight could be costly, if not catastrophic. While weightlessness *per se* might result in only subtle changes in color discrimination, it was recognized that atmospheric contaminants or other problems might pose a more severe problem. Since measurement of color discrimination anomalies requires equipment of considerable sophistication, the bulk, weight and power constraints of the present experiment precluded incorporation of a formal color test. Instead, we relied upon the verbal reports by the astronauts to give information in the event of any serious disruption of color vision (They would, for example, have had difficulty in using the color-coded sequence patterns within the Inflight Vision Tester if any grave failure of discrimination had occurred.), and upon the results of preflight and postflight data obtained by use of the Farnsworth-Munsell 100-Hue test.

Muscle Balance

Any tendency for the balance of the extraocular muscles to change from normal (orthophoria) to abnormal (heterophoria) could result in visual disability in some tasks, and possibly to visual discomfort (eyestrain, headache). While the importance of phoria changes was realized, especially in such operations as navigation and the use of certain optical devices, it was not possible to include a satisfactory test in the present instrument; primarily because of the above-mentioned constraints, but also because of the lack of time resulting from the accelerated launch schedules.

Accommodation

Both the amplitude and speed of accommodation (change of focus) of the human eye are of undoubted importance in space operations. A simple and obvious instance is that of rendezvous and docking, when the responsible astronaut must rapidly shift focus from the distant vehicle to his own instrument console and back. Proper measurement of this visual parameter, however, must await more satisfactory instrumentation than could be used during this study.

Dark Adaptation

The time course and degree of adaptation to low-level vision is of great interest, for it will govern the efficiency of the astronauts in performing useful work and accurate observations in the dark. This problem occurs not only in orbital flight with its 90-minute day-night cycle, but certainly also in extravehicular and lunar surface operations. Measurement of the dark adaptation of astronauts, however, is a time-consuming affair, and it was considered that its study must await more lengthy space flights, where the demands upon the observers are less severe and would allow proper assessment of the function.

Low-Level Vision

Having achieved whatever degree of sensitivity is possible under complete adaptation to a specific low level of luminance, the question of visual performance remains. Observation, for example, of dim-light astronomical phenomena, or during lunar light, will succeed only if the observers' low-level vision is unimpaired. While certain influences are known to be possible, such as dietary factors, toxic atmospheres and the like, there was no opportunity to incorporate a test on the Gemini flights.

These above factors in visual performance are representative of those which were discussed prior to the flights, although tests for them were not included in our experimental program. To each of them, one must address the question "Is it essential to test this parameter of vision in actual spaceflight, or will ground-based tests suffice?" During the Gemini program, when considerations of time, weight, and power consumption were exceedingly restrictive, these problems could not be justified for study. It must be realized, however, that each is deserving of careful evaluation, not only in isolation and on the ground, but as it interacts with the other factors in real spaceflight.

A symposium on visual tasks in spaceflight was held at the NASA Ames Research Center on 4 and 5 August 1964. The forty attendees came from the Armed Forces – National Research Council Committee on Vision, from various NASA laboratories and centers, and from various contractors in industry and universities. During this meeting a session was devoted to the solicitation of suggestions for vision experiments in space, and for modifications of the study proposed by the Visibility Laboratory. There were many valuable comments and suggestions received, both at the meeting and subsequently by correspondence. While most of these suggestions turned out not to be feasible ones in light of the constraints of the program, it is felt that the experiments eventually performed were benefitted by this meeting with some of the most competent professional people concerned with space operations.

1.2.3 CHOICE OF THE TARGET

General Considerations

Although the primary hypothesis tested in the experiment was "the visual acuity of an astronaut is not altered by prolonged stay in his space environment", it was desirable to attempt an experiment which would yield more than a yes-no answer with respect to the hypothesis. It was believed that if the hypothesis was disproved by the experiment, the data should be useful in determining the nature of the change in such a way that the astronaut's altered visual acuity could be predicted for visual tasks which he might likely be called upon to perform. In the present state-of-the-art of visibility engineering, i.e., prediction of visual performance, the most basic description of an observer's visual capability is obtained by specifying his summative function or element contribution function. The summative function is presently used to predict the detectability of objects having complex shape and internal contrast structure. It is also used to make predictions as to recognizability of complex objects. If the spacecraft observer suffered an alteration in visual acuity, then the experiment should yield information as to the observer's new summative function, in order that visual acuity prediction could be attempted.

Reasons are outlined elsewhere in this report for the choice of a recognition type experiment rather than a detection type experiment. In order to achieve a successful recognition experiment, it is necessary to make the objects to be recognized easily detectable in order to avoid contamination of the data by visual search and detection of the object prior to initiating the recognition phase of the visual task. These considerations suggest that the objects to be used should have a large ratio of detectability to recognizability. An additional requirement should be that the experiment must cover a range of recognizability which at one extreme has a case in which recognition will not occur even with a substantial improvement in visual acuity and at the other extreme a case in which recognition will occur even with a substantial degradation in visual acuity.

A further consideration which forces compromise with those considerations described in the preceding paragraph is that, for the ground objects, both cost and manpower associated with their manipulation dictate that the test objects should be as small as possible.

The Difference Image Concept

As an extension of detection theory, it has been shown that for a linear system limited in performance by Gaussian noise, the ability to distinguish between two object alternatives is equivalent to detecting their "difference image."[1,2] The difference image is obtained by superimposing the maps of the two objects in such a way as to achieve maximum cross correlation and taking a point by point difference between the two objects in that position. For example, to distinguish between a circle and a doughnut, it is necessary to detect the hole. The regions of the two objects which have unity cross correlation do not contribute information to the recognition task.

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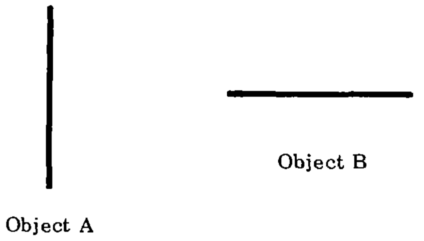
[1] Harris, J.L., J. Opt. Soc. Am. **54**, 606 (1964).

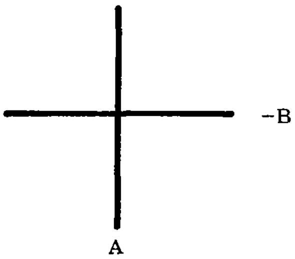
[2] Harris, J.L., Scripps Inst. Oceanog. Ref. 59-65 (1959)

It was earlier suggested that the experiment should contain a case in which the objects are easily recognizable but that the objects should be as small as possible. This suggests that the difference image area should be as large as possible with respect to the area of each object, i.e., the common area of the object alternative should be as small as possible.

The common area can, in fact, be made equal to zero by the use of any of a large number of possible pairs of object alternatives. Of these, probably the most simple pair from a geometric standpoint is two perpendicular lines, i.e.,

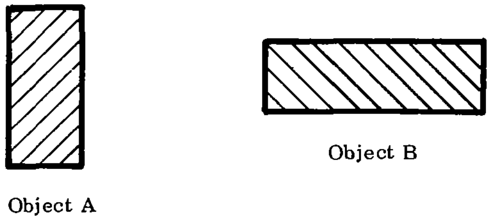


since the difference image is

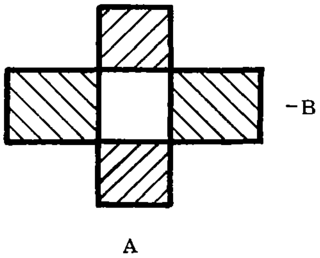


which fully utilizes the content of both objects.

If the objects are to be small in size and detectable by reflected sunlight, they cannot be true lines but can be rectangles such as



having a difference image



For a pair of 4 to 1 aspect ratio rectangles, the common area amounts to 25% of the area of one rectangle and, therefore, 75% of each rectangle contributes toward the difference image. Rectangle orientation is, therefore, an experiment involving simple geometric objects which satisfy the desire for minimum common area and, hence, minimum object area required in order to achieve a specified recognizability.

Theoretical Considerations of an Orientation Experiment

The summative function can be used to study the performance which would be expected in an orientation experiment.[2,3] The summative function concept treats the human visual system as a linear filter and, after deriving the filter characteristics from basic vision data, applies the filter to complex visual stimuli on the assumption that visual detection takes place when the combination of stimuli and filter produce a threshold neural output. The detectability of a complex object is, therefore, found by convolving the object and the summative function and determining the maximum value of this convolution integral. The summative function concept can be extended to the case of simple recognition tasks such as the rectangle orientation by convolving the summative function with the difference image and, as in the case of detection, assuming that recognition can only occur if the maximum value in the convolution integral is equal to or greater than some threshold value.

Such a calculation was made for rectangle orientation. The calculations were made on a computer and existing equipments at the Visibility Laboratory were used to supplement the numerical data with photographs which depict the results of the convolution. The photographs shown as Fig. 1-1 are greatly contrast enhanced in order to make the structure of the results visually apparent. The contrast of the rectangles used in the calculation were +1.0 and the maximum contrast in the convolution is indicated below each picture along with the angular size. All pictures were scaled up in size by a factor inversely proportional to angular subtense in order that the detail would remain easily visible.

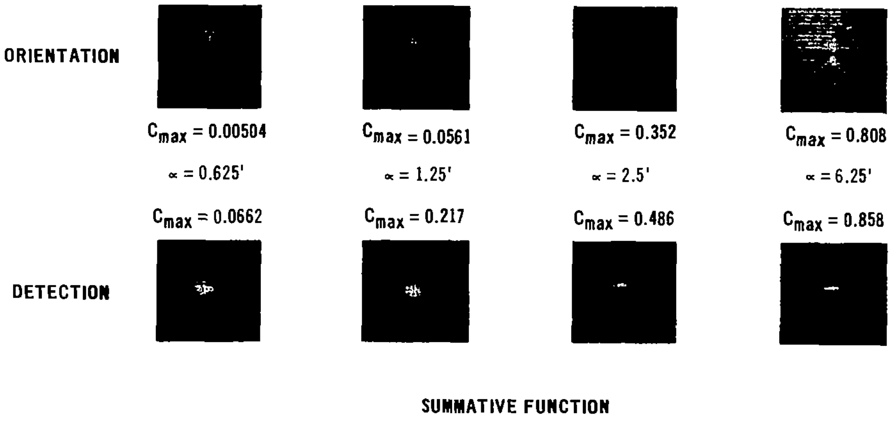


Fig. 1-1. Summative function convolution maps for the case of detection and orientation of rectangular objects.

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[3] Duntley, S. Q., et al, J. Appl. Opt. **3**, 550 (1964)

A corresponding set of calculations was made for the case of detection of a rectangle. Photographs of these convolution integrals were also made and are labeled in Fig. 1-1 as to the maximum contrast in the convolution just as was done in the case of the difference image calculation.

The summative function model predicts that contrast threshold for the objects must be proportional to the reciprocal of the maximum contrast values associated with the convolution integral in order to achieve a fixed neural excitation threshold level. Fig. 1-2 shows a graph of the relative contrast threshold versus relative angular subtense as predicted by the summative function model for both orientation and detection. The significant feature of this pair of curves is that in the region where the rectangle is easily resolved by the human visual system contrast thresholds for detection and orientation are almost the same value whereas for decreasing angular subtense the orientation threshold rises rapidly compared to the detection threshold thus satisfying the requirement that at low angular subtense high detectability be maintained while recognizability becomes an extremely difficult task.

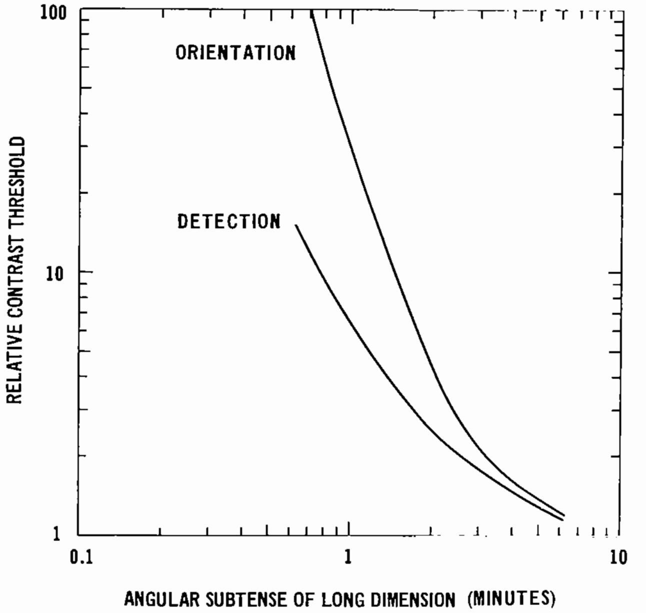


Fig. 1-2.

Relative contrast threshold versus relative angular subtense as predicted by summative function model for both orientation and detection. (See Fig. 1-1)

Additional evidence in support of these expectations can be obtained by considering the effect of diffraction of the eye on the retinal image of the rectangles. Figure 1-3 shows photographs of retinal imagery as degraded by diffraction only for both the difference image (orientation) and a single rectangle (detection). As before, image sizes have been scaled up in size inversely proportional to angular subtense in order to preserve the detail. Peak retinal contrast and relative angular size are shown for each photograph. The relative object contrasts which would be required in order to produce a constant peak retinal contrast are shown in the graph of Fig. 1-4. The results bear a close resemblance to the curves of Fig. 1-2.

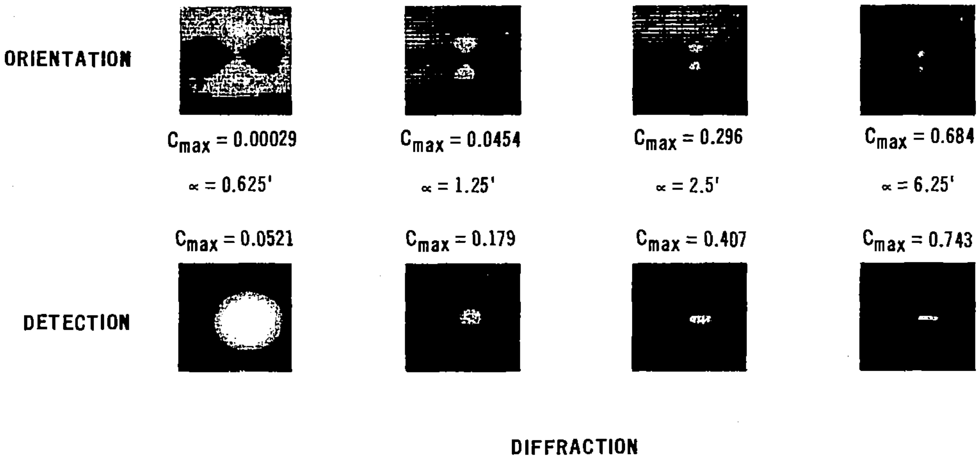


Fig. 1-3. Computer calculated retinal images for detection of bars and difference images for orientation of bars.

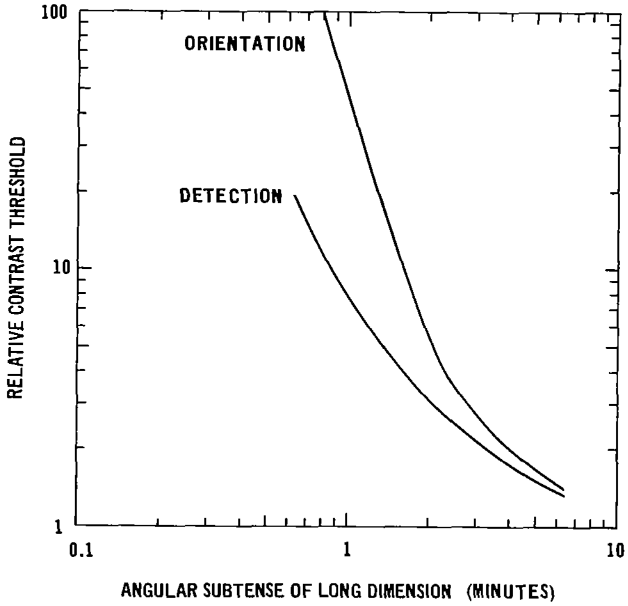


Fig. 1-4.

Relative object contrasts which would be required in order to produce a constant peak retinal contrast. (See Fig. 1-3)

Summary

The choice of an experiment involving the orientation of rectangular objects satisfies a number of important requirements. At large angular subtense, the contrast threshold for orientation is nearly the same as the contrast threshold for detection, thus minimizing the size requirements for the largest objects which must be made large enough to be easily recognizable. The requirement for very low recognizability but high detectability at small angular subtense is met.

The rapid rise of contrast threshold for orientation with decreasing angular subtense makes a sensitive experiment and minimizes the range of object sizes which are required. The rectangle orientation experiment is one which is extremely sensitive to changes in the summative function so that if visual acuity was altered by prolonged space environment the experimental results could be used to estimate the modified summative function of the observer and, therefore, provide the information required to predict his altered visual acuity in typical visual tasks.

1.2.4 OUT-OF-THE-WINDOW EXPERIMENT CONCEPT

The purpose of the out-of-the-window portion of the experiment was two-fold. First, it presented the opportunity in a controlled experiment to compare the ability of the astronaut to discriminate specified markings on the ground with predictions based upon (a) careful measurements of his preflight visual capabilities, (b) carefully measured optical properties of the ground markings under observation, and (c) measured contrast transmittances of the atmosphere and spacecraft window. Second, this portion of the experiment was to secure additional information beyond that provided by the on-board experiment regarding any changes which might occur to the astronaut's visual capabilities as a result of his exposure to the spacecraft environment for extended periods of time.

As originally conceived, the out-of-the-window experiment involved the use of a single large marking on the ground which would be adequately above the detection threshold of the astronauts to assure that there would be little or no time required in searching the area to determine the location of the marking. The task for the astronauts would be to determine and record the orientation of some feature of the marking as this orientation was quickly changed (10 to 20 times) during the interval that the ground site was within view.

Simultaneously with the out-of-the-window observations a series of measurements would be made at the site of the ground marking of its luminance and of the luminance of the background surrounding the marking in the direction of view from the spacecraft as it passed overhead. From these measurements the inherent contrast of the marking against its background at the instant and in the direction of observation could be determined. Similarly, by the additional measurement of the luminance of the solar disk and of the sky in the appropriate direction, a determination could be made of the contrast transmittance of the path of sight from the ground marking to the spacecraft window. By taking the product of this contrast transmittance and the inherent contrast of the marking, the apparent contrast available at the outside of the spacecraft as a function of time could be obtained. The remaining unknown factor in the determination of the apparent contrast of the marking as seen by the astronaut would be the contrast transmittance of the spacecraft window. This transmittance depends upon the luminance scattered into the path of sight by the window and any contamination on it. The magnitude of the luminance, in turn, depends primarily upon the lighting incident on the window contaminants. It is, therefore, imperative that its measurement be made at the instant of the observation of the marking, due to the transient nature of the lighting incident on a surface of the maneuvering spacecraft. To this end, then, it was decided to install in the spacecraft a telephotometer that would measure the required luminance (or one which would be related to it) and telemeter this information to the ground.

In addition to knowing the apparent contrast of the ground marking as a function of time, it was also necessary to determine its apparent angular size as a function of time as the spacecraft passed within range of the ground site. This could be computed from a knowledge of the linear dimensions of the mark, the instantaneous slant range of the path of sight from the spacecraft to the mark, and the zenith angle of the path of sight. This range and angle varied continuously during an overpass. Hence, accurate orbital information and the exact time of observation with respect to the time of closest approach was required to determine the solid angle subtended by the ground marking at the astronaut's eye at the time of observation.

It was the hypothesis of the out-of-the-window experiment that, having measured the astronaut's ability to perform an orientation discrimination task by means of controlled laboratory experiments, one could then predict the limiting angular size and contrast of the object whose orientation could be correctly discriminated. A comparison of the predictions with the results of the observation from the spacecraft would serve to demonstrate the validity of the hypothesis. Additionally, in the event that a sufficient number of observations could be obtained throughout the course of the flight, a second check could be obtained on the presence of longitudinal variation in visual performance with prolonged exposure to the spacecraft environment.

Such were the early concepts of the out-of-the-window experiment. As the experiment evolved, the major changes that occurred were in the type of ground markings which could be used and in their location.

The first proposals for the ground site operation were as follows: A rectangular mark having a maximum dimension of about 200 feet and variable in size and orientation would be placed in the center of a large, flat, background area which had been bulldozed to ensure uniform reflectance. During the period of perhaps 30 seconds that the site was in view from the spacecraft the orientation of the rectangle would be changed repeatedly and its size reduced with each change in orientation. The experimenter would be in direct communication with the astronauts and the latters' responses recorded in "real time" and correlated with the changes in size and orientation of the ground marking. Two alternative methods of construction of the variable rectangle were considered. First was the use of flip cards manually or mechanically operated to accomplish the required rapid changes and, second, was the use of an ensemble of electric lights operated by suitable switching arrangements.

It had been assumed at the time of these preliminary proposals that the distance from the spacecraft to the observation site would be 86 nautical miles as had been the case in the Mercury sightings made by Cooper on MA-9 flight. The 200-foot long dimension of the rectangle would subtend an angle of 1.3 arc-minutes in that case. However, the altitude of the Gemini flights was increased, and it was necessary to plan the size of the marking on the basis of a circular orbit of 161 nautical miles altitude. At this distance the 200-foot dimension subtended an unacceptably small 0.7 arc-minute, and it was necessary to approximately double the linear dimension thereby quadrupling the required area of the ground marking.

This larger area presented many problems in manpower or mechanical systems to operate flip cards or in switchgear and total power to operate a system of lights. Furthermore, it was not possible to obtain direct communication between the experimenter and the astronauts, and the difficulties in time coordination between the spacecraft observation and the manipulations of the rectangle were considerably increased as a consequence.

With these considerations the modus operandi of the out-of-the-window experiment was changed to one wherein a series of rectangles was laid out in an array on the ground with a range of sizes bracketing the expected orientation threshold but all exceeding the expected detection threshold. The rectangles were arranged in a prescribed order of decreasing size but were randomly arranged in four orientations, viz., north-south, northeast-southwest, east-west, and southeast-northwest. With this type of operation the astronaut could make his observations in a period of ±10 seconds from the time of closest approach, thereby considerably reducing the problems engendered by changes in slant range, foreshortening, target contrast and contrast transmittance. Furthermore, the only communication requirements were those of passing down to the capsule communicator the orientations as observed. By correlating the times of the astronaut's responses with the precisely known orbital position of the spacecraft, the position of the astronaut with respect to the target for each observation could be determined.

To assist the astronaut in locating the array and properly orienting it, various landmarks, smoke generators and special markings were used.

In order to preclude the possibility that the observers would learn the orientation of the individual rectangles, it was necessary to provide for the reorientation of any or all of them. In actual practice, it was not possible to change more than one of the smaller rectangles between successive passes (90 minutes). However, unless the observations on a pass were correct, it was unnecessary to change the orientations. Between passes on successive days sufficient time was available to change both the orientation and the size of the rectangles as required by consideration of contrast and angular subtense for the new pass.

The original location considered for the ground site was in the desert near El Centro, California. Here the weather conditions are such that a high probability existed of having very clear air and cloudless skies. Large areas of desert land were available as was gypsum from local mines for the rectangular markings. Due to changes in launch azimuth, it was necessary to forego this ideal site for the climatically and physiographically less desirable site north of Laredo, Texas. Furthermore, consideration of probable time of launch, orbital precession, and duration of flight made it necessary to construct and operate a second ground observation site in the southern hemisphere if the space-to-ground observations were to be obtained toward the end of the long duration missions. This second site was established on the Woodleigh Station south of Carnarvon, Australia.

Additional details on the factors involved in the evolution of the concepts, the design, and the selection of the ground site are given in Part IV of this report.

1.3 Organization and Support of the Experiment

Specific planning for the Visibility Laboratory's participation in an experiment on the Gemini series of space flights started in the Fall of 1963. It was at this time that the concept was generated for an experiment which would combine the test for "longitudinal" variations in the astronaut's visual acuity with the testing of the ability to predict what astronauts can see from orbit. Details of the experiment as conceived at that time were worked out with NASA and the U. S. Navy.

The Laboratory received authorization to initiate its work on the experiment early in 1964.

As the planning for the experiment progressed, many changes were introduced which affected, in a major way, the magnitude of the effort required by the Laboratory, NASA, and the Navy. A few of the more important of these changes will be enumerated as they will assist in obtaining an understanding of the way in which the experiment developed.

1. The original plan called for conducting an experiment during one of the longer flights such as the planned fourteen-day flight. It was quickly recognized, however, that with flights as complex as these were likely to be, and with the mission objectives for the various flights being changed as rapidly as they were during the early stages, that it would be unwise to place the success of the entire experiment on the outcome of a single Gemini flight. Therefore, the plan was changed to include both the fourteen-day mission and the shorter seven-day mission.
2. Original estimates of the project were based on the fourteen-day flight occurring sometime between the middle and end of fiscal year 1966. However, it became necessary to be prepared to conduct the experiment early in fiscal year 1966 because of the accelerated schedule of the entire Gemini program, and because the earlier seven-day as well as the fourteen-day mission was included.
3. The items of flight hardware required, namely the vision tester and the photometer, were originally conceived as simple laboratory fabricated devices which would be carried on board. As the Gemini program developed, however, the requirements to be met by experimenter's equipment which were used during the Mercury flights were no longer considered acceptable. Consequently, all of the experiment on-board equipment had to be subjected to rigid quality assurance procedures and to a lengthy and stringent qualification test program requiring elaborate engineering design, fabrication, documentation and testing procedures. Additionally, it was necessary to supply the flight hardware and back-up hardware far in advance of flight time. These facts, of course, resulted in a major enlargement, re-orientation, and rescheduling of the entire project.
4. Changes in the location, number and manner of operation of the ground sites presented an additional increase in the demands of the project on all concerned. The original experiment plans were based on spacecraft orbits similar to those used on the Mercury flights, namely, the 72° launch azimuth. Such an orbit would place the deserts in Southern California and Arizona directly beneath the spacecraft. Excellent locations in this area were available for the ground site, which were also close to sources of suitable, inexpensive materials for the markings. In addition, their closeness to the Visibility Laboratory was a major consideration in the original planning of the experiment. When the launch azimuth was changed to 90°, these desert areas became unavailable to the experiment and it was necessary to seek out locations having a lati-

> tude less than 28.5° for the site. Furthermore, as the study of the orbits and times of overpasses progressed it became obvious that in order to be assured that the out-of-the-window experiment could be conducted toward the end of the longer missions, a second observation site located in the Southern Hemisphere would be required. The support of two sites by the Laboratory required a major increase in the effort required for the site survey, instrumentation construction and preparation, and the manning of the sites during the flights.

Thus, what was originally conceived as a moderately simple experiment, became markedly more complex and demanding; and the time available to accomplish the preparation for the experiment was greatly reduced.

2. Support Experiments And Astronaut Training

2.1 SUPPORT EXPERIMENTS

Throughout 1964 and 1965 a number of experiments were conducted at the Visibility Laboratory which were in support of the inflight study. In general, these experiments were exploratory, and were intended to provide guidance for the conduct of the actual tests. Some were quite extensive and involved many hundreds of observations; others were brief and yielded only enough data to enable the assessment of one or another effect which might result from altering some detail of the experimental design. These support experiments are separate from the astronaut training procedures outlined elsewhere in this report, and need only summary description here.

2.1.1 Facilities

Four different experimental facilities were used at various times for the support experiments; these may briefly be described as follows:

Driveway

A straight and level stretch of macadam road was used for some of the initial tests. It was marked off at ten-foot intervals over a length of 250 feet, and the test targets were constructed so that one foot of actual distance on this range corresponded to one nautical mile of orbital altitude. The reflectances of target and background materials were chosen so as to be realistic in terms of expected conditions during the missions. The experimental variables used were either range (target subtense) or contrast. The driveway facility is shown in Fig. 2-1. High levels of natural daylight illuminated the target-background arrays.

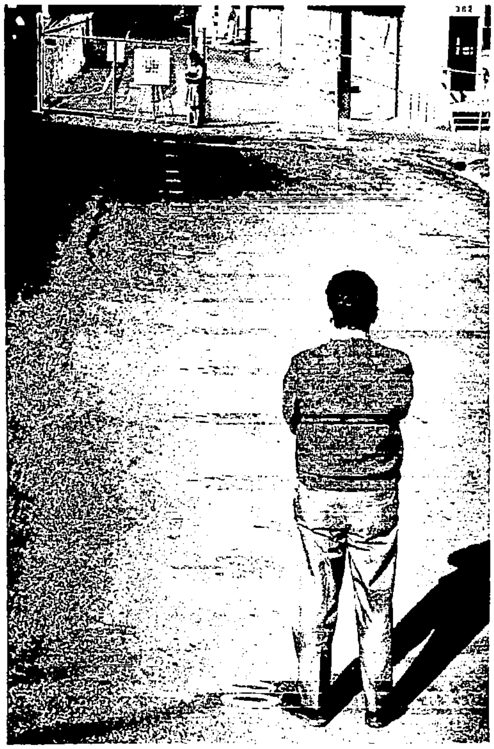


Fig. 2-1. Outdoor observing range at the Visibility Laboratory. The displays are scaled so that each foot on the range corresponds to one nautical mile of orbital altitude.

Tunnel

A long blackened room in the laboratory was used for viewing some of the targets. The observer sat before a high-luminance background which was square and subtended 30° x 30° at his position. Interposed between him and the background was a large sheet of high-quality plate glass. Targets were seen by reflection in this glass, and at the center of an array of four orientation lights which gave the cues to both location and distance of the bars. A standard slide projector was modified so that rectangular targets were seen in Maxwellian view at the plane of the objective lens. The system was folded, in order to achieve the desired optical distance from eye to target, by use of a first-surface optically flat mirror. The actual arrangement of elements may be seen in Fig. 2-2. In this system, then, the bar targets were seen as positive stimuli, brighter than the background, at the center of the display. The orientation of the bars was random from trial to trial, the changes being accomplished by rotation of the slit by the experimenter as shown in Fig. 2-3. Target exposure was limited to 3.0 seconds, with the background and orientation lights left on continuously. The background luminance was uniform, and held at 80 or 100 ft-L. The experimental variable was target contrast, changed by interposition of neutral density filters in the projection system.

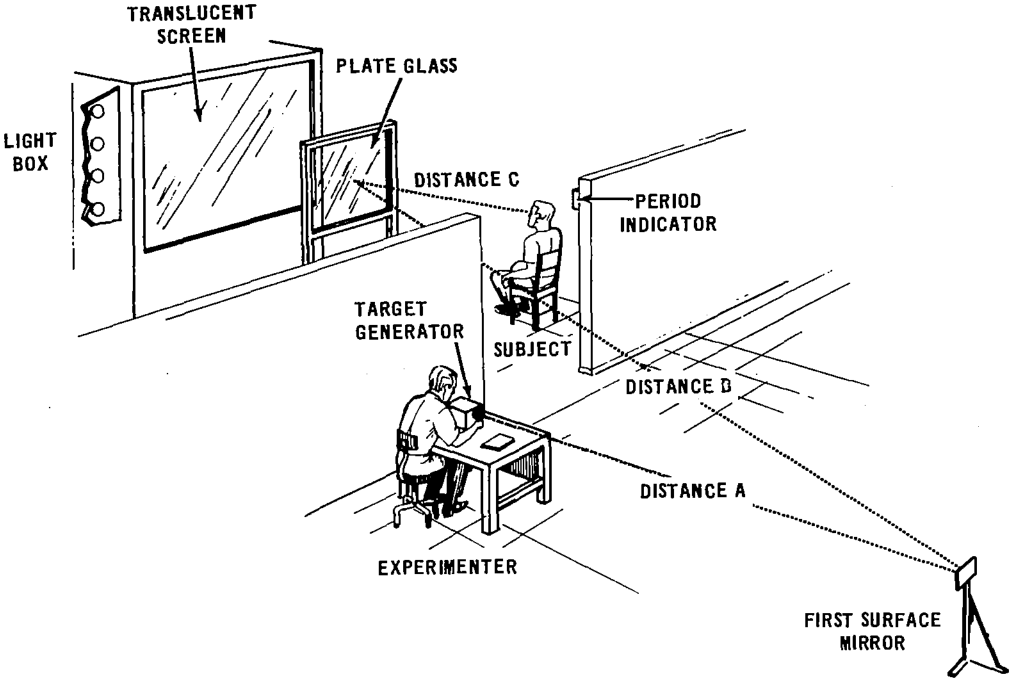


Fig. 2-2. Diagram of the Tunnel facility, showing the arrangement of elements. Targets appear as bright increments superimposed on the background.

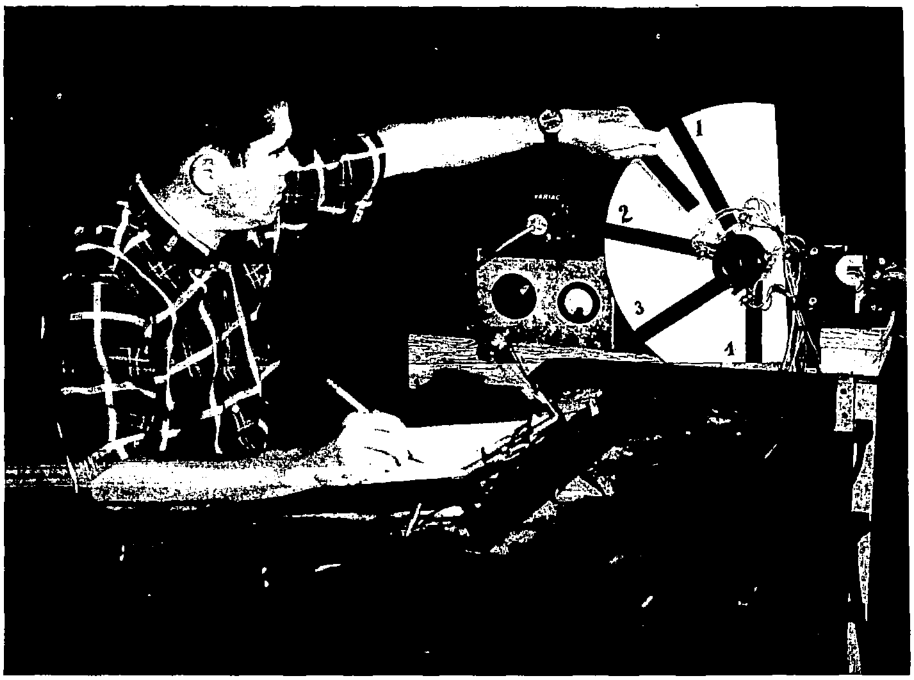


Fig. 2-3. Target bar projector used in the Tunnel facility. Orientation of the bars is changed by rotating the rectangular mask which covers the objective lens.

Cube

This is the standard vision research facility in use at the Visibility Laboratory. One to four observers look into a white-painted integrating cavity, approximately cubical in shape, through a partially open side. This arrangement provides a wide-angle background of uniform luminance at any desired level. Targets are produced by rear projection through a translucent part of the opposite wall of the cube, and orientation and accommodation cues are supplied by separate projectors external to the cavity on the observers' side. In the present instance, observer responses were made by pushing one of four buttons on their chair arms, indicating their choice of target bar orientation. The essential elements of the Cube facility are shown in Fig. 2-4. Targets were presented in a series of 80, with orientation randomly varied from trial to trial. It was found convenient to utilize a Kodak Carousel projector for this purpose, for it lends itself to programming by our standard automatic presentation and recording apparatus. The experimental variables can be either target subtense (through changes in image size on the slide or projection distance), or target contrast (by interposition of neutral density filters in the projection system), or target duration, by use of a variable shutter arrangement.

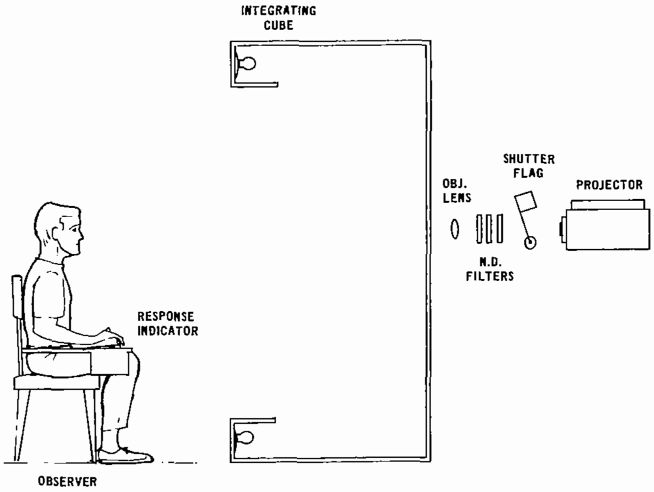


Fig. 2-4. Arrangement of the Cube facility and of the corresponding observing theater in the Vision Van.

Van

This is the same facility which is elsewhere described in connection with its use in the astronaut training program. (See pp. 2-17, ff.), and Figs. 2-4 and 2-15. It differed only in detail from the Cube, upon which its design philosophy was based.

2.1.2 Observers

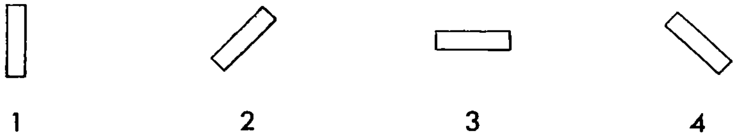
Fifteen observers were used in the support experiments, although participation by many of these was minimal, usually subserving expediency or the assessment of individual differences. All were members of the Visibility Laboratory staff and were screened for clinical visual acuities of 20/20 or better on the conventional Snellen test. The individuals used in the more extensive experiments were all highly trained in laboratory observing procedures, and had superior visual acuity without spectacle corrections. These "professional" observers provided data upon which the eventual target arrays were based, although the final target sizes were determined from results of the astronauts' own training experiments. We were fortunate in having one observer with superior vision (DG) who became, in effect, the Laboratory's "astronaut surrogate" during much of the program.

2.1.3 Observer Responses

Several discrete psychometric methods were used during the support experiments, depending upon the requirements of the data. All were standard psychophysical procedures which are well described in the literature and need not be detailed here, but it will be helpful to give a brief summary of each, indicating its essential features:

Spatial Forced-Choice

This is the most important and most frequently used method from the standpoint of the S-8/D-13 program. The observer is shown a rectangular bar target and is required to guess its orientation, i.e., to report that it is displayed in one of (usually) four positions;



and to respond appropriately, either by verbal means or by depressing a button corresponding to his choice. An essential feature of the method is that he is forced to choose one of the four positions – he cannot respond by saying "I don't know". It is thus evident that, at high stimulus levels (targets of high contrast and/or large size) he will respond correctly on essentially 100% of the trials. At some lower level, when targets become small or of low contrast, his percentage of correct responses will approach and approximate 25, since he enjoys a probability of 0.25 of being correct, even though he cannot make the required discrimination by visual means. In laboratory practice, it is usual to convert the obtained frequencies of correct responses by use of a standard formula which brings the chance level to zero. The data obtained by this method are plotted as proportions of correct responses at each of several (usually five) stimulus levels, ranging from approximately zero to about 1.00. The data points are fitted by a normal Gaussian integral by means of a maximum likelihood solution on the University of California's San Diego computer*. In some of the more casual experiments, the data were fitted by hand, using standard arithmetic probability paper. In either case, the desired probability can be determined by direct inspection of the hand fits or suitable interrogation of the computer.

Temporal Forced-Choice

This method is similar to the foregoing, except that the targets are presented in one of four time intervals and the observer must say which. Note that this type of response is quite different, in that the subject is really saying, in essence, that one of the four intervals was different from the other three; he is not required to report any feature of the target, save that it was probably present on one of the four occasions. This is the method used to establish the threshold for detection (not orientation), which was needed in devising an alternate experiment to be described later in this section. Data reduction is essentially similar to that used for the spatial forced-choice method.

Yes-No

This method, sometimes called the method of phenomenal report, was little used here. In some of our very early studies, however, it sufficed to give quick answers regarding detection of presence of targets under conditions where more precise laboratory data were lacking. Simply put, the observer responds by saying "yes" if he detects the target, "no" if he does not. A complete description of the method is out of place in a report of this length, and the reader is referred to any standard text on psychometric methods. It should be mentioned that data obtained in this manner are significantly less useful than those from the forced-choice methods.

In each method used the stimuli were presented at discrete values of size or contrast (method of constant stimulus), and in none of the experiments was the stimulus magnitude continuously variable (method of adjustment). Finally, it should be noted that the actual flight experiments, both on-board and out-the-window, were of the forced-choice variety, requiring spatial discrimination (target orientation).

2.1.4 Experiments

There were ten support experiments which deserve description here, since each contributed in some manner to the eventual experimental design. They will be described chronologically in the hope that the contribution of each will become clear in the context of the overall planning for the orbital experiments:

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* Richardson, W. H., "An Adaptation of the Method of Probit Analysis to Psychophysical Threshold Data." SIO Reference 60-47, June 1960.

Experiment VL-1

This experiment was done at high luminance in the Driveway range. Five observers were used; two experienced, three inexperienced, all with good vision. The background was a 30 in. x 30 in. square of matte gray cardboard with reflectance of 0.30. Four targets were affixed to the background, near the corners, each of a different contrast to the background. Contrast values, measured by means of an Ansco reflection densitometer were: +1.84, +1.25, +0.75, and +0.59. The viewing range (simulated orbital altitude) was decreased in discrete steps until each observer was able correctly to discriminate first the presence of the targets, then their orientation. All targets were 1:4 rectangles whose actual dimensions were 0.35 in. x 0.09 in. The position and orientation of target bars was varied by the experimenter between trials. Some representative results from this experiment are shown in Fig. 2-5, and the array is shown in Fig. 2-6. The intent of this experiment was to give a first-cut estimate of size and contrast requirements for the orientation task, as well as to permit an estimate of the detection-orientation differences, for it was desired that all targets in the orbital experiment be above detection threshold in order to obviate the necessity for search. The data give a rough estimate of the performance of observers with good visual acuity confronted with the proposed task at realistic illumination levels. (January 1964)*

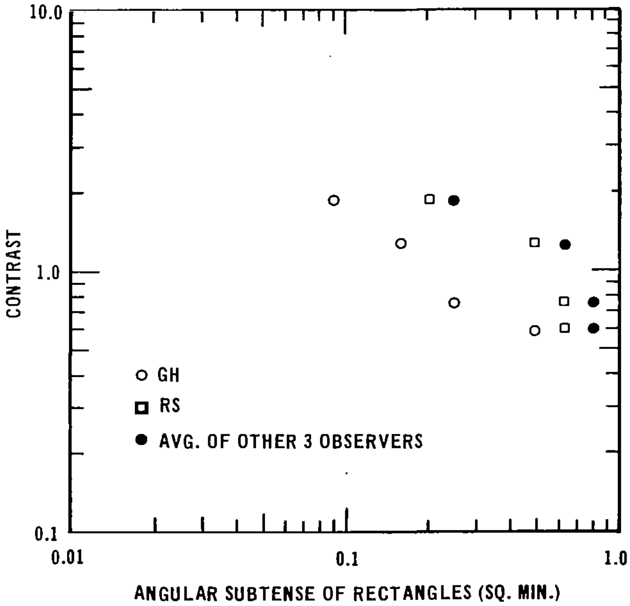

Fig. 2-5. Data from Experiment VL-1 in which detection and orientation thresholds were measured at high luminance levels. (Orientation thresholds plotted.)

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*Months in parenthesis denote period in which experiment was performed

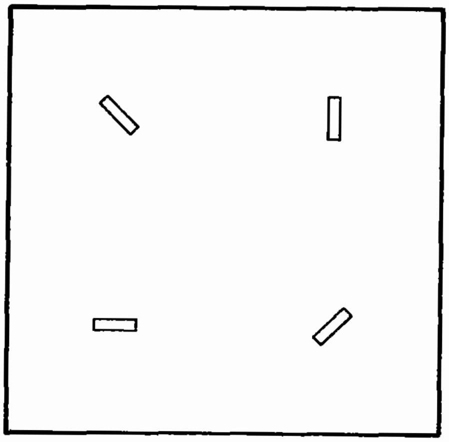

Fig. 2-6. VL-1 Experimental Display.

Experiment VL-2

At one point in the planning deliberations it was proposed that the field targets be arranged along a narrow strip of cleared terrain. In this experiment a group of six observers viewed an array of six 1:4 rectangles mounted on a narrow gray background which simulated an area ten miles long by 0.3 miles wide. The target bars were of uniform size but different contrasts, and were randomly oriented along the strip. The array is sketched in Fig. 2-7. Both detection and orientation thresholds were obtained by varying distance, but the data are extremely crude. The results appear in Fig. 2-8. A more significant result of this study was that it confirmed our intuitive feeling that such an array would be difficult to cope with from the observers' standpoint. That is to say, a long narrow strip with many targets is more likely to make it hard to report orientation of the individual bars, and to increase the likelihood of reading errors. The configuration was therefore abandoned in favor of the cellular arrays used in the final experiment. (February 1964)

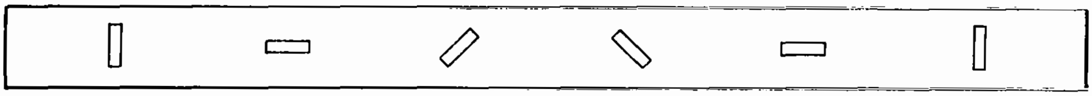

Fig. 2-7. VL-2 Experimental Display

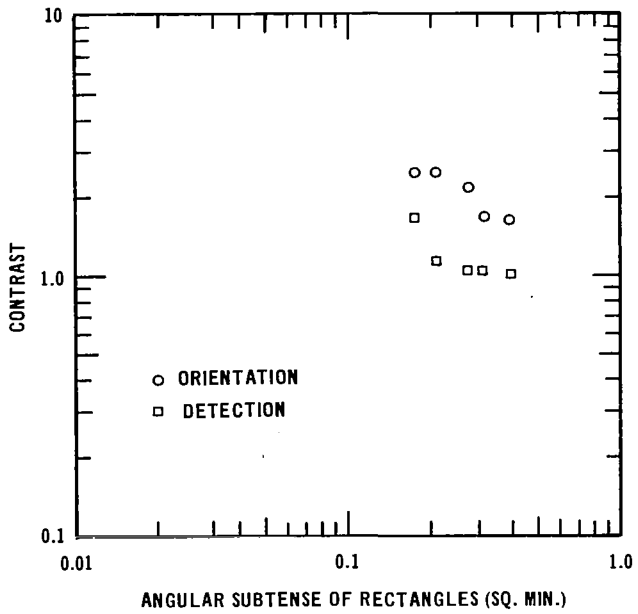

Fig. 2-8. Results from Experiment VL-2 — Detection and orientation of 4:1 rectangles at high luminance.

Experiment VL-3

In order to estimate the probable threshold target size, and thus the middle step to be used in the actual field array, an experiment was performed in the tunnel facility. Predictions based upon studies of target and background materials and the probable contrast losses along the astronauts' path of sight, led us to design the study so that target contrast was held constant at 2.88 and size was varied in five discrete steps (1.04, 0.625, 0.302, 0.101, and 0.053 square minutes). Background luminance was 80 ft-L. Target orientation was randomly varied from trial to trial. A total of twenty-six threshold determinations were made, representing 13 000 observations. Liminal size was estimated to be 0.21 square minutes, for the average of our four observers. It was recognized that an adjustment for the higher luminances predicted for the orbital experiments would reduce this value somewhat. (April-June 1964)

Experiment VL-4

First plans for targets for the inflight vision tester called for using the standard clinical pattern known as the "Illiterate E". This measure of acuity requires discrimination of the orientation of the arms of the pattern shown in Fig. 2-9, which is randomly presented in any of the four orthogonal positions and the observer is shown successively smaller targets until his performance becomes degraded to some selected degree. This test is considered by many to be preferable to the Snellen letters in that the problem of recognition is eliminated. The four

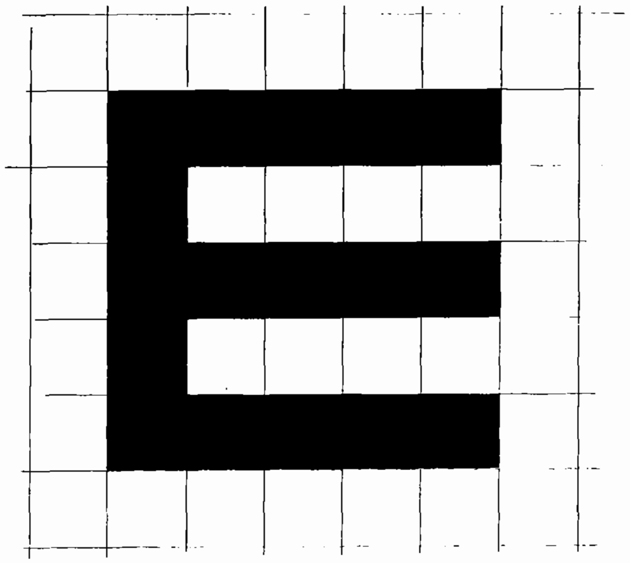

Fig. 2-9. The standard "Illiterate E" test pattern, based upon a 5x5 square matrix, as used in Experiment VL-4.

strokewidths which were used subtended 1.5, 1.0, 0.75, and 0.50 minutes of arc (nominally) at the eye. Contrast thresholds for six observers were obtained, and the results, based upon 48 000 observations are shown in Fig. 2-10. Although the Illiterate E pattern was not used in the ultimate experiments, these data are of interest because they allow comparison with both clinical and laboratory acuity estimates obtained by other means. (July-August 1964)

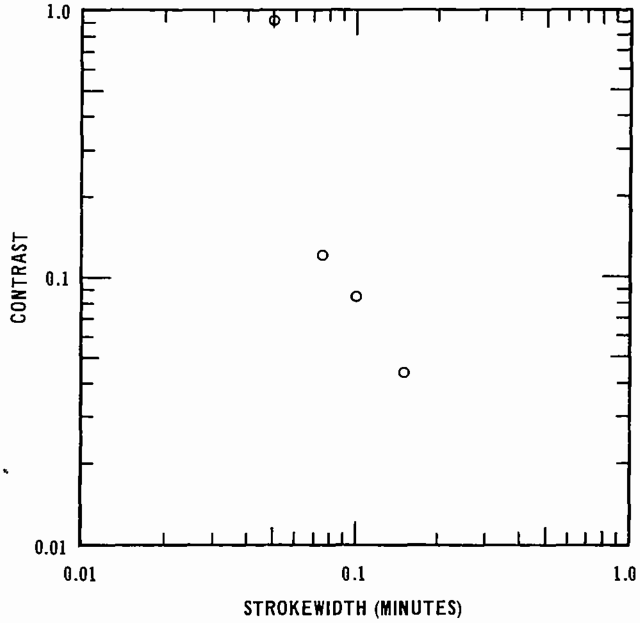

Fig. 2-10. Results of Experiment VL-4 — Illiterate E orientation.

Experiment VL-5

Upon completion of the Vision Van installations and checkout of the automatic equipment, a series of observations were made at the Visibility Laboratory before transferring the van to Manned Spacecraft Center (MSC). This experiment had the objectives of (1) thoroughly testing the van in order that no problems would be likely to occur at Houston, and (2) obtaining additional data on rectangle orientation by a highly selected group of observers under well-controlled conditions. Moreover, it was desirable to have parallel data for the laboratory observers in the unlikely event that differences in experimental results should occur as a function of the facility used. The data which were obtained in this experiment are shown in Fig. 2-11. (February-March 1965)

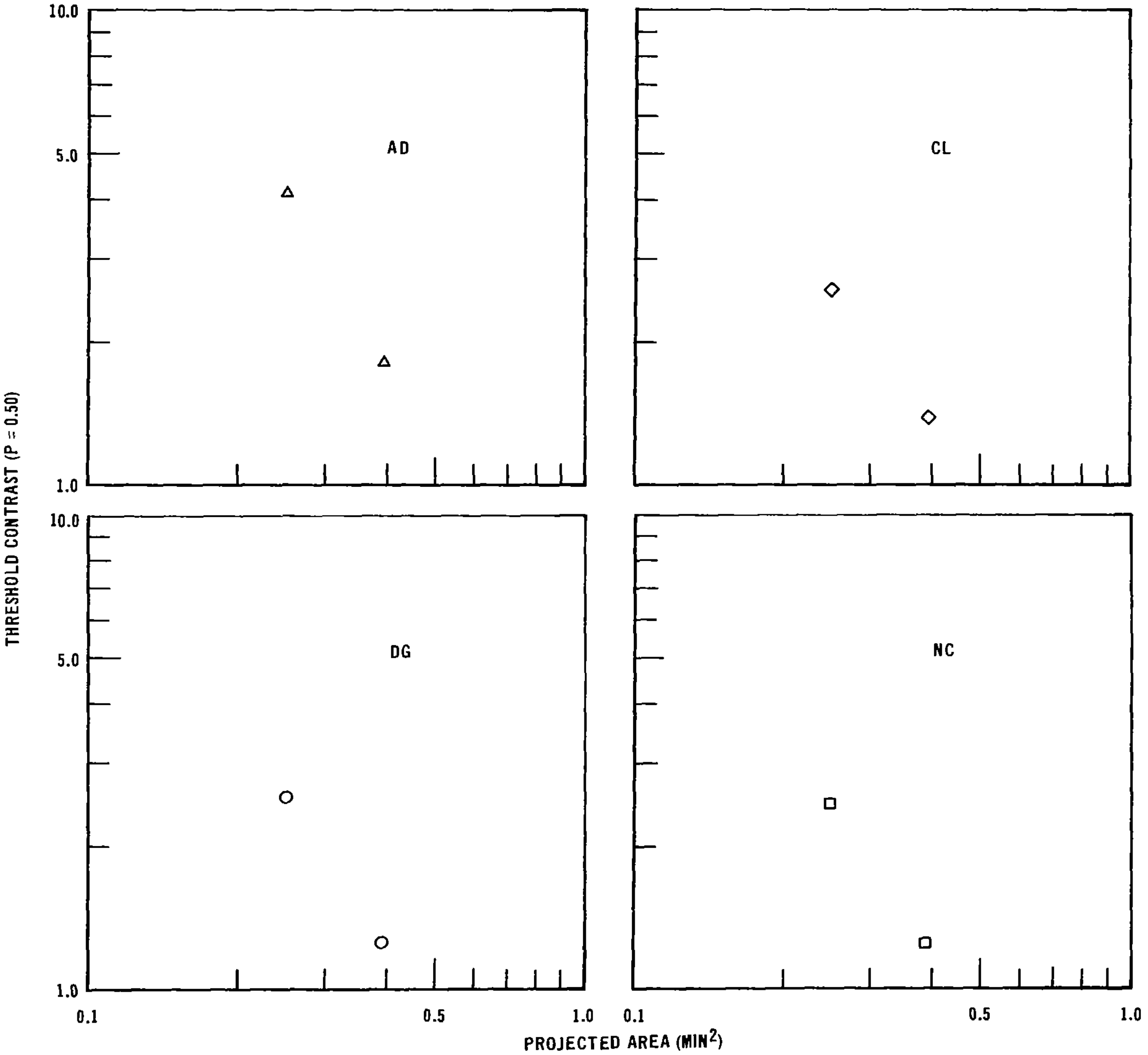

Fig. 2-11. Results of Experiment VL-5 showing obtained contrast thresholds for two target sizes by four trained observers.

Experiment VL-6

This brief experiment was intended as a check on the concept of trade-off between target area and contrast. If, in fact, the threshold for, say, a 4:1 of contrast 1.0 is equal to that of an 8:1 rectangle of the same length but half the width, of contrast 2.0, the notion is to a degree supported. Stated another way, the data from any target aspect ratio and contrast should fall on the same curve which relates contrast to target area at threshold. For this experiment three arrays of targets were prepared:

1. Seven 4:1 rectangles of contrast 1.58
2. Seven 4:1 rectangles of contrast 0.20
3. Seven 8:1 rectangles of contrast 0.82

Each array was linear, with the targets descending in size; they were exhibited at eight discrete distances in the driveway range (40 to 180 feet, in 20-foot increments). DG was the only observer whose data are shown, although two others participated in the study. The data of DG are shown in Table 2-1, and their relation to his results from others of the VL series is shown in the summary Fig. 2-21, which indicates the consistency of data from the four orientation discrimination experiments in which DG served. Even though the data of VL-6 are limited, the width/contrast principle seems to be borne out.

Table 2-1. Data of DG from Experiment VL-5

Aspect Ratio	Contrast	Area ($\min^2$)
4:1	1.58	.260
4:1	0.20	.487
8:1	0.82	.259

Experiment VL-7

The operational difficulties which were encountered on Gemini V had seriously hampered conduct of the S-8/D-13 ground sighting experiment, and it was recognized that such problems, or others, might also occur during Gemini VII. It was prudent, therefore, to devise an alternate experiment which could, in case of difficulty, be performed with greater ease than the rectangle orientation task. This contingency experiment would involve simple *detection* of targets, and could be arranged with a simplified ground array. Since we no longer had access to the astronauts of Gemini VII, it was necessary to rely upon data from the Visibility Laboratory observers and to make the rather reasonable assumption that an approximate conversion could be made in setting up the contingency ground patterns. This laboratory experiment was conducted in the Cube facility, and used the temporal forced-choice experimental method. Detection thresholds were obtained for two observers, for a 4:1 rectangle which subtended 1.00 square minutes. The experimental variables were contrast and orientation, since it was known that detection of elongated targets is not likely to be equiprobable between orientations. Data for the two observers, based upon 2 250 observations, are shown in Table 2-2. (Sept.-Oct. 1965)

Table 2-2. Detection Thresholds as a Function of Rectangle Orientation

Orientation	C_t DG	C_t AD
1	0.135	0.138
2	0.123	0.149
3	0.149	0.159
4	0.105	0.122

Experiment VL-8

This experiment, conducted in the Tunnel facility, sought better to define the shape of the function relating threshold size to target contrast. Three observers made a total of 11 500 observations of targets subtending 3.71, 2.25, 1.35, 0.584, 0.302, and 0.216 square minutes. The experimental results for one observer (DG) are shown in Fig. 2-12. Because this observer consistently yielded data in close agreement with the limited data of astronauts Lovell and Borman, it was decided to use his data (rather than some average of the three observers) to establish the probable shape of the full curve. Thus DG became, for our purposes, a sort of "astronaut surrogate" for experiments during the time that the flight crew was no longer available. After adjustment of the curve along the contrast ordinate (to allow for absolute differences in threshold between DG and the individual astronauts) it was, in fact, the curve obtained in this experiment (and the data of DG from VL-5) which was to be used in the preparation of the predictive curves which are shown later in this report in the discussion of experimental results. (September-October 1965)

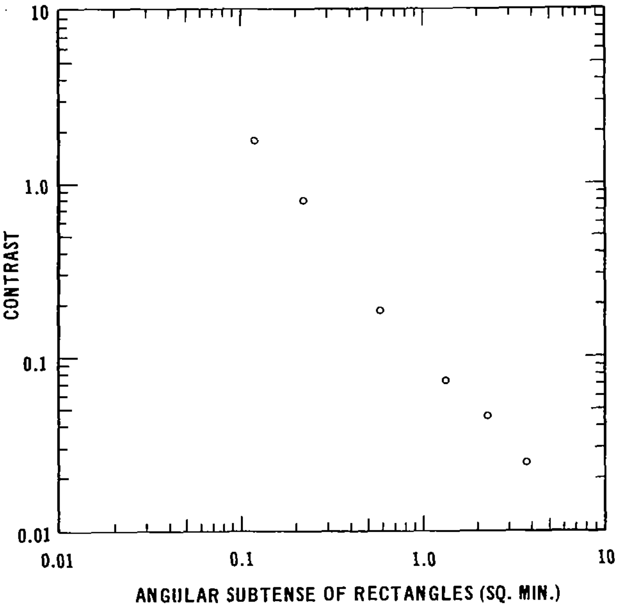

Fig. 2-12. Data of Experiment VL-8 – One observer (DG), tunnel facility.

Experiment VL-9

In October 1965 the plans for Gemini VII's orbital parameters were still in doubt. The question arose whether the experiment could be conducted successfully in the Yuma region if a last-minute decision by MSC enabled use of the site, yet came too late for the background squares to be prepared. Studies of the characteristics of undisturbed and disturbed desert soil had been made previously, so that it was possible to devise an experiment to investigate this problem. Three possible cases were compared, *viz.*:

Case I consisted only of a 4:1 rectangle against a surround which simulated the undisturbed desert soil.

Case II showed a similar target rectangle on a circular background whose diameter equalled the longer dimension of the bar; the whole displayed against the surround. The reflectance of the background circle simulated soil which had been disturbed by raking.

Case III had the target bar at right angles to a "ghost" bar of the same reflectance as the background in Case II. It can readily be seen that Case I simulates the instance of a bar simply laid on the uniform, undisturbed terrain, as might happen on the first occasion of installing such a target. Case II represents the possibility that circular cleared areas, which would permit rotation of targets between observations, would be present. Case III could occur if only 90-degree rotations between passes were permitted. The objective of the experiment was to evaluate the effect of the presence of the local areas of disturbed soil. The three cases are shown in Fig. 2-13. The values of contrast, both inherent and apparent (based upon reasonable estimates of attenuation along the path of sight) for the real case and for the present experiment are indicated in Table 2-3. C_0 values for our model are, of course, calculated. Three specimens of each case were prepared and mounted on a square of cardboard with reflectance equal to the surround, using a Latin Square design. Thus, four orientations of the display could be used. The observers were not allowed to see the display prior to running the tests, since we were interested in the possible influence of the circular and "ghost" bar backgrounds. For this same reason, the experimental trials were begun at the longer observation ranges. The driveway range was used, with five viewing distances. The display was shown eight times at each distance to each of four observers. Three of the observers repeated the entire series, so that the data shown in Table 2-4 are derived from 2 520 trials. The differences appear to be unsystematic and, on the average, inconsequentially small. Since the need for such an array on the ground during Gemini VII vanished, no additional data were gathered, and the present data were not rigorously analyzed. (October 1965)

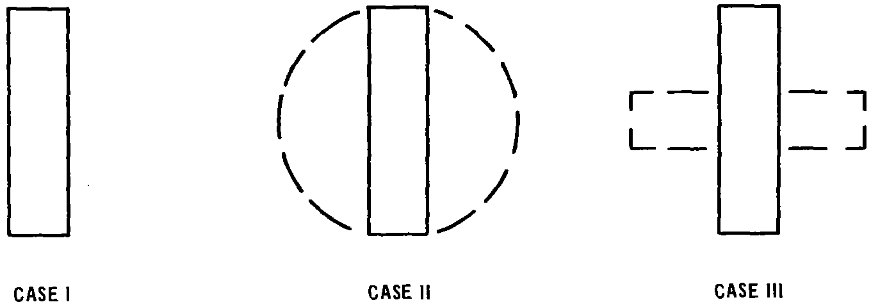

Fig. 2-13. Stimulus patterns used in Experiment VL-9.

Table 2-3

	Real Case		Vis Lab Model	
	C_o	C_r	C_o	C_r
Background/Surround	.25	.19	(.255)	.178
Target/Background	2.0	1.4	(1.94)	1.36

Table 2-4

	Observers				
	DG	SG	RK	NS	MEAN
Case I	176	146	178	190	172
Case II	180	153	170	176	170
Case III	179	144	186	168	169

Experiment VL-10

The final support experiment was intended to provide data at daylight luminance levels as would be encountered in flight, so that a conversion could be made from the data collected in the van at 100 ft-L. Observer DG served as the only subject. An array of 16 randomly oriented 4:1 bars were mounted on background squares which were, in turn, arranged in a 4 x 4 matrix on a square surround. The reflectances of bars, backgrounds, and surrounds were chosen to span the range of anticipated contrasts at the Laredo site. Background luminance varied, according to the reflectance of the materials, from about 2000 to 3000 ft-L. Each array was viewed at five discrete distances, selected to bracket the range from chance to 100% correct discrimination. One of the target arrays is shown in Fig. 2-14. The data resulting from 3200 presentations are given in Table 2-5. The driveway range was used for this experiment. (Nov. 1965)

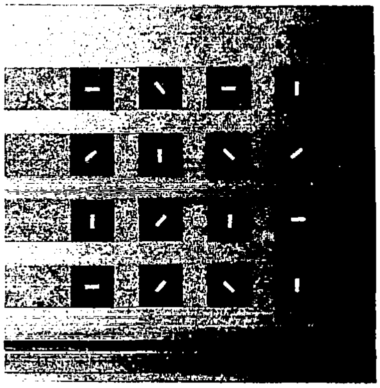

Fig. 2-14. One of the target arrays used in Experiment VL-10.

Table 2-5

Target Contrast	Visual Angle (min^2)
6.31	0.185
3.09	0.242
1.13	0.297
0.466	0.490
0.141	1.10

The number and variety of support experiments described above reflects the fact that the seemingly simple inflight study required a great deal of background and preliminary work. The frequent changes in flight plan, too, added the necessity for additional studies.

2.2 ASTRONAUT TRAINING PROCEDURES

A program of astronaut training and familiarization was begun as soon as crew selection had been made. The eight crew members comprising the primary and backup teams on the two missions underwent briefings, optometric examinations, practice flights over a scale model of the ground array, and extensive testing to establish baseline data. These procedures had these important objectives:

1. To provide sufficient practice with the discrimination task which was to be used (both on the ground and in the Inflight Vision Tester (IFVT) so that there would be no residual learning – or practice – effect during the missions.
2. To yield reliable baseline data which would be used not only for comparison with the inflight results, but also to govern the size of the targets in the ground array, especially for the first useful overpass. It should be noted that both the average size and the spread of sizes were based on these data.
3. To familiarize the astronauts with the geographical location and topography of the two ground arrays, especially with reference to easy acquisition of the site by use of available landmarks. The value of this part of the training process was abundantly borne out during the actual flights; it is not believed that search or orientation problems were present.
4. To allow as much practice as possible in such activities as spacecraft orientation, use of the photometer and the IFVT, and data recording and communications.

Facilities which were used in the training program included many which do not need to be described here; examples being the MSC Crew Station Mockup and Gemini Mission Simulator, the Visibility Laboratory's C-130 aircraft (which is described elsewhere and in this context was used only as a platform from which the astronauts could observe a scaled-down model of the actual ground arrays). The primary facility used for the collection of baseline data on orientation discrimination of rectangles was the so-called Vision Van to which reference has already been made. This van will be described in detail in this section, and certain other training aids which were used will be enumerated.

2.2.1 Vision Van

It has already been said that the primary design of the van followed that of the Cube facility at the Visibility Laboratory (p. 2-4). It is accurate to sây that the Vision Van as now configured is a tremendously useful and versatile mobile vision research facility, requiring only a simple power hookup to be used anywhere in the world.

General features of the Vision Van can best be seen by inspection of Fig. 2-15. At the rear of the van there is a space which accommodates two observers in comfort. In the orientation discrimination series of tests, the subjects occupy two upholstered theater chairs, facing a large, uniformly bright adapting field generated by lamps within the integrating cavity. At the center of the background there is an array of four small dark points, each subtending less than a minute of arc at the eye, arranged in a diamond pattern. These points give clues to the location and distance of the screen center so that the observers' fixation and accommodation are correct for the target rectangles when they appear at the center of the array. Targets are produced by rear pro-

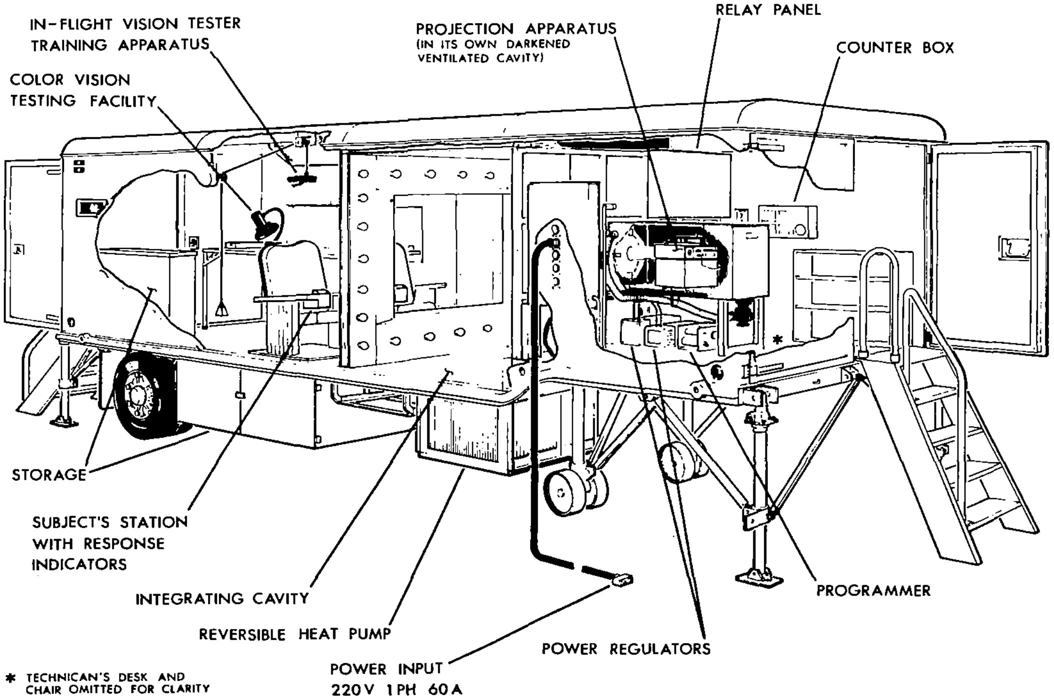

Fig. 2-15. Cutaway view of the Vision Van – a portable research laboratory used to gather baseline data from the eight astronauts.

jection from the equipment in the forward end of the van. This compartment also contains the automatic programming and recording apparatus, power regulators, and the single experimenter required for the conduct of the tests.

