stant-amplitude snaking oscillation as the operator translates toward or away from the target.

The foregoing procedures first appear complicated and overly sophisticated. In actual practice, the pilot never consciously thinks of the rules while using the Hand Held Maneuvering Unit. Application of the procedures may be compared with the actions and reactions required to ride a bicycle. The skilled operator of the Hand Held Maneuvering Unit looks directly at the target. The control loop is closed directly from the target motion to the eyes and brain of the operator, with resulting error signals feeding the operator's muscular command system. The control system of the Hand Held Maneuvering Unit is a personal adaptive control system. The accuracy of this system in space with all the 6 degrees of freedom active is not yet known, inasmuch as the planned Gemini flight evaluations did not cover this point.

On the 3-degree-of-freedom air-bearing facility, using any one of the three rotational axes and two translation axes, the accuracy of a skilled operator is within less than 1 inch of the intended target (from distances of approximately 25 feet). At longer ranges, the same degree of accuracy could be maintained because the control logic is a terminal-guidance type. Also, the operator's axis system does not have to be alined with the direction of motion while using the Hand Held Maneuvering Unit. The operator must physically see the target and point at the target while keeping the thrust force through his center of gravity. With regard to ease of use, the Hand Held Maneuvering Unit was designed so that when held in the operator's right hand with the thrust line along the operator's X-axis, the muscles in the right arm and hand are in a completely unstrained position.

Astronaut Maneuvering Unit Control Logic

The control logic preferred by the pilots of Gemini IX-A and Gemini XII follows. From an initially stabilized position, generally facing the target, thrust is applied to produce a forward velocity proportional to the range to be flown. As soon as this velocity is achieved, yaw 90° away from the original attitude and coast toward the target. The line-of-sight drifts of the target can be eliminated by using the up-and-down and fore-and-aft translational thrusters. Just prior to arriving at the target, yaw back to the original attitude facing the target and apply braking thrust.

This control procedure involves only two discrete yaw rotations and no roll or pitch rotations. The control procedure minimizes attitude-control fuel requirements because the inertia of the extravehicular pilot is at a minimum about the yaw axis. Also, the control procedure is probably the simplest for a maneuvering unit that does not have lateral-translation capability.

Air-Bearing Training Equipment

The most important requirement for an air-bearing facility, and the most difficult to achieve and maintain, is a flat, hard, smooth floor. The floor of the Air-Bearing Facility at the Manned Spacecraft Center consists of 21 cast-steel machinist's layout tables each 3 feet wide by 8 feet long. Each table weighs about 2200 pounds and is flat to within approximately 0.0002 inch. The pattern is seven tables wide and three tables long comprising a total floor area of 21 by 24 feet. After leveling, the joints between adjacent tables are accurate to about 0.0004 inch, and the overall floor is estimated to be flat within approximately 0.002 inch. The leveling procedure must be repeated about every 6 months, due to settling of the building foundation. This degree of floor accuracy allows free movement of simulators with air cushions approximately 0.001 inch thick. Such low flight altitudes are desirable because the required airflow is quite low, and the attendant possible turbine-blade (jet propulsion) effect resulting from uneven exhaust of the air from the air bearings is negligible. This turbine-blade effect is extremely undesirable because it confuses the results produced by low-thrust jets such as those of the Hand Held Maneuvering Unit.

Figures 9–10 to 9–13 show some of the air-bearing simulators utilized for extravehicular training during the Gemini Program. Figure 9–10 shows the Gemini X pilot on a yaw training simulator in preparation for that mission. In this particular case, compressed air for the Hand Held Maneuvering Unit, for the pressurized suit, and for floating the air-bearing equipment flowed from a 130-psi service air supply through a dual umbilical identical to the one used in the Gemini X flight. A skilled technician was employed to minimize the effect of the umbilical drag during training.

Figure 9–11 shows the Gemini VIII pilot during a yaw training session prior to the mission. The Extravehicular Support Package was supported by metal legs; three supporting air pads were utilized for the necessary added stability because of the large combined mass and volume of both the Ex-

FIGURE 9–10.—Single-pad air-bearing simulator for yaw-axis training with Hand Held Maneuvering Unit.

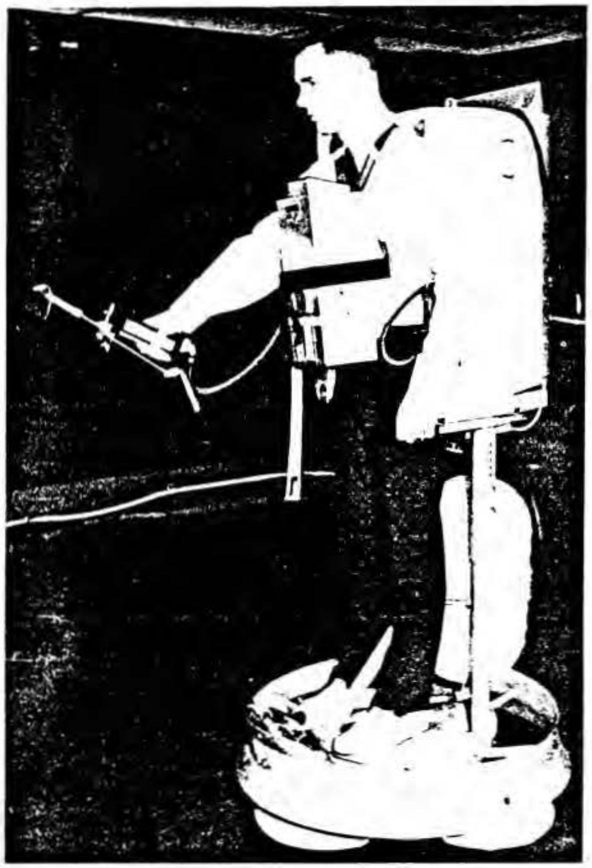


FIGURE 9–11.—Three-pad air-bearing simulator for yaw-axis training with backpack-supported maneuvering devices.

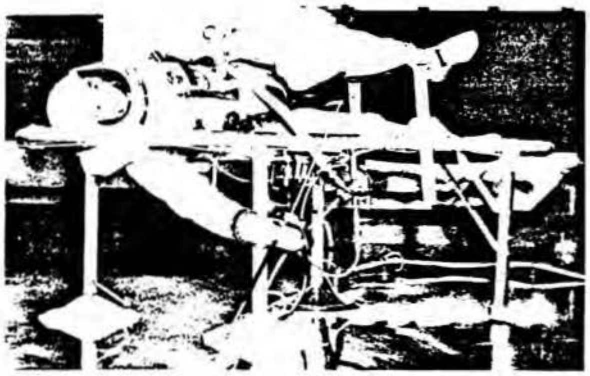


FIGURE 9–12.—Three-pad air-bearing simulator during pitch-axis training with Hand Held Maneuvering Unit.

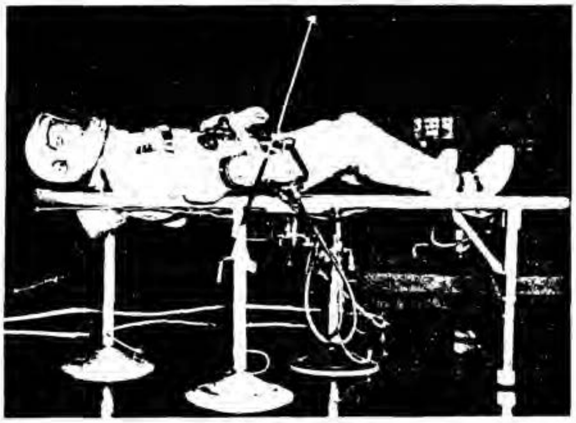


FIGURE 9–13.—Three-pad air-bearing simulator during roll-axis training with Hand Held Maneuvering Unit.

travehicular Support Package (backpack) and the Extravehicular Life-Support System (chest pack). In the simulator, compressed air for floating the platform is carried in an oxygen bottle mounted on the platform; and compressed air for the Hand Held Maneuvering Unit is carried in a high-pressure bottle located inside the Extravehicular Support Package (as on Gemini VIII). No umbilical or tether was utilized. This simulator was also used in training for the Astronaut Maneuvering Unit.

Figure 9–12 shows the Gemini X pilot in pitch-axis training on a different type of simulator. The cot is made of lightweight aluminum tubing which does not appreciably change his inertia in pitch. Three pads are used to provide satisfactory tipping stability. The compressed air needed to power the Hand Held Maneuvering Unit, to pressurize the suit, and to float the air-bearing equipment is supplied by the service air supply through the 3/8-inch-inside-diameter umbilical (fig. 9–12). This umbilical contains small air-bearing supporters which allow more accurate simulation of the in-space effect of a similar umbilical.

Figure 9–13 shows the Gemini X pilot in roll-axis training on the same simulator. Roll-axis training was practiced by looking at the target while translating to it, and by looking at the ceiling while translating to the side. The latter case is important because in normal use of the Hand Held Maneuvering Unit, rolling velocity should be kept at zero while translating and looking forward.

Types of Training Runs

The following is a representative list of the types of training runs made on the air-bearing equipment in preparation for extravehicular activity maneuvering. The runs were made in the yaw and pitch modes; most were also made in the roll mode.

(1) Familiarization with air bearing.

(2) Use of muscle power to control attitude.

(3) With Hand Held Maneuvering Unit in hand, control attitude while being towed to target.

(4) With hip-kit compressed-air bottle and no umbilical, translate from point *A* to a collision with point *B*. The points *A* and *B* are any two specific points in the training area.

(5) Repeat preceding step, but completely stop 1 foot in front of point *B*.

(6) With initial rotational velocity at point *A*, stop rotation, proceed to point *B*, and stop completely 1 foot in front of point *B*.

(7) With both initial random rotation and translation in vicinity of point *A*, stop both initial rotation and translation, proceed to point *B*, and stop completely 1 foot in front of point *B*.

(8) Starting from rest at point *A*, intercept a target moving with constant velocity at right angles to the line of sight.

(9) Make precision attitude changes of 45° and 90°, stopping any translation existing at end of run.

(10) Without the Hand Held Maneuvering Unit, practice pushing off from simulated spacecraft and stopping completely by gently snubbing the umbilical.

(11) Practice hand walking the umbilical back to the simulated spacecraft, being careful not to generate excessive translational velocity.

(12) Investigate elasticity and wrap-up tendencies of umbilical by bitting end of umbilical with various initial translational and rotational velocities.

Amount of Training

Air-bearing training received by the prime pilots of Gemini IV, VIII, IX–A, X, and XI follows:

Mission	*Training, hr*
IV	12
VIII	20.5
IX–A	3
X	13.25
XI	20

The 6-Degree-of-Freedom Simulator

In addition to the 3 hours of air-bearing training with the Astronaut Maneuvering Unit in preparation for Gemini IX–A extravehicular activity, the pilot completed approximately 11 hours of training on the Manned Aerospace Flight Simulator (fig. 9–14). This simulator consisted of a production-type Astronaut Maneuvering Unit with controls wired into a hybrid computer facility. The simulator provided the subject with small-amplitude pitch, roll, and yaw rotations and up-and-down translation acceleration cues which later were damped out. The visual display simulated clouds over an ocean, and a horizon with blue and red dots representing the front and rear ends of a target vehicle. These were all projected on the inner surface of a spherical screen mounted about 8 feet in front of the pilot. The dots varied in size to represent a target vehicle at ranges from approximately 250 feet to essentially zero range. The object of most training runs was to aline the two ends of the spacecraft (superimpose the dots), and to move in to a simulated arrival position with respect to the target.

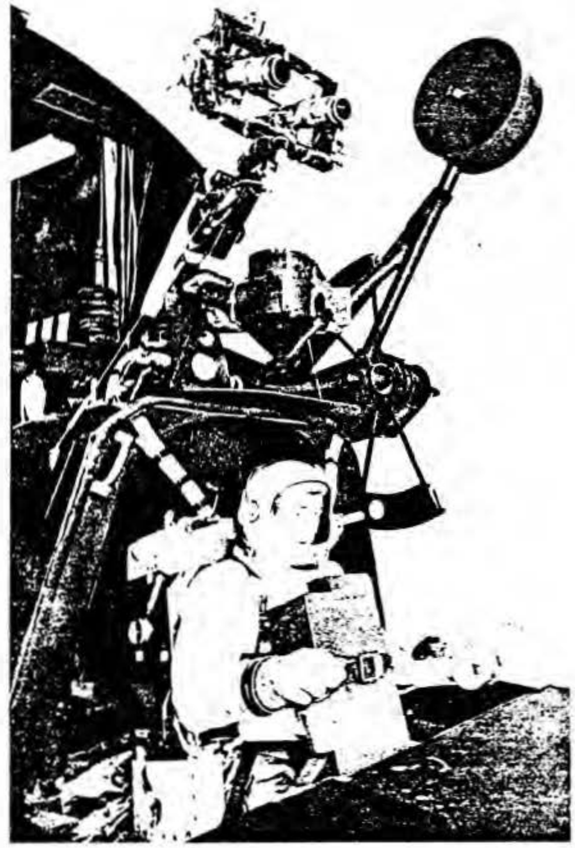


FIGURE 9–14.—The Manned Aerospace Flight Simulator used during training with the Astronaut Maneuvering Unit.

Inertia Coupling Training-Aid Model

During the Gemini VIII extravehicular training, the question arose as to whether controlled rotations about one axis of an extravehicular pilot might lead to uncontrolled rotations about the other two axes due to inertia coupling or product-of-inertia effects. To gain a qualitative idea of the possible seriousness of these effects, a 1-to-4.5 scale model of the Gemini VIII pilot was constructed and mounted in a set of extremely light gimbals. The model (fig. 9–15) was based upon three-view scale photographs of the pilot in a pressurized suit, and carved from wood. The scale weight and center-of-gravity position of the pilot, the Extravehicular Support Package, and the Extra-

FIGURE 9–15.—Inertia coupling training-aid model.

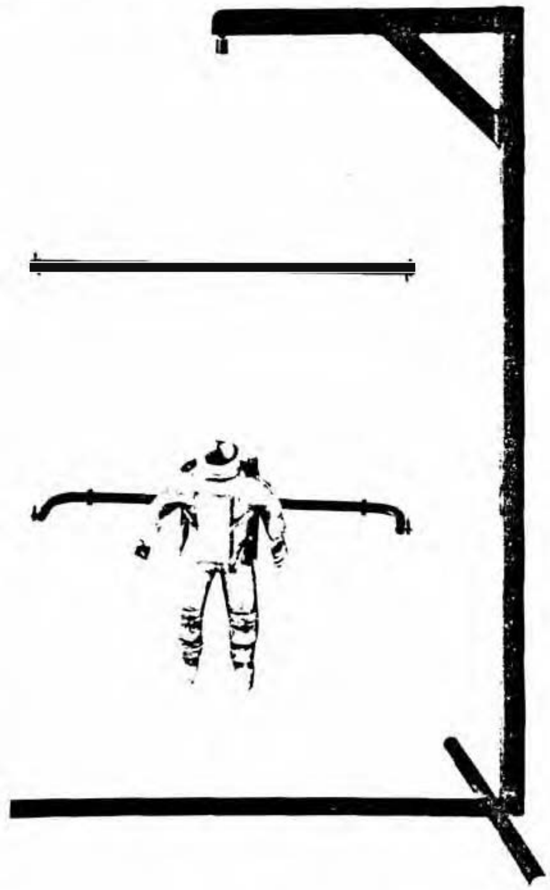


FIGURE 9–16.—Inertia coupling training-aid model showing gimbal suspension system.

vehicular Life-Support System were closely duplicated, although no attempt was made to measure and duplicate the moments of inertia of these items. The gimbal arrangement is shown in figure 9–16. The yaw axis is at the top; the half-pitch gimbal is next; innermost is the roll gimbal, which consisted of two ball bearings inside the body of the model. The yaw and pitch gimbals were also mounted on ball bearings. The gimbal weight was only about 0.2 that of the model.

Investigations of inertia coupling effects were conducted by rotating the model about one of the major axes while holding the other two axes fixed, then by suddenly releasing the two fixed gimbals. The following results were observed.

(1) Following a pure yaw rotational input, when the pitch and roll gimbals were released, slow up-and-down changes in pitch attitude resulted. As the motion slowed due to gimbal-bearing friction, the model rotated 90° in roll so that the original yawing motion became a pure pitching motion. This attitude then was stable because no coupling was evidenced if the model was again spun about the original axis of rotation.

(2) Following a pure pitch rotational input, the model merely slowed to zero rotational velocity (because of gimbal-bearing friction) without exhibiting inertia coupling tendencies of any kind.

(3) Following a pure roll rotational input, release of the pitch and yaw gimbals immediately resulted in a confused pitching, yawing, and rolling tumbling motion.

The behavior of the model was obviously in consonance with the observed shape of the model. For example, the mass distribution of the model, and also of an extravehicular pilot, are almost symmetrical about the YZ plane; therefore, practically no rolling or yawing moments are generated due to the effects of centrifugal force acting upon local mass asymmetry when the model is pitched. However, the model with backpack and chest pack is considerably asymmetrical about the *YZ* plane; therefore, it is not surprising that large pitching and yawing moments resulted from pure roll.

The tests performed with the model resulted in adoption of the following simple maneuvering rules for the extravehicular pilot. The rules are designed to eliminate or reduce greatly the chance of encountering inertia coupling effects.

(1) Never roll. Always establish the attitude toward the target by yawing, then pitching. Never roll while translating.

(2) In case inertia coupling effects are encountered, always stop the rolling velocity first, the yawing velocity second, and the pitching velocity last.

In connection with possible inertia coupling effects, two final comments should be made. First, the extravehicular pilots were not unique in being subject to inertia coupling effects. Airplanes and spacecraft are also subject to such coupled motions. Second, it is difficult to understand how these effects could be encountered by an extravehicular pilot at the end of an umbilical or tether. In such a case, the umbilical or tether should effectively eliminate all large rotations other than those about the axis of the umbilical or tether. This observation strongly suggests that tether and umbilical reels, controlled by the extravehicular pilot, should be developed as soon as possible. Air-bearing tests indicate that body rotations which can cause umbilical wrap-up about the subject tend to be eliminated rapidly by the umbilical as long as the subject does not already possess translational velocity toward the spacecraft umbilical attach point. The reason for this action is that the rotational energy causing wrap-up has to be converted to translational kinetic energy in order for wrap-up to continue. The proportionality factor for energy transformation in this direction is qualitatively very low. Therefore, the practice of always operating at the end of a straight umbilical may help eliminate undesirable angular rotations about the two body axes not coincident with the axis of the umbilical.

Hand Held Maneuvering Unit Flight Performance and Comparison With Ground Training

Gemini IV Extravehicular Activity

The Gemini IV pilot made the first powered extravehicular maneuvering in history. Figure 9–17 is one of the many photographs taken by the command pilot and shows the extravehicular pilot in the perfect posture for maneuvering with a Hand Held Maneuvering Unit. The pilot described his experiences with the Hand Held Maneuvering Unit and with the umbilical as follows:

> I left [the spacecraft] entirely under the influence of the gun, and it carried me right straight out, a little higher than I wanted to go. I wanted to maneuver over to your [command pilot's] side, but I maneuvered out of the spacecraft and forward and perhaps a little higher than I wanted to be. When I got out to what I estimate as probably one-half or two-thirds the way out on the tether, I was out past the nose of the spacecraft. I started a yaw to the left with the gun and that's when I reported that the gun really worked quite well. I believe that I stopped that yaw, and I started translating back toward the spacecraft. It was either on this translation or the one following this that I got into a bit

FIGURE 9–17.—Extravehicular activity during Gemini IV. Note classic posture exhibited by pilot for maneuvering with Hand Held Maneuvering Unit.

of a combination of pitch, roll, and yaw together. I felt that I could have corrected it, but I knew that it would have taken more fuel than I had wanted to expend with the gun, so I gave a little tug on the tether and came back in. This is the first experience I had with tether dynamics and it brought me right back to where I did not want to be. It brought me right back on top of the spacecraft, by the adapter section.

This is the first time it had happened. I said [to command pilot]: "All right, I'm coming back out [to front of sparecraft] again." This is one of the most impressive uses of the gun that I had. I started back out with the gun, and I decided that I would fire a pretty good burst too. I started back out with the gun, and I literally flew with the gun right down along the edge of the spacecraft, right out to the front of the nose, and out past the end of the nose. I then actually stopped myself with the gun. That was easier than I thought. I must have been fairly fortunate, because I must have fired it right through my cg. I stopped out there and, if my memory serves me right, this is where I tried a couple of yaw maneuvers. I tried a couple of yaw and a couple of pitch maneuvers, and then I started firing the gun to come back in [to the spacecraft]. I think this was the time that the gun ran out. And, I was actually able to stop myself with it out there that second time too. The longest firing time that I put on the gun was the one that I used to start over the doors up by the adapter section. I started back out then. I probably fired it for a 1-second burst or something like that. I used small bursts all the time. You could put a little burst in and the response was tremendous. You could start a slow yaw or a slow pitch. It seemed to be a rather efficient way to operate. I would have liked to have had a 3-foot bottle out there—the bigger the better. It was quite easy to control.

The technique that I used with the gun was the technique that we developed on the air-bearing platform. I kept my left hand out to the side [fig. 9–17] and the gun as close to my center of gravity as I could. I think that the training I had on the air-bearing tables was very representative especially in yaw and pitch. I felt quite confident with the gun in yaw and pitch, but I felt a little less confident in roll. I felt that I would have to use too much of my fuel. I felt that it would be a little more difficult to control and I didn't want to use my fuel to take out my roll combination with the yaw.

As soon as my gun ran out [of fuel] I wasn't able to control myself the way I could with the gun. With that gun, I could decide to go to a part of a spacecraft and very confidently go.

Now I was working on taking some pictures and working on the tether dynamics. I immediately realized what was wrong. I realized that our tether was mounted on a plane oblique to the angle in which I wanted to translate. I remember from our air-bearing work that every time you got an angle from the perpendicular where your tether was mounted, it [the tether] gave you a nice arching trajectory back in the opposite direction. You're actually like a weight on the end of a string. If you push out in one direction and you're at an angle from the perpendicular, when you reach the end of a tether, it neatly sends you in a long arc back in the opposite direction. Each time this arc carried me right back to the top of the adapter, to the top of the spacecraft, in fact, toward the adapter section.

One thing though that I'll say very emphatically—there wasn't any tendency to recontact the spacecraft in anything but very gentle contacts. I made some quite interesting contacts. I made one that I recall on the bottom side of the right door in which I had kind of rolled around. I actually contacted the bottom of the spacecraft with the back of my head. I was faced away from the spacecraft, and I just drifted right up against it and just very lightly contacted it. I rebounded off. As long as the pushoffs are slow, there just isn't any tendency to get in an uncontrollable attitude.

Gemini X Extravehicular Activity

It was intended that the Gemini X pilot perform an extensive evaluation of the Hand Held Maneuvering Unit including precise angular attitude changes and translations. However, the flight plan for the extravehicular activity required a number of other activities prior to this evaluation. One of the planned activities was to translate to the target vehicle at very short range using manual forces alone and to retrieve the Experiment S010 Agena Micrometeorite Collection package attached near the docking cone. The pilot described the use of the Hand Held Maneuvering Unit at this time as follows:

Okay, we're in this EVA. I got back and stood up in the hatch and checked out the gun and made sure it was squirting nitrogen. That's the only gun checkout I did. In the meantime, John maneuvered the spacecraft over toward the end of the TDA, just as we had planned. He got in such a position that my head was 4 to 5 feet from the docking cone. It was upward at about a 45° angle, just as we planned. I believe at one time there you said you had trouble seeing it, and I gave you [command pilot] some instructions about "forward, forward." "stop, stop." So I actually sort of talked John into position.

I translated over by pushing off from the spacecraft. I floated forward and upward fairly slowly and contacted the Agena. I grabbed hold of the docking cone as near as I can recall, at about the 2 o'clock position. If you call the location of the notch in it, the 12 o'clock, I was to the right of that—at about the 2 o'clock position and I started crawling around. No, I must have been more about the 4 o'clock position, because I started crawling around at the docking cone counterclockwise, and the docking cone itself, the leading edge of the docking cone, which is very blunt, makes a very poor handhold in those pressure gloves. I had great difficulty in holding on to the thing. And, as a matter of fact, when I got over by the S010 package and tried to stop my motion, my inertia [the inertia of] my lower body, kept me right on moving and my hand slipped and I fell off the Agena.

When I fell off, I figured I had either one of two things to do. I could either pull in on the umbilical and get back to the spacecraft, or I could use the gun. And I chose to use the gun. It was floating free at this time. It had come loose from the chestpack. So, I reached down to my left hip and found the nitrogen line and started pulling in on it and found the gun, and unfolded the arms of the gun and started looking around. I picked up the spacecraft in view. I was pointed roughly toward the spacecraft. The spacecraft was forward and below me on my left. The Agena was just about over my left shoulder and below me, or down on my left side and below me. I used the gun to translate back to the cockpit area. Now, I was trying to thrust in a straight line from where I was back to the cockpit, but in leaving the Agena I had developed some tangential velocity, which was bringing me out around the side and the rear of the Gemini. So what happened was, it was almost as if I was in an airplane on down wind for a landing, and in making a left-hand pattern I flew around and made a 180° left descending turn, and flew right into the cockpit. It was a combination of just luck, I think, being able to use the gun. At any rate, I did return to the cockpit in that manner, and John again maneuvered the spacecraft. When I got to the cockpit, I stood up in the hatch and held on to the hatch. John maneuvered the spacecraft again up next to the Agena. This time we were, I think, slightly farther away, because I felt that rather than trying to push off I would use the gun and translate over. And I did, in fact, squirt the gun up, depart the cockpit and translate over to the docking cone using the gun as a control device. The gun got me there. It wasn't extremely accurate. What happened was, as I was going over, I guess in leaving the cockpit, I somehow developed an inadvertent pitch-down moment, and when I corrected this out with the gun, I developed an upward translation as well as an upward pitching moment. So I did damp out the pitch. I converted that downward pitch moment into an upward pitching moment, and then I was able to stop my pitch entirely. But in the process of doing that, I developed an inadvertent up translation, which nearly caused me to miss the Agena. As a matter of fact, I came very close to passing over the top of the Agena; and I was just barely able to pitch down with the gun and snag a hold of the docking cone as I went by the second time.

During further technical debriefings, the Gemini X pilot made several other comments. Concerning the response characteristics of the Hand Held Maneuvering Unit, he stated that the thrust levels of 0 to 2 pounds were about right. These levels provided adequate translational response without making the rotational response seem overly sensitive. The Gemini IV pilot made the same comment.

With respect to ability to transfer the control skills acquired on the 3-degree-of-freedom air-bearing simulators to the 6 degrees of freedom existing in space, the Gemini X pilot stated that the transfer was easy and natural. He was, perhaps, a little surprised that the pitch degree of freedom gave more control trouble than the yaw degree of freedom. Due to a very low body inertia about the yaw axis, yawing motions generated with the Hand Held Maneuvering Unit are naturally much faster than either pitch or roll motions.

Finally, in answer to the question of whether he had acquired any rolling motions during brief periods of maneuvering with the Hand Held Maneuvering Unit, the Gemini X pilot stated that no rolling motions whatever had been experienced. This is significant for two reasons:

(1) Based upon indications of the inertia coupling model, and upon the Gemini IV extravehicular activity, the Gemini X pilot had trained specifically to avoid rolling motions, and to stop them immediately if they should occur.

(2) If rolling motions can be totally eliminated, then control with the Hand Held Maneuvering Unit is reduced practically to a simple 3-degree-of-freedom situation involving yawing and pitching rotations, and linear translations.