A schematic representation of the essentials of the target presentation and observing arrangements can be seen in Fig. 2-4. A Kodak Carousel projector was modified so that (a) it could be programmed to change slides on command from the automatic sequencing equipment, and (b) the slide being projected on any one of the 80 randomly arranged trials would be correctly recorded by the counter bank. (This latter modification was done by attaching a conducting collar of shim brass to the slide-bearing drum; this was overlaid with an insulating strip of thin Mylar with punched holes corresponding to the slides' orientation at that position; the information was then picked up by a series of contact wipers and relayed to the panel.) The forced-choice method was used – each observer indicating his guess about bar orientation by pressing one of four response buttons on the arm of his chair. The drum on the projector contained eighty slides bearing images of white bars on otherwise opaque film. The bars were of identical size, and the orientation was randomly varied between the four positions. Size of the target bars as seen by the observers could be varied by changing the optical arrangements behind the translucent screen (or by substituting a set of slides with larger or smaller images). Since the targets were always positive in contrast (i.e., they constituted a luminance increment at the center of the screen) their contrast could readily be controlled by interposition of various calibrated neutral density filters in the projector beam. Each target was presented for 2.5 seconds as the flag shutter was withdrawn from the beam and then returned, on command by the automatic sequencing equipment. Each trial took a total of five seconds, during which period the events were as shown in Fig. 2-16. Five levels of target contrast were run for each point determination, so that 200 observations are represented in the individual data estimates.

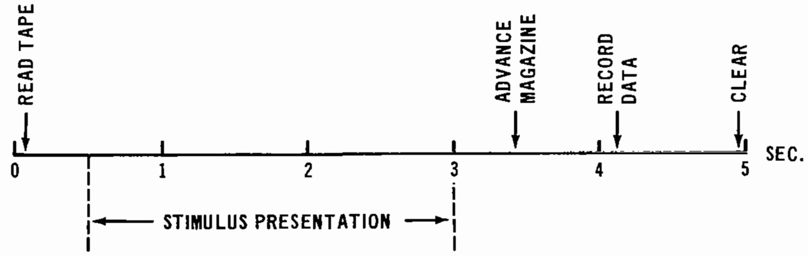

Fig. 2-16. Time sequence on an individual target presentation trial.

Additional information is given to the observers on each trial. At the beginning of the 5-second trial he receives auditory signals (one to five buzzes) which tell him the contrast level being presented as well as a subsequent auditory cue to the time of presentation of the target. Thus, the observer knows where, when, and how difficult the target will appear; only orientation must be determined. This, of course, corresponds with the task in space. Complete information about each trial is recorded on the counter array and is transcribed for later computer analysis. A flow diagram of the van experimental sequence for a trial is shown in Fig. 2-17.

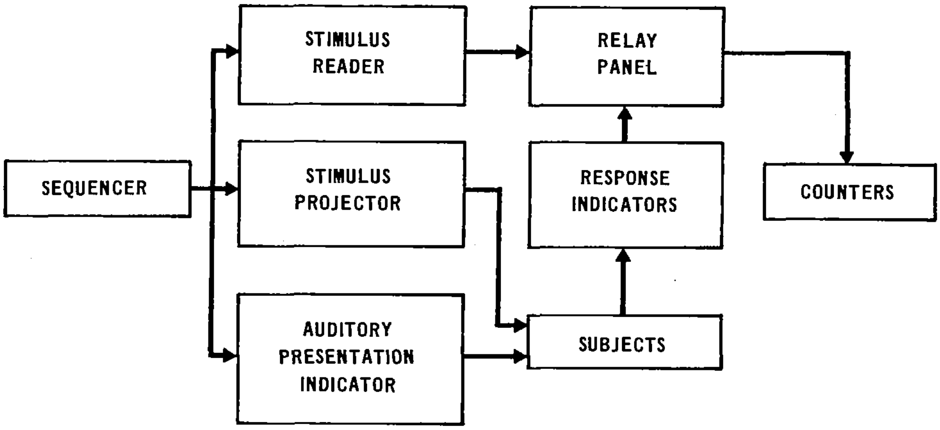

Fig. 2-17. Flow diagram of van equipment during a single observation.

2.2.2 Other Training Aids

Although the Vision Van was the single most important training facility from the standpoint of our experiments, there were several other aids which found important use during the period of astronaut training. Among these one must include, of course, the flight crew briefings, during which the familiarization aspects of the training regimen were undertaken. The Gemini VII crew, happily, could take advantage of the Gemini V experience, and were even provided with a photograph of the Laredo site taken by the earlier crew. (This photograph was especially useful in aiding acquisition of the site during Gemini VII; in fact, it was carried aloft by the crew for use.) Some of the other materials which were used were:

Training Model of the Inflight Vision Tester

One model of the IFVT was suspended by a light cable and counterweight in the Vision Van. With this the astronauts practiced operation of the device, including handling with spacesuit gloves, and provided the real data which are elsewhere reported as the preflight results from the IFVT. The counterweighting arrangement (visible in Fig. 2-15) was not intended to simulate the weightless condition, but merely aid in supporting this rather heavy device by means of the biteboard. IFVT's bearing various serial numbers found application in the van at various times. As a matter of record, the actual instruments which were used in various phases of the training and observation program are shown in Table 2-6, which also shows how many runs were made with each instrument by the astronauts. It was fortuitous, as well as fortunate, that S/N 5 entered into the experiment for all observers in flight and on the ground for both preflight and postflight measures, albeit not on the same individuals.

Table 2-6

Serial Numbers of IFVT's used in S-8/D-13: Numbers in parentheses indicate how many times instrument was used.

Observer	Preflight	N	Inflight	N	Postflight	N
Cooper	1	(7)	5	(9)	1 and 5	(1), (1)
Conrad	1	(6)	5	(9)	1 and 5	(1), (1)
Borman	3 and 5	(3)	5	(14)	3 and 5	(1), (1)
Lovell	3 and 5	(4)	5	(14)	3 and 5	(1), (1)

Graphic Training Aids

A part of the acquisition training and familiarization with the ground arrays was done with the help of various graphic aids, primarily maps, pasteup displays and still and motion picture photography. The maps used were from several sources, and included the National Geographic Society Maps, World Aeronautical Charts, and maps provided by the Commonwealth of Australia, among others. Still photography was abundantly and generously provided by the Australians, as well as by local agencies in the United States (See section on site selection in the US). Motion pictures made of the Australian array from an aircraft following the approximate track of the Gemini vehicle were displayed to members of the Gemini VII crews. Projection of these films was by means of an optical system incorporating a Dove prism, so that the image could be rotated on the screen to simulate the visual effects of spacecraft roll, etc., on target location and subsequent discrimination. Pasteup displays were prepared, sometimes in the form of overlays on maps and photographs, as training adjuncts. These were intended to minimize errors of orientation and to optimize initial acquisition of the arrays in both Texas and Australia.

Aircraft Flights Over Scale Model in Laredo

On 18 June 1965 an attempt was made to perform a scale model flight test at Laredo by flying the astronaut crews (primary and backup) of Gemini V over a small (1/15th scale) model of the array. These flights were to be made in the Visibility Laboratory's C-130, and an attempt was to have been made to collect real data, although this was not possible. Nevertheless, the exercise proved very valuable to both astronauts and experimenters, as it pointed up the several problems of array orientation and communication which were able to be ameliorated before the launch of Gemini V. Difficulties with wind buffeting, vibration, and cloud intervention caused data from this study to be discarded. Subsequent flights over the scale model were accomplished on an irregular basis by members of both mission flight teams. They may be regarded as ancillary aids to acquisition techniques and pattern familiarization aids, even though they are not productive of quantitative data.

2.2.3 Color Discrimination Test

Since there was no possibility of incorporating a sensitive test of color vision in the inflight device, we had to content ourselves with preflight baseline data and immediate postflight retest done aboard the recovery ship as a part of the postflight medical examinations. This procedure, naturally, can only yield information about effects which persist beyond the period of prolonged weightlessness. The test had to be one which could be administered rapidly and conveniently, even by relatively untrained personnel (as might be required to administer it aboard either recovery ship). It had also to be self-contained in the sense that extrinsic factors would not influence the data. Finally, the test had to be sensitive enough to detect very minor changes in color discrimination in any spectral or extra-spectral region of color space. To satisfy these criteria we adopted the Farnsworth-Munsell 100-Hue Test.* This test is highly dependent upon the illuminant used during its administration, and must be used only under I.C.I. standard "Illuminant C", which approximates natural daylight. Accordingly, special luminaires were used which provided light of the required color temperature; other sources were eliminated. These luminaires were taken aboard each of the recovery vessels.

Briefly stated, the observer is required to arrange a randomly presented series of colored samples into an ordered series in terms of hue. The 85 test colors are chosen so that the test is quite difficult for color normals, and color defectives will exhibit a failure to perform the correct ordering at certain regions in the (essentially circular) series, according to the nature of the difficulty. The data are plotted conveniently on polar coordinate paper, and these plots readily show any tendency for the subject to make color confusions anywhere among the spectral or extra spectral regions. Thus, the confusion patterns of any of the clinically recognized varieties of anomalous color vision can be seen at a glance, but also, the pattern which emerges in cases of generally poor hue discrimination (without any clear axis of confusion such as typifies color defectives of specific sorts) can easily be recognized.

The Farnsworth-Munsell 100-Hue test was administered to all four flight crew members as a part of the postflight checkup aboard the recovery carrier. Baseline data for all except Cooper had been collected during the training program at Houston. The results of both pre- and postflight tests are shown in Fig. 2-18. A perfect score would be represented by a curve following the inner circle (level 2). Reversals of two immediately adjacent colors in the series results in a rise to level 3, as seen in the Lovell data. Confusions of more remote colors are plotted at succeedingly higher levels.

All of the plots are well within the normal range of hue discrimination. It can be seen that there is a slight tendency to make more errors in the postflight tests. It is quite probable, in our opinion, that this small difference can be ascribed to the general conditions of the postflight examining environment, or to simple fatigue, or to both. It seems unlikely that a genuine effect upon color discrimination has occurred on these two long-duration missions – at least an effect which could be detected immediately upon termination of the flights. It would be desirable, of course, to incorporate an onboard color vision test on subsequent long-duration missions, when space, weight, and astronaut workload constraints will have been relaxed.

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* Farnsworth, D., "The Farnsworth-Munsell 100-Hue and Dichotomous Tests for Color Vision", J. Opt. Soc. Am. **33**, 568 (1943).

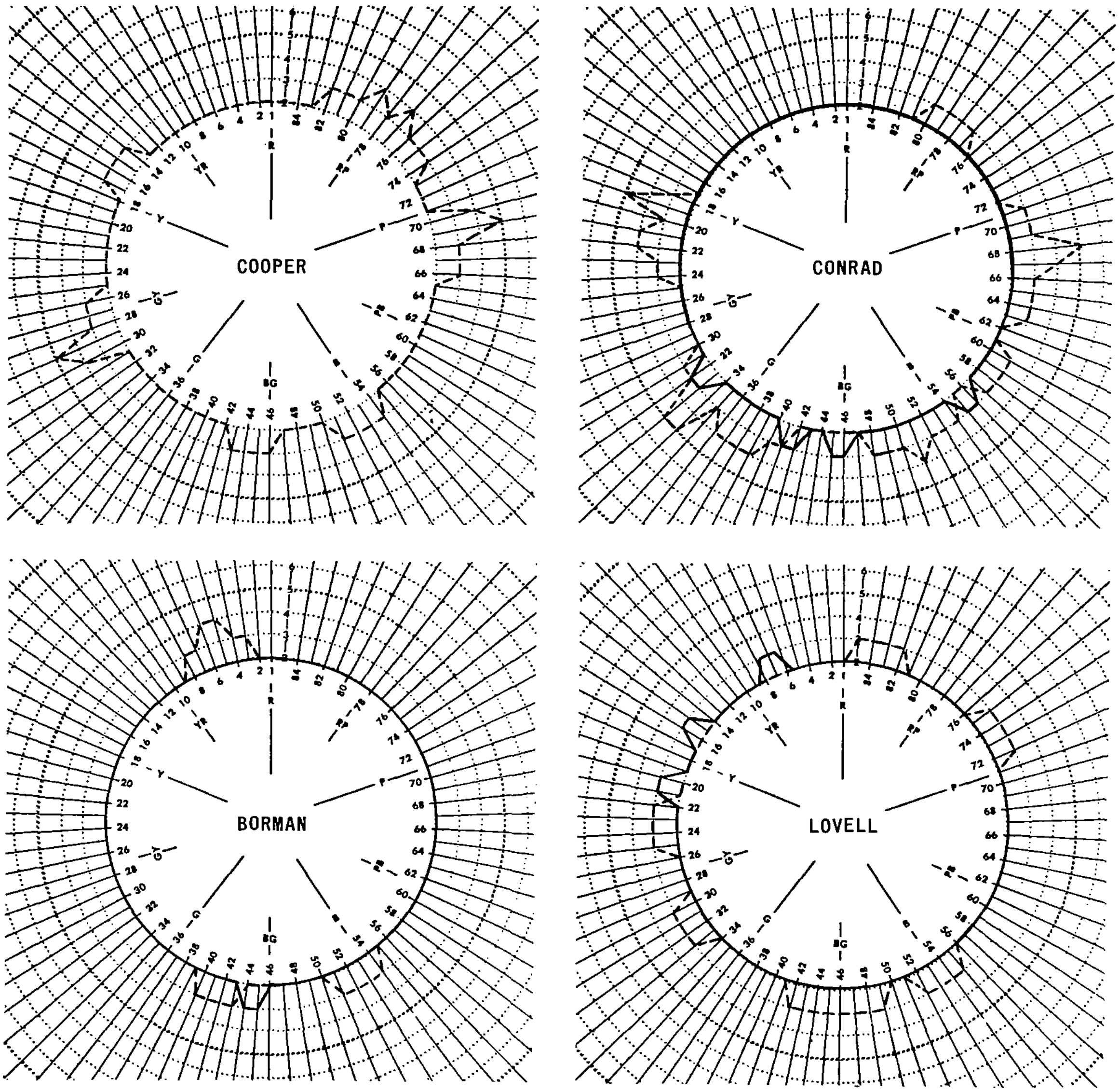


Fig. 2-18. Results of color discrimination test. Solid lines are preflight data; dashed lines are data taken onboard recovery vessel.

2.2.4 Summary of Training Procedures

The various elements of the training, familiarization, and baseline data collection procedures are summarized in Fig. 2-19. This figure gives some idea of the number of experimental and instructional activities which were undertaken. It cannot convey an idea of the energy, motivation, dedication and conscientiousness with which the individual astronauts prepared themselves for the inflight experiments.

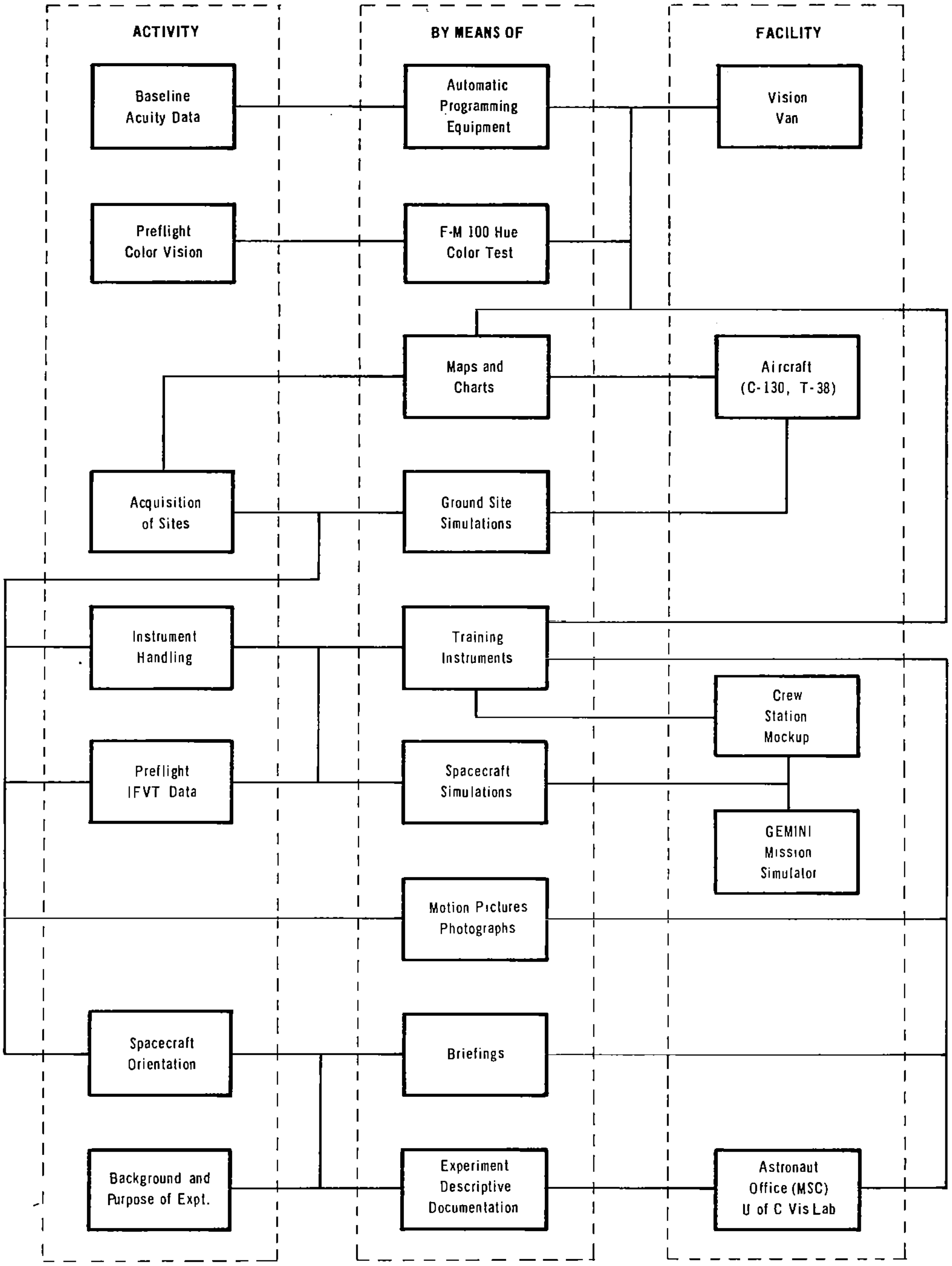


Fig. 2-19. Block Diagram showing the S-8/D-13 training, familiarization, and preflight data collection procedures.

2.3 RESULTS: BASELINE DATA

The quantitative data which resulted from the training sessions were of three kinds, viz.:

1. Rectangle orientation discrimination, collected in the Vision Van, which provided the basis for comparison with performance during the actual flights, and also guided the design of the ground arrays.
2. Inflight Vision Tester scores, to be compared with the daily scores which would be obtained during the spaceflights.
3. Hue discrimination, for comparison with immediate postflight performance.

Of the three, the rectangle orientation data were, of course, the most extensive. It was these data which were used for the preparation of the predictive curves which were used by the experimenters during the missions, and upon which the responses of the orbiting astronauts were plotted. Data regarding preflight performance on the IFVT and the hue discrimination test will be presented later, in relation to the orbital and postflight results.

The eight astronauts involved in Gemini V and Gemini VII made an impressive total of more than 22600 observations in the rectangle orientation experiment. Many of these, naturally, resulted from the training period and do not figure in the ultimate data plots. Moreover, the data are by no means equally distributed among the eight men. There were two reasons for this: (1) the availability of the men was extremely variable, with the command pilot of the primary crew being the least available as a rule; (2) the experimental design was in terms of observations to be made by the pilot through the right-hand spacecraft window (which was monitored by the photometer), with the command pilot as backup. Nevertheless, it was possible to prepare the baseline data plots, together with their confidence limits, by fitting the "standard" – shaped curve of DG to the few points measured in Houston.

The data obtained from the four flight crew members of the two missions are shown in Fig. 2-20. In each case the mean curve has been shifted in contrast to provide the best fit to the data points. The curves showing the $+1\sigma$, $+2\sigma$, and -1σ for each man are based upon the average obtained slopes of that individual's psychometric curves, which, with the obtained threshold values, determine the coefficient of variation. While only the data from the actual flight crews are germane to this report, complete results from all eight astronauts are on file at the Visibility Laboratory, and will be made available on request.

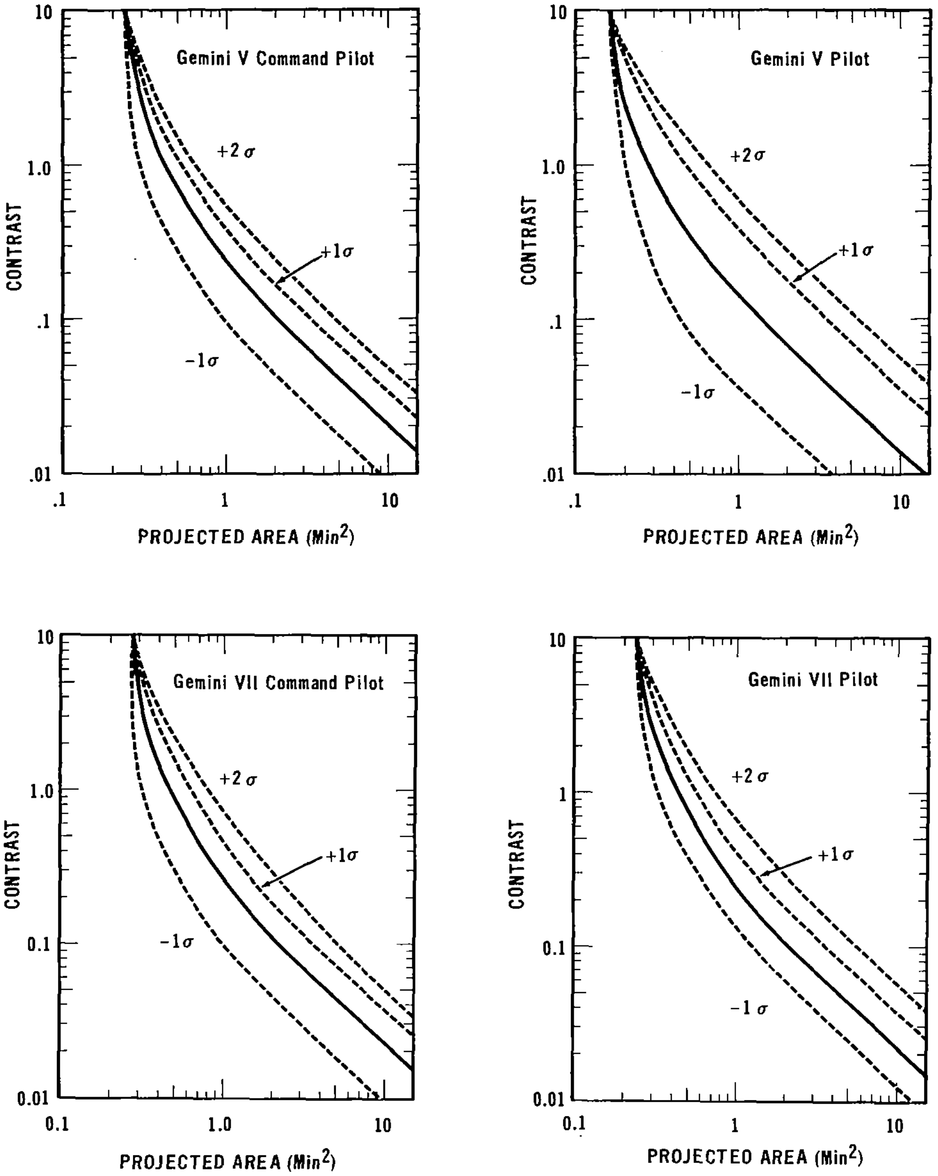


Fig. 2-20. Baseline data curves for the flight crews of Gemini V and Gemini VII. The shape of the solid curve was determined from extensive experiments with laboratory observers. This curve was then adjusted on the contrast ordinate to fit the astronauts' limited data points. Sigma limits were determined for each man, according to his Vision Van results.

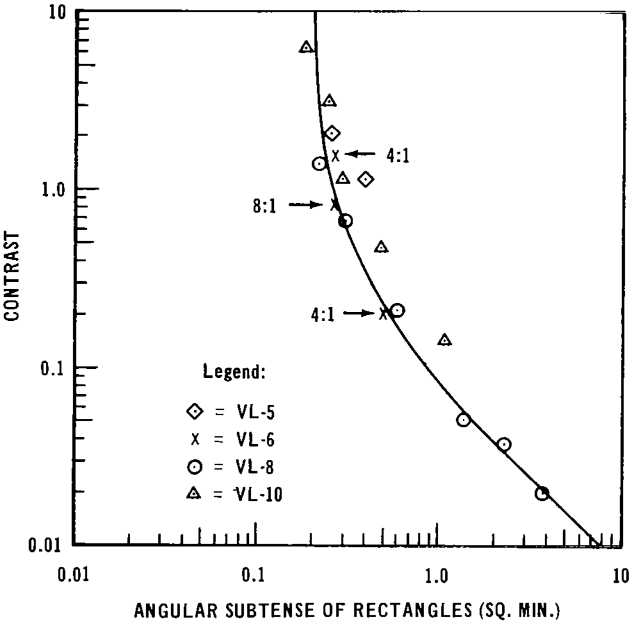


Fig. 2-21. Summary of orientation discrimination data for observer DG. The three cases studied in Experiment VL-6 are labeled points X.

3. On Board Experiment

3.1 INFLIGHT VISION TESTER

3.1.1 Introduction

The on-board portion of the experiment involved the use of a specially designed vision tester which could be used by the astronauts to administer to themselves frequent tests of the state of their visual performance capabilities. By means of the self-administered tests, it was possible to determine the effects of orbital spacecraft environment upon the visual functions relative to earthbound baseline values. The influence of weightlessness, the five psi pure oxygen breathing atmosphere, and any other factors associated with their environment could be assessed by comparison with pre- and post-mission results. Additionally, the daily use of the instrument during the course of the 7- or 14-day missions permitted the investigators to search for long term effects which might not appear on the shorter missions. An important consideration in the design of the instrument was that the test should be one which could be administered and scored by the astronaut himself in order that the results could be transmitted to the ground for a real time analysis of trends.

The vision tester had to meet all of the requirements placed upon spacecraft hardware such as minimum size, weight, and electrical power consumption; ability to withstand rugged environmental conditions of vibration, shock, humidity, and 100 percent oxygen; explosion proof; fungus proof, etc. Additionally, the instrument was to be mounted on the hatch for stowage during launch and re-entry. In the event of an emergency, these hatches were to be explosively opened to permit the rapid ejection of the pilots from the spacecraft. As a result, it was required that the devices which were attached to the hatch should withstand accelerations of 150 g's without becoming detached from their mountings or having broken components become missiles which could endanger the astronauts under these conditions. Such requirements placed severe limitations on the design of the vision tester and upon the variety of individual tests which could be performed by the use of the instrument.

During the early design stages, seven different visual properties were listed which would be desirable to test in space. In order of priority, these were:

1. Visual acuity
2. Phoria
3. Peripheral acuity
4. Adaptation time
5. Campimetry
6. Color vision
7. Astigmatism

As the investigation leading to the instrument's design proceeded, it became obvious that only the first two of these could be considered. Plans went ahead then to test for visual acuity and for phoria. In October, 1964, the Laboratory was requested to include in its Inflight Vision Tester the necessary modifications to accommodate the Human Otolity Function Experiment (medical experiment M-9). The inclusion of this modification pre-empted the space which had been assigned the phoria test on the vision tester eye pieces. Thus, the only visual function which was finally measured by the instrument was visual acuity.

A total of five instruments were constructed to serve the various purposes of training, flight qualification, space systems testing, flight, and flight back-up. Three of the five instruments were fully flight qualified. Due to slight individual differences, however, one was preferred for actual flight use and was used on both Gemini V and Gemini VII as the flight instrument. The first instrument was completed and sent to McDonnell Aircraft in late January, 1965, for Space Systems Test procedures. The qualification tests on the instrument began on 30 April and ended 28 June 1965. A completely functional instrument was made available for astronaut training in early June, 1965. On 7 July the flight instrument for Gemini V was forwarded to Cape Kennedy.

3.1.2 Description of Inflight Vision Tester

The Inflight Vision Tester (Fig. 3-1) was constructed as a binocular instrument which presented the required visual test patterns to the observer at optical infinity. The interpupillary distance (IPD) was adjustable to fit the user. This was the only adjustment provided as all other parameters were, by the very nature of the tests to be performed, predetermined and fixed at manufacture. The instrument was held in its proper position by means of a bite board individually fitted to the astronaut. This assured that at each use, providing the astronaut had made the proper IPD adjustment, the instrument would be identically located with respect to the visual axis. The test patterns consisted of rectangular bars having an aspect ratio of four to one. The bars were presented at the center of a 30° circular field having a luminance level of approximately 100 foot-lamberts. These bars were photographically produced on a circular presentation disk located at the normal image plane of a pair of microscope objectives (Fig. 3-2). The optical path from the presentation disk to the objective lenses was folded and divided by use of prisms. A reduced image of the bar on the presentation disk was produced at

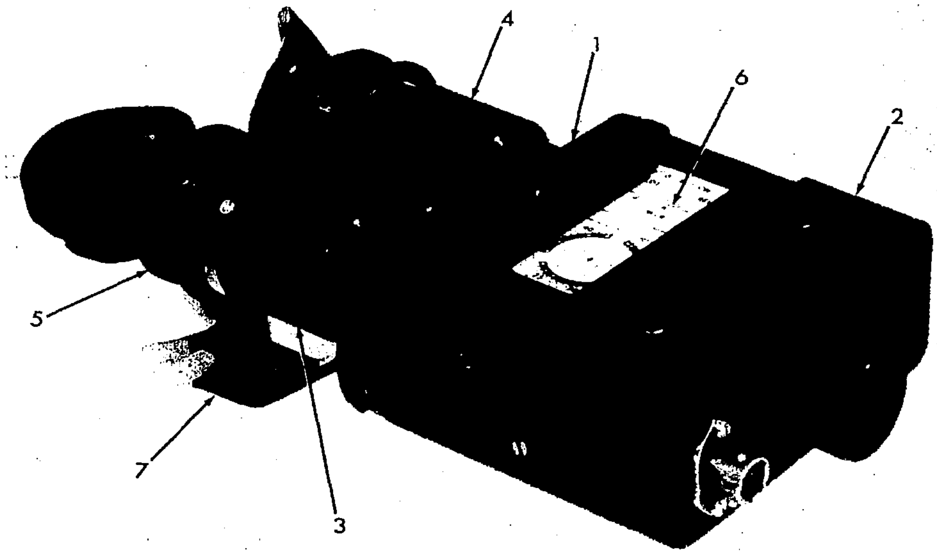
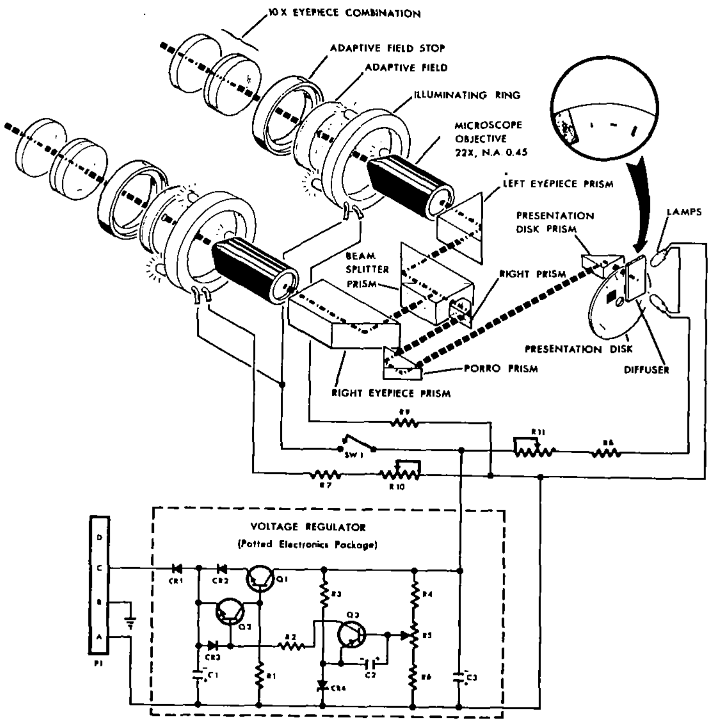


Fig. 3-1. Inflight Vision Tester Assembly – (1) Front Frame Assembly, (2) Presentation Disk Frame Assembly, (3) Right Eyepiece Assembly, (4) Left Eyepiece Assembly, (5) M-9 Assembly, (6) Data Card, (7) Biteboard Assembly.



Index	Item	Value
R1	Resistor	1.5K – 1W
R2	Resistor	270
R3	Resistor	1.5K – 1W
R4	Resistor	1.5K – 1W
R5	Var. Resistor (Potentiometer)	100
R6	Resistor	620
R7	Resistor	50Ω
R8	Resistor	50Ω
R9	Resistor	61Ω
R10	Var. Resistor (Potentiometer)	50Ω
R11	Var. Resistor (Potentiometer)	50Ω
C1	Capacitor	4.7 mfd – 100 V
C2	Capacitor	.0022 – 200 V
C3	Capacitor	4.7 mfd – 35 V
CR1	Diode	IN4005
CR2	Diode	IN4005
CR3	Diode	IN4005
CR4	Zener	IN3512
Q1	Transistor	TI 1131
Q2	Transistor	2N 2222
Q3	Transistor	2N 3065

Fig. 3-2. Inflight Vision Tester Optical-Electrical Schematic

the position that is normally the object plane of these microscope objectives. These reduced images were placed in the center of a 0.004 inch (15 arc-minute diameter) circular hole at the center of the 30° Ft-L adaptation field. Two 10 power microscope eye pieces were then used to observe these minified images at apparent optical infinity. An appreciation for the sizes involved may be obtained by realizing that the largest object to be observed was a bar 4.5 arc-minutes and the smallest 0.6 minutes in length. These bars were approximately 0.027 in. and 0.0035 in. long respectively on the presentation disk and their images were reduced 0.0012 in. and 0.00016 in. in length respectively by the microscope objectives.

The bar to be presented was selected by means of a knob located at the rear of the instrument. Using this knob, the presentation wheel could be rotated through 45 accurately positioned locations. These 45 wheel positions were divided into three groups of 12 bars each, separated by three blank positions. The 36 positions used for presenting bars held 24 high-contrast bars having a contrast of approximately - 0.9, and 12 low-contrast bars with a contrast of approximately - 0.21. Half of these 36 bars had their long dimensions oriented horizontally and the other half vertically. The bars were further subdivided into sizes. The high contrast series consisted of 4 each of six different sizes ranging from 3 minutes to 0.6 minutes in the long dimension; and the low contrast series consisted for four each of three sizes from 4.5 minutes to 1.125 minutes in long dimension. The center position of the three "blank" positions between the groups of 12 bars was colored red, green, or blue to identify the starting location for a particular exercise. Table 3-1 shows the orientation, size, and contrast of the 36 markings and their location in each of the 45 positions.

The instrument received its power from the spacecraft using a utility cord attached to the instrument panel. It contained its own voltage regulator for the operation of the instrument's eight lamps. The regulator provided an output of 22 volts dc ±1 percent with an input power from the spacecraft of between 22 and 33 volts dc. It also provided protection for the lamps against voltage spikes of 100 volts dc with a duration of 20 milliseconds or less which were permissible on the spacecraft power. Careful regulation and over-voltage protection was required in order that a known constant value of luminance could be obtained from the special lamps used in the instrument and also to protect them from burn-out. As the operating voltage on these small lamps was a careful compromise between the required luminance levels and lamp life, relatively small over-voltage on these lamps might have caused immediate burn-out or markedly shorten their life.

The instrument carried its own store of data record cards. These were small plastic cards which were inserted into the instrument and upon which a permanent record of the responses of the observer was made. Each card was individually marked to indicate the color of the position from which the exercise should start and the direction, either clockwise or counterclockwise, in which the presentation should proceed. With three possible starting locations and two directions, a total of six different sequences was obtained which reduced the probability that the user would memorize the sequence of presentations with any likely number of usages.

The procedure followed in the use of the instrument was to insert the individual's biteboard into the bottom of the instrument, plug the instrument into the spacecraft power supply, adjust the interpupillary distance to the value obtained for the individual by careful laboratory measurements, remove the data card from the top of the pack in the data card storage area atop the instrument, note the color of the starting position and the direction of the rotation, insert the card

Table 3-1. Inflight Vision Tester Presentation Bar Arrangement ***Disk "A"**

Position	Orientation	Angular Size Long Dimension (Arc Minutes)	Contrast	Difficulty Rank
1	½ Green			
2	H	2.250	Lo	2L
3	H	1.577	Hi	3H
4	V	.600	Hi	6H
5	H	3.000	Hi	1H
6	V	.828	Hi	5H
7	H	1.125	Lo	3L
8	V	2.250	Lo	2L
9	H	1.142	Hi	4H
10	V	3.000	Hi	1H
11	H	1.125	Lo	3L
12	H	.828	Hi	5H
13	V	1.142	Hi	4H
14	½ Red			
15	Full Red			
16	½ Red			
17	V	4.500	Lo	1L
18	H	2.174	Hi	2H
19	H	4.500	Lo	1L
20	V	2.174	Hi	2H
21	H	1.142	Hi	4H
22	V	.600	Hi	6H
23	V	2.174	Hi	2H
24	H	3.000	Hi	1H
25	V	1.125	Lo	3L
26	H	.600	Hi	6H
27	V	2.250	Lo	2L
28	H	4.500	Lo	1L
29	½ Blue			
30	Full Blue			
31	½ Blue			
32	H	2.174	Hi	2H
33	V	4.500	Lo	1L
34	H	2.250	Lo	2L
35	H	.828	Hi	5H
36	V	.828	Hi	5H
37	V	1.125	Lo	3L
38	V	1.142	Hi	4H
39	V	1.577	Hi	3H
40	H	.600	Hi	6H
41	V	3.000	Hi	1H
42	V	1.577	Hi	3H
43	H	1.577	Hi	3H
44	½ Green			
45	Full Green			

ORIENTATION: H = Horizontal V = Vertical CONTRAST: Hi = HIGH Lo = LOW

DIFFICULTY RANK: 1H through 6H, High Contrast Series in Order of Decreasing Size
1L through 3L, Low Contrast Series in Order of Decreasing Size

*Disk "A" For Inflight Vision Tester Serial Numbers 3, 4, and 5

into the card slot at the top-rear of the instrument, insert the biteboard into the mouth and adjust the compliant eye-cups for comfort, rotate the knob at the rear of the instrument until the proper color appears in the central 15-minute field, and rotate two steps in the given direction to the first observation mark. At this juncture the observer must decide that the object being observed is either horizontal or vertical. If he decides the bar is vertical, he pushes the knob in toward the face, releases it, and proceeds to the next position. This operation punctures the card with a small pin making a permanent record of the decision. Should the observer decide that the bar was horizontal, he would proceed to the next position without first punching the card and repeat the operation. Thus, after passing through the 36 locations containing bars and making the required determinations, the instrument could be removed from the face and the results of the exercise scored by observing the recorded punches on the card. The data card was printed with black areas where the punch marks should occur. Thus, the scoring process consisted of adding the number of black areas *not containing* punch marks to the number of clear areas *containing* punch marks as all of these decisions would have been incorrect. The total number missed was then immediately available for a preliminary evaluation of the performance of the astronaut in space. Later a more complete examination of the card was performed on the ground in order to ascertain the size, contrast, and orientation of the markings which were incorrectly called. In this manner, a detailed analysis of the astronaut's performance before flight, during flight, and postflight could be obtained.

Table 3-2 below lists in summary the specifications of the instrument. Appendix B provides exploded views, part descriptions, and Visibility Laboratory drawing numbers of the Inflight Vision Tester which was designated as Government Furnished Aerospace Equipment (GFAE) No. 34999.

Table 3-2. Inflight Vision Tester, GFAE No. 34999

SPECIFICATIONS	
A. Number of targets presented	36
B. Angular size of targets	0.6 to 4.5 arc-minutes
C. Adaptation field angular size	30° minimum
D. Adaptation field luminance	100 ft-lamberts, minimum
E. Central field angular size	15 ± 2 arc-minutes
F. Central field luminance	100 ft-lamberts, minimum
G. Number of target contrast levels	2
H. Limits of target contrast range	-1 to 0
I. Optical alignment tolerances:	
(1) Individual eyepiece collimation	20 ft. to ∞
(2) Parallelism (eyepiece optical axes)	
(a) Horizontal diverging	10 minutes
(b) Horizontal converging	4 minutes
(c) Vertical	4 minutes
(3) Centering	± 5 minutes
(4) Size	± 10%
(5) Lean	No apparent lean
J. Power requirements	22 to 33 volts dc unregulated 0.5 ampere maximum
K. Power connector	PT 02C-8-4P (Bendix-Scintilla)
L. Weight:	
With M-9 assemblies	47 ounces maximum
M. Size (without biteboard)	9½ in. L x 4-5/8 in. W x 1-5/16 in. H

3.2 OPTICAL PERFORMANCE OF THE INFLIGHT VISION TESTER

The actual angular size and contrast of the patterns presented to the eye by the Inflight Vision Tester had to be determined by measurement and calculation during and after the instrument's construction in order that it could be ascertained that the design goals were adequately met. The focal lengths and nodal positions of the several lenses in the instruments were individually measured; these measurements were then used to determine the proper positions for these components in order that the patterns would be of the correct angular size and at optical infinity as seen by the eye.

The photographically generated patterns on the presentation disks were individually examined and disks were selected which provided the contrasts, angular sizes, and quality of the rectangular images nearest to the design specifications when combined with the instruments optics. The photographic emulsion available on the plastic base material from which the disks were made had a high "gamma" which made it difficult to obtain the desired value of contrast in the low contrast rectangles and at the same time obtain sharp, uniform density images in the smaller rectangles. To facilitate measuring the contrast actually obtained on the disks, two large test areas on each disk were exposed in the same manner and at the same time as the small rectangular patterns. These areas were of sufficient size to be measured in a photographic densitometer. From these measured densities and the measurement of the base density of the clear, unexposed areas it was possible to compute the contrasts which existed on the disk for the larger patterns. Microscopic examination of the smaller images on the disk showed that the gradation from base density to full density extended over a portion of the image and it remained to determine if this was significant to the visual processes.

It was also necessary to determine how much of the disks' inherent contrast was lost by the passage of the optical signal through the many optical elements in the instrument.* A simple test was performed which permitted the contrast transmittance for the instrument for large area

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* It should be noted that there are two types of transmittances which cause losses in an optical instrument. Although they are interdependent, they can manifest themselves in different ways.

The first is beam transmittance T, which results from reflection of flux at the air-glass surfaces and from absorption of flux in the bulk glass material. In the presence of this type of loss alone, a reduction occurs in the flux in all portions of the optical signal uniformly in accordance with the beam transmittance factor, T. Thus, the total flux in the optical signal is reduced but the contrast which exists in the signal (where contrast is defined as

$$C = \frac{{}_tB - {}_bB}{{}_bB},$$

${}_bB$ = Luminance of the background and ${}_tB$ = Luminance of the target or pattern) remains unchanged.

The second loss is that caused by contrast transmittance, τ, which may be described by the following equation:

$$\tau = \frac{C_r}{C_o} = \frac{1}{1 + \frac{B^*/T}{{}_bB}}$$

where C_o is the inherent contrast existing at the object,
C_r is the apparent contrast existing at the observer's eye,
B^* is the luminance scattered into the path of sight,
${}_bB$ is the luminance of the background at the object,
and T is the beam transmittance.

The scattered luminance B^* can be caused by (1) scattering from dirt on the various optical surfaces, (2) scattering from inclusions in the bulk of the glass in the optical elements, or (3) spurious light being reflected from one or more of the optical surfaces into the path of sight. One can see from the above equation that as $T \rightarrow 0, \tau \rightarrow 0$
and $B^* \rightarrow 0, \tau \rightarrow 1.0$.

Thus, in designing the vision tester, in order to obtain the desired background adaptation luminance with the minimum expenditure of electrical power, it was necessary to keep the beam transmittance as high as possible and in order to obtain the desired high contrast rectangles, it was necessary to reduce the scattered luminance B^* to as low a value as possible.

patterns to be measured. This consisted of blocking the flux in one half of the central 15-minute field by means of an opaque shutter suitably inserted into the optical path at the presentation disk position, and measuring the flux emitted by the instrument in the two halves of this central circular field. The measurement was performed by adjusting the position of the eyepiece a few thousandths of an inch to obtain a true image of the disk plane at a distance of about 20 feet from the instrument and scanning the image at this position with a sensitive photometer having a suitably small aperture. Additionally, a 4 millimeter aperture was inserted at the location where the pupil of the eye would be situated in normal use in order to exclude from the measurement any scattered light which might otherwise have been improperly included and assure that any image degradation caused by optical aberations was limited to those same rays which would enter the pupil of an observer using the instrument. From the readings obtained in the light and dark areas it was determined that the contrast transmittance, at least for large patterns, would be approximately 0.90. The implication here was that the high contrast series of rectangles which had a measured inherent contrast on the presentations disk of -1.0, would have a maximum apparent contrast at the observers eye of -0.9 and the low contrast series would be reduced by the same factor.

To answer the question of whether the smaller rectangles suffered a greater contrast transmission loss than that incurred by the larger ones, two measurement techniques were used. The minute quantities of flux contained in the image (or in a like solid angle of background) made direct noise-free measurement of the contrast difficult with the equipment which was at first available. To increase the flux change to be measured, a special disk was prepared which contained a series of long opaque bars (extending through the entire 15-minute central field) whose widths encompassed the range of widths which existed in the 4 x 1 rectangular patterns. The image deterioration encountered in these narrow bars should be similar to that found in the narrow dimension of the 4 x 1 rectangles. The Vision Tester eyepieces were again adjusted to form images of these long bars about 20 feet from the instrument. These images were scanned with a long narrow aperture having the same physical width as the undiffracted images. A circular pupil 4 mm in diameter was placed at the location for the reasons given previously. Fig. 3-3a compares the measured values obtained in this manner (the plotted points) with values computed theoretically for this same scanning process including the effects of diffraction (solid curve). The dotted curve shows this same theoretical data multiplied by the large pattern contrast transmittance of 0.9. Fig. 3-3b shows the ratio of the measured values to the theoretical values for a diffracted image (solid curve in Fig. 3-3a). The points thus obtained represent the contrasts which exist outside the observer's eye, as the effect of diffraction by the pupis has been removed.

Unfortunately, because of the difficulty of aligning the very narrow aperture slit with the very dim diffracted image, some doubt existed that the contrasts measured represented the maximum values, particularly for the smaller bars. It is probably safe to infer from these measurements, however, that the apparent contrast for the smaller bars lay between -0.7 and the value of -0.9 found for large areas. The actual value depended upon to what extent the lower indicated values resulted from deterioration of the photographic image on the disk and narrow angle forward scatter in the optical system and to what extent the reduction below -0.9 resulted from the problem of alignment.

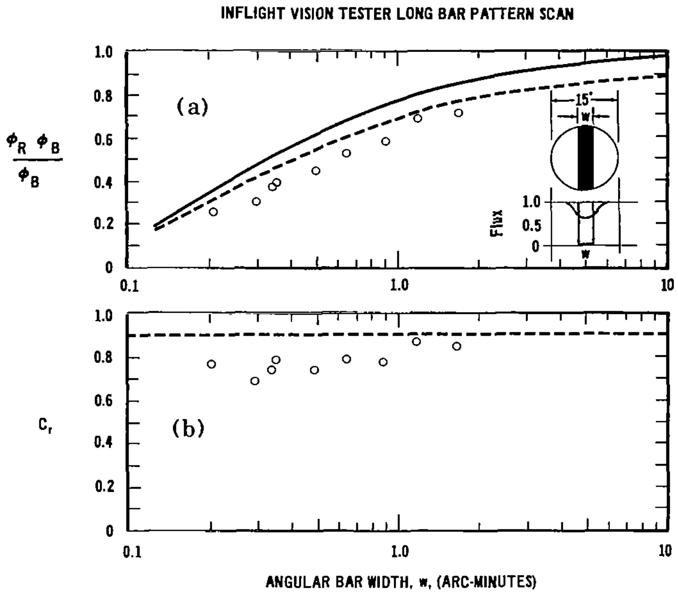


Fig. 3-3. Inflight Vision Tester long bar pattern scan.

Because of the difficulty in making the above measurements and interpreting them in terms which directly relate to the contrast of the 4 x 1 rectangular patterns presented by the vision tester in its normal use, a second series of measurements was made using more sensitive and sophisticated equipment (described below) which recently became available. The results of these measurements were also compared with theoretical calculations for the same technique to obtain a more direct measure of the apparent contrast of the rectangles. Although a special high luminance source was used to increase the flux in the central 15-minute field and a specially selected, ultrasensitive photomultiplier tube was procured to perform the photometry, the measurement was still severely limited by the small amounts of flux which were available. A description of this second procedure follows.

The equipment used to perform the measurements was an optical scanner originally developed by the Visibility Laboratory for image processing studies. With the aid of this device, it was possible to examine incrementally and record digitally the flux levels existing at each incremental position in the image. For the test, the Inflight Vision Tester eyepieces were adjusted to form images of the rectangular patterns 57½ inches from the instrument. An externally mounted 100 watt zirconium crater-arc lamp was used to provide the flux for illuminating the patterns on the presentation disk in lieu of the small lamps contained in the vision tester. Whereas this more intense source was required in order to obtain an adequate signal level for the measurement, its output has an inherent fluctuation which reduced the gain in signal-to-noise ratio one would otherwise realize. Its use also meant that it was not possible to match the luminance of the surrounding 30° adaptive to the now brighter 15-minute field. As a result, the adaptive field was turned off for these measurements and its effect on contrast transmittance was separately ascertained.

The image was scanned with a 0.1 millimeter scanning aperture stepped in increments equal to its size (i.e., 0.1 mm/step). The rectilinear raster scan contained 32 lines with 32 steps per line. At a distance of 57½ inches (1460 mm) each 0.1 mm in the image plane represented 0.235 arc-minutes and the 32 x 32 raster represented, approximately, a 7.5 minute square portion of the image. As the largest rectangle was 4.5 minutes long, it could wasily fit within the raster. A 3 mm pupil was inserted at the eyepiece to assure that the same aberations and stray light conditions prevailed during the measurement as during use. The diffraction pattern from this circular aperture had a diameter of 0.65 mm (Airy disc) at the image (scan) plane. Thus, the 0.1 mm square scanning aperture was sufficiently small to permit an adequate examination of the flux in the diffracted images.

All thirty-six rectangles were scanned through the left eyepiece and five were examined through the right eyepiece. The results of the scans of three representative high contrasts rectangles, namely, positions number 10 (3 x 0.75 arc-minutes), 39 (1.58 x 0.4 arc-minutes), and 6 (0.83 x 0.215 arc-minutes) are shown in Fig. 3-4. The data from the measurements are plotted along with computed curves for idealized cross-sections through similarly diffracted images. Because it was necessary to insert the pupil in the measurement, the information obtained represents the angular distribution of flux as it might have been at the retina and not that available outside the observer's eye. A measure of the contrast transmittance of the instrument, however, can be obtained by taking the ratio of the measured to the computed diffracted-image contrasts. The contrast available to the observer's eye can be obtained, in turn, by multiplying this contrast transmittance by the contrast of the rectangles on the presentation disk. It can be seen from Fig. 3-4 that the measured and computed distributions are quite similar in shape. Some of the minor lack of correspondence between the shapes may be attributed to the spatial and temporal variation in the output of the crater-arc lamp and some may be due to noise in the output of the photomultiplier tube.

The ratios of the measured to the computed "diffracted-image contrasts" for the three images in Fig. 3-4 are given in the table below.

Disk Position No.	Angular Size of Undiffracted Image	Measured Diffracted-Image Contrast	Calculated Diffracted-Image Contrast	Contrast Transmittance
10	3' x 0.75'	-.68	-.75	.91
39	1.58' x 0.4'	-.43	-.47	.91
6	0.83' x 0.21'	-.22	-.23	.96

The indicated contrast transmittances are of the same order as those determined by the method described above of opaquing half of the 15-minute central field and measuring the resulting fluxes in the illuminated and unilluminated fields in image space, i.e., 0.9. The agreement is well within the precision limits of the measurement, especially for the smaller bars. As a result of the several methods of approach to the determination of the contrast of the bars presented by the Inflight Vision Tester to an observer, we found no evidence that the contrast of the smaller images was preferentially reduced by the optical system of the instrument more than for the large images.

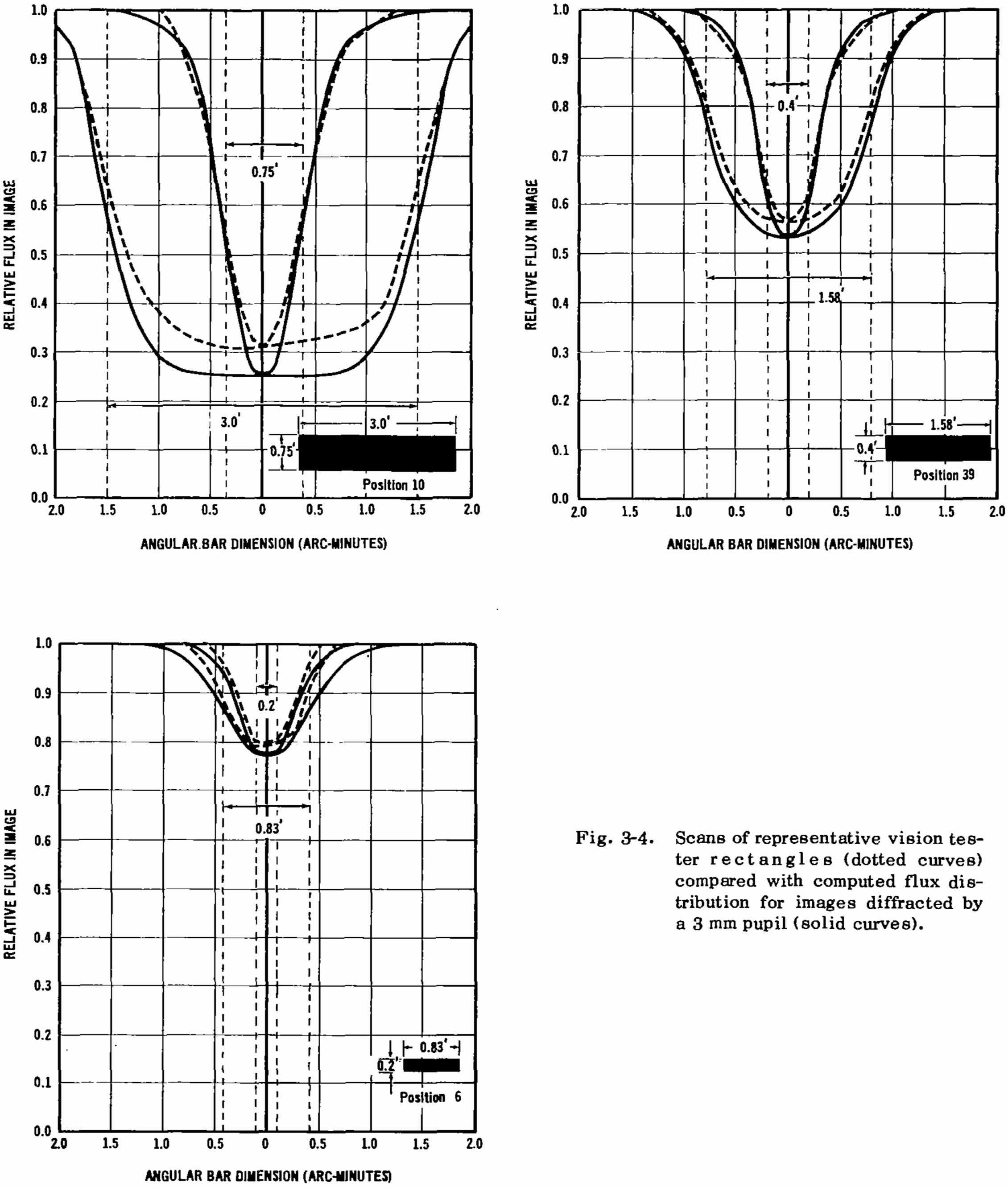


Fig. 3-4. Scans of representative vision tester rectangles (dotted curves) compared with computed flux distribution for images diffracted by a 3 mm pupil (solid curves).

We also found that a satisfactory value for the contrast transmittance of the large images was 0.9. There was no evidence that deterioration of the photographic image of the smaller bars on the presentation disk caused any loss of apparent contrast to an observer.

The contrasts on the presentation disks as determined by measurement of the optical density of the large test areas and the corresponding apparent contrasts presented by the instruments are given in the table below.

IFVT Serial Number	Use	Inherent Contrast Co.		Apparent Contrast Cr = 0.9 x Co.	
		High	Low	High	Low
1	Gemini V Training and Postflight	-1.0	-0.332	-0.9	-0.30
2	Visibility Laboratory	-1.0	-0.229	-0.9	-0.21
3	Gemini VII Postflight	-1.0	-0.324	-0.9	-0.29
4	Gemini VII Training	-1.0	-0.187	-0.9	-0.17
5	Gemini V Flight and Postflight, Gemini VII Training, Flight and Postflight	-1.0	-0.233	-0.9	-0.21

3.3 RESULTS FROM THE INFLIGHT VISION TESTER

The first use made of the results obtained with the Inflight Vision Tester was a statistical analysis of correct responses. Three other forms of analysis were made subsequently. All of these analyses will be described in the sections which follow; none indicate a change in the visual performance of any of the crew members before, during, or after their apace flights.

3.3.1 Analysis of Correct Scores

Gemini V

A comparison of the correct scores made by the Gemini V crew members on the ground (preflight) and in space (inflight) can be used to ascertain whether their observed visual performance differed in the environments or changed during the 7-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown for both crew members in Fig. 3-5. The results of standard statistical tests applied to these data are shown in Tables 3-3 through 3-6.

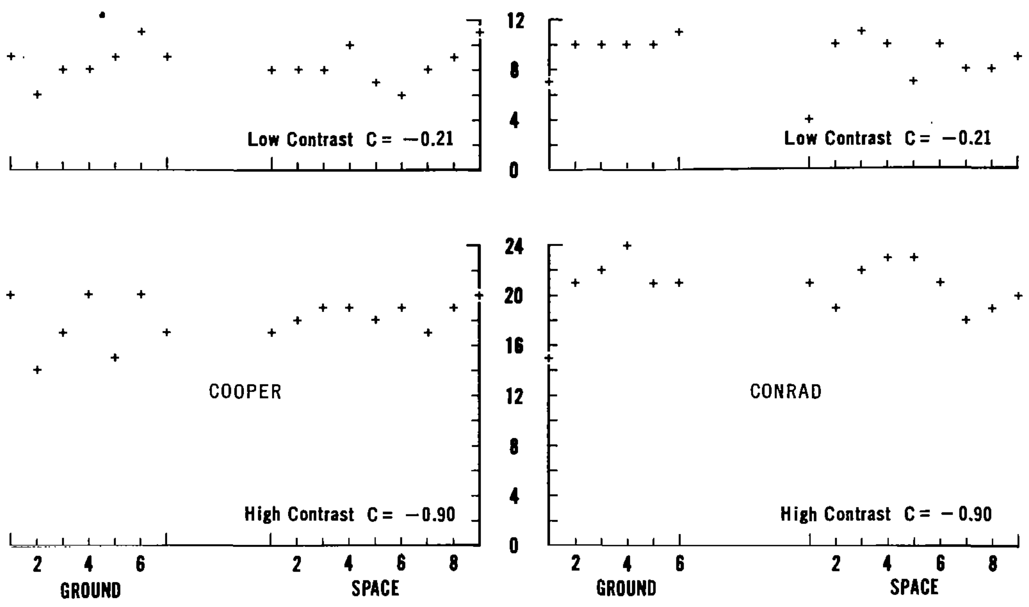


Fig. 3-5. Correct vision tester scores for Gemini V flight crew.

Table 3-3. Vision Tester (Ground Versus Space)

CORRECT RESPONSES

GT-V Cooper	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number -----	7	9	7	9
Mean -------	17.6	18.4	8.6	8.3
Standard deviation -------	2.3	.96	1.3	1.4
t ----------	0.96		0.31	
$t_{0.05}$ -------	2.14		2.14	
F ---------	6.12		1.02	
$F_{0.05}$ ------	3.58		3.58	
$F_{0.01}$ -------	6.37		-----------	

Table 3-4. Vision Tester (Ground Versus Space)

CORRECT RESPONSES

GT-V Conrad	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number -----	7	9	7	9
Mean	20.7	20.7	9.7	8.6
Standard deviation ------	2.7	1.7	1.2	2.0
t ----------	0		1.13	
$t_{0.05}$ -------	2.14		2.14	
F ---------	2.79		2.43	
$F_{0.05}$ ------	3.69		4.82	

Table 3-5. Vision Tester (Inflight Trend)

CORRECT RESPONSES

GT-V Cooper	C = -0.9		C = -0.21	
	First 4	Last 4	First 4	Last 4
Number -----	4	4	4	4
Mean -------	18.2	18.8	8.5	8.5
Standard deviation ------	.83	1.1	.87	1.8
t ---------	0.68		0	
$t_{0.05}$ -------	2.45		2.45	
F ---------	1.73		4.33	
$F_{0.05}$ ------	9.28		9.28	

Table 3-6. Vision Tester (Inflight Trend)

CORRECT RESPONSES

GT-V Conrad	C = -0.9		C = -0.21	
	First 4	Last 4	First 4	Last 4
Number -----	4	4	4	4
Mean -------	21.3	19.5	8.8	8.75
Standard deviation ------	1.5	1.1	2.8	.83
t ---------	1.64		0	
$t_{0.05}$ -------	2.45		2.45	
F ---------	1.96		11.19	
$F_{0.05}$ ------	9.28		9.28	
$F_{0.01}$ ------	-----------		29.5	

Comparisons between preflight and inflight data are given in Tables 3-3 and 3-4. All Student's t tests show no significant difference in means. All Snedecor's F tests show no significant difference in variances at the 0.05 level, with the exception of Cooper's high-contrast comparison which shows no significant difference at the 0.01 level.

Comparisons between the inflight data at the beginning of the mission with that at the end are made in Tables 3-5 and 3-6. All Student's t tests and Snedecor's F tests show no significant difference at 0.05 level, with the exception of the F test on Conrad's low-contrast comparison which shows no significant difference at 0.01 level.

These statistical findings support the null hypothesis advanced by many scientists before the Gemini V mission was flown; i.e., there is no evidence that the visual performance of either member of the Gemini V crew was affected by space flight.

Gemini VII

A comparison of the correct scores made by the Gemini VII crew members on the ground (preflight) and in space (inflight) can be used to ascertain whether their observed visual performance differed in the environments or changed during the 14-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown for both crew members in Fig. 3-6. The results of standard statistical tests applied to these data are shown in Tables 3-7 through 3-10.

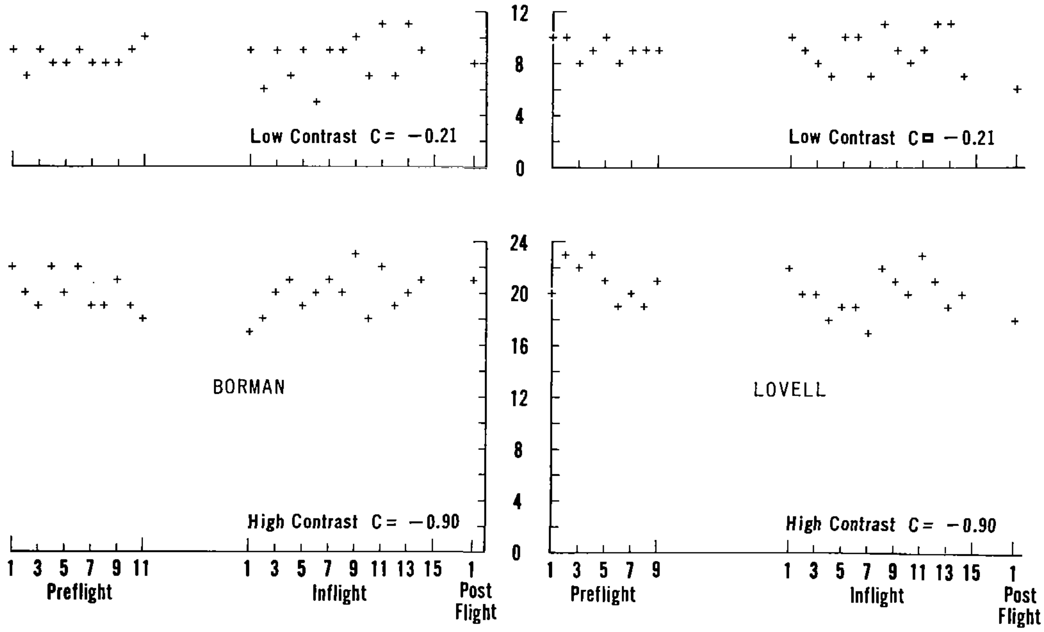


Fig. 3-6. Correct vision tester scores for Gemini VII flight crew.

Table 3-7. Vision Tester (Ground Versus Space)

CORRECT RESPONSES

GT-VII Borman	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number	11	14	11	14
Mean	20.0	19.9	8.45	8.4
Standard deviation	1.3	1.6	.78	1.7
t	0.12		0.017	
$t_{0.05}$	2.07		2.07	
F	1.49		4.74	
$F_{0.05}$	2.89		2.89	
$F_{0.01}$	4.66		4.66	

Table 3-8. Vision Tester (Ground Versus Space)

CORRECT RESPONSES

GT-VII Lovell	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number	9	14	9	14
Mean	20.9	20.0	9.1	9.1
Standard deviation	1.4	1.6	.74	1.4
t	1.29		0.073	
$t_{0.05}$	2.08		2.08	
F	1.17		3.64	
$F_{0.05}$	3.26		3.26	
$F_{0.01}$	5.62		5.62	

Table 3-9. Vision Tester (Inflight Trend)

CORRECT RESPONSES

GT-VII Borman	C = -0.9		C = -0.21	
	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.0	20.0	8.0	9.0
Standard deviation	1.4	1.4	1.3	1.8
t	1.00		0.91	
$t_{0.05}$	2.31		2.31	
F	1.00		2.00	
$F_{0.05}$	6.39		6.39	

Table 3-10. Vision Tester (Inflight Trend)

CORRECT RESPONSES

GT-VII Lovell	C = -0.9		C = -0.21	
	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.8	20.4	8.8	9.2
Standard deviation	1.3	1.5	1.2	1.6
t	0.60		0.91	
$t_{0.05}$	2.31		2.31	
F	1.27		1.88	
$F_{0.05}$	6.39		6.39	

Comparisons between preflight and inflight data are given in Tables 3-7 and 3-8. All Student's t tests showed no significant difference in variances at the 0.05 level, with the exception of Borman's low-contrast comparison which shows a weakly significant difference at the 0.0 level.

Comparisons between the inflight data at the beginning of the mission with that at the end are made in Tables 3-9 and 3-10. All Student's t tests and Snedecor's F tests show no significant difference at 0.05 level, with the exception of the F test on Borman's low-contrast comparison which shows no significant contrast at the 0.01 level.

These statistical findings provide additional support for the conclusion that the visual performance of the crews was not affected by space flight.

3.3.2 Non-parametric Analysis of Correct Scores

Distribution-free (non-parametric) statistical methods were also used to analyze the correct scores obtained with the inflight vision tester. The trend test outlined in *Measurement and Analysis of Random Data,* Bendat and Piersol, Wiley & Sons (1966), P. 158, par. 4.8.2 was used.

This procedure considers the number of reverse arrangements in a sequence of observations of a random variable and determines if there is a statistically significant trend. This test is not dependent on the distribution of the random variable. The results are given in Table 3-11.

The results of this analysis fortify the conclusion that none of the astronauts showed statistically significant trends in their visual performance before or during space flight. The few scattered indications of trend seem to depict a very slight improvement in performance with time, which may represent only a small residual learning effect. This is borne out by the predominance of cases in which the total reverses are less than expected (see WRT MEAN column in Table 3-11).

Table 3-11. Non-parametric Analysis of Correct Vision Tester Scores

Astronaut	Data	Contrast	ACCEPTANCE LEVEL				WRT* Mean
			0.05	0.02	0.01	<0.01	
CONRAD	Preflight	High	No trend				<
	Inflight	High	No trend				>
	Combined	High	No trend				<
	Preflight	Low	No trend				<
	Inflight	Low	No trend				<
	Combined	Low	No trend				<
COOPER	Preflight	High	No trend				<
	Inflight	High		No trend			<
	Combined	High	No trend				<
	Preflight	Low		No trend			<
	Inflight	Low	No trend				<
	Combined	Low	No trend				<
BORMAN	Preflight	High	No trend				>
	Inflight	High	No trend				<
	Combined	High	No trend				<
	Preflight	Low			**	No trend	<
	Inflight	Low		No trend			<
	Combined	Low			**	No trend	<
LOVELL	Preflight	High	No trend				<
	Inflight	High	No trend				<
	Combined	High	No trend				>
	Preflight	Low	No trend				>
	Inflight	Low	No trend				<
	Combined	Low	No trend				<

* Magnitude of total reverses with respect to mean or expected magnitude.

** "No trend" hypothesis barely rejectable at the 0.01 level; shows improvement.

3.3.3 Visual Thresholds from the Inflight Vision Tester

Immediately following the delivery of the recorded data from the inflight vision tester to the experimenter's thresholds of angular size were determined by a rapid but approximate phychophysical procedure. Figures 3-7 through 3-14 show those thresholds for each use of the inflight vision tester before, during, and after the space flights.

It is interesting that, in subsequent studies of the inflight data, the use of standard probit analysis techniques and various other procedures ordinarily employed with large bodies of laboratory psychophysical data did not prove to be satisfactory. Alternative procedures, described elsewhere in this report, were based upon nonparametric statistics and binomial analysis, but they served only to substantiate the conclusion expressed by Figs. 3-7 through 3-14: *No change in the visual threshold performance (visual acuity) of the astronauts during their long-duration space flight was detected.*

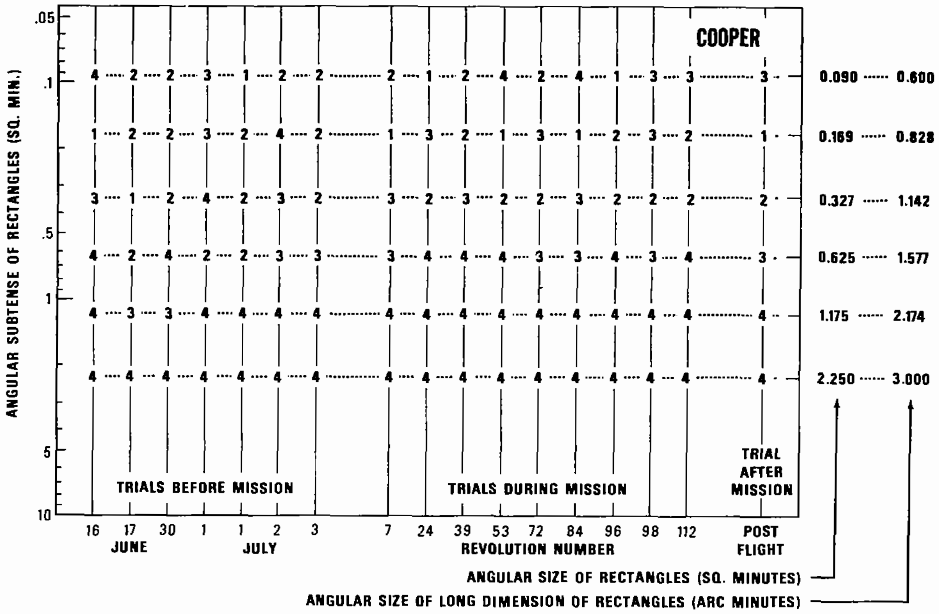
The method used to generate Figs. 3-7 through 3-14 will now be described:

Table 3-12 gives the number of correct vision tester scores at each of the six rectangle sizes in the major (high contrast) series of the vision tester data taken by astronaut Cooper before, during, and after Gemini V. Each of the rectangles was presented four (4) times so that a perfect score on that rectangle is denoted by 4. It was decided to assign a probability of 1 to each instance in which 4 correct reports were made, i.e. (1.00 −0.50)/0.50 = 1.0. Similarly, the case of 3 correct reports was denoted by probability 0.50 since (0.75 −0.50)/0.50 = 0.50. On this basis a probability rating of zero is assigned in the case of fewer than 3 correct reports.The numbers in Table 3-12 can now be replaced by probabilities through the use of these rules, as has been done in Table 3-13. A threshold was then assigned on the basis of the sequence of these probabilities. For example, in the case of the data taken by astronaut Cooper on revolution 96 it will be noted that the probability is unity for the three largest rectangle sizes and 0 for the three smallest. It is inferred that the probability of correctly discriminating the orientation of the rectangle fell from unity to 0 between the third and fourth rectangles or at an angular area of approximately 0.45 sq. min. To cite another example, consider the data taken on revolution 39. Here, the probability for the three largest rectangles is 1 falling to probability ½ for the next smaller rectangle and to 0 for the two smallest ones. Thus, the probability is seen to drop from unity to 0 between the third and fifth rectangles and the threshold is therefore placed on the fourth, or at an angular size of 0.32 sq. min. In many instances the assignment of threshold position is less clear and is much more a matter of personal judgment. No high degree of reliability or exactitude is claimed for this procedure, but it did provide a quick means for making a preliminary assessment of the vision tester scores immediately after the flight.

Confidence Intervals

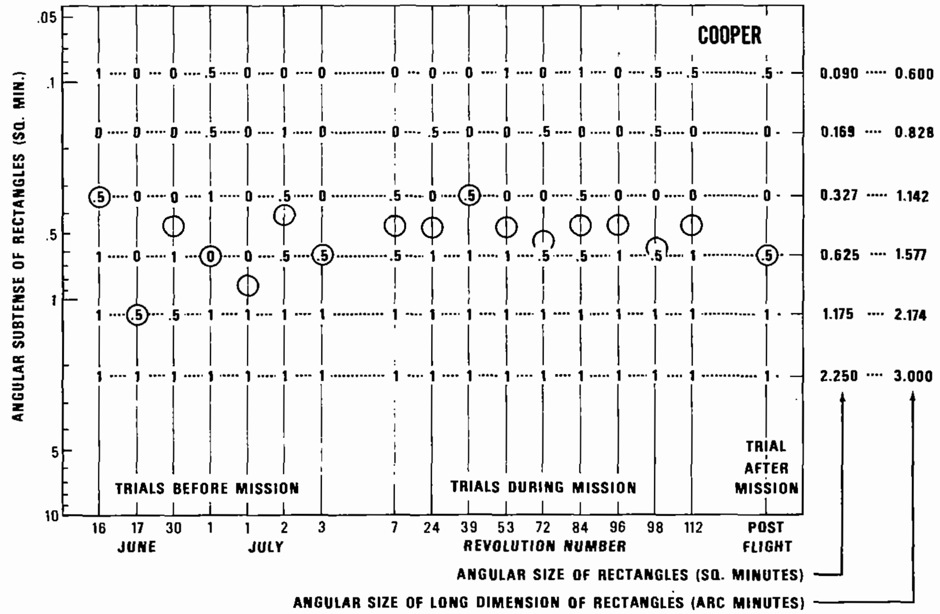
Figures 3-7 through 3-14 contain horizontal broken lines which indicate confidence intervals for the threshold data. The method used to derive these limits is described in the following paragraphs.

Table 3-12. Gemini V Correct Scores Vision Tester Apparent Contrast = -0.90



SQ. MINUTES	ARC MINUTES	16 June	17 June	30 June	1 July	1 July	2 July	3 July	Rev. 7	24	39	53	72	84	96	98	112	Post flight
0.090	0.600	4	2	2	3	1	2	2	2	1	2	4	2	4	1	3	3	3
0.169	0.828	1	2	2	3	2	4	2	1	3	2	1	3	1	2	3	2	1
0.327	1.142	3	1	2	4	2	3	2	3	2	3	2	2	3	2	2	2	2
0.625	1.577	4	2	4	2	2	3	3	3	4	4	4	3	3	4	3	4	3
1.175	2.174	4	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4	4
2.250	3.000	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4

Table 3-13. Gemini V Probability of Correct Score Vision Tester Apparent Contrast = -0.90



SQ. MINUTES	ARC MINUTES	16 June	17 June	30 June	1 July	1 July	2 July	3 July	Rev. 7	24	39	53	72	84	96	98	112	Post flight
0.090	0.600	1	0	0	.5	0	0	0	0	0	0	1	0	1	0	.5	.5	.5
0.169	0.828	0	0	0	.5	0	1	0	0	.5	0	0	.5	0	0	.5	0	0
0.327	1.142	.5	0	0	1	0	.5	0	.5	0	.5	0	0	.5	0	0	0	0
0.625	1.577	1	0	1	0	0	.5	.5	.5	1	1	1	.5	.5	1	.5	1	.5
1.175	2.174	1	.5	.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2.250	3.000	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

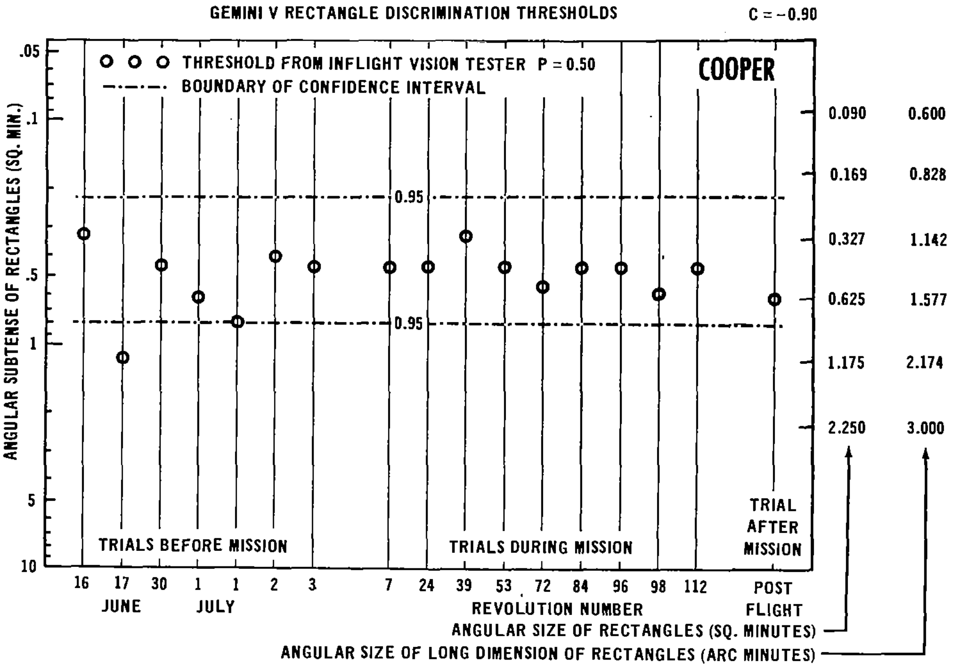


Fig. 3-7. Gemini V command pilot's rectangle distrimination thresholds.

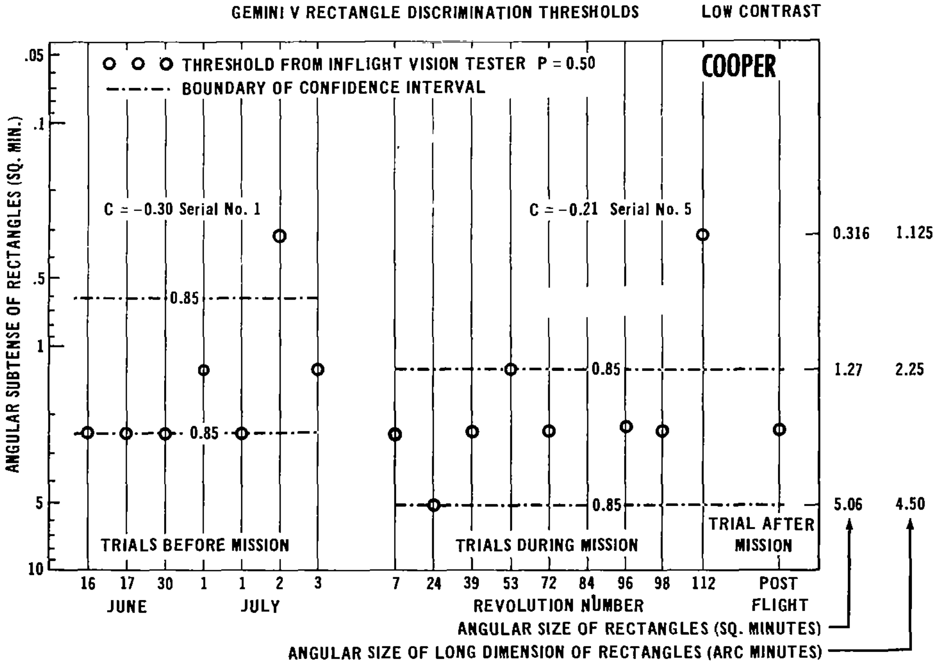


Fig. 3-8. Gemini V command pilot's rectangle discrimination thresholds.

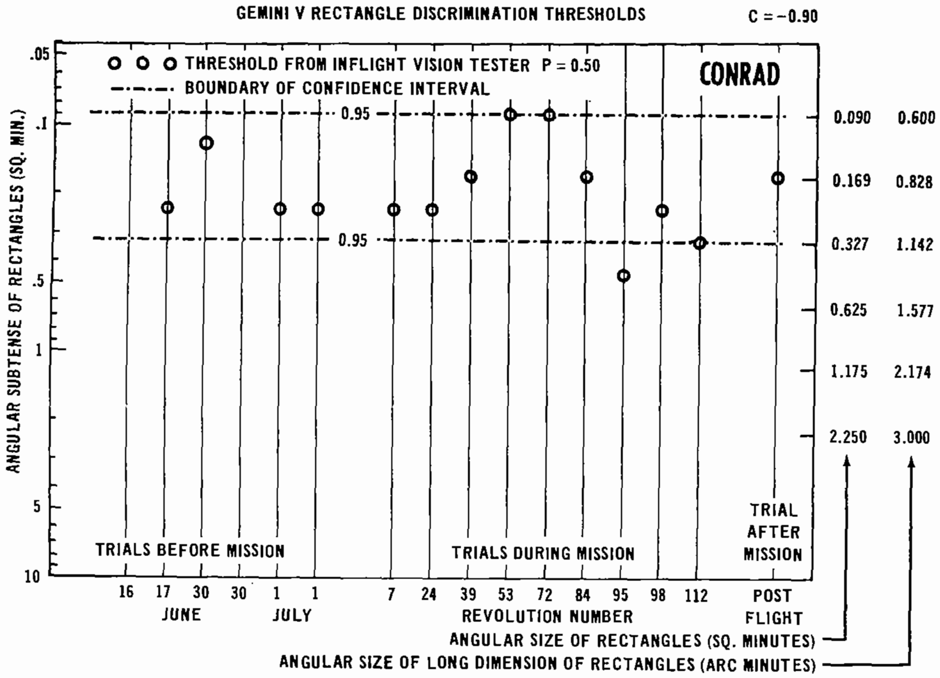


Fig. 3-9. Gemini V pilot's rectangle discrimination thresholds.

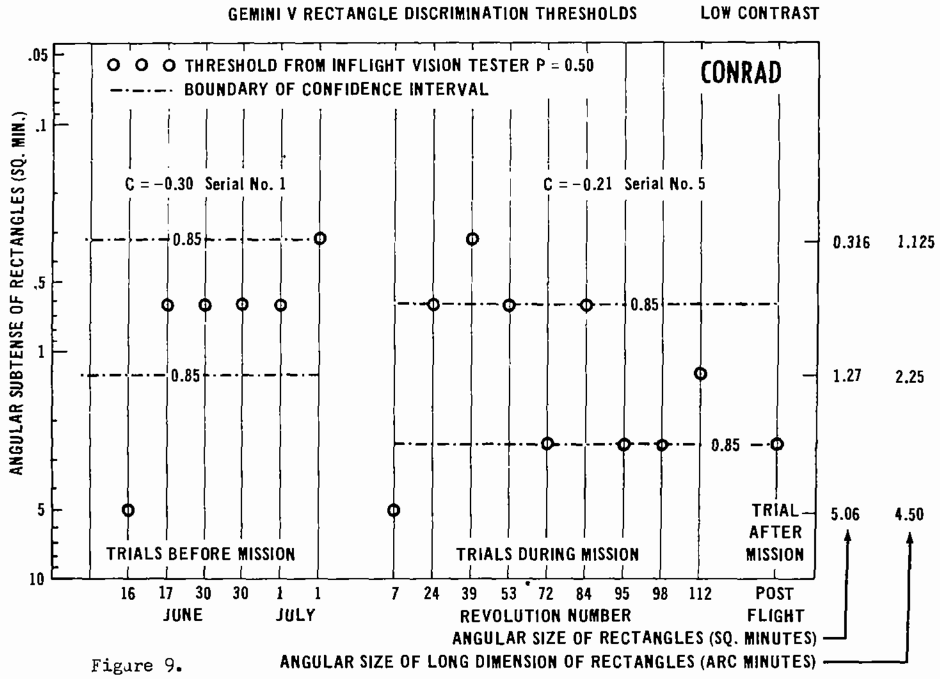


Figure 9.

Fig. 3-10. Gemini V pilot's rectangle discrimination thresholds.

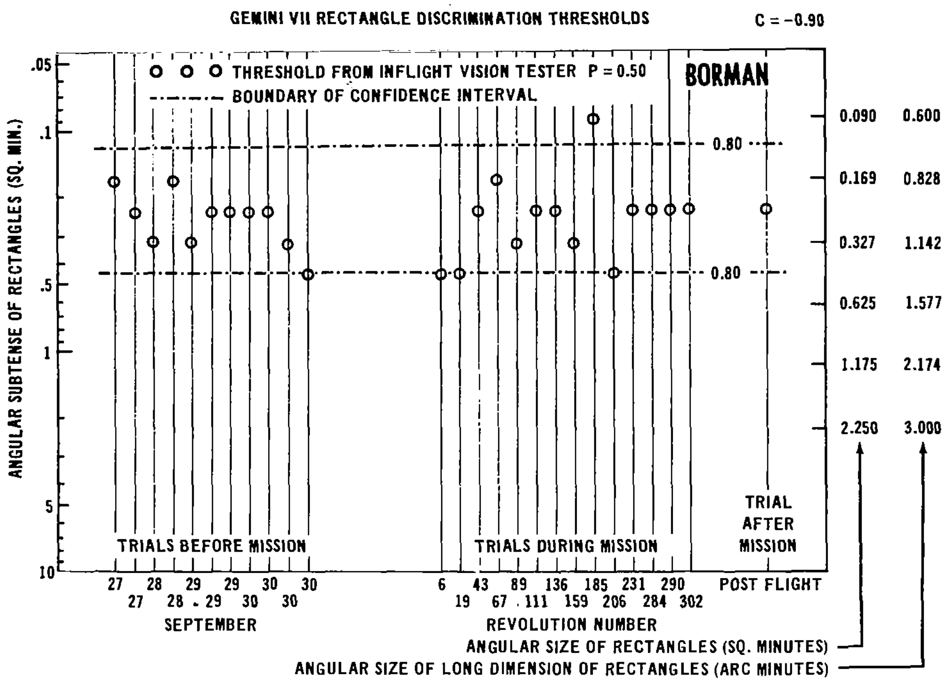


Fig. 3-11. Gemini VII pilot's rectangle discrimination thresholds.

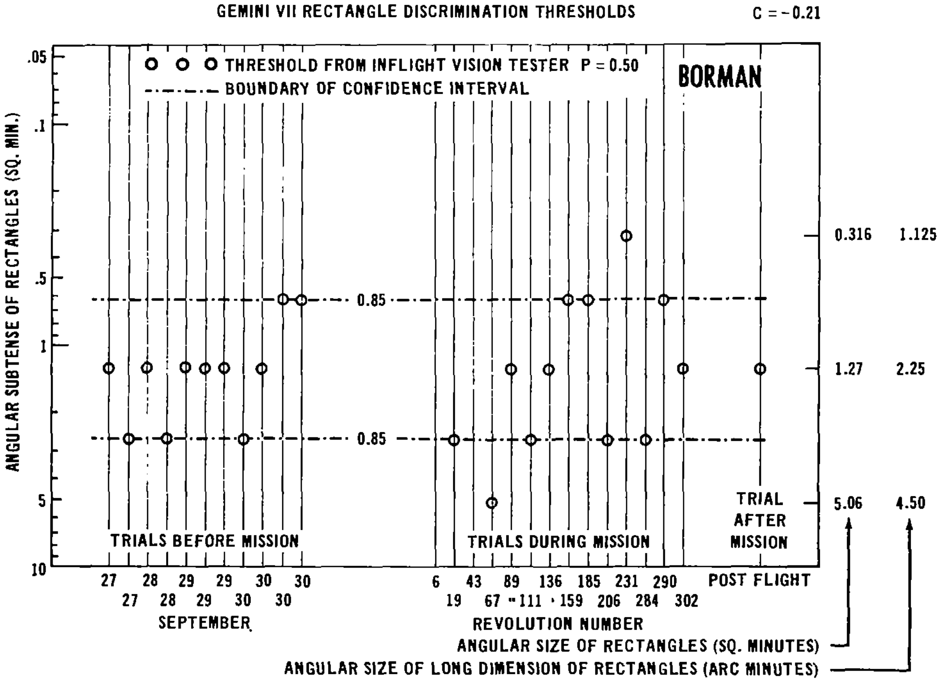


Fig. 3-12. Gemini VII command pilot's rectangle discrimination thresholds.

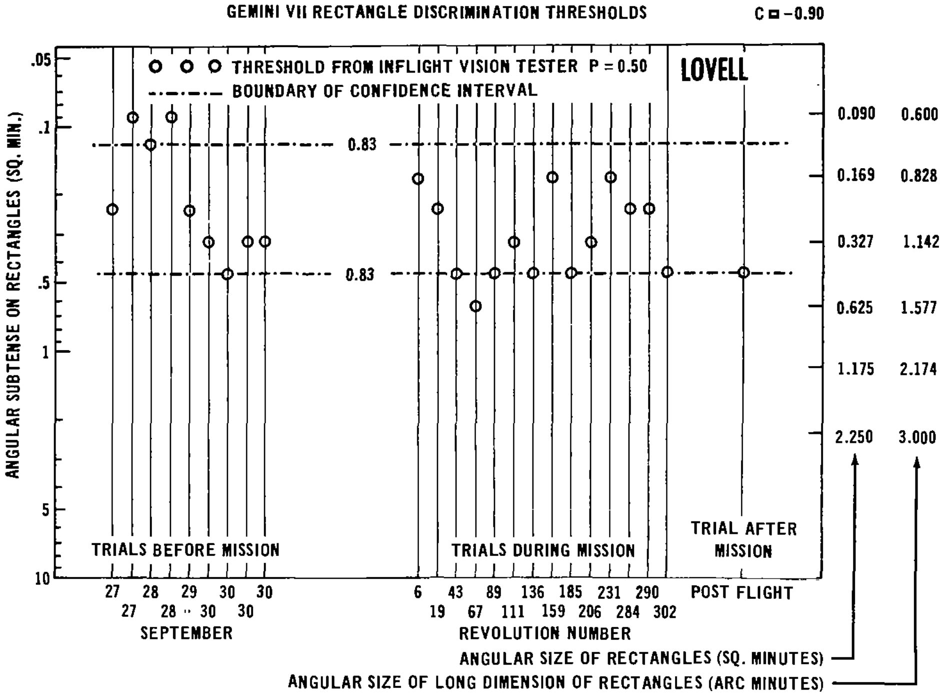


Fig. 3-13. Gemini VII pilot's rectangle discrimination thresholds.

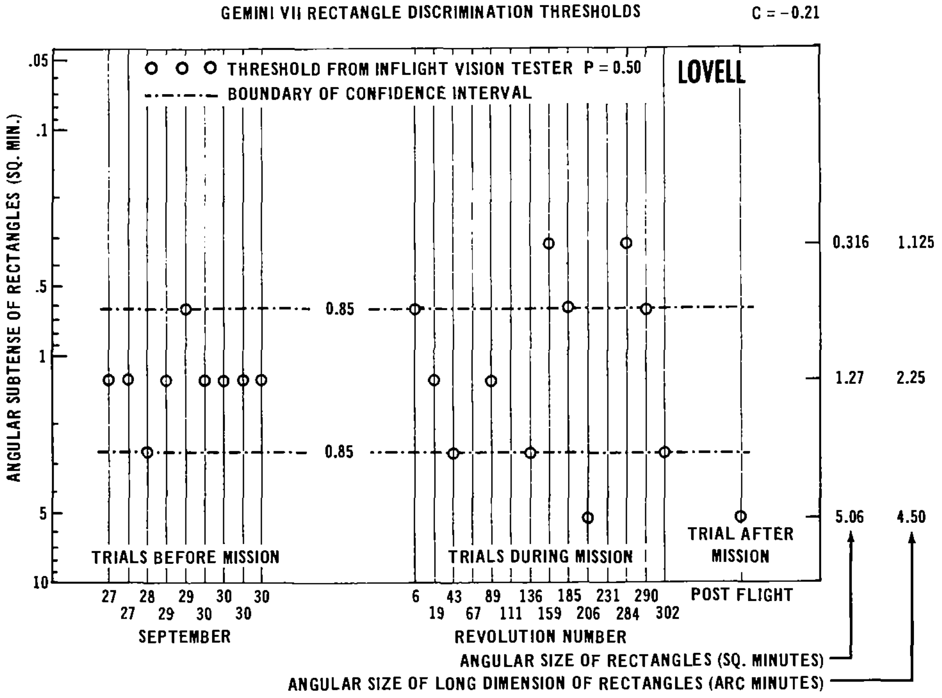


Fig. 3-14. Gemini VII pilot's rectangle discrimination thresholds.

The threshold data from the vision tester did not lend itself to description by an analytic expression in closed form that could be used to calculate confidence limits. An approximate numerical method based on several assumptions was used, therefore, to estimate the desired confidence limits. Fortunately, the experiments in the training van had produced visual threshold data for each astronaut as he performed the rectangle orientation visual task. These data, plotted in Figs. 2-21 (a, b, c, d) and Appendix A, Fig. 5, were used as the basis for the prediction of confidence limits for the vision tester thresholds. Although separate calculations were necessarily made for each of the four flight crew members, only one set of those calculations will be used in this section to illustrate the method; the results of all such calculations are indicated by the horizontal broken lines in Figs. 3-7 through 3-14. Data for Astronaut Borman will be used.

The calculations were begun by assuming that the plot of probability of correct decision versus apparent contrast of the bar is a Gaussian ogive which, for a two element forced choice experiment, has a probability value of 0.5 at zero contrast; i.e., pure guessing. A threshold plot of angular area versus apparent contrast for a probability of correct response of 0.9 for Borman appears in Appendix A as Fig. 28, and is reproduced in Fig. 3-15 of this section in order to add curves for other probabilities in accordance with the Gaussian ogive assumption. A cross-plot of Fig. 3-15 is shown in Fig. 3-16 for the angular subtense corresponding to each of the 5 largest high contrast rectangles in the inflight vision tester. The contrast scale of Fig. 3-16 was left relative (rather than absolute) in order to use the figure for all astronauts despite their individual differences in threshold.

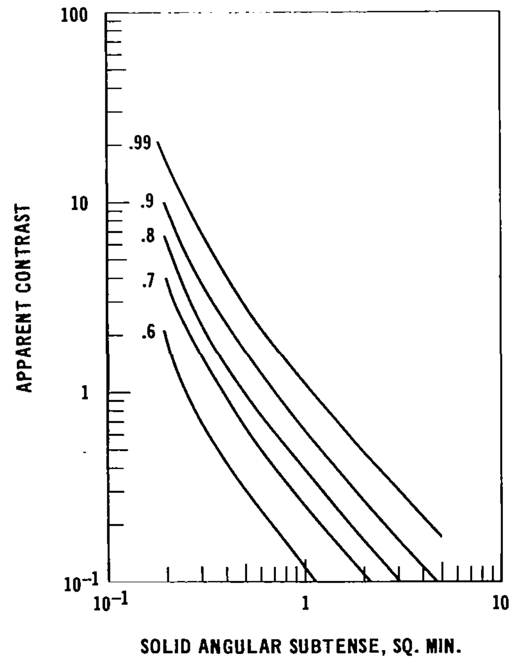
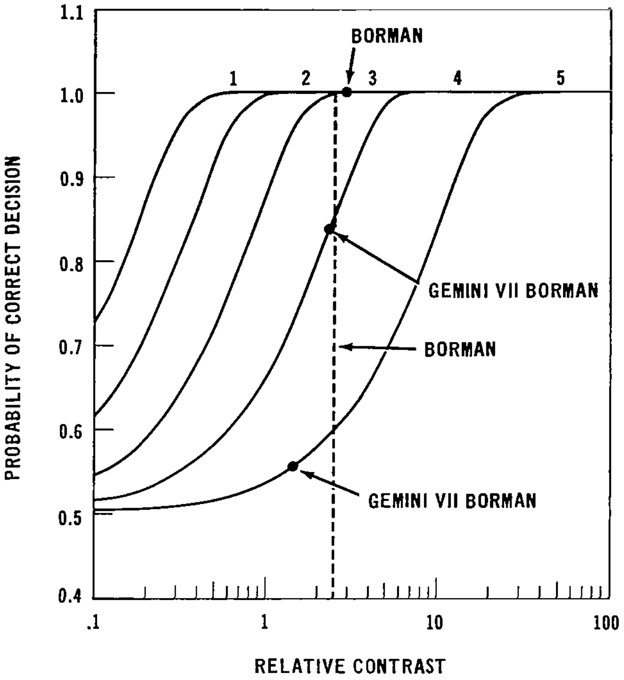


Fig. 3-15. The original 0.9 probability of correct response function of angular subtense with calculated curves for other selected probability values.

Fig. 3-16. Calculated curves for probability of correct decision as a function of relative contrast for rectangles of size corresponding to targets 1 through 5.



The overall probability performance data for Borman are plotted on the appropriate curves. If the Gaussian assumption holds and the data are exact all of the points should form a vertical column. Since they do not a vertical dashed line was drawn among them; this was an arbitrary visual fit. No claim is made for high precision in this matter.

From the straight vertical line of Fig. 3-16, probability of correct decision values can be read for each of the rectangle sizes. On the assumption that the threshold is statistically stationary, these probabilities can be used to generate the confidence intervals.

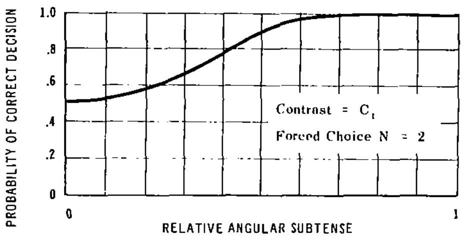
A random number table was used to produce many dummy "runs" of four "settings." The number of these runs was much larger than the number occurring in the actual experiment. This was accomplished by reading down the random number table and assuming that a number from the table equal to or greater than the probability value read from Fig. 3-16 represented a correct response, while a number from the table less than the probability represented an incorrect response.

The dummy runs were processed to obtain threshold estimates in exactly the same manner, described at the outset of this section, used to obtain the threshold estimates from the real data. Confidence intervals were obtained by counting the fraction of observations in the dummy runs which fell within a given interval. An attempt was made to obtain a confidence interval on the order of 0.9. No attempt was made to interpolate the results, however, and so the actual confidence intervals derived turned out to have values of 0.85 and 0.95, etc., depending on the interval in the dummy runs which came closest to being 0.9.

3.4 BINOMIAL INFLIGHT VISION TESTER DATA ANALYSIS

3.4.1 Introduction

In order to understand clearly the basis of this analysis, it is first necessary to define what is meant by a stable threshold. Let it be assumed that the specific vision task is that of specifying the orientation (one of two possible as in the vision tester) of 4 to 1 rectangles of uniform luminance, viewed against a uniform background with a fixed contrast. A forced choice experiment is made in which a bar is presented to the observer and he is forced to specify one of the two orientations, even if he feels that he is guessing. A large number of presentations are made to the observer and the number of correct responses are recorded. The probability of correct decision is the ratio of the number of correct responses and the number of presentations. The entire experiment just described is repeated many times with the angular subtense of the bars used as a variable. When all experiments have been run, a graph can be plotted relating probability of correct decision and angular subtense as shown in the following sketch:



The curve shows a probability of 0.5 at zero angular subtense which represents guessing and rises to a probability of 1.0 at sizes where the bars are easily resolved in both dimensions. The threshold is said to be stable if the probability values associated with the curve are invariant with time.

In any short experiment it would not be expected that exactly the right number of correct decisions would be obtained. Rather, it would be expected that the probability value associated with the stable threshold becomes the parameter of a binomial distribution which describes the probability of achieving any given number of correct responses for a specified number of presentations. Specifically the binomial distribution is of the form,

$$P = \binom{n}{r} p^r q^{n-r} \tag{3-1}$$

where P is the probability of achieving exactly r correct responses out of n presentations with a probability of correct response, p, and a probability of incorrect response q = 1−p. The binomial distribution shows the fluctuations in experimental results which should be expected even under conditions of an absolutely stable threshold. It is important to note the magnitude of these expected fluctuations so that they will not be mistaken as a change in threshold.

3.4.2 The Importance of Angular Subtense as a Variable

As stated elsewhere in this document, considerable importance was placed on the idea that if the observer underwent a change in visual performance during flight, the experiment should, in so far as possible, allow determination of the nature of this change in order that the findings could be translated into predictions of his altered performance in other visual tasks.

With the present state-of-the-art of visibility calculations, the most important single tool used for predicting the detectability of complex objects is the summative function. The summative function quantitatively describes the relative weighting which the human visual system associates with the various spatial components of an object. The summative function is derived from detection threshold experiments in which angular subtense is the variable.

Two general categories of visual performance changes which could occur would be (1) those in which the shape of the summative function is altered and (2) those in which the overall contrast threshold of the observer is altered without affecting the shape of the summative function. A category (1) change might for example result from some change which alters the retinal image quality whereas a category (2) change could for example result from some neural change which alters the inherent neural noise level. These two basic categories are distinguished by the fact that category (1) implies a change in visual performance which is an alteration of contrast threshold by a fixed amount at each angular subtense. For these reasons it is important to attempt to analyze the data from the inflight vision tester as a function of angular subtense.

3.4.3 The Binomial Analysis

The hypothesis that the threshold is stable and is unchanged from preflight to inflight will be assumed. On the basis of that hypothesis the best estimate of the correct probability of correct response is obtained by dividing the sum of the number of correct responses inflight and preflight by the sum of the number of presentations inflight and preflight. For example, Cooper scored 36/36 inflight and 26/28 preflight on target No. 2. The best estimate of his probability of correct response is therefore 36 + 26/36 + 28 or 0.97. On the basis of the hypothesis of stable threshold, it is then possible to construct from equation (3-1) the probability distributions for both the inflight and preflight cases. This is done in Fig. 3-17. The vertical dashed lines indicate the actual number of correct responses achieved by Cooper inflight and preflight.

In the context of Fig. 3-17 the stable threshold hypothesis would be subject to question if the vertical lines were located such as to represent highly improbable events with respect to their respective binomial distributions. Fig. 3-17 for example, would tend to support the hypothesis of a stable threshold. Figs. 3-18 to 3-45 show similar plots for each of the observers and for each angular subtense. Conrad had a perfect score on both preflight and inflight target No. 3, and therefore, that distribution is not shown. In the case of Borman, Figs. 3-39 to 3-45, the number of preflight trials was the same as the number of inflight trials and there is therefore a single binomial distribution.

Fig. 3-17

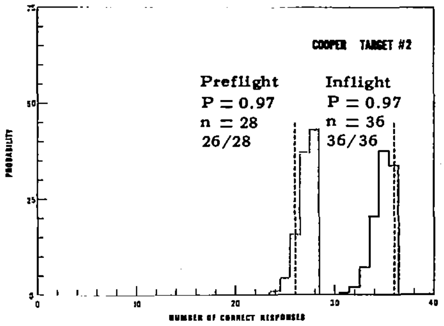


Fig. 3-18

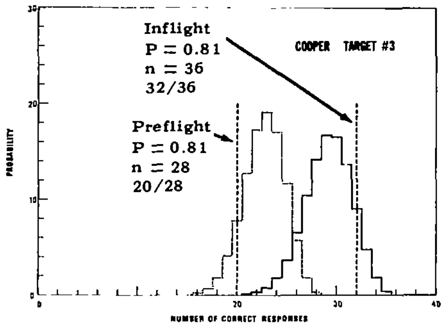


Fig. 3-19

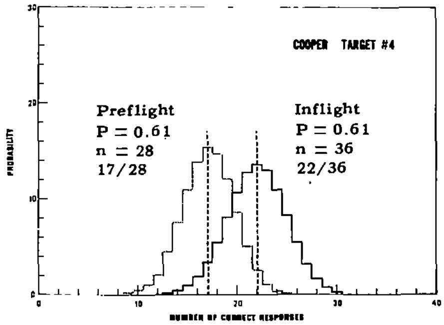


Fig. 3-20

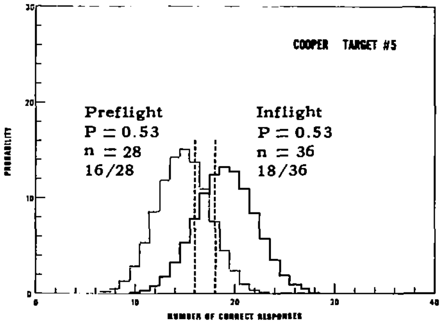


Fig. 3-21

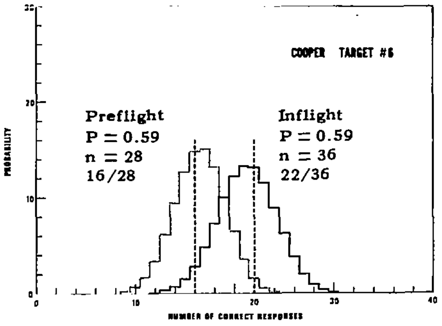


Fig. 3-22

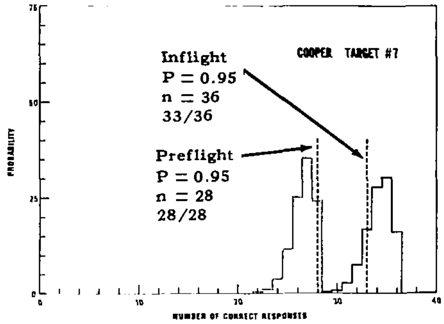


Fig. 3-23

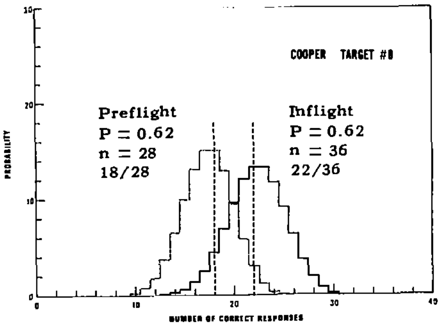


Fig. 3-24

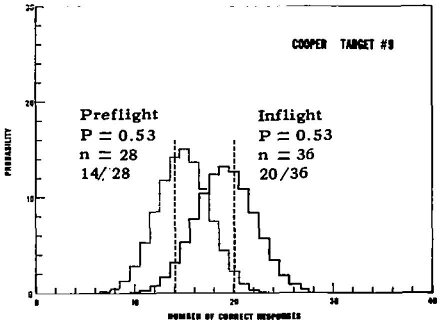


Fig. 3-25

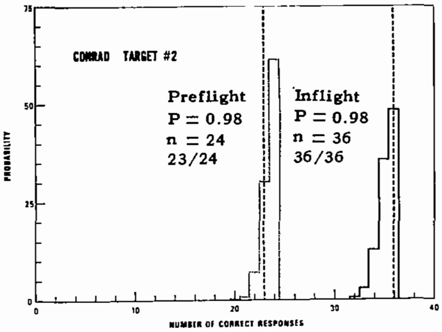


Fig. 3-26

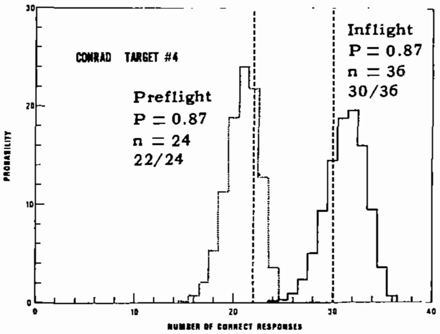


Fig. 3-27

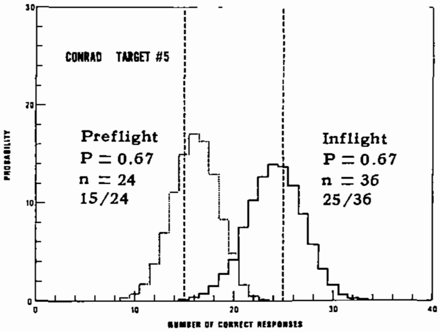


Fig. 3-28

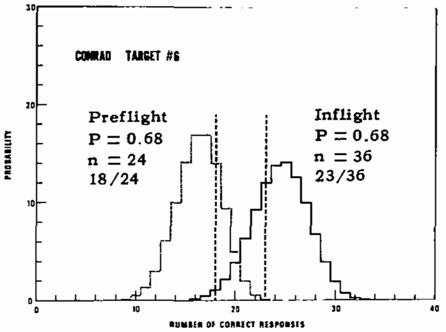


Fig. 3-29

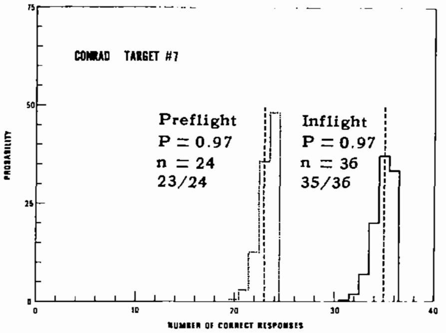


Fig. 3-30

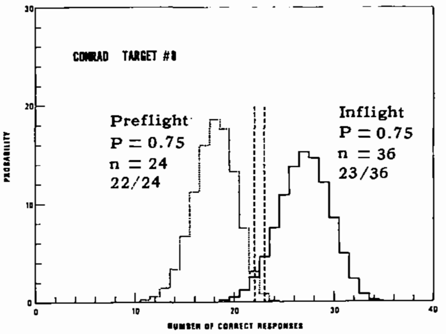


Fig. 3-31

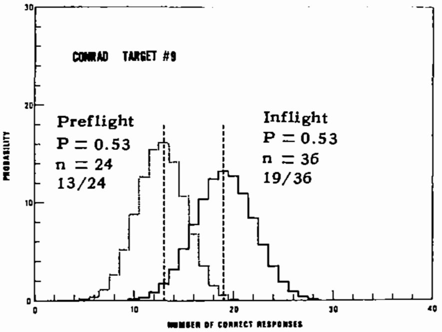


Fig. 3-32

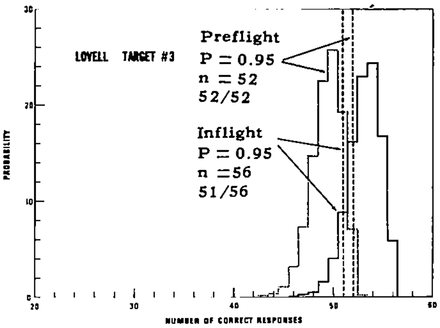


Fig. 3-33

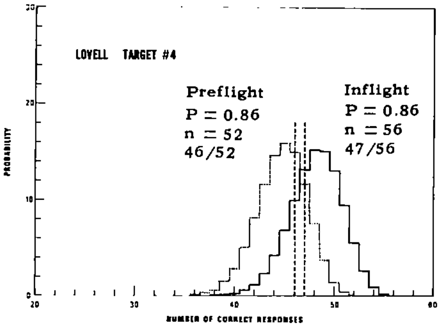


Fig. 3-34

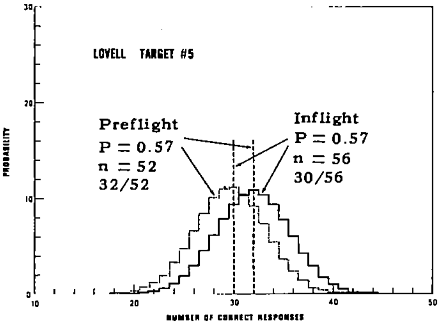


Fig. 3-35

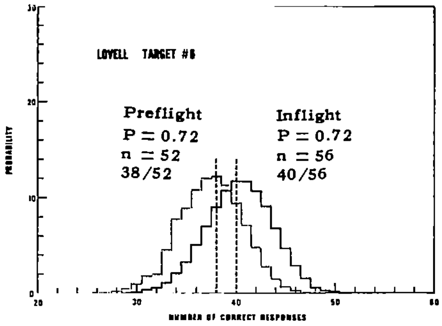


Fig. 3-36

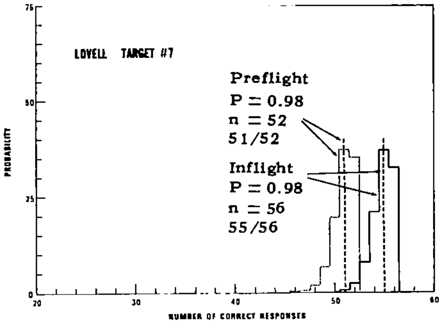


Fig. 3-37

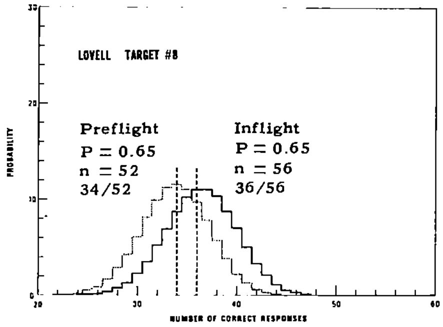


Fig. 3-38

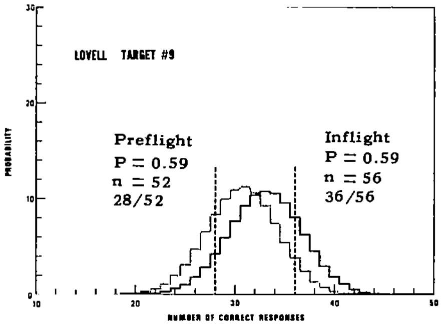


Fig. 3-39

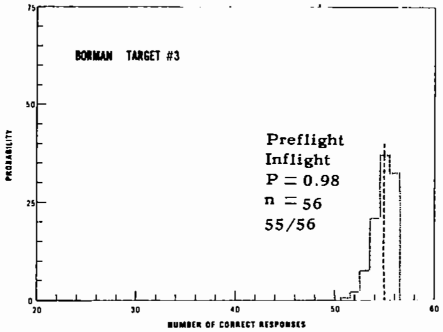


Fig. 3-40

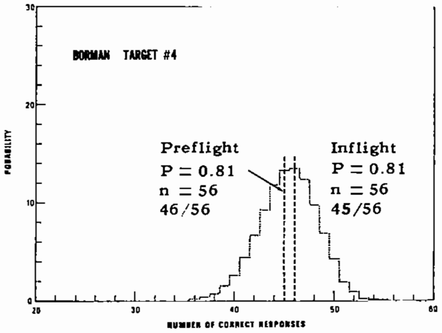


Fig. 3-41

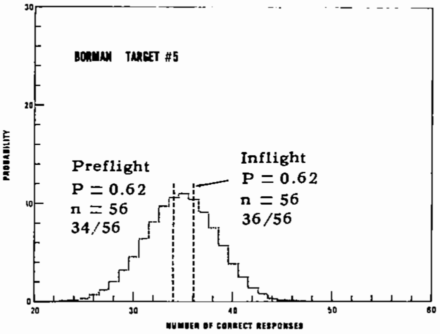


Fig. 3-42

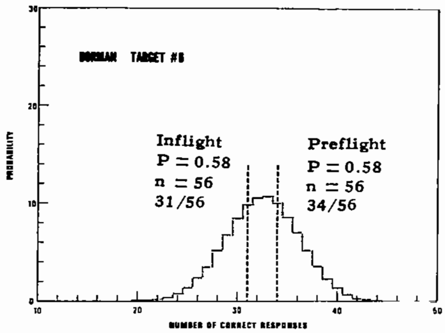


Fig. 3-43

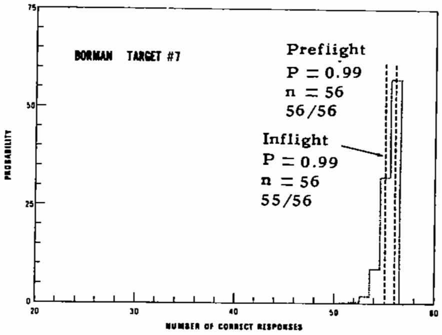


Fig. 3-44

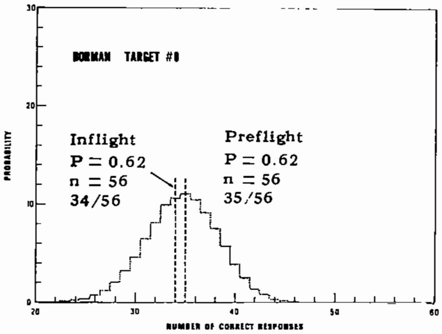
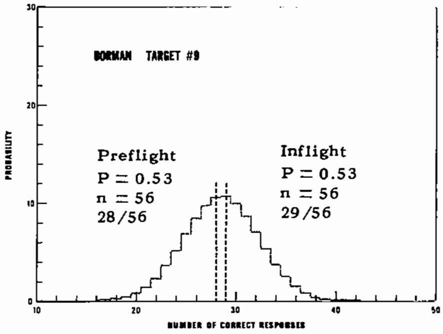


Fig. 3-45



3.4.4 Analysis of the Results

A study of Figs. 3-17 to 3-45 indicated that there were no rare events and hence all Figures support the hypothesis of a stable threshold. A further exploration of the Figures indicates no consistent trend with angular subtense, i.e., for one angular subtense performance was above average expectation preflight and below average expectation inflight, whereas for the next larger angular subtense target the reverse may be true. The comparison of best performance between inflight and preflight appears to be randomly related to angular subtense and it is therefore necessary to conclude that no angular dependent changes are shown by this data. Fig. 3-46 tends to demonstrate this conclusion. It is a graph on which Cooper's inflight correct responses are plotted for each of the high and low contrast targets. Alongside each data point are 90% confidence intervals derived from the corresponding binomial distributions of Figs. 3-17 to 3-24 it can be seen that the data points fall nicely within the confidence intervals and that they are sometimes above the average expectation and sometimes below in a manner which appears to be randomly related to the angular subtense.

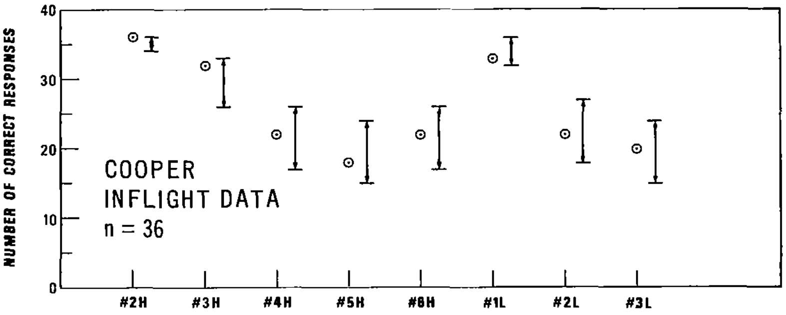


Fig. 3-46. Comparison of inflight performance with confidence intervals derived from the mathematical model.

3.4.5 Conclusion

No change was detected in the visual acuity of any of the four crew members who flew the 7-day and 14-day missions as measured on the Inflight Vision Tester.

4. The Out-of-the-Window Experiment

4.1 INTRODUCTION

The out-of-the-window sightings by the astronauts of prepared ground markings constituted a major portion of the total effort of the Gemini S-8/D-13 Visual Acuity Experiment. It also was the part that caught the fancy of the press and the public. The "giant eye charts" stretched out on the ground in Texas and Australia that the astronauts would "read" as they passed overhead seemed like a conceptually simple experiment that the public felt they understood and the press assumed to pass upon with the expert judgement that comes from hindsight. The problems that evolved and confronted the experimenters, however, in planning, preparing, and conducting this portion of the experiment were so numerous and the effort required for their solution so demanding and time consuming, that it is doubtful they would have had the courage to undertake this task had they initially been endowed with the clear vision that comes with hindsight.

A complete enumeration of the problems encountered would include changing launch azimuth and times, changing orbital parameters, selecting the method of conducting the experiment and operating the ground site, selecting locations for the sites, preparing the sites, selecting and obtaining suitable material in sufficient quantities for the rectangular markings, establishing suitable communications links between the ground sites and the Manned Spacecraft Center, devising, constructing, and calibrating two sets of instrumentation for documenting the optical contrast of the rectangular marks against the surrounding soil and the optical contrast transmittance of the atmosphere, the development, construction, and flight qualification of the inflight photometer carried on the spacecraft for the measurement of scattered light from the spacecraft window, and the training of the astronauts in their task. An account of the solution of some of these problems not covered elsewhere in this report is the subject of the following paragraphs.

4.2 CONSIDERATIONS IN THE DESIGN OF THE EXPERIMENT

The basis for the selection of the rectangle orientation discrimination experiment is given in Section 1.2.3. Having made this decision, it was necessary to determine how best to carry out this experiment within the constraints of an earth-orbital space mission whose primary objectives were the solution of the engineering problems associated with spacecraft, spaceflight, rendezvous, reentry, etc., directed toward the goal of future successful manned lunar missions. It should be recognized that as the scientific experiments were not the primary mission objective, many compromises had to be made in the design and execution of the out-of-the-window experiment. No criticism is meant to be implied by this for, indeed, the cooperation and support of all branches of NASA from start to finish was complete and in many instances changes were made to accommodate the experiment which were beyond what we were led to believe we could expect. However, other factors dictated such matters as: launch date, time and azimuth, orbital altitude, mission duration, inability to have uninterrupted direct communication with the astronauts, the amount of astronauts' time available for performing some of the tasks, the size and amount of equipment which could be carried on board, etc. It was then necessary to design the experiment with these and other considerations continually in mind.

The apparent size and contrast of the ground markings and the length of time they were in the astronaut's field of view were, of course, primary factors in the experimental design. The requirements for these factors were determined in the Laboratory and their study is described elsewhere in this report. The angular size of a ground object when viewed from space may be readily computed from geometrical considerations alone. The determination of the apparent contrast, however, requires a knowledge of the luminance of both the object and its surrounding background in the direction of view and knowledge of the optical factors of the atmosphere and spacecraft window which determine how the optical signal existing at the ground will be transmitted to the astronaut. As all of these contrast determining factors are temporally and directionally dependent, it is necessary to measure them at the time and in the direction of concern.

4.2.1 Selection of Operational Method

Two methods of operation of the experiment were considered. The first was to have only one rectangle visible to the observer at any instant of time. By varying its size and orientations repeatedly during the brief interval the site was in view, a time series of presentations could be made. The second method was to display a number of rectangles simultaneously in a prearranged array but with their orientations unknown to the observer. Whereas the second method was finally selected, a discussion of the considerations affecting the decision will be given as it might appear to the reader that the first was a more logical choice.

The angular size of an object whose orientation can be determined will, of course, depend upon its degree of asymmetry and its apparent contrast. Laboratory studies on subjects having better than average visual acuity demonstrated, however, that if the test object was rectangular with an aspect ratio of 4 to 1 or greater, the long dimension of the rectangle had to exceed about 0.9 minutes of arc in order that its orientation could be ascertained regardless of how high the contrast of the rectangle was with respect to its background. This, then, represented a lower limit of angular size of the test objects which would be expected to yield correct responses under ground-based conditions. However, some of the theories propounded to explain the MA-9 sightings reported by Cooper implied that the visual capabilities of man improved in the environment of space and, therefore, test objects having smaller angular dimensions than the 0.9-minute figure found in the laboratory were planned for the experiment. Because some passes over the ground observation site could be expected to occur under conditions which precluded presenting a high apparent contrast object to the astronaut and because of the necessity of presenting angularly larger markings in the event the performance capabilities worsened with prolonged exposure to the spacecraft environment, it was considered desirable to have the capability for presenting markings whose angular dimensions were several times the laboratory minimum of 0.9 arc-minutes.

To translate the desired angular size of the ground marking to the corresponding linear dimensions, it was necessary to consider both the slant range between the spacecraft and the site and the foreshortening of the marking due to any obliquity of the path of sight. Constraints were placed on the acceptable paths of sight due to the problems engendered by foreshortening and the marked decrease in the contrast transmittance of the longer oblique paths. Consideration of these factors led to the early establishment of a limit of 60° as the maximum acceptable angle between the vertical at ground site and the path to spacecraft (an elevation angle of 30° above the local horizontal at the site). Preliminary estimates of the spacecraft orbit for Gemini V were that its orbit would be circular at an altitude of 161 nautical miles. The minimum range, therefore, would be this value, i.e., 161 nautical miles. The maximum acceptable slant range would occur when the zenith angle of the path of sight was 60° and would be 303 nautical miles, taking earth curvature into account. The foreshortening factor of the marking would vary from 1.0 when the spacecraft was overhead to 0.5 when the spacecraft was down at 60°.

The linear dimension of a rectangular marking with a 4 x 1 aspect ratio and a long dimension of 0.9 arc-minutes would vary from a minimum of 256 x 64 feet (16 400 square feet) for the directly downward view to 964 x 241 feet (232 000 square feet) for the case where the spacecraft was at a zenith angle of 60° (303 nautical miles slant range). The latter dimensions have included compensation for foreshortening in the two orthogonal dimensions, whereas such compensation need be applied in only one direction at any one time. However, if the marking was to subtend fixed angular dimensions at the eye during the interval of observation, provision had to be made to continuously vary the foreshortening compensation in the two orthogonal axes as the azimuth of the path of sight changed during an overpass.

The requirement to provide a range of larger rectangles to compensate for changes in atmospheric contrast transmittance and the astronaut's visual capability would mean that the linear dimensions would increase in direct proportion to the required angular increase. Thus, if a maximum size of 2.7 arc-minutes was desired, the dimensions would scale up to 769 x 192 feet for the directly downward view and to 2892 x 723 feet for the most oblique view.

The above sizes are for a single orientation of the rectangle. If a minimum of two orientations are required and if it is assumed that the two orientations share the same central area to form a cross, the total area required increases by 7/4. The minimum area required, therefore, would be 28 700 square feet and the maximum would be 3 660 000 square feet or 84.5 acres. Table 4-1 summarizes the physical dimensions of rectangular markings required for the various conditions discussed above.

Table 4-1. Ground Marking Dimensions,Changeable Orientation During Single Overpass

			S/C Directly Overhead (Slant Range 161 N Mi)		S/C 60° from Vertical (Slant Range 303 NMi)	
			Min.	Max.	Min.	Max.
Angular Subtense (Long Dimension)	α	(arc-min.)	0.9	2.7	0.9	2.7
Length	L	(ft.)	256	769	964	2 892
Width	$w = \frac{L}{4}$	(ft.)	64	192	241	723
Bar Area	$A = L \times w$	(ft.^{2})	16 390	147 500	232 200	2 090 000
Total Area Cross	$A_t = \frac{7A}{4}$	(ft.^{2})	28 680	258 150	406 400	3 658 000

The table assumes 4 x 1 rectangular bars and a spacecraft altitude of 161 nautical miles. The dimensions were computed as follows:

$$L = 1.767 \alpha \, r \sec \theta$$

where α = required projected angular subtense of long direction of marking in arc-minutes

r = slant range, S/C to site in nautical miles (6076 ft.)

θ = zenith angle line of site to S/C

The velocity of the spacecraft over the ground for the expected orbit was approximately 3.75 nautical miles per second (about 96 minutes per revolution). The maximum time which the spacecraft could spend within the zenith angle limits of 60° would occur on those occasions when it passed directly overhead. In those instances the ground track distance would be 502 nautical miles and the spacecraft would be within range for 502/3.75 or 134 seconds. All other passes over the site would provide shorter observation times. Assuming that (1) a good pass provided 120 seconds, that (2) the astronaut should have a minimum of 10 seconds to acquire the site and get properly oriented, and that (3) a total of 5 to 6 seconds would be required to determine the orientation of the marking and to change its orientation for the next observation, a total of about 20 observations would be considered the maximum which could be planned for. As it was necessary to use passes which did not go directly over the observation site (thereby increasing the number of useable passes) and to consider the desirability of reducing the zenith angle limits to 45° or 30° (reducing the length of the air path and the amount of foreshortening compensation to be handled), still shorter observation periods were likely. The number of independent observations which could be expected in a single pass might then be reduced to between 8 and 14.

Several methods were conceived for accomplishing the change in size and orientations of the ground markings and all were found wanting in one or more respects. As can be appreciated, the large areas required for the markings presented problems of a major magnitude. One of the first proposals was that a large number of flip charts painted white on one side and an earth-matching color on the other, each operated by a man, be arranged in a large matrix. Prior to an overpass, the men would be instructed in the proper positioning of the individual boards to provide the required size and orientation of the ground marking. It was planned that both the size and orientation of the array would change approximately every 5 to 6 seconds throughout the overpass. Considering the necessity for maintaining the boards properly oriented with respect to the sun and to the spacecraft and the fact that a strong wind would increase the severity of the orientation problem markedly as the board area increased, the maximum size board per individual was considered to be 4 feet on a side. Thus, even for the smallest of the markings in Table 4-1 requiring an area of 28 730 square feet, about 1800 men would be needed. The problem of obtaining an adequate number of individuals to handle the number of boards and training them to manipulate the boards with the split-second precision required for a coordinated change in size and orientation was deemed sufficient to render this approach infeasible.

Another method of providing ground markings which would eliminate the necessity for the large number of men was to use mechanically operated flip charts. A cursory survey of the requirements indicated that the problem of fabricating such a mechanical device which could be quickly controlled in the functions and over the areas described above would be of such magnitude that it could not be economically justified for use in the proposed experiment.

The third method which, superficially, seemed to provide the answer, was to use banks of lights which could be controlled by appropriate switching arrangements. The basic problem with this approach was that while operating during daylight hours it was necessary to compete with the luminance of the sun-lit terrain to provide a marking having a suitable contrast. Based on some rather reasonable assumptions on terrain reflectance and incident illumination, a quick survey of incandescent light sources having the highest available luminous efficiency indicated that a total power of between 5 and 10 megawatts would be required. The problem of providing the necessary switch gear and control for such a system seemed to preclude the application of this method, even if power was available at a site which was otherwise suitably located for the experiment. The possibility of using diesel locomotives or portable steam or gas turbine generating equipment was considered; but the overall lack of feasibility of this approach did not warrant a detailed investigation into the availability of these sources of power.

Another variation to the use of lamps and large sources of power considered was to use one or two mothballed U. S. Navy aircraft carriers which could have their generators activated and be towed to a suitable location. This method had the advantage that the site could be picked to optimize its location with respect to each overpass, and could be situated in an area which generally could be expected to have clear weather during the experiment. The carrier approach had the same switching and control problems as its ground based counterpart and in addition was confronted with the not inconsiderable cost of partially reactivating the carriers and having them towed to the site.

The conclusion reached from this investigation of methods of presenting patterns of varying orientation and contrast from the ground was that the use of a single pattern which changed during the overpass was not economically or logistically feasible. Instead, it was decided to use a fixed array of patterns, all simultaneously visible during an overpass, each having a different orientation and size. The orientation of the individual patterns in the array would be changeable between overpasses. The details of the multiple pattern scheme are discussed in a later section.

4.2.2 Site Selection Considerations

A great deal of effort went into an attempt to find and prepare ground sites that would meet all of the many requirements for a successful experiment. A great many individual factors had to be considered and a number of different organizations and people assisted in the selections. The account given in Section 4.3 of the selection, preparation, and operation of the Australian site may help in obtaining an appreciation of the effort involved.

Several major factors will be discussed here.

Launch Azimuth

The launch azimuth determines the north-south limits of the ground track which the spacecraft will follow. Thus for a 90° launch azimuth, i.e., due east from Cape Kennedy (28.3°N Latitude), the orbit will be inclined 28.3° with the equator and the spacecraft will be passing over points lying between 28.3° north and 28.3° south latitude. For a 72° launch, i.e., 18° north of due east, the limits are about 32.3° north to 32.3° south latitude. These two launch azimuths represent the extremes with which we were confronted. The 72° launch was the most desirable from the viewpoint of the experiment as it opened up the entire southern part of the United States for site selection consideration. In the early planning of both the Gemini V and the Gemini VII missions the 72° launch was requested and the prospects of its realization were considered excellent. Consequently, a thorough examination was made of the desirable sites in the southern California and Arizona desert regions where weather, logistics, and available land areas were ideally suited to the experiment. As the planning progressed on both missions, it became obvious that other overriding considerations would make it unlikely that we could plan on the 72° launch with reasonable assurance. It was necessary, therefore, in each mission to revert to those land areas between 28.3°N and 28.3°S Latitude for the site. Figs. 4-1 and 4-2 show selected computer generated plots for passes over the U. S. in the early parts of Gemini V and Gemini VII, respectively. They resulted from computer programs prepared at the Manned Spacecraft Center in support of the Visual Acuity Experiment before the missions and do not show the actual tracks as they finally occurred. They do represent them adequately well for the purposes of illustration. It should be noted in Fig. 4-1 that the launch azimuth shown (and the one that was finally used in the Gemini V mission) was 72° which made the latitude of the Laredo site further south than was optimum. For example, note that revolutions 18 and 31 pass north and south of the site and with different headings. Ideally, (and this would occur for a site located near the northernmost excursion of the orbit) for all uses of the site, the spacecraft would pass directly overhead or slightly south of the site and always with the same heading viz. due east. Note also, that revolutions 17, 18, and 32 all passed directly over the Calexico site. It was not possible to prepare two sites, however, and the chance that the launch azimuth would be changed to 90° existed until well beyond the cut-off time for final site selection decision.

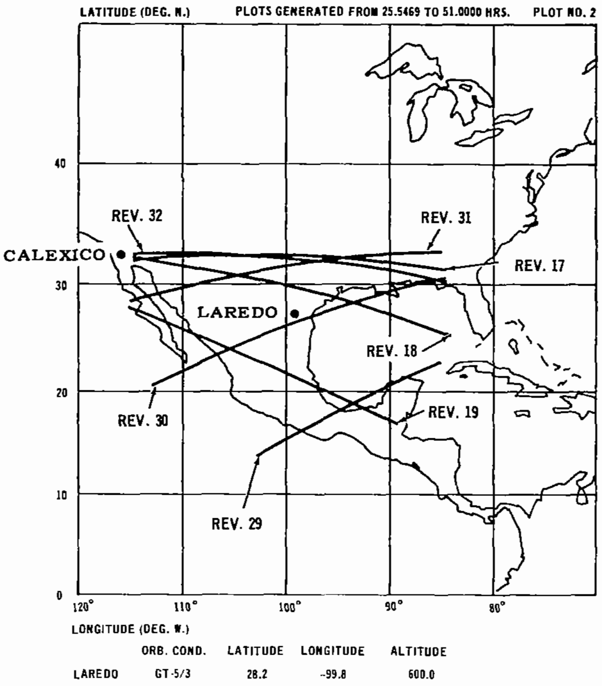


Fig. 4-1

Computer Generated Tracks for Gemini V passes over Laredo, Revolutions 17 through 31.

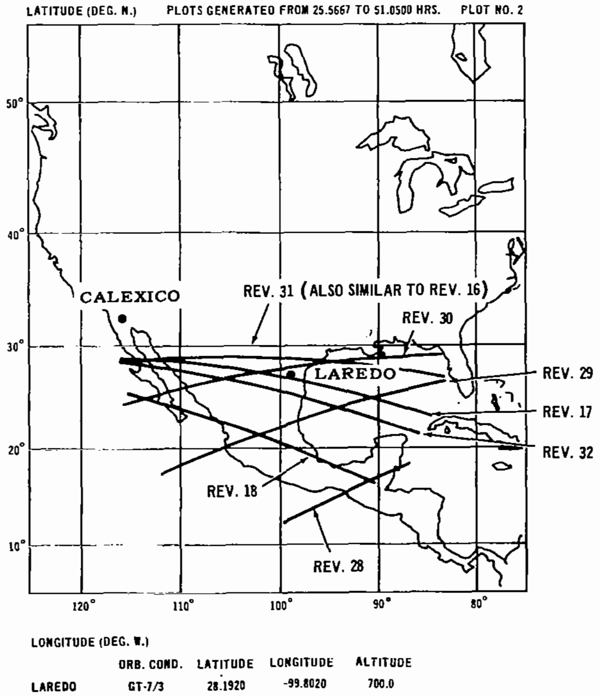


Fig. 4-2

Computer Generated Tracks for Gemini VII passes over Laredo, Revolutions 17 through 32.