Concluding Remarks

Based upon the short periods of extravehicular maneuvering during two Gemini missions, the Hand Held Maneuvering Unit is a simple device suitable for translating easily between selected points on a spacecraft or anywhere in the general vicinity of the spacecraft. Thrust values ranging from 0 to 2 pounds are desirable for present-day Hand Held Maneuvering Units. Controlled movement about a spacecraft on a fixed-length umbilical without a maneuvering device is difficult, if not impossible. However, such maneuvering does not appear to result in uncontrollable attitudes if care is taken to avoid large translational velocity inputs when leaving the spacecraft.

As a result of work with a gimbal-mounted scale model of an extravehicular pilot, it appears that confused tumbling motions due to inertia coupling effects are likely to occur during extravehicular maneuvering if excessive simple rotational velocities (especially rolling velocities) are attained. Therefore, it is recommended that until additional extravehicular maneuvering experience has been gained, rolling velocities be maintained close to zero during extravehicular maneuvering, and the extravehicular pilot mass distribution be kept nearly symmetrical.

Three-degree-of-freedom air-bearing simulators are satisfactory devices for extravehicular maneuvering ground training. A minimum of 10 hours of such training is recommended.

10. MEDICAL ASPECTS OF GEMINI EXTRAVEHICULAR ACTIVITIES

By C. FRED KELLY, M.D., *Medical Operations Office, NASA Manned Spacecraft Center;* and D. OWEN COONS, M.D., *Medical Operations Office, NASA Manned Spacecraft Center*

Introduction

The medical aspects of Gemini extravehicular activities are principally concerned with the physiological responses to high workloads, high thermal stresses, and low fatigue tolerance. Analysis of physiological instrumentation data from extravehicular flights and training operations contributed significantly to the understanding of extravehicular workloads and the means of controlling these workloads.

Background

The success of the Gemini IV extravehicular activity provided the initial confidence that man could accomplish extravehicular operations easily and with a minimum of physiological constraints. The Gemini IV mission also tended to indicate that elaborate physiological instrumentation would not be required. Accordingly, medical instrumentation requirements for future extravehicular activities were kept to a minimum. The requirements included one lead for an electrocardiogram and one lead for obtaining respiration rate. Because the pilot was able to monitor the suit pressure, this measurement was deleted for Gemini IX–A and subsequent flights. Other instrumentation which would have been desirable included carbon-dioxide concentration and body temperatures; however, feasible means of measuring these parameters were not readily available.

Medical Evaluation of Extravehicular Activities

During the extravehicular portions of Gemini IX–A and XI, excessive workload appeared to be a limiting factor. An evaluation of flight data indicated that there may have been an excessive thermal load imposed upon the extravehicular pilot during these activities. The high respiration rates encountered during Gemini XI indicated that a buildup in the carbon-dioxide level may have been a problem. Since there were no actual data on thermal conditions, oxygen, or carbon-dioxide levels, and no direct measure of metabolic load, a quantitative evaluation of the potential problem areas was not possible.

Although there was no direct measure of metabolic load, the electrocardiogram and impedance pneumogram provided some useful information, but only if certain limitations and inaccuracies were considered. These parameters have been monitored during a great many physiological and psychological tests under widely varying conditions. This information reconfirms that heart rate responds to psychological, physiological, and pathological conditions. There is considerable individual variation in these responses. However, in the absence of a more scientific approach to the problem, and because a quantitative indication of the workload actually experienced in flight appeared to be of primary importance, the feasibility of using heart rate as a quantitative indication of workload was investigated.

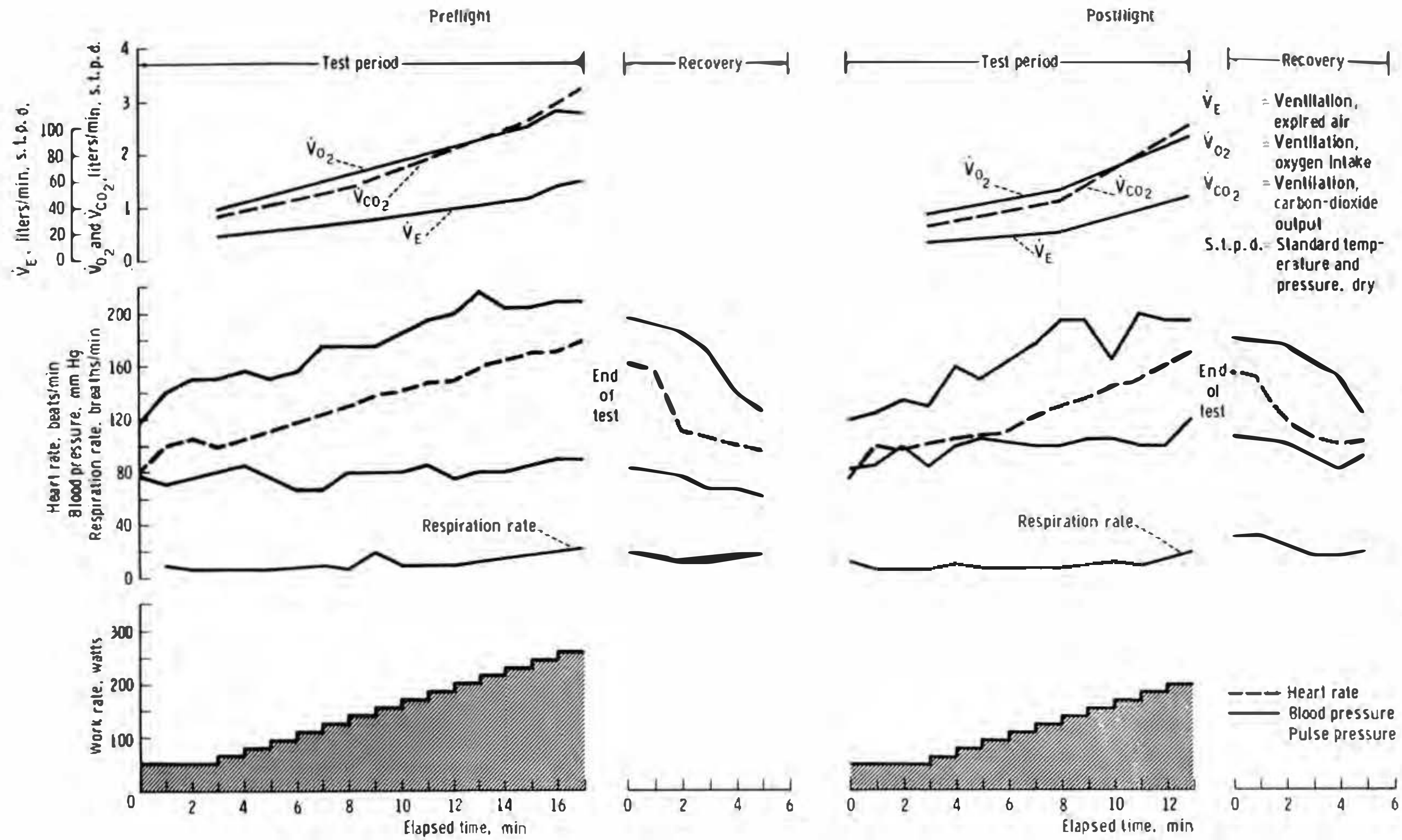
On Gemini IX–A, X, XI, and XII, preflight and postflight exercise tests using the bicycle ergometer were performed on the pilots. During the tests, the subject performed a measured amount of work in increasing increments while heart rate, blood pressure, and respiration rate were monitored; periodic samples of expired gas were collected for analysis. The data were translated into oxygen utilization curves and heat-energy plots (fig. 10–1). Using the plots and the heart-rate data obtained during each flight (figs. 10–2 and 10–3), an approximate workload curve was plotted against the time line for the extravehicular activity. The derived data were not entirely believable, since there is no method to account for the effect on heart rate resulting from thermal or other environmental variations. Also, the psychogenic effect of a new and different environment could certainly increase the heart rates without a corresponding change in metabolic rate. The plots were useful in evaluating the workloads for the Gemini XII extravehicular activity. The accuracy of the plots may be expected to increase as the oxygen consumption increases toward maximum oxygen utilization. This value varies with individuals and with the degree of physical conditioning, and is dependent upon the amount of oxygen which can be transported from the environment to the body tissues.

The area of major interest in evaluating workloads during extravehicular activities is during high workload periods. Furthermore, any error introduced by unknown factors would increase the observed heart rate for a given workload level. This tends to increase the usefulness of such a plot for preflight planning and for inflight monitoring of extravehicular activities. When data from previous flights, altitude chamber tests, 1g walk-throughs, and underwater zero-g simulations are examined in this manner, a quantitative indication may be derived of work expended on various tasks (fig. 10–4). This is important in the postflight assessment of the relative physiological cost of various tasks, and in determining acceptable tasks and realistic time lines during simulations and preflight planning. The use of heart-rate and respiration-rate data, when coupled with voice contact and an understanding of programed activities, proved an extremely important and useful method for real-time monitoring of extravehicular pilots.

The major factors which apparently produced the highest workload prior to Gemini XII were high suit forces, insufficient body-position restraints, and thermal stress. This was indicated when the Gemini XI pilot expended an exceptionally high effort in attaching the spacecraft/target-vehicle tether to the docking bar. Difficulties in maintaining body position in the weightless environment made the task much more difficult than had been expected.

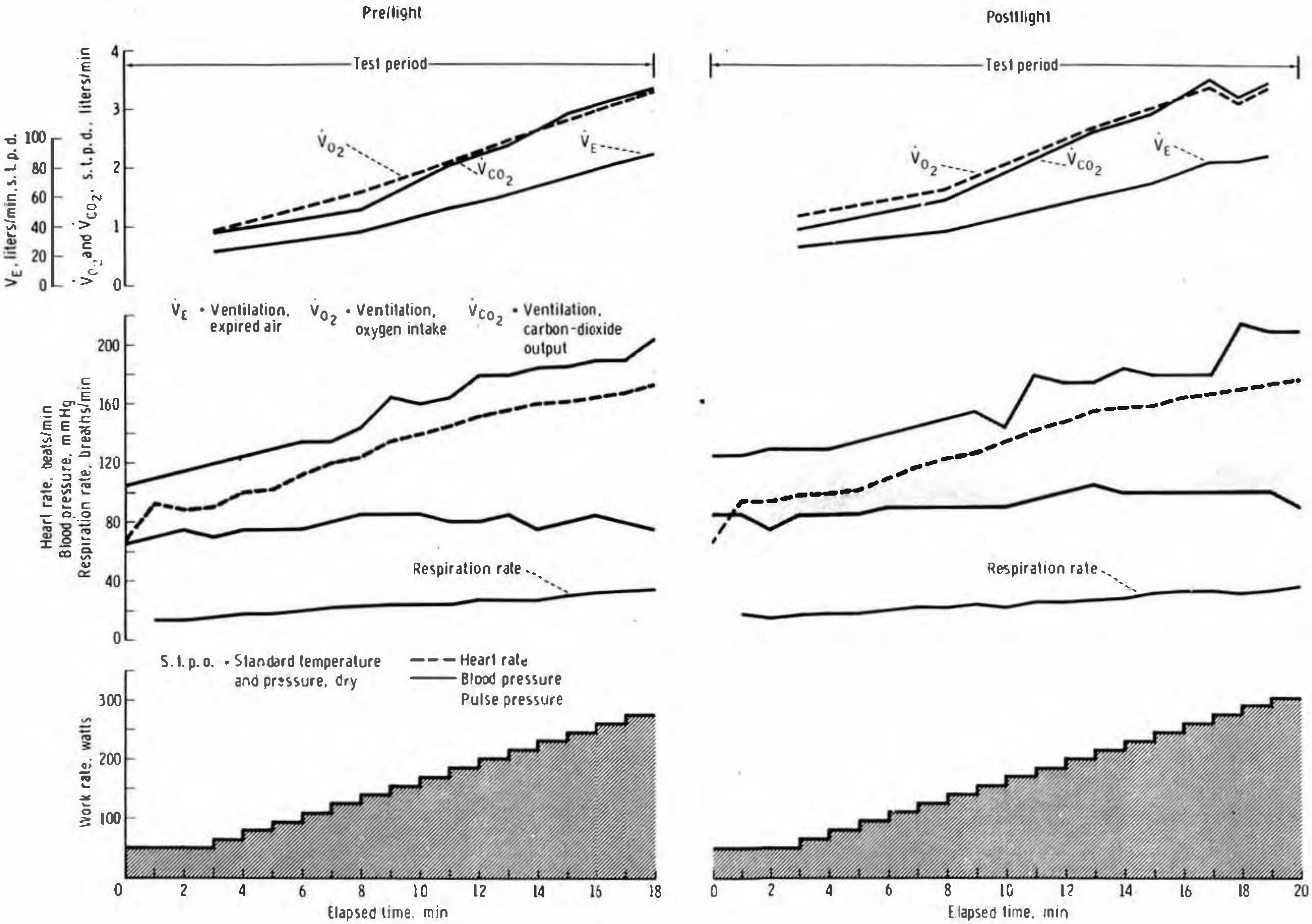
The pilot used the large torso and leg muscles in attempting to straddle the spacecraft nose and found that he had to work against the pressurized space suit in order to force his legs into an unnatural position. The high workload subjectively described by the pilot was confirmed by heart and respiration rates (fig. 10–2(*d*)). The high respiration rates also indicate the possibility of increased carbon-dioxide level. The Extravehicular Life-Support System was not designed to handle workloads of the magnitude indicated by these rates in terms of either thermal control or carbon-dioxide removal. It is probable that the thermal and carbon-dioxide buildup, along with psychogenic factors which were certainly present, contributed to the high heart rates recorded. However, this would make heart rate and respiration rate data no less useful in the real-time monitoring of a crew during flight if stress or potential danger were in fact present.

In planning for Gemini XII, it was deemed important to avoid workloads which would exceed the capacity of the Extravehicular Life-Support System. It had been determined that the Extravehicular Life-Support System was capable of handling 2000 Btu/hr while maintaining a carbon-dioxide level equal to approximately 6 mm of mercury. During the



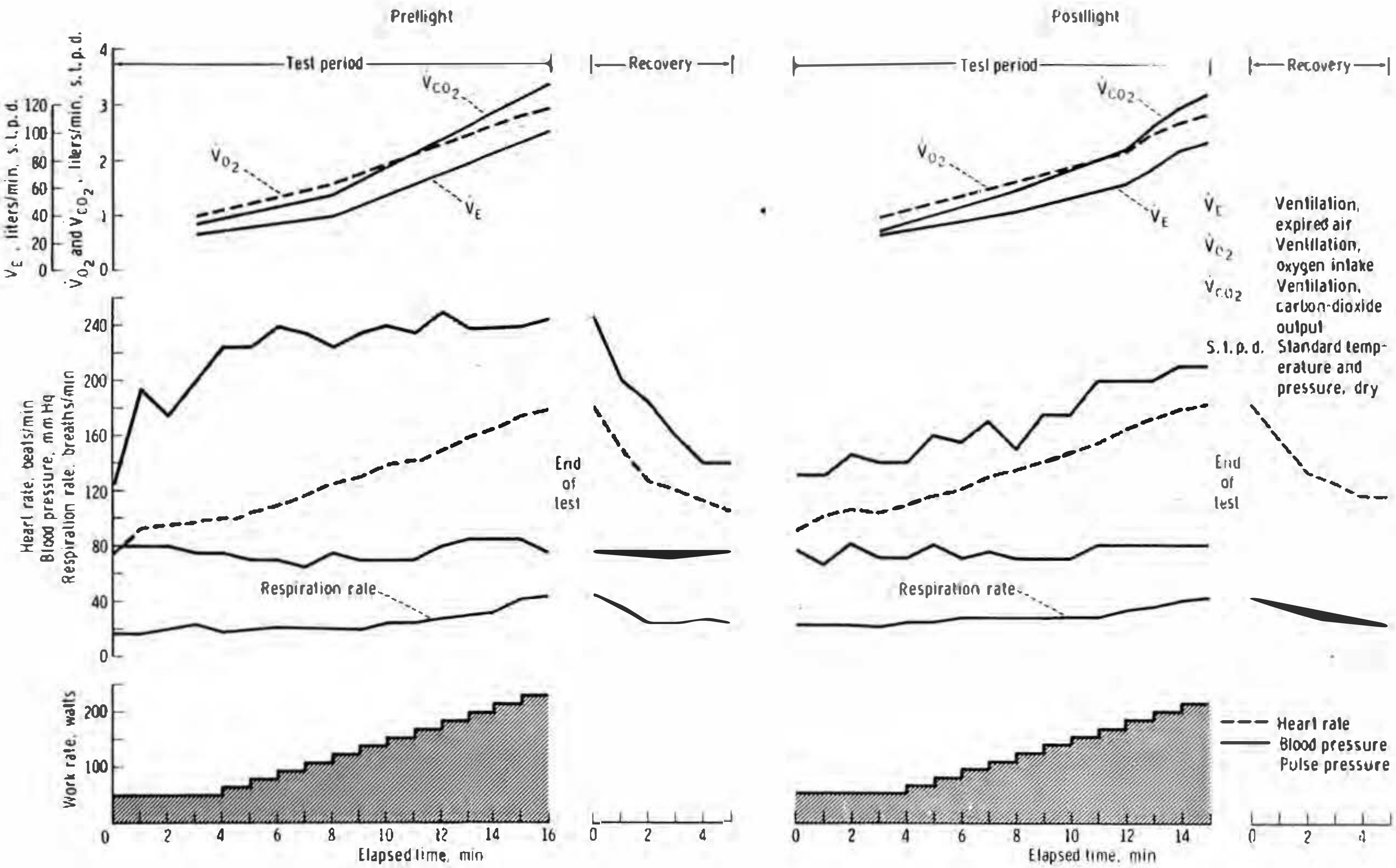
(*a*) Gemini IX–A pilot.

FIGURE 10-1.—Ergometry studies.



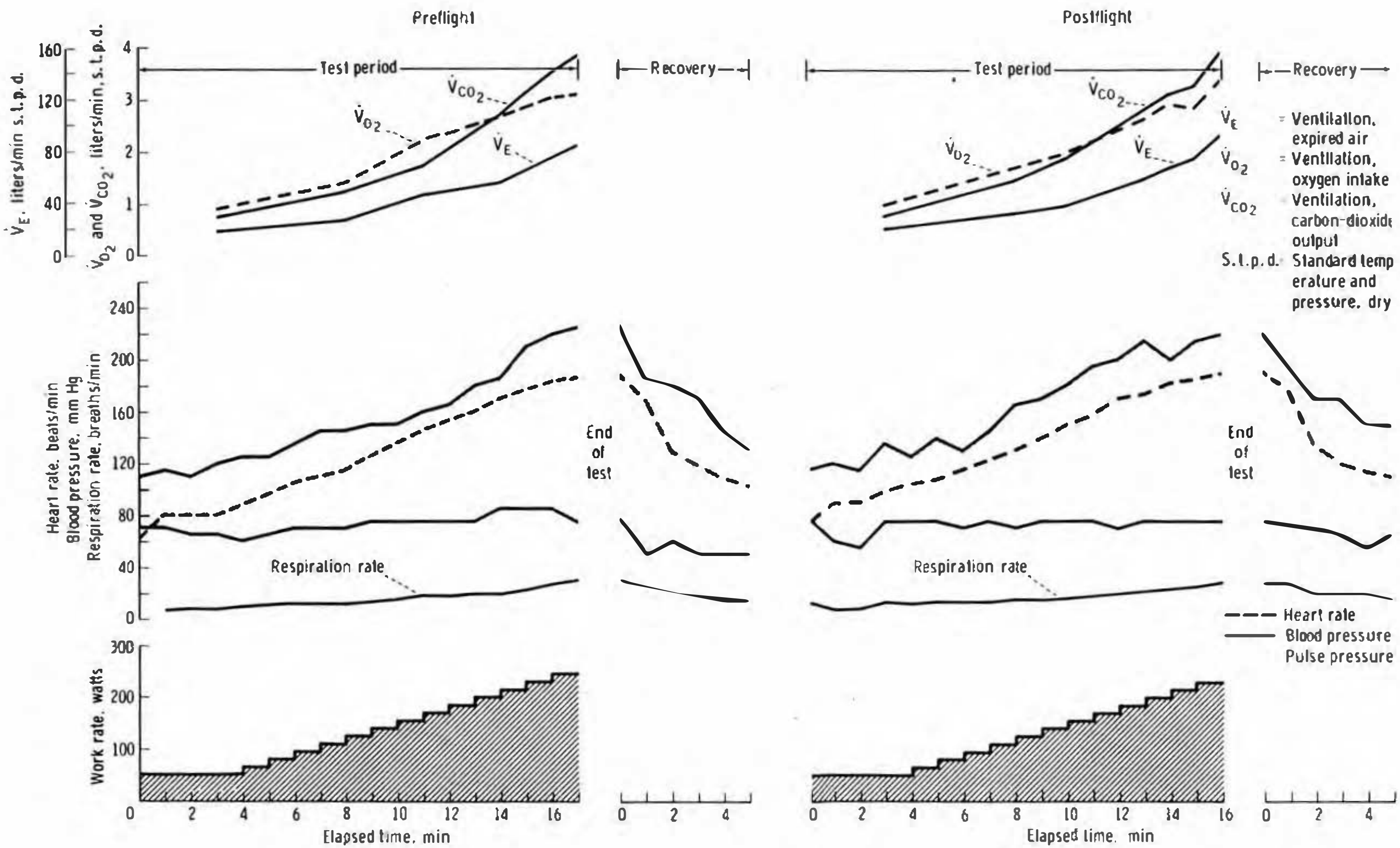
(*b*) Gemini X pilot.

FIGURE 10–1.—Continued.



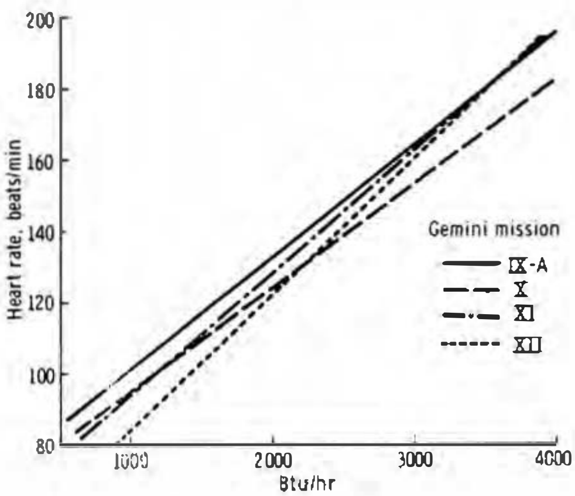
(c) Gemini XI pilot.

FIGURE 10-1.—Continued.



(*d*) Gemini XII pilot.

FIGURE 10-1.—Continued.



(c) Gemini IX-A through XII preflight studies.

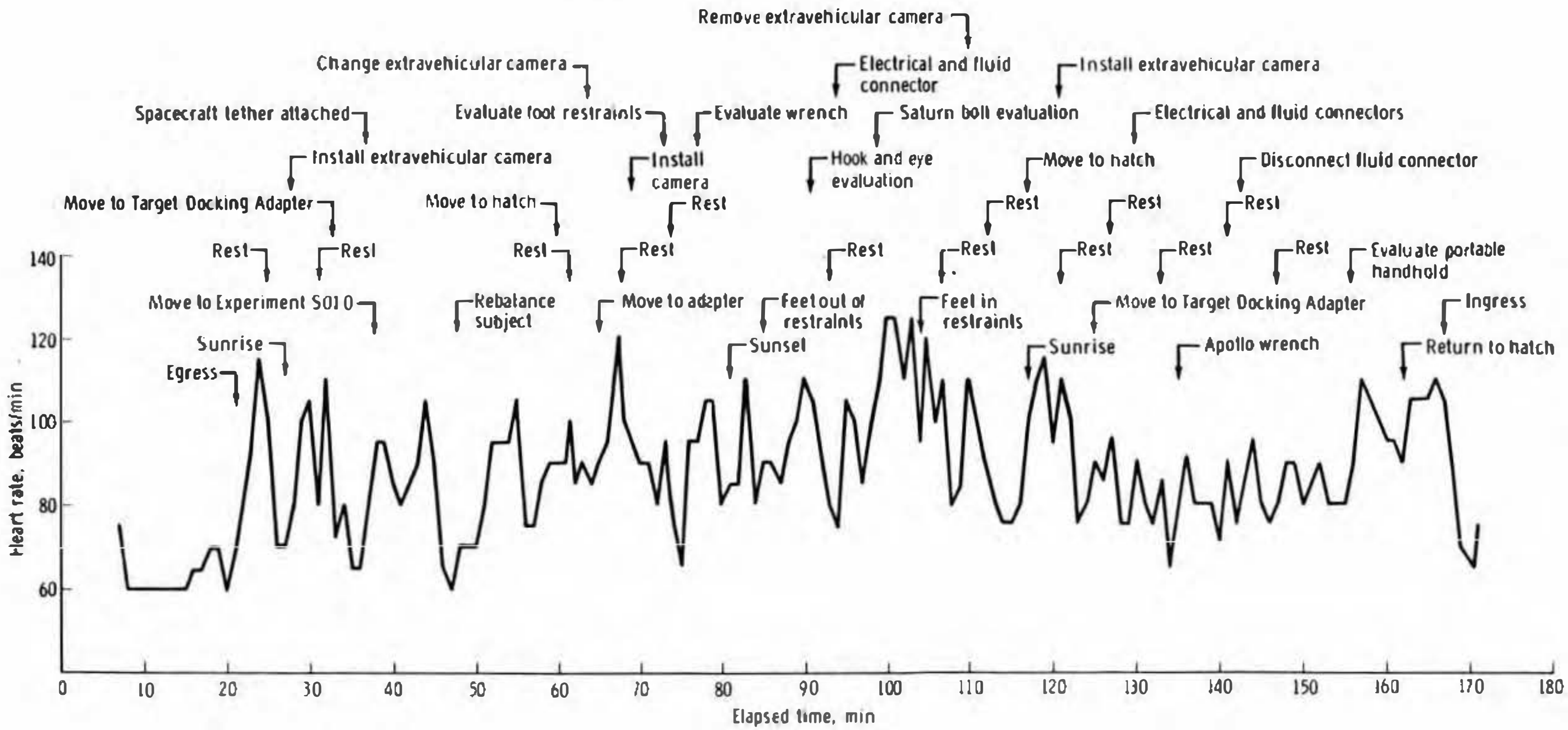
FIGURE 10-4.—Concluded

preflight ergometer studies (fig. 10-5), the pilot heart rate was 122 beats per minute when the workload was 2000 Btu/hr. It should be noted that a total heat capacity higher than 2000 Btu/hr was possible for short periods of time and that sustained heat dissipation of a percentage of thermal load produced by higher levels of work was also within the capabilities of the Extravehicular Life-Support System. Because of these and other factors which are known to cause increases, heart rates above 122 beats per minute were expected and observed during the planned extravehicular activities on Gemini XII. Figure 10-3(e) is a graph of heart rate related to events during the Gemini XII umbilical extravehicular activity. Only once did the pilot's heart rate exceed expected levels. This occurred during a period of unscheduled activities when psychogenic factors contributed heavily to the heart rate. When the pilot was asked to decrease the activities, heart rates returned to a resting level in less than 1 minute.

During each period of standup extravehicular activity in Gemini XII, two sessions of programed exercise were performed. The exercises consisted of moving the arms against the restrictive forces of the pressurized space suit. Both arms were brought from the neutral position to the sides of the helmet once each second for 60 seconds. An attempt was made to correlate heart rate during these inflight exercise periods with preflight exercise tests (fig. 10-5). When compared in this manner, there appeared to be no significant difference between the heart-rate data for the exercises performed before flight and those performed in flight. Only qualitative conclusions, however, can be drawn from these data. Quantitative and scientifically valid conclusions must await the results of more detailed and precisely implemented inflight medical experimentation in which controlled conditions are possible and adequate data collection is feasible.

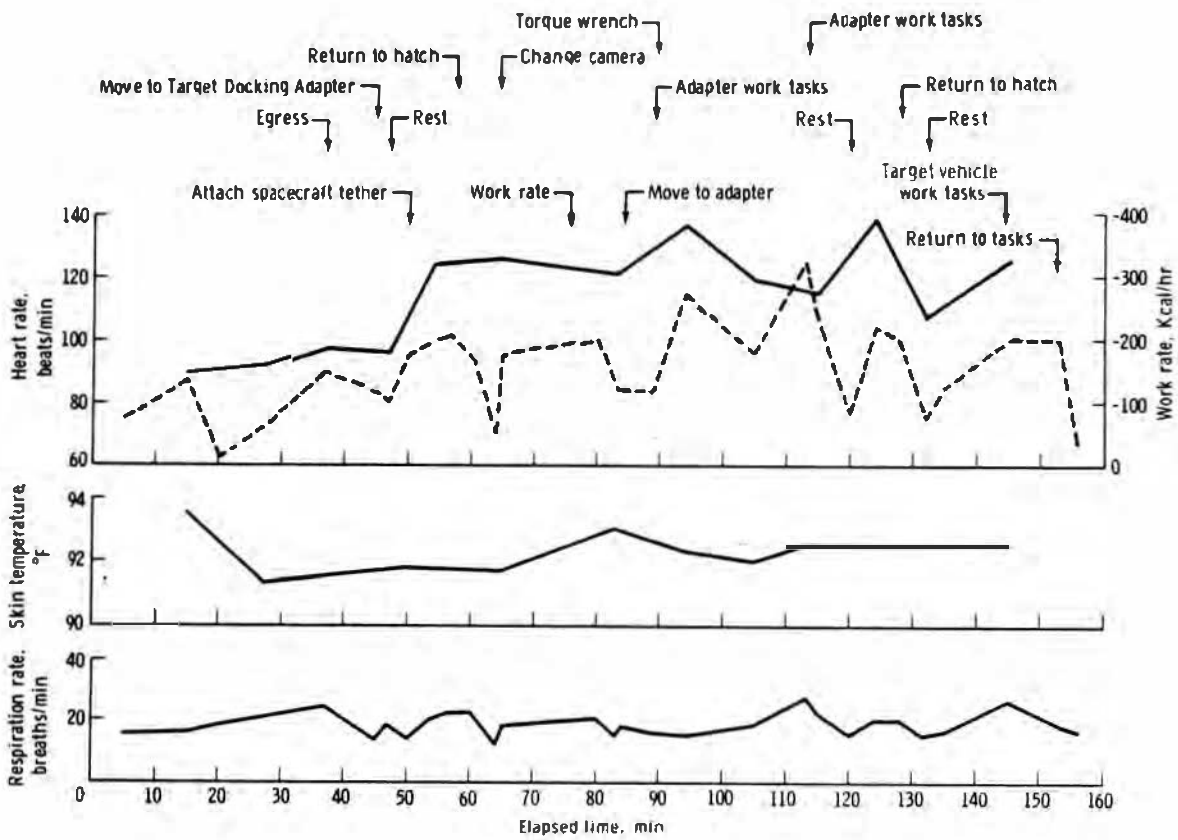
Certain other factors are considered significant in the medical aspects of the Gemini extravehicular activities. One of these factors, the art of conserving energy, has been briefly mentioned, and was demonstrated by the pilot of Gemini XII. The pilot of Gemini XII was able to condition himself to relax completely within the neutral position of the suit. He consciously tried to determine when a group of muscles was found to be tense while performing no useful work, and then tried to subjectively relax these muscles. All movements were slow and deliberate. When small movement of the fingers was sufficient to perform a task, the pilot used only the necessary muscles. If a restraint strap would substitute for muscle action, the pilot would rely on the restraint strap to maintain position, and would relax the muscles which would otherwise have been required for this task.

Chronic fatigue and degraded physical condition may have been a problem during extravehicular activity. Sleep during the first night of each flight was inadequate, and preparation activities for extravehicular maneuvers were detailed and fatiguing. Furthermore, the pace of preflight activities and the pressures of planning, training, and preparation to meet a flight schedule predisposed the crew to fatigue. During the final weeks of preparation for a flight, each crew found that time



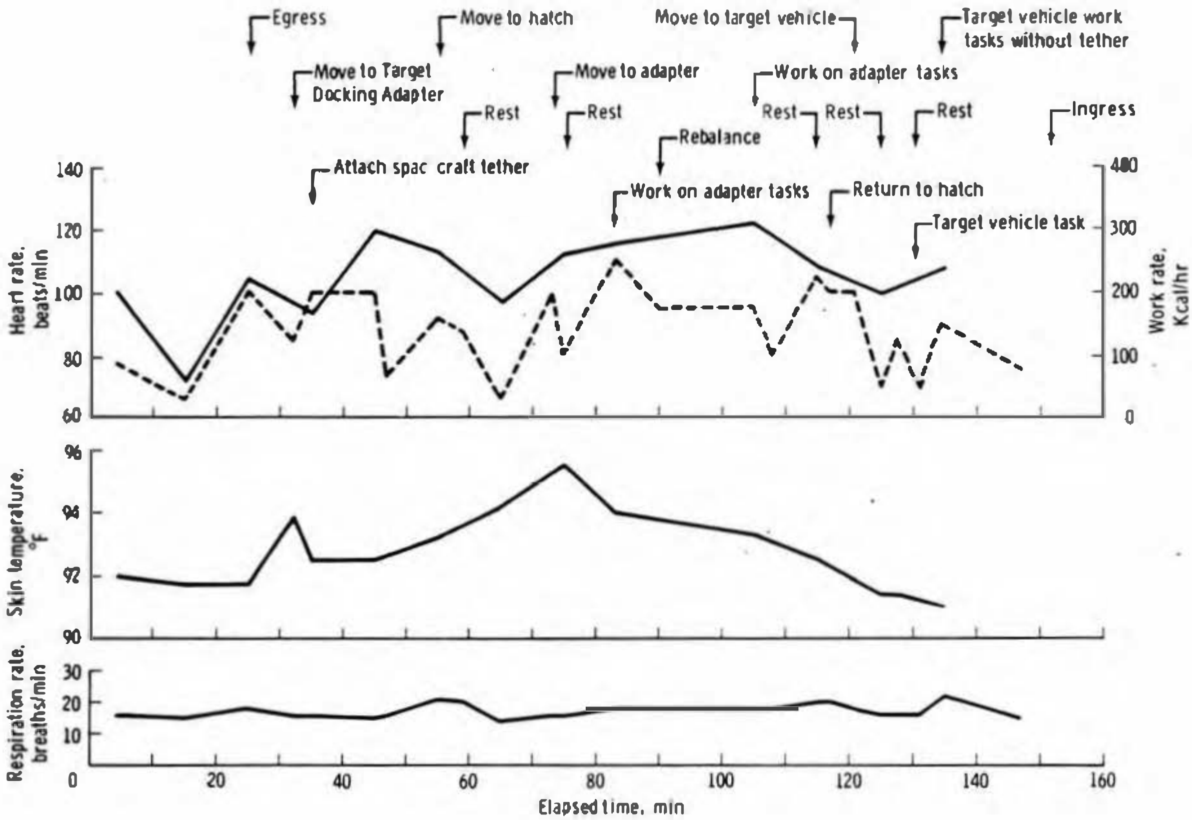
(a) Gemini XII pilot.

FIGURE 10-2.—Heart rates from underwater simulations.



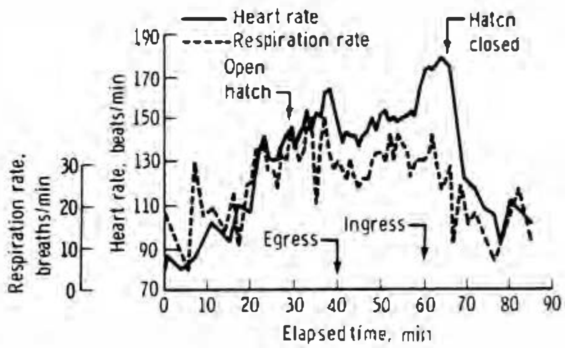
(*b*) Gemini XII pilot.

FIGURE 10-2.—Continued.



(c) Gemini XII pilot.

FIGURE 10-2.—Concluded.



(a) Gemini IV pilot.

FIGURE 10–3.—Physiological data during umbilical extravehicular activity.

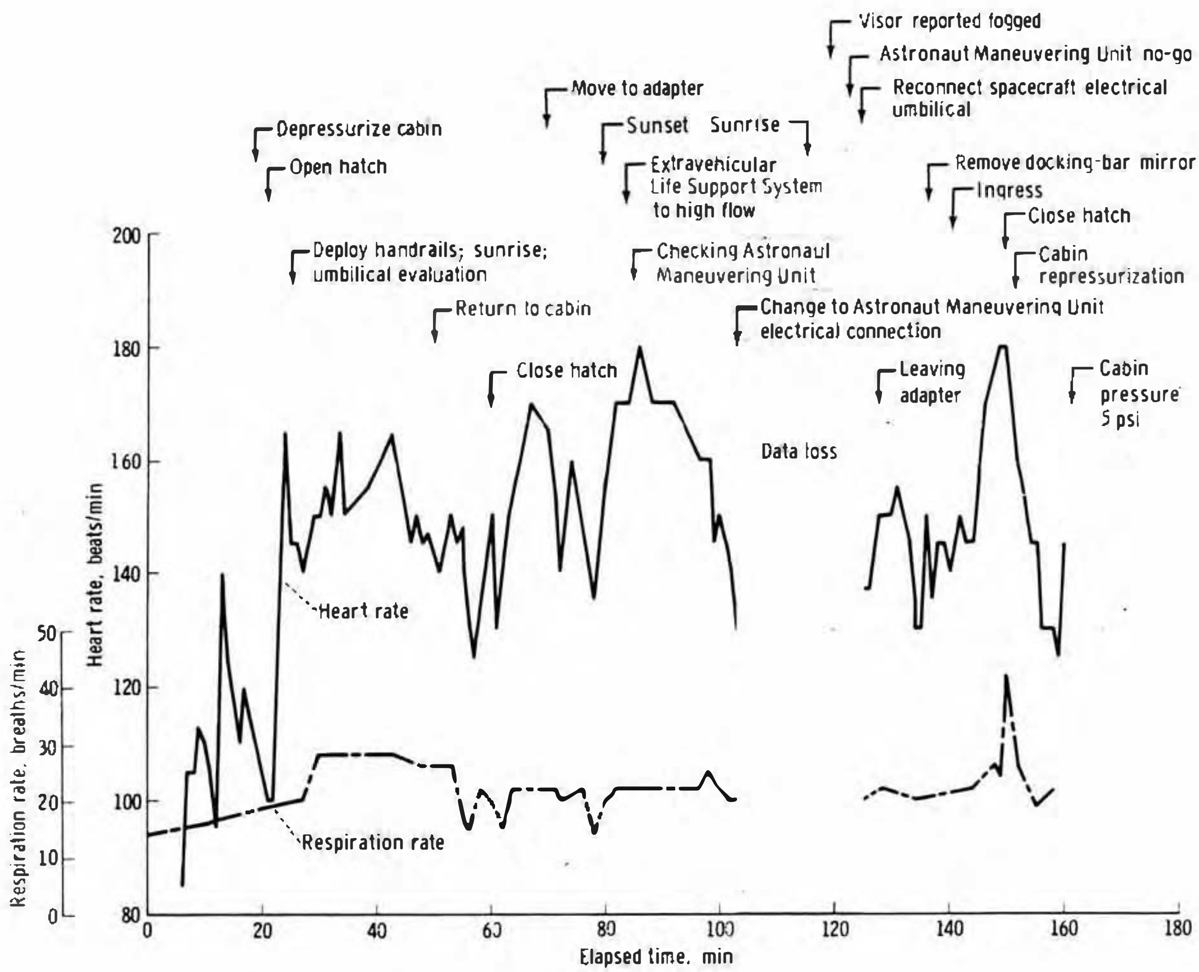
for rest, relaxation, and even physical conditioning was at a premium, and often these activities were omitted.

The possibility exists that hematological or cardiovascular changes observed in weightless flight decrease the metabolic efficiency of man during the extravehicular activities requiring a relatively high workload. Until more detailed information is available from well-founded medical experimentation during flight, the relative importance of such factors cannot be assessed.

Conclusions

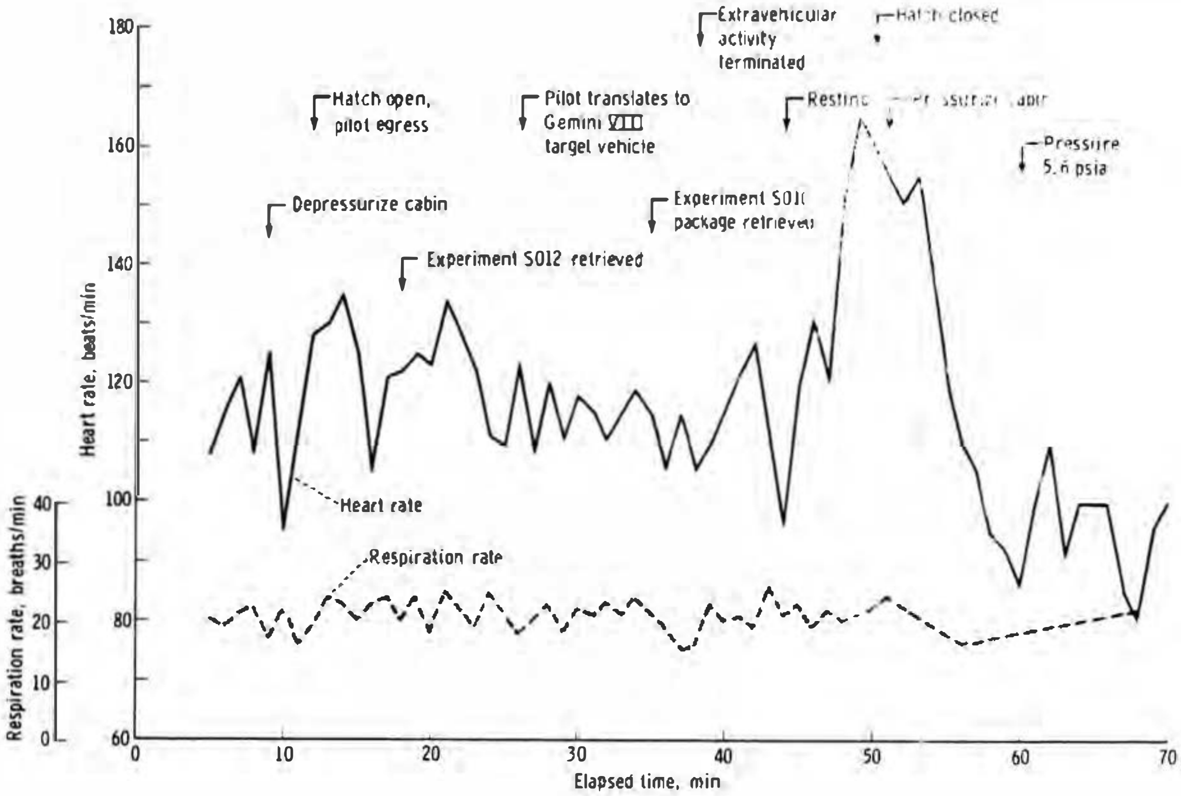
The experience gained from the Gemini extravehicular activities has provided information which will be invaluable in planning future missions. There have been no indications that the efficiency of man during extravehicular activities is significantly altered. The major factors which appear to have produced the highest workload during the extravehicular activity are high suit forces, insufficient body-position aids, and thermal stress. The success of Gemini XII conclusively demonstrated that these factors can be minimized through careful planning. Evaluation of physiological factors during the extravehicular activity has been significantly compromised by the lack of adequate instrumentation. Much can be learned about the physiological responses to extravehicular activities from simulations in the zero-g aircraft and in an underwater mockup. Without specific knowledge of the thermal and environmental conditions, however, a realistic simulation of extravehicular activities will be incomplete and possibly misleading.

The successful completion of the Gemini extravehicular activities indicates that life-support planning has been essentially sound. The success of Gemini XII indicates that within the limitations of the experience gained, time lines and work tasks can be tailored so that flight objectives can be accomplished. There are no medical contraindications to presently planned extravehicular activities.



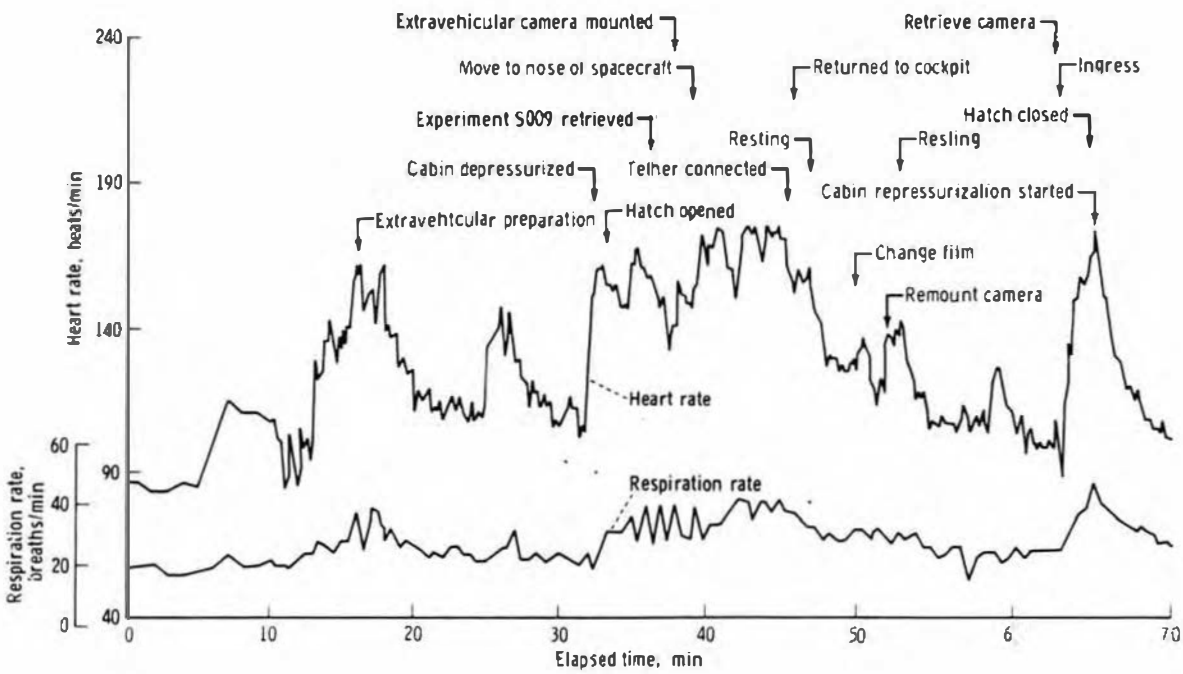
(b) Gemini IX–A pilot.

FIGURE 10–3.—Continued.



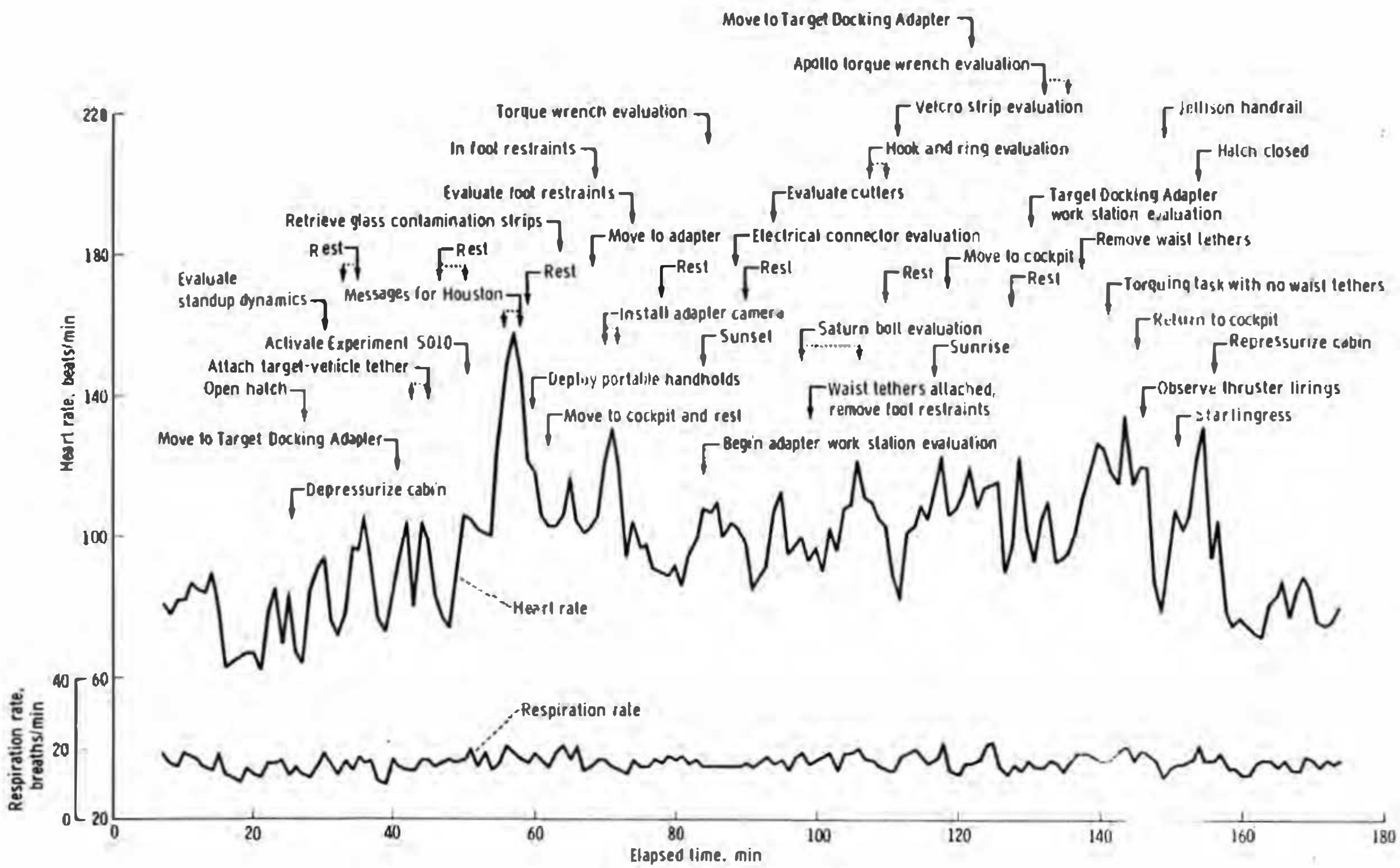
(c) Gemini X pilot.

FIGURE 10–3.—Continued.



(d) Gemini XI pilot.

FIGURE 10-3.—Continued.



(c) Gemini XII pilot.

FIGURE 10-3.—Concluded.

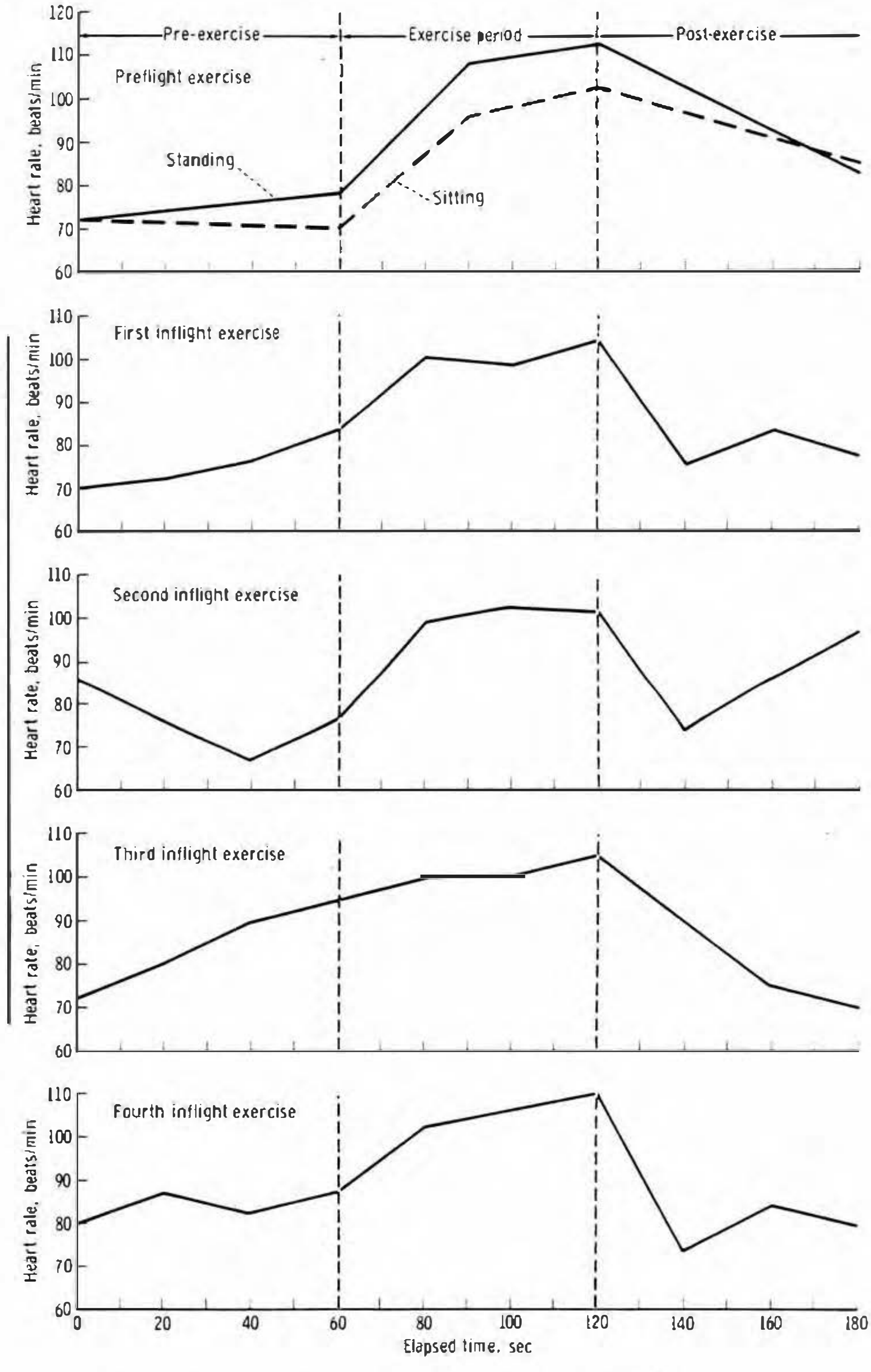
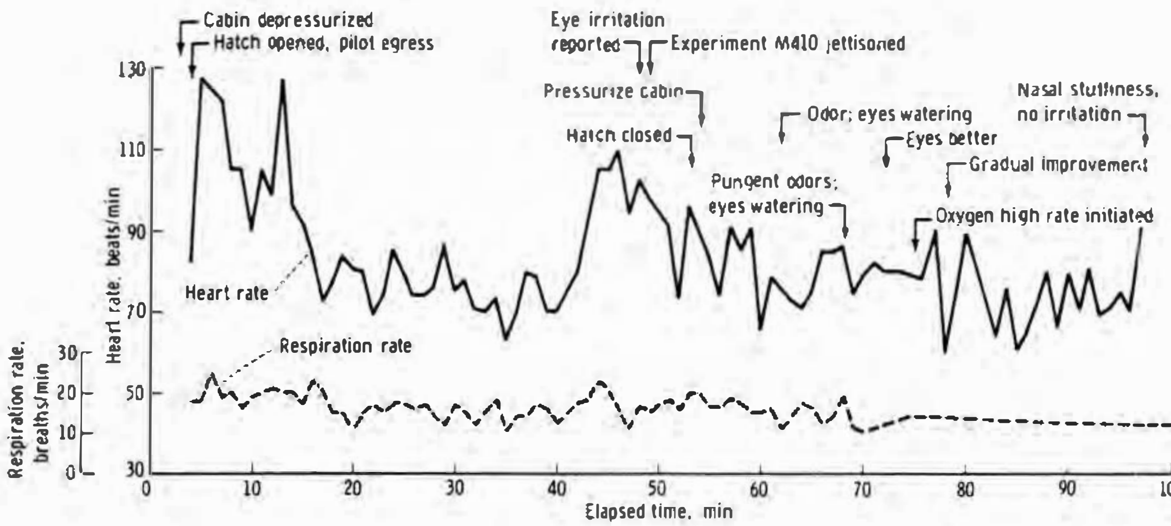
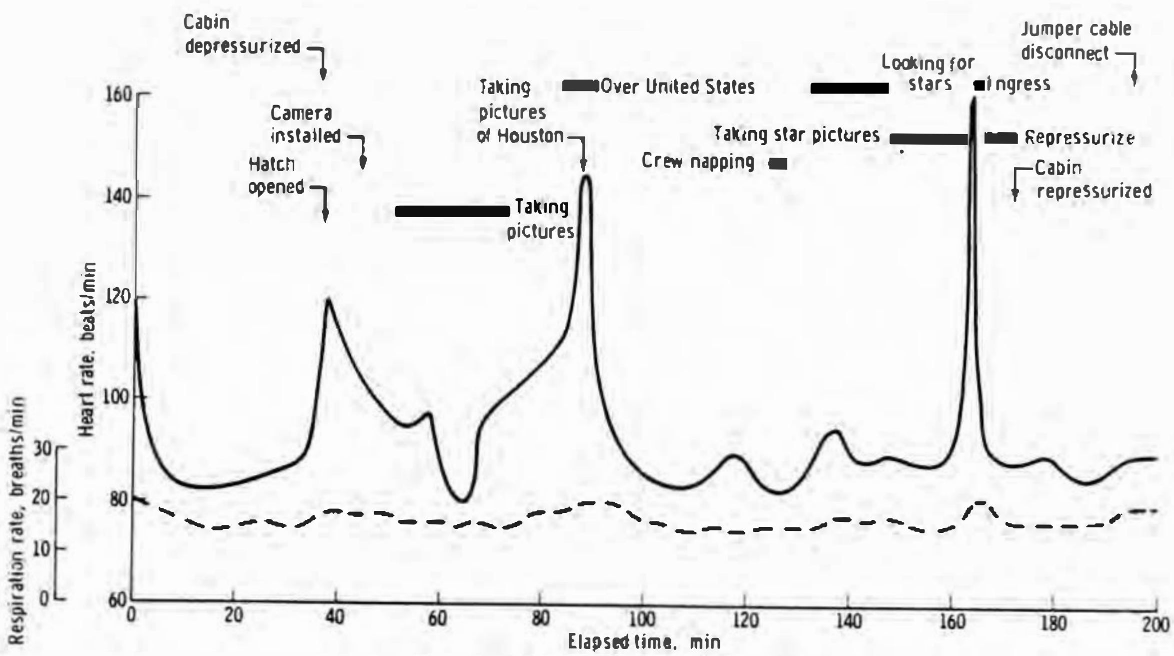


FIGURE 10-4.—Preflight and inflight exercise test, Gemini XII pilot.