Fig. 4-2 was prepared on the basis of the 82.5° launch azimuth dictated by the rendezvous between Gemini VII and Gemini VI. In this case, Laredo was near the northern extremity of the orbit and the Calexico site would have been too far north of the track to be useful. Note that revolution 32 has shifted about 7° to the west with respect to revolution 17, fifteen revolutions (23 hours, 54 minutes) earlier.

Launch Time

The time of launch, of course, affects the time of passage over the ground site. Two to three satisfactory passes usually were available each day for sites in the southern United States. The time required for the spacecraft to make successive meridianal crossings was about 95.5 minutes (the orbital period was about 90 minutes at the start of both missions and another 5.5 minutes was required for the spacecraft to "catch-up" with the earth's 22.5° eastward rotation during this 90 minutes). Fifteen revolutions took 6 to 12 minutes less than one day to complete near the start of the mission. The total effect of the resulting orbital shift was that although the spacecraft may have passed the same meridian only a few minutes earlier each day, the orbit shifted westward by a few degrees a day. It can be readily appreciated that the revolutions providing the best passes on successive days over the site were not necessarily spaced by a fixed 15 revolutions. When a pass 15 revolutions after a satisfactory one had shifted (westward) too far from the site to be useful, it was usually necessary to choose the one spaced by 14 revolutions or about 96 minutes earlier. The result of the shifting orbits was that the satisfactory passes became earlier each day, either by a few minutes or by one and one half hours.

The first few revolutions of the mission passed over sites in the United States. If the launch was in the early morning, successful passes in daylight hours could be obtained only in the first few days. This situation worsened, of course, in the shorter winter days and improved as the launch approached the summer solstice. For the purpose of obtaining a long period of satisfactory operation in the United States, a late launch time was required. Fortunately, in Gemini V the 8 A.M. (Central Standard Time) launch on 21 August gave useful passes throughout the entire mission for the Laredo site.

The site at Woodleigh Australia was almost diametrically opposed to the United States site. The early passes over this site occurred at night and it was not until the third day of Gemini V that the site was visible in the late afternoon. As the mission progressed, the useable passes (one a day) came earlier each day.

For Gemini VII the launch time was 1330 C.S.T. on 4 December and the normal daily regression of the time of geometrically satisfactory passes would have permitted the use of the Laredo site during the entire 14-day mission. Unfortunately, the late launch meant that the Australian site would not open up to useful daylight passes until the last few days and only one of those met all of the criteria set down for a completely satisfactory pass.

Land

A number of factors had to be taken into consideration in selections of land areas for the ground site. From the start it was agreed that if two sites were to be required, one of them should be located in the southern part of North America in order that the many logistic and communications problems could be kept to a minimum. The location of any site obviously would have to be between the north and south limits of the orbital path. The site's location, east and west, would, along with the launch time, determine the revolutions which could pass overhead during daylight hours. The site for North America as discussed in the paragraphs on launch azimuth above, had to be selected from those areas lying south of 28.3° north latitude (the latitude of Cape Kennedy). This constraint meant that the only areas in the United States that could be used lay in southern Texas, or southern Florida. Moving west into Mexico opened up other large land areas to consideration. However, after a thorough study of the problems of logistic supply, communication, and other operational considerations, the desirability of using United States land areas for one of the sites was judged to be overriding.

The early concept of the site layout for the multiple rectangle array was to have 12 to 16 square background areas of uniform reflectance stretched out in an east-west line. Each square was to be approximately 2 000 feet on a side and was to be separated from the others by a minimum of 1 000 feet. In this manner each rectangle could be centered in an area such that it would be clearly separable from the others and the determination of its effective contrast would be independent of the reflectance of the land area beyond the perimeter of the square. If this array of 2 000-foot squares was stretched in an unbroken series the total east-west distance required would be 47 000 feet for 16 patterns. It was considered desirable to break this long series into several groups to facilitate the reading of the array by the observers. To this end it was necessary to insert additional spacing between, say, each group of 4 patterns. If an additional 1 000-foot space was provided between 4 groups of 4 the total length of the array became 50 000 feet. Other compromises included the use of two rows of squares separated in the north-south direction by 1 000 feet or more. Although the total area required was the same, the construction and operational problems of such an array had obvious advantage. Whatever the configuration it was necessary to find locations where land areas of such size could be found that were flat, unbroken by rivers, lakes, deep ravines, and had relatively uniform reflectance; furthermore, this area should have distinguishing landmarks in the vicinity to assist the astronaut in locating the site. The site had to be reasonably close to communications, sources of equipment and labor for construction and operation, and be accessible by road to the equipment and personnel. Finally it was necessary to find an area which could be made available to the experiment for this use at a reasonable cost.

Weather

Of the many locations which were considered as possible ground sites, one of the primary considerations in the selection was the prognosis of obtaining satisfactory meteorological conditions for the site use during the expected mission times. As the early estimates of these times kept changing it became necessary to consider the year-round weather picture for these areas in our period of preliminary review. In these meteorological studies the Laboratory was greatly assisted by the National Geographic Society and the Texas Instrument Corporation, both of whom provided excellent summaries of precipitation, cloud cover, wind velocity, etc., for the various areas under consideration. Because of the requirement to have a high probability of clear weather, the search was limited primarily to desert and semi-arrid areas.

4.3 SITE SELECTION STUDIES

4.3.1 United States Site Selection Studies

The desert area in the vicinity of Yuma, Arizona and El Centro, California was the subject of considerable study because of its excellence in almost all respects. Studies were performed prior to Gemini V when the 72° launch azimuth was considered firm. Flights were made over the area by the Visibility Laboratory personnel in the University of California's DC-3. On the basis of this aerial reconnaissance, a number of possible sites were selected. At that time, contact was made with the Yuma Marine Corps Air Station and the possibility was discussed of establishing the site within the boundaries of the large Government preserve east of the Air Station which is used jointly by the Navy and the Air Force as an aerial bombing and gunnery range. In addition to having excellent weather with extremely clear air and large areas of land available at no cost to the project, a large commercial gypsum mining operation located a few miles west of El Centro, California could have provided the necessary quantities of white material from which inexpensive rectangular markings could have been prepared. Before the study of this area had proceeded beyond its preliminary stages, it became obvious that the probability of a 90° launch azimuth was sufficiently high that it would be unwise to gamble the success of the entire out-of-the-window experiment on a site that might possibly be several hundred miles north of the track. The final launch for the Gemini V was in fact, finally selected as 72° and the astronauts obtained some excellent sightings and photographs of this very area which had been under study.

Again, early in the planning of the Gemini VII operation, it appeared that there was a high degree of probability that the 72° launch azimuth would this time be used. Although the Laredo site had already been prepared and could have been refurbished for use on the Gemini VII, the probability of rain and generally poor meteorological conditions for the experiment during December made its successful use highly problematical. It was agreed that the additional cost of preparation of a completely new site would be warranted in view of the much greater probability of success which would be obtained by moving the site. A thorough analysis of the climatological data for the period 1959-64 which was available from the Marine Corps Air Station and U. S. Weather Bureau, was performed by the Visibility Laboratory staff. The results of this study indicated for December, (1) the cloud cover was between 0 – 0.3, 63 percent of the time; (2) the horizontal visibility, during daylight hours, was seven miles or more 99 percent of the time; (3) wind was less than 13 knots 77 percent of the time, and (4) the average precipitation was 0.32 in. Whereas, these data were for Yuma, it was the opinion of those knowledgeable of the meteorological conditions of the area, that the other sites under consideration would be essentially the same.

The site selection team studied various locations from the air and from the ground within the confines of the bombing and gunnery range and east of the Colorado river along the All American Canal. Because of (1) certain hazards to personnel and difficulties of operation within the military reservation, and (2) the excellent visual acquisition aids which were available to the sites in the vicinity of the All American Canal, the latter was chosen. The actual site location which was selected was between the Mexican Border and the All American Canal on property which was owned by the government and could be made available to the experiment at no charge. In the photographs taken from Gemini V of the area, one of which is reproduced as Fig. 4-3, one can

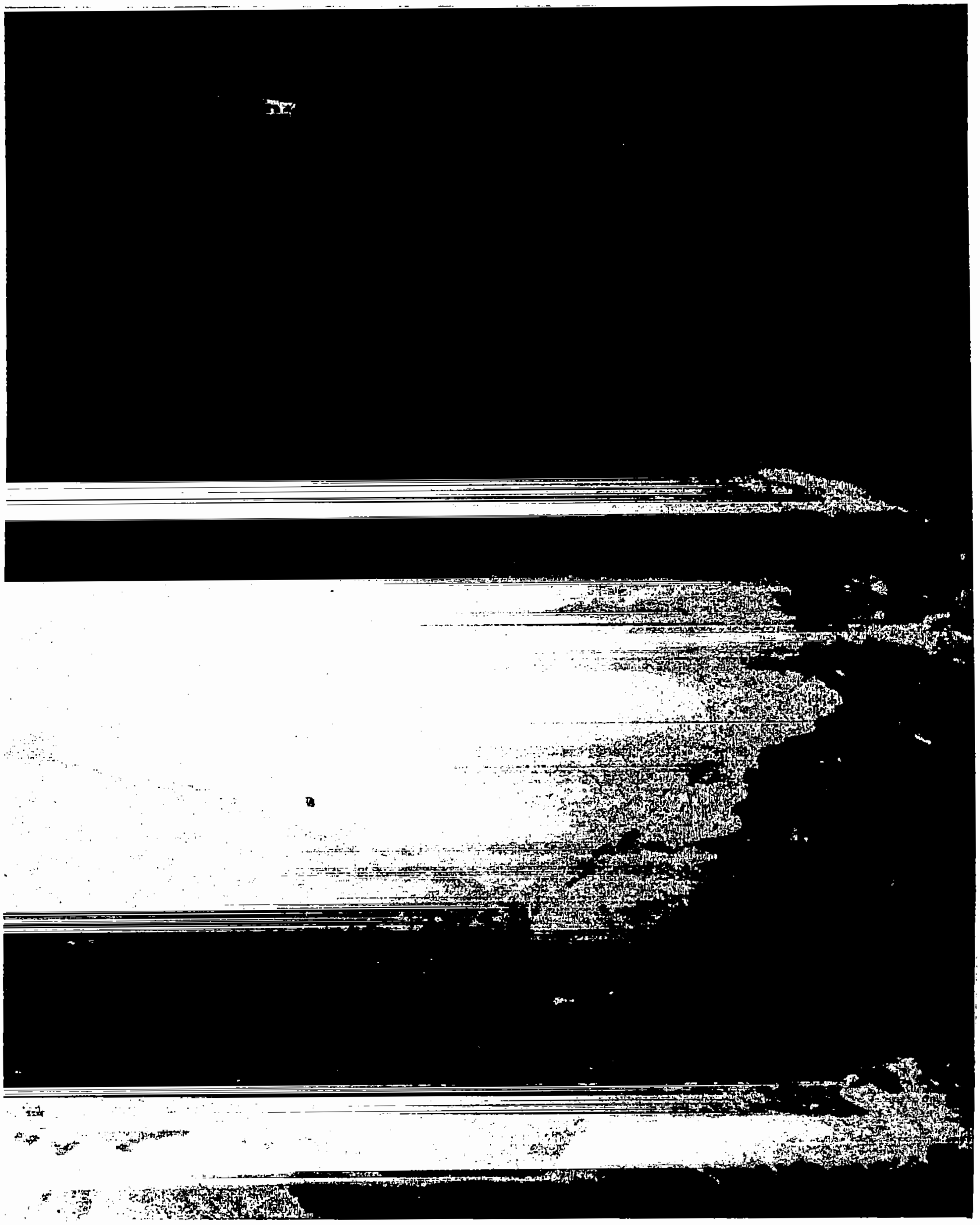


Fig. 4-3. Photograph from Gemini V of site in southern California desert proposed for use in Gemini VII. Linear array of eight squares shows selected location and excellent acquisition features surrounding site.

plainly see the All American Canal, the irrigated areas to the west and south, the large sand dune area to the east and two clumps of vegetation caused by seepage from the canal. The plan for the site layout was to use two groups of four rectangles in a linear array paralleling the canal. The area was surveyed by the Visibility Laboratory and the contractor had made a preliminary estimate of the cost of preparing the site when, due to the decision to have the Gemini VI and Gemini VII capsules rendezvous, the launch azimuth was changed to 82.5°. This decision precluded the possibility of using this otherwise excellent site.

Laredo

United States' sites located south of 28.3° north latitude were, as mentioned earlier, confined to southern Texas and southern Florida. The latter area was not given serious consideration because of the marine air mass from the Gulf of Mexico which dominated the meteorological situation. The frequent buildup of cumulus clouds over the peninsula made the likelihood of the site being seen from space considerably less than from areas in southern Texas. Furthermore, it was anticipated that there would be a considerable problem in obtaining suitable land areas in Florida. An attempt was made in studying the Texas area to get as far away from the meteorological effects of the Gulf of Mexico as possible. Consequently, areas east of the Rio Grande river and between Laredo and Del Rio, Texas were given priority consideration. It was anticipated that the Rio Grande would provide a landmark which could be used by the astronauts to assist in locating the site.

Captain Robert Mercer, USAF, (at the time assigned to NASA Manned Spacecraft Center) greatly assisted in the study of this area by making a preliminary aerial reconnaissance and obtaining excellent aerial photographic coverage. On the basis of this work, certain general areas were selected for detailed study. In February of 1965, a party from the Laboratory and the 8th Naval District Public Works Office at New Orleans made an aerial and ground reconnaissance of the area and discussed the various problems and possibilities of site location and preparation with local government agricultural representatives. Although there was an abundance of uninhabited land, the suitability and availability of it for the experiment was considerably less than had been anticipated. Many areas were deeply cut with arroyos, virtually inaccessible by road, involved dealing with a multiplicity of land holders, consisted of nonuniform colored earth, or were covered with dense mesquite.

A thorough study of the meteorological records for a 10 year interval in the Laredo area, showed that expectations for good weather during the two missions was certainly less than excellent but it was probably the best that was available in the United States for this latitude. Equipment was set up at the U. S. Weather Bureau, situated on the Laredo Air Force Base, to measure the atmospheric contrast transmittance during the months of December 1964 and January 1965. During the period the equipment was installed, completely clear, satisfactory weather occured only 8 out of the 35 days when data were taken.

Assuredly, a longer, more exhaustive search might have led to a superior site. However, because of the problems of scheduling and economics, the selection was narrowed to areas in the northern part of Webb County, south Dimmit County and western La Salle County. The consensus was that although this area was not ideal, no better choice within the United States had been uncovered.

At first it was planned to split the site into two components separated by as much as 15 miles in an east-west direction with a pattern of 8 rectangles in each component. It was later decided, however, that the east-west separation of these two units would cause untenable difficulties in the site preparation and operation. Furthermore, it became difficult to find two sites which were sufficiently well aligned that separate site acquisition problems would not be encountered by the astronauts. The site was changed, therefore, to an arrangement wherein the total number of individual rectangles was reduced from 16 to 12. The separation between the 2000 ft. background squares was reduced from 2000 ft. to the minimum value of 1000 ft., and the squares were grouped in three rows of four squares each. In this manner the entire array was condensed into an area 11 000 ft. in the east-west direction by 8000 ft. north to south, and the possibility of finding a topographically suitable site within the confines of a single ranch was thereby increased. The preliminary aerial and ground observation of the area showed that such a possibility existed on the land operated by the Gates Ranch Company about 65 miles north of Laredo. The area was gently rolling, contained some water reservoirs, but showed promise of satisfactorily accommodating the site if adequate uniformity of soil reflectance could be obtained by the site preparation techniques.

The details of the use of land on the ranch for the visual acuity site were discussed with Mr. Albert E. Gates, managing partner of the Gates Ranch Company, and after satisfactory arrangements for the preparation of the land and operation of the site had been worked out, 2222 acres were leased by the U. S. Navy for the experiment.

The site was located about two miles from the ranch headquarters and about 23 miles from Catarina, Texas, the nearest small town. The last 7 miles of the road into the site were unpaved and impassable for conventional vehicles in rainy weather. Permission was obtained to use a landing strip on a neighboring ranch about 7 miles distant for the University of California DC-3 and miscellaneous aircraft chartered for photography and aerial observation of the site.

4.3.2 Non-United States Site Selection Studies

In a briefing at the Visibility Laboratory on 24 September 1964 Capt. Mercer provided new information which caused a significant change in the experimental plan. Revised orbital parameters (launch azimuth and time of liftoff) required a second experimental area for the ground observations, somewhere in the Southern Hemisphere. This new requirement was especially compelling for the 14-day mission, for otherwise no advantage would be realized over the shorter flight. Even for the 7-day mission, however, the second array would be extremely desirable, since orbital regression caused there to be fewer and fewer satisfactory overpasses at the northern site as the week progressed, while those over the southern one increased in number during the seven days. Moreover, the availability of a second array constituted insurance against a number of possible difficulties, such as weather, demands of the flight plan, the need to make drastic pattern changes, and so on.

At the same time, it had already been realized that some Northern Hemisphere site outside the continental United States might be better than Laredo, specifically in regard to terrain uniformity and weather. Accordingly, information was sought for possible experimental locations anywhere within the belt between 28.3°N and 28.3°S latitudes. In response to a request from the AFSC Field Office at MSC, a series of reports was kindly prepared by the National Geographic Society, under the direction of Mr. George Crosette, Chief of Geographic Research. These reports, which included maps, meteorological information, and general comments regarding accessibility, were concerned with the following regions:

NORTHERN HEMISPHERE	SOUTHERN HEMISPHERE
El Refugio, Mexico	Broome, Western Australia
Torreon, Mexico	Onslow, Western Australia
Guaymas, Mexico	Carnarvon, Western Australia
Massawa, Ethiopia	Ambovombe, Madagascar
Aden, Saudi Arabia	Tulear, Madagascar
Las Lagunas, Mexico	Morondava, Madagascar
Villa Cisneros, Sp. Sahara	Atacama Desert, Chile

Additional data and comments on the Western Australia region were supplied by Mr. Norman Harding of Texas Instruments, Inc.

The information contained in these reports was evaluated by MSC and presented at a meeting at the Visibility Laboratory on 15 December 1964. At that time it was decided, on the basis of the reports from National Geographic Society and Texas Instruments, Inc. as well as various logistic, diplomatic and fiscal considerations, (a) to abandon the idea of a northern site outside the U. S., and (b) to investigate the Western Australian and Chilean sites in greater detail.

A site selection party was formed, consisting of the following persons: LCDR Harold Hilz, representing the AFSC Field Office at MSC; Capt. Robert D. Mercer, representing the Flight Crew Support Division at MSC; Dr. John H. Taylor, representing the Visibility Laboratory. It was intended that the party should proceed to Antofagasta, Chile, and thence to the Atacama Desert. Following this, they would proceed to Western Austrailia, using Carnarvon as a base for reconnaissance of the region. In both instances the following information was to be gathered:

1. Terrain and weather characteristics; suitability for the proposed experiments.
2. Materials available for making the patterns to be viewed from orbit; including cost, ease of handling, and attainable contrast against the terrain.
3. Logistic support; site preparation, handling of target materials, communications, living provision for experimental team, and aircraft maintenance.
4. Availability of land and access thereto; cooperativeness of landholders, and adequacy of roads.

In addition, samples of soils and target materials were to be measured in the field and returned to the laboratory for analysis. These procedures are described later in this report.

The site selection field trip was planned for early January 1965, but sundry delays caused its postponement until February. Furthermore, on the advice of the State Department, it was decided to visit Australia first, and to make a later and separate trip to Chile only if the Australian region proved unsuited to the experiment. Thus it happened that our attention was converged upon Western Australia, and a visit there by the site selection team was arranged.

4.3.3 Equipment for the Australian Site Selection Survey

Some of the factors which would be important to the success of an operation in Western Australia, such as logistic support, communications, and general geophysical properties, could be evaluated by consultation and inspection of the area. Some of the more critical ones, however, could only be assessed by direct measurement and observation in the field. Accordingly, the site selection party took along a number of portable instruments which enabled the immediate assessment of local terrains, possible target materials and the micrometeorology of specific locations. Certain of these instruments were entirely conventional and need only be listed and their use indicated; one or two were developed (albeit hastily) specifically for the purposes of the trip, and will briefly be described:

Anemometer

A hand-held direct-reading instrument which was used to measure wind velocities at the proposed sites, especially as a function of height above the terrain since available data were from remote stations (Carnarvon and Geraldton) and taken from elevated instruments. This device was also used (v.i.) to test the stability of the target material as a function of wind velocity.

Hygrometer

A hand-held psychrometer with battery-driven fan which was used to measure water vapor content of the local air masses. While neither these nor the wind velocity measurements noted above could be considered more than spot checks, it was hoped that comparison with data taken simultaneously at the Carnarvon weather station would reveal any gross disparities which might make the long-term Carnarvon records useless for predicting on-site conditions. Finally, by measuring humidity at various points relative to the coast (assuming stable conditions during the time required to move from point to point), it might be possible to detect differences in the water vapor content of the air mass which, in turn, would influence the visibility of ground targets from orbit.

Illuminometer

A portable visual-comparison photometer (Macbeth) which was used, with appropriate color correction filters and calibrated reflectance standard, to measure natural illumination, and to provide an absolute calibration standard for other instruments.

Photographic Equipment

This consisted of two 35 mm still cameras, correction filters, and calibrated gray scale. One camera was used primarily for color work, from which only qualitative information was used. The other found its most important use in photographic photometry of soils and target materials. Plus-X film was used, with a Wratten K-2 filter which causes the film to render scene luminances in agreement with the human eye operating at daylight levels. It should be noted that data from these films were invaluable in measuring soil-target contrasts on those occasions when weather conditions made the more time-consuming photometric procedures impossible to complete.

Goniophotometer

Portable instrument which was built especially for the survey. It consisted of a modified photoelectric telephotometer (Gamma Scientific Model 721 Linear Photometer), a collapsible protractor mount, and a sample tray which could hold specimens of soil or target materials. This instrument is shown in Fig. 4-4, By its use it was possible to measure the luminous reflectance characteristics of any sample as a function of altitude and azimuth of the sun and the direction of the path of sight. By removing the sample tray it was possible to make direct measurement of undisturbed soils. As in the case of the cameras already discussed, response of the photometer was corrected to correspond with human photopic sensitivity. The goniometric frame was designed to fold flat for carrying in a suitcase.

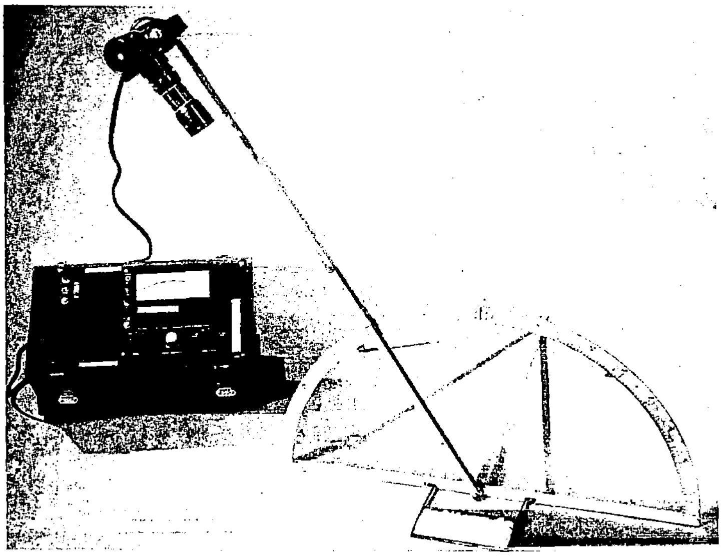


Fig. 4-4. Portable goniophotometer used in field tests of soil and target materials in Australia.

The above instruments were supplemented by surveying equipments, additional cameras for documentation of the trip, battery-powered transceivers, etc. Four-wheel drive vehicles, portable antenna masts and incidental supplies were provided by the Department of Lands and Surveys and the Carnarvon Tracking Station.

4.3.4 Site Selection Trip to Australia

A detailed chronicle of the visit by the site selection team to Australia will not be attempted in this report. Full accounts of the trip may be found in documents prepared by the Visibility Laboratory, the Australian Department of Supply, and the NASA Manned Spacecraft Center; copies of these are on file here and elsewhere. For our present purposes it will suffice to give a brief account of the visit, and thereby to provide a record of the events leading to the ultimate selection of the Western Australia experimental site. For convenience, and because each substantive step relates to a specific locality, we will outline this section of the report in terms of the places visited.

Canberra

The site selection party arrived in Canberra, A.C.T., on 12 February 1965, and were met by Mr. Ray Hooker, NASA Representative from the Department of Supply, Melbourne. Protocol visits were made throughout the day at the United States Embassy, with Australian and U.S. officials. The nature and scope of the proposed experiment was described by the visitors, and mechanisms for funding and conducting possible Australian activities on its behalf were discussed in a preliminary way.

Adelaide

Initial discussions were held on 15 February at the American Projects Division of the Weapons Research Establishment, Department of Supply, Salisbury, S.A. Mr. Kirkpatrick explained the function of APD in implementing inter-government agreements with the U.S.A., and outlined the working methods adopted to achieve this. LCDR Hilz explained the objectives of the acuity experiment in broad terms and Capt. Mercer and Dr. Taylor discussed requirements for the hoped-for site. All phases of site preparation, operation and support were explored, and it was decided that Mr. John A. G. Walton would accompany the team to Western Australia, where discussions were planned with officials of the State and Commonwealth governments at Perth and Carnarvon. Additional talks were held until midday on 16 February, at which time the party proceeded to Perth.

Perth

The U.S. Consul at Perth, W.A., Mr. Mayfield met the party on 16 February and meetings were held at the office of Mr. James Mills, State Controller, DOS, and elsewhere. Many individuals and organizations were involved in these discussions; all were enthusiastic about assisting the experiment and gave truly splendid help to the visitors. In addition to Mssrs. Mayfield and Mills and the site selection team (now including Mr. Walton) the following persons were significantly involved:

Mr. W. McGovern – Vice Consul of the U.S.A.
Mr. W. J. Lonney – Undersecretary, Premier's Department
Mr. H. Camm – Surveyor General
Mr. Jones – Superintendent, Mapping Dept., Lands and Surveys
Mr. Tweedale – Bureau of Meteorology
Mr. J. Utting – Department of Works
Mr. J. Yule-Dean – Chief Property Officer, Dept. of Interior
Mr. C. VonSenden – Supervising Surveyor, Dept. of Interior

Considerable assistance was given by the Department of Lands and Surveys in providing aerial photographs which enabled us to make a selection of the most suitable sites before visiting the Carnarvon area. A number of maps were also provided, which proved invaluable in our subsequent survey and, ultimately, in many other phases of the program, including astronaut briefings. The Bureau of Meteorology provided important information on weather patterns between 20° and 29° South, and led us to a decision to limit our site selection possibilities to the belt between 24° and 28° South because of tropical cyclonic weather to the north and higher rainfall to the south. Finally, it was agreed that the site selection party would be joined at Carnarvon by Mr. Arthur Dawson, a surveyor from the Department of Interior, and Mr. Ted Edmiston, representing the State Controller's Office.

Carnarvon

The party visited the Carnarvon, W.A. region during the period 18 to 25 February. Initial protocol visits and briefings were held with: Mr. C. Wilson Tuckey, President of Gascoyne Shire Council and Major of Carnarvon; Messrs. Lewis Wainwright and Colin MacNish, Director and Executive Officer, respectively, of the Carnarvon Tracking Station; Mr. R. Shaw, Department of Main Roads; Mr. H. Lendich of the same office; Mr. C. Clark, Postmaster General's Department, Post and Telegraphs. Informal meetings were also held (on 18 February) with Mr. Phillips, meteorologist in charge of the Carnarvon Observing Station, and Capt. John Roulston, manager of Nor'west Air Taxis Pty., Ltd., who was engaged to fly members of the party over those local areas which had been selected earlier on the basis of aerial photographs.

On 19 February the site selection party made an aerial survey of the region which covered approximately 800 air miles, inspecting areas north and east of Carnarvon, along the Gascoyne River to Gascoyne Junction, thence south on an inland course until turning west to Shark Bay, landing at Denham to collect shell samples from the shore of Lharidon Bight. Further flying enabled evaluation of the areas near the Butcher's Track dogleg and Woodleigh, Yaringa, and

Edagee stations. On the basis of these surveys five areas were selected for further investigation, as may be seen in the map of Fig. 4-5.

Ground surveys of the Butcher's Track (Meadow Station) and Edagee Station were made on 20 February, using two 4-wheel drive vehicles. The former area proved to be difficult of access (as well as remote from Carnarvon), and there were nonuniformities of soil color, undulations of the terrain, and a dense cover of wanyu scrub (between 12 and 20 feet high) which would be difficult to clear. Edagee had the advantages of easy access and flat terrain, but the soil showed color differences and a relatively high clay content which might create a serious dust problem. Further, it was thought that Edagee's proximity to the coastline, coupled with the prevailing SSW winds, might result in an unfavorable local air mass, and a variable one, along the path of sight.

Visits made to the region of the Gascoyne River and Jimba Jimba Station on 24 February all but eliminated these areas from further consideration. Unsuitable terrain, difficulty of access and support, and reluctance of the leaseholders (based upon the serious danger of later wind erosion) to cooperate, all mitigated against use of these areas.

The ground survey of Woodleigh Station, however, firmly established it as our preferred site. Detailed measurements of soil reflectance (described elsewhere in this report), flatness of the terrain, and the ease of clearing background squares all recommended the area east of the homestead, along an existing track. Further, discussions with Mr. Fred Thompson, Woodleigh's manager, made it clear that he was happy to cooperate with the experiment. The 1500 acres required for the site could easily be spared from the 695 000 acres of Woodleigh, and the removal of vegetation from the squares would greatly facilitate construction of a much-needed fire break subsequent to the missions.

The remainder of the visit to Carnarvon was taken up with meetings, sample gathering, testing, and the preparation of tentative cost estimates.

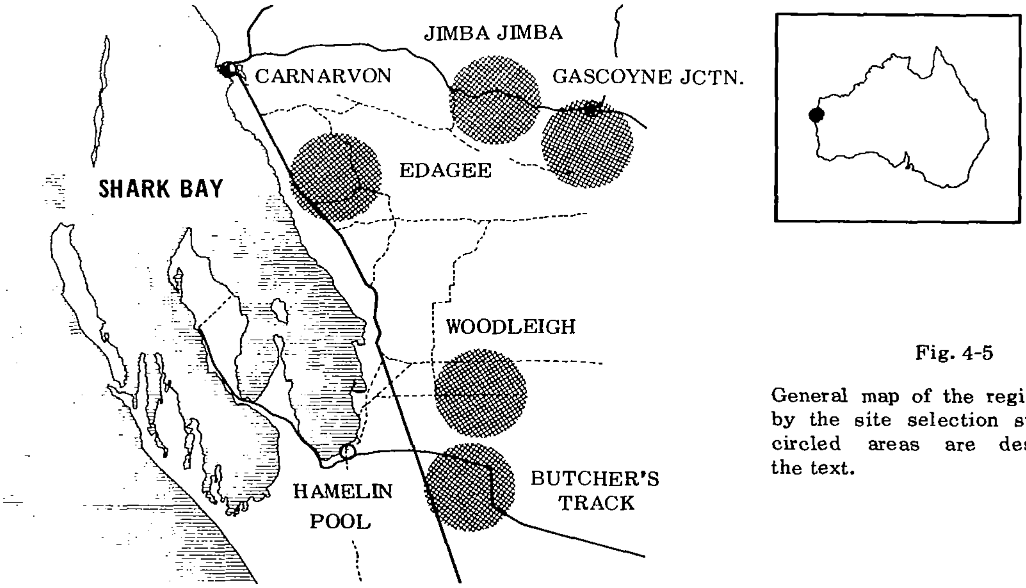


Fig. 4-5

General map of the region covered by the site selection survey. The circled areas are described in the text.

Perth

The results of the Carnarvon visit were presented at final meetings at Perth on 26 February. These discussions included representatives of the Department of Interior, Department of Works, Department of Main Roads, and the Mapping Department of Lands and Surveys. In sum, it was established that:

1. Although Main Roads would be happy to cooperate as fully as possible, they were unable to undertake the entire construction and support of the site, and
2. The Department of Works would be willing to do any work associated with preparation of the site, as well as to provide the labor and plant required for target changes during the mission, and
3. The Department of Interior would provide any needed surveys and photographic support.

At this stage of the visit it had become abundantly evident that the choice of Western Australia for the Southern Hemisphere experimental site would be auspicious indeed, and consideration of the Atacama Desert was effectively ended. It remained only to prepare specific plans and estimates, establish discrete responsibilities, and reaffirm various meteorological and geophysical data.

Adelaide

Concluding briefings at WRE were held on 1 and 2 March, during which lines of responsibility were drawn, funding was discussed, and communications possibilities were considered. It was also arranged for testing of target materials to be conducted at Carnarvon. Logistic support was discussed in some detail, and a draft Statement of Work was prepared by Mr. Walton in consultation with the U.S. visitors.

Melbourne

A brief visit was made to The Department of Supply on 3 March. A resume of the trip was given to Mr. Hooker and to Mr. Ian Homewood. On 4 March the party returned to San Diego.

4.3.5 Tests of Soils and Target Materials in Western Australia

Reconnaissance of the Carnarvon region left little doubt of its suitability for the study. It remained only to settle upon one specific site for the background squares and to select the best of several available target materials. Site selection had ultimately to be made on the basis of several criteria, of which the following were considered to be most important:

1. Accessibility, by both land vehicles and light aircraft.
2. Communications, by VHF, with UHF and telephone backup.
3. Availability, for the required construction and experimental periods, and assuming cooperativeness of the leaseholder.
4. Proximity to supplies of target material, water, fuel.
5. Terrain characteristics, including flatness, soil reflectance, and uniformity of soil color; arability.
6. Micrometeorology; proximity to coastal influences, wind and cloud cover probabilities.
7. Identifiability, by astronauts, in relation to prominent geographic features.

None of the sites was ideal in all respects, but it became clear to the site selection party and their Australian advisors that Woodleigh homestead was by far the most desirable of the lot. Accordingly, preliminary sampling and testing of both soils and possible materials for targets was begun.

The tests were conducted in three parts:

1. Preliminary studies, in Carnarvon and at Woodleigh, made during the visit, and including collection of samples for additional testing at the Visibility Laboratory.
2. Handling and weathering tests of various target materials, conducted by personnel at the Carnarvon Tracking Station during March and April 1965.
3. Tests of the sample materials and soils returned to the Visibility Laboratory.

Preliminary Studies

At the time of the initial site visit it was intended that adequate measurement of the optical properties of both background soils and target materials would be made so that one might realistically estimate the amount of material needed, and perhaps foresee any problems associated with the handling or weathering of the materials. Further, since soil samples returned to the United States are required to undergo sterilization (by autoclave), which might conceivably alter their properties, it was desirable that *in situ* measurements be made. The tests were conducted by the site selection party, using a specially designed portable goniophotometer, an anemometer, and cameras for photometric photography. Although intermittent cloud cover prevented us from obtaining complete goniophotometric data in the field, it was possible to establish a number of useful facts; these were later verified and supplemented by additional measurements.

Very briefly stated, the findings from these preliminary studies may be summarized as follows:

1. Marl, which had been suggested as a possible target material, was ruled out on account of its relative remoteness from the sites, and because it would have to be crushed before use.

2. Lime, applied in a dry state, was rejected because of difficulties with laying it under even light wind conditions, and because of purchase and transportation costs.

3. Lime, applied in a water slurry, was more easily applied, but became coated with fine particles of soil. This dust was impossible to remove if it was deposited while the slurry was still wet. Cost considerations were commensurrate with dry lime, but additional material might be required to refurbish the targets if they became soiled.

4. Shell, available in easily handled form at several points along the shore of Hamelin Pool, and at no cost excepting for handling and transportation, seemed most promising. Its reflectance characteristics were excellent over the range of anticipated sun angles and paths of sight, and if soiled by dust deposits it was readily cleaned by a gentle water spray. A test of its resistance to movement by winds was improvised by using the propwash from a Cessna aircraft and a hand-held anemometer. No serious shell movement occurred over the range of wind velocities from 0 to approximately 50 mph, at which time the person holding the anemometer was blown away and the test was discontinued.

5. Soil reflectance measurements were made both by photographic and direct photometric means. Specimen data are shown in Figs. 4-6 through 4-8. Samples of soil from several localities were collected for subsequent analysis, if needed, but it was recognized that these might differ in some degree from undisturbed and unsterilized soils.

6. Soil arability and vertical uniformity were confirmed; the latter being an important attribute which suggested that soil reflectance would not be altered by the clearing, plowing and raking operations involved in preparation of the background squares.

Although the preliminary testing seemed clearly to indicate that the soil-and-shell combination was best, it was realized that further testing was needed in order to assess the effects of weathering and the relative ease of handling both shell and lime. Since the site selection party had to leave the Carnarvon region and could not perform these tests, it was decided that additional studies would be made by personnel at the Tracking Station and the results transmitted to the AFSC Field Office in Houston, then forwarded to the Visibility Laboratory.

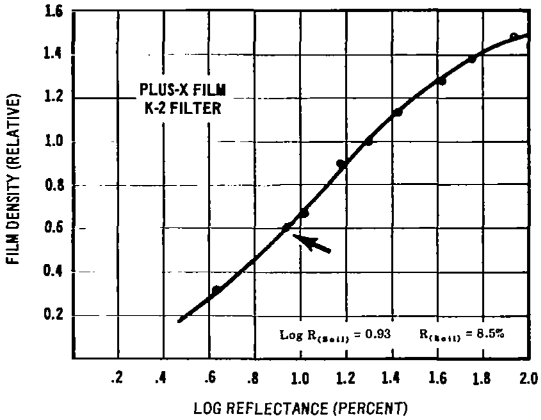
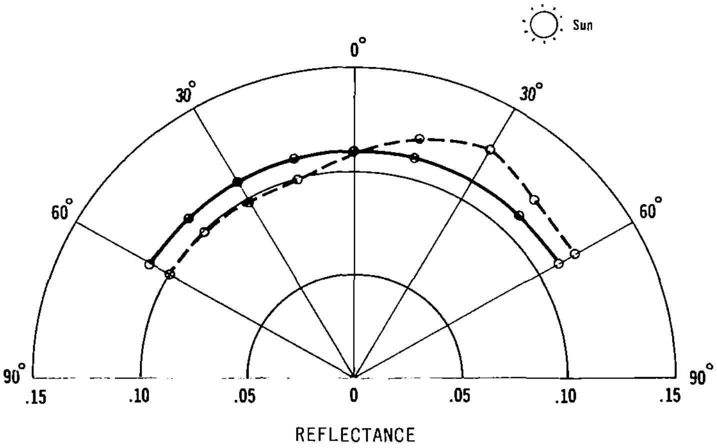


Fig. 4-6

Specimen data from photographic photographic photometry of soil samples. The negative density of the soil (arrow) is compared with that of gray scale patches of known reflectance.

Fig. 4-7

Specimen goniophotometric data. In this case, the reflectance of a soil sample is shown as a function of angle of view. The dashed curve resulted from measurements along the sun's azimuth; the solid curve shows the result 90° away (cross-sun).



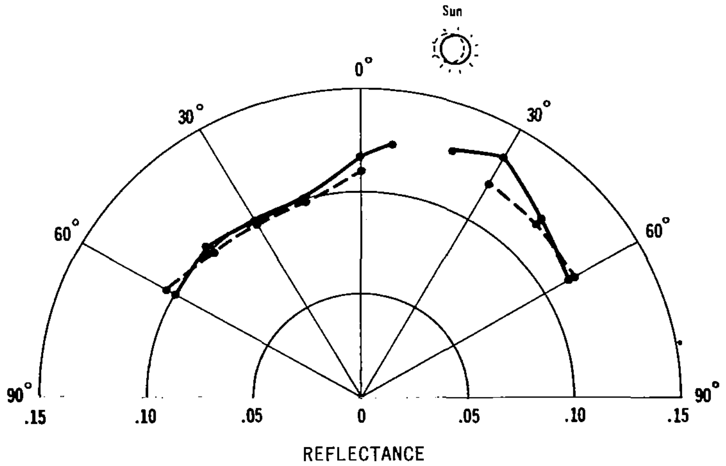


Fig. 4-8

Specimen goniophotometric data. Measurements taken in the azimuth of the sun of soil samples (undisturbed at the two ends of the proposed Woodleigh site.

Carnarvon-Woodleigh Tests

In discussions at the Weapons Research Establishment on 26 February 1965 it was decided that responsibility for additional material tests would be assumed by the Carnarvon Tracking Station, with its Director managing the site as WRE's representative. The tests, which were based upon suggestions made by the Visibility Laboratory, were carried out by personnel of Amalgamated Wireless (Australasia), Ltd.

During the period from 8 March to 27 April 1965 extensive testing was carried out by AWA personnel under the direction of Mr. Fred B. Mitchell, Senior Company Representative at Carnarvon. The tests, which were performed with exemplary thoroughness, provided detailed information about the handling and weathering properties of the materials of interest. Seven valuable reports were prepared and forwarded to the United States. These contained complete descriptions of the test procedures, all relevant meteorological data, and insightful comments by members of AWA's team. Complete photographic documentation was provided, with inclusion of a gray scale where it might be desirable to recover photometric information from the negatives. (This information, ultimately, was not required; it can be had at any time by densitometry of the original negatives.)

Since no short summary of these reports can do justice to their real worth to the program, nor convey an adequate impression of the effort required to produce them, it must suffice to list the major findings, *viz.*:

1. Lime, applied to the soil in a thin slurry, was difficult to apply under moderate wind conditions, and tended to move out of the marked area when winds reached 10 – 15 mph.
2. Lime, in a thicker slurry, was somewhat easier to control, but upon drying tended to drift in 4 – 5 mph winds.
3. Lime mixed with cement and applied as a slurry was stable, but blowing dust (typical of the test area used) soon discolored the material. The dust tended to deposit irregularly, influenced by minor nonuniformities of the surface. It was not possible to remove the dust by washing. All work with lime was abandoned when rain "completely destroyed this experiment" and dramatically demonstrated that rain occurring during the missions could easily demolish the entire target array.
4. Shell, which was gathered from weathered deposits at Hamelin Pool southwest of the Carbla homestead, proved to have none of the handling or weathering problems of lime. It could easily be laid, even under strong wind conditions, remained in place, and could readily be freed of any dust deposits by light spraying. Rain had no effect other than to clean the material. See Fig. 4-9.

At the conclusion of the Carnarvon-Woodleigh tests it was evident that shell was from all points of view the preferred target substance.

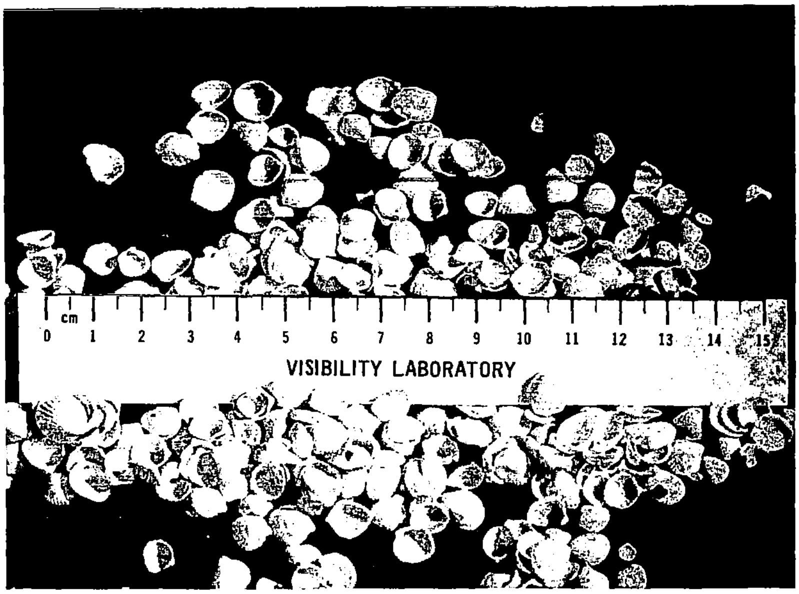


Fig. 4-9. Shells used to form the Woodleigh target bars.

Visibility Laboratory Tests

Further studies of soil and shell were made after the return of the site selection team, using samples which had been collected during the trip and by analysis of the photometric photography. There was no indication that sterilization of the soil samples in any way affected their photometric properties, possibly because of the absence of organic material in them. It was found that:

1. The goniophotometric properties of both soils and shell were satisfactory with regard to contrast and at the anticipated viewing angles and illumination conditions. The goniophotometer used is shown in Fig. 4-10, and some specimen data appear in Fig. 4-11. Soil samples from the Woodleigh site were more satisfactory, presumably because of their lower clay content.

2. The reflectance difference between undisturbed and disturbed soil was estimated from densitometry of the negatives from Woodleigh. Undisturbed soil reflectance was .087; disturbed was .083. Since there was no significant moisture content in either case, it is believed that this small change might be due to orientation changes in the individual soil grains, especially those with pronounced cleavage or of a micaceous nature.

The target contrast information obtained in the above manner was used in planning the experimental ground arrays for the Australian site. Complete data, consisting of sixty curves which relate reflectance and contrast to viewing angle and sun position, are on file at the Visibility Laboratory.

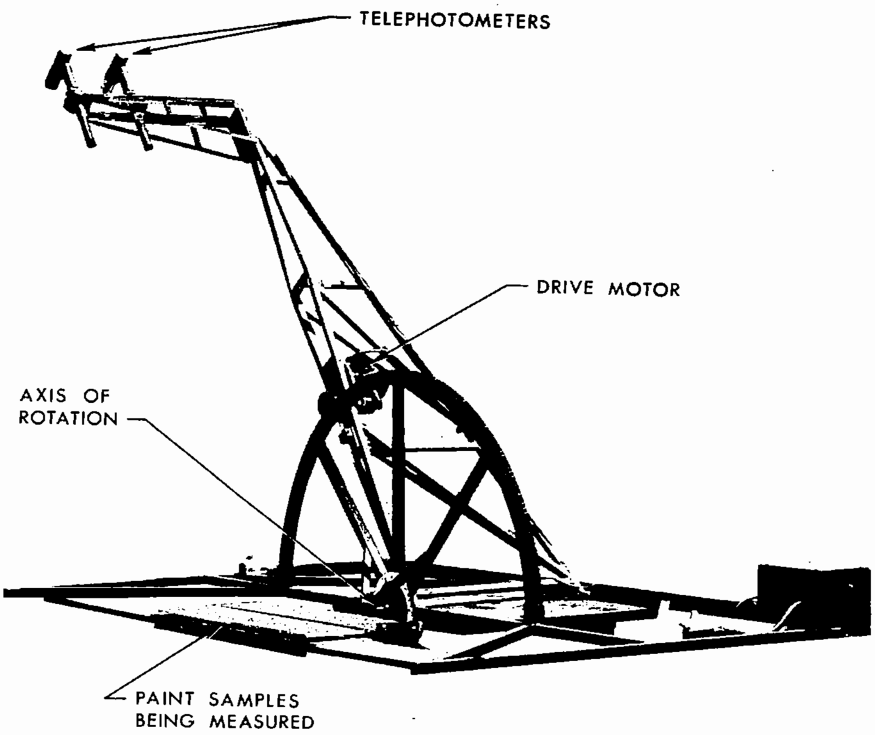


Fig. 4-10. Goniophotometer used at the Visibility Laboratory to measure the reflectance characteristics of soils and target materials.

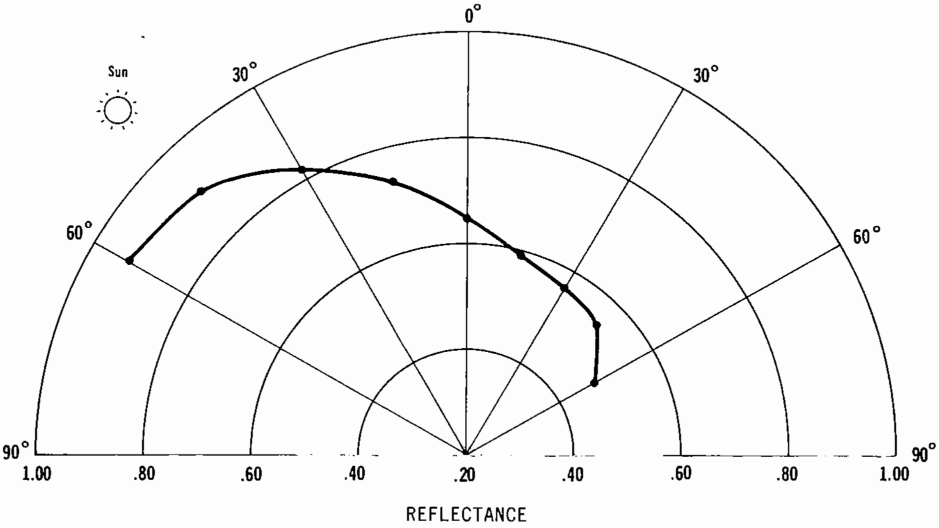


Fig. 4-11. Gonioreflectance curve of shell in the azimuth of the (low) sun.

4.4 SITE PREPARATION

4.4.1 Preparation of the Laredo Site

The major site preparation effort was accomplished by the H. B. Zachary Company, of San Antonio, Texas under contract to the U. S. Navy, Bureau of Yards and Docks, Gulf Division, New Orleans, Louisiana. The work was started by the contractor in April of 1965.

The preparation of the twelve, 2000-foot background squares was accomplished as follows:

1. Each square was root plowed to a depth of 8 to 12 inches, thereby cutting the roots of all major plants at that depth. This procedure left the surface disoriented but many of the plants were still standing.
2. The root plowed areas were raked and the vegetation piled into windrows.
3. The vegetation in the windrows was thoroughly burned.
4. After burning, the windrows were reraked to distribute the ash and eliminate any distinguishing marks on the soil.
5. The central areas of each square were leveled and graded to facilitate the placement of the rectangular marks.
6. After the soil had had a chance to settle and just prior to the missions, the entire surface of each square was lightly disk harrowed to a depth of 2 to 3 inches to remove any regrowth and break up any surface crust that may have formed as a result of rain. This technique provided as uniformly dark background as possible for the rectangular markings.

Aerial observations of the site after completion showed that the soil coloration was not as uniform as had been hoped. Lighter soil existed in the northwest corner of the array and the natural drainage system of the land had caused the lower areas to become appreciably darker than the rest. These features were particularly noticeable in the absence of shadows on the plowed areas as on an overcast day or with the sun at one's back. The effect of the shadows caused by clods of earth and furrows became particularly important in the site preparation as it was necessary that the site be readily distinguishable from the surrounding countryside, and that the outline of each square could be seen in order that the visual task of calling out the orientation of each rectangle in the prescribed order of succession could be properly accomplished.

Particular care was taken to have the furrows on all squares run in the same direction. The direction chosen for Gemini V was north-south in order that the shadows of the furrows caused by the morning sun would render the backgrounds as dark as possible when viewed from a spacecraft approaching from the west. This would provide the maximum contrast between the squares in the array and the surrounding countryside to assist in acquiring the site.

It should be appreciated, however, that the reflectance of the plowed field increased rapidly as the direction of observation approached that where the sun was at the observer's back. For that situation, the observer sees no shadows and the contrast of the essentially matte white markers against the background became a minimum. There were, of course, all degrees between these two extremes and it can be realized how important it was to measure the luminance of both the marking and the surrounding earth in the direction of view and with the lighting conditions which existed for each pass.

For Gemini VII it was rationalized that, as many of the passes would occur midday and as the winter sun would always be low in the south (maximum solar elevation was about 40°), the best direction for the furrows would be east-west. In this way, those passes directly over the site and to the north of the site would have the darkest possible background and it would change the least as the spacecraft progressed from west to east.

A large variety of materials were considered for the white rectangular markings. Some of the criteria which had to be met by the material are enumerated below:

1. It must have a high reflectance in order to provide the maximum effective contrast with the background square with the minimum quantity of material.
2. It should be a diffuse reflector in order that its luminance remain constant with angle of view.
3. It should be inexpensive and readily available.
4. It had to be easily handled for construction and reorientation of the rectangles.
5. It had to be able to withstand reasonable amounts of rain and wind without major loss or requiring major amounts of rework.
6. It should cause no irreparable damage to the rancher's soil nor should it be harmful to his cattle.

Among the materials examined were granular lime, granular gypsum, slurries of lime or gypsum, a white silica sand, white plastic-coated burlap, white polyethylene, white cement and silica flour coated boards, and fiberboard coated with styrofoam. Angular reflectance measurements were performed on samples of all of these materials. The last named material, suggested and fabricated by the H. B. Zachary Co. was the one finally selected.

The panels were made from 4 x 8 foot sheets of 5/8 inch thick fiberboard to which were cemented 1/8 inch slabs of styrofoam. The slabs were sawed from large blocks of styrofoam and the cellular nature of the material plus the sawing operation provided an excellent matte white surface which was reproducible from board to board. The panels were easily handled for construction and rearrangement of the rectangles and if soiled could be renovated by sweeping with a coarse push broom. Fig. 4-12 shows the panels being put in place. The forklift was used to carry the supply of panels to the field crew for replacement. Almost 5000 of these panels were provided by the contractor for Laredo site operation. During Gemini V and the early part of the Gemini VII mission, about 2200 of the panels were in place. In preparation for the higher altitudes and longer slant ranges which occurred in the latter part of Gemini VII, the sizes of the rectangles were considerably increased and almost 4500 panels were in place. The rain and occasional strong winds which occurred in the period encompassing both the Gemini V and Gemini VII missions caused little permanent damage to the boards. It was occasionally necessary to reposition

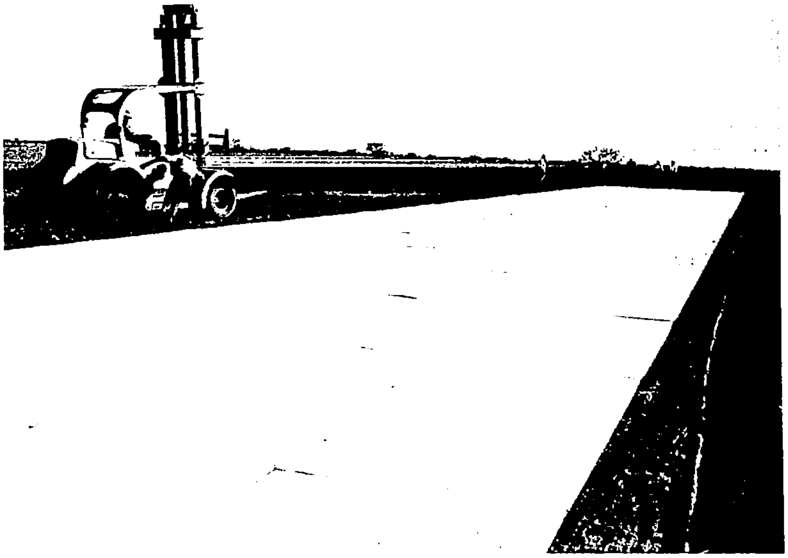


Fig. 4-12. Styrofoam covered fiberboard panels being put in place at Laredo visual acuity site. Note plowed background at right.

panels or substitute new panels for damaged ones following a particularly severe windstorm. They were readily picked up and stored in a warehouse between missions. The contractor became very efficient in handling the boards and changing the orientation of the rectangles.

To assist in the acquisition of the site, and to assist the astronauts in maintaining the orientation as they passed overhead, the northwest corner of the northwest square of the array contained a chevron consisting of spare styrofoam coated panels. The dimension of the chevron were 324 feet in length and 56 feet in width. To provide additional assistance in acquiring the site, a Pulse-Jet Fog Generator Model PJ-102 was obtained for the experiment by the Navy and operated to provide a large smoke plume which would be readily detectable. Additional Navy pyrotechnic smoke flares were also used to define the downwind border of the array. The smokes were not as visible as had been hoped, but were apparently of assistance on some of the passes.

As is mentioned in a subsequent section of this report, the four northern squares in the Laredo array were used solely for acquisition and orientation in Gemini VII by placing a 200 foot wide band of gypsum through the entire 2000 foot width of each of them. This technique was the most successful of any of the ground-based site acquisition aids. The reader is referred to the several aerial photographs of the sites contained in Appendix A for further details of the appearance of the arrays prior to and during the missions.

Telephonic communication between the site and the Manned Spacecraft Center was provided by the Southwestern Bell Telephone Company via a microwave radio link to Asherton, Texas, 18 airline miles to the north and by leased wire to Houston. By this means the site was in constant communication with the experimenters at the Mission Control Center.

4.4.2 Site Preparation at Woodleigh

The area chosen for the experiment in Western Australia lay ten miles due east of the Woodleigh homestead. This location had the advantages of uniformity of soil color, flatness, relatively thin vegetation and ready access by an existing East-West track. The array of background squares was made so that the southernmost row was close to and parallel with the track; additional access tracks were made perpendicular to the main track. Sixteen squares were cleared, as shown in Fig. 4-13. Each square was 2000 x 2000 feet, with 1000 feet separating the squares in each of two eight-square groups. The east and west groups were separated by 6500 feet. The stockpile of shell to be used for target changes, and the camp for the on-site team were midway between the two halves of the array close to the main track. Approximate distances by road from the camp were: ten miles to the homestead; twenty miles to the Northwest Coastal Highway; thirty-six miles to the shell deposits; one hundred twenty-five miles to Carnarvon. A map of the region is given in Fig. 4-14.

The steps performed in preparing the background squares were:

1. Survey of the area and laying out of the 16 squares.
2. Dragging of each square with a huge chain between two bulldozers, to uproot scrub growth.
3. Raking (bulldozers with rake blade) the resulting rubbish into piles which were then burned and buried on the spot by bulldozers.
4. Levelling, again with the chain.
5. Plowing of the entire square.
6. Center area (400 x 500 ft.) levelled by bulldozer, then by a road grader or dragbar.
7. Center area further levelled and compacted by multi-wheeled roller to provide a firm base for the shell.

This rather involved procedure resulted in there being no point-to-point height differences more than 5/8 inch. All slopes were less than one degree.

Shell for the target bars was obtained from a location on the eastern shore of Hamelin Pool southwest of the Carbla (formerly Yaringa South, cf. map, Fig. 4-14) homestead. Considerable roadwork was required to render the existing track suitable for the heavy trucking operations, both on Carbla and Woodleigh stations. It was found necessary to loosen the shell, since the older deposits had become partially compacted; this was accomplished by driving trucks over the shell windrows. Sufficient shell was obtained for the initial target bars and for a stockpile which would suffice for the projected target changes between orbits.

Additional preparations of the site included improvements to the Woodleigh airstrip, erection of an antenna mast, and the establishment of a camp for the Department of Works party and the scientific team. A radio relay station was constructed atop a hill at Gladstone so that VHF communications with the Carnarvon Tracking Station could be established. The camp consisted

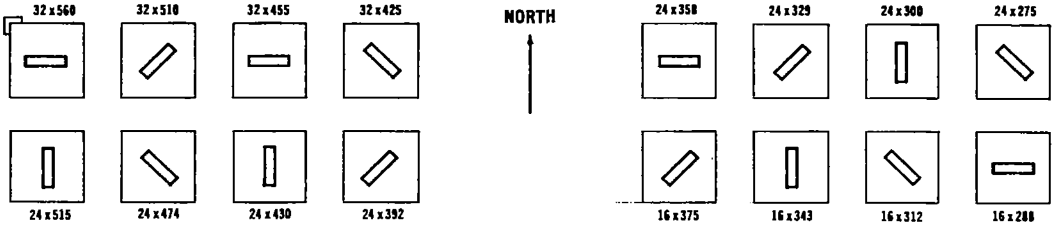


Fig. 4-13. Target array used at Woodleigh. The bars are not to scale, but their real dimensions are shown by the numbers.

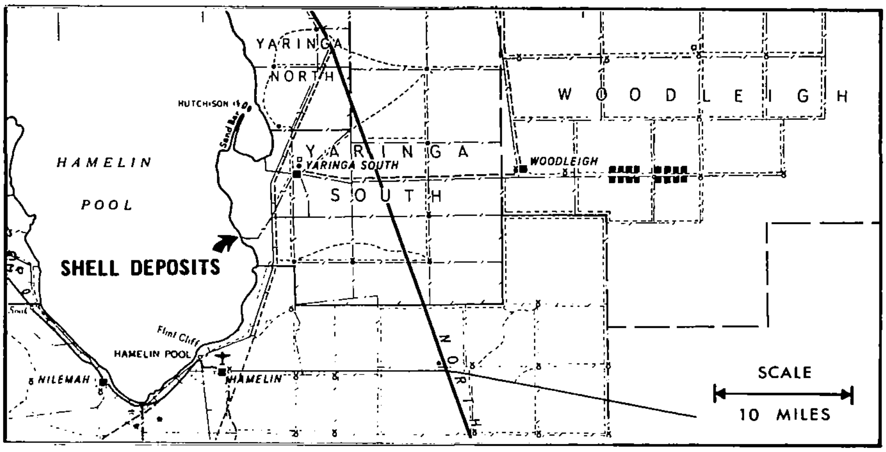


Fig. 4-14. Region of the shell deposits and Woodleigh experimental site. (N. B.: Yaringa South homestead is now Carble.)

of four vans with living quarters, one for communications and food preparation, power generators, battery chargers, water tanks, toilet and shower facilities, vehicles and supplies of petrol.

Although there were highly conspicuous and distinctive features of the coastline of Western Australia which would aid in initial acquisition of the Woodleigh array, it seemed prudent to provide additional aids to location and orientation of the site, especially if clouds should obscure the coastal contours. Accordingly, two further steps were taken in preparing the experimental area:

1. The northwesternmost background square was partially outlined by a white shell chevron embracing its northwest corner. Each leg of the chevron was 250 feet long by 40 feet wide.
2. Chemical smokepots, modified for electrical ignition, were placed in a line due west of the array. These had sufficient burning time so that they could be ignited in time to generate a long, low-lying plume of dense white smoke which could readily be seen by the astronauts during the overpass.

4.5 SITE OPERATIONS

4.5.1 Operations at Woodleigh: Gemini V Mission

Although there were no successful sightings of the Woodleigh array during Gemini V, owing to the tumbling of the spacecraft and associated problems, it is desirable to describe, briefly at least, the operations at the site. Experience gained on this occasion led to some changes in the plan for Gemini VII, and might have a bearing upon any subsequent experiments which may be planned for this nearly ideal location.

Logistics

Three cooperating units were involved in the Woodleigh exercise; the Carnarvon Tracking Station, a team from the Department of Works, and the scientific party. The tracking station, under the direction of Mr. Lewis Wainwright, provided supporting communications with the spacecraft and the SCAMA network. In addition, they rendered assistance in all phases of the operation, provided vehicles for the Woodleigh site, and were outstandingly cooperative throughout the program. Mr. Charles Lewis, of NASA Manned Spacecraft Center, was Carnarvon Capsule Communicator for the flight.

The Department of Works provided a work team from Perth, under the supervision of Mr. Colin McWhaie. It was this group that prepared the site initially, and performed the necessary target size changes for the mission.

The scientific party was composed of Dr. John H. Taylor (scientist-in-charge), Mr. Richard W. Johnson (engineer), and Mr. Kenneth W. McMaster (electronics technician); all from the Visibility Laboratory. Other members of this group were Mr. John A. G. Walton (Department of Supply) and Mr. Andrew Drummond (Carnarvon Tracking Station). Because of the remoteness of the site from Carnarvon (125 miles) living quarters were arranged on location. The camp consisted of two caravans for sleeping quarters, a large van which served both as a galley and as communications center, a large water tank (all water had to be brought in by truck from the Wooramel River, some fifty miles distant), a radio transmitting tower, and a generator. Supplies of petrol were brought in for powering the vehicles and generator. Food supplies were brought from Carnarvon, although locally procured fish, mutton, and kangaroo formed a significant part of the diet. The Department of Works group had a similar camp, but (with characteristic Australian ingenuity) had improvised sanitary facilities, a laundry, and a hot shower, all of which the scientific party were fortunate to share.

Target changes were made by use of the equipment already mentioned. It was found best to remove the shell entirely when changes in orientation of the target bars were made; this was done by scooping it carefully with a skip-loader and hauling it away in trucks. (It was used to improve the surface of the track south of the array.) New shell had been stockpiled for target changes, so that it would not be necessary to make the long trip to the source.

Communications

Telephone lines to Woodleigh were judged to be inadequate for our purposes. The existing system uses a single iron wire, with earth return, serving several homesteads on a party line. Signal strength was low at the Woodleigh station, and intelligibility variable, as was the use of the line by other subscribers. Cost estimates for running a special line from the PMG office in Carnarvon were prohibitive, and it was decided to use radio communication entirely.

Two radio links were established: one Redifon transceiver, Type GR 410, operating HF/SSV at 2-16 MHz/s, and one FM Carphone Type MR 20B operating VHF at 70-85 MHz/s were installed at the site as prime units, and a VHF relay was installed on a hilltop at Gladstone. The HF was generally too noisy for effective use, owing to teletype interference. The VHF was generally satisfactory, but required daily battery changes to be made at the relay point. Continuous battery charging was required from the generator at Woodleigh, and one man and one vehicle were tied up for approximately three hours each day, carrying batteries to and from Gladstone and making the necessary changeovers. Three chargers were required to maintain the eight 240 Ampere-hour, 12 Volt batteries, operating for about 18 hours a day.

Two walkie-talkie transceivers were used to maintain communications between the CRM station in the field and the radio van at the camp. Arrangements at the van permitted active, two-way communications with the tracking station and over the SCAMA network, but only passive reception of spacecraft voice transmissions. Data from the on-board window scan photometer were telemetered to the tracking station and delivered to Woodleigh by courier.

Chronology

The Australian portion of the Gemini V effort began, excepting for preliminary work already described, on 27 July 1965 with the arrival of Dr. Taylor in Adelaide. On this and the succeeding two days discussions were at Weapons Research Establishment (WRE) headquarters in Salisbury, and final plans laid for activities during the mission proper. It was decided that Mr. Walton would join the scientific party later, as WRE's on-site representative. Dr. Taylor arrived in Carnarvon on 30 July, and the next few days were taken up with conferences at the tracking station. Arrangements were made for communications links (v.s.), living facilities on site, special weather forecasting for the Woodleigh area, and general support of the experiment. On 3 August the remaining U.S. members of the scientific party arrived in Carnarvon.

Preliminary inspection of the target array was begun on 4 August by use of Nor'West Air Taxis' Cessna. It was found that blowing dust had noticeably invaded some of the target bars, typically, however, to a distance of about six feet from the windward edge. It was decided that fairly extensive target refurbishment should be attempted before the mission.

A scientific briefing was held on 5 August at the Carnarvon Tracking Station for all involved personnel, including Mr. Lewis who was to act as Mission Controller during Gemini V. Final assembly of the locally-made platform tower was completed and it was mounted to a flat-bed truck.

The Woodleigh site was visited by the party on 6 August, and the need for refurbishing the targets was communicated to the Department of Works team. In addition, the Department of Works supervisor, Mr. McWhaie was apprised of the details of the experiment and the strategy to be used for target changes during the mission. The Visibility Laboratory equipment arrived in Carnarvon on 7 August, and was checked over prior to moving it and the scientific party into the bush.

On 9 August the party moved to Woodleigh and began installation and checkout of the equipment. They also set up housekeeping for the three-week period on site. Mr. Walton arrived at the camp, along with Mr. Drummond, on 11 August, and in the succeeding days a full checkout of the Contrast Reduction Meter and the communications systems was made. The target bars were refurbished by the Department of Works team on 12 and 13 August. At that time it was decided that a considerably augmented stockpile of shell might be required, and Mr. McWhaie was able to find a private local contractor who had both the desire and the equipment to accomplish this, even though it necessitated working around the clock throughout the weekend.

Simulated data taking runs were made on 15, 16, and 19 August (Rain on the 17th and 18th prevented activity.) with the Contrast Reduction Meter mobile tower at Square 9. On 20 August the Contrast Reduction Meter was moved to Square 3 in preparation for the mission. The target bar sizes and aspect ratios were radically altered on 22 and 23 August, in response to instructions from Dr. Duntley, based upon updated experimental data from the Visibility Laboratory.

After the Gemini V launch on 21 August the Woodleigh team had little to do but anticipate the first usable overpass on Revolution 73, 26 August. The local weather on that and the following day, during Revolution 88, was ideal, and although data were taken with the Contrast Reduction Meter and all local systems were fully operational, spacecraft difficulties with attitude control precluded observation of the target array by the astronauts. The same difficulty obviated sightings on Revolutions 118 and 133, but in these cases the local weather was unfavorable. The Woodleigh site was closed down and secured until Gemini VII, and the equipment returned to Carnarvon on 1 September.

Before departing Carnarvon, Dr. Taylor photographed the Woodleigh site and the landmarks along the coast which would aid in acquiring the target array from orbit during Gemini VII. Several hundred feet of 16 mm color film was made using a camera borrowed from the Weapons Research Establishment, and by use of a chartered DC-3 aircraft belonging to Adastra Aerial Surveys Pty., Ltd., which had fortuitously, and almost literally, dropped into Carnarvon for repairs. This film found subsequent use in training the Gemini VII primary and backup crews.