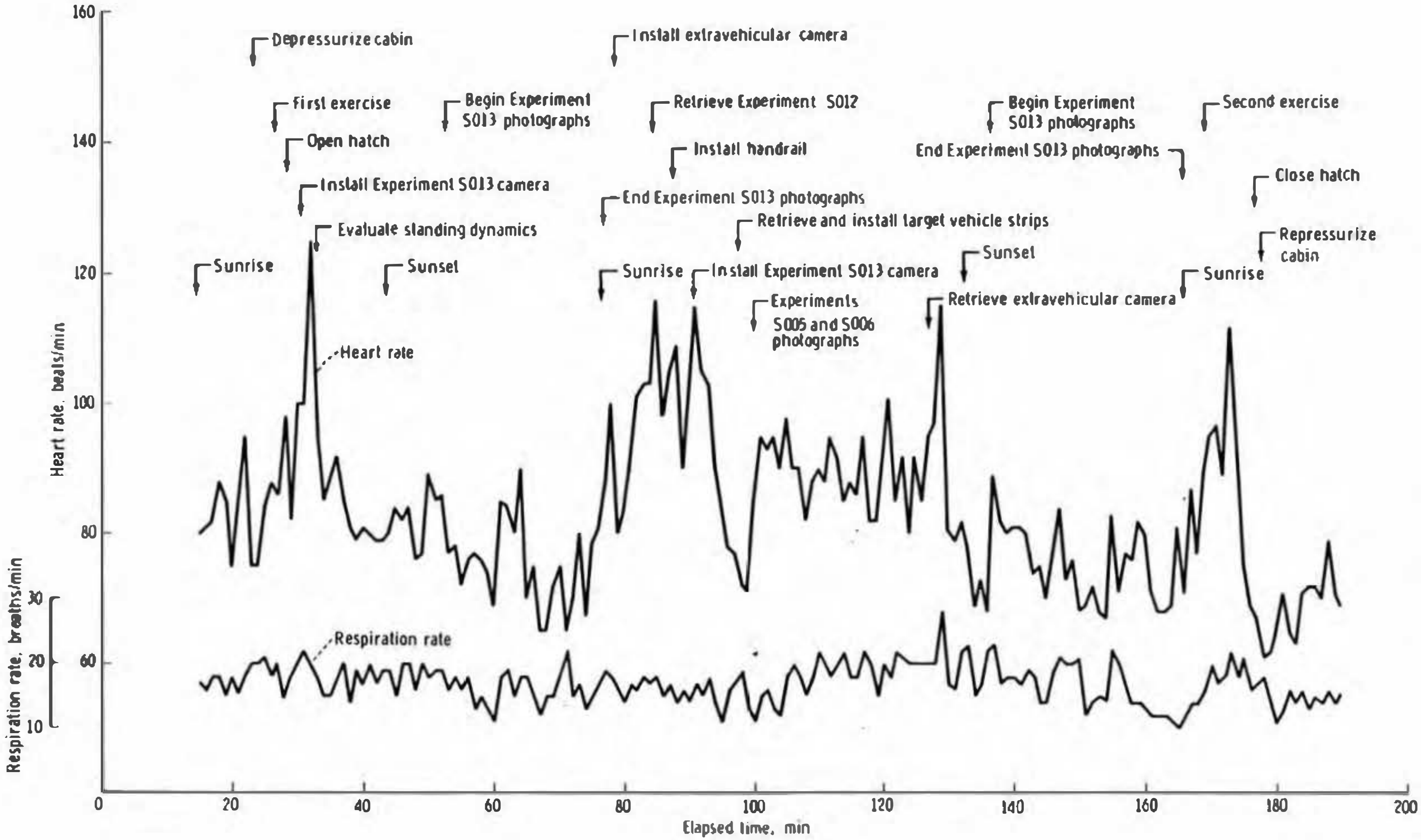
(*a*) Gemini X pilot.

FIGURE 10-5.—Physiological data during standup extravehicular activity.



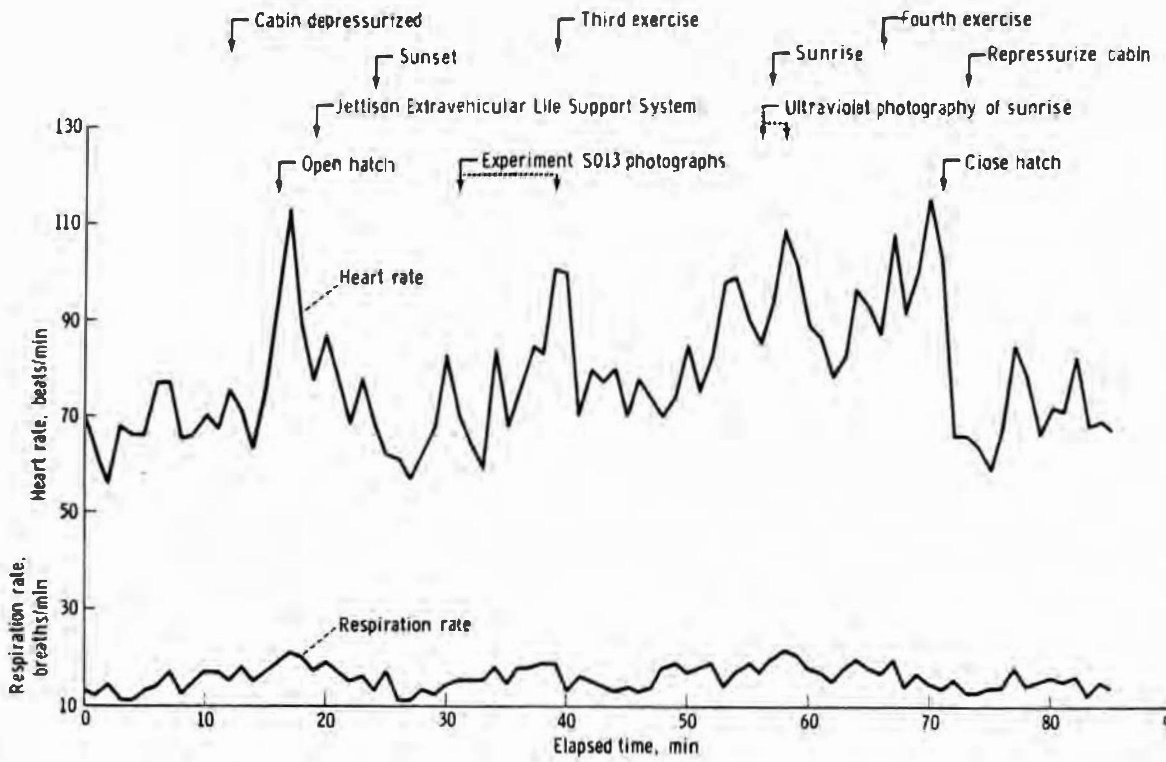
(*b*) Gemini XI pilot.

FIGURE 10-5.—Continued.



(c) First standup extravehicular activity of the Gemini XII pilot.

FIGURE 10-5.—Continued.



(*d*) Second standup extravehicular activity of the Gemini XII pilot.

FIGURE 10-5.—Concluded.

11. SUMMARY OF GEMINI EXTRAVEHICULAR ACTIVITY

By REGINALD M. MACHELL, *Office of Spacecraft Management, Gemini Program Office, NASA Manned Spacecraft Center;* LARRY E. BELL, *Crew Systems Division, NASA Manned Spacecraft Center;* NORMAN P. SHYKEN, *Senior Engineer, McDonnell Aircraft Corp.;* and JAMES W. PRIM *III, Office of Spacecraft Management, Gemini Program Office, NASA Manned Spacecraft Center*

Introduction

The Gemini Program has provided the first experience in extravehicular activity in the U.S. manned space effort. The original objectives included the following:

(1) Develop the capability for extravehicular activity in free space.

(2) Use extravehicular activity to increase the basic capability of the Gemini spacecraft.

(3) Develop operational techniques and evaluate advanced equipment in support of extravehicular activity for future programs.

In general, these principal objectives have been met. Some of the problems encountered during the equipment evaluation caused the emphasis to be shifted from maneuvering equipment to body-restraint devices.

The initial Gemini design guidelines contemplated missions with 30 to 60 minutes of extravehicular activity with very low workloads and metabolic rates (500 Btu/hr). Various ground simulations subsequently indicated the need for longer periods of extravehicular activity and greater heat-dissipation capabilities if significant useful results were to be obtained. The design criteria for the extravehicular life-support equipment were ultimately set at a mission length of 140 minutes with a normal metabolic rate of 1400 Btu/hr and a peak rate of 2000 Btu/hr. The flight results indicated that in several instances this metabolic rate was unintentionally exceeded. The final mission, Gemini XII, demonstrated the equipment and procedures by which the workload and the metabolic rates could be maintained within the desired limits.

One of the most difficult aspects of developing an extravehicular capability was simulating the extravehicular environment. The combination of weightlessness and high vacuum was unattainable on Earth. Zero-gravity aircraft simulations were valuable but occasionally misleading. Neutral buoyancy simulations underwater ultimately proved to be the most realistic duplication of the weightless environment for body positioning and restraint problems. The novel characteristics of the extravehicular environment and the lack of comparable prior experience made intuition and normal design approaches occasionally inadequate. The accumulation of flight experience gradually led to an understanding of the environment and the techniques for practical operations.

Extravehicular Mission Summary

Extravehicular activity was accomplished on 5 of the 10 manned Gemini missions. A total of 6 hours 1 minute was accumulated in five extravehicular excursions on an umbilical (table 11–I). An additional 6 hours 24 minutes of hatch-open time were accumulated in six periods of standup extravehicular activity including two periods for jettisoning equipment. The total extravehicular time for the Gemini Program was 12 hours 25 minutes.

Preceding page blank

TABLE 11-I.—*Summary of Gemini Extravehicular Activity Statistics*

Mission	Life-support system	Umbilical length, ft	Maneuvering device	Umbilical extravehicular activity time, hr:min	Standup time, hr:min[a]	Total extravehicular activity time, hr:min
IV	VCM	25	Hand Held Maneuvering Unit	0:36	None	0:36
VIII	ELSS, ESP	25	Hand Held Maneuvering Unit	None	None	None
IX-A	ELSS, AMU	25	Astronaut Maneuvering Unit	2:07	None	2:07
X	ELSS	50	Hand Held Maneuvering Unit	0:39	0:50	1:29
XI	ELSS	30	Hand Held Maneuvering Unit	0:33	2:10	2:43
XII	ELSS	25	None	2:06	3:24	5:30
Totals for Gemini Program				6:01	6:24	12:25

[a] **Includes mission equipment jettison time.**

Gemini IV

Two of the objectives of the Gemini IV mission were to establish the initial feasibility of extravehicular activity and to evaluate a simple maneuvering device. The life-support system was a small chest pack called the Ventilation Control Module, with oxygen supplied through a 25-foot umbilical hose assembly (fig. 11-1). The Hand Held Maneuvering Unit was a self-contained, cold-gas propulsion unit which utilized two 1-pound tractor jets and one 2-pound pusher jet. The G4C space suit was worn with an extravehicular cover layer for micrometeorite and thermal protection. While outside the spacecraft, the pilot also wore a special sun visor designed for visual protection.

The Gemini IV pilot was outside the spacecraft for 20 minutes and followed the time line shown in figure 11-2. The results proved the feasibility of simple extravehicular activity without disorientation. The utility of the Hand Held Maneuvering Unit for self-propulsion without artificial stabilization was tentatively indicated, although the 20 seconds of available thrust were not enough for a detailed stability and control evaluation. The

FIGURE 11-1.—Gemini IV extravehicular system.

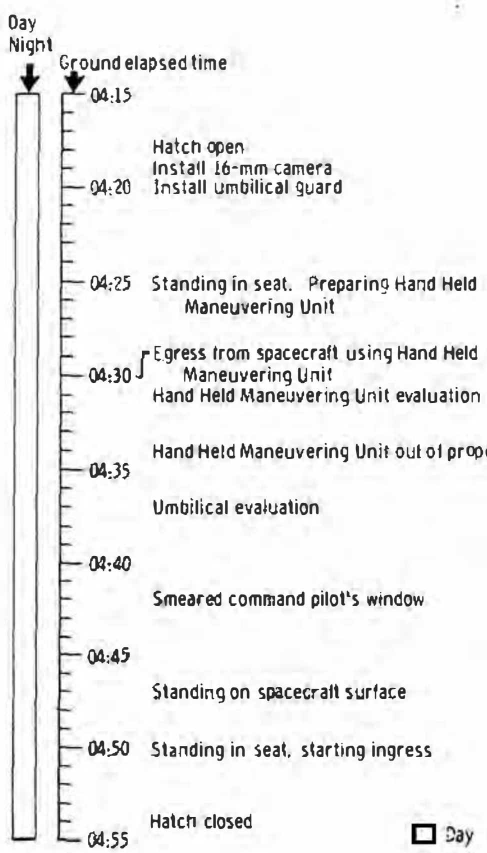


FIGURE 11-2.—Gemini IV extravehicular time line.

extravehicular pilot evaluated the dynamics of a 25-foot tether, and was able to push from the surface of the spacecraft under gross control. The umbilical tether caused the pilot to move back in the general direction of the spacecraft. The tether provided no means of body positioning control other than as a distance-limiting device. Ingress to the cockpit and hatch closure was substantially more difficult than anticipated because of the high forces required to pull the hatch fully closed. The hatch-locking mechanism also malfunctioned, complicating the task of ingress. Efforts by the extravehicular pilot in coping with the hatch-closing problems far exceeded the cooling capacity of the Ventilation Control Module. The pilot was overheated at the completion of ingress, although he had been cool while outside the spacecraft. Several hours were required for the pilot to cool off after completion of the extravehicular period; however, no continuing aftereffects were noted. Because of the previous hatch-closing problems, the hatch was not opened for jettisoning the extravehicular equipment.

The inflight experience showed that substantially more time and effort were required to prepare for the extravehicular activity than had previously been anticipated. The increased hazards of extravehicular activity dictated meticulous care in the inflight checkout before the spacecraft was depressurized. The flight crew found the use of detailed checklists a necessary part of the preparations for extravehicular activity. The Gemini IV mission proved that extravehicular activity was feasible, and indicated several areas where equipment performance needed improvement.

Gemini VIII

The next extravehicular activity was planned for the Gemini VIII mission and was intended to evaluate the Extravehicular Life-Support System. This system was a chest pack with a substantially greater thermal capacity than the Ventilation Control Module used during Gemini IV, and had an increased reserve oxygen supply. In addition, the extravehicular activity was intended to evaluate the Extravehicular Support Package, a backpack unit containing an independent oxygen supply for life support; a larger capacity propellant supply for the Hand Held Maneuvering Unit; and an ultrahigh-frequency radio package for independent voice communications. A detailed evaluation was also planned on the Hand Held Maneuvering Unit while the pilot was on a 75-foot lightweight tether. The extravehicular equipment is shown in figure 11–3. The Gemini VIII mission was terminated before the end of the first day because of a spacecraft control-system malfunction, and no extravehicular activity was accomplished.

Equipment design became very complicated during preparation for the Gemini VIII mission because of the need to provide the pilot

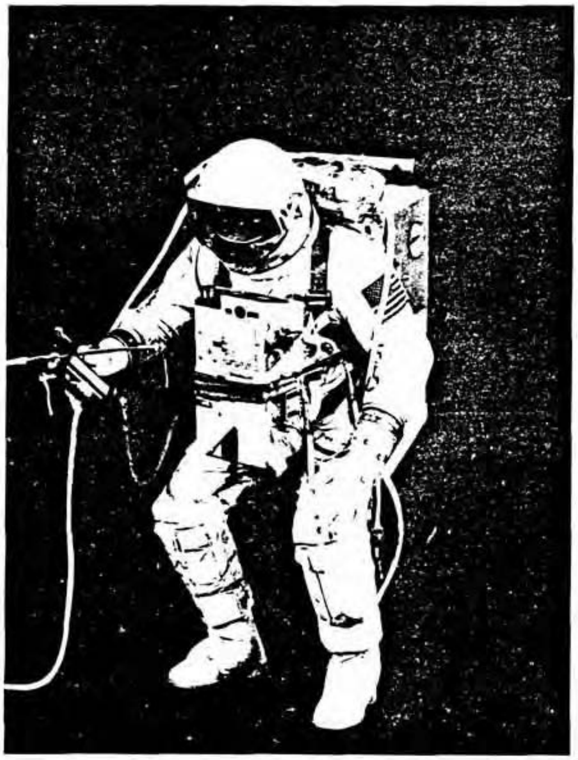


FIGURE 11–3.—Gemini VIII extravehicular system.

with connections to a chest pack, a backpack, several oxygen and communication lines, and a structural tether. Acceptable designs and procedures were established; however, the handling procedures were more difficult than was desirable. Although the Gemini VIII extravehicular equipment was not used in orbit, its use in training and in preparation for flight provided initial insight into the problems of complicated equipment connections.

Gemini IX–A

The prime objective of the Gemini IX–A extravehicular activity was to evaluate the Extravehicular Life-Support System and the Air Force Astronaut Maneuvering Unit. The Astronaut Maneuvering Unit was a backpack which included a stabilization and control system, a hydrogen-peroxide propulsion system, a life-support oxygen supply, and an ultrahigh-frequency radio package for voice

communications. The mission p
for the extravehicular activity
lar to the profile intended for
The hatch was to be opened a
daylight period when good c
could be established with the
tions in the continental Unite
first daylight period was to
familiarization with the envir
performance of preparing simp
and experiments. The succ
period was to be spent in the a
ment section of the spacecraft
and donning the Astronaut
Unit. The second daylight per
spent evaluating the Astronaut
Unit. At the end of this period
to return to the cockpit, disca
naut Maneuvering Unit, comp
scientific photographic experi
gress. The equipment for extr
tivity during Gemini IX–A is
ures 11–4 and 11–5.

The Gemini IX–A extravehi
proceeded essentially as planne
daylight period, and is indicat
line of figure 11–6. The pilo
higher forces than expected i
hatch in the partially open pos
condition did not cause any in
culties. While outside the sp
pilot discovered that the familia
and evaluations required more
fort than the ground simulati
minor difficulties were experie
trolling body position. Prior to
first orbital day, the pilot pro
spacecraft adapter and began
tions for donning the Astrona
ing Unit. The task of prepari
naut Maneuvering Unit requi
work than had been anticipate
because of the difficulties in mai
position on the foot bar and th
At approximately 10 minutes
the visor on the extravehicular
began to fog. The fogging incr
erage and severity until the crew
to discontinue the activities wit

FIGURE 11-4.—Gemini IX–A extravehicular system.

FIGURE 11-5.—Gemini IX–A adapter provisions for extravehicular activity.

naut Maneuvering Unit. After sunrise, the fogging decreased slightly, but increased again when the extravehicular pilot expended any appreciable effort in his tasks. Although the Astronaut Maneuvering Unit was finally donned, the extravehicular activity was terminated early because of the visor fogging, and the Astronaut Maneuvering Unit was not evaluated. The pilot experienced further difficulties in moving the hatch in the intermediate position; however, the forces required to close and lock the hatch were normal. The overall time line for the Gemini IX–A extravehicular activity is shown in figure 11–6.

Postflight evaluation indicated that the Extravehicular Life-Support System functioned normally. It was concluded that the Astronaut Maneuvering Unit preparation tasks and the lack of adequate body restraints had resulted in high workloads which exceeded the design limits of the Extravehicular Life-Support System. Visor fogging was attributed to the high respiration rate and high humidity conditions in the helmet. The pilot reported that he was not excessively hot until the time of ingress. It was concluded that the performance of the Extravehicular Life-Support System heat exchanger may have been degraded at this time because the water supply of the evaporator became depleted.

As a result of the problems encountered during the Gemini IX–A extravehicular activity, several corrective measures were initiated. To minimize the susceptibility to visor fogging, it was determined that an antifog solution should be applied to the space-suit helmet visors immediately prior to the extravehicular activity on future missions. Each extravehicular task planned for the succeeding missions was analyzed in greater detail for the type of body restraints required and the magnitude of the forces involved. An overshoe type of positive foot restraint was installed in the spacecraft adapter and was designed to be used for the extravehicular

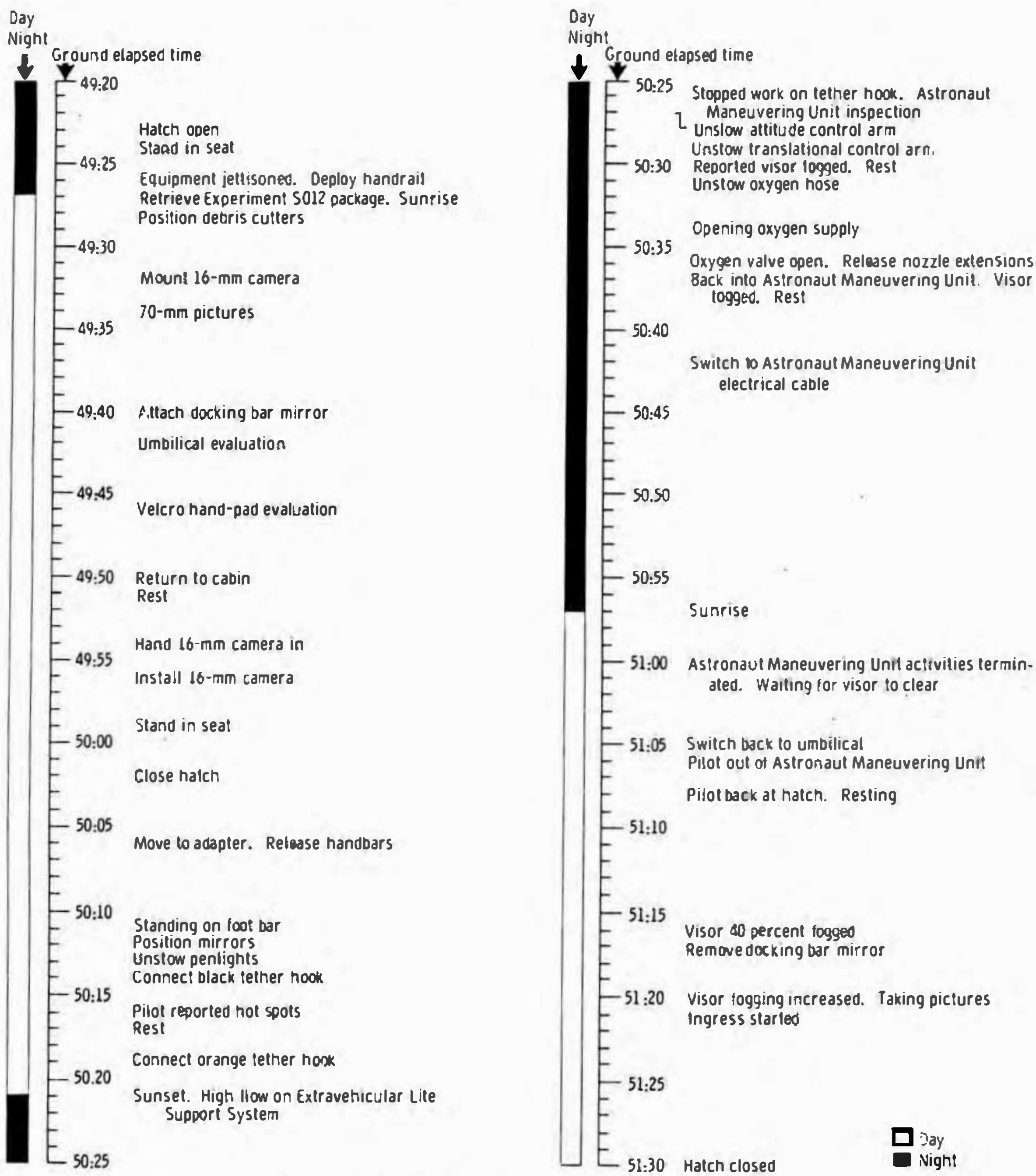


FIGURE 11-6.—Gemini IX-A extravehicular time line.

tasks planned for Gemini XI and XII. The analysis showed that all extravehicular tasks planned for the Gemini X, XI, and XII missions could be accomplished satisfactorily. As another corrective step, underwater simulation was initiated in an attempt to duplicate the weightless environment more accurately than did the zero-gravity aircraft simulations.

Gemini X

The prime objective of the Gemini X extravehicular activity was to retrieve the Experiment S010 Agena Micrometeorite Collection package from the target vehicle that had been launched for the Gemini VIII mission. The package was to be retrieved immediately after rendezvous with the Gemini VIII target vehicle, and the umbilical extravehicular activity was to last approximately one daylight period. In addition, it was planned to continue the evaluation of the Hand Held Maneuvering Unit; to retrieve the Experiment S012 Gemini Micrometeorite Collection package from the spacecraft adapter; and to conduct several photographic experiments. Photography was scheduled for 1½ orbits during a period of standup extravehicular activity.

The extravehicular equipment included the Extravehicular Life-Support System, the improved Hand Held Maneuvering Unit, and the new 50-foot dual umbilical. One hose in the umbilical carried the normal spacecraft oxygen supply to the Extravehicular Life-Support System. The other hose carried nitrogen for the Hand Held Maneuvering Unit. The umbilical was designed so that the Hand Held Maneuvering Unit and all oxygen fittings could be connected before the hatch was opened; however, the nitrogen supply for the Hand Held Maneuvering Unit had to be connected outside the spacecraft cabin. The configuration and operation of this umbilical were simpler than the complicated connections with the Gemini VIII and IX–A equipment. The 50-foot umbilical had the disadvantage of requiring a substantial increase in stowage volume over the 25-foot single umbilical assembly used on Gemini VIII and IX–A. The extravehicular equipment for Gemini X is shown in figure 11–7. For the standup extravehicular activity, short extension hoses were connected to the spacecraft Environmental Control System to permit the pilot to stand while remaining on the spacecraft closed-loop system. The pilot also used a fabric-strap standup tether to take any loads required to hold him in the cockpit.

The standup activity commenced just after sunset at an elapsed flight time of 23 hours

FIGURE 11–7.—Gemini X extravehicular system.

24 minutes, and proceeded normally for the first 30 minutes (fig. 11–8). The pilot was well restrained by the standup tether, and since there were no unusual problems with body positioning, ultraviolet photographs of various star fields were taken with no difficulty. Immediately after sunrise, both crewmembers experienced vision interference caused by eye irritation and tears, and the crew elected to terminate the standup activity at this time.

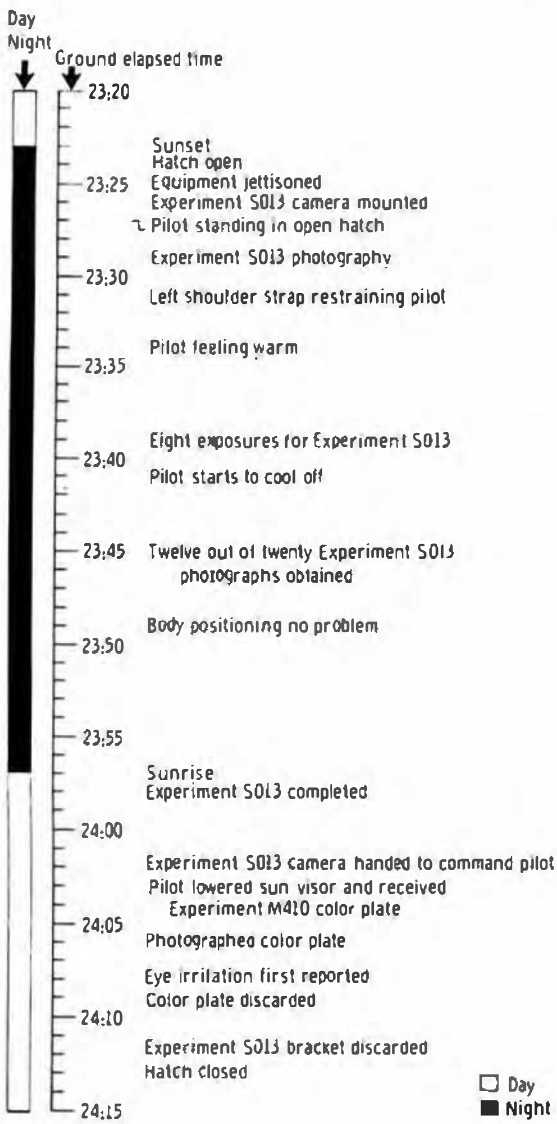


FIGURE 11–8.—Gemini X standup extravehicular time line.

The eye irritation subsided gradually after ingress and hatch closure. The cause of the eye irritation was not known, but was believed to be related to the simultaneous use of both compressors in the spacecraft oxygen-supply loop to the space suits. The crew verified that, prior to the umbilical extravehicular activity, no significant eye irritation was experienced when only one suit compressor was used while the cabin was decompressed.

The Gemini X umbilical extravehicular activity was initiated at an elapsed flight time of 48 hours 42 minutes, immediately after rendezvous with the Gemini VIII target vehicle. The sequence of events is indicated in figure 11–9. The pilot retrieved the Experiment S012 Gemini Micrometeorite Collection package from the exterior of the spacecraft adapter, then moved outside to connect the nitrogen umbilical supply line for the Hand Held Maneuvering Unit. The pilot then returned to the cockpit. Meanwhile, the command pilot was flying the spacecraft in close formation with the target vehicle (fig. 11–10). With the docking cone of the target vehicle approximately 5 feet away, the pilot pushed off from the spacecraft and grasped the outer lip of the docking cone. In moving around the target vehicle to the location of the Experiment S010 Agena Micrometeorite Collection package, the pilot lost his hold on the smooth lip of the docking cone and drifted away from the target vehicle. He used the Hand Held Maneuvering Unit to translate approximately 15 feet back to the spacecraft. The pilot then used the Hand Held Maneuvering Unit to translate to the target vehicle. On his second attempt to move around the docking cone, the pilot used the numerous wire bundles and struts behind the cone as handholds, and was able to maintain satisfactory control of his body position. Retrieval of the Experiment S010 Agena Micrometeorite Collection package was accomplished without difficulty. While carrying the package, the pilot used the umbilical to

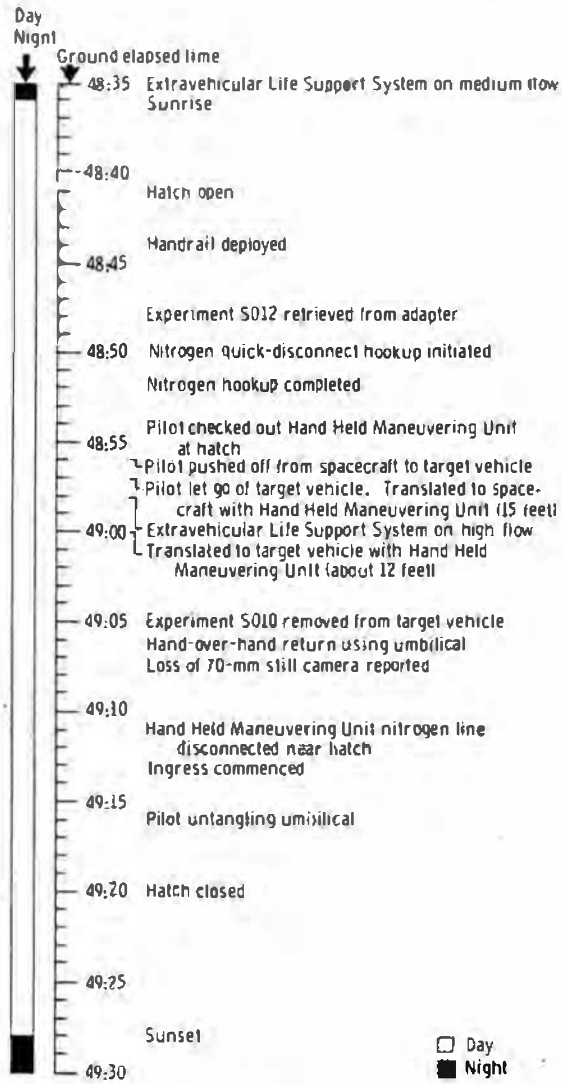


FIGURE 11-9.—Gemini X umbilical extravehicular time line.

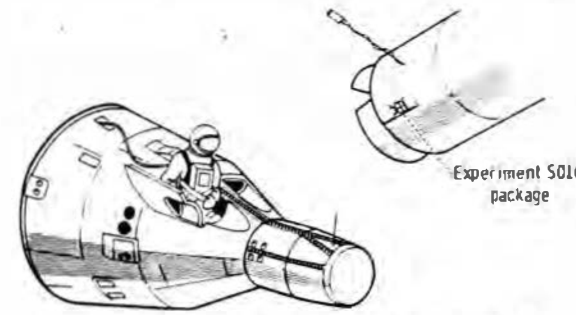


FIGURE 11-10.—Beginning of the Gemini X extravehicular transfer.

pull himself back to the cockpit. At this time, the spacecraft propellant supply had reached the lower limit allotted for the extravehicular activity and the station-keeping operation, and the extravehicular activity was terminated.

During the first attempt to ingress, the pilot became entangled in the 50-foot umbilical. Several minutes of effort were required by both crewmembers to free the pilot from the umbilical so that he could ingress. The hatch was then closed normally. Fifty minutes later the crew again opened the right hatch and jettisoned the Extravehicular Life-Support System, the umbilical, and other miscellaneous equipment not required for the remainder of the mission.

During the umbilical extravehicular activity, the pilot reported the loss of the 70-mm still camera. The camera had been fastened to the Extravehicular Life-Support System with a lanyard, but the attaching screw came loose. It was also discovered that the Experiment S012 Gemini Micrometeorite Collection package had been accidentally thrown out or had drifted out of the hatch. The package had been stowed in a pouch with an elastic top, but appeared to have been knocked free while the 50-foot umbilical was being untangled.

The principal lessons learned from the extravehicular phase of this mission included the following:

(1) Preparation for extravehicular activity was an important task for which the full-time attention of both crewmembers was desirable. Combining a rendezvous with a passive target vehicle and the extravehicular activity preparation caused the crew to be rushed, and did not allow the command pilot to give the pilot as much assistance as had been planned.

(2) The tasks of crew transfer and equipment retrieval from another satellite could be accomplished in a deliberate fashion without excessive workload. Formation flying with another satellite could be accomplished

readily by coordination of thruster operation between the command pilot and the extravehicular pilot.

(3) Equipment not securely tied down was susceptible to drifting away during extravehicular activity, even when precautions were being taken.

(4) The bulk of the 50-foot umbilical was a greater inconvenience than had been anticipated. The stowage during normal flight and the handling during ingress made this length undesirable.

Gemini XI

The prime objectives of the Gemini XI extravehicular activity were to attach a 100-foot tether between the spacecraft and the target vehicle, and to provide a more extensive evaluation of the Hand Held Maneuvering Unit. In addition, several experiments, including ultraviolet photography, were scheduled for standup extravehicular activity. The umbilical extravehicular activity was scheduled for the morning of the second day so that the spacecraft/target-vehicle tether evaluation could be accomplished later in that same day.

The equipment (fig. 11–11) for the Gemini XI extravehicular activity was the same as for the Gemini X mission, except that the dual umbilical was shortened from 50 to 30 feet to reduce the stowage and handling problems. An Apollo sump-tank module was mounted in the spacecraft adapter section, and incorporated two sequence cameras designed for retrieval during extravehicular activity. The Hand Held Maneuvering Unit was also stowed in the adapter section. A molded overshoe type of foot restraint was provided for body restraint while performing tasks in the spacecraft adapter (fig. 11–12).

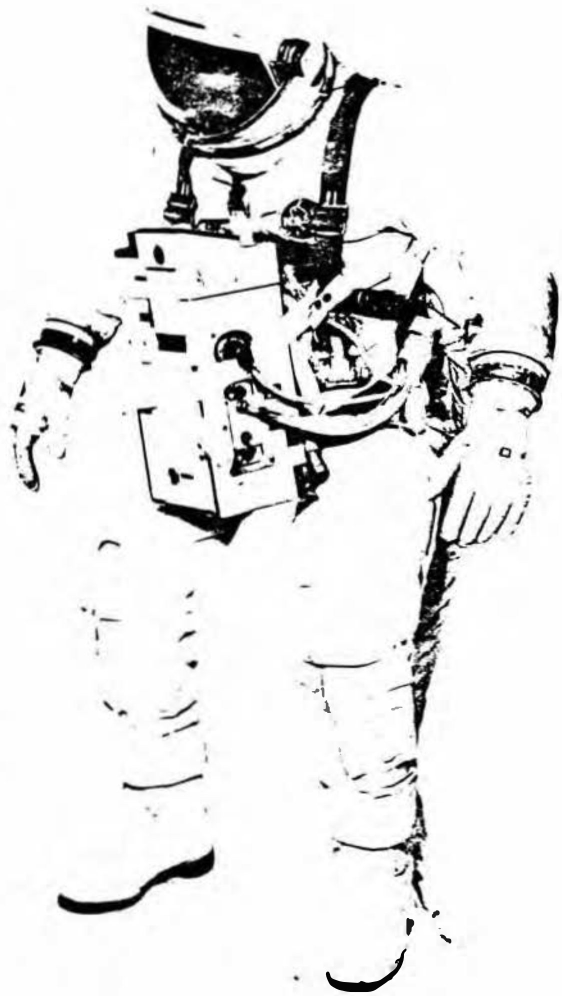


FIGURE 11–11.—Gemini XI extravehicular system.

The Gemini XI umbilical extravehicular activity was initiated at an elapsed flight time of 24 hours 2 minutes. Almost immediately, there were indications of difficulty. The first significant task after egress was to position and secure the external sequence camera. After the camera was secured, the pilot indicated that he was fatigued and out of breath. The pilot then moved to the front of the spacecraft, and assumed a straddle position on the Rendezvous and Recovery Section in preparation for hooking up the spacecraft/target-vehicle tether. While maintaining position and attaching the tether, the pilot expended a high level of effort for several minutes. After returning to the cockpit to rest, the pilot continued to breathe very heavily and was apparently fatigued. In view of the unknown effort required for the re-

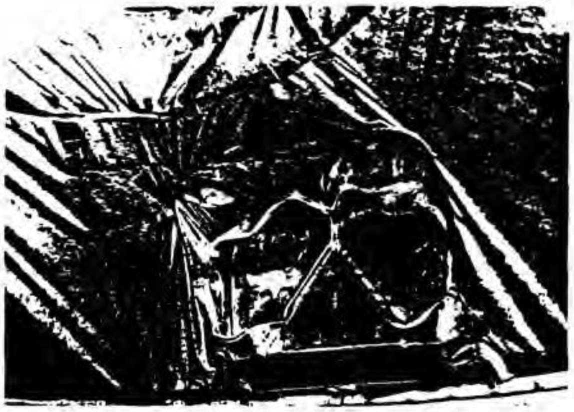


FIGURE 11-12.—Foot restraints installed in the adapter section for Gemini XI and XII missions.

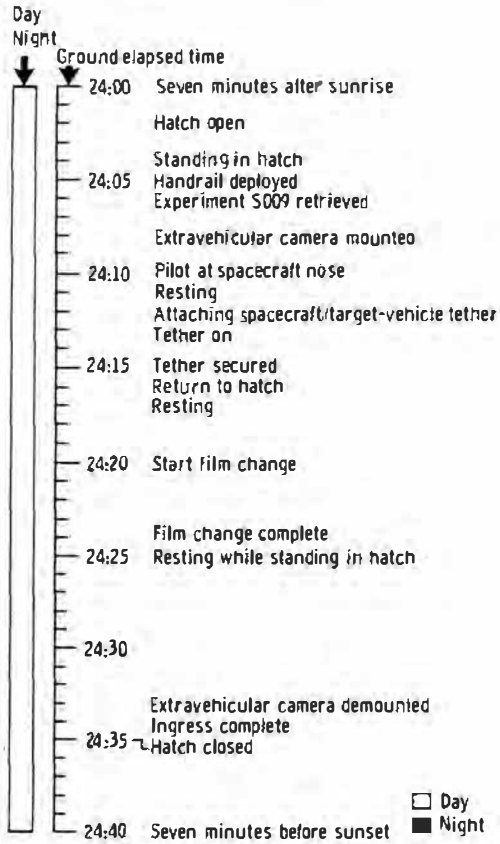


FIGURE 11-13.—Gemini XI umbilical extravehicular time line.

maining tasks, the crew elected to terminate the extravehicular activity prior to the end of the first daylight period. Ingress and hatch closure were readily accomplished. The time line for the umbilical extravehicular activity is shown in figure 11-13.

The Gemini XI standup extravehicular activity was initiated at an elapsed flight time of 46 hours 6 minutes, just prior to sunset. The crew began the ultraviolet stellar photography as soon as practical after sunset, and the photography of star patterns was readily accomplished. The extravehicular pilot operated at a very low work level, since he was well restrained by the standup tether. As in the Gemini X standup extravehicular activity, the crew had little difficulty with the standup tasks. After completing the planned activities (fig. 11-14), the pilot ingressed and closed the hatch without incident.

Discussions with the crew and analysis of the onboard films after the flight revealed several factors which contributed to the high rate of exertion during the umbilical activity and the subsequent exhaustion of the pilot. The factors included the following:

(1) The lack of body restraints required a high level of physical effort to maintain a straddle position on the nose of the spacecraft.

(2) The zero-gravity aircraft simulations had not sufficiently duplicated the extravehicular environment to demonstrate the difficulties of the initial extravehicular tasks.

(3) The requirement to perform a mission-critical task immediately after egress did not allow the pilot an opportunity to become accustomed to the environment. This factor probably caused the pilot to work faster than was desirable.

(4) The high workloads may have resulted in a concentration of carbon dioxide in the space-suit helmet high enough to cause the increased respiration rate and the apparent exhaustion. Although there was no measurement of carbon-dioxide concentration in flight, there was an indication of an increase in concentration at high workloads during testing of the Extravehicular Life-Support System. For workloads far above design lim-

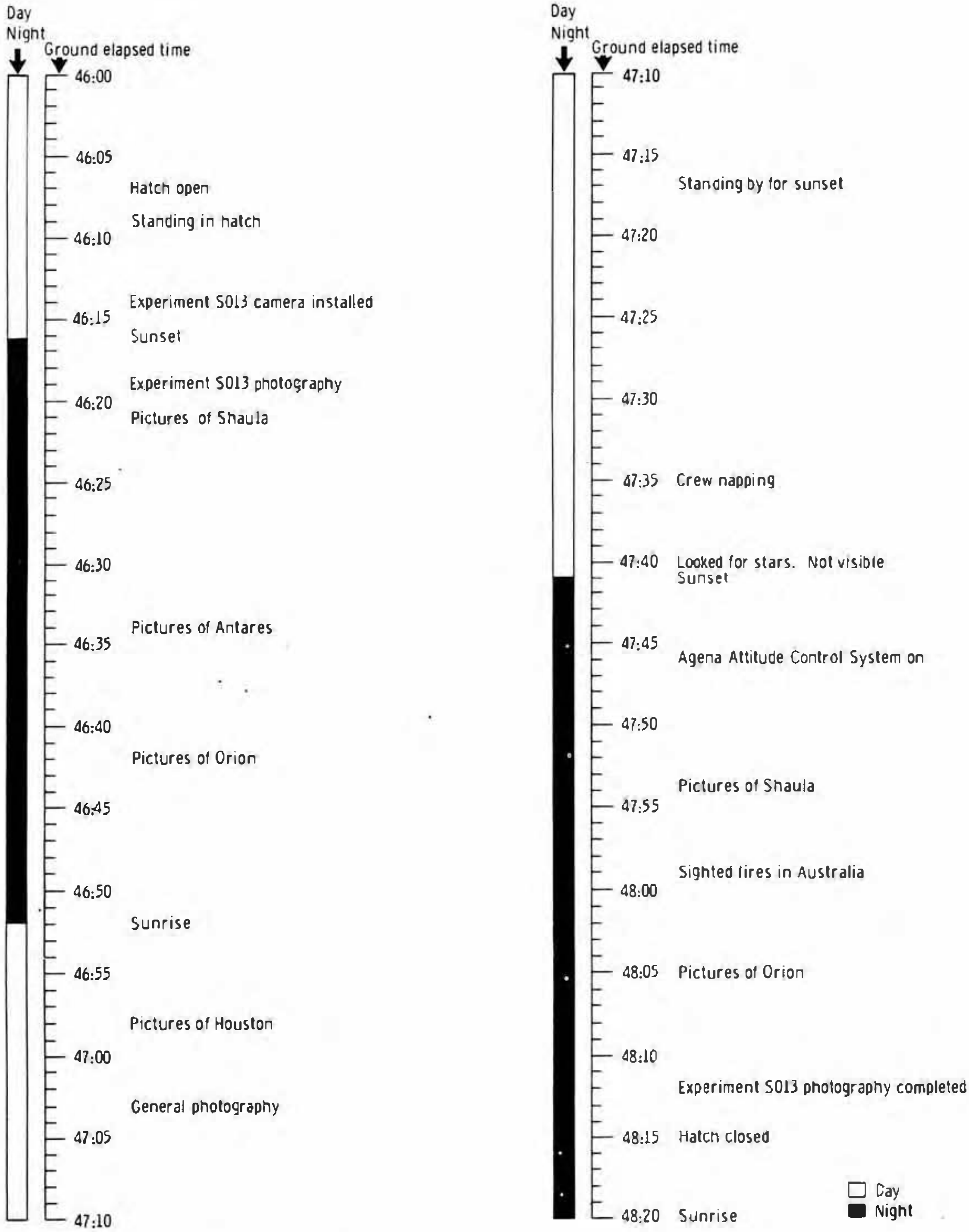


FIGURE 11-14.—Gemini XI standup extravehicular time line.

its, this concentration could reach values that would cause physiological symptoms, including high respiration rates and decreased work tolerances.

Gemini XII

The results of the Gemini XI mission raised significant questions concerning man's ability to perform extravehicular activity satisfactorily with the existing knowledge of the tasks and environment. The Gemini X umbilical activity results had established confidence in the understanding of extravehicular restraints and of workload; however, the Gemini XI results indicated the need for further investigation. The Gemini XII extravehicular activity was then redirected from an evaluation of the Astronaut Maneuvering Unit to an evaluation of body restraints and extravehicular workload. Attachment of the spacecraft/target-vehicle tether and ultraviolet-stellar photography were other objectives. The extravehicular equipment for the Gemini XII mission included a new work station in the spacecraft adapter (fig. 11-15), a new work station on the Target Docking Adapter (fig. 11-16), and several added body restraints and handholds. The pilot's extravehicular equipment (fig. 11-17) was nearly identical to that of Gemini IX-A.

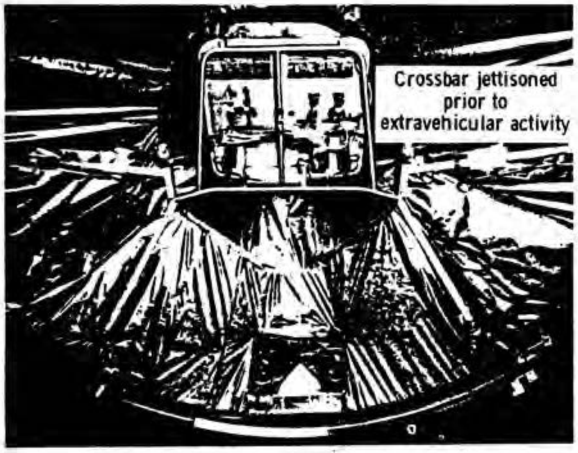


FIGURE 11-15.—Gemini XII adapter provisions for extravehicular activity.

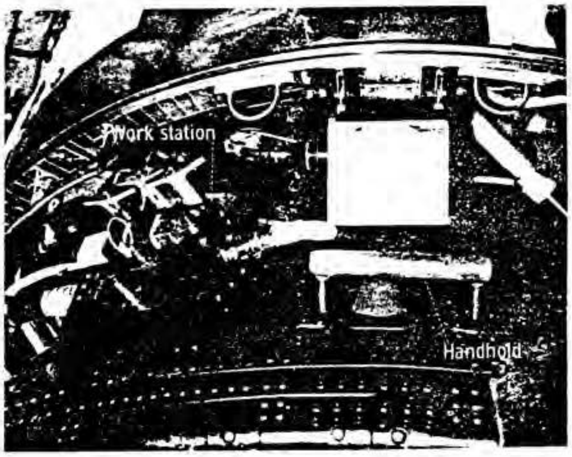


FIGURE 11-16.—Gemini XII extravehicular work station on Target Docking Adapter.

The flight-crew training for the Gemini XII extravehicular activity was expanded to include two periods of intensive underwater simulation and training (fig. 11-18). During these simulations, the pilot followed the intended flight procedures, and duplicated the planned umbilical extravehicular activity on an end-to-end basis. The procedures and times for each event were established, and were used to schedule the final inflight task sequence. The underwater training supplemented extensive ground training and zero-gravity aircraft simulations.

To increase the margin for success and to provide a suitable period of acclimatization to the environment before the performance of any critical tasks, the standup extravehicular activity was scheduled prior to the umbilical activity. The planned extravehicular activity time line was intentionally interspersed with 2-minute rest periods. Procedures were also established for monitoring the heart rate and respiration rate of the extravehicular pilot; the crew were to be advised of any indications of a high rate of exertion before the condition became serious. Finally, the pilot was trained to operate at a moderate work rate, and flight and ground personnel were instructed in the importance of workload control.

The first standup extravehicular activity

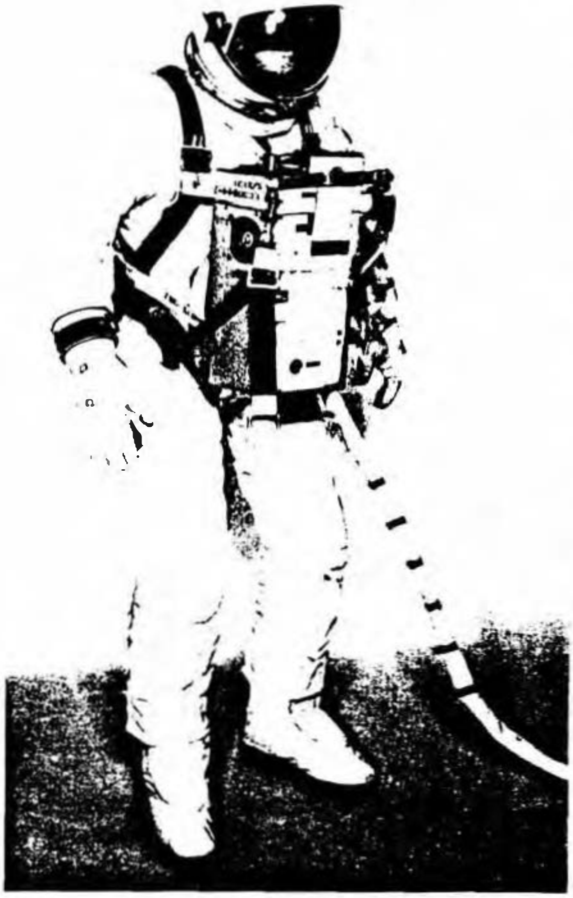


FIGURE 11-17.—Gemini XII extravehicular system.

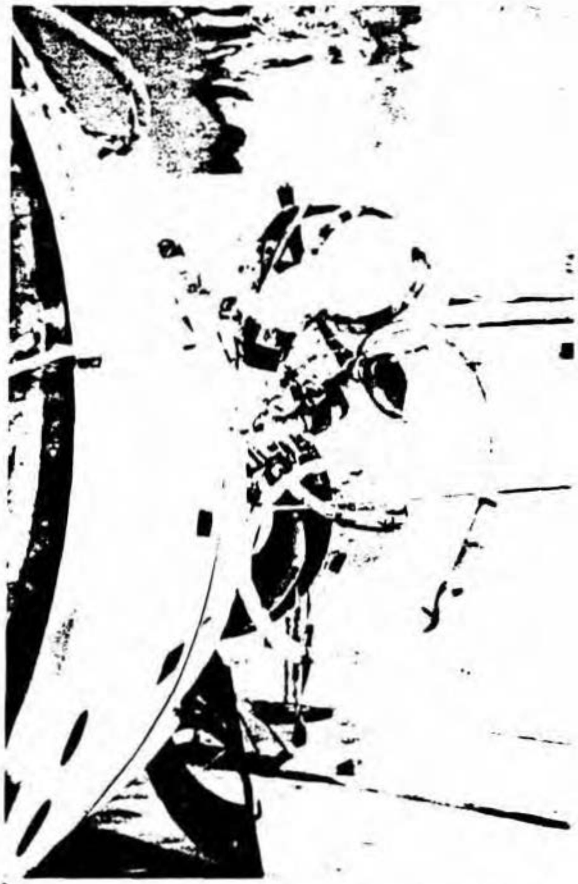


FIGURE 11-18.—Underwater simulation of Gemini XII extravehicular activity.

was very similar to that of the two previous missions. As indicated by the time line in figure 11-19, the ultraviolet stellar and the synoptic terrain photography experiments were accomplished on a routine basis. During the standup activity, the pilot performed several tasks designed for familiarization with the environment and for comparison of the standup and umbilical extravehicular activities. These tasks included mounting the extravehicular sequence camera and installing an extravehicular handrail from the cabin to the docking adapter on the target vehicle. The standup activity was completed without incident.