* * *

Although the Woodleigh operation was thwarted by contingencies of the Gemini V mission and was eliminated from consideration for Gemini VII owing to orbital factors, several comments should be made regarding the site:

1. Acquisition of the site is aided by prominent coastal features of easily recognizable size and form. Astronaut Conrad was able to acquire these features and then to see the smoke pots *even while in tumbling flight,* and (by his estimate) at two or three hundred miles.

2. Should future use be found for the site, it would be a relatively easy matter to renovate the background squares (regrowth of native vegetation is very slow), and to replace the target array.
3. Proximity to the Carnarvon Tracking Station and the Northwest Coastal Highway, combined with a favorable latitude and good weather make Woodleigh a desirable location for this or related sorts of experiments.
4. Cooperation by all individuals and organizations involved in the effort was most outstanding and gratifying.

4.5.2 Operations at Laredo

The primary operations control for the out-of-the window experiment rested with the principal investigator who was situated at the Mission Control Center, M.S.C. in Houston. It was the purpose of the Laredo site operations group: (1) to provide current information to Houston regarding the weather, especially cloud cover, expected over the site at the time of the next overpass, (2) to change size and orientation of the markings as required for the next use of the site and to provide Houston with information regarding the condition of the site, (3) to operate the smoke generator and pyrotechnic smoke flares before each overpass to assist in the astronauts' acquisition of the site and (4) to obtain the quantitative data required to calculate apparent contrast of the markings against their background at the time of the overpass and in the directions of view used by the astronauts.

Staffing

The scientific party consisted of R. W. Austin, Research Engineer, in charge, G. H. Tate, Associate Engineer, and G. F. Simas, Senior Electronics Technician, who together operated the photometric equipment used to perform the measurements from which contrasts were determined, and T. J. Petzold (Gemini V) and R. W. Johnson (Gemini VII), Senior Engineers, who assisted in many ways with data acquisition, calculations, calibrations, etc.

The site contractor, H. B. Zachary Co., maintained a general foreman, equipment operators, and laborers on the site as required to move panels, change areas, replow background areas to darken or improve uniformity and operate the smoke generator and flares.

The Navy maintained an inspector on the site at all times who also acted as official liason between the Visibility Laboratory and the contractor and assisted in many other ways.

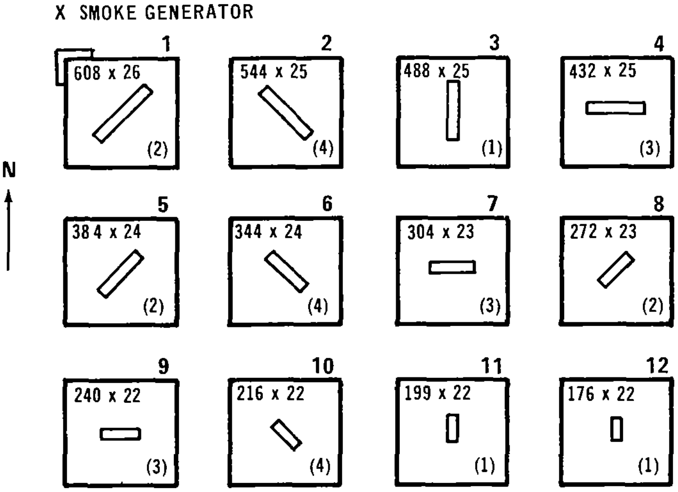
The Southwestern Telephone Company maintained a technician on the site each day as long as there was a likelihood of a critical communications need. Although their equipment required little attention, on the few occasions when due to power outages, etc., a requirement for service arose, his presence saved many hours of communicationless isolation.

Site Arrangements

For Gemini V, rectangles were placed in the centers of all twelve background squares. The site was arranged as shown in Fig. 4-15 with the largest rectangular bar in the northwest corner square. The size of the bars decreased in order as one went from left to right, top to bottom as one would read a printed page. For convenience, the squares were numbered in the same manner, i.e., from one in the northwest to twelve in the southeast. The trailer which acted as field headquarters and communication center was located in the north center of square number seven. It was in this square also that the contrasts and contrast transmittances were measured. Check measurements were made in some of the other squares and aerial photography and observations were also used to judge the validity of making measurements in one location only and applying the values so obtained to the entire site. Whereas there were obvious differences in the reflectances of the backgrounds, square number seven was intermediate in its reflectance and uniformity. Furthermore, by design it was expected that the threshold of orientation discrimination would occur in the vicinity of this rectangle.

The arrangement shown in Fig. 4-15 was designed for revolution 18, the first scheduled use of the site. As no successful sightings were made of the markings on this pass nor on the next two, viz. revolutions 33 and 45, and as the subtended angles were all sufficiently close to the required range of values, the rectangles were left unchanged in size or orientation through revolution 48. Thus, Fig. 4-15 shows how the site was configured for revolution 48, the only pass when the orientation of any of the rectangles was properly designated.

The site arrangement for Gemini VII was different only by the reduction of the number of operating squares from twelve to eight. The four squares in the north row were given over to the large white east-west orientation bars as shown in Fig. 4-16 and 4-17 for revolutions 17 and 31 respectively. The remaining squares contained the eight rectangles to be discriminated, arranged in the same order of decreasing size, left to right, top to bottom, as used in Gemini V.



REVOLUTION: 48

DATE: 24 August 1965

CST: 12:17:14

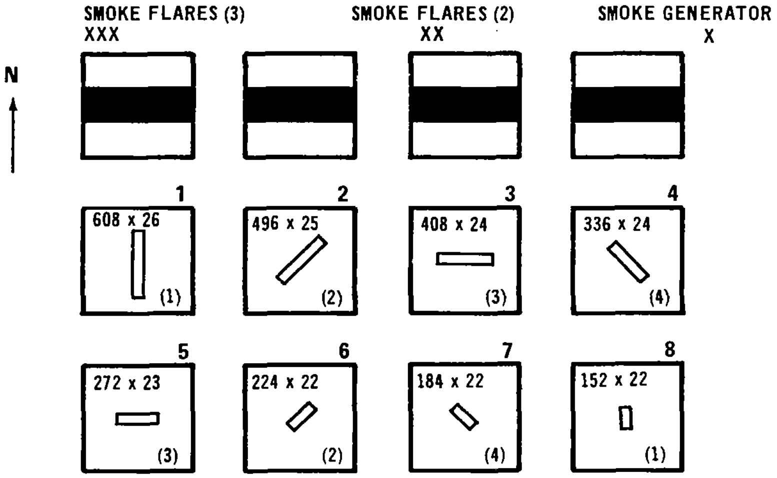
SLANT RANGE (N.M.): 135

SPACECRAFT ELEVATION: 54.3°

WIND: South

SKY: Clear, Deep Blue, Small Puffs
Cumulus to N & E

Fig. 4-15. Laredo Site Arrangement Plan Gemini V, Revolution 48.



REVOLUTION: 17

DATE: 5 December 1965

CST: 16:34:52

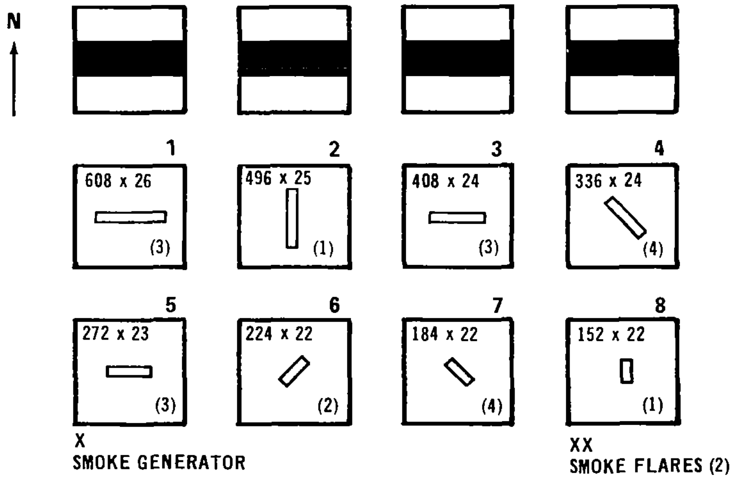
SLANT RANGE (N.M.): 141

SPACECRAFT ELEVATION: 57.5°

AIR TEMPERATURE: 70° F (Est.)

WIND: Southwest – 6 mph

Fig. 4-16. Laredo Site Arrangement Plan Gemini VII, Revolution 17.



REVOLUTION: 31

DATE: 6 December 1965

CST: 12:56:51

SLANT RANGE (N.M.): 126.5

SPACECRAFT ELEVATION: 71°

AIR TEMPERATURE: 70° F (Est.)

WIND: North – 4-6 mph

Fig. 4-17. Laredo Site Arrangement Plan Gemini VII, Revolution 31.

The site arrangement plans show the size and orientation of each rectangle, the wind direction and velocity, and the location of the smoke generator and smoke flares for the three reported uses of the site.

Size of the Rectangles

The sizes of the twelve rectangular bars used at Laredo in Gemini V and the eight used in Gemini VII were chosen to make a quasi logarithmic progression.

In Gemini V the ratio of lengths of the longest to the shortest bar was about 3.45:1. As discussed in Section 4.7 below, the bars were treated in the experimental design as though they were rectangular with a 4 to 1 length to width ratio. Thus the nominal area, A, of a rectangle of length L would be $L^2/4$. The size ratio of the nominal areas was, therefore, about 12:1.

The actual widths of the rectangles were less than one-fourth their length. The ratios of these actual widths, W, to the nominal widths, L/4 were used to reduce the effective contrast of the bars as seen by an observer unable to resolve them in width.

The widths were adjusted to the nearest foot by overlapping the panels. The lengths were changed in increments of 8 feet as this provided adequately fine control and permitted the use of an integral number of the 8 ft. x 4 ft. Styrofoam panels.

Table 4-2 shows the nominal and actual sizes of the rectangle used in Gemini V and their solid angles subtended by each at the spacecraft at the time of closest approach for revolution 48. The solid angle, Ω, in square minutes subtended by an area, A, square feet at a slant range, r, nautical miles and being observed from an elevation angle θ is given by the following equation:

$$\Omega = 0.320 \frac{A}{r^2} \sin \theta$$

At the closest approach for revolution 48 the slant range was 135 nautical miles and the spacecraft elevation above the site horizontal was 54.3°. Thus the solid angle equation for this case becomes

$$\Omega = 1.43 \times 10^{-5} A$$

The areas used for the computation are the nominal areas given in column 6. For convenience of reference the effective apparent contrast of each of the rectangles for this pass are listed in Column 8. A description of the method of obtaining these values will be given later.

In Gemini VII the ratio of lengths of the longest to the shortest bar was 4:1, making the area ratio 16:1. In this instance the range of sizes was divided into eight quasi logarithmic steps for the eight squares. Table 4-3 shows the sizes of the rectangles used in the early part of Gemini VII and the solid angle subtended by each at the spacecraft at the times of closest approach for revolutions 17 and 31. The effective apparent contrast of each rectangle is shown for the two overpasses.

Table 4-2. Gemini V Size and Contrast Data for Laredo Ground Markings

						TCA REV 48	
Square	L	L/4	W	W/(L/4)	"A" = $L^2/4$	$\Omega = 1.43 \times 10^{-5}$A	$_{eff}C'_r$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	608	152	26	.171	92 400	1.32 min^2	0.40
2	544	136	25	.184	74 000	1.06	0.48
3	488	122	25	.205	59 600	.85	0.53
4	432	108	25	.232	46 700	.67	0.60
5	384	96	24	.250	36 900	.53	0.65
6	344	86	24	.279	29 600	.42	0.73
7	304	76	23	.303	23 100	.33	0.79
8	272	68	23	.338	18 500	.26	0.88
9	240	60	22	.367	14 400	.21	0.95
10	216	54	22	.407	11 700	.17	1.06
11	192	48	22	.459	9 230	.13	1.20
12	176	44	22	.500	7 744	.11	1.30

At Time of Closest Approach (TCA) Revolution 48

r = 135 Nautical Miles (Slant Range)

θ = 54.3° (Elevation of Spacecraft Above Site Horizontal)

C_o = 3.9 (Inherent Contrast of Panel Material Against Plowed Field)

τ_r = 0.667 (Contrast Transmittance of Atmosphere)

τ_w = 1.0 (Contrast Transmittance of Spacecraft Window – (B^*_w = 0))

Table 4-3. Gemini VII Size and Contrast Data for Laredo Ground Markings

						TCA REV 17		TCA REV 31	
Square	L	L/4	W	W/(L/4)	"A" = $L^2/4$	$\Omega = 1.36 \times 10^{-5}$A	$_{eff}C'_r$	$\Omega = 1.9 \times 10^{-5}$	$_{eff}C'_r$
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
1	608	152	26	.171	92 400	1.26 min^2	0.44	1.76 min^2	0.65
2	496	124	25	.202	61 500	.84	0.52	1.17	0.77
3	408	102	24	.235	41 600	.58	0.63	.79	0.89
4	336	84	24	.279	28 200	.38	0.71	.54	1.06
5	272	68	23	.338	18 500	.25	0.86	.35	1.28
6	224	56	22	.393	12 500	.17	1.00	.24	1.49
7	184	46	22	.478	8 460	.12	1.20	.16	1.81
8	152	38	22	.579	5 780	.08	1.50	.11	2.20

At Time of Closest Approach (TCA)

	Rev. 17	Rev. 31		
r =	141	126	Nautical Miles	(Slant Range)
θ =	57.5°	71°		(Elevation of Spacecraft Above Site Horizontal)
C_o =	8.8	12		(Inherent Contrast of Panel Material Against Plowed Field)
τ_r =	.29	.43		(Contrast Transmittance of Atmosphere)
τ_w =	1.0*	.74		(Contrast Transmittance of Spacecraft Window)

*No Evidence of Scattering from S/C Window, i.e., $B^*_w = 0$

Spacecraft Position

Computer calculated orbital information was made available for project planning purposes many months in advance of the mission launch. These data, as updated from time to time, were used to determine the best passes of the spacecraft over the site as to time of day, elevation angle of the spacecraft above the local horizontal and slant range at time of closest approach. Having made selections it was necessary to plan the location of the equipment used to measure the contrast of the marking against the background in order that both the panel and the earth could be measured from the same directions as the astronaut would be viewing the site as he passed overhead. Furthermore, it was necessary to know the angular coordinates of the sun at the time of the overpass in order that the equipment used to measure the atmospheric transmittance could be properly set up. This equipment consisted of a special photometer mounted on a modified astronomical equatorial mount which could (a) measure the apparent luminance of the solar disk (b) the luminance of the sky in a plane containing the sun and the zenith, and (c) the luminance of the background and panel materials in the required direction of view. The diameter of the field of view of the instrument for the solar disk measurement was about 5 minutes of arc. This field was placed at the center of the solar disk by means of a carefully boresighted sight for the sun luminance measurement. For the other measurements the telephotometer had a field of view of 5° diameter. As the plowed field had features which were of the order of one foot in extent, it was necessary to keep the telephotometer 20 feet or more from the furrows in order that they not be individually resolved in the measurement. Therefore, the equipment was mounted on top of a staging secured to the roof of a station wagon to provide the height and the mobility required to permit changes in the direction of view. This equipment, called a Contrast Reduction Meter (CRM) because it measures the necessary quantities from which the contrast transmittance can be computed, is shown mounted in position in Fig. 4-18, and may be seen in greater detail in Figs. 21 and 22 in Appendix A.

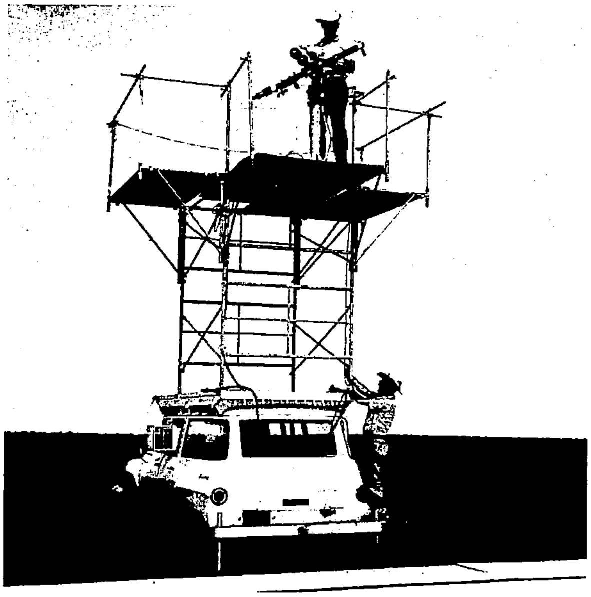


Fig. 4-18. Photometric Equipment for Ground Site Measurements.

After launch when the orbital parameters became known in greater detail, new orbital updates were provided to the site from which precise setup data could be determined. Examples of the type of information which was generated are shown in Figs. 4-19, 4-20, and 4-21 for revolution 48 in Gemini V and revolutions 17 and 31 in Gemini VII, respectively. These plots contained all the information necessary for setting up the equipment.

It was necessary, for example, to have the measurement equipment (CRM) on the south side of the rectangular bar for revolution 17 and move it to the north side for revolution 31 as can be seen by simple examination of Figs. 4-20 and 4-21. The remaining details of the angles to be set into the various axes of the instrument could be determined from the information on these plots.

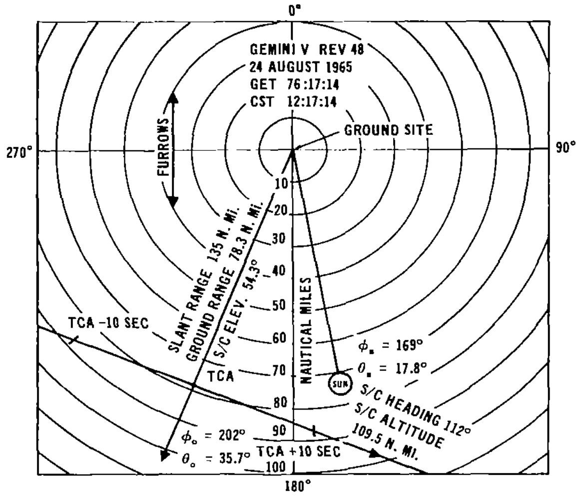


Fig. 4-19. Closest approach orbital set-up data for Laredo site, Gemini V Revolution 48.

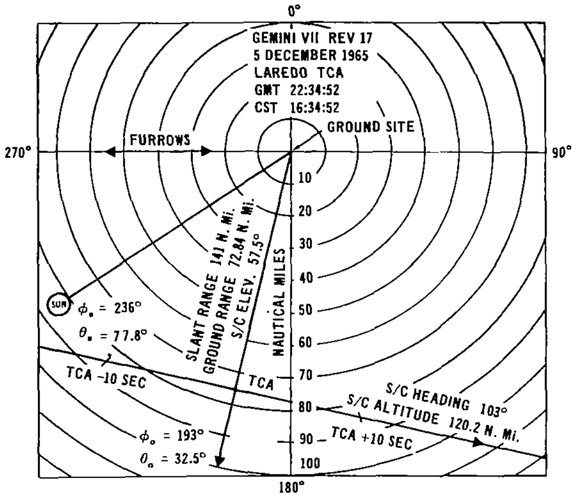


Fig. 4-20. Closest approach orbital set-up data for Laredo site, Gemini VII Revolution 17.

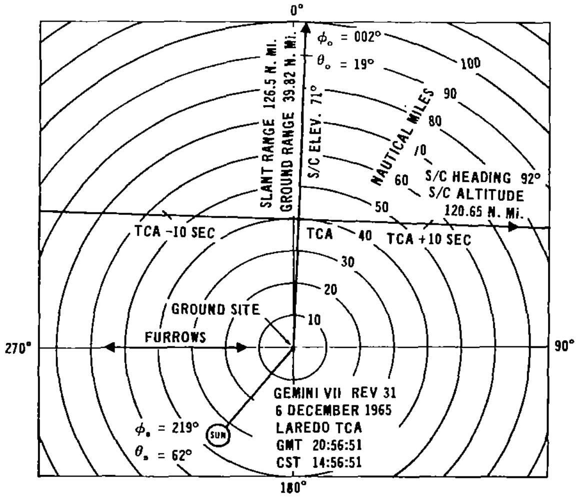


Fig. 4-21. Closest approach orbital set-up data for Laredo site, Gemini VII Revolution 31.

Effective Apparent Contrast

From the values of luminance of the background ${}_bB_o$ and the luminance of the Styrofoam panels ${}_tB_o$, both obtained in the direction of view, the inherent contrast, C_o, of the rectangle as seen from the direction of the spacecraft can be obtained, i.e.

$$C_o = \frac{{}_tB_o - {}_bB_o}{{}_bB_o}$$

The contrast transmittance of the atmosphere, ${}_b\tau_r$, may be determined from a knowledge of the luminance of the path of sight from the spacecraft to the site, B^*, the luminance of the background, ${}_bB_o$, and the beam transmittance of the path of sight, T_{θ_o}. Thus,

$${}_b\tau_r = \frac{1}{1 + \dfrac{B^*}{{}_bB_o\, T_{\theta_o}}}$$

B^* is determined from measurements of sky luminance in appropriate directions, taking into consideration the angle between the path of sight and the sun. T_θ may be computed from the measurement of the apparent luminance of the solar disk, a knowledge of its inherent luminance (outside the atmosphere) and corrections for air mass. ${}_bB_o$ was measured in order to obtain the inherent contrast.

The effective apparent contrast that existed outside the spacecraft window was obtained by multiplying the inherent contrast by the contrast transmittance of the atmosphere and then for each rectangle in the array by its width ratio W/(L/4). Thus

$${}_{eff}C_r = C_o\, {}_b\tau_r \frac{W}{L/4}$$

For those cases where a luminance reading was obtained on the inflight photometer ${}_{eff}C_r$ had to be multiplied by the contrast transmittance of the spacecraft window τ_w to obtain the effective apparent contrast available at the eye of the observer. The τ_w computed in a similar manner to the atmospheric contrast transmittance, viz

$$\tau_w = \frac{1}{1 + \dfrac{B^*_w}{{}_bB_r\, T_w}}$$

where B^*_w was the value obtained from the inflight photometer, ${}_bB_r$, is the apparent luminance of the background squares which can be computed from the information taken at the ground site, and T_w is the beam transmittance of the spacecraft window which was approximately 0.85.

Typical values for the various parameters at closest approach as occurred during revolution 48 on Gemini V and during revolution 17 and 31 on Gemini VII are given in Tables 4-2 and 4-3, respectively. The resulting effective apparent contrast are tabulated in column 8 of Table 4-2 and column 8 and 10 of Table 4-3.

4.6 INFLIGHT PHOTOMETER

The photometer was designed by the Visibility Laboratory. The circuit, optical, and mechanical features are shown in Appendix C. As this instrument was also mounted on the hatch, it had to meet the same 150g acceleration tests that were mentioned earlier in the description of the Inflight Vision Tester. The photometer also passed all aspects of its qualification test procedure and remained a completely operationally useful instrument. The instrument was powered by a specially packaged mercury battery. Because of concern with possible hazards from mercury poisoning, the batteries were completely encapsulated in plastic. They were further sealed when in place within the photometer by a gasketed cover plate. Some of these batteries are still intact and operational after three years.

Purpose

The Inflight Photometer measured the amount of light scattered by the spacecraft window into the astronaut's path of sight during the course of his observation of the prepared ground markings. This measurement permitted a computation to be made of the degree to which the optical signal from the marking was degraded by passage through the window.

Use

The Inflight Photometer was stored on the inside of the hatch for launch and reentry. It was used in two distinct modes. When in use-mode A, it was mounted on the 16 mm camera bracket on the right window. It was so aligned that its field of view fell entirely within a black light trap located on the hatch outside the window. This alignment was accomplished prior to launch and all adjustments locked. The astronaut did not make any alignment adjustments in flight.

In use-mode A, the output from the photometer during the period of time that the astronaut was observing the ground markings was recorded on the dumped telemetry system and subsequently telemetered to the ground. The data so obtained were converted into luminances of the spot on the spacecraft window examined by the photometer. The window was illuminated by a light field that was changing from moment to moment, depending upon the orientation of the spacecraft, and from orbit to orbit because of changing solar position, orbital track, cloud cover, and window condition. It was considered important, therefore, that the measurement be made frequently during the two-minute period of actual observation and during each such observational period during the course of the flight. As the photometer field of view fell entirely within the light trap, the only flux received by it was that scattered by the window.

Use-mode A permitted the determination of the amount of scattering from one point on the window under the conditions of the experiment as noted above. To answer the question of how uniform the scattering was over the entire window area, a second method of measurement was used – use-mode B. In this mode the spacecraft was oriented so that the sun was striking the right-hand window obliquely, and the spacecraft axis was pointed at a dark portion of the sky. The astronauts then removed the photometer from the camera bracket or stowage location and with the instrument connected to the telemetry system, performed a systematic scan of the windows in the manner prescribed in the Experiment Procedure Section of the Flight Plan Check (see Appendix D). The time correlated telemetry provided the necessary data for determining the degree to which the scattering from the window varied from point-to-point as shown in Appendix A, Figs. 26 and 27.

Description

The Inflight Photometer is a photoelectric telephotometer having an aperture of one (1) centimeter diameter, a field of view of one (1) centimeter at a distance of 46 centimeters (14.4 inches), and a full-scale sensitivity of 3000 foot lamberts. Two outputs were provided. The primary output was a 0-5 volt signal for the high level dumped telemetry system, and the secondary output was a meter integral with the photometer which provided the astronaut with a means of determining that the instrument was functioning, adjusting zero when necessary, and obtaining on-board magnitudes and changes of luminance levels. Power was supplied by a special battery pack internal to the instrument. The only electrical interface with the spacecraft was the connection to the high-level telemetry system through the utility cord and a special connector on the right-hand side of the spacecraft. In use-mode A, the photometer attached to the 16 mm movie camera bracket which could be mounted on the right-hand window, thereby maintaining proper alignment between the photometer and the light trap. This mounting and the mounting for stowage were the two mechanical interfaces between the instrument and the spacecraft.

Two controls were available to the astronaut; a switch which completely interrupted all current flow from the batteries, thereby deadfacing the connector, and a zero-adjustment which could accommodate for changes in the electrical zero which occurred with time or temperature variations. An integral sun-shade could be removed when necessary for cleaning the exterior surface of the first prism. All other optical surfaces were contained within the sealed volume of the instrument. The sunshade contained a metal screen neutral density filter which had a filter factor of approximately 0.20. Thus, with the filter removed, the full scale sensitivity of the photometer was about 600 foot-lamberts. This increased sensitivity facilitated the calibration of the instrument at luminance levels which could be more readily generated with the required accuracy. The filter factor of the screen could be measured directly and simply in the instrument after obtaining the calibration curve at the lower levels.

The light trap (fabricated and installed on the spacecraft hatch by McDonnell) had a 0.75-inch diameter entrance hole and a cavity one inch in diameter (minimum) behind the entrance extending for a distance of approximately three inches. The interior surface of the cavity was black. The outside surface of the trap facing the photometer also was black.

Table 4-4 below lists in summary the specifications for the Inflight Vision Tester which was designated as Government Furnished Aerospace Equipment (GFAE) Number EC 34998.

Table 4-4. Inflight Photometer, GFAE EC 34998

SPECIFICATIONS	
A. Full-scale sensitivity	3000 ± 150 ft-L
B. Aperture diameter	10 ± 1 mm
C. Field of view diameter at light trap entrance	11 mm Max.
D. Telemetry output voltage	0 to +5 volts
E. Telemetry output reproducibility	Within .25 volt of calibration curve
F. Telemetry output calibration factor	About 600 ft-L/volt
G. Telemetry output impedance	< 1000 ohms
H. Power required	Special self-contained battery pack
I. Electrical Controls	(1) Switch, On-Off (2) Zero adjust
J. Mechanical adjustments	
(1) Yaw alignment	± 10°
(2) Pitch alignment	± 13°
K. Electrical connector	PT 02C-8-4P (Bendix-Scintilla)
L. Weight	49 ounces ± 5 ounces with battery pack
M. Size	7.13 in. L x 3.40 in. H x 2.7 in. W

4.7 SIZE OF THE GROUND MARKINGS

It was the basic design of the Gemini visual acuity experiment that each of the white rectangles which served as ground markings should be large enough to exceed the threshold of detection but that the range of sizes be sufficient to bracket the threshold of orientation discrimination. Thus, the orientation of only the largest markings in the series could be discriminated. This was a difficult requirement to meet unless the increments in size between markings was made greater than was desirable from the standpoint of adequate precision of threshold determination. Practical considerations dictated that the array could contain only a small number of rectangles; e.g., eight during Gemini VII. It was necessary therefore, to adjust the range of rectangle sizes prior to each pass in order to bracket the threshold.

Many factors entered into the specification of the size of the bars. These will be discussed separately in the following paragraphs:

1. The visual threshold for each of the 8 astronauts had been measured in the vision training van. Individual differences were found (see Section 2, Fig. 2-20.) The size of the array had to be tailored to the visual performance of the particular astronaut scheduled to perform the observations. Although one astronaut was always designated as the primary observer and the size of the array adjusted accordingly, there was always a possibility that the other pilot might have to make the observations because of adverse lighting conditions on one of the spacecraft windows. The range of rectangle sizes was chosen, therefore, to bracket the thresholds of orientation discrimination of both astronauts if possible.
2. Even at the point of closest approach the spacecraft was never directly above the markings. They were seen, therefore, foreshortened by an amount depending upon the zenith angle of the path of sight from the spacecraft to the rectangles. This foreshortening was different in the case of every pass and changed, moreover, throughout the two-minute period during which the ground site could be seen by the astronauts. The apparent angular size of each marking depended, moreover, upon the slant range of observation; this changed continuously throughout the pass and was different from pass-to-pass, depending upon the ground track of the spacecraft and its altitude.
3. The apparent contrast of the ground markings depended both upon their inherent contrast and upon the contrast reduction imposed by the atmosphere and by the spacecraft window. Each of these three factors varied throughout the overpass of the spacecraft.

The effects listed in the preceding paragraphs made it infeasible to use the entire two-minute viewing period to obtain visual thresholds. Study of the problem indicated that the data must be obtained within a twenty-second period centered about the time of closest approach. The astronauts were told that they might watch the array throughout as much of the pass as they cared to use but that they were to read the orientations serially beginning with the largest of the rectangles during a twenty-second period beginning 10 seconds before closest approach and ending 10 seconds after the time of closest approach. The predicted time of closest approach was transmitted from the ground in advance of each pass. By specifying the time of observation in this manner it was possible for the experimenters to set the size of the array for each pass so that it bracketed the expected orientation discrimination thresholds of both crew members. Any change in the visual thresholds would then be apparent.

The considerations described above are illustrated by Fig. 4-22, which depicts conditions at the Laredo site at the time of the overpass during revolution 48 of Gemini V. This figure is similar to Fig. 25 in Appendix A. It shows apparent contrast vs. angular size for the 12 rectangular markings at the Laredo site at the time of this overpass and at the point of closest approach. The solid and dotted curves represent the P = 0.90 discrimination thresholds of the pilot as measured in the training van. The diagonal row of 12 solid points represents the apparent contrast and angular size of each of the 12 rectangular bars at the moment of closest approach. The 3 rows of 12 open circles represent the corresponding apparent contrast and angular size of the same markings as they appeared to the astronauts 60 seconds, 30 seconds, and 10 seconds, respectively, before the time of closest approach. The diagonal rows of points marked by squares represent the corresponding apparent contrast and angular size of the 12 ground markings as they appeared 10 seconds, 30 seconds, and 60 seconds, respectively, after the time of closest approach. As would be expected, both the apparent size and the apparent contrast of the ground markings were greatest at the time of closest approach because the slant range was least; also, the foreshortening was minimal. Fig. 4-22 shows that the apparent size and contrast of the rectangles changed continuously throughout the 2-minute period that the array could be viewed from orbit. It demonstrates that the appearance of the rectangles remained constant only for a brief interval centered on the time of closest approach and explains why the astronauts were asked to read the rectangle orientations at the time of closest approach ± 10 seconds.

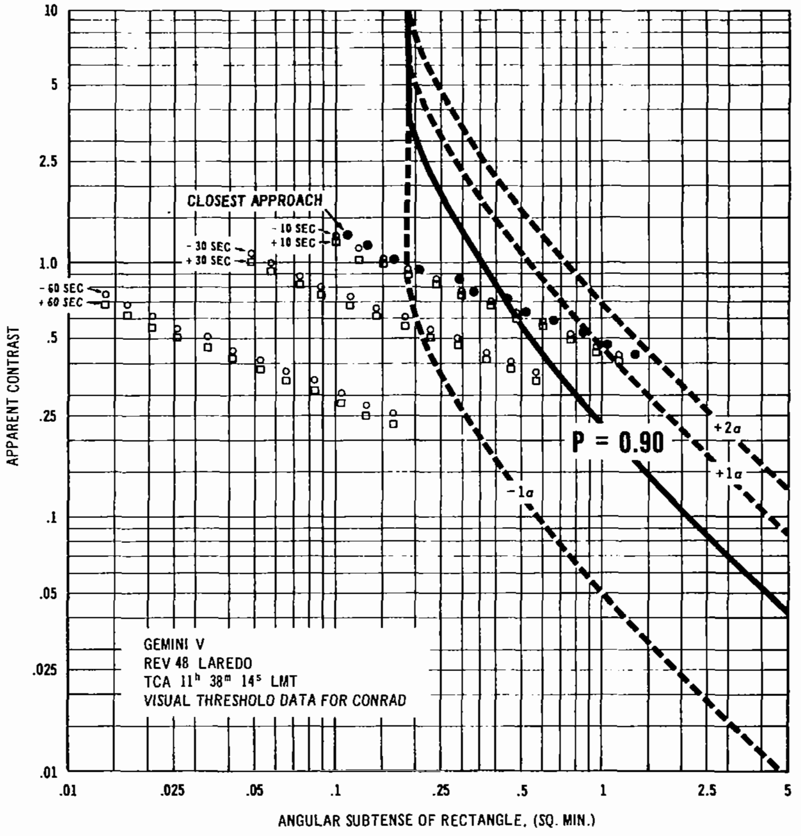


Fig. 4-22. Apparent contrast versus angular size of rectangles for Gemini V Rev 48 for all rectangles 60 seconds before closest approach through 60 seconds after closest approach.

It is interesting to note that whereas the apparent angular size of the markings varied symmetrically with time before and after the time of closest approach, this was not true of the apparent contrast. Thirty seconds before closest approach, for example, the apparent contrast of the markings was somewhat higher than when observed from the position of the spacecraft 30 seconds after closest approach. A corresponding effect is seen at the 10-second and 60-second positions in the figure. These differences in apparent contrast reflect the fact that the inherent contrast of the markings against their background differed depending upon the azimuth of the path of sight. The effect was due chiefly to variations in the luminance of the background against which the markings were seen. This was composed of dirt that had been plowed, the direction of the furrows being north and south. Thus, one of the sides of the furrows was more sunlit than the other. The ground track of the spacecraft is shown in Fig. 4-19; obviously, different proportion of the sides of the furrows were presented to the astronauts during their approach than while going away from the site. No soil is truly matte* even without furrows, and the inherent gloss of the dirt contributed to the observed asymmetry.

Many hours were required to move the white panels which composed the markings at the Laredo site. A similar time would have been required to move the layers of white shells which composed the markings at the Australian site. It was necessary, therefore, for the experimenters to prescribe both the changed positions of the rectangles and their new size long before the pass occurred. Thus, in the case of a midday pass, to be followed by a similar pass on the following day, it was necessary to specify the configuration and size of the rectangles almost immediately after the first pass so that the labor force would have enough time to make the required changes in the positions of the panels and in their number.

Immediately after the first pass the experimenters could obtain from the computer at the Manned Spacecraft Center, a prediction of the coordinates of the point of closest approach. From this they could calculate the azimuth and elevation of the path of sight and the slant range. From the time of closest approach the aximuth and elevation of the sun at the time of the next pass could be found. A forecast of the meteorological conditions expected to prevail at the site on the next day and an estimate of the probability of rainfall during the intervening hours was provided by the weather office in the Mission Control Center. Rain, of course, served to darken the soil and increase the apparent contrast of the rectangles. Similarly, drying winds could lighten the soil, thereby decreasing the inherent contrast of the array. It was necessary to estimate, on the basis of previous measurements, the directional luminance characteristics of the soil for the solar position and line of sight expected for the succeeding overflight. The contrast transmittance for the expected path of sight was then predicted from the meteorological forecast and experience gained from atmospheric measurements made at the site prior to the mission. All of these data were then combined to predict the apparent contrast and apparent angular size that the existing rectangles would be expected to produce at the position of closest approach. This prediction was plotted on Fig. 4-22. If this new position for the array did not bracket the solid curve in Fig. 4-22, an alteration in the size of the rectangles was necessary.

If the data from the on-board vision tester or the results of sightings on previous overflights of the array had indicated that the astronauts were changing in their visual capabilities, it would

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* See Applied Optics, Vol. 3, No. 5 (1964), p559, Table 3.2.

have been necessary to have extrapolated their thresholds and to have incorporated this prediction into the design of the array for each ensuing overpass. This complication did not arise because no evidence appeared during either Gemini V or Gemini VII that the human visual capabilities were changing.

Practical considerations limited the amount of change which could be made in the array during any one day. The number of panels which the labor force could move in that period depended upon the weather and upon the wetness of the soil. Obviously, moving the panels on a muddy field was a slower and more difficult task than when the field was dry.

The requirement for changing the orientation of the rectangles depended upon the success of the astronauts during the preceding pass in reporting the rectangle orientations correctly. In cases when the array was not seen or was reported completely incorrect there seemed little reason to change any of the orientation. Nevertheless, the orientations were nearly always changed. Because it was never possible to alter the orientations of all of the rectangles, careful consideration was given to randomizing the changes within the series.

The primary consideration was to get the size of the rectangles and their apparent contrast adjusted such that they would bracket the family of curves for the astronaut during his next pass. This was accomplished with consistent success whenever there was sufficient time to move the panels. Early in Gemini VII, however, observations were made on successive revolutions, 16 and 17. In this case, the array had been designed for revolution 16, as scheduled in the flight plan. The ground track of the spacecraft passed north of the site and the plowed furrows ran from east to west. The shadowed side of the furrows were, therefore, presented to the spacecraft. Thus, the background squares appeared very dark and the inherent contrast was high. The sizes chosen for the rectangles placed the array nicely across the visual threshold curves of the pilot for revolution 16, but when the pass occurred he found that the severe contamination of his window prevented him from performing the sighting task. Since the command pilot's window was clear the experimenters requested and received permission to repeat the experiment on revolution 17 with the command pilot making the sightings. The ground track of the spacecraft on revolution 17 passed south of the Laredo site; from this position the observer saw the sunlit sides of the furrows so that the soil appeared much brighter and the inherent contrast of the markings was correspondingly reduced. The slant range was also greater, so that the apparent angular size was smaller. It was necessary, moreover, to allow for the fact that the visual thresholds of the command pilot were slightly higher than those of the pilot. When best estimates of all these factors were combined, it was discovered that the array was too small for proper use on revolution 17. There was insufficient time between the passes to enlarge the biggest rectangles significantly. Hence, it was only possible to use the array without change. It was predicted that the Command Pilot would be able to discriminate the orientation of the largest panel only.

Because weather predictions made continuation of favorable seeing conditions from orbit over Laredo unlikely during most of the days to follow, it was decided to perform the experiment on revolution 17 despite the fact that there was not enough time to increase the size of the array. As will be noted from Fig. 4-25, page 4-62, the position of the largest panel measured at the moment of closest approach and in the direction of the spacecraft, fell exactly on the visual threshold curve of the command pilot and all of the other 7 markings were below his threshold of orientation discrimination. The pilot correctly reported the orientation of the largest marking but was unable to report smaller members of the series correctly. His visual performance was, therefore, exactly as predicted by his preflight visual threshold data. Had time permitted, however, the experimenters would have increased the size of the entire array so that his visual threshold would have occurred near the middle of the series, much as it did in the case of the subsequent sighting by the command pilot on revolution 31, which is also shown in Fig. 4-25.

A more complete account of the observations made on revolutions 17 and 31 of Gemini VII is given in Section 4.10 of this report.

Effective Apparent Contrast

It might be mentioned again that as previously set forth in Section 4.5.2 of this report, the effective apparent contrast plotted in Figs. such as 4-22 and 4-25, represents the apparent contrast of a 4:1 rectangle equal in length to the actual bar that was on the ground and having an area x contrast product equal to the area x contrast product of the actual ground marking. Actually, the experimenters could control the effective apparent contrast of the markings because the bars were not resolved in width and could, therefore, be made arbitrarily narrow. The effective contrast as seen by naked eye from the orbital point of closest approach could be given any desired value less than that actually produced by the white panels and the surrounding soil. A nearly linear trade-off exists between the width of the bar and its effective apparent contrast; a theoretical study of this relationship is given in the following section; experimental checks of this linearity are described in Section 2, Experiment VL-6.

In practice the bars were narrowed until the apparent contrast was low enough to avoid the steep, convergent portions of the visual threshold curves near the top of Figs. 4-22 and 4-25. The ratio of width to length was smaller for the longer bars in order to reduce the required number of panels; the number of man-hours required to change their orientation was thereby decreased and fewer panels had to be purchased. Each of the rows of 12 dots in Fig. 4-22 is inclined downward to the right because each successive rectangle had a smaller width-to-length ratio, i.e., a smaller effective apparent contrast.

A Theoretical Test of the Width-Contrast Trade-off

The summative function can be used to test theoretically the validity of the alteration of the width of the rectangles as a means of changing their effective contrast. A computer study was made to test the technique.

Two rectangles of length 2 minutes of arc and 2.5 minutes of arc were convolved with the summative function and the peak value of the convolution integral taken as a measure of detectability. The width of the rectangle was a variable of the calculation with the product of width and contrast maintained constant.

The relative effective contrast of each of the two rectangles as a function of the width of the rectangle is plotted in Fig. 4-23. Both curves are normalized to give a value of unity at the point corresponding to 4:1 aspect ratio. The calculations indicated that even for the case of 2.5 minutes of arc target the maximum change in effective contrast, which is for zero width, is 9.9 percent. For smaller aspect ratios the change in effective contrast is less. It is also less for targets of length, less than 2.5 minutes of arc as is shown by the curve for the 2.0 minutes of arc target. Several aspect ratios are marked on the two curves for ease of interpretation.

Photographs of the original 4:1 rectangles and the convolution integral result for a number of aspect ratios are shown in Fig. 4-24.

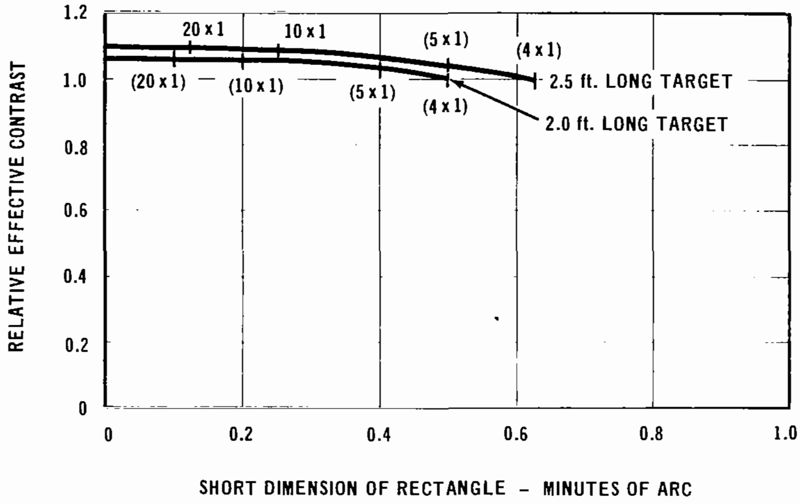

Fig. 4-23. Summative function calculations which show the relative detectability of rectangles of 2 and 2.5 minutes of arc. The width of the rectangle is the variable with the inherent contrast of the rectangle adjusted such that the product of the width and inherent contrast is constant.

(2.0 Minutes of Arc)

4 x 1 **4 x 1** **5-1/3 x 1** **8 x 1** **∞ x 1**

SUMMATIVE FUNCTION CONVOLUTION INTEGRALS

(2.5 Minutes of Arc)

4 x 1 **4 x 1** **5 x 1** **10 x 1** **∞ x 1**

Fig. 4-24. Computer generated summative function convolution integrals for targets of 2 and 2.5 minutes of arc with aspect ratio (length to width) as shown below each picture.

4.8 CHRONOLOGY OF THE OUT-OF-THE-WINDOW EXPERIMENT ON GEMINI V

The flight plan for Gemini V designated passes on certain revolutions for daily sightings at the Laredo or Woodleigh sites. It also identified several "contingency passes for use in case clouds obscured the sites at the time of the flight plan." Actually, difficulties of various kinds caused the out-of-the-window experiment to develop in a rather complex pattern, as will be described in this section.

Two forms of the spacecraft malfunctions importantly affected the experiment.

1. Early in the flight, loss of oxygen pressure in the fuel cell system caused the available electrical power to be drastically curtailed. Many spacecraft systems had to be shut down, including the gyro-platform by means of which the astronauts could orient their ship in accordance with pitch and yaw coordinates to center the ground site within the field of view of their windows. Without platform guidance, acquisition of the sites, particularly the Laredo site which had no prominent landmarks, was extremely difficult.
2. Late in the flight, after full electrical power became available, trouble developed in the thrusters by means of which the crew could control the altitude of their craft. Because the spacecraft was in tumbling flight throughout much of the latter portion of the mission, no quantitative sighting data were obtained.

During the middle of the mission, where the spacecraft operated normally, the only possible quantitative sighting occurred. This was on revolution 48. Attempts on other passes during this period failed chiefly because of the early morning times involved. In these instances the usable pass occurred just after sunrise. The spacecraft flew toward the rising sun. Sunlight on the windows, especially on the pilot's window, made acquisition difficult or impossible. At the point of closest approach, moreover, the ground was so dimly lit that it was seriously obscured by the scattering of light in the atmosphere and by the spacecraft window. Fortunately, the use of a contingency pass on revolution 48 was approved. This occurred near noon when the lighting was favorable.

Each day at about 16:00 during Gemini V the experimenters delivered a brief report of the day's events to the mission controllers. Excerpts concerning the out-of-the-window experiments have been lifted almost verbatim from these informal documents and are given below. The reports were prepared by different persons on different days, so that some variation in style is noticible.

August 22, 1965

The following reports the results for the subject experiment up until 3:30 p.m. on August 22, 1965. During the preceding days the final stages of ground marking preparation were completed. As a result of photographs taken by the U. S. Navy Reconnaissance Squadron from Miramar, California on August 17, 1965, some further final raking and site preparation was undertaken at Laredo to avoid the appearance of any light patches close to the white markings. The markings were also reduced in width in order to effectively reduce contrast(which is high) between the marking and the background. On August 20 and 21, color photographs of Laredo site were taken by personnel of the Photography Division flying in a NASA T-38 aircraft. These photographs showed a marked improvement in the characteristics of ground markings. Reports from the Woodleigh site show it to be in good condition and ready for the mission.

The first observation of a ground site was planned for the eighteenth revolution or at 28:35:13 elapsed time. At the preceding Hawaii pass, the crew was given an update of data for the pass which included pitch and yaw angles required for the crew to acquire the ground marking. As the spacecraft approached the States, Cap Com began transmitting some routine operational messages. A request was sent to him by the experiments specialist to stop transmitting in view of the fact that the crew should be preparing to acquire the Laredo site. Conditions at the site at the time of closest approach were good except for some clouds to the northwest. Ground range was 104 nautical miles. Elevation was 41 degrees. Altitude was 97.35 nautical miles. Slant range was 145 miles. This was not considered by the experimenters to be a good pass in view of the low elevation angle. Subsequent to the pass, a conversation of some length took place between Cap Com and Conrad in which a number of the experiments carried out were described by Conrad.

With regard to the S-8/D-13 experiment, he reported as follows: That he could see Corpus Christi, but that he had passed over Laredo without being able to acquire it. It should be noted that the spacecraft platform was not operating. Conrad reported that the yaw angles he had been given were poor. When asked by Cap Com if he had any further ideas about acquiring the Laredo site for the next observation, he mentioned the possibility of using a large lake which is believed to be Falcon Lake.

Action Items

A request was made to the experiments specialist that he attempt to insure that the crew will have time, uninterrupted by voice communication from the ground, to acquire the Laredo site on revolution 33 tomorrow.

August 23, 1965

The second planned observation was due August 23, 1965, during revolution 33 at elapsed time of 2 days 4 hours 25 minutes and 50 seconds. This was a pass to the north of the site. Ground range was 45 nautical miles. Slant range was 114 nautical miles at the time of closest approach. The crew were given an update of data for the pass including pitch and yaw angle and, contrary to the circumstances of the first observation, the spacecraft platform was operating this time. There was some routine conversation between Cap Com and the spacecraft before acquisition took place as in the case of the first day's attempt.

Conrad and Cooper reported as follows on the results of their attempt to acquire the Laredo site: Conrad stated that he did not see it but that the weather was clear. Cooper stated that he had managed to acquire the ground pattern and that he had been able easily to identify a number of the markings against the background squares, but that he had not had time to write down a list of the orientations of the markings. The weather at the time of the pass was good.

Immediately after the pass, consultation took place and later, in conversations with Capsule Communicator, James McDivitt, the operations problems of site acquisition were discussed. Later in the day, a message from the experimenters was passed to the crew asking whichever crew member first acquired the site to be the one to note the orientations of the ground markings.

Close to the time of the pass, the NASA T-38 aircraft again took color photographs of the Laredo site. These were processed immediately on return and proved to be excellent of the ground patterns. Before the pass took place, all of the roads crossing the background squares were oiled. The photographs showed a marked improvement in uniformity of the dark background as a result of this procedure.

On ground square number 7, a miniature pattern was set up in the early morning for overflights in T-38 aircraft by the Gemini VII flight crew. Borman and Lovell made an early morning flight and were able to identify the orientations of the miniature markings correctly through the sixth marking. White and Collins made a similar flight later in the day and were able to identify correctly through the seventh marking.

Further attempts were made to provide additional aids to the visual acquisition of the site. A large smoke generator, already in use, was supplemented by colored smoke from smoke pots, but aerial observation did not indicate that this measure provided any appreciable gain in noticeability of the site. The possible use of long-burning, 2-million candle-power flares dropped from aircraft was explored; calculations predicted them to be virtually invisible against a sunlit earth background when viewed from the spacecraft.

A request was made to the experiments specialist that a further attempt be made to insure that the crew will have ample time uninterrupted by voice communication from the ground to acquire the Laredo site on revolution 45 tomorrow.

A request was made to the experiments specialist to include revolution 48 as an S-8/D-13 Laredo pass. The use of this pass for S-8/D-13 is not in the flight plan, but it is described as a contingency pass. The request was made in view of the fact that no quantitative results were obtained from the first two of the passes scheduled in the flight plan.

The possible use of sky-writing aircraft to aid site acquisitions was explored. Efforts failed to arrange for a trial of this concept.

August 24, 1965

The third planned visual acuity observation test was carried out soon after sunrise on August 24, 1965, on revolution 45 at an elapsed time of 2 days, 23 hours, 33 minutes, and 46 seconds. At closest approach the ground range was 8.1 nautical miles and the slant range was 115 nautical miles. The spacecraft passed south of the site on a heading of 72.6°. Astronaut Conrad reported acquiring the smoke marker approximately 200 miles out, but neither astronaut acquired the target array. Acquisition of smoke at such a distance can be attributed to the vertical development of the smoke cloud and to intense forward scattering due to the low sun angle, which resulted in very bright smoke. At closest approach, however, the low sun angle reduced the contrast of the ground pattern too much to permit the array to be seen. It should be noted that the spacecraft platform was operating during this pass and that adequate updated data had been passed on to the pilots.

At the request of the experimenters, the experiments specialist arranged for revolution 48 to be used as a visual acuity data acquisition pass. It occurred at an elapsed time of 3 days, 4 hours, 17 minutes, and 14 seconds under high sun conditions. This pass was south of the target array on a heading of 109°, with a ground range of 78.62 miles and a slant range of 135 miles. Astronaut Cooper reported acquisition of the smoke marker at an estimated slant range of 200 to 250 miles, before turning the spacecraft to remove sunlight from Astronaut Conrad's window. The latter reported sighting the stimulus array after closest approach but he was unable to give a reading for all of the markings. He only reported the orientations on "the second and third squares in the second row" as 2's. This was not correct; the true orientations on these squares were 4 and 3, respectively. Astronaut Conrad stated that his inability to make readings on all markings was due to the fact that he did not acquire the array until after he had gone by. The experimenters noted that when viewed going away, the orientation of the markings on the "second and third squares in the second row" of the array were 2's. Because of this possibility, several questions were generated to be passed on to the Cap Com for relay to Astronauts Cooper and Conrad on the next pass over the United States. Some of these questions were transmitted but they failed to clarify the confusion.

A request was made to the experiments specialist to include revolutions 77 and 90 as additional S-8/D-13 data passes. Also, a request was made to use revolution 73 as a trial or anecdotal sighting over the Woodleigh, Australia pattern array. Such a sighting would provide practice for the actual data acquisition sighting. It was also requested that revolutions 88 and 103 be used as data acquisition passes over the Woodleigh, Australia sight for S-8/D-13.

In order to further enhance the acquisition probability of the Laredo site and to clarify marking orientation, arrangements were made to place smoke pots along the northern boundary of the pattern array.

August 25, 1965

On August 25, 1965, the visual acuity observation test was planned for the 60th revolution at an elapsed time of 95 hours, 24 minutes, and 32 seconds, with a closest approach of a ground range of 80.87 miles, an altitude of 115.47 miles, and a slant range of 140 miles. This observation was scrubbed due to prohibitive cloud layers. A request was made to the experiments specialist for a contingency pass, but this was not approved due to conflict with other scheduled experiments.

The experiments specialist was further requested to confirm:

> The use of revolution 73 as a practice for the Woodleigh site with revolutions 88 and 103 as data passes for visual acuity observation on the

Woodleigh site, and the use of revolution 77 as a contingency pass for acuity observation on the Laredo site. He was able to give tentative confirmation for these items. Updated data on closest approach to the Woodleigh site showed revolutions 88 and 103 to be particularly good passes.

The 75th revolution is a scheduled observation pass for the Laredo site. However, this pass is very marginal in terms of the early hour, angle of the sun, angle of flight path, and slant range. Consequently, it has been decided to allow the D-6 experiment to use this pass.

It should be noted that the platform was not used on subsequent passes, due to a necessity for maintaining a "power-down" spacecraft configuration. Although this loss of platform was detrimental to pattern array acquisition, the probability of acquiring the Laredo site had been increased by the sightings to date, and the geographic features of the Woodleigh area should have enhanced acquisition of that array.

In the hope of clarifying the confusion concerning Astronaut Conrad's observation of the Laredo site on revolution 48, a brief set of debriefing questions was generated and sent to the carrier to be used by Dr. Earl Miller in his debriefing of the astronauts.

August 26, 1965

The results obtained for the subject experiment on August 26 are as follows: Revolution 73 was not used as a practice acquisition on the Woodleigh site due to marginal range and angular parameters and in order to conserve fuel for a more optimum pass, in light of updated orbit data. Revolution 77 was substituted; however, due to malfunction in the Gemini V thrusters, experiments requiring attitude control were scrubbed until further notice.

The experiments specialist requested alternative plans, where possible, in order to obtain meaningful information during drifting flight; the following items were submitted for consideration:

a. Astronauts should carry out the inflight-vision-tester exercise three times every 24 hours, instead of once every 24 hours.

b. Astronauts should attempt to acquire the Woodleigh and Laredo sites during drifting flight, and, if acquisition was obtained, a reading should be made, if possible.

c. Astronauts should attempt to photograph the general areas of Woodleigh, Laredo, and Yuma, using the Hasselblad. These photographs will provide a very valuable training aid for the Gemini VII crew.

Every effort is to be made to obtain a visual acuity observation on any pass where the attitude control system is used and where range and angular parameters are within limits.

August 28, 1965

On revolution 88, Astronaut Cooper acquired the array area and the smoke marking at the Woodleigh site from some considerable distance. Both astronauts also saw the smoke marking when they were 300 miles (estimated) beyond the array, but no readings could be made near the point of closest approach because the spacecraft was tumbling in drifting flight and the site was not within the field of view of the windows.

On revolution 92, Astronaut Cooper acquired the array area at Laredo and had a fleeting glimpse of the markings. Both astronauts attempted to photograph the site. It is interesting to note that Astronaut Conrad described the visual task of reading the array as if he were attempting this task while in an inverted spin.

Several plans for improving procedures for Gemini VII were discussed. Briefly, the suggestions were the following:

1. Use of movies of the Woodleigh and Laredo arrays as training films. These movies would simulate the inflight task and would be taken from appropriate altitudes, headings, elevation angles, and speeds and should enhance acquisition probability for the Gemini VII crew.
2. The back-up Gemini VII crew should serve as a ground baseline control for the inflight crew, using the inflight vision tester at the same time that the flight crew carries out the inflight vision test during the entire Gemini VII flight.
3. The inflight-vision-tester should be used by subjects carrying out long-duration chamber tests under 100 percent 0_2.
4. A special meeting should be held with the Gemini V crew, Gemini VII crew, principal investigator, and experiments personnel as soon as possible after splash down, in order to resolve detailed problem areas.

Word has been received from the experiments section that attempts will be made to carry out acuity observations on revolutions 103 (Woodleigh), 107 (Laredo), and 118 (Woodleigh), and, if possible, fuel will be used to obtain attitude control. Of course, this depends on the condition of the thruster system.

August 29, 1965

Clouds obscured the Woodleigh site on revolutions 103 and 118.

Acquisition of the site at Laredo was achieved by both pilots during drifting flight on revolution 92 and by the Command Pilot under conditions of damped rates on revolution 107. Weather conditions were ideal at Laredo on both occasions. Observation of the site on revolution 92 was fleeting due to high spacecraft tumbling rate, but both astronauts reported acquisition of the pattern and both attempted to photograph it. During revolution, 107 observations were made only by the Command Pilot since sunlight on the pilot's window obscured his view. The Command Pilot had only a brief inspection of the pattern at/or near the time of closest approach before yaw of the spacecraft swept the site from his field of view. During this momentary observation, he was able to note the orientation of two rectangles in the first row. Some ambiguity concerning which of the rectangles were reported will remain unresolved until the astronauts can be debriefed. Questions intended to resolve this ambiguity and that associated with the observations at Laredo on revolution 48 were forwarded to the aircraft carrier at the prime recovery area.

4.9 PLANS FOR GEMINI VII

Many valuable lessons were learned in the course of the visual acuity experiment conducted on Gemini V. The astronauts who flew that mission were most generous with their time both to the experimenters and to the Gemini VII crew. They made numerous suggestions to the experimenters that were subsequently adopted and they discussed their flight experiments at length with the Gemini VII crew.

The successful performance of the inflight vision tester and the inflight photometer as well as the many pieces of equipment used at the ground station throughout the Gemini V flight made alterations or changes in these items of equipment unnecessary. The principal changes suggested by the experience of the Gemini V out-of-the-window experiments involved alterations in the ground patterns, replacement of the Laredo site with one which could be more easily acquired by the flight crews, and the incorporation of a contingency pattern which could be used in the event of tumbling flight such as that experienced in Gemini V.

In response to the recommendations of the Gemini V crew, NASA produced a flight plan for Gemini VII in which both astronauts would sleep simultaneously, depending upon surveillance by tracking stations to ensure that all systems on the spacecraft remained functional throughout the sleep period. This departure resulted in many simplifications of the experiment programs. The Gemini V crew expressed concern that their visual performance as measured by the inflight vision tester might be seriously affected by fatigue level and they suggested that future inflight vision tests be made at some constant time with respect to the sleep cycle of the mission. The experimenters had designed the inflight vision tester on a forced-choice psychophysical procedure intended to measure thresholds below the onset of awareness which are unaffected by ordinary levels of fatigue. Spacecraft and spaceflight requirements, however, had forced the design of the inflight tester to present each given test pattern only four times during any one experimental session. This unfortunate circumstance tended to make the experiment work at an impoverished statistical level and, therefore, any opportunity to diminish or eliminate a second order effect was eagerly sought. For this reason it was requested and granted that the vision tester would be used each day immediately after the astronauts had finished a sleep period and had completed their morning meal. It was also arranged that they would perform the experiment with the vision tester near the end of a night pass of the earth so that there was no question about recovery from full daytime adaptation. It is interesting that the statistical analyses of the Gemini VII inflight vision tester data, detailed elsewhere in this report, do not show any appreciable effect attributable to this refinement in the technique of using the inflight vision tester.

It was the plan to launch Gemini VII into the same orbit used for most of the Mercury flights, an orbit having a launch azimuth of 72°. In this orbit the spacecraft would pass over the desert areas of southern California and Arizona in precisely the same way that Lt. Col. Cooper's Mercury capsule had done when he made his excellent sightings in the vicinity of El Centro, California. The attractive possibility of making a new ground site in that area for use on Gemini VII has been described in an earlier section. Had this plan been carried out, Gemini VII would have afforded two excellent, easily acquired sites having clear weather throughout the mission.

The out-of-the-window experiment on Gemini VII was nearly wiped out of existence when it became necessary to combine the Gemini VI and Gemini VII missions, following the failure of the Gemini VI target Agena to achieve orbit. In order to make the rendezvous mission possible in Gemini VII it was necessary to change launch azimuth to 82.5° and to shift the launch time to 1430 hours EST. This had the effect of causing the spacecraft to pass over the Australian site during hours of darkness throughout almost all of its mission. Only one pass suitable for the experiment could be made at the Australian site and this only on the last day of the mission. Change in launch azimuth caused the track of the spacecraft to pass more than 300 miles south of the proposed new site in California, thus, the plan for that site had to be abandoned. Due to the very limited time available after the decision by NASA to change the orbit of Gemini VII, there was no opportunity to find or to construct another site where the out-of-the-window experiment could be conducted. The choice lay between abandoning the experiment altogether or reopening the site at Laredo in the hope that the gloomy weather predictions for that area would prove to be untrue during December of 1965, so that the experiment could be performed. This was, admittedly, a gamble with poor odds but it was one which NASA and the U. S. Navy decided to accept. It was also decided not to reopen the Australian site because of its usefulness on only the last day of the fourteen-day mission. It was noted that spacecraft would pass over the Laredo site during favorable daytime hours on that occasion so that if suitable weather existed at Laredo, the experiment could be done there at that time, if indeed, Gemini VII was still in orbit on the fourteenth day. The very great expense of sending equipment and personnel to Australia for a long period of time plus the necessary refurbishing of the Australian site represented too great an investment for the fairly unlikely chance that the site would be cloudfree and the spacecraft would still be in orbit at the extreme end of its planned mission.

The Laredo site was in a countryside providing virtually no useable natural landmarks. For hundreds of miles the pattern of the countryside repeated and repeated in such a fashion that acquisition of the site was extremely difficult. Smoke, back-lighted by the rising sun, had helped the Gemini V crew to acquire the site, but the passes over Laredo expected in Gemini VII were to be with a high sun; under this circumstance, smoke was bound to be much less effective. Experience in Gemini V had indicated, moreover, that after the spacecraft was pitched down and underwent a combined yaw and roll manuever in order to keep the experimental site in view of the windows throughout the overpass, it was difficult to identify directions on the ground. The Gemini V pilot suggested that the northernmost row of four squares at Laredo could contain very large permanent marker bars to identify the site as well as to define the northern edge of the array.

The northernmost row of squares in the Laredo array were less favorable from the standpoint of uniformity of the background soil than the eight squares which comprised the middle and southernmost rows of the array. The Gemini V crew also felt that a twelve-element array was unduly difficult to inspect during the limited time available during the overflight and strongly recommended that the number of rectangles be reduced at least to eight. Although the use of fewer rectangles made the choice of bar-lengths more critical, based as it was on weather predictions and soil moisture forecasts necessarily made twenty-four hours in advance, it was decided to use only eight rectangles and to place very large permanent bars in the northernmost row of squares. These bars were made of white granular gypsum. They were long rows of this white material, 200 feet wide and extending east-west across the middle of each of the four northernmost squares. There were, therefore, four large white rectangles in line extending from east to west just north of the array, each rectangle being 200 x 2000 feet. These were, far above the visual threshold from space so that they were easily seen and fulfilled the purpose of identifying the site. In addition they insured that the orientation of the rectangles would be unambiguous.

Plans were made for a contingency pattern to be used in case the spacecraft was in tumbling flight. This pattern can be seen on page 9 of the Mission Operation Plan and on page 77 of the Experiment Procedure Section of the Gemini VII Flight Plan which are reproduced in Appendix D of this report. If it had become necessary to invoke the emergency plan, the third square in the middle row of the Laredo array would have had its rectangle replaced with a pattern of five white circular discs ranging in size from a very large one in the middle of the square to a disc only one-eighth of that diameter in one of the corners with graded sizes of circular discs in the other corners of the square. The largest disc should have been easily seen from space and the astronaut would have been asked to tell at a glance how many of the circular discs he could see. This vision experiment would not have provided as significant information as the rectangle orientation test but probably could have been performed during tumbling flight. Fortunately, no need arose to use the contingency patterns.

4.10 THE CHRONOLOGY OF OPERATIONS ON GEMINI VII

Gemini VII was launched from Cape Kennedy at 2:30 p.m. Eastern Standard Time on December 4, 1965. Rains at the Laredo target site which had hampered the work of preparation, had ended and the skies were clear. Except for the slightly muddy condition of the ground squares and the service roads at the site, conditions were ideal for the purposes of the experiment. Fortunately, clear weather continued throughout the next two days. In this time, quantitative observations of the site were made three times, on revolutions 16, 17, and 31. Thereafter, the rain clouds returned and persisted. Never again was it possible for the Gemini VII crew to see ground in the vicinity of Laredo.

Despite the gloomy predictions of the meteorologists at the Manned Spacecraft Center, the Visibility Laboratory crew and the construction personnel manned the Laredo site throughout almost the entire mission. This futile effort, based upon hope but not upon meteorological forecasts, became increasingly difficult because of the continuing rains. These were almost a steady downpour which turned the plowed land into quagmires and made the roads increasingly difficult to traverse. The site was located twenty-one miles from the main highway. A secondary all-weather road existed most of the way to the site but the last seven miles were without gravel or any other form of all-weather road construction. As the rains continued it became impossible to reach the site even with four-wheel drive military vehicles. Thereafter, only horseback riders could traverse the muddy roads and at this point the scientific party and the labor force abandoned their attempts to be at the site each day. They continued, however, to be on standby in nearby towns. Bad weather continued even beyond the end of the Gemini VII flight. Roads were impassable for a considerable period after the flight terminated. The various trailer vans and other equipments could not be brought out for more than a month.

So far as the out-of-the-window experiment is concerned the chronology of Gemini VII was short. The first scheduled observation was revolution 16. This was the first time that the crew had attempted to find the site from space. To help, they carried a picture of the site that had been taken by the Gemini V crew. This showed the pattern of the rivers and some distinctive bands of red soil in the vicinity. The command pilot succeeded in acquiring the site and maneuvering the spacecraft to provide a view of it for the pilot prior to the time of closest approach. The latter, on the other hand, was severly handicapped by the extreme degree of contamination on his window. This had occurred during launch when, during booster engine cutoff, a cloud of material produced by the separation mechanism enveloped the spacecraft and left deposits on the outer surface of its windows. Sketches made by the flight crew and careful maps derived from data taken with the inflight photometer were in agreement concerning the pattern of the contamination of both of the windows. The pilot's window was much more severely contaminated. Fortunately, the effect was minimal in the lower right corner where the inflight photometer was located. It was worse at the center of the window where the pilot was obliged to do his inspection. During the postflight scientific debriefing, the pilot reported that the contamination was so severe in some parts of his window that he could not see the nose of the spacecraft clearly. Not all parts of the central portion of his window were obscured to this extent and he was able to find a spot where he could make out the ground well enough to acquire the site. He reported that the four large marker bars were plainly discernible and fulfilled their purpose in providing easy orientation information. The small rectangles were, however, much less visible to him than had been planned and it was not, therefore, possible for him to make the quantitative observations that would enable his visual threshold to be ascertained in the manner desired. Nevertheless, the pilot endeavored to give a quantitative report, but the observations were not made within the prescribed time period centered about the closest approach. He did not discriminate the rectangle orientations correctly.

The command pilot reported that he had seen the pattern well and that the inboard portion of his window was free of contamination. The experimenters immediately requested and received permission to repeat the experiment on the following revolution. Instructions were passed to the spacecraft for the command pilot to make the sightings through the clear portion of his window.