The umbilical extravehicular activity preparations proceeded smoothly, and the hatch was opened within 2 minutes of the planned time (fig. 11-20). The use of waist tethers during the initial tasks on the Target Docking Adapter enabled the pilot to rest easily, to work without great effort, and to connect the spacecraft/target-vehicle tether in an expeditious manner. In addition, the pilot activated the Experiment S010 Agena Micrometeorite Collection package on the target vehicle for possible future retrieval. Prior to the end of the first daylight period, the pilot moved to the spacecraft adapter where he evaluated the work tasks of torquing bolts, making and breaking electrical and fluid connectors, cutting cables and fluid lines, hooking rings and hooks, and stripping patches of

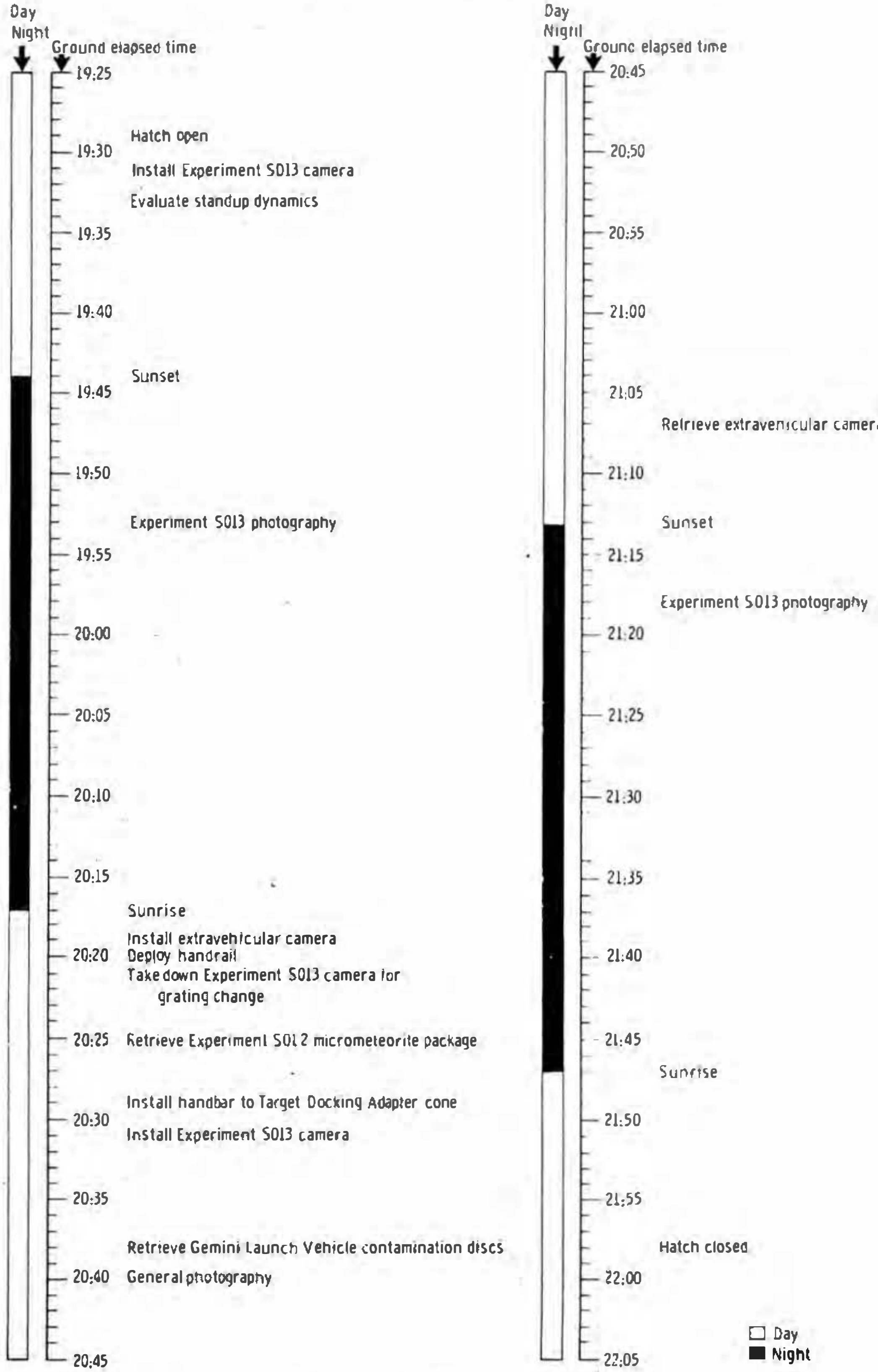


FIGURE 11-19.—Gemini XII first standup extravehicular time line.

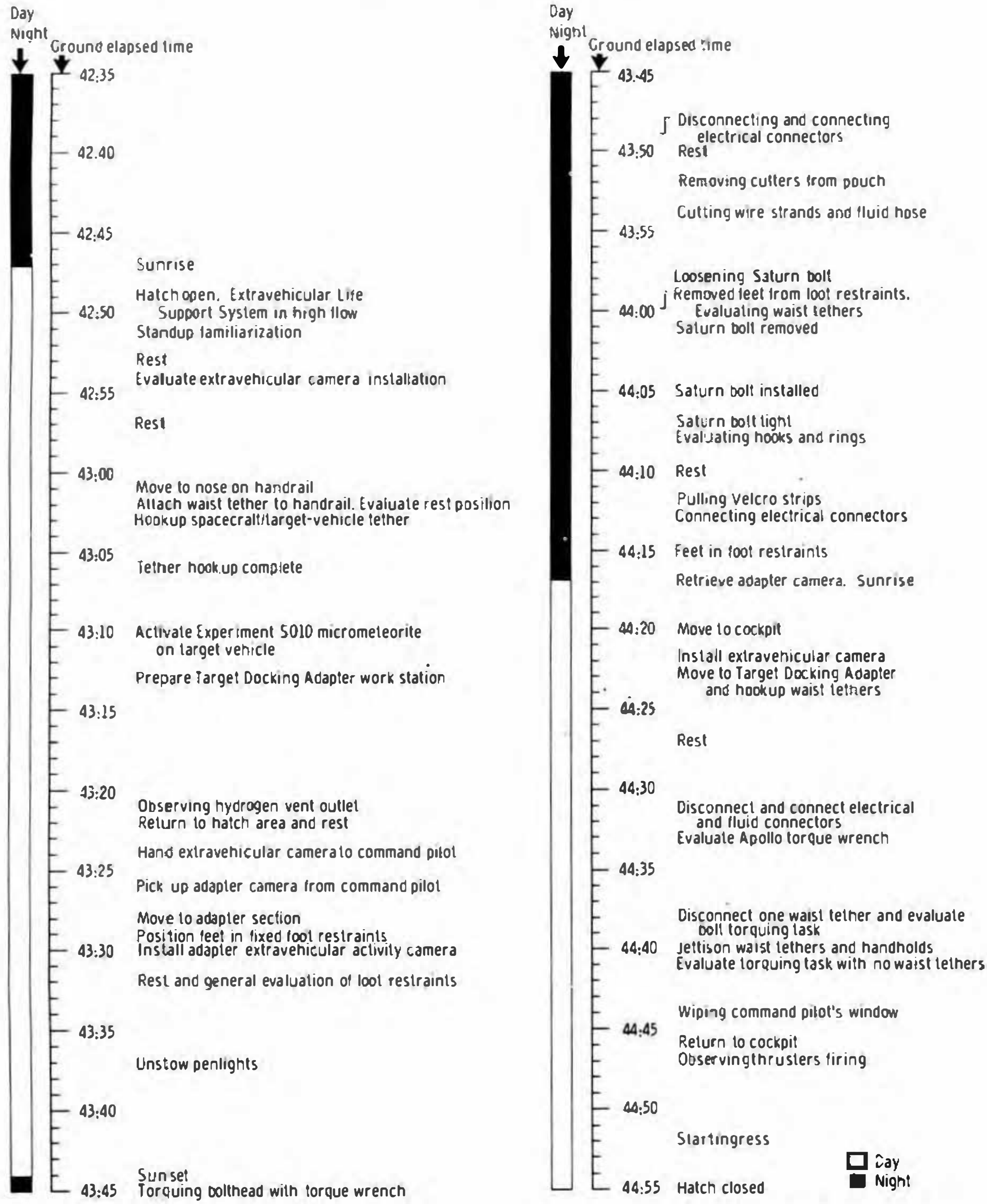


FIGURE 11-20.—Gemini XII umbilical extravehicular time line.

Velcro. The tasks were accomplished using either the two foot restraints or the waist tethers, and both systems of restraint proved satisfactory.

During the second daylight period of the umbilical activity, the pilot returned to the target vehicle and performed tasks at a small work station on the outside of the docking cone. The tasks were similar to those in the spacecraft adapter and, in addition, included an Apollo torque wrench. The pilot further evaluated the use of two waist tethers, one waist tether, and no waist tether. At the end of the scheduled extravehicular activity, the pilot returned to the cabin and ingressed without difficulty.

A second standup extravehicular activity was conducted (fig. 11–21). Again, this activity was routine and without problems. The objectives were accomplished, and all the attempted tasks were satisfactorily completed.

The results of the Gemini XII extravehicular activity showed that all the tasks attempted were feasible when body restraints were used to maintain position. The results also showed that the extravehicular workload could be controlled within desired limits by the application of proper procedures and indoctrination. The final, and perhaps the most significant, result was the confirmation that the underwater simulation duplicated the actual extravehicular environment with a high degree of fidelity. It was concluded that any task which could be accomplished readily in a valid underwater simulation would have a high probability of success during actual extravehicular activity.

Extravehicular Capabilities Demonstrated

In the course of the Gemini missions, a number of capabilities were demonstrated which met or exceeded the original objectives of extravehicular activity. The basic feasibility of extravehicular activity was well established by the 11 hatch openings and the more than 12 hours of operations in the environment outside the spacecraft. The Gemini missions demonstrated the ability to control the extravehicular workload and to maintain the workload within the limits of the life-support system and the capabilities of the pilot. Standup and umbilical extravehicular operations were accomplished during eight

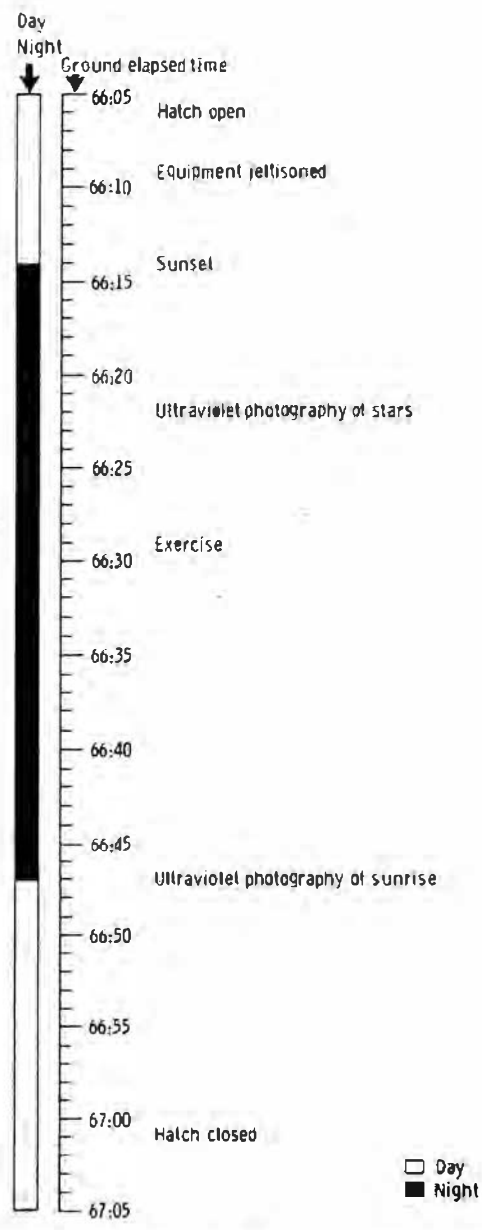


FIGURE 11–21.—Gemini XII second standup extravehicular time line.

separate nighttime periods to confirm the feasibility of extravehicular operations at night.

The need for handholds for transit over the exterior surface of the spacecraft was shown, and the use of several types of fixed and portable handholds and handrails was satisfactorily demonstrated.

The capability to perform tasks of varying complexity was demonstrated. The character of practical tasks was shown, and some of the factors that limit task complexity and difficulty were identified.

Several methods were demonstrated for crew transfer between two space vehicles and include: (1) surface transit while docked, (2) free-floating transit between two undocked vehicles in close proximity, (3) self-propulsion between two undocked vehicles, and (4) tether or umbilical pull-in from one undocked vehicle to another. All of these methods were accomplished within a maximum separation distance of 15 feet.

The Hand Held Maneuvering Unit was evaluated briefly, but successfully, on two different missions. When the maneuvering unit was used, the extravehicular pilots accomplished the maneuvers without feeling disoriented and without loss of control.

Retrieval of equipment from outside the spacecraft was demonstrated on four missions. One equipment retrieval was accomplished from an unstabilized passive target vehicle, which had been in orbit for more than 4 months.

Gemini X demonstrated the capability for the command pilot to maneuver in close proximity to the target vehicle while the pilot was outside the spacecraft. The close-formation flying was successfully accomplished by coordinating the thruster firings of the command pilot with the extravehicular maneuvers of the pilot. No damage nor indication of imminent hazard occurred during the operation.

Photography from outside the spacecraft was accomplished on each extravehicular mission. The most successful examples were the ultraviolet stellar spectral photographs taken during standup extravehicular activities on three missions and the extravehicular sequence photographs taken with the camera mounted outside the spacecraft cabin.

The dynamics of motion on a short tether were evaluated on two missions. The only tether capability that was demonstrated was for use as a distance-limiting device.

The requirements for body restraints were established, and the capabilities of foot restraints and waist tethers were demonstrated in considerable detail. The validity of underwater simulation in solving body restraint problems and in assessing workloads was demonstrated in flight and further confirmed by postflight evaluation.

In summary, the Gemini missions demonstrated the basic techniques required for the productive use of extravehicular activity. Problem areas were defined sufficiently to indicate the preferred equipment and procedures for extravehicular activity in future space programs.

Extravehicular Limitations and Solutions

While most of the Gemini extravehicular activities were successful, several areas of significant limitations were encountered. Space-suit mobility restrictions constituted one basic limitation which affected all the mission results. The excellent physical capabilities and conditions of the flight crews tended to obscure the fact that moving around in the Gemini space suit was a significant work task. Since the suit design had already been established for the flight phase of the Gemini Program, the principal solution was to optimize the tasks and body restraints to be compatible with the space suits. For the 2-hour extravehicular missions, glove mobility and hand fatigue were limiting factors, both in training and in flight.

The size and location of the Extravehicular Life-Support System chest pack was a constant encumbrance to the crews. This design was selected because of space limitations within the spacecraft, and the crews were continually hampered by the bulk of the chest-mounted system.

The use of gaseous oxygen as the coolant medium in the space suit and Extravehicular Life-Support System was a limiting factor in the rejection of metabolic heat and in pilot comfort. The use of a gaseous system required the evaporation of perspiration as a cooling mechanism. At high workloads, heavy perspiration and high humidity within the suit were certain to occur. These factors were evident on the missions where the workloads exceeded the planned values. As in the case of suit mobility, the cooling system design was fixed for the Gemini Program; hence, any corrective action had to be in the area of controlling the workload.

Work levels and metabolic rates could not be measured in flight; however, the flight results indicated that the design limits were probably exceeded several times. Inflight work levels were controlled by providing additional body restraints, allowing a generous amount of time for each task, and establishing programed rest periods between tasks. These steps, coupled with the underwater simulations techniques, enabled the Gemini XII pilot to control the workload well within the design limits of the Extravehicular Life-Support System.

The Gemini XI results emphasized the limitations of the zero-gravity aircraft simulations and of ground training without weightless simulation. These media were useful but incomplete in simulating all extravehicular tasks. The use of underwater simulation for development of procedures and for crew training proved effective for Gemini XII.

The sequence in which extravehicular events were scheduled seemed to correlate with the ease of accomplishment. There appeared to be a period of acclimatization to the extravehicular environment. The pilots who first completed a standup extravehicular activity seemed more at ease during the umbilical activity; therefore, it appears that critical extravehicular tasks should not be scheduled until the pilot has had an opportunity to familiarize himself with the environment.

Equipment retention during extravehicular activity was a problem for all items which were not tied down or securely fastened. By extensive use of equipment lanyards, the loss of equipment was avoided during the last two missions.

Concluding Remarks

The results of the Gemini extravehicular activity led to the following conclusions:

(1) Extravehicular operation in free space is feasible and useful for productive tasks if adequate attention is given to body restraints, task sequence, workload control, realistic simulations, and proper training. Extravehicular activity should be considered for use in future missions where a specific need exists, and where the activity will provide a significant contribution to science or manned space flight.

(2) Space-suit mobility restrictions were significant limiting factors in the tasks which could be accomplished in Gemini extravehicular activity. For future applications, priority efforts should be given to improving the mobility of space suits, especially arm and glove mobility.

(3) The Extravehicular Life-Support System performed satisfactorily on all Gemini missions. The necessity for a chest-mounted location caused some encumbrance to the extravehicular pilots. The use of gaseous cooling is undesirable forthe increased workloads which may be encountered in future extravehicular activity.

(4) Underwater simulation provides a high-fidelity duplication of the extravehicular environment, and is effective for procedures development and crew training. There is strong evidence indicating that tasks which can be readily accomplished in a valid underwater simulation can also be accomplished in orbit. Underwater simulation should be used for procedures development and crew training for future extravehicular missions.

(5) Loose equipment must be tied down at all times during extravehicular activity to avoid loss.

(6) The Hand Held Maneuvering Unit is promising as a personal transportation device in free space; however, the evaluations to date have been too brief to define the full capabilities or limitations of this equipment. Further evaluations in orbital flight should be conducted.

(7) The Gemini Program has provided a foundation of technical and operational knowledge on which to base future extravehicular activity in subsequent programs.

OPERATIONAL EXPERIENCE

12. RADIATION ENVIRONMENT AT HIGH ORBITAL ALTITUDES

By PETER W. HIGGINS, *Space Physics Division, Science and Applications Directorate, NASA Manned Spacecraft Center;* JOSEPH C. LILL, *Space Physics Division, Science and Applications Directorate, NASA Manned Spacecraft Center;* and TIMOTHY T. WHITE, *Space Physics Division, Science and Applications Directorate, NASA Manned Spacecraft Center*

Introduction

The Gemini X and XI space flights were highlighted by high-altitude apogees achieved by firing the Primary Propulsion System of the Gemini Agena Target Vehicle. In both flights, the docked spacecraft/target-vehicle combinations were carried much higher into the Van Allen trapped radiation belt than ever before in manned space flight.

This paper deals with the radiation environment at these altitudes and the effect of the environment on the two missions. An attempt will be made to describe the premission radiation planning for the flights, the inflight radiation measurements, the results of the postflight data analysis, and the preliminary conclusions.

Mission Planning Radiation Analysis

Environment Model

The radiation environment at the altitudes under consideration was previously mapped by unmanned satellites. The environment is composed of electrons and protons trapped in the Earth's magnetic field. Figure 12–1 shows the electron distribution. A large portion of the electrons were injected into space by a high-altitude nuclear test conducted by the United States in July 1962. These electrons augmented the natural electrons by several orders of magnitude and produced a dangerous radiation environment in near-Earth space. It has been observed that, fortunately, the intensity of these artificially injected electrons has been decaying. The decay follows the relationship

$$e^{-\Delta t/\tau} \qquad (1)$$

where Δt is the elapsed time in days from the test, and τ is the decay parameter. The energy of these trapped electrons ranges from several thousand to several million electron volts, but with a fast dropoff in intensity with energy. The electrons are especially hazardous to lightly shielded spacecraft.

Figure 12–2 shows the spacial distribution of protons. These protons result from natural causes and seem to remain relatively constant in intensity with time. The energy of the protons ranges from a few thousand electron volts to hundreds of million electron volts.

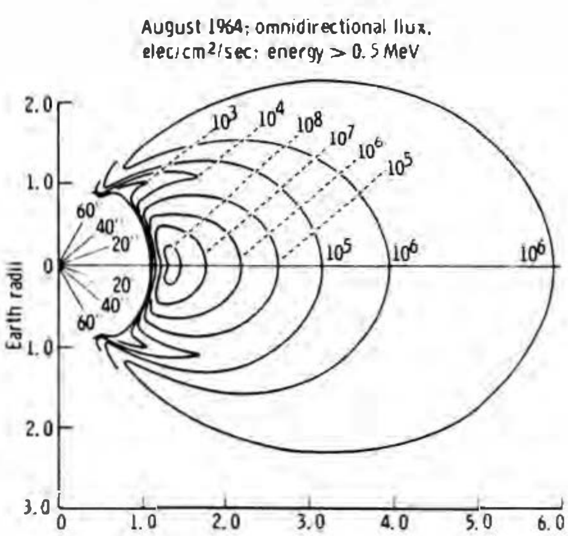


FIGURE 12–1.—Electron distribution in the Earth's field.

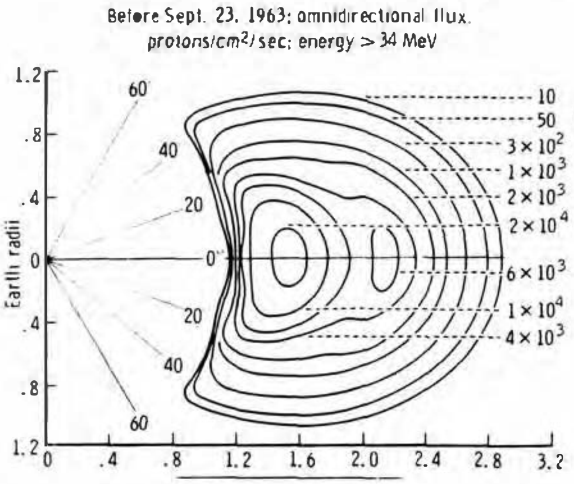


FIGURE 12-2.—Proton distribution in the Earth's field.

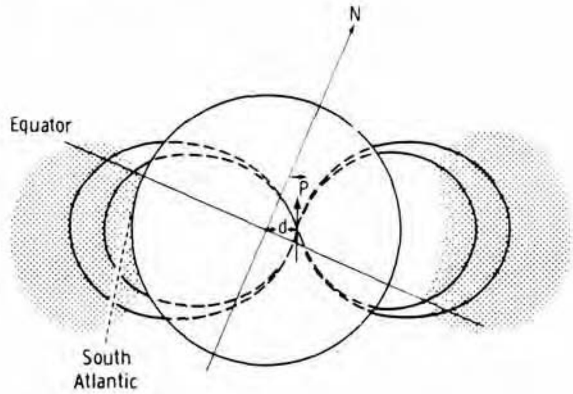


FIGURE 12-3.—South Atlantic anomaly diagram.

The higher energy protons are quite penetrating and would contribute a radiation within almost any spacecraft.

Electron and proton intensities and spectra for near-Earth space have been carefully analyzed and all of the recent satellite data have been assembled into an environmental model (refs. 1 and 2). Since the electrons are time dependent, the environment was presented as that which would have existed in August 1964. With the use of equation (1), this environment can be modified to apply to other times.

South Atlantic Anomaly

Although the spacial distribution of the trapped radiation is generally symmetrical in azimuth, the exception to this is quite important at lower altitudes. It should be recalled that the magnetic field of the Earth is approximately that which may be described by a dipole magnet at the center of the Earth (fig. 12-3). Actually, this idealized dipole magnet is both displaced from and tilted with respect to the rotational axis of the Earth. Because of the displacement of the imaginary dipole location, a region of trapped radiation (indicated by dots in fig. 12-3) is closer to the Earth's surface on one side. In addition, the tilt of the dipole rotates the region of close approach southward from the equator to the general vicinity of the South Atlantic. Since the Earth's magnetic field rotates with the Earth, the region remains in this location, and has been named the "South Atlantic anomaly." In this location, the radiation belt extends to the top of the atmosphere. Figure 12-4 shows the South Atlantic anomaly as viewed on a constant altitude contour of 160 nautical miles.

The radiation fluxes and associated spectra of the trapped electrons and protons in the South Atlantic anomaly have been measured by the following experiments flown aboard several Gemini flights:

Experiment no.	Subject	Mission
M404	Proton-electron spectrometer	IV, VII
M405	Tri-axis magnetometer	IV, VII, X, XII
M408	Beta spectrometer	X, XII
M409	Bremsstrahlung spectrometer	X, XII

These experiments measured the exterior spacecraft radiation environment during all four flights and the interior cabin radiation environment during Gemini X and XII. The preliminary results of these experiments produced a valuable description of the radiation levels in the South Atlantic anomaly at Gemini altitudes. At these altitudes the previous

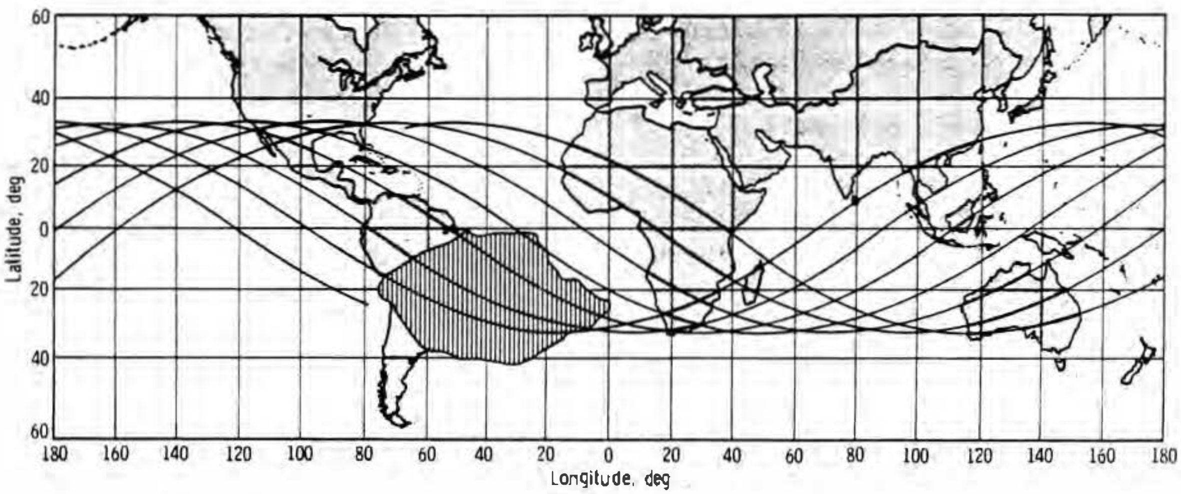


FIGURE 12-4.—Location of radiation fluxes in the South Atlantic anomaly for 160-nautical-mile altitude, 28.5° orbital ground track.

satellite model environments relied on very limited data and were consequently inaccurate.

The experiment results obtained during Gemini IV and VII were used in the premission planning of the Gemini X and XI flights to define a realistic time rate of artificial electron belt decay.

Radiation-Dose Calculations

Radiation-dose calculations are made by determining the radiation environment within the spacecraft and its resultant effect on the crew. The exterior environment, the attenuation by the spacecraft, and the response of the body to the radiation must all be considered in the calculations. In practice, the calculation of radiation dose is performed at intervals along the spacecraft trajectory and then summed to express a total dose.

A precise calculation of radiation dose received by a crewman is prohibited by the uncertain factors in the calculations. The definition of the radiation environment used is estimated to represent the actual environment only to within a factor of 2 or 3 when the variations of particle flux, energy, and direction of motion are considered. In addition, the description of the shielding about a point on the body of a crewman introduces another error factor into the calculations. In the case in point, the shielding attenuation produced by the Gemini spacecraft, the shielding geometry is quite complex. The shielding description resulting from an examination of the Gemini spacecraft mechanical drawings is estimated to be accurate only to within a factor of 2 in the subsequent calculation of radiation dose within. Finally, after assumption of an environment and the attenuation of the environment by the spacecraft shielding, a probable error results in the calculation of a tissue dose to a crewmember. The error arises from the uncertainty that as an individual proton or electron progresses into the human body, it will deposit its energy in a certain volume of the tissue, and from the uncertainty that the tissue will respond in a precise biological way to the dose. The conversion from flux at the dose point to dose in the Gemini calculations is also estimated to be accurate to within a factor of 2 or 3.

The uncertainties just described rarely add at the same point in the calculation. Instead, each uncertainty may be treated as a mathematical distribution with the factor mentioned as a deviation from the mean. In any one calculation for an individual particle, the resultant error approximates a random sampling from each of the three distributions. In the end, all the uncertainties mentioned combine to produce an uncertainty factor of about 3 in the published dose.

In figure 12–5, the preflight estimate of the radiation dose per revolution is a function of orbital position for a 160-nautical-mile circular orbit. The dashed curve represents the dose using the August 1964 model without consideration of decay; the solid line shows the dose decayed to time of flight. The orbits are identified by a symbol which is used again to denote the dose per revolution for each revolution. The effect of the South Atlantic anomaly is clearly indicated. At this altitude, virtually all of the radiation dose is received during the six orbits passing through the anomaly.

The preflight estimate of the radiation dose per revolution is shown in figure 12–6 for the Gemini X high-altitude orbits. The dose as of August 1964 and the dose decayed to the time of flight are plotted. Figure 12–6 illustrates the dramatic increase in dose due to achieving high altitudes in the anomaly. In this case, the decayed dose increased by a factor of up to 50 in comparable revolutions; however, the Gemini X projected dose was within the allowable radiation limits for space flight.

The predicted dose for the two-revolution high-altitude portion of the Gemini XI mission was less than 1 millirad, and indicated that the Gemini XI high-altitude passes would subject the flight crew to an insignificant amount of radiation. This seemed reasonable since the Gemini XI flight would achieve apogee away from the anomaly, but not high enough to penetrate the intense regions of trapped radiation.

Protection of S009 Experiment Package

The high-altitude excursion of Gemini XI was not expected to pose a crew safety problem since the radiation doses were anticipated to be very low; however, the exterior flux of protons at these high altitudes presented a threat to an important onboard experiment package. The package was the Goddard Space Flight Center/Naval Research Laboratories cosmic-ray detector designated as scientific Experiment S009, Nuclear Emulsions. If the experiment were successful, an unshielded, time-differentiated, nuclear emulsion would be exposed at several magnetic latitudes out-

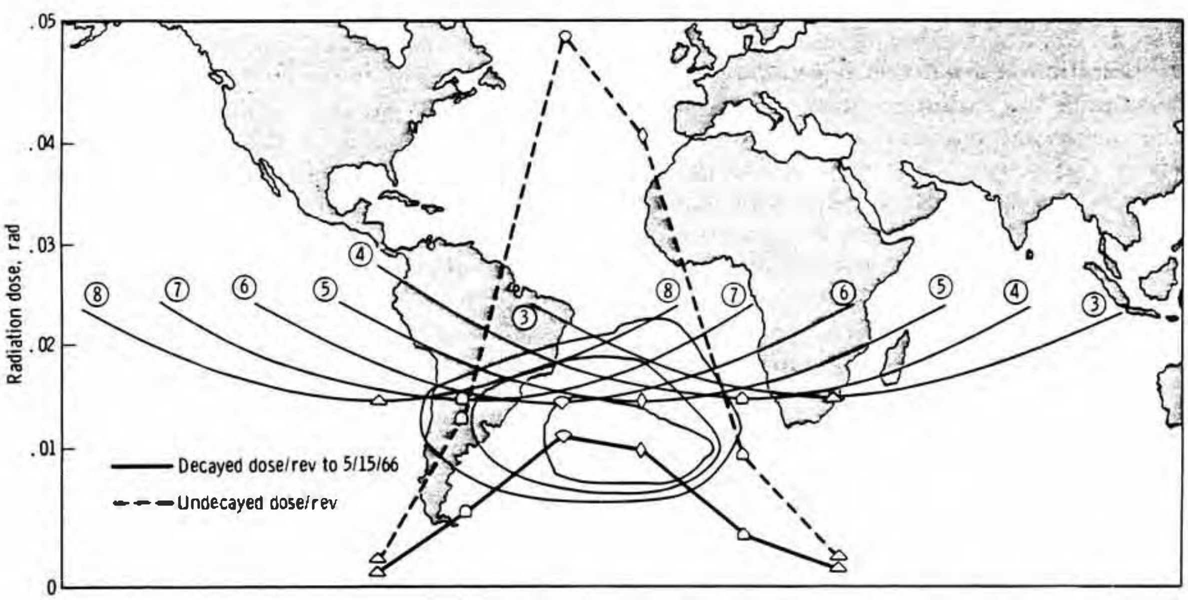


FIGURE 12–5.—Variation in radiation dose in South Atlantic anomaly. Circular orbit, 160 nautical miles.

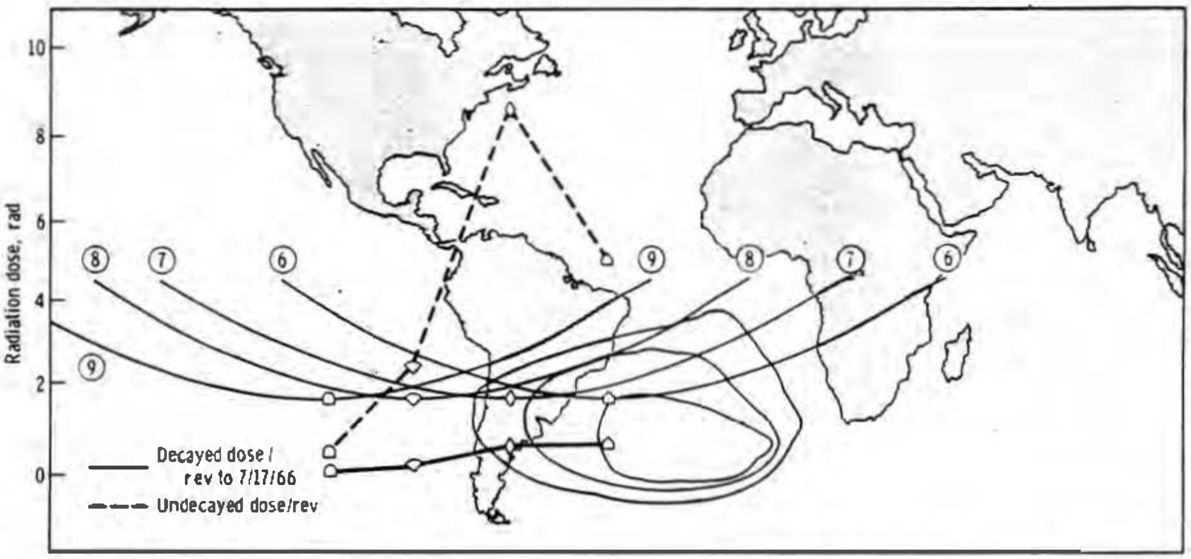


FIGURE 12–6.—Variation in radiation dose in the South Atlantic anomaly for Gemini X. Orbit, 160 by 400 nautical miles.

side the Earth's atmosphere for the first time. Subsequent identification of the cosmic rays recorded in the emulsions was considered of prime scientific importance in determining the composition of cosmic rays. Therefore, it was considered imperative that the high-altitude excursion of Gemini XI not jeopardize the success of this experiment by exposure to the higher fluxes of Van Allen belt protons (fig. 12–2) present at the higher altitudes. These protons could have rapidly ruined the emulsion in the experiment by producing an intense background from which the characteristic cosmic-ray tracks could not have been distinguished.

In establishing the flight plan for Gemini XI, many possible locations for firing the target-vehicle Primary Propulsion System to achieve the high-altitude orbits were examined for potential proton exposure. The high-altitude damage threshold of the Experiment S009 package was established as 2×10^5 proton/cm^2 within the emulsion. Upon examination, most of the possible locations for initiating the firing had to be discarded. The result of this analysis showed that initiating the high-altitude maneuver over the Canary Islands (so that the apogee would be achieved in the Southern Hemisphere over Australia) satisfied the minimum proton flux condition and the flight-plan constraints. The numerical results of this analysis are indicated in figure 12–7. A third revolution was considered as a safety factor, in the event that descent to a lower altitude had to be postponed for one revolution.

The electrons were not expected to produce a background in the emulsion because the experiment package, located on the exterior surface of the spacecraft adapter, was to be retrieved by the extravehicular pilot and placed in the crew station footwell before the high-apogee orbits. The relatively heavy shielding provided by the footwell would screen the lightly penetrating electrons, but would not completely attenuate the protons.

Inflight Measurements

During the Gemini X and XI missions, an active radiation dosimeter was utilized to enhance flight safety by providing a real-time measurement of the radiation-dose and dose rate, and to take advantage of the high-altitude portion of the flight to obtain valuable radiation data. This instrument (fig.

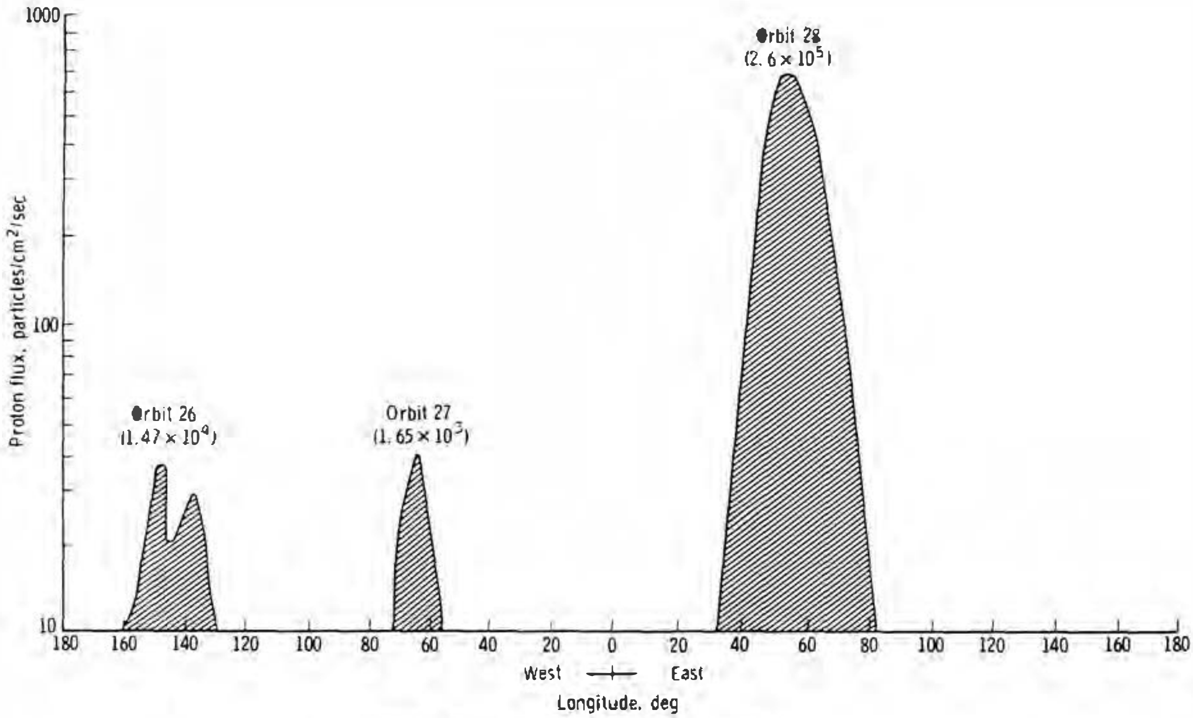


FIGURE 12-7.—Proton flux for Gemini XI

12-8), which was designated the Gemini Radiation Monitoring System, was designed, developed, and fabricated at the Manned Spacecraft Center especially for these flights. The Gemini Radiation Monitoring System consisted of two separate dosimeters sharing the same package. Each dosimeter had an ion chamber, electronics, and batteries. One dosimeter sensed the dose rate between 0.1 and 100 rads hr and the reading was indicated on the large meter face. The other dosimeter was an integrating sensor that accumulated the dose in rads with time. This reading was indicated on the small register and ranged from 0.01 to 99.99 rads. The switch in the center was used to snub the dose-rate meter needle to prevent launch vibration damage to the delicate meter movement. The readings from the Gemini Radiation Monitoring System approximated the skin dose at the location of the instrument. No direct measurement of the depth dose was made in real time.

FIGURE 12-8.—Gemini Radiation Monitoring System.

During the two high-altitude flights, the Gemini Radiation Monitoring System was stowed aboard the spacecraft until shortly before the maneuver for attaining the high-apogee orbits. After the Gemini Radiation Monitoring System was unstowed, it was placed at head height between the crewmen on the Gemini X mission, and was affixed to the inside of the left hatch on the Gemini XI mission. In either case, the instrument was read before the high-altitude excursion in order to establish a baseline reading. Subsequent readings were made near the high apogees, and the dose values were reported to the ground flight controllers. Table 12–I presents the inflight crew radiation reports of the readings from the Gemini Radiation Monitoring System. In neither mission did the readings have any influence on the flight, since the reported values were well below the preplanned mission allowable dose limits.

Passive dosimeters have been worn by crewmembers on all manned Gemini flights. The passive dosimeters were packaged in plastic (fig. 12–9) and contained: thermal luminescent powder which, when heated, radiates visible light proportionate to the radiation absorbed; and various nuclear emulsions which, under microscopic analysis, determine the extent of radiation exposure. The measured doses approximated a normal skin dose at the location of the dosimeter. A summary of the measurements for all manned Gemini flights is provided in table 12–II.

TABLE 12–I.—*Summary of Gemini Radiation Monitoring System Readings*

Mission	Greenwich mean time, hr:min	Ground elapsed time, hr:min	Reading network station	Dose, rad
X	3:34	6:54	*Rose Knot Victor*	0.00
	4:49	8:09	*Rose Knot Victor*	.04
	4:59	8:20	*Rose Knot Victor*	.18
	5:17	8:37	Tananarive	.23
	14:53	18:14		.78
	Postflight			.91
XI	19:49	29:09	*Rose Knot Victor*	.00
	7:52	41:14	Carnarvon	.02
	10:02	43:23	Carnarvon	.02
	Postflight			.03 (After background removed)

FIGURE 12–9.—Gemini passive dosimeter.

Postflight Analysis of Radiation Data

The Gemini IX–A readings (table 12–III) are representative of Gemini missions not attaining the high altitude. The table contrasts the increase in dose due to the Gemini X high-altitude passes through the South Atlantic anomaly with the negligible doses received on Gemini XI after a much higher

TABLE 12–II.—*Passive Dosimeter Results for Gemini Manned Flights*

Mission	Duration of mission	Dose to left chest of command pilot, rad
III	3 revolutions	0.020
IV	4 days	.040
V	8 days	.190
VI-A	1 day	.025
VII	14 days	.192
VIII	11 hours	All dosimeters read less than 0.010
IX-A	3 days	.018
X	3 days	.770
XI	3 days	.025
XII	4 days	.015

altitude flight opposite the anomaly in the Southern Hemisphere.

Figure 12–10 is a comparison of Gemini X inflight readings from the Gemini Radiation Monitoring System with the decayed and undecayed calculational model. The dose readings were made by the crew during the first and seventh high-altitude revolutions. The readings in the first revolution established that the environment at that altitude would not endanger the mission, and the crew was advised to begin a sleep period. After awakening, the crew reported the reading for the seventh revolution. Because of the lack of data, it is difficult to reach any definite conclusion based upon the relationships shown in figure 12–10.

The proton environment calculated for the high-altitude orbits of Gemini XI could not be confirmed by inflight measurements. The proton spectrometer data required for this comparison were not obtained on the Gemini XI flight. However, the Experiment S009 package indicated that the background of protons in the emulsion was within tolerance limits.

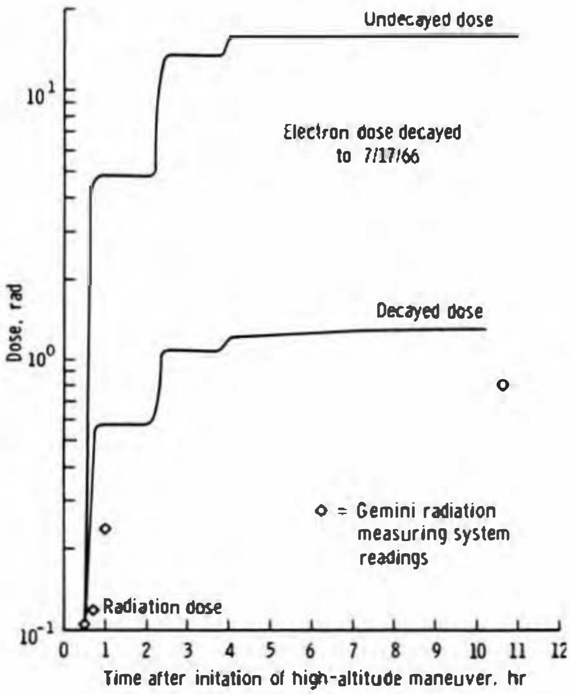


FIGURE 12–10.—Comparison of the Gemini X Radiation Monitoring System readings and the calculation model.

TABLE 12–III.—*Accumulated Radiation-Dose Comparisons*

Mission	Calculated		Measured	
	Aug. 1964 estimate, rad	Decayed estimate, rad	Passive dosimeter, rad	Gemini Radiation Monitoring System, rad
IX-A[a]	0.30	0.090	0.018	Not applicable
X[b]	17.3	1.4	.770	0.910
XI[c]	.303	.091	.025	.030

[a] Readings based upon 161-n.-mi. circular orbit for 3 days.
[b] Readings based upon 161- by 400-n.-mi. orbit for 12 hours, and 161-n.-mi. circular orbit for 2½ days.
[c] Readings based upon 161- by 750-n.-mi. orbit for 3⅓ hours, and 161-n.-mi. circular orbit for 2½ days.

Conclusions

One of the most important results of the high-altitude flights of Gemini X and XI is that manned space flight at higher altitudes is possible with a minimum of radiation dose. This is due to the confirmed continuing decay of the artificially injected electrons and to careful planning of the trajectory. Extravehicular activity, for example, would be possible during many high-altitude orbits if not performed while the spacecraft is passing through the South Atlantic anomaly.

Gemini X demonstrated the effect of the South Atlantic anomaly on the rapidly increasing dose rate at the higher altitudes of approximately 400 nautical miles. On the other hand, Gemini XI attained the highest apogee, 742 nautical miles, over Australia and was still free from significant radiation doses.

Another important result is the reasonable amount of agreement between the preflight calculations and the measured values of radiation dose. The differences are explained when the uncertainties of making these calculations are considered. It is anticipated that the shielding breakdown description for the Apollo missions will be more accurate than the description used for Gemini. An operational environment sensor is to be included on the Apollo missions; consequently, the radiation calculation should agree more closely with the measured values. As a result, greater confidence is provided for further exploration of the relatively unknown radiation environment in space.

References

1. VETTE, JAMES I.: Models of the Trapped Radiation Environment. Vol. I: Inner Zone Protons and Electrons. NASA SP-3024, 1966.
2. VETTE, JAMES I.; LUCERO, ANTONIO B.; and WRIGHT, JON A.: Models of the Trapped Radiation Environment. Vol. II: Inner and Outer Zone Electrons. NASA SP-3024, 1966.

13. CONTROLLED REENTRY

By DAVID M. BOX, *Mission Planning and Analysis Division, NASA Manned Spacecraft Center;* JON C. HARPOLD, *Mission Planning and Analysis Division, NASA Manned Spacecraft Center;* STEVEN G. PADDOCK, *Dynamics Engineer, McDonnell Aircraft Corp.;* NEIL A. ARMSTRONG, *Astronaut, Astronaut Office, NASA Manned Spacecraft Center; and* WILLIAM H. HAMBY, *Office of Spacecraft Management, Gemini Program Office, NASA Manned Spacecraft Center*

Summary

One of the primary objectives of the Gemini Program has been successfully achieved, that of controlling the landing point by modulating the direction of the inherent lift vector of the spacecraft during reentry. The program has utilized two reentry guidance techniques which provided steering commands based upon a logical assessment of current and predicted energy conditions. This paper presents a brief description of these two sets of reentry guidance logic, and a detailed description of the results obtained from each Gemini spacecraft reentry. During the Gemini Program, successful landing-point control has been accomplished from Earth orbits varying from an apogee/perigee of 110 by 45 nautical miles to an apogee/perigee of 215 by 161 nautical miles. The Gemini spacecraft has been flown with an average lift-to-drag ratio of approximately 0.19. This has resulted in an average reentry maneuver capability of 300 nautical miles downrange and ±27 nautical miles crossrange. The average footprint shift due to the retrofire maneuver has been 25 nautical miles, and the average navigation accuracy has been 2.2 nautical miles.

Introduction

One of the major objectives of the Gemini Program was to demonstrate accurate touchdown-point control through the use of trajectory-shaping techniques during reentry. This trajectory control was used to compensate for dispersions caused by unpredicted retrofire maneuvers, by atmospheric variations, and by uncertainties in the aerodynamic characteristics of the spacecraft. Further, trajectory control greatly minimized the recovery task for emergency reentries such as occurred on Gemini VIII.

This paper describes the results of the reentry phase of each Gemini mission. However, a brief review of the aerodynamic characteristics of the spacecraft and the guidance logic used during Gemini will be helpful in understanding the reentry results of each flight.

Aerodynamic Characteristics

Aerodynamic lift is established on a symmetrical body, such as the Gemini vehicle, by placing the center of gravity so that the resultant trim angle of attack provides the desired lift characteristics. To maintain the least amount of aerodynamic heating on the spacecraft hatches and windows during reentry, the spacecraft was flown inverted with the center-of-gravity offset toward the pilots' feet (fig. 13-1). In this inverted position, the spacecraft was rolled to the bank angle required to utilize the lift vector for downrange and lateral range-control capability. The range control, or touchdown footprint, provided with the Gemini reentry center of gravity was approximately 300 nautical miles down range and 50 nautical miles lateral range. When the maximum range was desired, the spacecraft maintained a heads-down or zero-degree bank angle (fig. 13-1).

Preceding page blank

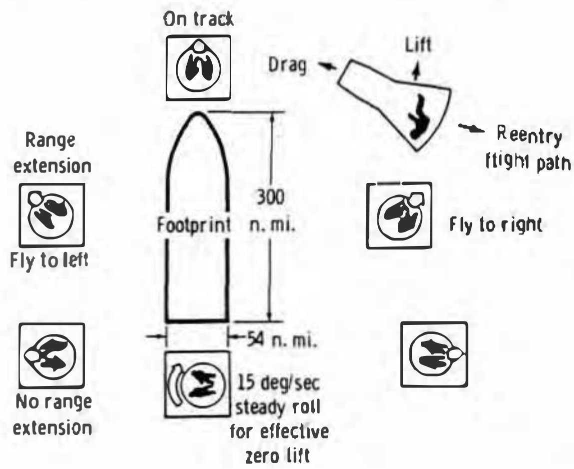


FIGURE 13-1.—Reentry control concepts.

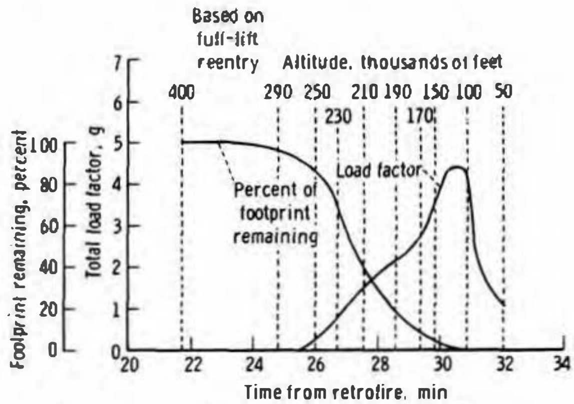


FIGURE 13-2.—Reentry maneuver capability as a function of elapsed time from retrofire.

Minimum range was obtained with either a 90° bank angle or a rolling reentry to null the effects of the lifting force.

The responsiveness of the spacecraft to the required maneuvers for accurate touchdown on the target point was dependent upon the static and dynamic stability of the spacecraft in the reentry region where the range-control capability was most significant. When a stable vehicle was not provided, the correct bank angle could not adequately be maintained for the correct response, and thereby created touchdown errors. The most significant amount of range-control capability existed while the spacecraft was in the upper reaches of the atmosphere (fig. 13-2); 80 percent of the range-control capability existed between an altitude of approximately 250 000 and 170 000 feet. The total reentry time from start of retrograde to deployment of drogue parachute varied from 29.0 minutes for Gemini VI-A to 32.5 minutes for Gemini XII, and depended on the particular retrograde orbit of each flight. Only 2.5 minutes were available for utilizing the lift capability to accurately adjust the reentry trajectory. The necessity for accurate commands and spacecraft responses during that time was clearly indicated.

It was essential that the spacecraft exhibit good stability characteristics during the effective lift portion of the trajectory in order to achieve accurate touchdown control. A qualitative summary of the stability characteristics of the spacecraft indicated that good static and dynamic stability were present in the region of most significance. At lower Mach numbers, the stability characteristics were from marginal to unstable, but the range errors were minimum. The drogue parachute was deployed at 50 000 feet to avoid the unstable dynamic stability characteristic. Results of the first few Gemini reentries raised questions concerning the accuracy of the aerodynamics; however, the analysis of the last seven flights indicated reasonably consistent aerodynamic characteristics for the Gemini reentry configuration.

Guidance Logic

Two different reentry steering techniques were developed and used during the Gemini Program, a rolling reentry technique and a constant bank-angle technique. Both utilized a predicted range computed from the range-to-go of a reference trajectory, and from the range contribution that was realized from the deviation of navigated flight conditions from corresponding reference quantities. The reference ranges and the range-to-flight condition sensitivity coefficients were stored in the onboard computer memory as a function of a parameter relating navigated velocity and measured acceleration. Figure 13–3 illustrates the rolling reentry technique employed during the Gemini Program; this technique was based on a zero-lift reference trajectory. The control logic commanded the direction of the spacecraft lift vector necessary to steer to a zero-lift trajectory which would terminate at the target. A lifting profile was flown until a zero-lift trajectory coincided with the target point. At this point a constant roll rate was commanded to neutralize the effect of the inherent lifting capability of the spacecraft.