There was not enough time between the overpass on revolutions 16 and 17 to make any change in the size or orientation of the rectangles at the Laredo site. This was indeed unfortunate because the array had been designed with the geometry of revolution 16 in mind. In that instance the ground-track of the spacecraft was north of the site, so that the shadowed side of the east-west furrows was presented to the astronauts. Thus, the background of the panels appeared very dark and the inherent contrast was correspondingly high. The width of the rectangles had been reduced to make the apparent contrast at the spacecraft fall in a sensitive portion of the curve and to bracket the visual threshold data of the pilot. The geometry of revolution 17, however, was quite different. On this pass the ground track of the spacecraft passed south of the target site so that the sunlit side of the east-west furrows was presented to the astronauts. The background soil was, therefore, much brighter and the inherent contrast was correspondingly lower. The slant range of observation for revolution 17 was somewhat longer than that for revolution 16. Thus, the apparent angular size of the rectangles was smaller in the case of revolution 17. Both of these factors combined to make the position of the array as plotted on Fig. 4-25* far from desirable. To make matters worse, the visual threshold curves determined in the training van for the command pilot were in a slightly different position on the diagram than those for the pilot and this effect was also in the wrong direction for the good of the experiment.

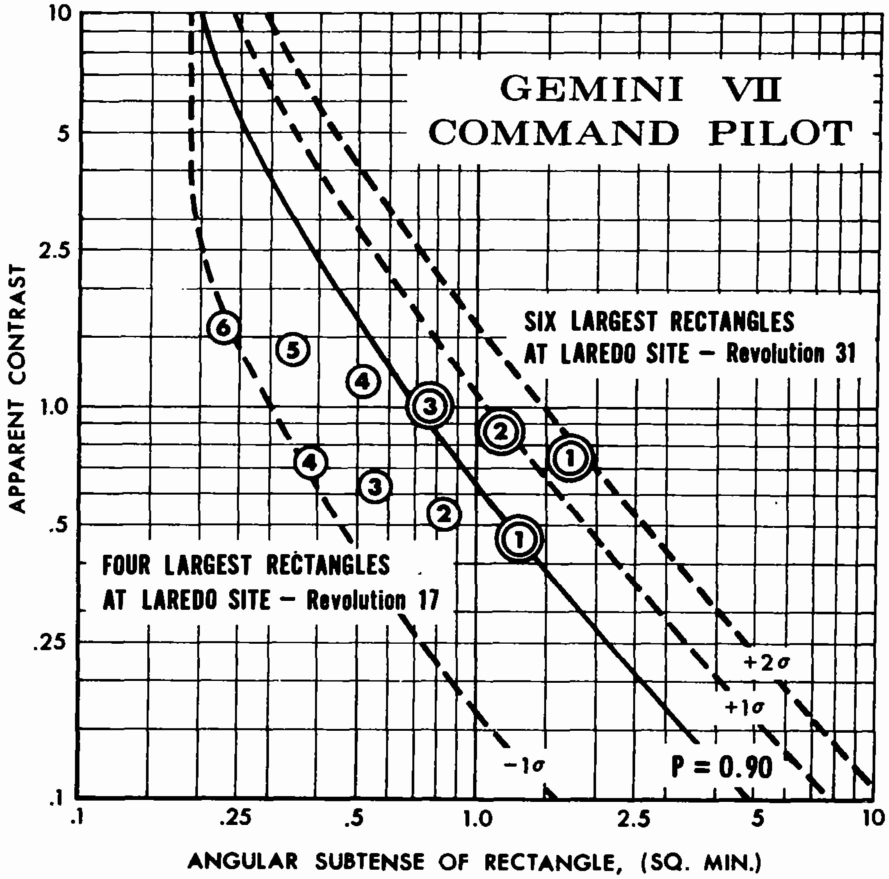

Fig. 4-25. Apparent contrast versus angular size of rectangles.

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[*] This figure appears in Appendix A as Fig. 28, and is reproduced here as Fig. 4-25 for convenience of the reader.

A hasty plot of the expected new conditions for revolution 17 showed that the command pilot would be expected to discriminate correctly only the largest square in the array. This unfortunate circumstance cast doubt upon the wisdom of attempting the experiment on revolution 17 because of a different consideration. This involved the budget of maneuvering fuel for Gemini VII. From the outset this was critical because of the possible requirements of the forthcoming rendezvous with Gemini VI. The allotment of maneuvering fuel for all of the Gemini VII experiments had been reduced. That allowed for the visual acuity experiment was seven pounds. About one pound of fuel was ordinarily used in controlling the attitude of the spacecraft throughout an overpass, although expert piloting sometimes accomplished the overpass maneuver with less. The experimenter was faced with the prospect of having fuel for only seven attempts at the out-of-the-window experiment. It should be noted, however, that a favorable revision of the fuel budget during the latter portion of the flight was a possibility, depending upon how much fuel was actually consumed in the rendezvous maneuver. The decision with respect to revolution 17 was, of course, whether to commit one of the seven pounds of fuel to a sighting experiment the result of which was dubious because the array was not properly sized for the pass geometry. The question was resolved by conference with the Meteorology Office at the Mission Control Center whose forecast for continued fair weather at the Laredo site was gloomy indeed. Their advice which proved to be completely accurate, was that favorable weather past the third day of the mission was extremely unlikely, although there was a possibility of clearing before the end of the fourteen-day period. The experimenter decided to go ahead with an observation attempt on revolution 17.

It has already been mentioned in this report that the command pilot acquired the Laredo site on revolution 17 and read the array at precisely the time of closest approach. Exactly as predicted, he correctly reported the orientation of the largest rectangle but was unable to discriminate correctly the orientation of the smaller one. This result was indeed heartening to the experimenters and to the crew in the spacecraft. Optimism ran high that conditions could be made ideal for the sighting experiment scheduled on the flight plan for revolution 31 on the following day. The meteorologist at the Mission Control Center predicted continuing fair weather for that revolution.

The ground track of the spacecraft for revolution 31 was such as to take it north of the site. High inherent contrast was expected, therefore, much as in the case of revolution 16. The combination of sunshine and light dry winds was rapidly reducing the moisture content of the surface of the soil in the background squares at Laredo. For this reason the reflectivity of the soil was increasing and it was necessary to make a careful estimate of the luminance of the background soil at the time of closest approach for revolution 31. The success with which this was accomplished is attested by Fig. 4-25, which shows that the array bracketed the performance threshold curve of the command pilot nicely.

Despite the muddy working conditions in the background squares at Laredo which denied the work force the use of motorized vehicles on the squares and required all panels to be hand carried, the orientation of several squares was changed and the widths were adjusted in accordance with the predicted requirements. All was in readiness as the time approached for the observation on revolution 31.

The skies were cloudless and atmospheric conditions clear at the time of revolution 31. The command pilot acquired the site without difficulty and read the orientation of the array at precisely the specified time. As shown by Fig. 4-25 he correctly reported the orientation of the three largest rectangles and was unable to discriminate the remainder of the array. He chose not to attempt guesses but to limit his reports to the orientations of those rectangles which he felt he could correctly discriminate. Fig. 4-25 shows that, just as in the case of his performance on revolution 17, the command pilot correctly discriminated and reported the orientation of the rectangles equal to or larger than his P = 0.90 threshold curve as determined in the training van before flight.

The results depicted by Fig. 4-25 for revolutions 17 and 31 on Gemini VII constitute the principal results of the out-of-the-window experiment. They support the conclusion drawn from the inflight vision tester that the visual capability of the command pilot in orbit was identical with that which he exhibited in the training van before flight. They demonstrate, moreover, that the measurement of the rectangle and background optical properties, the lighting, the atmosphere, and the properties of the spacecraft window enabled the apparent contrast at the astronaut's eye to be predicted correctly. They show that the visibility calculation methods that have been used to predict the visual capabilities of aviators to discriminate small objects on the ground from aircraft can be applied to make valid predictions of the visual capabilities of astronauts in orbit.

The sightings on revolution 31 were the last to be made by the crew of Gemini VII. Before their next scheduled overpass on the following day, clouds had overspread the Laredo site and shortly thereafter the heavy rains began which persisted until well after the termination of Gemini VII.

APPENDIX A

A succession of summary reports were produced soon after the Gemini V and Gemini VII missions, respectively, and were published by NASA, primarily in NASA Special Publication 121, February 1966, issued in connection with the Gemini Mid Program Conference, which was held at the Manned Spacecraft Center in Houston. The same material appeared subsequently as a Visibility Laboratory Report identified as Scripps Institution of Oceanography Reference 66-17, July 1966. That report with minor updates and corrections follows as Appendix A.

VISUAL ACUITY AND ASTRONAUT VISIBILITY

GEMINI V AND GEMINI VII MISSIONS

MANNED SPACE FLIGHT EXPERIMENT S-8/D-13

SUMMARY

Preflight, inflight, and postflight tests of the visual acuity of both members of the Gemini V and Gemini VII crews showed no statistically significant change in their visual capability. Observations of a prepared and monitored pattern of rectangles made at a ground site near Laredo, Texas, confirmed that the visual performance of the astronauts in space was within the statistical range of their respective preflight thresholds, and that laboratory visual acuity data can be combined with environmental optical data to predict correctly man's limiting visual capability to discriminate small objects on the surface of the earth in daytime.

INTRODUCTION

Reports by Mercury astronauts of their sighting small objects on the ground prompted the initiation of a controlled visual acuity experiment which was conducted in both Gemini V and Gemini VII. The first objective of Experiment S-8/D-13 was to measure the visual acuity of the crew members before, during, and after long-duration space flights in order to ascertain the effects of a prolonged spacecraft environment. The second objective was to test the use of basic visual acuity data combined with measured optical properties of ground objects and their natural lighting, as well as of the atmosphere and the spacecraft window, to predict the flight crew's limiting naked-eye visual capability to discriminate small objects on the surface of the earth in daylight.

INFLIGHT VISION TESTS

INFLIGHT VISION TESTER

Throughout the flights of Gemini V and Gemini VII the visual performance of the crew members was tested one or more times each day by means of an inflight vision tester. This was a small, self-contained, binocular optical device containing a transilluminated array of 36 high-contrast and low-contrast rectangles. Half of the rectangles were oriented vertically in the field of view and half were oriented horizontally. Rectangle size, contrast, and orientation were randomized; the presentation was sequential; and the sequences were nonrepetitive. Each rectangle was viewed singly at the center of a 30-degree adapting field, the apparent luminance of which was about 100 foot-lamberts.* Both members of the flight crew made forced-choice judgments of the orientation of each rectangle and indicated their responses by punching holes in a record card. Electrical power for illumination within the instrument was derived from the spacecraft.

The space available between the eyes of the astronaut and the sloping inner surface of the spacecraft window, a matter of 8 or 9 inches, was an important constraint on the physical size of the instrument. The superior visual performance of all crew members, as evidenced by clinical test scores, made it necessary to use great care in aligning the instrument with the observer's eyes, since the eyes and not the instrument must set the limit of resolution. In order to achieve this, the permissible tolerance of decentering between a corneal pole and the corresponding optical axis of the eyepiece was less than 0.005 of an inch. This tolerance was met by means of a biteboard equipped with the flight crew member's dental impression to take advantage of the fixed geometrical relation between his upper teeth and his eyes. Figure 1 shows a photograph of the inflight vision tester.

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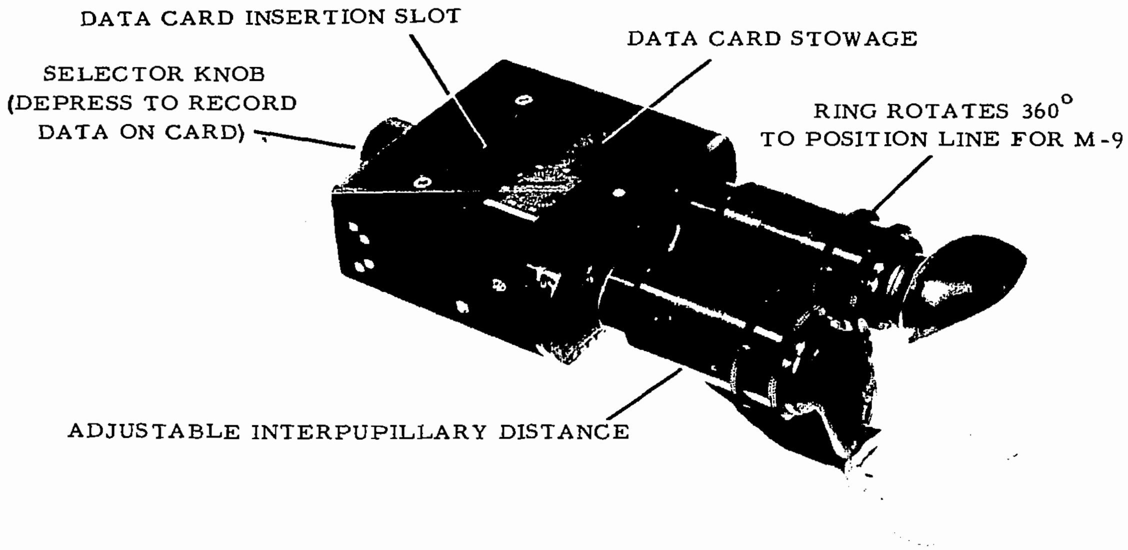
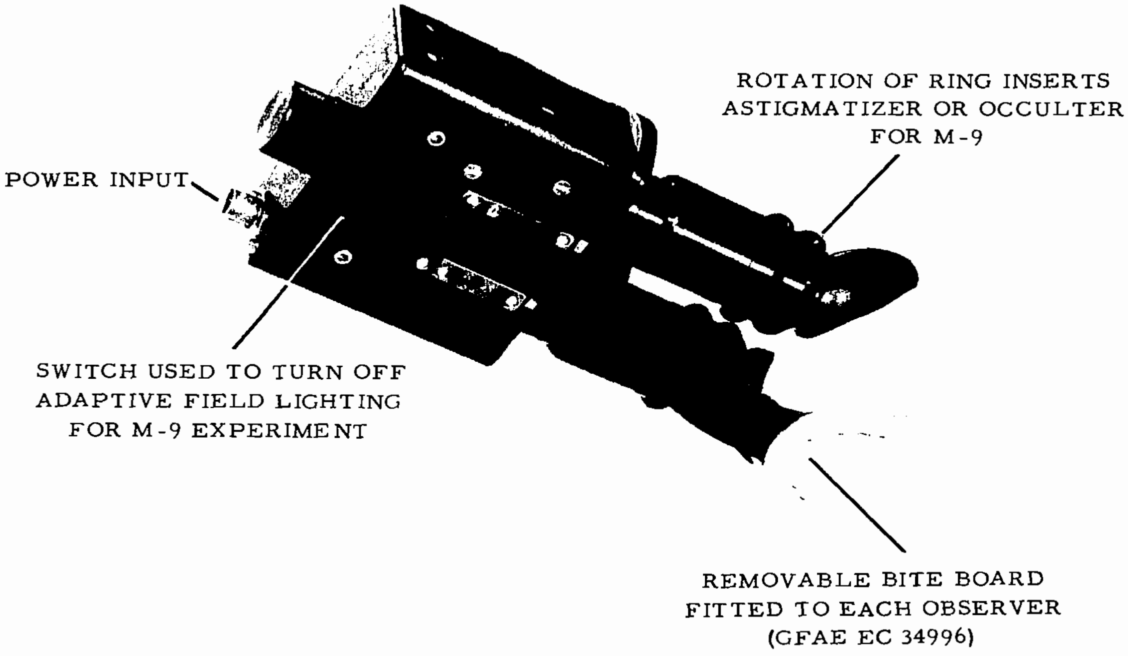
* The measurements before flight were 110 ft-L for left eye, 114 ft-L for the right eye. The corresponding numbers postflight were 99 and 102 ft-L, respectively.


DATA CARD INSERTION SLOT
DATA CARD STOWAGE
SELECTOR KNOB (DEPRESS TO RECORD DATA ON CARD)
RING ROTATES 360° TO POSITION LINE FOR M-9
ADJUSTABLE INTERPUPILLARY DISTANCE


ROTATION OF RING INSERTS ASTIGMATIZER OR OCCULTER FOR M-9
POWER INPUT
SWITCH USED TO TURN OFF ADAPTIVE FIELD LIGHTING FOR M-9 EXPERIMENT
REMOVABLE BITE BOARD FITTED TO EACH OBSERVER (GFAE EC 34996)

SELECTION OF THE TEST

The choice of test was made only after protracted study. Many interacting requirements were considered. If, for example, the visual capabilities of the astronauts should change during the long-duration flight, it was of prime importance to measure the change in such a way that man's inflight ability to recognize, classify, and identify landmarks or unknown objects on the ground or in space could be predicted. These higher-order visual discriminations depend upon the quadratic content of the difference images between alternative objects, but virtually all of the conventional patterns used in testing vision yield low-precision information on this important parameter. Thus, the prediction requirement tended to eliminate the use of Snellen letters, Landolt rings, checkerboards, and all forms of detection threshold tests.

The readings must not go off-scale if visual changes should occur during flight. This requirement for a broad range of testing was not readily compatible with the desire to have fine steps within the test and yet have sufficient replication to insure statistically significant results.

It was also deemed desirable that the pattern chosen for the inflight vision tester should be compatible with that used on the ground where search contamination of the scores must be carefully avoided; this consideration made any conventional detection threshold test undesirable. The pattern on the ground was within sight for at least 2 minutes during all usable passes, but variations due to atmospheric effects, geometrical foreshortening, directional reflectance characteristics, et cetera, made it necessary to select a test which could be completed in a 20-second period centered about the time of closest approach.

The optimum choice of test proved to be the orientation discrimination of a bar narrow enough to be unresolved in width but long enough to provide for threshold orientation discrimination. The size and apparent contrast of all of the bars used in the test were sufficient to make them readily detectable, but only the larger members of the series were above the threshold of orientation discrimination. These two thresholds are more widely separated for the bar than for any other known test object. The inherent quadratic content of the difference image between orthogonal bars is of greater magnitude than the inherent quadratic content of the bar itself. Interpretation of any changes in the visual performance of the astronauts is, therefore, more generally possible on the basis of orientation discrimination thresholds for the bar than from any other known datum.

RECTANGLES IN THE VISION TESTER

The rectangles presented for viewing within the inflight vision tester were reproduced photographically on a transparent disc. Two series of rectangles were included, the major series being set at a contrast of -0.9 and the minor series being set at about one-fourth of this value. The higher contrast series constituted the primary test and was chosen to simulate the expected range of apparent contrast presented by the ground panels to the eyes of the crewmen in orbit. The series consisted of six sizes of rectangles. The sizes covered a sufficient range to guard against virtually any conceivable change in the visual performance of the astronauts during the long-duration flight. The size intervals were small enough, however, to provide a sufficiently sensitive test.

The stringent requirements imposed by conditions of space flight made it impossible to use as many replications of each rectangle as was desirable from statistical considerations. After much study it was decided to display each of the six rectangular sizes four times. This compromise produced a sufficient statistical sample to make the sensitivity of the inflight test comparable to that ordinarily achieved with the most common variety of clinical wall chart. This sensitivity corresponds roughly to the ability to separate performance at 20/15 from performance at 20/20. It was judged that this compromise between the sensitivity of test and the range of the variables tested was the proper one for this exploratory investigation.

A secondary test at lower contrast was included as a safeguard against the possibility that visual performance at low contrast might change in some different way. With only 12 rectangles assignable within the inflight vision tester for the low-contrast array, it was decided to use only three widely different rectangle sizes, presenting each of these sizes four times.

Because of the accelerated launch schedule of Gemini V it was not possible to use the flight instrument for preflight experiments. These data were, therefore, obtained with the first of the inflight vision testers (Serial No. 1) while the last instrument to be constructed (Serial No. 5) was put aboard the spacecraft. The two instruments were optically identical except for their 12 low-contrast rectangles, which measured a contrast of -0.30 and -0.21, respectively. In Gemini VII all of the reported data (preflight, inflight, and postflight) were obtained with Serial No. 5 tester.

ANALYSIS OF CORRECT SCORES IN GEMINI V

A comparison of the correct scores made by the Gemini V crew members on the ground (preflight) and in space (inflight) can be used to ascertain whether their observed visual performance differed in the environments or changed during the 7-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown for both crew members in Figure 2. The results of standard statistical tests applied to these data are shown in Tables I through IV.

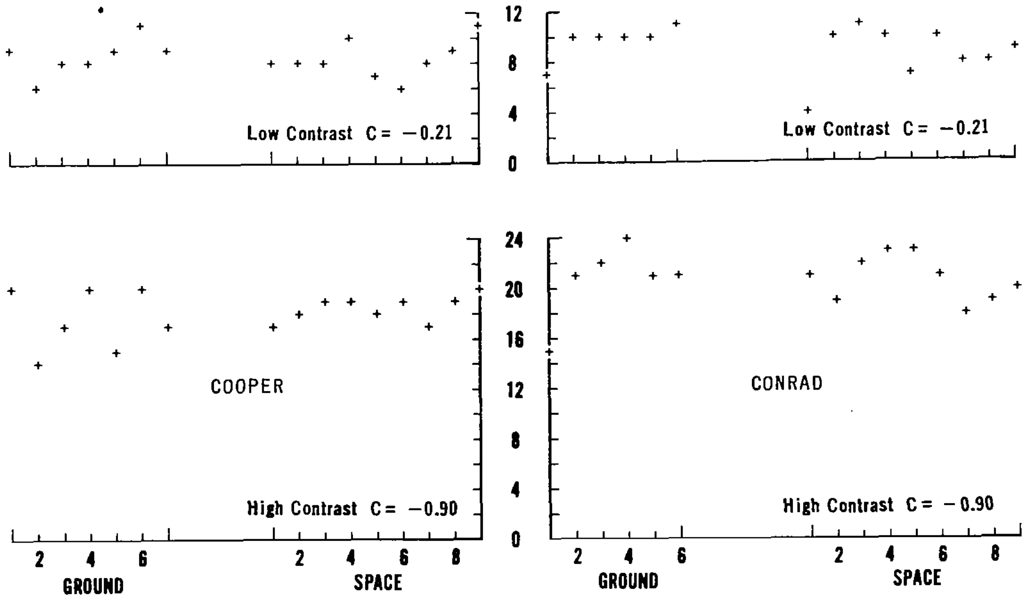


Fig. 2. Correct scores for the vision tester.

Comparisons between preflight and inflight data are given in Tables I and II. All student's t tests show no significant difference in means. All Snedecor's F tests show no significant difference in variances at the 0.05 level, with the exception of Cooper's high-contrast comparison which shows no significant difference at the 0.01 level.

TABLE I .- VISION TESTER (GROUND VERSUS SPACE)

CORRECT RESPONSES

GT-V Cooper	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number	7	9	7	9
Mean	17.6	18.4	8.6	8.3
Standard deviation	2.3	.96	1.3	1.4
t	0.96		0.31	
$t_{0.05}$	2.14		2.14	
F	6.12		1.02	
$F_{0.05}$	3.58		3.58	
$F_{0.01}$	6.37		-----------	

TABLE II .- VISION TESTER (GROUND VERSUS SPACE)

CORRECT RESPONSES

GT-V Conrad	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number	7	9	7	9
Mean	20.7	20.7	9.7	8.6
Standard deviation	2.7	1.7	1.2	2.0
t	0		1.13	
$t_{0.05}$	2.14		2.14	
F	2.79		2.43	
$F_{0.05}$	3.69		4.82	

Comparisons between the inflight data at the beginning of the mission with that at the end are made in Tables III and IV. All Student's t tests and Snedecor's F tests show no significant difference at 0.05 level with the exception of the F test on Conrad's low-contrast comparison which shows no significant difference at 0.01 level.

These statistical findings support the null hypothesis advanced by many scientists before the Gemini V mission was flown.

TABLE III.- VISION TESTER (INFLIGHT TREND)
CORRECT RESPONSES

GT-V Cooper	C = -0.9		C = -0.21	
	First 4	Last 4	First 4	Last 4
Number	4	4	4	4
Mean	18.2	18.8	8.5	8.5
Standard deviation	.83	1.1	.87	1.8
t	0.68		0	
$t_{0.05}$	2.45		2.45	
F	1.73		4.33	
$F_{0.05}$	9.28		9.28	

TABLE IV.- VISION TESTER (INFLIGHT TREND)
CORRECT RESPONSES

GT-V Conrad	C = -0.9		C = -0.21	
	First 4	Last 4	First 4	Last 4
Number	4	4	4	4
Mean	21.3	19.5	8.8	8.75
Standard deviation	1.5	1.1	2.8	.83
t	1.64		0	
$t_{0.05}$	2.45		2.45	
F	1.96		11.19	
$F_{0.05}$	9.28		9.28	
$F_{0.01}$	-----------		29.5	

ANALYSIS OF CORRECT SCORES IN GEMINI VII

A comparison of the correct scores made by the Gemini VII crew members on the ground (preflight) and in space (inflight) can be used to ascertain whether their observed visual performance differed in the environments or changed during the 14-day mission. The correct scores from the low-contrast and high-contrast series in the vision tester are shown for both crew members in Figure 3. The results of standard statistical tests applied to these data are shown in Tables V through VIII.

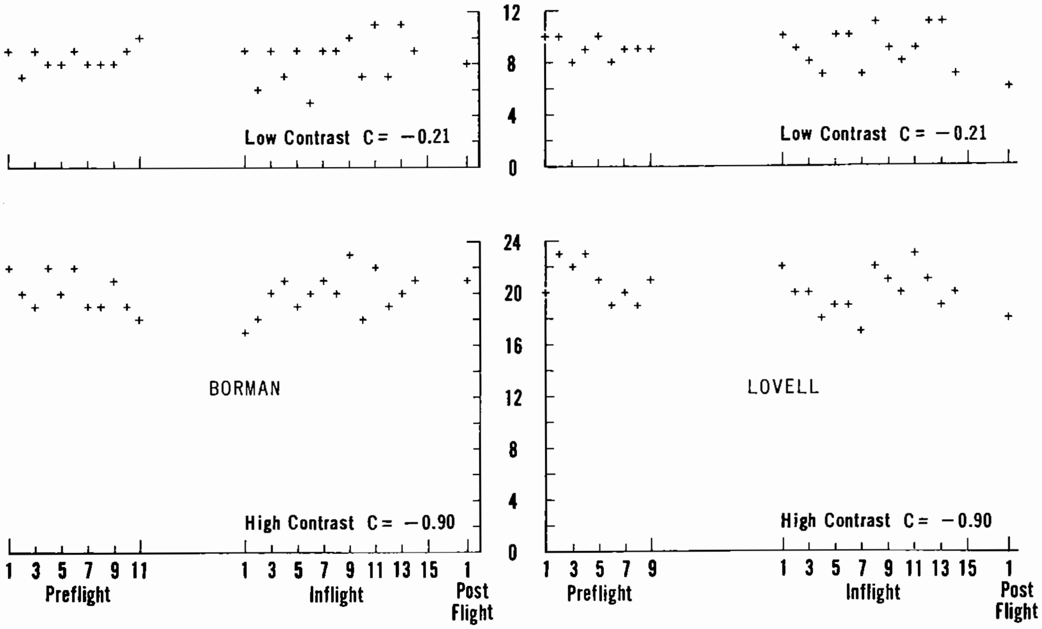


Fig. 3. Correct scores for the vision tester, Gemini VII.

Comparisons between preflight and inflight data are given in Tables V and VI. All Student's t tests show no significant difference in means. All Snedecor's F tests show no significant difference in variances at the 0.05 level, with the exception of Borman's low-contrast comparison which shows a weakly significant difference at the 0.01 level.

Comparisons between the inflight data at the beginning of the mission with that at the end are made in Tables VII and VIII. All Student's t tests and Snedecor's F tests show no significant difference at 0.05 level with the exception of the F test on Borman's low-contrast comparison which shows no significant contrast at the 0.01 level.

These statistical findings provide additional support for the null hypothesis advanced by many scientists before the Gemini missions were flown. Examination of the sensitivity of the test must be considered next. This topic is treated in the following paragraphs.

TABLE V .- VISION TESTER (GROUND VERSUS SPACE)
CORRECT RESPONSES

GT-VII Borman	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number	11	14	11	14
Mean	20.0	19.9	8.45	8.4
Standard deviation	1.3	1.6	.78	1.7
t	0.12		0.017	
$t_{0.05}$	2.07		2.07	
F	1.49		4.74	
$F_{0.05}$	2.89		2.89	
$F_{0.01}$	4.66		4.66	

TABLE VI .- VISION TESTER (GROUND VERSUS SPACE)
CORRECT RESPONSES

GT-VII Lovell	C = -0.9		C = -0.21	
	Ground	Space	Ground	Space
Number	9	14	9	14
Mean	20.9	20.0	9.1	9.1
Standard deviation	1.4	1.6	.74	1.4
t	1.29		0.073	
$t_{0.05}$	2.08		2.08	
F	1.17		3.64	
$F_{0.05}$	3.26		3.26	
$F_{0.01}$	5.62		5.62	

TABLE VII .- VISION TESTER (INFLIGHT TREND)

CORRECT RESPONSES

GT-VII Borman	C = −0.9		C = −0.21	
	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.0	20.0	8.0	9.0
Standard deviation	1.4	1.4	1.3	1.8
t	1.00		0.91	
$t_{0.05}$	2.31		2.31	
F	1.00		2.00	
$F_{0.05}$	6.39		6.39	

TABLE VIII .- VISION TESTER (INFLIGHT TREND)

CORRECT RESPONSES

GT-VII Lovell	C = −0.9		C = −0.21	
	First 5	Last 5	First 5	Last 5
Number	5	5	5	5
Mean	19.8	20.4	8.8	9.2
Standard deviation	1.3	1.5	1.2	1.6
t	0.60		0.91	
$t_{0.05}$	2.31		2.31	
F	1.27		1.88	
$F_{0.05}$	6.39		6.39	

PREFLIGHT PHYSIOLOGICAL BASELINE

Design of the inflight vision tester, as well as the ground sighting experiments described in subsequent paragraphs and the interpretation of the results from both experiments, required that a preflight physiological baseline be obtained for both crew members. For this purpose a NASA van was fitted out as a portable vision research laboratory, moved to the Manned Spacecraft Center at Houston, Texas, and operated by Visibility Laboratory personnel. Figure 4 is a cutaway drawing of this research van. The astronauts, seated at the left, viewed rear-screen projections from an automatic projection system located in the opposite end of the van. Each astronaut participated in several sessions in the laboratory van, during which they became experienced in the psychophysical techniques of the rectangle orientation discrimination visual task. A sufficiently large number of presentations was made to secure a properly numerous statistical sample. The astronauts' forced-choice visual thresholds for the discrimination task were measured accurately and their response distributions determined so that the standard deviations and confidence limits of their preflight visual performance were determined.

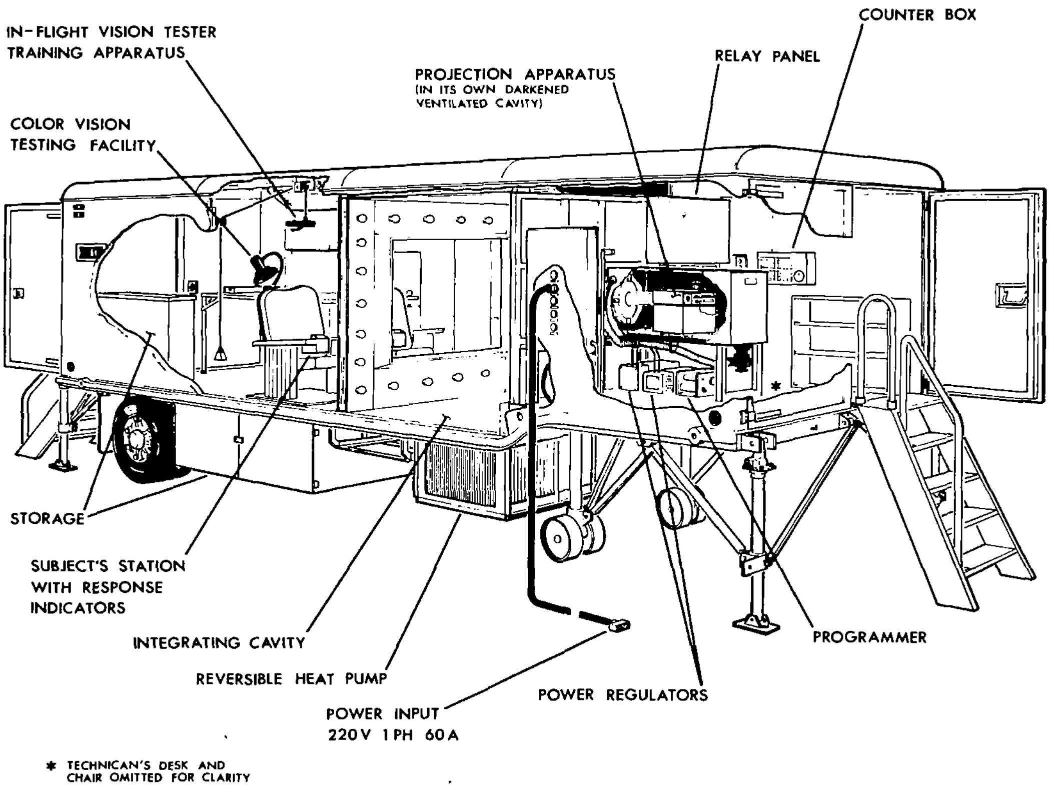


Fig. 4. Vision research and training van.

Figure 5 is a logarithmic plot of the Gemini V pilot's preflight visual thresholds for the rectangle orientation discrimination task. In this figure the solid angular subtense of the rectangles is plotted along the horizontal axis because both the inflight vision tester and the ground observation experiments used angular size as the independent variable. The solid line in this figure represents the forced-choice rectangle orientation threshold of the pilot at the 0.50 probability level. The dashed curves indicate the $-\sigma$, $+\sigma$, and $+2\sigma$ levels in terms of contrast. The six circled points in the upper row indicate the angular sizes of the high-contrast (C = -0.9) rectangles presented by the inflight vision tester. The three circled points of the middle and lower rows show the angular sizes of the low-contrast rectangles used in the preflight unit (Serial No. 1) and the flight unit (Serial No. 5), respectively.

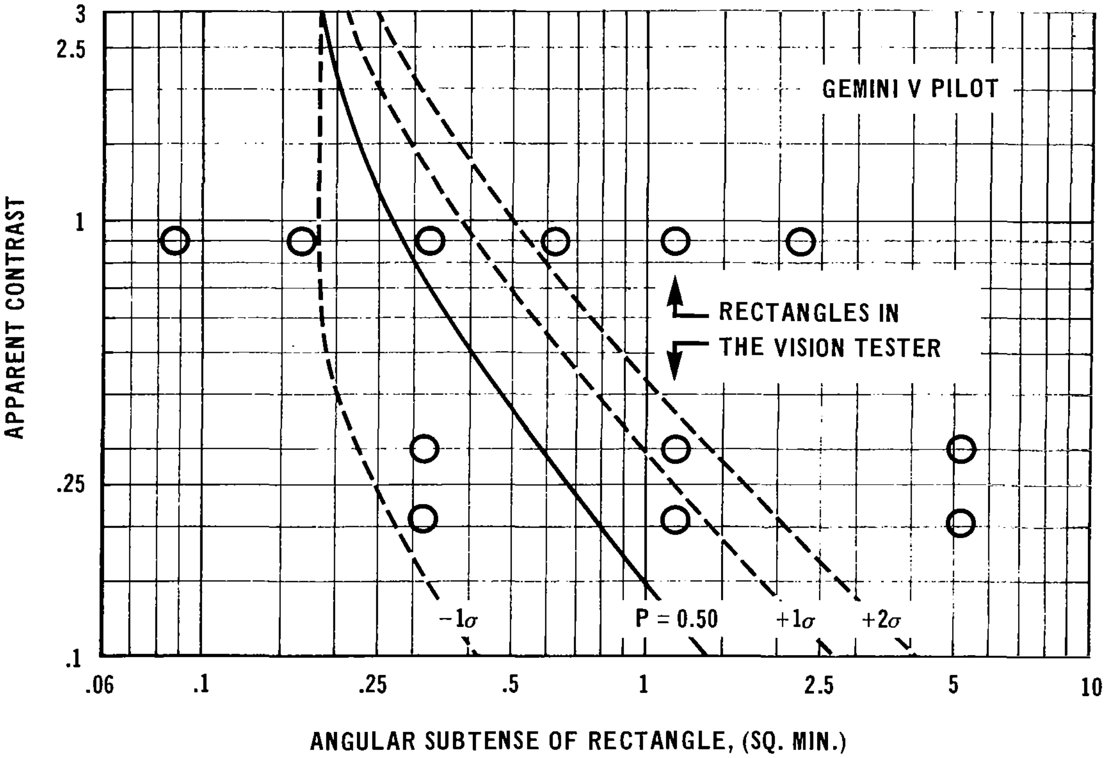


Fig. 5. Logarithmic plot of Gemini V pilot's visual thresholds.

The separate discriminations recorded on the record cards in the inflight vision tester can be used to determine a threshold of angular size. These thresholds and corresponding statistical confidence limits derived with the aid of Figure 5 are plotted for the high- and low-contrast tests of the Gemini V command pilot in Figures 6 and 7 and for the Gemini V pilot in Figures 8 and 9. Corresponding thresholds and confidence limits for the vision tester data secured by the Gemini VII command pilot are shown in Figures 10 and 11. Similar data secured by the Gemini VII pilot are shown in Figures 12 and 13.

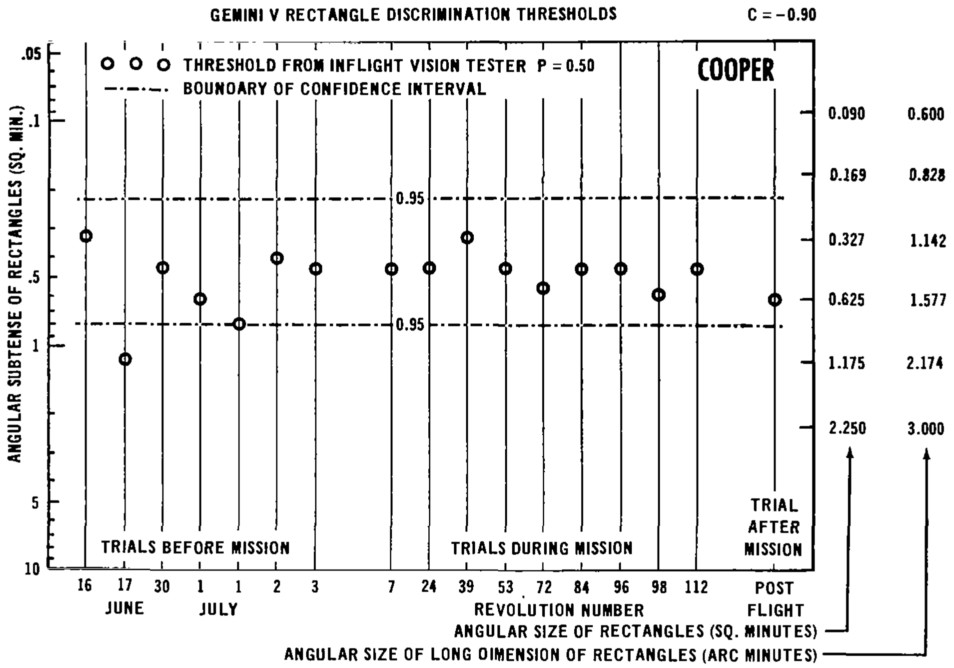


Fig. 6. Gemini V command pilot's rectangle discrimination thresholds HIGH CONTRAST.

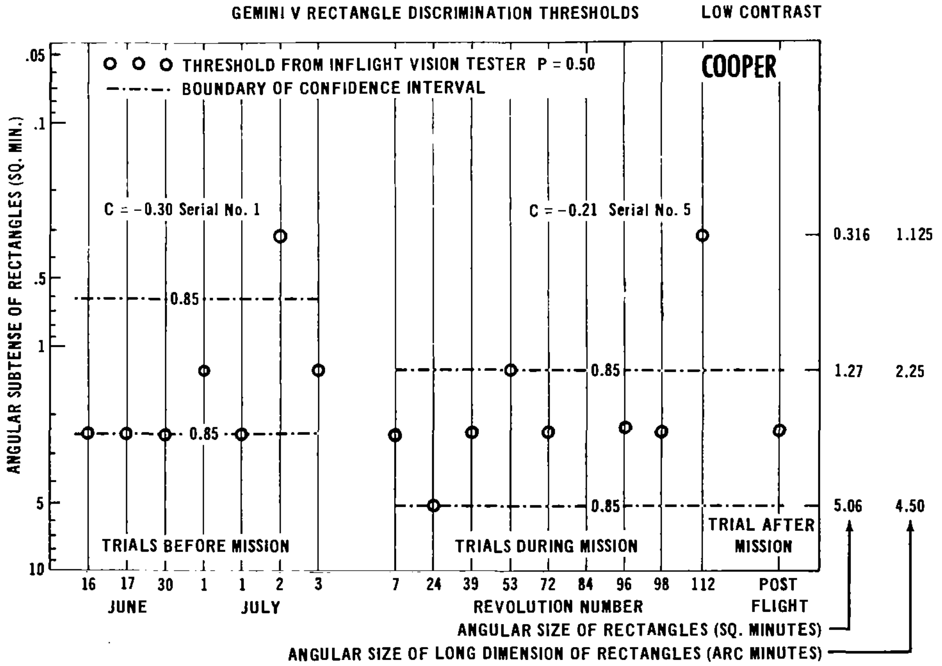


Fig. 7. Gemini V command pilot's rectangle discrimination thresholds LOW CONTRAST.

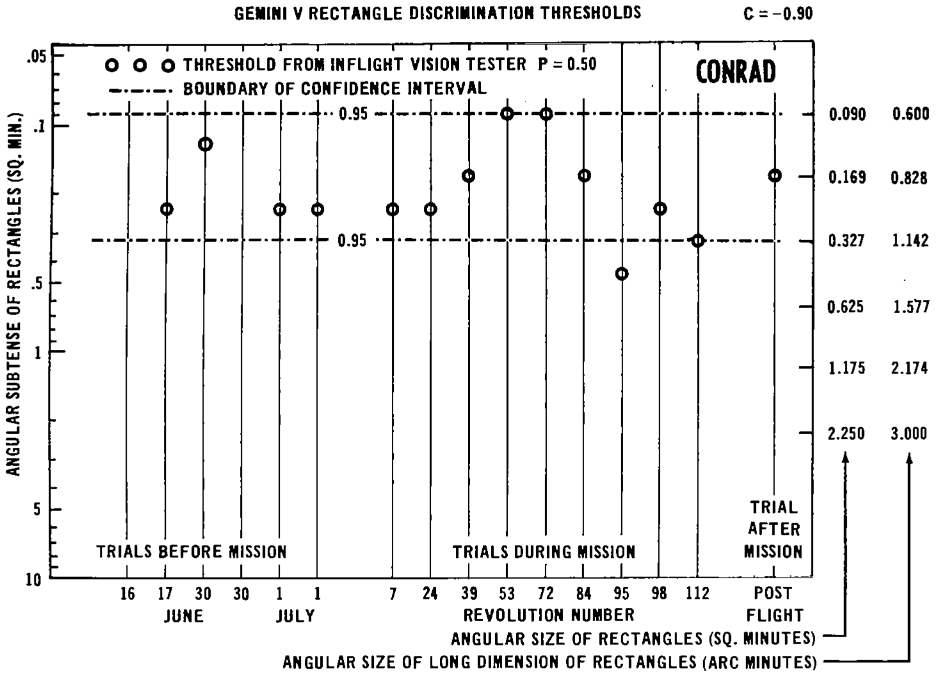


Fig. 8. Gemini V pilot's rectangle discrimination thresholds HIGH CONTRAST.

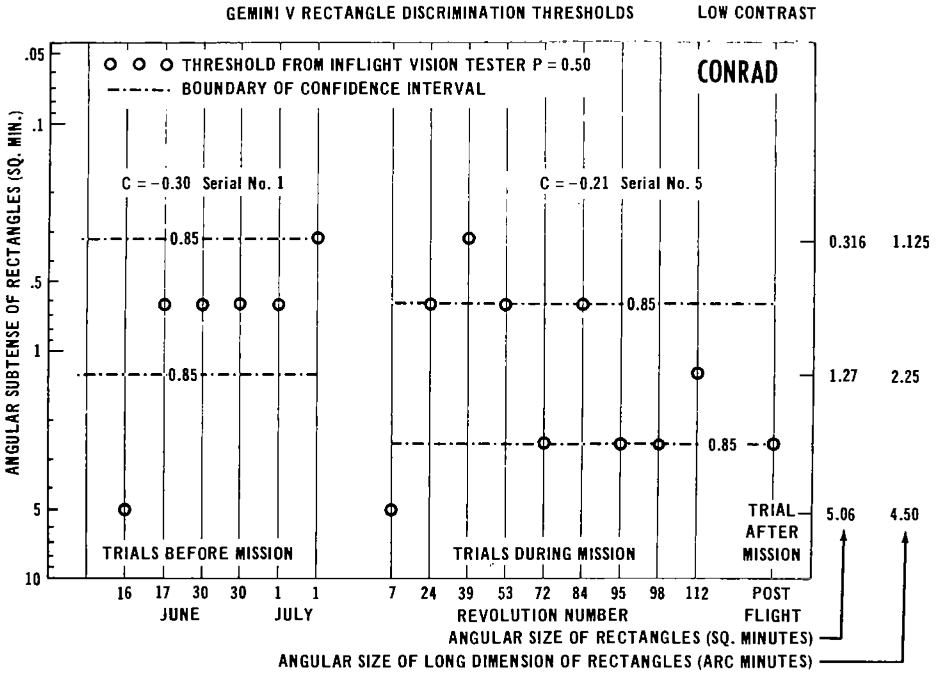


Fig. 9. Gemini V pilot's rectangle discrimination thresholds LOW CONTRAST.

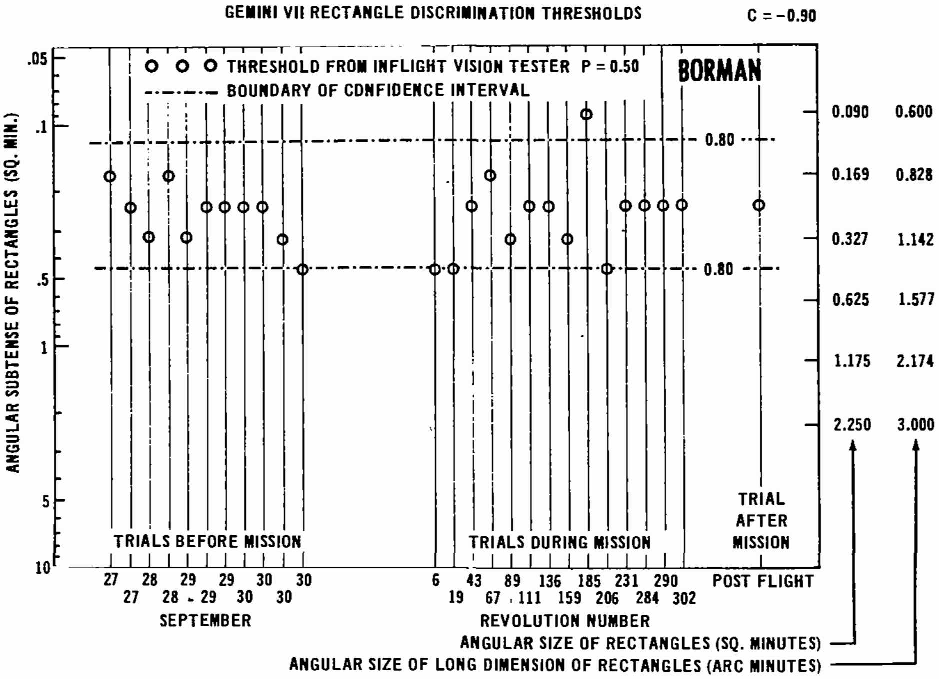


Fig. 10. Gemini VII pilot's rectangle discrimination thresholds HIGH CONTRAST.

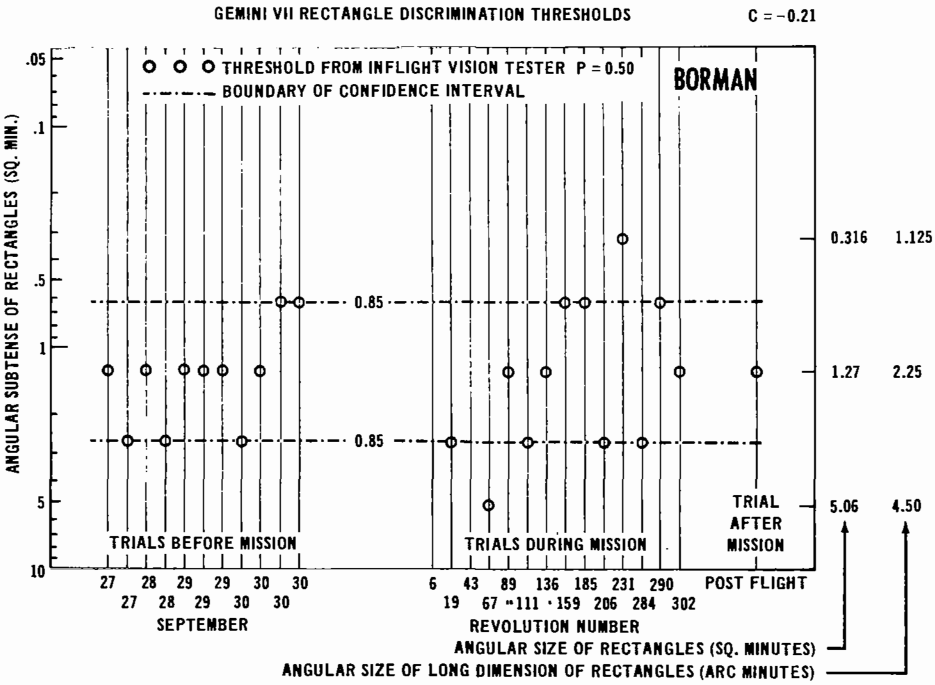


Fig. 11. Gemini VII command pilot's rectangle discrimination thresholds LOW CONTRAST.

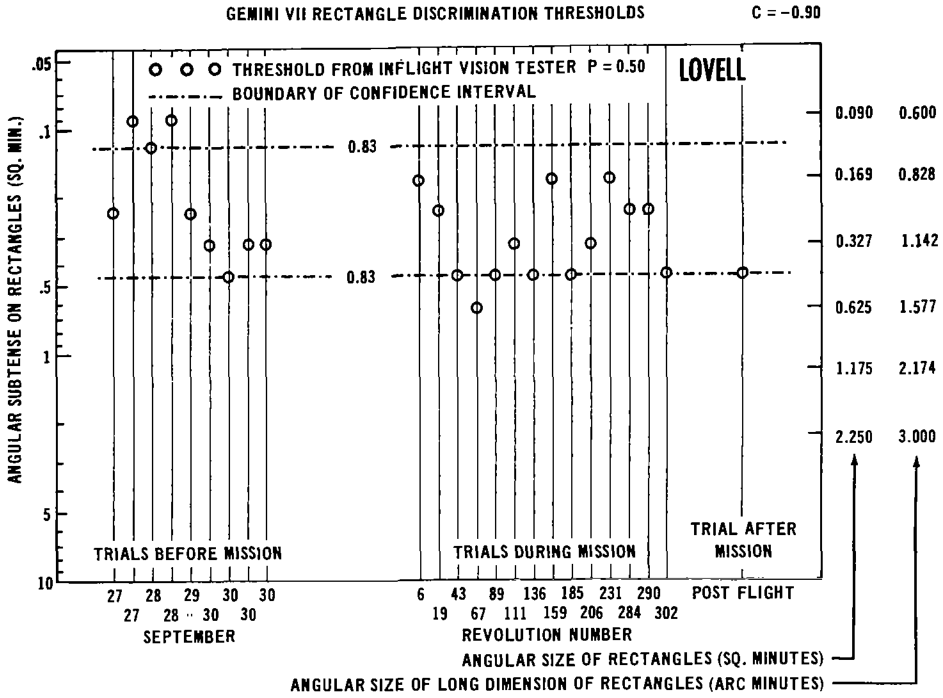


Fig. 12. Gemini VII pilot's rectangle discrimination thresholds HIGH CONTRAST.

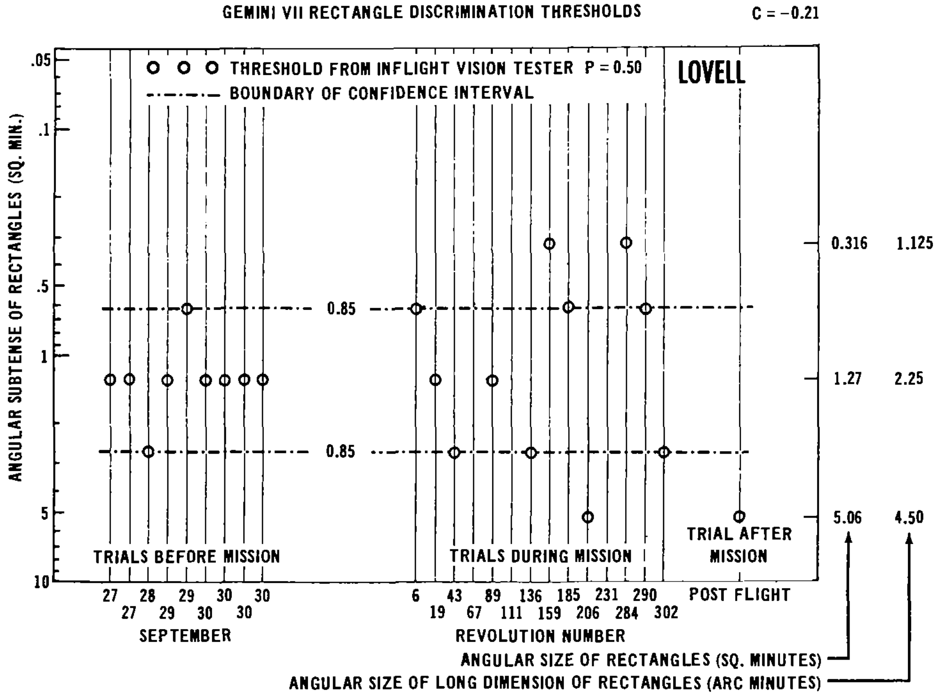


Fig. 13. Gemini VII pilot's rectangle discrimination thresholds LOW CONTRAST.

These eight figures also support the null hypothesis, and their quantitative aspect constitutes a specification of the sensitivity of the test. Thus, as planned, variations in visual performance comparable with a change of one line on a conventional clinical wall chart would have been detected. Preflight threshold data can, therefore, be used to predict the limiting visual acuity capabilities of astronauts during space flight provided adequate physical information concerning the object and its background, atmospheric effects, and the spacecraft window exists. A test of such predictions was also carried out and is described in the following paragraphs.

GROUND OBSERVATIONS

The crews of both Gemini V and Gemini VII observed prepared and monitored rectangular patterns on the ground in order to test the use of basic visual acuity data combined with measured optical properties of ground objects and their natural lighting, the atmosphere, and the spacecraft window to predict the limiting naked-eye visual capability of astronauts to discriminate small objects on the surface of the earth in daylight.

EQUIPMENT

The experimental equipment consists of an inflight photometer to monitor the spacecraft window, test patterns at two ground observation sites, instrumentation for atmospheric, lighting, and pattern measurements at both sites, and a laboratory facility (housed in a trailer van) for training the astronauts to perform visual acuity threshold measurements and for obtaining a preflight physiological baseline descriptive of their visual performance and its statistical fluctuations. These equipments, except the last, are described in the following paragraphs.

SPACECRAFT WINDOW PHOTOMETER

A photoelectric inflight photometer was mounted near the lower right corner of the pilot's window of the Gemini V spacecraft, as shown in Figure 14, in order to measure the amount of ambient light scattered by the window into the path of sight at the moment when observations of the ground test patterns were made. The photometer (Fig. 15) had a narrow (1.2°) circular field of view, which was directed through the pilot's window and into the opening of a small black cavity a few inches away outside the window. The photometric scale was linear and extended from approximately 12 to 3 000 foot-lamberts. Since the apparent luminance of the black cavity was always much less than 12 foot-lamberts, any reading of the inflight photometer was ascribable to ambient light scattered by the window. Typical data during passes of Gemini V over the Laredo site are shown in Figure 16. This information combined with data on the beam transmittance of the window and on the apparent luminance of the background squares in the ground pattern array enabled the contrast transmittance of the window at the moment of observation to be calculated. Uniformity of the window could be tested by removing the photometer from its positioning bracket and making a handheld scan of the window, using a black region of space in lieu of the black cavity. A direct-reading meter incorporated in the photometer enabled the command pilot to observe the photometer readings while the pilot scanned his own

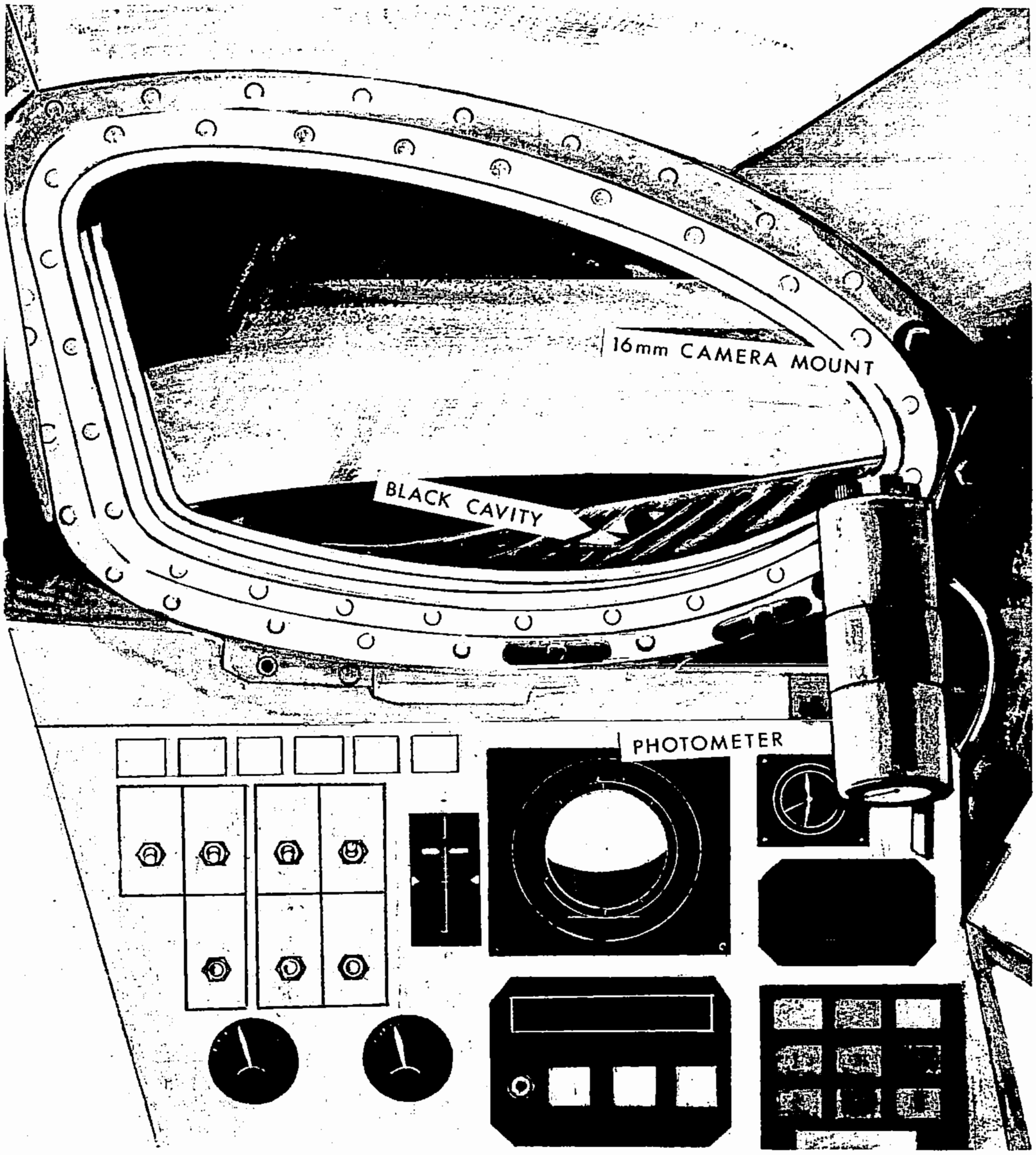


Fig. 14. Location of the inflight photometer.

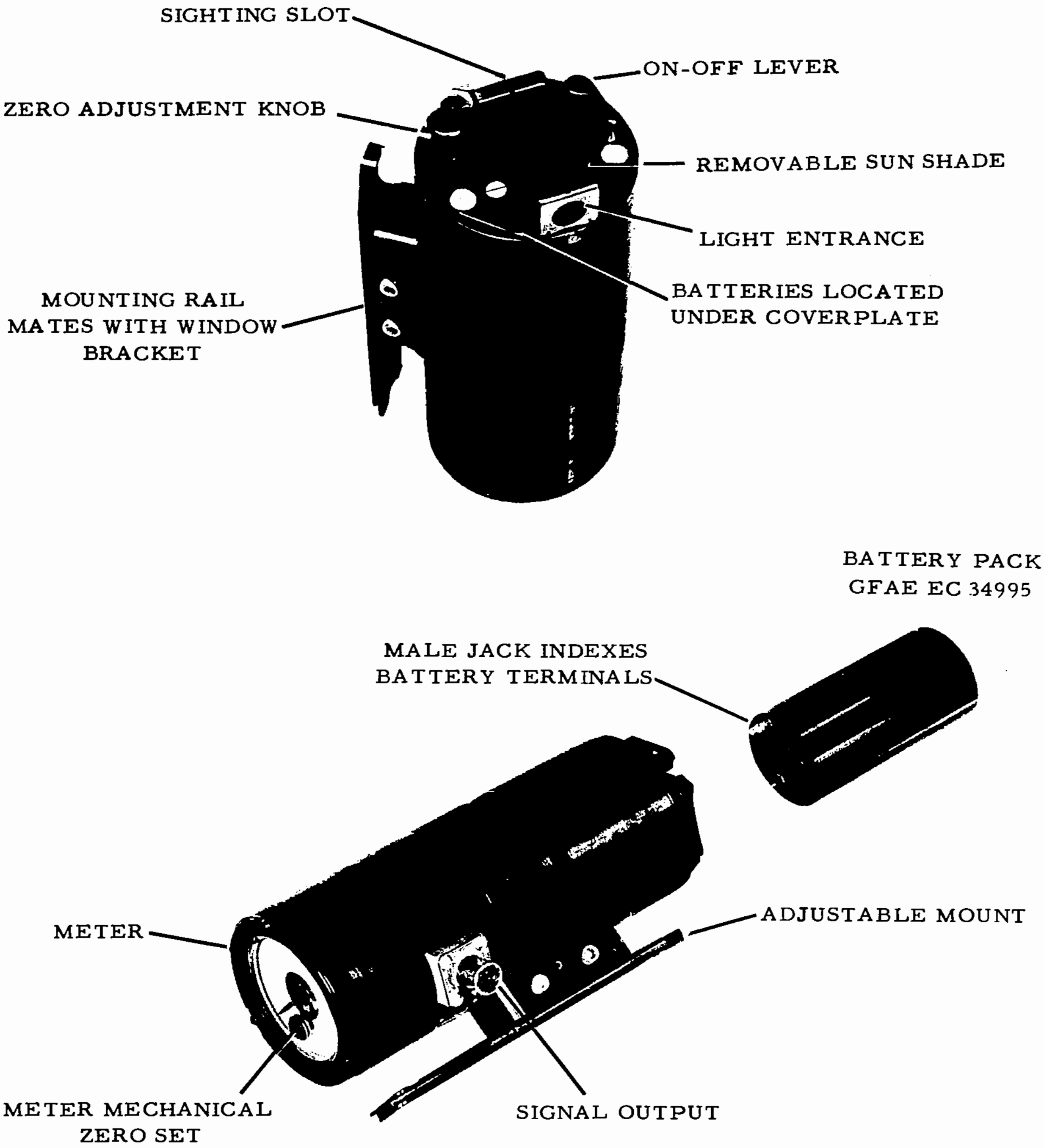


Fig. 15. Inflight photometer components.

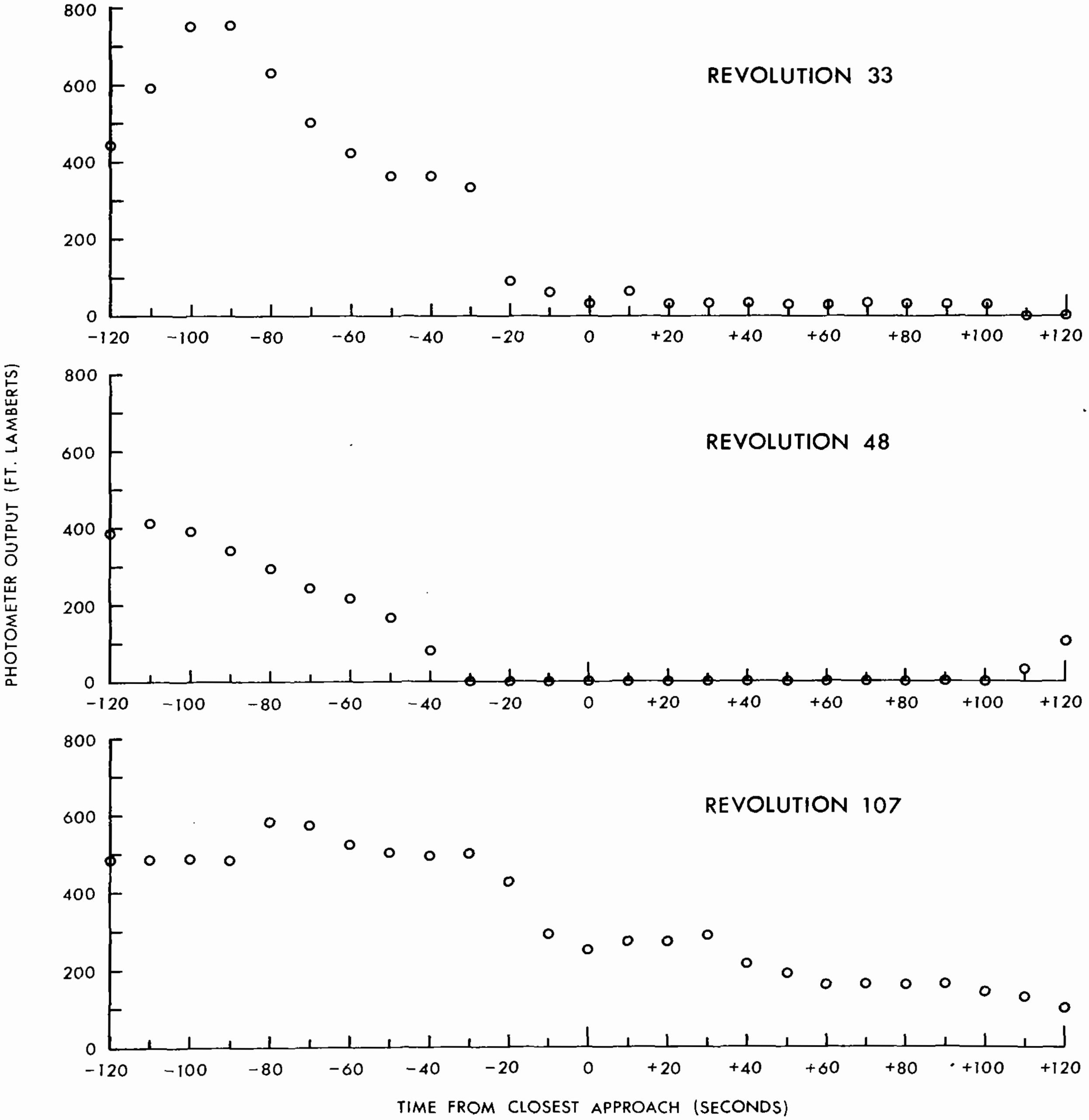


Fig. 16. Laredo site photometer data.

window for uniformity. A corresponding scan of the command pilot's window could be made in the same way. Data from the photometer were sent to the ground by real-time telemetry. Electrical power for the photometer was provided entirely by batteries within the instrument.

GROUND OBSERVATION SITES

Sites for observations by the crew of Gemini V were provided on the Gates Ranch, 40 miles north of Laredo, Texas (Fig. 17), and on the Woodleigh Ranch, 90 miles south of Carnarvon, Australia (Figs. 18 and 19). At the Texas site, 12 squares of plowed, graded, and raked soil 2000 feet by 2 000 feet were arranged in a 4 by 3 matrix. White rectangles of styrofoam-coated wallboard were laid out in each square. Their length decreased in a uniform logarithmic progression from 610 feet in the northwest corner (square number 1) to 152 feet in the southwest corner (square number 12) of the array. Each of the 12 rectangles was oriented in one of four positions (i.e., north-south, east-west, or diagonal), and the orientations were random within the series of 12. Advance knowledge of the rectangle orientations was withheld from the flight crew since their task was to report the orientations. Provision was made for changing the rectangle orientations between passes and for adjusting their size in accordance with anticipated slant range, solar elevation, and the visual performance of the astronauts on preceding passes. The observation site in Australia was somewhat similar to the Texas site, but, inasmuch as no observations occurred there, the specific details are unnecessary in this report.

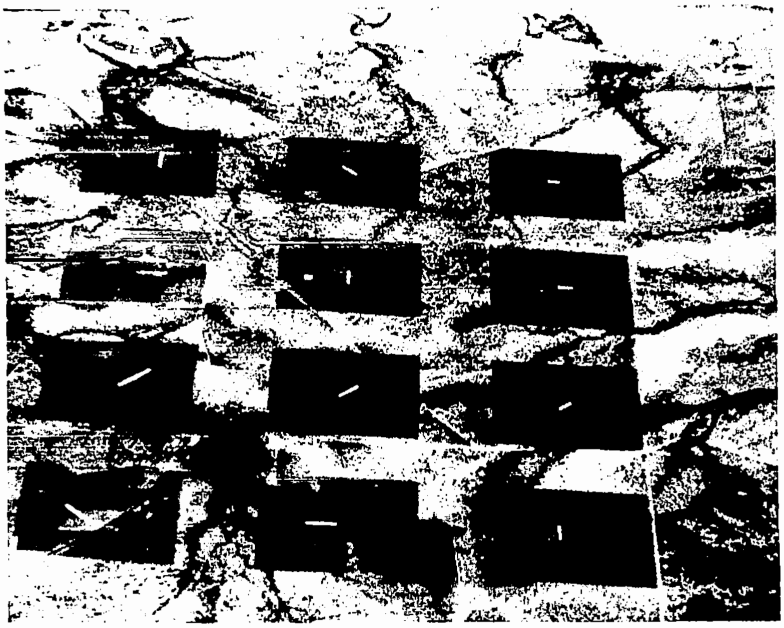


Fig. 17. Aerial photograph of the Gemini V visual acuity experiment ground pattern at Laredo, Texas.

The Australian ground observation site was not manned during Gemini VII because the afternoon time of launch caused no usable daytime overpasses to occur there until the last day of the mission. The 82.5° launch azimuth used for Gemini VII prevented the use of an otherwise highly desirable ground site in the California desert near the Mexican border. Weather statistics

Fig. 18. Aerial photograph of the Gemini V visual acuity experiment ground pattern at Carnarvon, Australia.

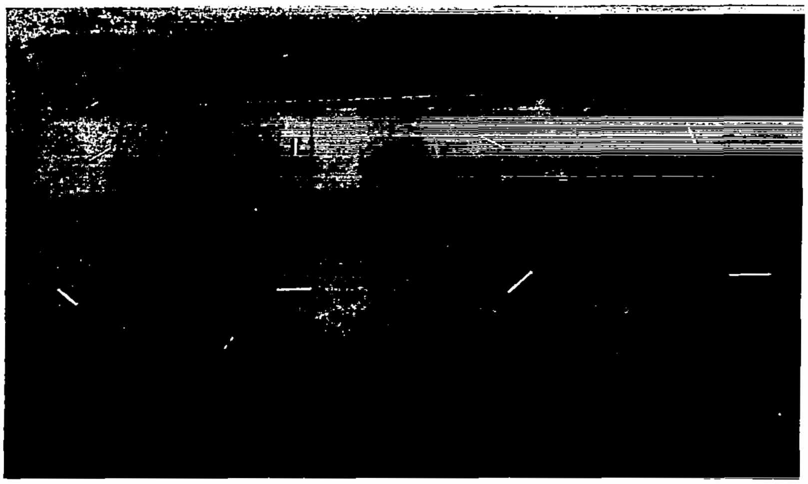


Fig. 19. Aerial photograph of the Gemini V visual acuity experiment ground pattern at Carnarvon, Australia.

for December made the use of the Texas site appear dubious but no alternative was available. The afternoon launch made midday passes over this site available on every day of the mission. Experience gained on Gemini V pointed to the need for a more prominent orientation marking. This was provided by placing east-to-west strips of crushed white limestone 26 feet wide and 2 000 feet long across the center of each of the four north background squares in the array. Thus, only eight test rectangles were used in a 2 by 4 matrix on the center and south rows of background squares, as shown in Figure 20. The largest and smallest rectangles were of the same size as those used in Gemini V.

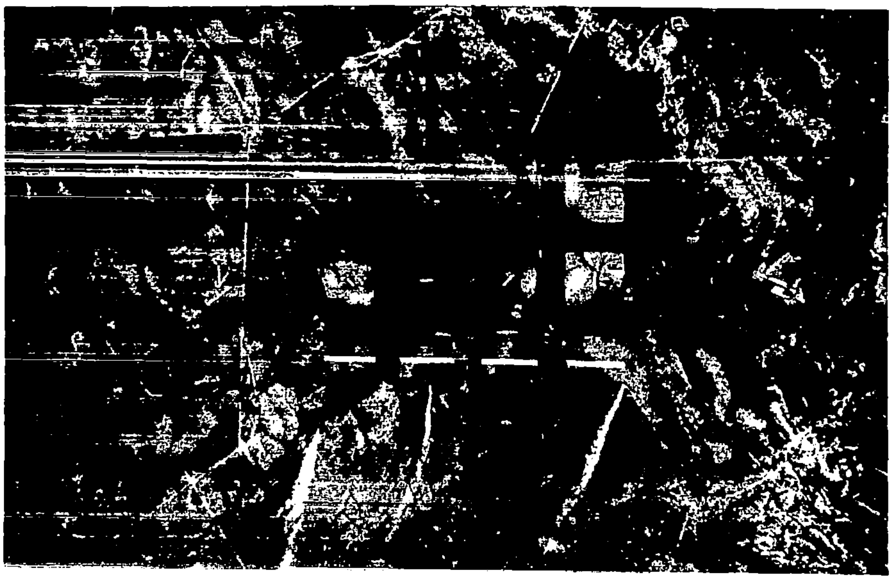


Fig. 20. Aerial photograph of the Gemini VII visual acuity experiment ground pattern at Laredo, Texas (rev. 17).

INSTRUMENTATION

Instrumentation at both ground sites consisted of a single tripod-mounted, multipurpose, recording photoelectric photometer (Figs. 21 and 22) capable of obtaining all the data needed to specify the apparent contrast of the pattern as seen from the spacecraft at the moment of observation. The apparent luminance of the background squares needed for evaluation of the

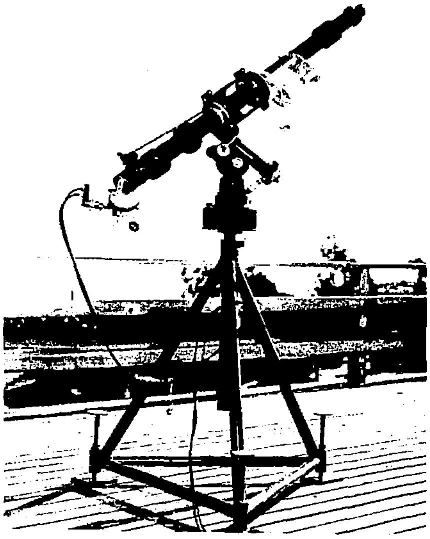


Fig. 21. Ground site tripod-mounted photoelectric photometer.

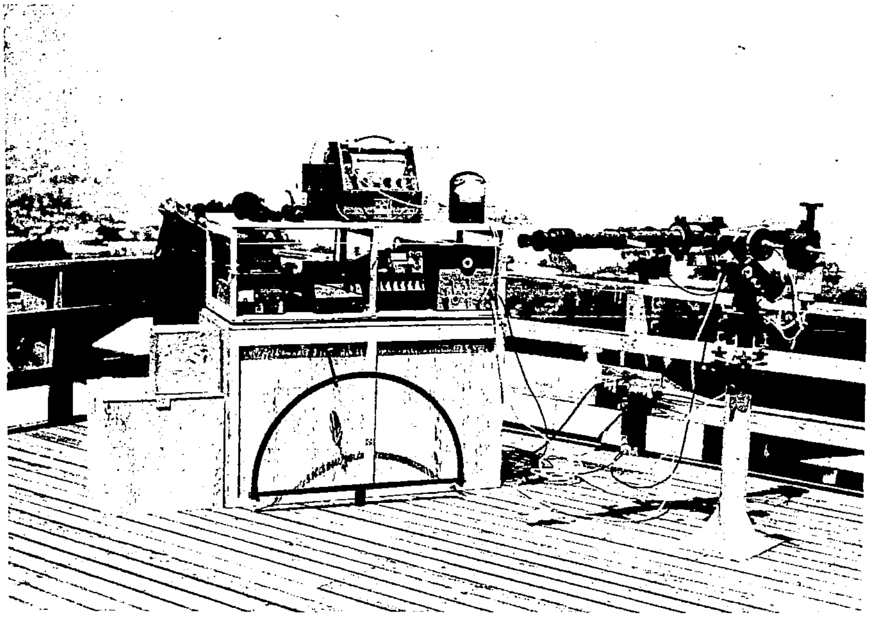


Fig. 22. Ground site photoelectric photometer with recording unit.

contrast loss due to the spacecraft window was also ascertained by this instrument. A 14-foot high mobile tower, constructed of metal scaffolding and attached to a truck, supported the tripod-mounted photometer high enough above the ground to enable the plowed surface of the background squares to be measured properly. This arrangement is shown in Figs. 23 and 24.

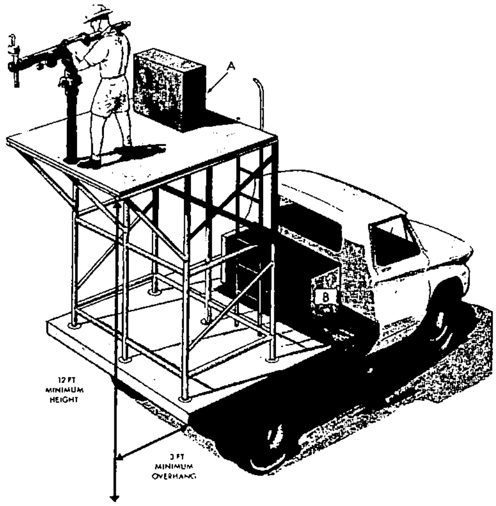


Fig. 23. Ground site photoelectric photometer mounted on a truck.

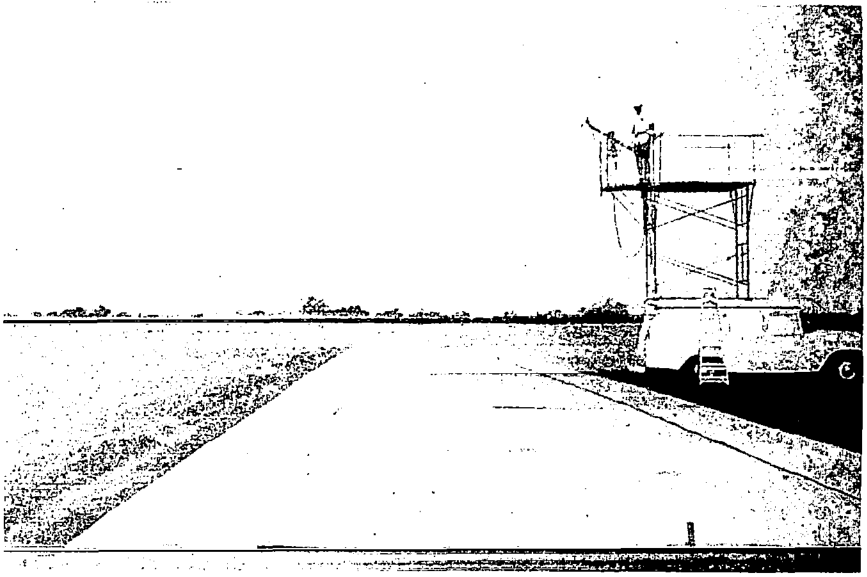


Fig. 24. Photograph of truck-mounted photoelectric photometer.

OBSERVATIONS IN GEMINI V

Observation of the Texas ground pattern site was first attempted on revolution 18, but fuel-cell difficulties which denied the use of the platform were apparently responsible for lack of acquisition of the ground site.

The second scheduled attempt to see the pattern near Laredo was on revolution 33. Acquisition of the site was achieved by the command pilot but not by the pilot, and no readout of rectangle orientation was made.

At the request of the experimenters, the third attempt at Laredo, scheduled originally for revolution 45, was made on revolution 48 in order to secure a higher sun and a shorter slant range. Success was achieved on this pass and is described in the paragraphs on results.

Unfavorable cloud conditions caused the fourth scheduled observation at the Texas site, on revolution 60, to be scrubbed. Thereafter, lack of thruster control made observation of the ground patterns impossible, although excellent weather conditions prevailed on three scheduled occasions at Laredo (revolutions 75, 92 and 107) and once at the Australian site (revolution 88). Long range visual acquisition of the smoke markers used at both sites was reported in each instance, but the drifting spacecraft was not properly oriented near the closest approach to the pattern to enable observations to be made. A fleeting glimpse of the Laredo pattern during drifting flight on revolution 92 enabled it to be successfully photographed with hand cameras. Another fleeting glimpse of the pattern was also reported on revolution 107.

RESULTS OF OBSERVATIONS IN GEMINI V

Quantitative observation of ground markings was achieved only once during Gemini V. This observation occurred during revolution 48 at the ground observation site near Laredo, Texas, at 12:17:14 CST on the third day of the flight. Despite early acquisition of the smoke marker by the command pilot and further acquisition by him of the target pattern itself well before the point of closest approach, the pilot could not acquire the markings until the spacecraft had been turned to eliminate sunlight on his window. Telemetry records from the inflight photometer show that the pilot's window produced a heavy veil of scattered light until the spacecraft was rotated. Elimination of the morning sun on the pilot's window enabled him to make visual contact with the pattern in time to make a quick observation of the orientation of some rectangles. It may be noted that, during approach, the reduction of contrast due to light scattered by the window was more severe than that due to light scattered by the atmosphere.

An ambiguity exists between the transcription of the radio report made at the time of the pass and the written record in the flight log. The writing was made "blind" while the pilot was actually looking at the pattern; it is a diagram drawn in the manner depicted in the Gemini V flight plan, the Mission Operation Plan, the Description of Experiment, and other documents. The orientation of the rectangles in the sixth and seventh squares appears to have been correctly noted. The verbal report given several seconds later correctly records the orientation of the rectangle in the sixth square if it is assumed that the spoken words describe the appearance of the pattern as seen from a position east of the array while going away from the site.

Despite the hurried nature of the only apparently successful quantitative observation of a ground site during Gemini V, there seems to be a reasonable probability that the sighting was a valid indication of the pilot's correctly discriminating the rectangles in the sixth and seventh squares. Since he did not respond to squares 8 through 12, it can only be inferred that his threshold lay at square 6 or higher.

Tentative values of the apparent contrast and angular size of the sixth and seventh rectangles at the Laredo site at the time of the observation are plotted in Figure 25. The solid line represents the preflight visual performance of Astronaut Conrad as measured in the vision research van. The dashed lines represent the 1- and 2-sigma limits of his visual performance. The positions of the plotted points indicate that his visual performance at the time of revolution 48 was within the statistical range of his preflight visual performance.

OBSERVATIONS IN GEMINI VII

Observations of the Texas ground pattern site were made on revolutions 16, 17, and 31 under very favorable weather conditions. Heavy clouds blanketed the site throughout the remainder of the mission, however, and no further observations of the site were possible. Contamination of the outer surface of the pilot's window made observation of the ground pattern difficult and the result uncertain. The contamination, which was observed to have occurred during launch, was mapped during revolution 19 by means of a window scan with the inflight photometer in the manner described in an earlier section. Figure 26 shows some numerical results of this scan and Figure 27 is a photograph of a shaded pencil sketch intended to portray the appearance of the window deduced from the telemetered scan curves. Comparison of this sketch with a similar one made by the pilot during flight shows good correlation.

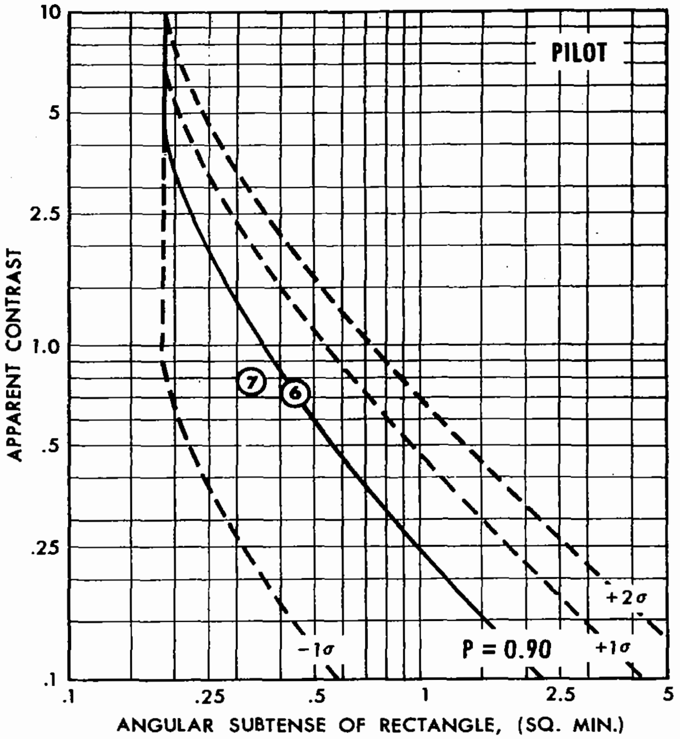


Fig. 25. Apparent contrast versus angular size of the sixth and seventh rectangles. GT V Revolution 48.

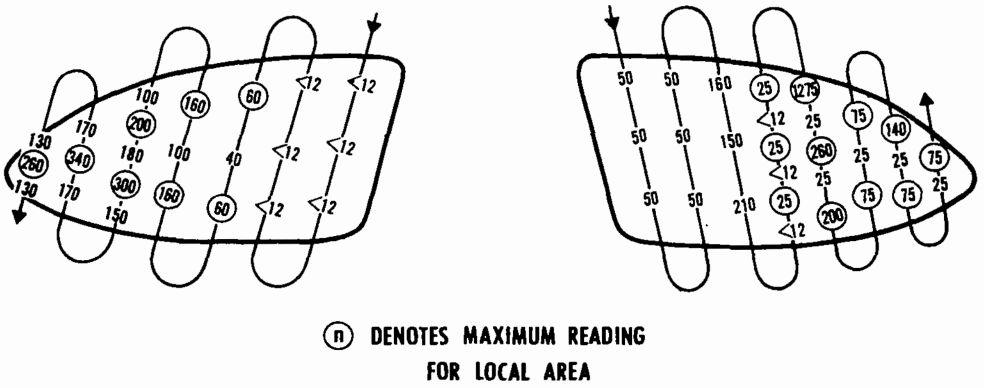


Fig. 26. Results of window scan (numerical values of luminance in foot-lamberts).

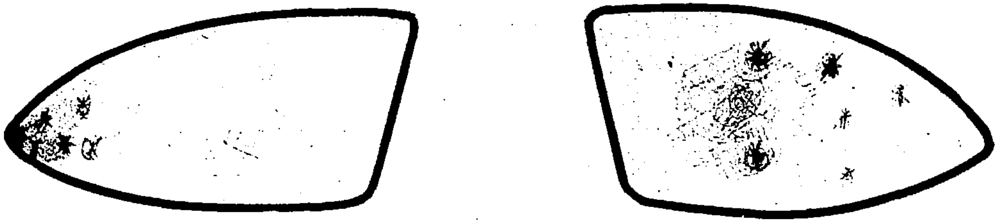


Fig. 27. Photograph of shaded pencil sketch of window contamination.

Figures 26 and 27 show that the command pilot's window was not measurably contaminated on its inboard side. Successful observations of the ground pattern were made by the command pilot through this clear portion of his window on revolutions 17 and 31. No direct sunlight fell on the window during those observations.

RESULTS OF OBSERVATIONS IN GEMINI VII

The results of observations by the command pilot on revolutions 17 and 31 of Gemini VII are shown in Fig. 28. These observations occurred at 16:34:52 CST and 14:56:51 CST on the second and third day of the flight, respectively.

In Figure 28 the circled points represent the apparent contrast and angular size of the largest rectangles in the ground pattern. Apparent contrast was calculated on the basis of measured directional luminances of the white panels and their backgrounds of plowed soil, of atmospheric optical properties measured in the direction of the path of sight to the point of closest approach, and of a small allowance for contrast loss in the spacecraft window based upon window scan data and readings of the inflight photometer at the time of the two observations. Angular sizes and apparent contrast were both somewhat larger for revolution 31 than for revolution 17 because the slant range was shorter and because the spacecraft passed north of the site, thereby causing the background soil to appear darker, as can be noted by comparing Figure 20 with Figure 29. The orientations of those rectangles indicated by double circles were reported correctly but those represented by single circles were either reported incorrectly or not reported at all.

The solid line in Figure 28 represents the preflight visual performance of Borman as measured in the vision research van. The dashed lines represent the $-\sigma$, $+\sigma$, and $+2\sigma$ contrast limits of his visual performance. The positions of the plotted points indicate that his visual performance was precisely in accordance with his preflight visual thresholds.

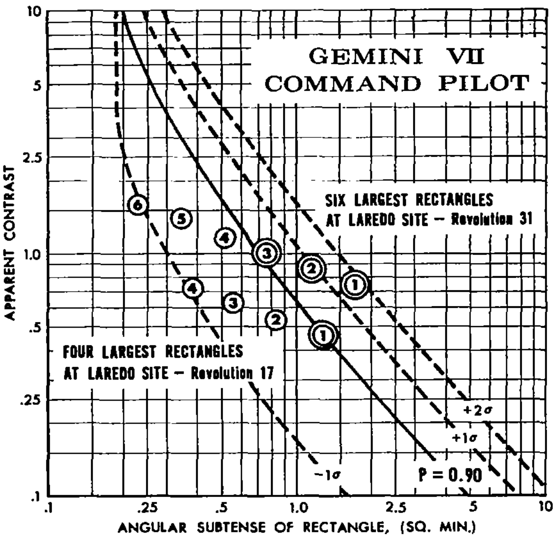


Fig. 28. Apparent contrast versus angular size of rectangles.

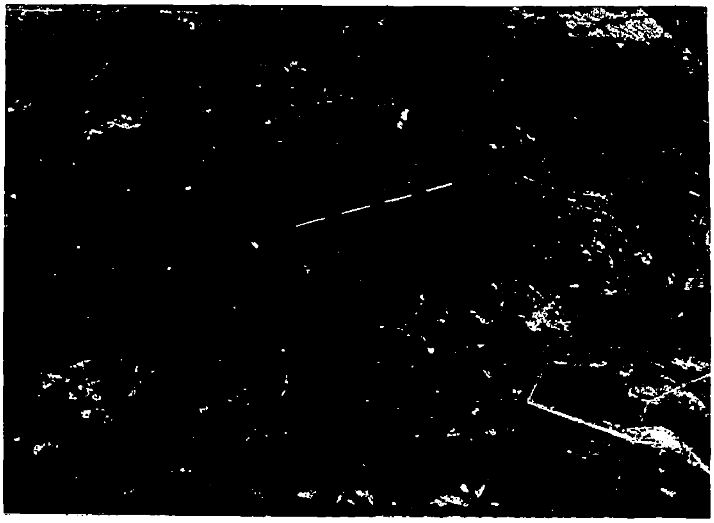


Fig. 29. Aerial photograph of the Gemini VII visual acuity experiment at Laredo, Texas (rev. 31).

CONCLUSIONS

The stated objectives of experiment S-8/D-13 were both achieved successfully. Data from the inflight vision tester show that no change was detected in the visual performance of any of the four astronauts who composed the crews of Gemini V and Gemini VII. Results from observations of the ground site near Laredo, Texas, confirm that the visual performance of the astronauts during space flight was within the statistical range of their preflight visual performance and demonstrate that laboratory visual data can be combined with environmental optical data to predict correctly the limiting visual capability of astronauts to discriminate small objects on the surface of the earth in daylight.

APPENDIX B

INFLIGHT VISION TESTER

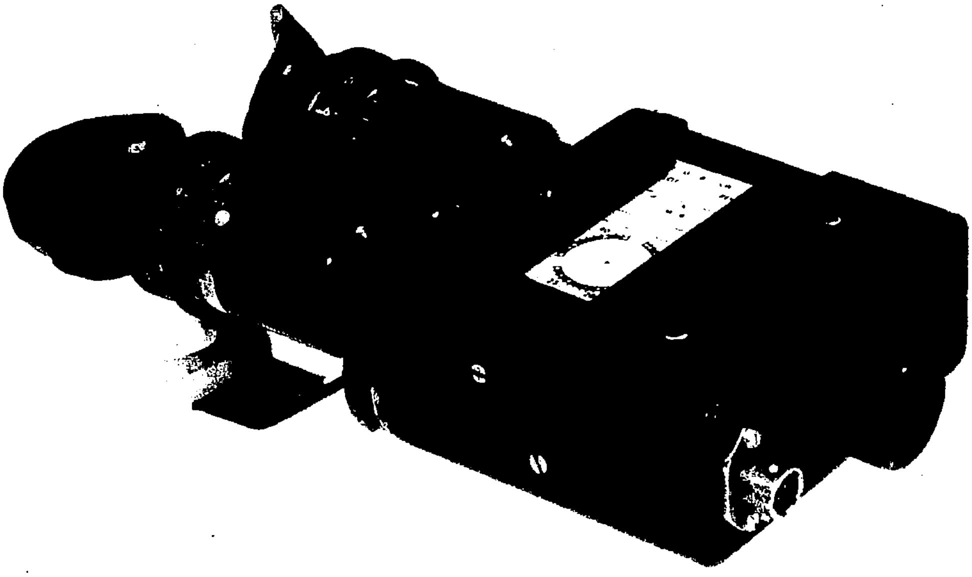
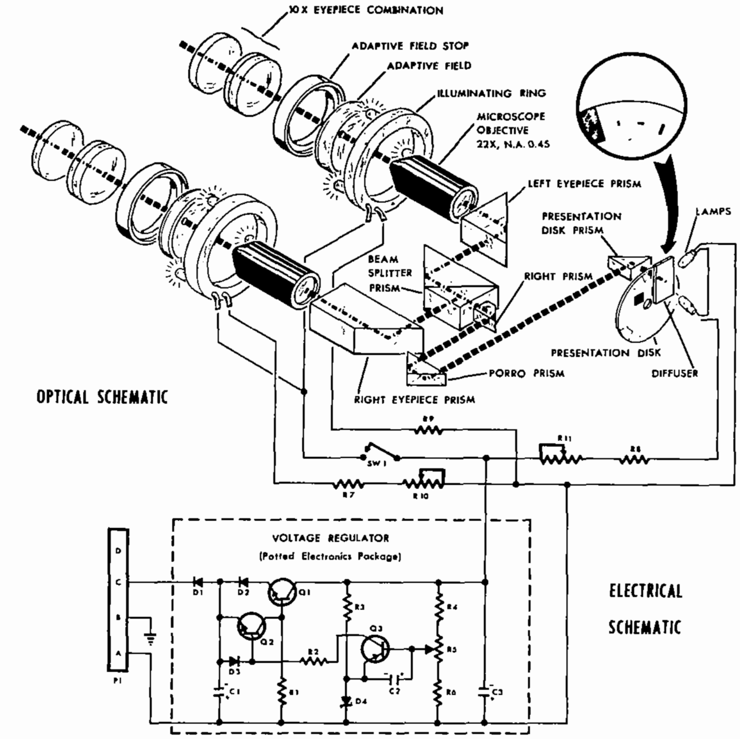


Fig. 1. Inflight Vision Tester GFAE EC 34999

DESCRIPTION

The Gemini Inflight Vision Tester is designed primarily to measure the visual acuity of the astronauts. Dark rectangular test patterns are displayed at two levels of contrast upon a wide adapting field of constant high luminance (100 ft-L). Observer responses and pattern changes are made by use of the large knob at the front of the instrument, while the device is held in alignment by use of the bite board. By switching off the adapting field and introducing an astigmatizer, a rotatable bright streak may be presented for testing otolith function as measured by the astronaut's orientation of the streak when external cues are eliminated by the eye-cups. Both the acuity and orientation functions are measured at intervals during the missions to assess possible effects of prolonged weightlessness and/or other environmental factors. Power required to operate the vision tester is 22 – 33 volts D.C. at 300 ma current.



Index	Item	Value	Manufacturer's #	Index	Item	Value	Manufacturer's #
R1	Resistor	1.5K - 1W		C1	Capacitor	4.7 mfd - 100 V	Sprague 109D475 x0100C2
R2	Resistor	270					
R3	Resistor	1.5K - 1W		C2	Capacitor	.0022 - 200 V	Electron 02-222
R4	Resistor	1.5K - 1W		C3	Capacitor	4.7 mfd - 35 V	STA 626-1
R5	Var. Resistor (Potentiometer)	100	Atohm 6344-326-101	D1	Diode		IN4005
R6	Resistor	620		D2	Diode		IN4005
R7	Resistor	50 Ω ± 1%	Conrad Carson CMR-200-50	D3	Diode		IN4005
R8	Resistor	50 Ω ± 1%	Conrad Carson CMR-200-50	D4	Zener		IN3512
R9	Resistor	61 Ω ± 1%	Conrad Carson CMR-200-61	Q1	Transistor		TI 1131
R10	Var. Resistor (Potentiometer)	50Ω	Bourns 3280L-1-500	Q2	Transistor		2N 2222
				Q3	Transistor		2N 3065
R11	"	"	"				

Fig. 2. Inflight Vision Tester Optical-Electrical Schematic

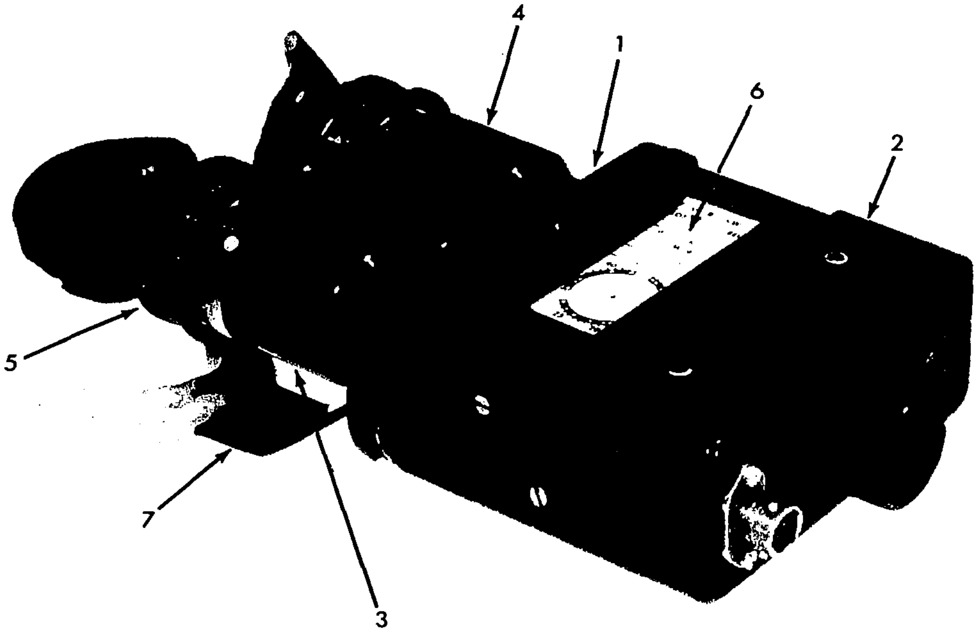


Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
3			
	700-2000	INFLIGHT VISION TESTER ASSEMBLY	Ref.
	700-2000-3	INFLIGHT VISION TESTER, shown	Ref.
-1	700-200-2	FRONT FRAME ASSEMBLY, (see Figure 4 for breakdown)	1
-2	700-201-2	PRESENTATION DISK FRAME ASSEMBLY (see Figure 5 for breakdown)	1
-3	700-202-3	RIGHT EYEPIECE ASSEMBLY (see Figure 6 for breakdown)	1
-4	700-202-4	LEFT EYEPIECE ASSEMBLY (same as 700-202-3)	1
-5	700-203-1	"M-9" ASSEMBLY (see Figure 7 for breakdown)	2
-6	700-2000-12	DATA CARD (see Instruction Manual for information concerning this item)	Ref.
-7	700-2000-13	BITE BOARD ASSEMBLY (see Instruction Manual for information concerning this item)	Ref.

Fig. 3. Inflight Vision Tester Assembly

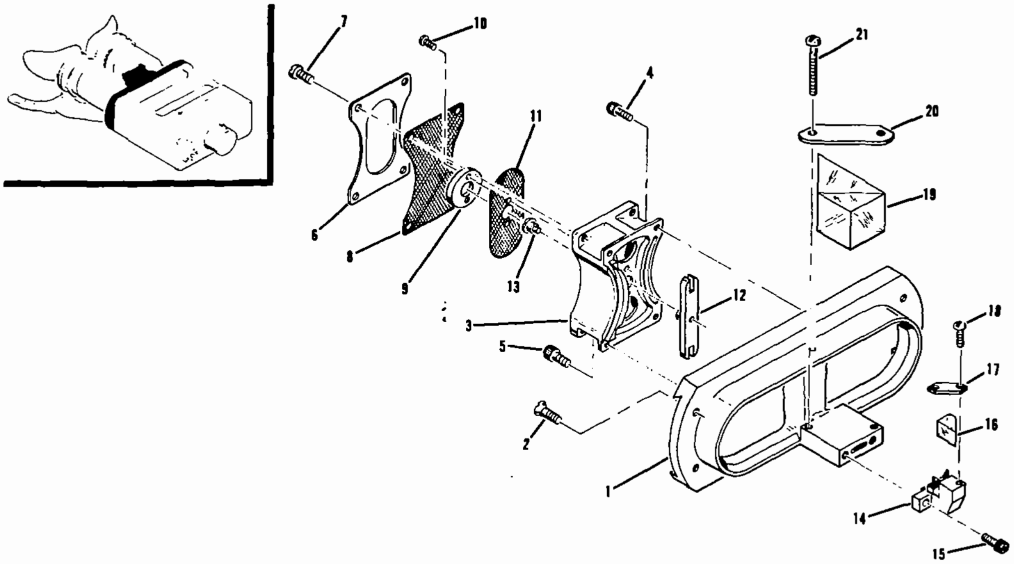


Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
4	700-200	FRONT FRAME ASSEMBLY	Ref.
	700-200-2	FRONT FRAME ASSEMBLY, shown	Ref.
-1	700-200-11	FRAME, AMERICAN OPTICAL SO., P/N'S 95-4 and 95-5 (Modified)	1
-2		SCREW, No. 4-40 x 7/16", FLAT HEAD	4
-3	700-200-17	DESICCANT BOX	1
-4		SCREW, No. 1-72 x 3/8", SOCKET HEAD	2
-5		SCREW, No. 2-56 x 3/8", SOCKET HEAD	2
-6	700-200-21	SCREEN FRAME	1
-7		SCREW, No. 2-56 x 3/16", ROUND HEAD	4
-8	700-200-20	TOP DESICCANT SCREEN	1
-9	700-200-18	SCREW COVER	1
-10		SCREW, No. 1-72 x 3/8", SOCKET HEAD	2
-11	700-200-19	BOTTOM DESICCANT SCREEN	1
-12	700-200-22	ADJUSTMENT ARM	1
-13		SCREW, No. 2-56, (Modified)	1
-14	700-200-14	2391A PRISM MOUNT	1
-15		SCREW, No. 2-56 x 1/4", FILLISTER HEAD	2
-16	700-2000-2005	PRISM, (Right Prism) (2391 A ref.)	1
-17	700-200-15	PRISM HOLD DOWN STRAP	1
-18		SCREW, No. 0-80 x 7/16", ROUND HEAD	2
-19	700-2000-2006	BEAM SPLITTER PRISM	1
-20	700-200-16	BEAM SPLITTER HOLD DOWN STRAP	1
-21		SCREW, No. 2-56 x 7/8", ROUND HEAD	2

Fig. 4. Inflight Vision Tester Front Frame Assembly

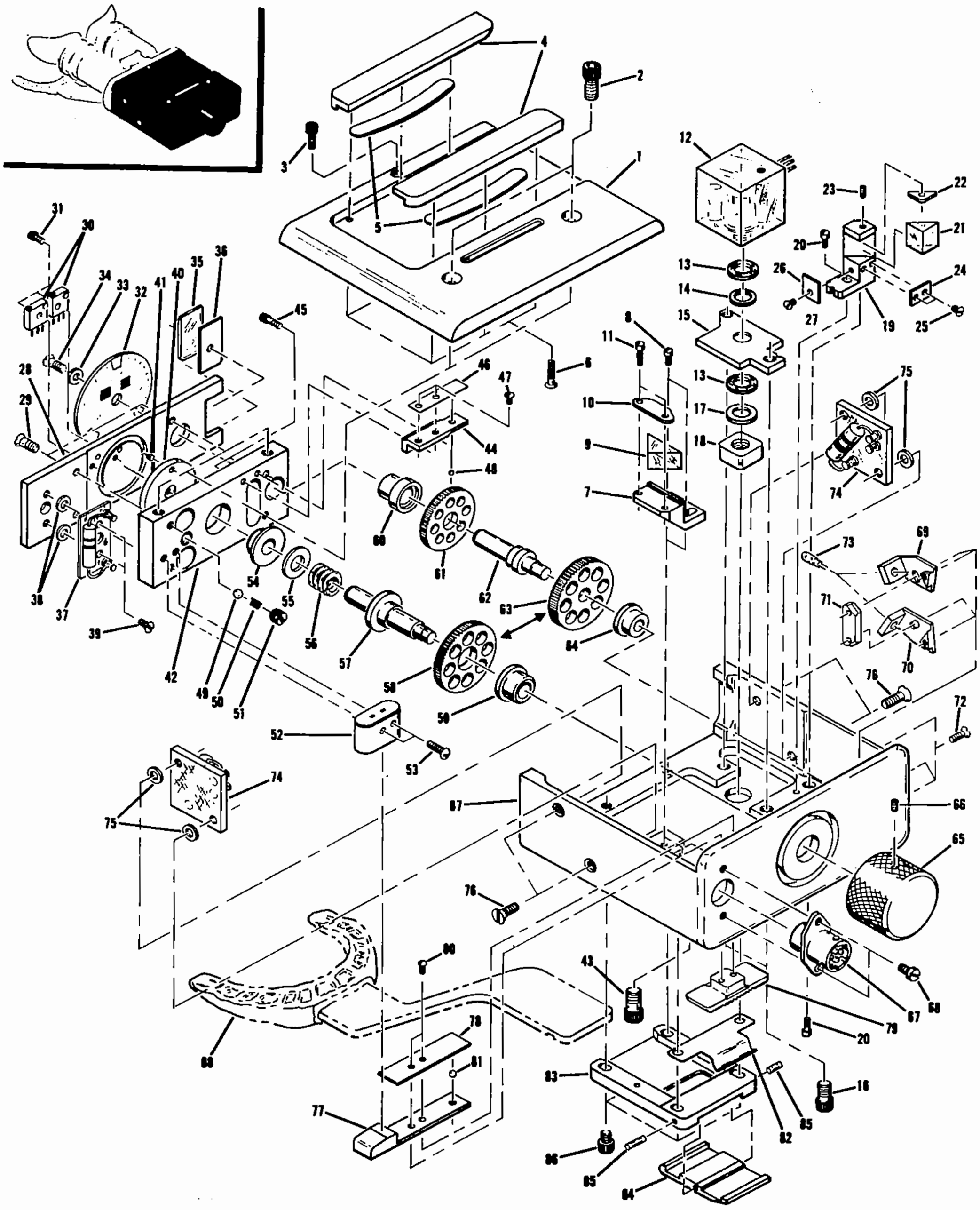


Fig. 5. Inflight Vision Tester Presentation Disk Frame Assembly

Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
5	700-201	PRESENTATION DISK FRAME ASSEMBLY	Ref.
	700-201-2	PRESENTATION DISK FRAME ASSEMBLY, shown	Ref.
-1	700-201-53	TOP PLATE	1
-2		SCREW, No. 8-32 x 3/8", SOCKET HEAD (Mates with P/N 700-201-59)	2
-3		SCREW, No. 4-40 x 1/4", SOCKET HEAD (Mates with P/N 700-200 ASSY.)	1
-4	700-201-45	CARD RETAINER	2
-5	700-201-46	RETAINER SPRING	
-6		SCREW, No. 0-80 x 5/32", FLAT HEAD	6
-7	700-201-15	PRISM MOUNT	1
-8		SCREW, No. 2-56 x 1/4", FILLISTER HEAD	2
-9	700-2000-2004	PRISM, (Porro)	1
-10	700-201-26	PRISM STRAP	1
-11		SCREW, No. 2-56 x 1/2", FILLISTER HEAD	2
-12	700-201-74	ELECTRONICS MODULE MOUNTING ACCESSORIES (Potted Electronics Package, reference Figure 2 for schematic)	1
-13		MICA INSULATOR, 7/16" Dia.	2
-14		SPACER, .257 ID.	1
-15	700-201-65	ELECTRONICS MODULE MOUNTING PLATE	1
-16		SCREW, No. 6-32 x 1/4", SOCKET HEAD	2
-17		BRASS WASHER	1
-18	700-201-21	RETAINER NUT	1
-19	700-201-16	PRISM MOUNT	1
-20		SCREW, No. 2-56 x 1/4", FILLISTER HEAD	2
-21	700-2000-2003	PRISM, (Presentation) 2002A ref.	1
-22	700-201-71	PRISM PAD	1
-23		SCREW, No. 2-56 x 3/8", SET SCREW	1
-24	700-201-49	PRISM RETAINER	1
-25		SCREW, No. 0-80 x 1/8", ROUND HEAD	2
-26	700-201-57	PRISM RETAINER	1
-27		SCREW, No. 0-80 x 1/8", FLAT HEAD	1
-28	700-201-55	CARD RETAINER	1
-29		SCREW, No. 2-56 x 1/4", FLAT HEAD	4
-30		POTENTIOMETER, BOURNS, No. 3280L-1-500	2
-31		SCREW, No. 1-72 x 9/32", SOCKET HEAD	2
-32	700-201-54	PRESENTATION DISK	1
-33	700-201-72	PRESENTATION DISK RETAINING WASHER	1
-34		SCREW, No. 2-56 x 3/16", FLAT HEAD	1
-35	700-201-70	DIFFUSER	1
-36	700-201-77	DIFFUSER SHIELD	1
-37	700-201-75	RESISTOR MOUNTING BOARD (CMR-200-50 Ω)	1
-38	700-201-76	INSULATING SPACER	2
-39		SCREW, No. 2-56 x 5/16", FLAT HEAD	1
-40	700-201-27	PUNCH WHEEL	1
-41	700-201-28	PUNCH NEEDLE	1

Inflight Vision Tester Presentation Disk Frame Assembly Parts List for Fig. 5

Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
5 (Cont'd)			
-42	700-201-59	SPACER BLOCK	1
-43		SCREW, No. 8-32 x 3/8", SOCKET HEAD	2
-44	700-201-67	DETENT BALL RETAINER	1
-45		SCREW, No. 2-56 x 1/4", SOCKET HEAD	2
-46	700-201-68	DETENT SPRING	1
-47		SCREW, No. 2-56 x 1/8", ROUND HEAD	2
-48		BALL, .093 DIA., Stainless Steel	1
-49		BALL, .125 DIA., Stainless Steel	1
-50	700-201-29	DETENT SPRING	1
-51	700-201-20	SPRING RETAINER	1
-52		SWITCH, HAYDON No. 61854	1
-53		SCREW, No. 2-56 x 5/8", ROUND HEAD	2
-54	700-201-69	INNER BUSHING	1
-55	700-201-22	WASHER	1
-56	700-201-25	SPRING	1
-57	700-201-24	SHAFT	1
-58	700-201-48	GEAR, PIC No. J4-72, (Modified)	1
-59	700-201-19	OUTER BUSHING	1
-60	700-201-33	FORWARD DRIVEN SHAFT BUSHING	1
-61	700-201-66	DETENT WHEEL, 45 POSITION	1
-62	700-201-32	DRIVEN SHAFT	1
-63	700-201-34	GEAR, PIC No. G16-72, (Modified)	1
-64	700-201-31	REAR DRIVEN SHAFT BUSHING	1
-65	700-201-17	ADJUST KNOB	1
-66		SCREW, No. 4-40 x 3/16", SET SCREW	2
-67	700-201-58	CONNECTOR; BENDIX No. PT02C-8-4P	1
-68		SCREW, No. 4-40 x 1/4", FILLISTER HEAD	2
-69	700-201-82	LAMP MOUNT	1
-70	700-201-81	LAMP MOUNT	1
-71	700-201-83	NUT PLATE	1
-72		SCREW, No. 2-56 x 5/16", FLAT HEAD	4
-73		LAMPS, LOS ANGELES MINIATURE PRODUCTS No.16	2
-74	700-201-52	ELECTRONICS BOARD, with resistors (CMR-200-50Ω -right, CMR-200-61Ω-left)	2
-75	700-201-76	INSULATING SPACER	4
-76		SCREW, No. 4-40 x 7/16", FLAT HEAD	4
-77	700-201-60	SWITCH RAMP	1
-78	700-201-61	SWITCH SPRING	1
-79	700-201-62	SWITCH ACTUATOR	1
-80		SCREW, No. 2-56 x 3/16", ROUND HEAD	2
-81		BALL, .125 DIA., Stainless Steel	1
-82	700-201-79	SPRING	1
-83	700-201-80	BITE BOARD RETAINER	1
-84	700-201-78	LOCK CAM	1
-85		PIN, ROLL, 1/16" DIA.	2
-86		SCREW, No. 4-40 x 1/4", SOCKET HEAD	4
-87	700-201-51	HOUSING	1
-88	700-2000-13	BITE BOARD	Ref

Inflight Vision Tester Presentation Disk Frame Assembly Parts List (Con't.)

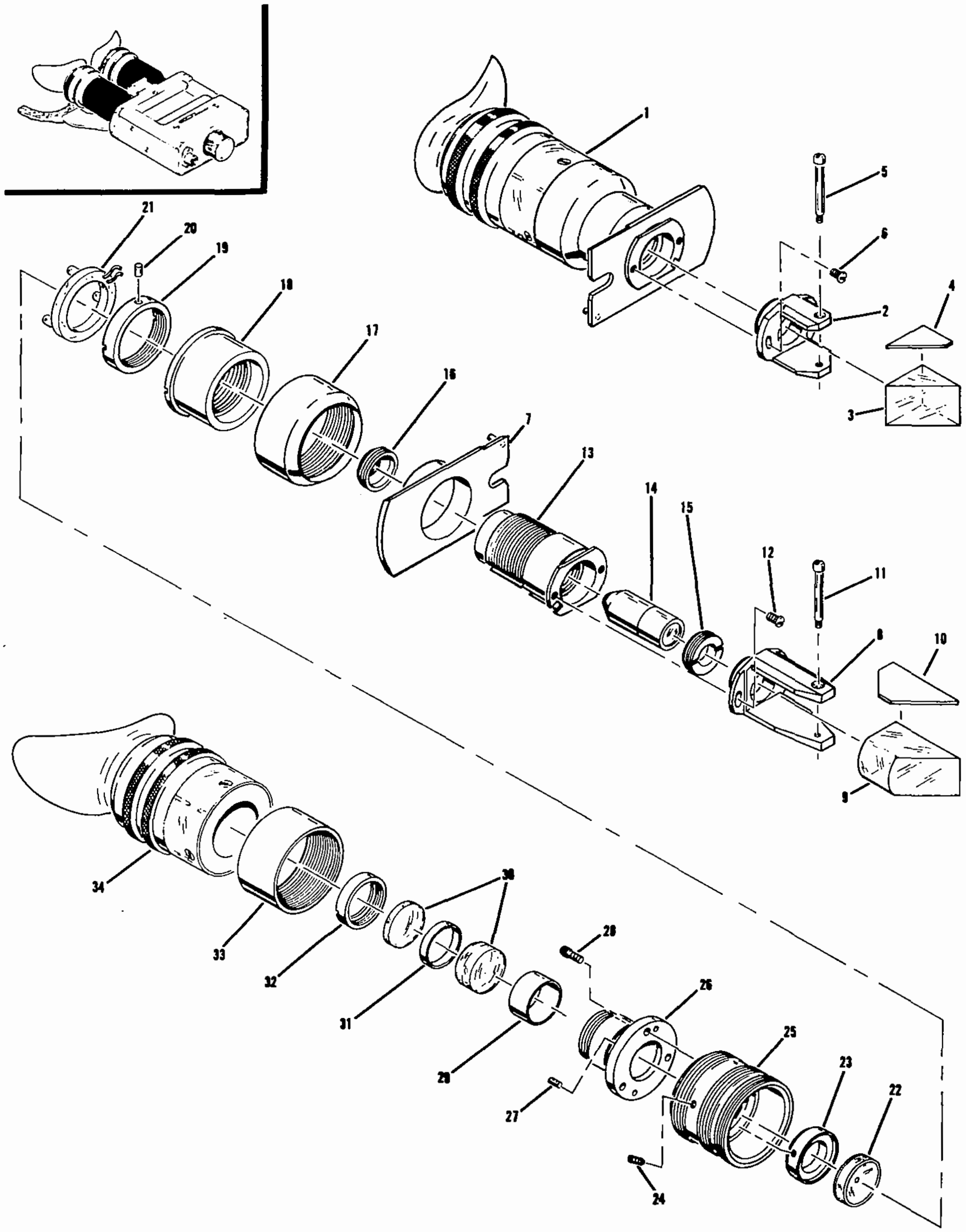
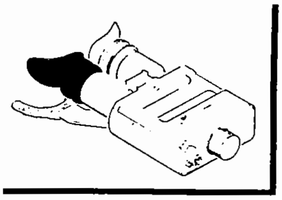


Fig. 6. Inflight Vision Tester Eyepiece Assembly

Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
6	700-202-	EYEPIECE ASSEMBLY	Ref.
	700-202-3	RIGHT EYEPIECE ASSEMBLY, shown	Ref.
-1	700-202-4	LEFT EYEPIECE ASSEMBLY, identical to 700-202-3 assembly except as noted.	Ref.
-2	700-202-36	LEFT EYEPIECE PRISM MOUNT	1
-3	700-2000-2008	LEFT EYEPIECE PRISM (American Optical Co. No. C-98-602)	1
-4	700-202-44	LEFT PRISM PAD	1
-5	700-202-45	SHOULDERED SCREW, (Special made)	1
-6		SCREW, No. 2-56 x 3/16", FILLISTER HEAD	2
-7	700-202-11	RIGHT EYEPIECE MOUNT	1
-8	700-202-35	RIGHT EYEPIECE PRISM MOUNT	1
-9	700-2000-2007	RIGHT EYEPIECE PRISM (American Optical No. C-98-601)	1
-10	700-202-43	RIGHT PRISM PAD	1
-11	700-202-45	SHOULDERED SCREW, (Special made)	1
-12		SCREW, No. 2-56 x 3/16", FILLISTER HEAD	2
-13	700-202-27	INTERIOR SLEEVE	1
	700-202-28	INTERIOR SLEEVE, (Mirror image of P/N 700-202-27, use on 700-202-4 assembly)	
-14		MICROSCOPE BARREL ASSEMBLY (E. Leitz, Inc. No. UO 2210.45)	1
-15	700-202-13	RETAINER, REAR	1
-16	700-202-15	RETAINER, FRONT	1
-17	700-202-29	INNER BARREL RETAINER	1
-18	700-202-30	INNER SLEEVE RETAINER	1
-19	700-202-34	INTERIOR LOCK RING	1
-20	700-202-41	INNER BARREL LOCATING PIN	1
-21	700-202-42	LIGHTING RING	1
-22	700-2000-2001	ADAPTIVE FIELD	1
-23	700-202-32	ADAPTIVE FIELD HOLDER	1
-24		SCREW, No. 2-56 x 3/16", SET SCREW (Mates with P/N 700-202-33)	3
-25	700-202-33	INNER BARREL	1
-26	700-202-37	LENS BARREL	1
-27		PIN, ROLL, 1/16" DIA. x .218 L	3
-28		SCREW, No. 2-56 x 3/16, ALLEN HEAD	3
-29	700-202-39	LENS SPACER	1
-30	700-2000-2009	10X EYEPIECE ASSEMBLY (WIDE FIELD) (Made from American Optical Co. No. C1146)	1
-31	700-202-40	FORWARD LENS SPACER	1
-32	700-202-38	LENS RETAINER	1
-33	700-202-31	EXTERIOR LOCK RING	1
-34	700-203-000	"M-9" ASSEMBLY (see Figure 7 for breakdown)	Ref.

Inflight Vision Tester Eyepiece Assembly Parts List for Fig. 6



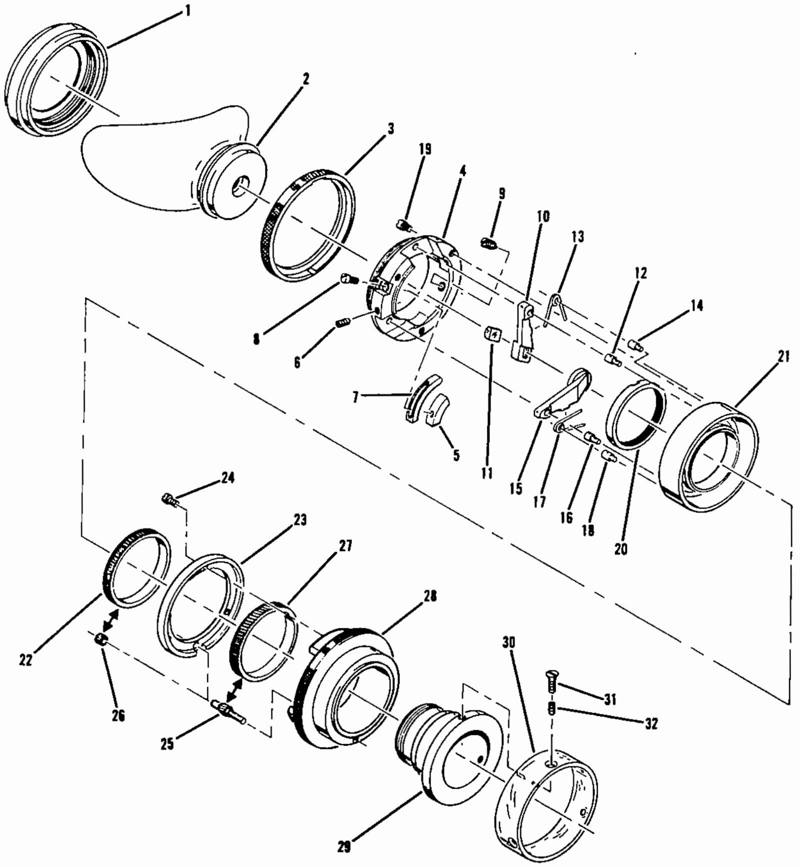


Fig. 7. Inflight Vision Tester "M-9" Assembly

Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
7			
	700-203	"M-9" ASSEMBLY	Ref.
	700-203-1	"M-9" ASSEMBLY, shown	Ref.
-1	700-203-22	RETAINER	1
-2	700-203-24	EYECUP MOUNT	1
-3	700-203-21	ACTUATING RING	1
-4	700-203-20	SWING ARM HOUSING	1
-5	700-203-27	BACK-UP SEGMENT	1
-6		SCREW, No. 0-80 x 3/16", SET SCREW	1
-7	700-203-26	ADJUSTMENT ARM STOP	1
-8		SCREW, No. 0-80 x 5/16", FILLISTER HEAD	1
-9		BALL PLUNGER, Vlier No. SSB-46N	1
-10	700-203-25	MADDOX ROD MOUNTING ARM	1
-11	700-2000-2010	MADDOX ROD	1
-12	700-203-29	ARM PIVOT PIN (Mates with P/N 700-203-19)	1
-13	700-203-31	ARM RETURN SPRING	1
-14	700-203-30	SPRING PIVOT PIN (Mates with P/N 700-203-19)	1
-15	700-203-28	OCCULTING ARM	1
-16	700-203-29	ARM PIVOT PIN (Mates with P/N 700-203-19)	1
-17	700-203-31	ARM RETURN SPRING	1
-18	700-203-30	SPRING PIVOT PIN (Mates with P/N 700-203-19)	1
-19		SCREW, No. 0-80 x 3/16", FILLISTER HEAD	3
-20	700-203-23	RETAINER	1
-21	700-203-19	DRIVEN DRUM	1
-22	700-203-17	SPUR GEAR, DYNACO GEAR No. 551-108 modified	1
-23	700-203-15	PINION MOUNT RING	1
-24		SCREW, No. 000-120 x 1/8", FLAT HEAD	3
-25	700-203-14	PINION GEAR	1
-26	700-203-18	PINION MODIFICATION, PIC DESIGN CORP. No. F4-1 modified	1
-27	700-203-16	HELICAL GEAR	1
-28	700-203-13	DRIVING DRUM	1
-29	700-203-11	INNER SLEEVE	1
-30	700-203-12	INDEX COLLAR	1
-31		SCREW, No. 2-56 x 3/16", FLAT HEAD	3
-32		SCREW, No. 2-56 x 1/8", SET SCREW (Mates with P/N 700-202-3 Assembly)	3

Inflight Vision Tester "M-9" Assembly Parts List for Fig. 7

APPENDIX C

INFLIGHT PHOTOMETER

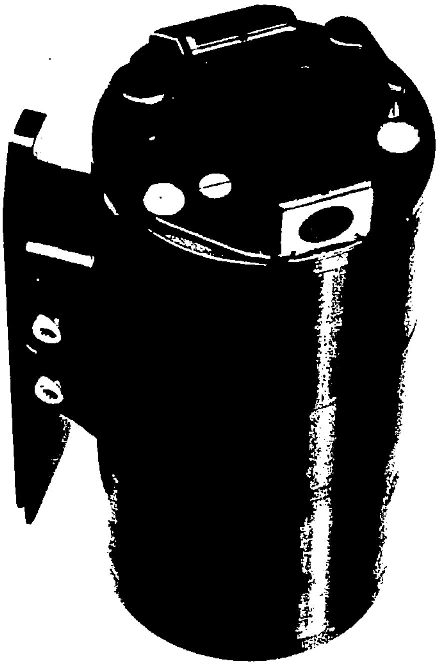
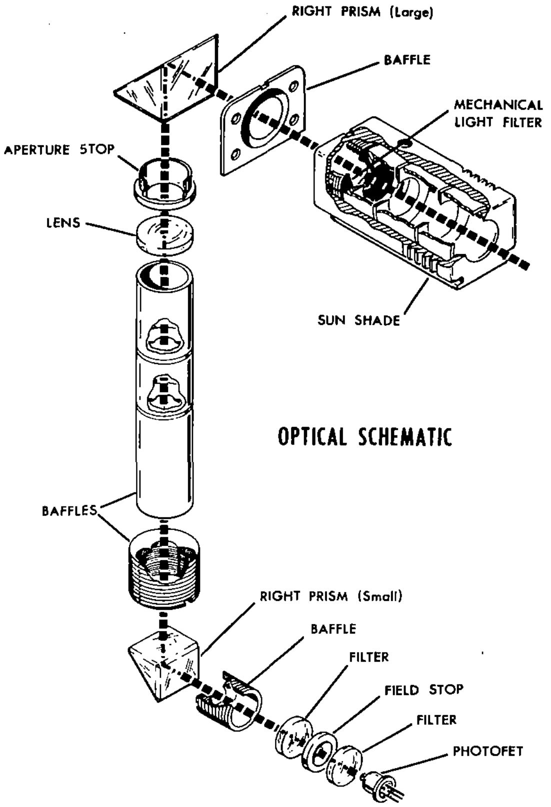


Fig. 1. Inflight Photometer GFAW EC 34998

DESCRIPTION

The Gemini Inflight Photometer acquires window-luminance information which is telemetered to the ground concurrently with the observation of the prepared ground sites. The photometer is aligned by means of the 16 mm camera bracket so that its field of view falls within a light trap exterior to the window. Thus, the only flux it receives is that scattered by the window into the capsule when the window is illuminated by the light field existing at the time of observation. The data thus obtained are used to compute the contrast loss which the optical signal suffers in passing through the spacecraft window. The analog voltage output is fed to the high-level PCM TM system and to a self-contained meter. The instrument is powered by a specially fabricated battery package which provides 160 hours of operation.



OPTICAL SCHEMATIC

Index	Item	Value	Manufacturer's *
R1 -R7	Resistor*	Selected at assembly	Mil-R-10509, RN 55C
R8 and R9	Var. Resistor* (Potentiometer)	50 Ω	Bourns 220L 1 - 500
R10 -R13	Resistor	5.11 MΩ	American CE - 1/2 ± 1% ± 50 PPM/°C
R14	Var. Resistor (Potentiometer)	50 Ω	Bourns 220L 1 - 500
R15 -R17	Resistor	Selected at assembly	Mil-R-10509, RN 55C
R18 and R19	Resistor	1.78 K	Mil-R-10509, RN 55C
C 1	Capacitor	220 mfd -10 V	Sprague 150D227 x0010S2
C 2	Capacitor	.047 mfd -20 V	Electron D2 - 473
Q 1	Photofet		Siliconix P102
Q 2	Transistor		Siliconix aN2608
Q3	Dual Transistor		G.E. 2N2916
Q 4	Dual Transistor		Motorola 2N3811
SW 1	Switch	2P ST	Daven 128-GB-2
B1 -B3	Battery	5.4 V	Mallory TR134N
M 1	Meter	0 - 500ma	Phaostron 20-012595
P 1	Connector		Bendix PT 02C-8-4P

*At assembly either R1 and R8 or R2 and R9 to be used.

ELECTRICAL SCHEMATIC

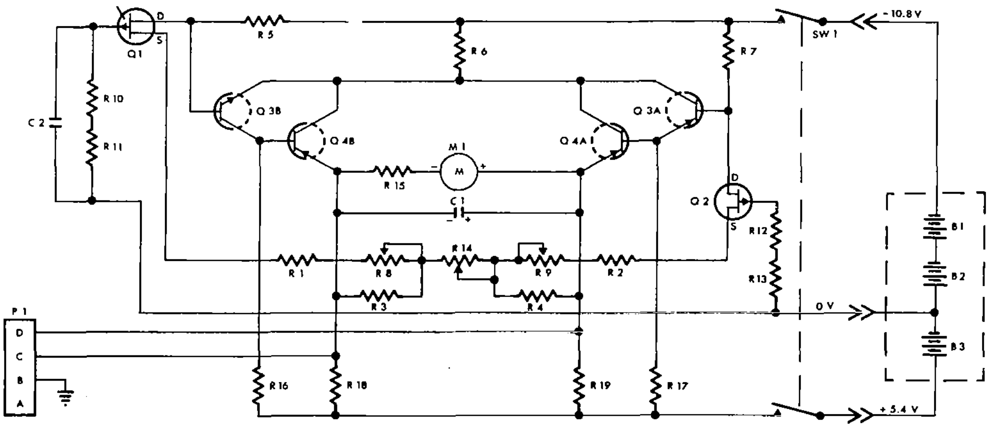


Fig. 2. Inflight Photometer Optical-Electrical Schematic

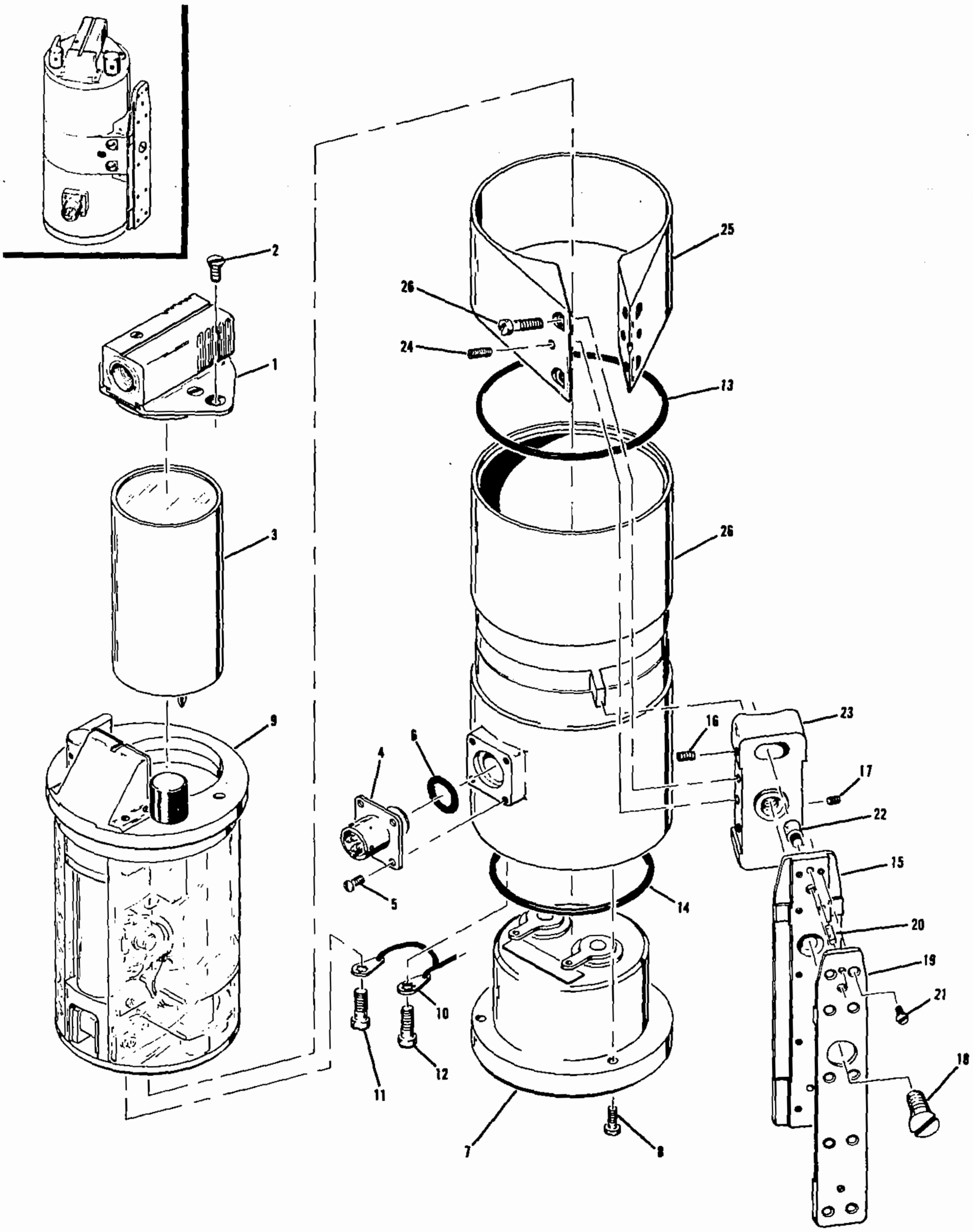


Fig. 3. Inflight Photometer – Exploded View

Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
3			
	700-100-1	HOUSING ASSEMBLY	Ref.
-1	700-103-54	BATTERY COVER (Ref. Fig. 4)	1
-2		SCREW, NO. 6-32x5/16 FLAT HEAD PHILLIPS (Ref. Fig. 4)	2
-3	700-104-1	BATTERY PACKAGE (Ref. Fig. 5)	1
-4		CONNECTOR, BENDIX PT02C-8-4P	1
-5		SCREW, NO. 4-40 x 3/16 ROUND HEAD	4
-6		O-RING, PARKER NO. 2-13	1
-7		METER, PHAOSTRON 20-012595	1
-8		SCREW, NO. 4-40 x 1/2 ROUND HEAD	3
-9	700-102-2 700-103-2	ELECTRICAL ASSY. OPTICAL ASSY. } (Ref. Fig. 4)	1
-10		GROUND LUG (LOCKING TYPE)	2
-11		SCREW, NO. 6-32x 1/4 PAN HEAD	1
-12		SCREW, NO. 8-32x 1/2 FILLISTER HEAD	2
-13		O-RING, PARKER NO. 2-37	1
-14		O-RING, PARKER NO. 2-227	1
-15	700-100-12	ALIGNMENT RAIL	1
-16		SET SCREW, NO. 8-32x 3/8 SOCKET	2
-17		SET SCREW, NO. 4-40x 1/4 SOCKET	1
-18		SCREW, 1/4-20 FLAT HEAD	1
-19	700-100-23	RETAINING RAIL	1
-20		PIN, 1/16 DIA. x 3/16 LONG	2
-21		SCREW, NO. 2-56 x 3/16 FLAT HEAD	10
-22	700-100-20	ADJUSTMENT PIN	1
-23	700-100-21	MOUNTING BLOCK	1
-24		SET SCREW, NO. 6-32x 1/2 SOCKET	2
-25	700-100-19	MOUNTING STRAP	1
		SCREW, NO. 8-32x 1/2 FILLISTER NYLOCK	4
-26	700-100-18	HOUSING	1

Inflight Photometer Parts List for Fig. 3

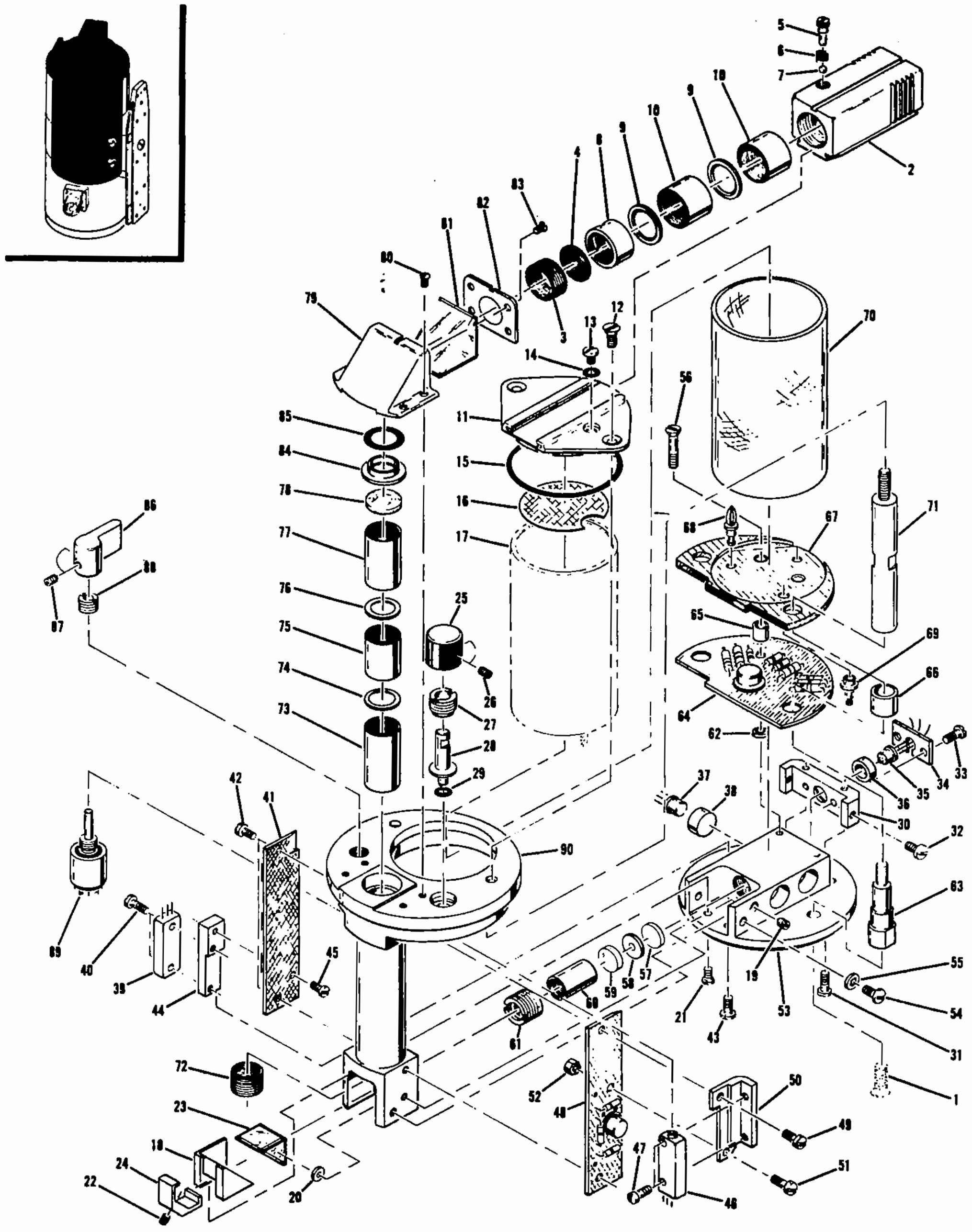


Fig. 4. Inflight Photometer Optical-Electrical Assembly

Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
4			
	700-102-2	ELECTRICAL ASSEMBLY, shown	Ref.
	700-103-2	OPTICAL ASSEMBLY, shown	Ref.
-1		SCREW, NO. 8-32 x 1/2 FILLISTER (See Fig. 3 for attaching hardware)	Ref.
-2	700-103-39	SUN SHADE	1
-3	700-103-67	BAFFLE RETAINER	1
-4	700-103-74	SHADE FILTER	1
-5	700-103-59	DETENT RETAINER	1
-6	700-103-56	DETENT SPRING	1
-7		STEEL BALL, 1/8 DIA. (Solid film lubricated)	1
-8	700-103-66	SPACER	1
-9	700-103-65	SUN SHADE BAFFLE	2
-10	700-103-64	SPACER	2
-11	700-103-54	BATTERY COVER	1
-12		SCREW, NO. 6-32 x 5/16 FLAT HEAD PHILLIPS (NYLOCK)	2
-13	700-103-72	VENT SCREW	1
-14		O-RING, PARKER NO. 2-3	1
-15		O-RING, PARKER NO. 2-28	1
-16	700-103-75	BATTERY PAD	1
-17	700-104-1	BATTERY PACKAGE (Ref. Fig. 5)	Ref.
-18	700-103-63	PRISM MOUNT	1
-19		SET SCREW NO. 4-40 x 3/16 SOCKET	1
-20	700-103-68	PRISM PAD	1
-21		SCREW, NO. 2-56 x 1/4 FILLISTER HEAD	2
-22		SET SCREW, NO. 2-56 x 1/8 SOCKET	1
-23	700-103-2006	PRISM (Right Prism)	1
-24	700-103-62	PRISM RETAINER	1
-25	700-103-43	CONTROL KNOB	1
-26		SET SCREW, NO. 4-40 x 3/16 SOCKET	2
-27	700-103-50	CONTROL SHAFT RETAINER	1
-28	700-103-51	CONTROL SHAFT	1
-29		O-RING, PARKER NO. 2-6	1
-30	700-103-49	PHOTOFET MOUNT	1
-31		SCREW; NO. 2-56 x 3/8 FILLISTER HEAD	2
-32		SCREW; NO. 4-40 x 1/4 FILLISTER HEAD	2
-33		SCREW, NO. 2-56 x 1/4 FILLISTER HEAD	2
-34	700-103-52	TRANSISTOR RETAINER	1
-35		Q1, PHOTOFET (See Fig. 2)	1
-36	700-103-53	PHOTOFET BUSHING	1
-37		TRANSISTOR Q2	1
-38	700-103-33	TRANSISTOR BUSHING	1
-39		TRIMPOT, BOURNS NO. 220L-1-201	1
-40		SCREW, NO. 2-56 x 3/8 FILLISTER HEAD	2
-41	700-103-48	ELECTRONICS BOARD (Components attached)	1
-42		SCREW, NO. 4-40 x 1/4 FILLISTER HEAD	2
-43		SCREW, NO. 2-56 x 1/4 FILLISTER HEAD	1
-44	700-103-69	GAIN POT MOUNT	1
-45		SCREW, NO. 2-56 x 1/4 FILLISTER HEAD	1

Inflight Photometer Optical-Electrical Assembly Parts List for Fig. 4

Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
4 (con't.)			
-46		TRIMPOT, BOURNS NO. 220L-1-500	1
-47		SCREW, NO. 2-56 x 3/8 FILLISTER HEAD	2
-48	700-103-47	ELECTRONICS BOARD (Components attached)	1
-49		SCREW, NO. 4-40 x 1/4 FILLISTER HEAD	2
-50	700-103-44	POTENTIOMETER MOUNT	1
-51		SCREW, NO. 2-56 x 1/4 FILLISTER HEAD	1
-52		NUT, NO. 2-56	1
-53	700-103-55	TRANSISTOR BLOCK	1
-54		SCREW, NO. 4-40 x 7/32 FILLISTER HEAD	2
-55		LOCK WASHER (STAR)	2
-56		SCREW, No. 2-56 x 5/8 FLAT HEAD	2
-57	700-103-2007A	FILTER	1
-58	700-103-57	FIELD STOP	1
-59	700-103-2007B	FILTER	1
-60	700-103-61	SPACER	1
-61	700-103-71	BAFFLE RETAINER	1
-62	700-102-25	WASHER	2
-63	700-102-17	SHORT STAND-OFF	2
-64	700-102-26	ELECTRONICS BOARD (Components attached)	1
-65	700-102-24	SPACER	2
-66	700-102-14	SPACER	2
-67	700-102-27	BATTERY CONTACT BOARD	1
-68		BANANA PLUG, DOT NO. 153276	2
-69		BANANA JACK, DOT NO. 3663	1
-70	700-102-23	BATTERY TUBE	1
-71	700-102-12	LONG STAND-OFF	2
-72	700-103-70	BAFFLE RETAINER	1
-73	700-103-73A	SPACER	1
-74	700-103-60B	BAFFLE	1
-75	700-103-73B	SPACER	1
-76	700-103-60A	BAFFLE	1
-77	700-103-73C	SPACER	1
-78	700-103-2009	LENS	1
-79	700-103-42	PRISM BLOCK	1
-80		SCREW, NO. 0-80 x 3/16 ROUND HEAD	4
-81	700-103-2008	PRISM	1
-82	700-103-41	PRISM RETAINER	1
-83		SCREW, NO. 0-80 x 1/8 FLAT HEAD	4
-84	700-103-40	LENS SEAL INSERT	1
-85		O-RING, PARKER NO. 2-13	1
-86	700-103-46	SWITCH LEVER	1
-87		SET SCREW, NO. 2-56 x 1/8 SOCKET	2
-88	700-103-58	SWITCH RETAINER	1
-89		SWITCH, DAVEN NO. 128-GB-2(with O-Ring)	1
-90	700-103-45	OPTICAL CHASSIS	1

Inflight Photometer Optical-Electrical Assembly Parts List for Fig. 4 (Con't.)

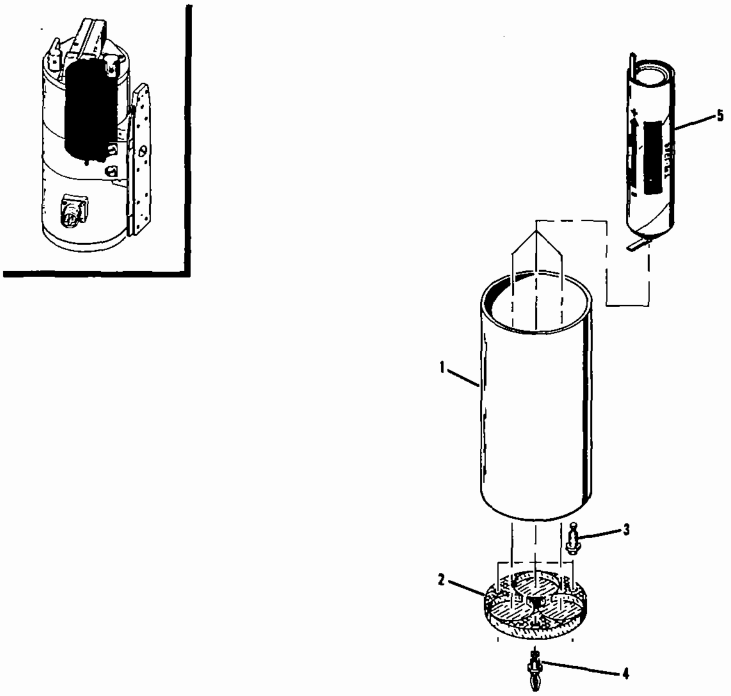


Figure & Index Number	PART NUMBER	NOMENCLATURE	Units per Assy.
5			
	700-104-1	BATTERY PACKAGE	Ref.
-1	700-104-12	BATTERY CASE	1
-2	700-104-11	BATTERY BOARD	1
-3		BANANA JACK, DOT NO. C3663	2
-4		BANANA PLUG, DOT NO. 153276	1
-5		BATTERY, MALLORY NO. TR-136R (with two end cells removed)	3

Fig. 5. Inflight Photometer Battery Package

APPENDIX D

Appendix D is attached in order that the reader may be apprised of some of the detailed information which it was necessary to provide for the flight operation. The mission operation plan was generated by the Visibility Laboratory and details the preflight, inflight, and postflight operations as well as contingency procedures. The experiment procedures for GT-V and GT-VII as they were presented in the final Flight Plan are included here to show the manner in which the information was presented to the astronauts and all others associated with flight operations. Finally, the summary Flight Plan for GT-V is included in order that the reader may appreciate the multitude of tasks which made demands upon the astronaut's time during flight, and the manner in which the Visual Acuity Experiment tasks were phased into this schedule.

GT VII MISSION OPERATION PLAN

GEMINI INFLIGHT VISUAL ACUITY EXPERIMENT S-8, D-13

1.0 Experiment Control: During the GT-7 mission the experiment will be controlled from the Manned Spacecraft Center by the Principal Investigator, Dr. S. Q. Duntley, and the Center Investigator, Dr. Robert L. Jones. Dr. Duntley and Dr. Jones will be located in the Mission Control Center (MCC). They will communicate with the Mission Controller through the Experiments Specialist situated in the Flight Crew Support Division Staff Support Room. Frequent communication will be required between Dr. Duntley and the observation site near Laredo, Texas. This will be achieved by two-way voice communication which is being established by Network Branch personnel and the Goddard Space Flight Center. Technical direction of activities at Southern Texas observation site near Laredo will be accomplished by Mr. Roswell W. Austin of the Visibility Laboratory. Operation and maintenance of the Texas observation site will be executed by the U.S. Navy. Management of the logistics of the preparation of the two observation sites is handled at MSC by Commander Harold Hilz, Code ZR 1, of the Air Force Systems Command Field Office.

2.0 Ground Observation Sites: Two ground observation sites have been established: one in southern Texas, and one in Western Australia; only the southern Texas site will be manned by a ground crew during the mission. The Western Australia site may, however, be seen on a few passes which occur during suitable daylight hours. Details of the two sites are as follows:

a. Southern Texas Site. This is situated about 40 miles north of Laredo, Texas on the Gates Ranch, coordinates 99° 48' west, 28° 12' north. This site consists of eight square background test areas and white markings of styrofoam-covered fibreboard. The pattern of the southern Texas site consists of two east-west rows of four squares each. A north row of four squares, used for the Gemini 5 mission, will not be operated during the GT-7 mission but will contain distinctive markings to aid in site acquisition and directional orientation. It is expected that these markings will consist of bars across the top portion of each of the four squares as indicated in the accompanying figure. Additionally, smoke generators and pyrotechnic smoke pots will be deployed to assist in the acquisition and orientation phase of the operation. The patterns will be read bookwise from the NW square and ending with the SE square.

b. Western Australia Site: This site is situated on Woodleigh Station about 137 miles south of Carnarvon, coordinates 114° 45' east, 26° 10' south. The site is about 25 miles from the coast on flat terrain covered with scrub. The scrub has been cleared at the test area and the square background areas bulldozed flat. Truckloads of white shells have been spread on the dark soil squares in the form of rectangles.

A total of 16 squares will be visible with markings in each. The 16 squares are divided into two groups of eight with about one mile separation. The markings may be used for observation in accordance with the same scheme used at the southern Texas site if the opportunity arises. No acquisition aids in the form of smoke pots, etc., will be available at this site.

c. Contingency Procedures. In the event of a period of uncontrolled flight during which any glimpses of the observation site may be only momentary, the Command Pilot will request the use of the contingency pattern shown in the middle figure. The ground crew will then remove the white rectangle from the third square and substitute a pattern of white dots graded in size and positioned as shown in the figure. Five or fewer dots will be used. The largest dot will be at the center of the square, but the surrounding dots will be placed at random on the diagonals of the square. Either astronaut (or both astronauts) who acquires the site will report the total number of dots he sees in the square. No other description of the dot pattern is required. Should sufficient viewing time be available, either or both astronauts will observe and report the orientation of the rectangles in the seven remaining squares. Further details of the ground observation sites, including maps, may be obtained from Cdr. H. Hilz, Code ZR 1, MSC.

3.0 In-Flight Operations Plan: Three activities will be carried out in flight: (a) observation of ground markings, (b) photometer measurements (scan) of light scattering by the spacecraft window, and (c) visual acuity testing within the spacecraft using the on-board vision tester.

a. Observation of the ground markings at the sites already described in this Appendix will be made by the pilot (or by the command pilot, if so requested by the Principal Investigator) on each occasion a usable pass for carrying out the experiment occurs. He will report the observed orientation of all eight rectangles by voice communications. As the observations are being carried out the photometer data will be telemetered in real time to the Corpus Christi tracking station and recorded there, together with the astronaut's voice report. The astronaut check-off list of this portion of the S-8/D-13 experiment is given below:

The letter "E" designates time of closest approach. All actions are carried out by the pilot except where indicated. The crew is informed that the next pass, E-30 to E-60, over Australian or American observation site is suitable for experiment, given anticipated weather conditions in region of observation site, and spacecraft yaw and pitch angles for acquisition of observation site at E-2.

E-20:
  (1) Detach photometer from hatch mount.
  (2) Connect one end of utility cord to photometer. Plug other end of utility cord into special T/M socket for experiment.
  (3) Switch on photometer.
  (4) Mount photometer on 16 mm camera bracket and push until detent is engaged.

E-10: Adjust photometer to read zero with one fingertip occluding light entry hole of photometer.

E-5: Final confirmation that zero reading is present on photometer. Confirm T/M switched on.

E-4: Informed by appropriate tracking station that observation site is ready.

E-3: Begin visual search for landmarks preceding the site. Vehicle controlled by command pilot or pilot, whichever is convenient.

E-2: Yaw and pitch data confirmed by command pilot. Vehicle controlled so that good view can be obtained by pilot.

E-30 sec. Pilot announces site acquired and that he is ready to begin observation of ground markings in about 20 seconds.

E-10 sec. Pilot begins observations of ground markings upon command from ground as previously instructed. (NOTE: "E" should occur at passage directly over ground markings.) (TCA)

E+10 sec. Pilot finished recording ground marking readings. Transmits results to ground. (At this point, if possible, the command pilot should transmit his results or comments.)

E+1 Tracking station to confirm that both pilots' readings received loud and clear.

After passage over the observation site the following sequence is carried out:

(1) Switch off photometer
(2) Disconnect utility cord
    a. From photometer
    b. From T/M socket
    c. Plug into S/C utility power socket

(3) Remove photometer from 16 mm camera bracket and stow on hatch.

b. Photometer measurements (scan) of light scattering by the spacecraft windows are for the purpose of ascertaining whether any light scattering by the spacecraft window is uniform over the window and whether there is any change in light scattering as the mission progresses (due to possible deposition of outgassing products.)

For this portion of the experiment the astronaut's comments are recorded on the voice tape, and the photometer data is recorded on the dump telemetry system and recovered and returned to the Principal Investigator at MSC, Houston, Texas as soon as possible, and preferably within 10 hours. The astronaut check-off list for this portion of the S-8/D-13 experiment is given below:

To be carried out by pilot any time during first 24 hours and last 24 hours of mission, during daylight. Carry out with platform operating if possible.

E-30: Astronauts notify Mission Control that they will carry out experiment.

E-20:
(1) Detach photometer from hatch mount.
(2) Connect one end of utility cord to photometer. Plug other end of utility cord into special T/M socket for experiment.
(3) Switch on photometer.
(4) Adjust photometer to zero.
(5) Mount photometer on 16mm camera bracket and lock.

E-10: Confirm that photometer still reading zero. If not, readjust to zero.

E-2:
(1) Final confirmation that photometer is reading zero.
(2) Confirm that on-board voice tape is switched on.
(3) Confirm that dump T/M recording operational.
(4) Command pilot orients vehicle so that right hand window is pointing at dark spot of the sky (not the Milky Way) with the sunlight striking the window at an oblique angle (estimated 30°). C/P orients S/C so that the shadow of window's left corner falls in center of the trailing edge of abort handle quadrant.

E Pilot removes photometer from 16mm camera bracket and begins slow scan of right hand window as instructed in training sessions, and calling out scan lines. Command pilot observes photometer as procedure is carried out and notes any change in readings. Advise next tracking station of results.

E+5: Command pilot records completion of experiment on voice tape.

Subsequent to experiment:

(1) Switch off photometer
(2) Disconnect utility cord
    a. From photometer
    b. From S/C
    c. Plug into S/C utility socket
(3) Stow photometer

Optional Additional Scans:

(1) Left window. (Pilot reads meter).
(2) Right (or both) window(s) if accumulation of light scattering film appears serious and/or time-varying.

c. Visual acuity testing within the spacecraft using the on-board vision tester. This is accomplished once every 24 hours at any convenient time according to the check-off list given below. Full details of the vision tester and its mode of operation are given in Appendix 2. Immediately after completion of this test the astronaut will carry out the M-9 experiment (which is incorporated in the vision tester.)

(1) Unplug vision tester from hatch.
(2) Plug in utility cord to vision tester.
(3) Plug in other end of utility cord to spacecraft power supply socket.
(4) Switch on spacecraft power and confirm that vision tester lights up.
(5) Unstow and insert appropriate biteboard.
(6) Unstow and insert headbrace.
(7) Place biteboard in mouth and carry out visual acuity testing as instructed during training in Visibility Laboratory Van (for details see Appendices 1 and 2 to this Experiment Plan.)
(8) At completion of S-8 experiment, carry out M-9 experiment without removing instrument from eyes. (for details see Definitive Experiment Plan for M-9 experiment.)
(9) After completion of M-9 experiment detach and stow biteboard and headbrace.
(10) Switch off power supply.
(11) Detach utility cord from vision tester.
(12) Pass vision tester to other astronaut, who will insert his own biteboard and repeat the above procedures.
(13) Indicate on the on-board voice tape that the experiment was completed.

4.0 <u>Post-Flight Requirements.</u> (including data processing): Assuming that the spacecraft lands in a primary recovery area, immediate post-flight testing for the S-8/D-13 and the M-9 experiments will be carried out on board the recovery carrier by Dr. Earl F. Miller, U.S. Naval School of Aviation Medicine, Pensacola, Florida, Telephone: 455-3211, Extension

3192, or by Mr. Richard Waite, also U.S. Naval School of Aviation Medicine (temporarily assigned to MSC, Houston, Telephone: HU3-4451.) Dr. Miller (or Mr. Waite) will have with him a spare vision tester in case the spacecraft vision tester should be damaged during the recovery procedure.

The following operations will be carried out after the spacecraft hatches have been opened on the carrier deck. The spacecraft photometer and spacecraft vision tester which are attached, respectively, to the right and left hatches of the spacecraft, will be removed by Landing and Recovery Division personnel and immediately taken to Dr. Earl Miller (or Mr. Richard Waite) in the post-flight medical examination area. Dr. Miller will receive the vision tester and photometer and will carry out a post-flight evaluation on both. Dr. Miller will return the vision tester and the photometer to the Visibility Laboratory, Attention: Mr. R. W. Austin, Building 348, San Diego, California 92152, as soon as he returns to the U.S.A. Immediately upon receiving the vision tester, Dr. Miller will check that all punched cards are in position and complete. These cards are situated in a slot in the vision tester. Dr. Miller will make several copies of each card and immediately package the originals to be flown either to MSC, Houston, or to Florida Operations Support Plans and Programs Office (Attention: Richard G. Arbic, HC4) from where they should be transmitted to Dr. Robert L. Jones, Manned Spacecraft Center, Code EC5, Houston, Texas. Dr. Miller will conduct the post-flight visual acuity tests using the spacecraft vision tester, provided it has not been damaged, and the spare vision tester as a part of the post-flight medical debriefing. Post-flight retest of color discrimination will be performed at this time. The precise timing of the post-flight visual acuity test will be arranged by the Center Medical Office personnel in charge of the examination. It is planned to carry out the post-flight portion of the S-8 and M-9 experiments in that order immediately after the cardiovascular tilt-table tests. If the spacecraft should land in an area where carriers are not situated and where the astronauts are picked up by a destroyer, the spacecraft vision tester and photometer should remain with the spacecraft and be returned to the Cape in it. At the Cape they should be removed. The punched cards should be left in the vision tester, and both vision tester and photometer, together with biteboards, should be returned immediately to Dr. Robert L. Jones, Code EC5, Manned Spacecraft Center.

After the conclusion of the mission, Dr. Duntley will prepare the four-day interim report at MSC. This will be forwarded to the Gemini Experiments Office - Mr. Norman Foster, from the Space Medicine Branch, Crew Systems Division - Dr. Robert L. Jones.

The complete mission report will be forwarded to the Gemini Experiments Office on the 14th day after mission is completed by Dr. Robert L. Jones. The final scientific report probably will not be available for six months or more after completion of the mission. Systems debriefings will probably be attended by Dr. Robert L. Jones. The scientific debriefing and any experiments debriefings will be attended by Dr. S. Q. Duntley, Mr. R. W. Austin, and Dr. J. H. Taylor, Visibility Laboratory, San Diego, California, and by Dr. Robert L. Jones, Code EC5.

The information collected during the mission as outlined in paragraph 3. 0 above will be forwarded to Dr. Duntley and Dr. Jones at MSC, Code EC5, Crew Systems Division, Houston, Texas, Telephone: HU3-4451 during or as soon as possible after the mission. The information required is as follows:

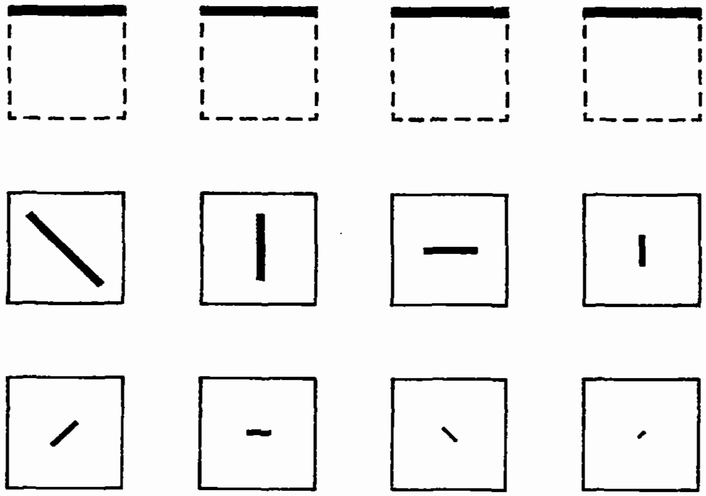
a. Dump telemetry data of on-board photometer readings. (Required within ten hours of transmission.)

b. On-board voice tape comments for any part of S-8/D-13 experiment.

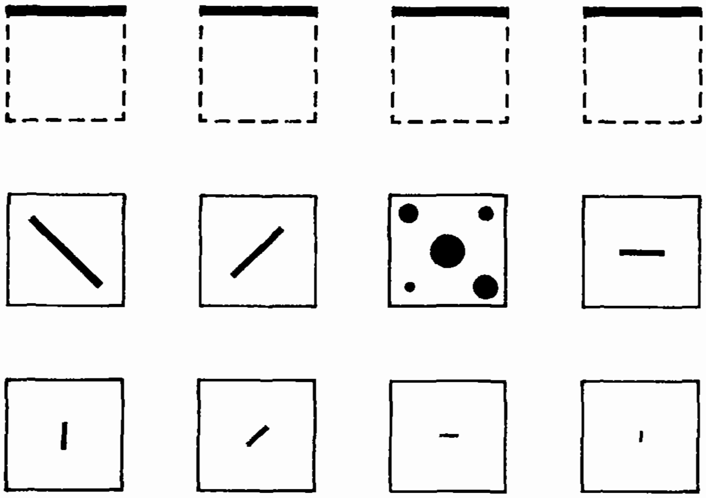
c. Punched cards extracted aboard the carrier from the spacecraft tester (see above.)

d. On-board photometer and vision tester.

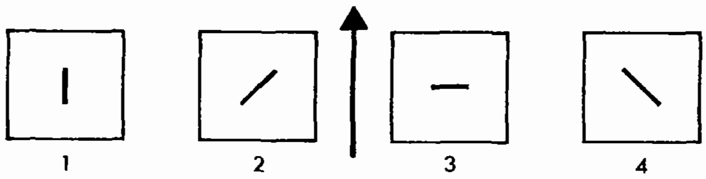
e. Estimates of sun angles for the window light scattering portion of the experiment (see paragraph 3. 0 above.)



ORIENTATION EXPERIMENT
LAREDO, TEXAS



CONTINGENCY EXPERIMENT
LAREDO, TEXAS



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GEMINI V FLIGHT PLAN
EXPERIMENT PROCEDURES S-8/D-13
VISUAL ACUITY/ASTRONAUT VISIBILITY

Purpose

Investigate the limits of man's visual acuity under weightlessness and changes thereto over long periods by identification of special ground patterns subtending small visual angles.

Spacecraft Systems Configuration

1. Photometer installed on 16mm camera bracket and connected to the high level multiplexer recepticle.

2. AC POWER - ACME

3. RATE GYROS - PRI

4. ATTITUDE CONTROL - PULSE

Conditions

Daylight

Procedures

1. S-8/D-13 Vision Tester: Once during each 24-hour period, each astronaut will use the Vision Tester to test his visual acuity.

    a. Unstow Vision Tester and Bite-Boards.

    b. Assemble equipment and connect to AUX RECP.

    c. Insert blank card and carry out visual acuity testing.

    NOTE: Depress knob for vertical rectangles, do not depress for horizontal rectangles. Make estimate for each marking.

    d. At conclusion remove card and write score on card (White squares punched and black squares not punched are wrong).

2. M-9 Vision Test

    a. Rotate knob until green central field is seen in eyepieces.

    b. Switch off adapting fields.

    c. Occlude left eyepiece (Cmd Pilot) or right eyepiece (Pilot) with ring on eyepiece and bring maddox rod in position.

d. Rotate white line until it is estimated to be parallel to the FDI pitch axis.

e. Other astronaut records, on the card, the marking on eyepiece and then spins white line randomly.

f. Repeat procedure for a total of 5 readings.

3. The other crewman then performs the M-9 Vision Test and then the S-8/D-13 Vision Tester portion. The reverse side of the card is used.

4. At conclusion of tests, stow equipment.

5. Ground Observations: (Pilot performs steps (a) thru (f)

a. Unstow photometer 20 minutes prior to observation.

b. Turn photometer on (15 minutes warmup required).

c. 15 minutes later zero photometer.

d. Turn photometer OFF and connect it to T/M via the utility cord.

e. Turn photometer ON.

f. Mount photometer on camera bracket (photometer is aligned with black cavity).

g. Confirm zero reading is holding.

h. Cmd Pilot visually aligns S/C on the test pattern array (series of white rectangles). Cmd Pilot and Pilot record description of the ground patterns on knee pads. Transmit sequence of 12 numbers (Laredo) or 16 numbers (CRO) to ground. See pattern sequence on page 66a.

6. Window Measurements: (accomplished during the first and last 24 hours and any other times if necessary)

(a) thru (f) same as above

g. Cmd Pilot align S/C so that right window points towards dark sky with sunlight striking window at an oblique angle (approximately 30°)

h. RECORD - CONT

i. Pilot removes photometer from camera-mount and makes slow scan of window calling out scan lines (shown below). Align photometer along roll axis during measurement. Measurements should be taken off the window on each scan line. Scan lines should be parallel to inboard window frame. See picture below.

j. Cmd Pilot reads photometer (if positive reading, notify next station.) For additional scans report to next station the time scan was made.

k. Repeat procedure for left window if possible.

l. No 2 AUDIO - UHF

Objects to be Observed

1. The objects are various patterns laid out near Laredo, Texas, and near CRO, Australia. (Woodleigh Ranch)

2. A minimum of six ground observations should be made (preferably early and later in the flight).

3. During an additional pass, the 35mm Zeiss camera should be used to photograph the pattern as part of the D-6 Experiment.

Voice Tape Recorder Usage

During observation:

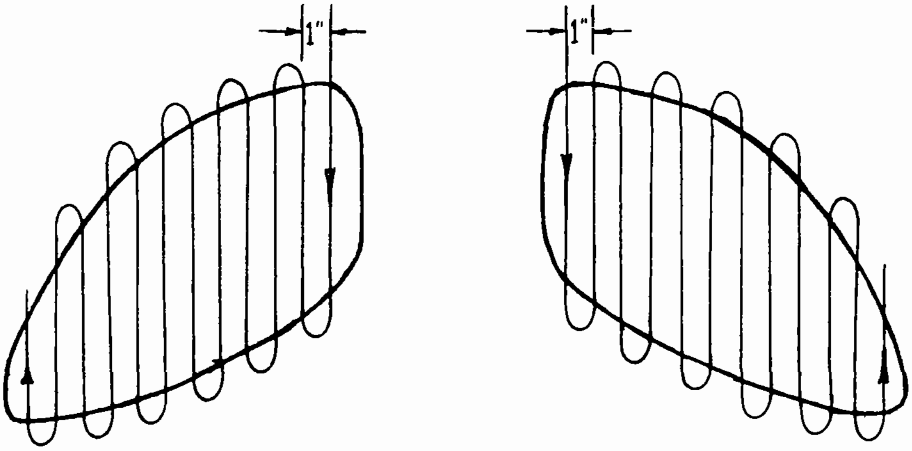
Cmd Pilot and Pilot record comments on knee pads and transmit comments via UHF over next station.

Propellant Requirements

$6\ (1) = 6\ \#$

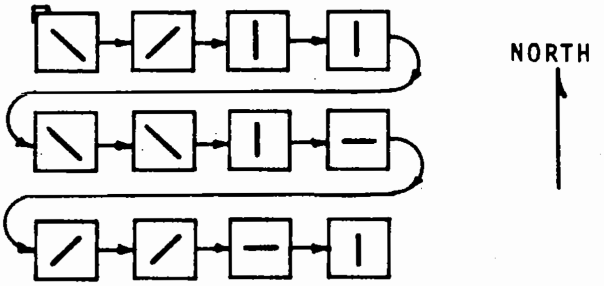
$2\ (\tfrac{1}{2}) = 1\ \#$

$7\ \#$

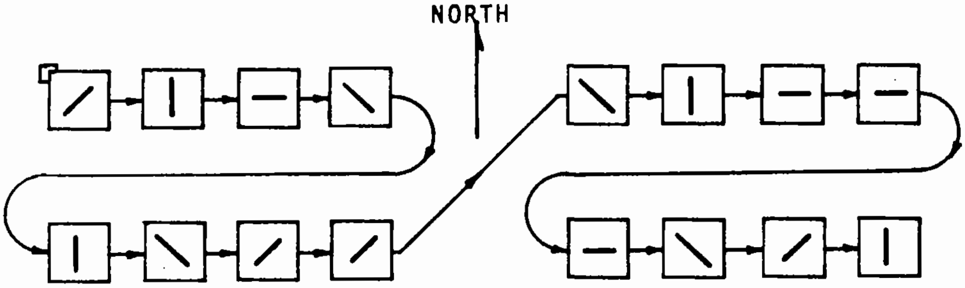


Window Scan Lines

PATTERN SEQUENCE

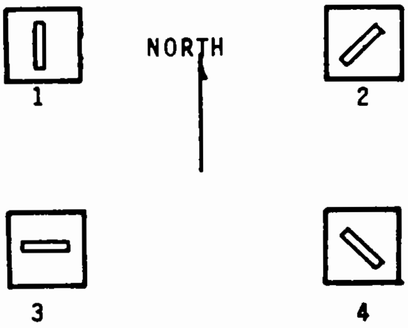


LAREDO GROUND MARKINGS



CRO GROUND MARKINGS

MARKING CODE



These numbers will be called out by the observing astronaut to indicate orientation of ground marking rectangles relative to geographic coordinator.

GEMINI VII FLIGHT PLAN
EXPERIMENT PROCEDURES S-8/D-13
VISUAL ACUITY/ASTRONAUT VISIBILITY

Purpose

Investigate the limits of man's visual acuity under weightlessness and changes thereto over long periods by identification of special ground patterns subtending small visual angles.

Spacecraft Systems Configuration

1. Photometer installed on 16mm camera bracket and connected to the high level multiplexer receptacle.

2. AC POWER - ACME

3. RATE GYROS - PRI

4. ATTITUDE CONTROL - PULSE

Conditions

Daylight

Procedures

1. S-8/D-13 Vision Tester: Once during each 24-hour period, each astronaut will use the Vision Tester to test his visual acuity.

   a. Unstow Vision Tester, Bite-Boards, and Head Brace.

   b. Assemble equipment and connect to AUX RECP.

   c. Tighten seat belt.
   d. Insert blank card and carry out visual acuity testing.
   NOTE: Depress knob for vertical rectangles, do not depress for horizontal rectangles. Make estimate for each marking.

   d. At conclusion remove card and hand it to other crewman and proceed with M-9 vision test without removing eyes from eyecups.

2. M-9 Vision Test

   a. Rotate knob until green central field is seen in eyepieces.

   b. Switch off adapting fields.

   c. Occlude left eyepiece (Cmd Pilot) or right eyepiece (Pilot) with ring on eyepiece and bring maddox rod in position.

   d. Close eyes. Offset line. Open eyes.

e. Rotate white line until it is estimated to be paralled to the FDI pitch axis. Close eyes.

f. Other astronaut records on the card the marking on eyepiece and then spins white line randomly. Open eyes.

g. Repeat procedure for a total of 5 readings.

h. Write S8/D13 scores on card. White squares punched and black squares not punched are wrong.

3. The other crewman then performs the S8/D13 and M-9 vision test. The reverse side of the card is used.
4. Record score on voice recorder.
5. At conclusion of tests, stow equipment.

6. Ground Observations: Pilot performs steps (a) thru (g).

a. Unstow photometer 20 minutes prior to observation.

b. Turn photometer on (15 minutes warmup required).

c. Fifteen minutes later zero photometer.

d. Turn photometer OFF and connect it to T/M via the utility cord.

e. Turn photometer ON.

f. Mount photometer on camera bracket (photometer is aligned with black cavity).

g. Confirm zero reading is holding.

h. Cmd Pilot visually aligns S/C on the test pattern array (series of white rectanges). Pilot transmits sequence of 8 numbers to ground. See pattern sequence on page 77.

7. Window Measurements: (Accomplished during the first and last 24 hours and any other times if necessary.)

(a) thru (g) same as above.

h. Cmd Pilot align S/C so that right window points towards dark sky with sunlight striking window at an oblique angle of approximately 30° (sunlight edge on abort handle).

i. Pilot - note sunlight pattern on right side.

j. Pilot removes photometer from camera mount and makes slow scan of window calling out scan lines (shown below). Align photometer along roll axis during measurement. Measurements should be taken off the window in each scan line. Scan lines should be parallel to inboard window frame. See picture below.

k. Cmd Pilot reads photometer (if positive reading, notify next station). For additional scans report to next station the time scan was made.

l. Repeat procedure for left window if possible.

Objects to be Observed

1 The object are various patterns laid out near Laredo, Texas.

2. A total of 14 ground observations should be made (one per day).

Sequence Numbers

01 S8/D13 and M-9 vision test

02 Ground observation (Laredo, Texas)

03 Ground observation (CRO) - DELETED

04 Window measurement

05 Drifting flight array

Propellant Requirements

14 runs x 1#/run = 14#

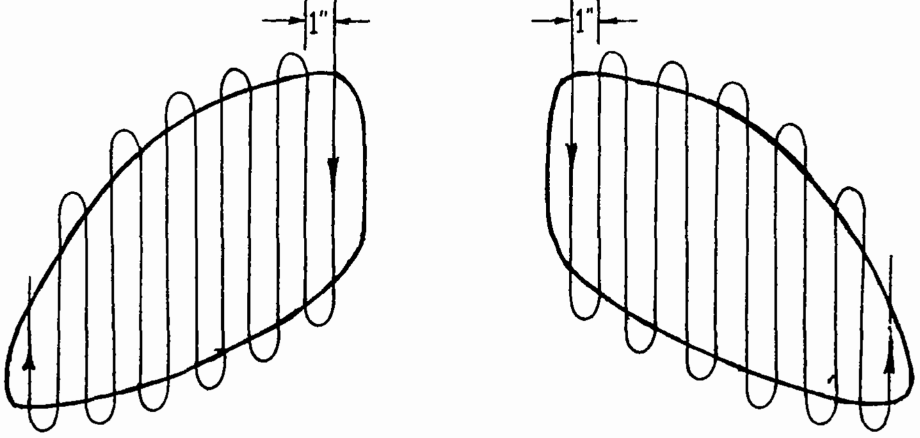
2 window measurements x $\frac{1}{2}$#/measurement = 1#

15# (original requirement)

9 runs x 1#/run = 9#

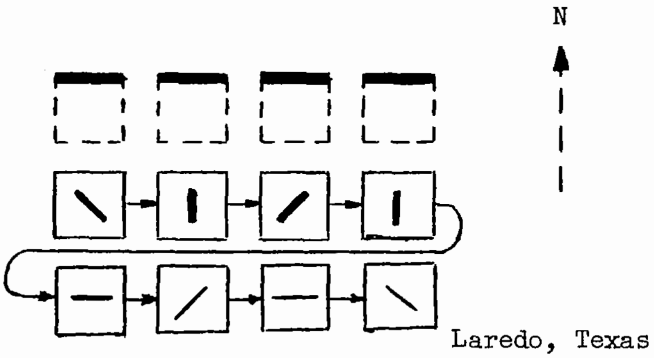
2 window measurements x $\frac{1}{2}$#/measurement = 1#

10# (revised requirement for VI rndz support)



Window Scan Lines

PATTERN SEQUENCE



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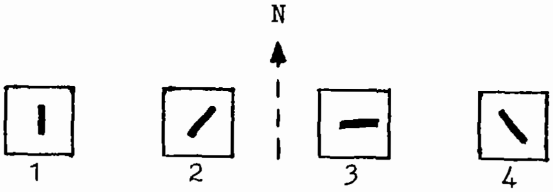
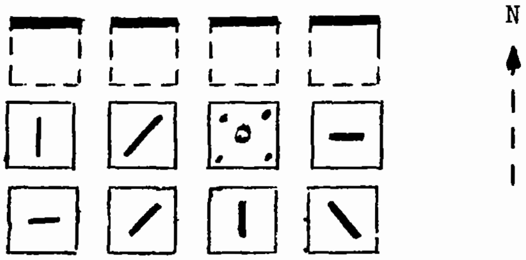


Sequence for Drifting Flight



SUMMARY FLIGHT PLAN

Day:Hr

0:00 Lift-off
Align PLAT, INSERTION Checklist
RAD-FLOW,
CRO: GO/NO GO 6-4, GO/NO GO D-4/D-7
Align PLAT - SEF
RADAR - STBY Radar Test No. 6
REP EJECT
RADAR-ON
COOLED SENSOR REP Measurements (D-4/D-7)
Align PLAT - SEF REP SEPARATION MANEUVER
S/C CLOSING MANEUVER, Radar Test No.2A
RNDZ MODE TEST
0:04 Radar Test No. 2B
Align PLAT - SEF
CO-ELLIPTICAL MANEUVER
$\omega T = 130^\circ$ Transfer Maneuver
$\omega T = 82^\circ$ Correction Maneuver
$\omega T = 34^\circ$ Correction Maneuver
RENDEZVOUS
D-2 EXP
SEPARATION MANEUVER
POWER DOWN: COMPUTER, RADAR, PLAT & SCANNER
RAD & IR SPECT Align (D4/D7)
GO/NO GO 18-1
PWR DOWN S/C
0:08
D-4/D-7 CRYOGENIC Gas Lifetime PILOT EAT
MED DATA (P)
PLA UPDATE 9-3 thru 13-2
D-4/D-7 CRYOGENIC Gas Lifetime
MSC-1 CMD SLEEP
0:12 D-4/D-7 CRYOGENIC Gas Lifetime
MED DATA (Pilot) PILOT EAT
S-8/D-13 Vision Test (Pilot)
M-9 TEST (Pilot) BRIEFING
M-9 TEST (CMD)
S-8/D-13 Vision Test (CMD) CMD EAT
0:16 MED DATA (CMD)
Cabin Lighting Survey D4/D7 CRY Gas Lifetime
PILOT SLEEP
PLA UPDATE 14-2 thru 19-4
0:20
UHF Test No. 3 CMD EAT
FLIGHT PLAN UPDATE FOR US PASSES BRIEFING
PILOT EAT CMD NAP
MED DATA (PILOT)
COMP - ON PLAT - ON
UHF Test No. 1
1:00

Day:Hr

1:00 D-6 (CYI)
D-6 (E. AFRICA)
CRO: D-4/D-7 STAR
D-6 (U.S.) & D4/D7 Desert (TEX)
CNV: GO/NO GO for 33-1 UHF Test No. 2
D-6 (W. AFRICA)
D-6 (E. AFRICA), MED DATA (Pilot) BOTH EAT
D-1 MOON TRACK, D-4/D-7 MOON MEASUREMENT
D-6 (U.S.) & D4/D7 MTS (CAL)
D-6 (Recovery Ship)
CRO: PLA UPDATE 20-4 thru 24-3
1:04
S-8/D-13 (LAREDO) plus Window MEASUREMENT
COMP - OFF PLAT - OFF
MED DATA (CMD) PILOT NAP
S-7 {Eastern Pacific, Caribbean / White Calibration CARD} CMD EAT
BRIEFING
PILOT EAT
1:08 MSC-1
Cabin Lighting Survey
Thruster Illumination Check
RKV: PLA UPDATE 25-D thru 29-2 CMD SLEEP
1:12
RKV: MED DATA (Pilot) PILOT EAT
S-8/D-13 Vision Test (Pilot)
M-9 TEST (Pilot) BRIEFING
M-9 TEST (CMD)
S-8/D-13 Vision Test (CMD)
MED DATA (CMD) CMD EAT
S-7 (Phillipines-GUAM)
1:16
Cabin Lighting Survey
S-7 (Phillipines-GUAM) PILOT SLEEP
MSC-1
Apollo Landmark (W. AFRICA) CMD EAT
1:20 CRO: PLA UPDATE 30-2 thru 34-4 BRIEFING
UHF Test No. 4 PILOT EAT CMD NAP
MED DATA (Pilot)
CRO: FLIGHT PLAN UPDATE FOR U.S. PASSES
MED DATA (CMD)
2:00 D-6 (LAREDO PHOTO PASS)
D-6 (BDA)

SUMMARY FLIGHT PLAN

Day:Hr

2:00
D-6 (KNO) & D4/D7 Veg (KNO)
CRO: D-4/D-7 (STARS)
BOTH EAT
D-6 (U.S.), GO/NO GO for 47-1
D-6 (W. AFRICA)
CRO: MED DATA (Pilot)
S-8/D-13 (LAREDO)

S-1
2:04
PLA UPDATE 35-4 thru 39-3
MED DATA (C)
S-7 (U.S., Caribbean)
PILOT NAP
SELAB II COMM
S-7 (U.S., CARIBBEAN)
CMD EAT
BRIEFING
PILOT EAT
2:08 Apollo Landmark (SO. AMERICA)
HAW: D-4/D-7 (ISLAND)
HAW: MED DATA (Pilot)
CMD SLEEP
Cabin Lighting Survey
2:12
RKV: PLA UPDATE 40-D thru 44-2
PILOT EAT
S-8/D-13 Vision Test (Pilot)
M-9 TEST (Pilot)
M-9 TEST (CMD)
BRIEFING
S-8/D-13 Vision Test (CMD)
CMD EAT
MED DATA (CMD), S-7 (Phillipines-GUAM)
2:16
Cabin Lighting Survey
PILOT SLEEP
MSC-1
CMD EAT
CYI: PLA UPDATE 45-2 thru 49-4
BRIEFING
CRO: FLIGHT PLAN UPDATE FOR U.S. PASSES
2:20
PILOT EAT
CMD NAP
CRO: MED DATA (Pilot)
S-5 (MEXICO)
S-5 (EAST AFRICA)
CRO: MED DATA (CMD)
S-8/D-13 (LAREDO), GO/NO GO 62-1
3:00

Day:Hr

3:00
CRO: D-4/D-7 (Milky Way & Void)
BOTH EAT
D-6 (EL CENTRO)
D-6 (CNV) & D4/D7 Water to Land & Veg (CNV)
CRO: D-4/D-7 (ZODIACAL Light)
HAW: MED DATA (Pilot)
D-6 (ASC) & D4/D7 Islands (ASC)

CRO: PLA UPDATE 50-4 thru 54-D
3:04 HAW: MED DATA (CMD)
S-7 (CARIBBEAN)
PILOT NAP
CMD EAT
S-7 (CARIBBEAN)
BRIEFING
PILOT EAT
3:08
Cabin Lighting Survey
CMD SLEEP
MED DATA (P)
RKV: PLA UPDATE 55-D thru 59-2
PILOT EAT
3:12
S-8/D-13 Vision Tests (Pilot)
M-9 TEST (Pilot)
M-9 TEST (CMD)
BRIEFING
S-8/D-13 Vision Tests (CMD)
MED DATA (CMD)
CMD EAT
Cabin Lighting Survey
MSC-1
3:16
PILOT SLEEP
CMD EAT
CYI: PLA UPDATE 60-2 thru 64-4
BRIEFING
CRO: FLIGHT PLAN UPDATE FOR U.S. PASSES
PILOT EAT
3:20
CMD NAP
CRO: MED DATA (Pilot)
D-6 (Recovery Ship)
D-6 (E. Africa)
CRO: MED DATA (CMD)
TEX: S-8/D-13 (LAREDO)
CNV: GO/NO GO for 77-1
BOTH EAT
4:00 D-6 (E. Africa)

SUMMARY FLIGHT PLAN

Day:Hr		
4:00		
	D4/D7 STAR (over CRO) D-4/D-7 WHITE SAND SLED RUN	BOTH EAT
	CRO: D-4/D-7 Night, Water and Land	
	HAW: MED DATA (Pilot)	
	D-6 (ASC)	
	CRO: PLA UPDATE 65-4 thru 70-D	
	HAW: MED DATA (CMD)	CMD EAT PILOT NAP
4:04		
		BRIEFING
		PILOT EAT
4:08		
	Cabin Lighting Survey	CMD SLEEP
	RKV: MED DATA (Pilot)	
		PILOT EAT
4:12	RKV: PLA UPDATE 71-D thru 75-2	BRIEFING
	CSQ: MED DATA (CMD)	CMD EAT
	Cabin Lighting Survey	
	MSC-1	PILOT SLEEP
4:16		
		CMD EAT
	S-8/D-13 Vision Test (CMD) M-9 TEST (CMD) M-9 TEST (Pilot) S-8/D-13 Vision Test (Pilot)	BRIEFING
	MED DATA (Pilot)	PILOT EAT CMD NAP
4:20		
	CRO: PLA UPDATE 76-1 thru 80-4	
	CYI: MED DATA (CMD) D-6 (EAST AFRICA)	BOTH EAT
	S-8/D-13 (LAREDO), GO/NO GO 92-1	
	D-6 (E. Africa)	
5:00		

Day:Hr		
5:00	MED DATA (Pilot)	
	D-4/D-7 WHITE SAND SLED RUN D-6 (S Africa)	
	D-6 (U.S.) D4/D7 Mountains (WHS)	
	D-4/D-7 ASC Calibration	
	HAW: MED DATA (CMD)	CMD EAT PILOT NAP
5:04		
	CSQ: PLA UPDATE 81-3 thru 85-D	
		BRIEFING
		PILOT EAT
5:08		
	Cabin Lighting Survey	CMD SLEEP
	RKV: MED DATA (Pilot)	
		PILOT EAT
5:12	RKV: PLA UPDATE 86-D thru 90-2 S-8/D-13 Vision Test (Pilot) M-9 TEST (Pilot) & (CMD) S-8/D-13 Vision Test (CMD) MED DATA (CMD)	BRIEFING CMD EAT
	MSC-1	PILOT SLEEP
5:16		
	CRO: S-5 (AUSTRALIA)	
		CMD EAT
		BRIEFING
	Flight Plan Update for U.S. passes activities D4/D7 [Desert land & water to land (CRO)]	PILOT EAT CMD NAP
5:20	MED DATA (Pilot)	
	CRO: PLA UPDATE 91-1 thru 95-4	
	D-6 (CYI) D-6 (E. AFRICA) MED DATA (CMD), D-1 (Celestial Body)	
	CNV: GO/NO GO 107-1 D-6 (AFRICA)- 2 runs	BOTH EAT
	D-1 (CELESTIAL BODY)	
6:00		

SUMMARY FLIGHT PLAN

Day:Hr

6:00 D-6 (U.S.) MED DATA (Pilot)

S-8/D-13 (LAREDO)
D-6 (S. America)

MED DATA (CMD)

CMD EAT

PILOT NAP

6:04 CSQ: PLA UPDATE 96-3 thru 101-D

BRIEFING

PILOT EAT

6:08

CMD SLEEP

Cabin Lighting Survey

MED DATA (Pilot)

PILOT EAT

S-8/D-13 Vision Test (Pilot)
M-9 TEST (Pilot)

BRIEFING

6:12 M-9 TEST (CMD)
S-8/D-13 Vision Test (CMD)
MED DATA (CMD)
RKV: PLA UPDATE 102-2 thru 106-1

CMD EAT

Cabin Lighting Survey

PILOT SLEEP

MSC-1

6:16

CMD EAT

BRIEFING

CRO: FLIGHT PLAN UPDATE FOR U.S. PASSES

PILOT EAT

CMD NAP

CYI: MED DATA (Pilot)

6:20

CRO: PLA UPDATE 107-1 thru 111-3
D-6 (CYI)
D-6 (E. AFRICA)
CRO: MED DATA (CMD)
GO/NO GO 122-1, Apollo Landmark

BOTH EAT

SEA LAB II COMM

7:00

Day:Hr

7:00 Apollo Landmark (FLORIDA)

MED DATA (Pilot)

S-8/D-13 (LAREDO) plus Window MEASUREMENT

MED DATA (CMD)

CMD EAT

PILOT NAP

7:04

BRIEFING

PILOT EAT

HAW: PLA UPDATE 112-3 thru 116-D

MED DATA (Pilot)

CMD SLEEP

7:08

Cabin Lighting Survey

PILOT EAT

S8/D13 Vision Tester (P)
M-9 Test (P) M-9 Test (C)
S8/D13 Vision Tester (C)
MED DATA (CMD)

BRIEFING

CMD EAT

7:12

RKV: PLA UPDATE 117-2 thru 121-1

PILOT SLEEP

Cabin Lighting Survey

7:16

CMD EAT

M-1

BRIEFING

S-8/D-13 (Pilot)

PILOT EAT

CMD NAP

MED DATA (Pilot)
CRO: PLA UPDATE 122-1 thru 126-3

7:20 Stow Equipment for Reentry

MED DATA (CMD), D-4/D-7 (SUN)
GYM: POWER UP CHECKLIST
Align PLATFORM
PRERETRO CHECKLIST

BOTH EAT

POST-RETRO Checklist
Guidance initiate
Post-Landing Checklist

8:00

APPENDIX E

DESIGN, CONSTRUCTION, AND ALIGNMENT OF THE BITEBOARD FOR THE INFLIGHT VISION TESTER

INTRODUCTION

The Inflight Vision Tester (IFVT) used during the Gemini missions could yield meaningful results only if precise alignment of its optical system with the astronauts' visual axes could be accomplished and maintained. There were three cardinal reasons for this requirement, *viz.*:

1. The optical configuration of the device demanded accurate centering of the target patterns in the central aperture of the adapting field.
2. The Stiles-Crawford effect and the possibility of vignetting necessitated that the exit pupils of the instrument be nicely centered in the pupils of the eyes.
3. In order to maintain a constant angular size of the adapting field and proper magnification of the patterns, the distance from eyes to instrument had to remain constant.

Because of the stringency of these requirements, and because failure to meet them might result in unreliable and possibly worthless data, it was recognized that a hand-held device could not be used. Accordingly a system was devised which enabled the instrument to be precisely positioned during the observations, so that both misalignment and relative movement between instrument and observer were effectively eliminated.

The most accessible rigid structure which bears a constant morphological relationship to the eyes in the bony orbits is, of course, the maxillary arch, via the upper teeth. Following common laboratory practice, it was decided to link observer to instrument by means of a biteboard. The development of this highly precise system for positioning the IFVT relative to the observers is outlined below.

ANTHROPOMETRIC CONSIDERATIONS

The bilateral symmetry of humans is only approximate, and differences between individuals, as regards their anthropometric characteristics, are great. It is essential, therefore, that a system which will enable construction of a precisely positioned device must have enough inherent flexibility to accommodate both the asymmetries and dimensional differences in men. The most obvious difference between individuals is the interpupillary distance (IPD), which can vary (and does, in fact, in the astronaut group) over a range of about 60 to 70 mm. The distance from the maxillary arch vertically to the eyes likewise varies. There are differences in the tilt of the maxillary arch relative to the frontal plane, and the eyes are never quite symmetrically placed relative to this, nor to the medial nor horizontal planes. While some of these irregularities are of scant concern for most experimental arrangements, it was felt that every effort should be made to ensure the best possible instrument alignment and positioning.

PROCEDURE

Preparation of individual biteboards proceeded by a number of steps. The method to be described has the significant advantage that the individual to be fitted need spend a minimum of time at it – an important consideration for the astronaut. Furthermore, by using an indirect procedure (rather than fitting the man directly to the instrument), an improvement in accuracy is achieved. The essential steps were:

1. Anthropometric survey of the head, including the position of the eyes, location and tilt of the maxillary arch.
2. Construction of a model "head" having the cardinal points derived from the survey precisely duplicated.
3. Alignment, by means of a special fixture, of the head model with the astronaut's dental impression on a biteboard mating to the IFVT.
4. Casting of the final biteboard, using an aluminum harp, or frame, and flight-qualified clear acrylic plastic.

The foregoing steps will be briefly described below; more detailed treatment of the process is on file at the Visibility Laboratory.

Anthropometric Survey

The measurements needed to establish the relationship of the maxillary arch to the corneal poles of both eyes were obtained by a photographic technique. A cubical frame was built which was large enough to accommodate the head of the subject. The front and sides of the frame bore a grid composed of fine black nylon threads which were stretched across notches in the frame that were milled on 0.500-inch centers. The astronaut was positioned within the grid box with his teeth engaged to a master biteboard whose position relative to the grids was fixed. Photographs were taken on high resolution 35 mm film, using a long focal length lens (300 mm) from a constant distance of 17 feet to the grid. Left, front, and right views were required (See Figure E-1), and extreme care was exercised to establish accurate alignment and leveling of the whole system. The subject fixated distant reference marks at eye level, so that the position of the corneal poles would be the same as they would be expected to be in the IFVT. Although the error in vergence at the distance used was small, we nevertheless took two front view pictures, one for each eye, with small differences in the fixation point position to compensate for this error. Likewise, the parallax error arising from the separation between the plane of the grid alines and the corneas, though small, was further minimized by making small compensatory adjustments in camera position to bring the optic axis of the system into alignment with a grid line when necessary. The arrangement is shown in Fig. E-2.

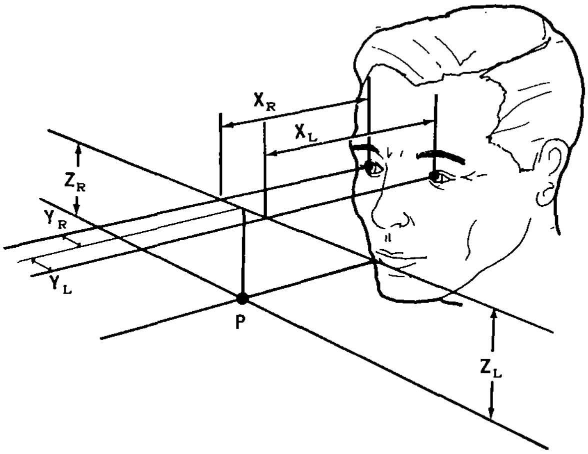


Fig. E-1. Dimensions required for alignment of the Inflight Vision Tester. Point P lies at the intersection of three planes; the median vertical plane of the instrument, the plane of the maxillary arch, and the fronto-parallel plane.

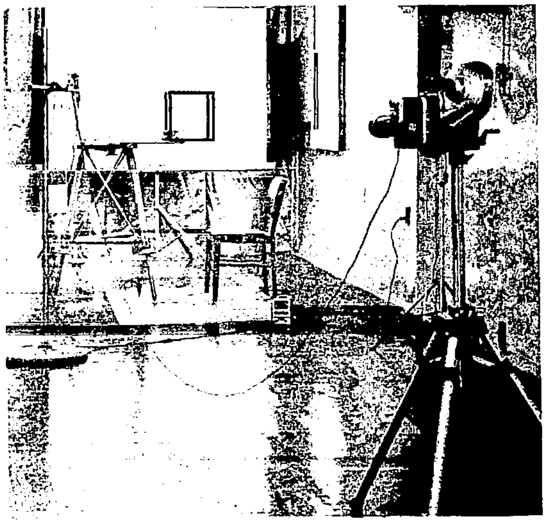
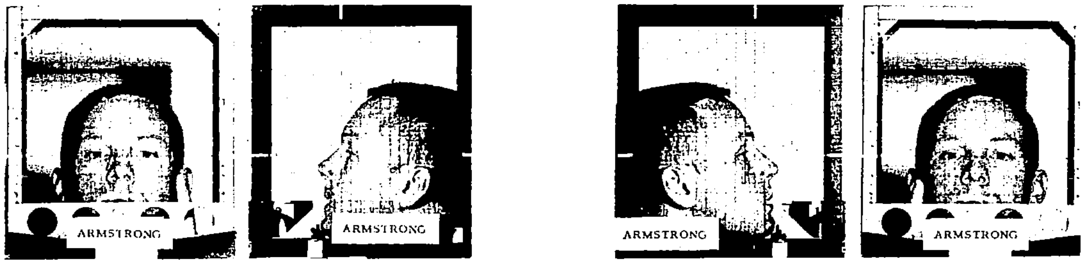


Fig. E-2. Camera and grid box arrangement used to obtain photographs in the anthropometric survey. Cables lead to strobe units.

The photographs obtained by this method were rendered into enlarged prints, and the necessary dimensions secured by conventional photogrammetric techniques. A sample set of photographs is shown in Fig. E-3.



LEFT EYE

RIGHT EYE

Fig. E-3. Specimen photographs from the grid box. Note that two photographs were used to establish eye position in the front view in order to correct for vergence error.

The Model Head

By use of the data obtained from the photographs described above, it was possible to construct a jig which related the two corneal poles and the upper teeth to the necessary reference points on the biteboard which would provide precise alignment with the IFVT proper. On this jig, or model head, the corneal poles are represented by two small spherical knobs, as may be seen in Fig. E-4. This figure also shows the relationships to the master biteboard from the grid box, although the bite is not shown in the drawing. It can be seen that sufficient flexibility is provided to take care of all dimensional variables.

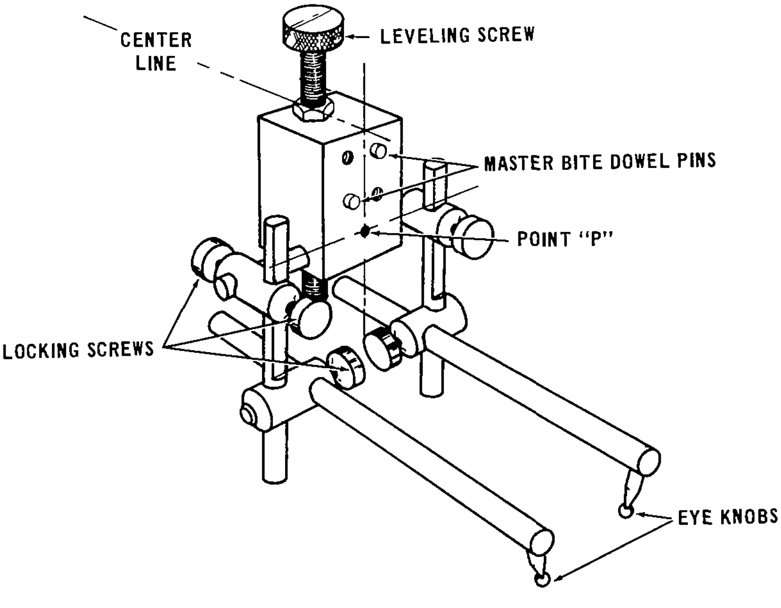


Fig. E-4. The Head Model. The master biteboard (not shown) attaches to the locator dowel pins on block, above Point P.

Alignment with the Teeth

At this stage, a conventional full-mouth cast was made for each astronaut and mounted on an ordinary dental articulator. Also, a special fixture was made with a surface plate into which were recessed two hemispherical cups to receive the eye knobs of the model head. These cups were independently adjustable in distance from the center line of the fixture. The master biteboard, which had been used in the grid box, was affixed to the model head and the articulated cast was clamped onto the bite as shown in Fig. E-5.

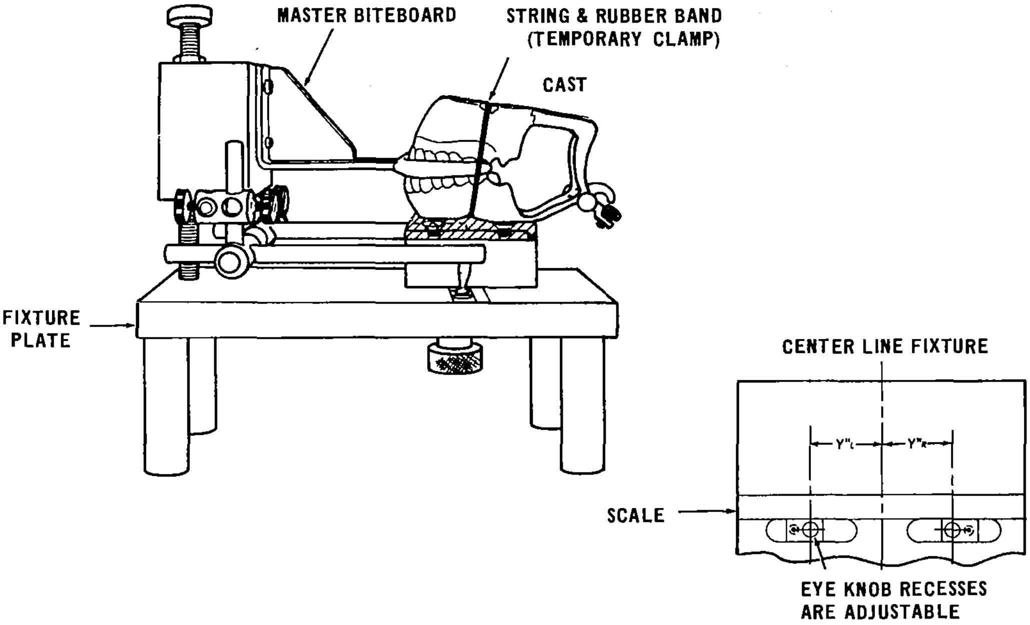


Fig. E-5. Articulated dental cast clamped to master biteboard and Model Head. Shaded area will be filled with additional dental stone.

A reference block mounted on the surface plate of the fixture provided orientation to the corneal pole positions. The space between the upper part of the maxillary cast and this block (shaded region in Fig. E-5) was filled in with dental stone. A second reference block, which related the IFVT optical system to the fixture was also mounted on the surface plate. This block had a clamp, similar to the one on the IFVT, which received the distal end of the biteboard. An intermediate biteboard with a wax impression of the teeth was prepared, and clamped into the articulated model as shown in Fig. E-6. The biteboard was shaped to fit into the reference block clamp, with all necessary fine adjustments accomplished by shimming, length changes, and bending.

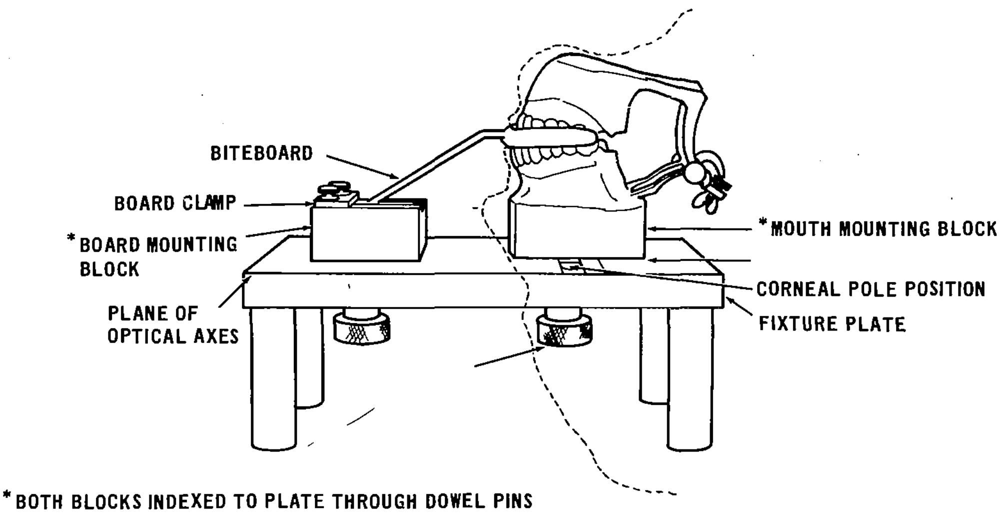


Fig. E-6. Fixture with biteboard clamped in dental cast and adjusted to reference block. Dashed line indicates head position.

The Final Biteboard

The intermediate biteboard which had been made by the techniques outlined above, was followed by a flight version in which the shape had been accurately milled, and the impression made in clear acrylic plastic which had been flight qualified. During the mission, then, each astronaut had only to insert his own biteboard into the IFVT, set the interpupillary distance of the instrument to the proper mark, and engage the bite. His precise alignment with the optical system for each eye was then assured, and his hands were free to operate the device.

NASA-Langley, 1968 —— 5