Figure 13–4 illustrates the guidance logic for the rolling reentry technique where *RN* is the downrange component of the total range between the spacecraft position and the target; *RC* is the crossrange component; and *RP* is the predicted zero-lift range. A bank angle *BC* is commanded based upon the ratio of *RC* *RN*—*RP*. The control technique simultaneously nulls the downrange and crossrange trajectory errors by continuously updating *BC* based upon the ratio of range errors, until the predicted zero-lift range *RP* is equal to the downrange distance to the target *RN*. At this point, if the crossrange error is greater than a 1-nautical-mile deadband, a 90° bank angle is commanded, the direction depending on the sign (plus or minus) of the crossrange error. When the crossrange error is within the deadband, a zero-lift trajectory is initiated by commanding a constant roll rate. The rolling portion of the trajectory is interrupted occasionally in order to command any additional lift necessary to steer back to the zero-lift trajectory. The predicted zero-lift trajectory is purposely biased early in the reentry to always place the spacecraft in an undershoot condition, thereby eliminating the need for negative lift in order to reach the target. This guidance logic was used on Gemini III, IV, VIII, IX–A, X, XI, and XII.

Figure 13–5 illustrates the constant bank-angle reentry technique. This technique is

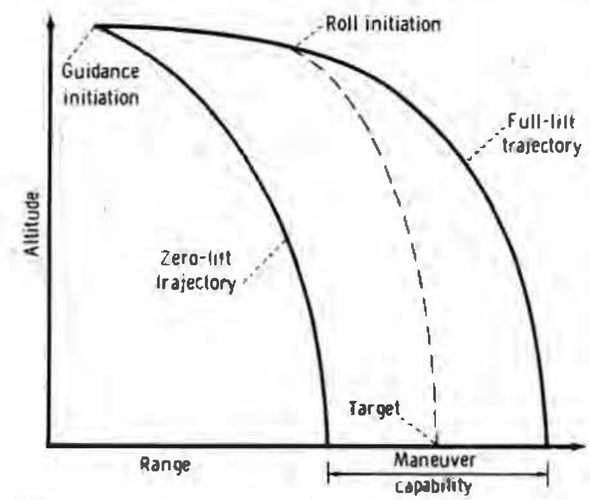


FIGURE 13–3.—Gemini rolling reentry technique.

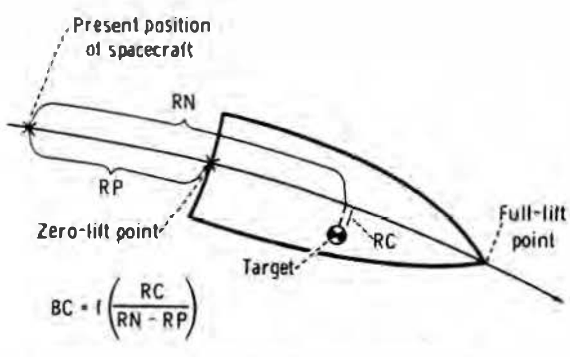


FIGURE 13–4.—Rolling reentry guidance logic.

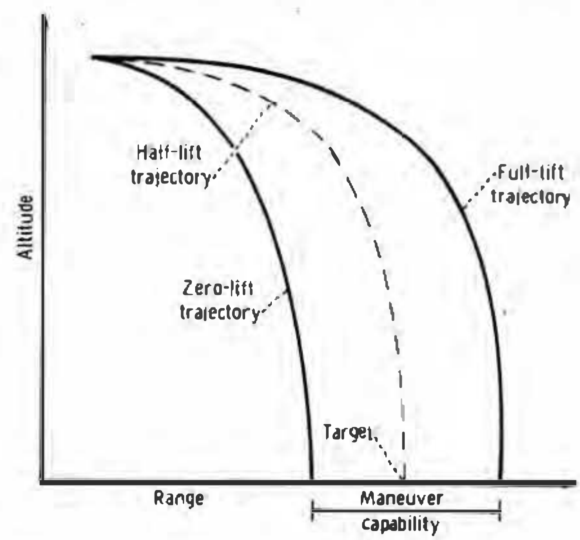


FIGURE 13–5.—Gemini constant bank angle reentry technique.

based upon a half-lift reference trajectory. The control logic commands a constant bank angle which results in a lift profile that will provide the proper longitudinal range for landing at the target point. This is accomplished by determining the difference between the range to the target and the half-lift reference-trajectory range, and by comparing the difference with a set of stored reentry-maneuver-capability data in the spacecraft computer.

Figure 13–6 shows the guidance logic used by the constant bank-angle reentry technique. In this technique, *RN* is defined as the downrange component of the total range between the spacecraft position and the target; *RC* is again the crossrange component; but *RP* is now the predicted half-lift range. A bank command is generated depending upon the value of *RN—RP*. If *RN* is equal to *RP*, a constant 60° bank angle is commanded; if *RN* is greater than *RP*, a more shallow bank angle is commanded; and if *RN* is less than *RP*, a steeper bank angle is commanded. The magnitude of this bank angle is determined by the stored downrange-extension capability of the spacecraft, ΔR. The crossrange error is controlled by reversing the direction of the bank angle when the crossrange error *RC* is equal to the crossrange capability of the spacecraft. The crossrange capability is again based upon the stored maneuver-capability data. This guidance system was flown on Gemini V, VI–A, and VII.

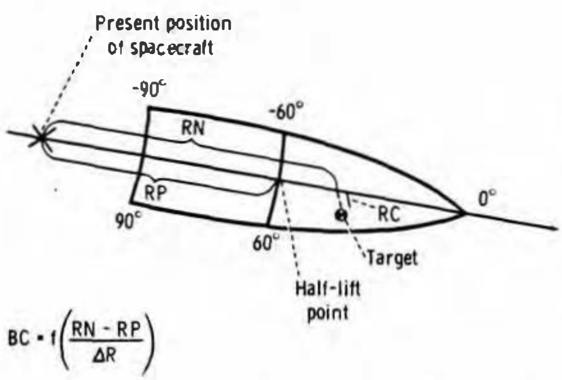


Figure 13–6.—Constant bank angle reentry guidance logic.

Retrofire Performance

In order for the guidance system to steer the spacecraft to a desired landing point, an accurate deorbit maneuver had to be performed. The spacecraft retrofire system consisted of four solid-propellant retrorockets which produced a velocity increment for deorbit of approximately 320 ft/sec. The spacecraft attitude was manually held at a predetermined constant inertial-pitch attitude throughout the maneuver, while the rates about the pitch, roll, and yaw axes were damped by the automatic control system. Excellent retrorocket performance was achieved on each of the missions, and the crew was able to hold the pitch attitude within approximately 2°.

Reentry Summary

The Gemini Program accomplished 11 successful reentries and showed that controlled reentry was an operational capability (fig. 13–7 and table 13–I). No reentry was attempted during the Gemini I unmanned orbital flight. Gemini II was an unmanned suborbital flight designed as a spacecraft heating test and as a check of the guidance and navigation system. The rolling reentry guidance logic was programed into the computer; however, this logic was bypassed and the reentry was flown open loop by continu-

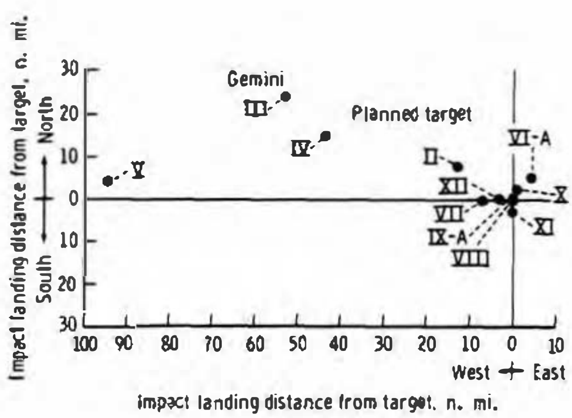


Figure 13–7.—Relative landing points.

TABLE 13-I.—*Gemini Reentry Summary*

Mission	Miss distance, n. mi.	Navigation error, n. mi.	Significant comments
II	14	1.2	Footprint shift
III	60	.8	Lift-drag reduction
IV	44		Footprint shift, inoperative computer
V	91	474	Invalid position update
VI-A	7	2.5	No radar below 180 000 ft
VII	6.4	2.3	Lift-drag reduction
VIII	1.4	....	Emergency reentry
IX-A	.38	2.2	
X	3.4	4.2	
XI	2.65	4.0	Automatic reentry
XII	2.6	2.4	Automatic reentry

ously rolling the spacecraft from the point of 0.05 g until an altitude of 80 000 feet was attained. The zero-lift point shifted 14 nautical miles due to the retrofire maneuver, and the spacecraft landed 14 nautical miles from the planned touchdown point. The footprint shift was caused by a combination of a pitch-attitude error of 3.2° during retrofire and a retrograde-velocity increment that was 1.1 percent low. Postflight analysis showed that the navigation accuracy at guidance termination was 1.2 nautical miles.

The first manned mission of the Gemini Program was Gemini III, a three-orbit mission. To assure spacecraft reentry in case of retrorocket failure, a preretrofire orbit maneuver was performed with the spacecraft propulsion system. This maneuver was completed 12 minutes before retrofire and resulted in a vacuum perigee of 45 nautical miles. The combined retrofire and preretrofire maneuver resulted in a footprint shift of 48 nautical miles. The retrofire maneuver accounted for 24.9 nautical miles of this shift. Before the deorbit maneuver, the target point was situated on the 60° contour line of the footprint, and was offset from the centerline approximately 10 nautical miles toward the south. The planned guidance technique was to fly the backup bank angle, which would simultaneously null the cross-range and downrange errors. When either the downrange or crossrange error was nulled, the crew would fly the commands generated by the spacecraft computer. The Gemini III spacecraft experienced a decrease of approximately 35 percent in the lift-to-drag ratio, resulting in a loss of approximately 160 nautical miles in the downrange maneuver capability. The loss in capability, combined with the shift of the footprint due to the deorbit maneuver, caused the target to be on the edge of the maneuver envelope of the spacecraft. Following the planned procedure, the spacecraft landed 60 nautical miles from the target. Postflight analysis indicated that if the crew had followed the commands generated by the spacecraft computer during the entire reentry, a miss distance of approximately 3 nautical miles would have occurred. Navigation accuracy on this mission was 0.8 nautical mile.

Gemini IV was a 4-day mission. A planned preretrofire maneuver was to be followed 12 minutes later by a normal retrofire. Based upon the results of Gemini III, it was planned for the crew to use the rolling reentry guidance logic and to manually follow the commands from the spacecraft computer during the entire reentry. However, because of an inoperative computer, it was necessary to fly open loop by manually rolling the spacecraft throughout reentry. The preretrofire orbit maneuver and the retrofire produced a footprint shift of 50 nautical miles, 10 nautical miles resulting from the retrofire maneuver. The spacecraft was to be rolled at a rate of 15 deg sec; however, because the roll-rate gyro had been turned off, the yaw thruster produced an acceleration in the roll direction which was not damped. This caused the roll rate to build to a maximum of 60 deg sec; the spacecraft was still rolling more than 50 deg sec at drogue parachute deployment. With the open-loop reentry, there was no way to compensate for the pre-retrofire and retrofire errors; thus, the spacecraft landed 44 nautical miles from the intended landing point.

Gemini V was an 8-day mission and was the first mission scheduled to use the constant bank-angle reentry guidance logic. As stated previously, the constant bank-angle logic commands were based upon a comparison of the range differences (actual range minus predicted half-lift range) with a set of stored maneuver-capability data. Because of the large reduction in the lift-to-drag ratio experienced by the Gemini spacecraft, the set of stored data was no longer valid; therefore, erroneous commands were generated by the spacecraft computer. Because of the short time between missions, it was impossible to update the constants in the program for Gemini V and VI–A. However, the computer calculations of the range errors (*RC* and *RN—RP*) were displayed to the crew and, as a result of preflight training, the crew could interpret these calculations to obtain the correct bank angle needed to attain a small miss distance. Therefore, it was planned for the crew to modulate the spacecraft lift vector based upon the display of these range errors.

The Gemini spacecraft normally required a navigation update before retrofire. This consisted of an Earth-centered inertial position and velocity vector, and a range angle through which the Earth had rotated from the initial alinement of the Earth-centered inertial system (midnight before lift-off) to the time that the vector was valid. When the update was sent to Gemini V, the range angle was in error by 7.9°. This caused a navigation error in the Gemini V computer of approximately 474 nautical miles. Therefore, throughout the reentry the computer displayed erroneous range data, and by the time the crew determined that the computer was in error, the spacecraft did not have the maneuver capability to steer to the target. The spacecraft landed approximately 91 nautical miles from the target. Postflight analysis indicated that after compensating for this initial-condition error, the navigation accuracy was 2.5 nautical miles. The footprint shift due to retrofire was only 5 nautical miles. The velocity increment produced by the retrorockets was 0.2 percent lower than predicted.

Gemini VI–A was a 1-day rendezvous mission; the constant bank-angle guidance logic was used in the same manner as on Gemini V. Retrofire occurred in approximately a 161-nautical-mile circular orbit with a resultant footprint shift of 22 nautical miles. The shift was due to a 0.6-percent high increment in the retrorocket velocity. The spacecraft landed 7 nautical miles from the target, and postflight evaluation indicated the navigation accuracy was approximately 2.5 nautical miles.

Gemini VII was a 14-day mission that employed the constant bank-angle logic. Modifications made to several of the guidance constants improved the usefulness of the bank command generated by the spacecraft computer; however, the primary crew display was still the range-error display. Retrofire occurred in approximately a 161-nautical-mile circular orbit with a resultant footprint shift of 41 nautical miles. The spacecraft touched down approximately 6.4 nautical miles from the target, and the navigation accuracy was 2.3 nautical miles. A 40-nautical-mile loss-of-maneuver capability was due to an overprediction of the movement of the center of gravity during the 14 days of the mission.

Gemini VIII, a scheduled 3-day rendezvous mission, was terminated by an emergency reentry into a secondary landing area. The reentry was ordered after the flight crew were forced to use the propulsion capability of the Reentry Control System to stop a high roll rate caused by a yaw-thruster anomaly in the primary spacecraft propulsion system. Because of the requirement for the propulsion capability of the Reentry Control System to control the spacecraft attitude during reentry, one of the mission rules required that activation of the Reentry Control System would require spacecraft reentry in the next planned landing area. The Gemini VIII spacecraft landed in the Western Pacific zone (area 7-3) in the seventh revolution.

The rolling-reentry logic was used for Gemini VIII and all subsequent Gemini flights, and enabled the crew to manually fly the bank-angle commands generated by the spacecraft computer. Retrofire occurred from approximately a 161-nautical-mile circular orbit and caused a 12-nautical-mile footprint shift. The spacecraft computer calculated that the spacecraft was 1.4 nautical miles from the planned target at drogue parachute deployment, and the spacecraft was sighted on the main parachute by the recovery aircraft. Because of the area in which the spacecraft was forced to land, no reentry tracking was possible; therefore, no navigation accuracy was determined for this flight.

Gemini IX-A, a 3-day rendezvous mission, used the rolling-reentry logic. The retrofire maneuver produced a footprint shift of approximately 55 nautical miles. The rather large footprint shift was caused by a retrorocket velocity that was 1.06 percent high and by a spacecraft pitch-attitude error of 2.3°. The crew manually flew the bank-angle commands generated by the spacecraft computer and landed 0.38 nautical mile from the target. Postflight evaluation showed a navigation accuracy of 2.2 nautical miles.

Gemini X was a 3-day rendezvous mission. Retrofire occurred from an orbit of 161 by 215 nautical miles. The footprint shift was approximately 43 nautical miles, and the spacecraft landed 3.4 nautical miles from the target with a navigation accuracy of 4.2 nautical miles. The rather large navigation error was caused by a yaw misalinement in the inertial platform.

Gemini XI, a 3-day rendezous mission, was the first to use the automatic mode of the attitude-control system coupled with the guidance commands to steer the spacecraft to the target. Using the rolling-reentry logic, the spacecraft landed 2.65 nautical miles from the planned target with a navigation accuracy of 4 nautical miles. A comparison of the bank-angle profile flown by the automatic system on Gemini XI with the profile manually flown on Gemini VIII and X showed only minor differences. The automatic system responded immediately to any change in the direction of the bank angle commanded by the spacecraft computer, whereas a time lapse occurred between command and response when the flight crew manually flew the bank commands. This time lapse, however, had no noticeable effect on the final landing point of the spacecraft.

The last flight in the Gemini Program, Gemini XII, was a 4-day rendezvous mission. Gemini XII used the rolling-reentry logic and was the second mission that employed automatic reentry. The spacecraft landed approximately 2.6 nautical miles from the planned target, with a navigation accuracy of 2.4 nautical miles. For the fifth time during the Gemini Program, the spacecraft descending on the main parachute was sighted by the recovery forces.

Concluding Remarks

The reentries performed during the Gemini Program have shown the following:

(1) The guidance technique had to be designed to be insensitive to large changes in spacecraft lift capability. The use of the constant bank-angle guidance technique was dependent on an accurate estimate of maneuver capability. It was, therefore, ineffective

for a mission of long duration where a large center-of-gravity variation was present or where spacecraft aerodynamic characteristics were uncertain, as on Gemini VII. The rolling-reentry guidance technique did not require a knowledge of the spacecraft lift capability, and would steer to a particular target as long as that target was within the footprint.

(2) Displays had to be available so the crew could evaluate the performance of the guidance and navigation system, and backup procedures had to be developed to assure safe reentry and accurate landing in the event of a guidance-system failure. These displays had to provide enough information to the crew to permit an intelligent evaluation of the primary guidance system. If the evaluation indicated a failure of the primary system, then backup procedures had to be available to meet the following criteria: (*a*) assure safe capture, (*b*) avoid violating heating and or load-factor limits, and (*c*) function with a degree of accuracy such that the recovery of the spacecraft could be accomplished in a reasonable amount of time.

(3) Consistently accurate navigation could be accomplished during reentry because of a navigation-system design which performed adequately in the presence of expected inertial-measurement-system uncertainties. Even when a large inertial-platform error did occur, as on Gemini X, the effect of the error on touchdown miss distance was small, because navigation errors built up slowly before the region of maximum load factor, then increased sharply; at the same time, the maneuver capability decreased to a small fraction of the total near-maximum load factor. Although the control commands were incorrect late in reentry, because of large navigation errors, the commands could not disperse the trajectory to a great extent because of the small maneuver capability. In addition, the computer navigation equations and integration techniques had been judiciously selected to be compatible with digital computer operation.

(4) Reentry of the Gemini spacecraft was successfully controlled both manually and automatically. The ability of the pilot to adequately control the spacecraft under high load-factor conditions after long periods of weightlessness was demonstrated. The desirability of manual versus automatic control was dependent upon the severity of the control-accuracy requirements, the frequency of the control commands, and the complexity of the control limits imposed for crew safety. Reentry from Earth orbit required some degree of control accuracy but did not require an immediate response to displayed commands.

14. LAUNCH AND TARGET VEHICLE SUPPORT BY THE DEPARTMENT OF DEFENSE

By ALFRED J. GARDNER, *Program Director, Gemini Target Vehicle, Headquarters Space Systems Division, Air Force Space Systems Command*

Introduction

Cooperation between the National Aeronautics and Space Administration (NASA) and the Department of Defense (DOD), and more specifically the Department of the Air Force (USAF), is based on long historical precedent and achievement. Many years of exchange of concepts, equipment, and experimental activities between the National Advisory Committee for Aeronautics and the Air Force and its organizational predecessors laid firm ground for later years. The National Aeronautics and Space Act of 1958, providing the responsibility for the direction of the aeronautical and space activities of the United States, further stipulated one of the duties of the President, ". . . provide for effective cooperation between the National Aeronautics and Space Administration and the Department of Defense. . . ." From the earliest days, the new NASA and the USAF cooperated in numerous formal and informal ways. Air Force support of Project Mercury established many of the mechanisms, techniques, and fundamental requirements for Department of Defense support of the Gemini Program. The lessons learned by both agencies in exchange of funds, selection of personnel, procurement of vehicles, pilot safety, assurance of mission success, and launch support provided a tested foundation for effective Air Force support of Gemini.

In late 1961, when the decision was made to proceed with what ultimately became the Gemini Program, an ad hoc group comprised of NASA and Air Force representatives was appointed to recommend a detailed management and operational plan "clearly indicating the division of efforts between NASA and the DOD (Air Force). . . ." The NASA-DOD Operational and Management Plan for the Gemini Program (December 1961), with subsequent revisions, became the basis for the Air Force support of the program. The Space Systems Division of the Air Force Systems Command was designated to establish the necessary relationships with the appropriate NASA organizations to provide for development, procurement, and launch of the required launch and target vehicles.

Program offices were established in Los Angeles at the Space Systems Division of the Air Force Systems Command to manage the Gemini Launch Vehicle, a modified Titan II Intercontinental Ballistic Missile; and the Gemini Agena Target Vehicle, a modified Agena upper-stage booster. The launch vehicle for the target vehicle, a modified Atlas standard launch vehicle (SLV-3), was provided by an existing program office of this vehicle.

The management of the integration of the three vehicles into the overall Gemini Program was a function of the Gemini Program Office, NASA Manned Spacecraft Center. Within the Gemini Program Office, the principal point of contact with the Air Force Space Systems Division program offices was the Office of Vehicles and Missions. A coordinating committee system was established to maintain liaison, organization, and direction between various Government organizations and contractors.

Highlights of Air Force Technical Support

One of the most difficult aspects of system program management is the need to freeze designs in order to produce hardware on schedule versus the ever-present need to introduce changes. Reliability, time, and economy depend upon strict control of configuration and maximum standardization of production items. However, program evolution invariably leads to changing or expanded mission requirements. In anything but a pure production contract, unexpected and difficult design problems and technical difficulties are encountered. In addition, attractive and desirable improvement areas are developed as the base of program knowledge broadens and progresses. All of these sources of change are exceedingly difficult or impossible to predict or schedule, and often require significant expenditures of resources. Program histories, however, support the premise that one of the keys to program success is the manner of administrative and technical response to such changes. The organization must incorporate a flexibility to change emphasis and absorb tasks. Technical talents must be available. Financial support must be timely and of sufficient magnitude. Skillful schedule planning must introduce the changes to provide maximum realization of improvements with minimum impacts on reliability, manufacture, test, and training. Finally, the motivation of all concerned must be adequately planned in order to define and maintain desired goals and purposes. During the development of the Gemini hardware, all of the typical change influences were encountered and dealt with within the framework of the basic Gemini objectives. Some influences never progressed beyond the analysis and study stage, while others were translated into actual hardware configuration changes, and still others were expanded into major programs having critical effects on the overall program.

Throughout the development of the Gemini Launch Vehicle, every potential change, every known vehicle characteristic, and every operational plan was primarily viewed against the framework of a formal pilot-safety program plan prior to any other consideration of the change. This primary consideration resulted in other studies and changes.

Gemini Launch Vehicle

Within the Air Force Space Systems Division, the Gemini Launch Vehicle Program Office was assigned the responsibility for developing and procuring the Titan II as a launch vehicle and for the technical supervision (under a NASA Launch Director) of the launches of these vehicles. In this function, the Air Force Space Systems Division acted as a NASA contractor, and established the necessary agreements and contracts to provide all of the necessary services, equipment, and vehicles.

The objectives of the Air Force program office, based upon the requirements outlined by the NASA statement of work, were expanded and established as the basis for all resulting agreements and contracts. The fundamental objective was to exercise maximum management and technical control to strictly minimize changes to the basic Titan II vehicle. Changes were to be limited to those in the interest of pilot safety, to those necessary to accommodate the Gemini spacecraft as a payload, and to those necessary to increase the probability of mission success. Implicit in the basic objective were economy, high reliability, maintenance of schedule, and maximum cooperation with the NASA Gemini Program Office.

During the early months of the program, extensive and intensive studies, analyses, and tests were conducted to firmly identify all required changes to the basic Titan II; to identify all tests, procedures, and experimental programs; and to provide the basis for a set of detailed, comprehensive specifications for the vehicle.

In February 1962, a Technical Operating Plan was coordinated between the Space Systems Division and the Aerospace Corp. The plan outlined areas of effort and responsibilities of the Aerospace Corp. support of the Space Systems Division by providing general systems engineering and technical direction of the Gemini Launch Vehicle Program.

As part of the established mission, function, and organization, the 6555th Aerospace Test Wing is an extension of the Space Systems Division at Cape Kennedy and the Eastern Test Range. The Wing represented the Air Force in the launch-site acceptance, testing, data evaluation, and launch of various vehicles. In addition, the Wing provided management control of the various vehicle contractors, and integrated contractor and Government efforts, and assured Range support and data during the checkout and launch sequences. In support of the Gemini Launch Vehicle, various reliability, crew-safety, operational, and other committees and working groups were organized or supported. One of the outstanding achievements of the Gemini Program was the scheduling and accomplishment of the Gemini Launch Vehicle turnaround required for the Gemini VII and VI–A missions leading to the historical first rendezvous of two manned space vehicles (December 1965). Reference 1 contains a brief review of the development of the Gemini Launch Vehicle and of the flight results of the first seven Gemini missions.

Typical Gemini Launch-Vehicle Test Chronology

After final assembly of the Gemini Launch Vehicle at the Baltimore plant of the Martin-Marietta Corp., the propulsion and hydraulic systems were checked for leaks, and the electrical system was checked for continuity. The vehicle was then tested in the Baltimore Vertical Test Facility; this included a series of countdowns and simulated launches. All operations were either performed or accurately simulated and recorded.

The two stages of the vehicle were transported by air to Cape Kennedy, erected, and assembled on Launch Complex 19. A detailed checkout and verification test series was completed, culminating in a combined systems test of the vehicle. After the spacecraft was mated with the launch vehicle, a series of joint tests was completed, including joint guidance and flight controls, simulated partial countdown and launch ascent, tanking exercise, and, for missions involving the target vehicle, simultaneous launch demonstration.

Gemini Launch-Vehicle Payload Margins

Development of payload capability and trajectory prediction techniques.—At the beginning of the Gemini Program, all trajectory and payload performance predictions were based upon nominal values for all parameters. Therefore, all launch vehicles had the same payload capability except for variations due to mission differences. As vehicle parameters became available they were incorporated, and frequently created substantial changes in predicted payload capability. Each parameter update was incorporated as soon as available in order to maintain the most up-to-date prediction possible. This was desired to keep NASA continually informed of the payload capability margin for each of the vehicles, so that mission changes could be made to improve capability or to take advantage of excess capability. It was also desired to show the necessity of making performance improvement changes to the Gemini Launch Vehicle. A number of performance improvements were considered for the Gemini Launch Vehicle during the early and mid-phases of the program.

Figure 14–1 illustrates the changes in predicted Gemini Launch Vehicle minimum payload capabilities compared with time, and the changes in spacecraft weights, without experiments, compared with time. Since experiment weight averaged about 160 pounds, the actual margins between predicted capabilities and spacecraft weights were less than those shown. Near the end of the Gemini Program, it was common for the predicted payload capability margin to be negative. The worst case was —282 pounds for Gemini IX–A.

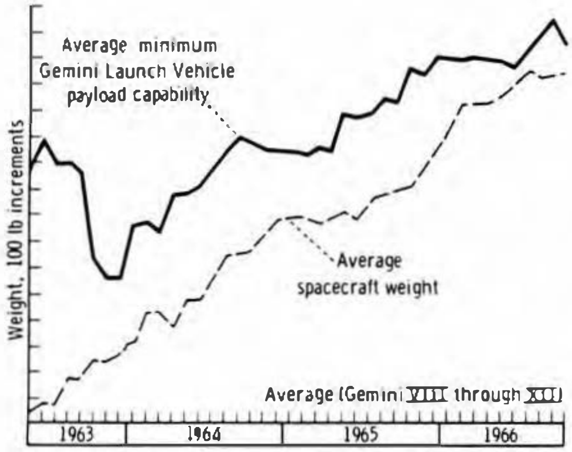


FIGURE 14-1.—History of spacecraft weight and predicted Gemini Launch Vehicle minimum payload capability.

As with any launch vehicle, the Gemini Launch Vehicle was constrained to remain within specified limits throughout the flight envelope. In particular, the vehicle was constrained by aerodynamic heating, aerodynamic loads, axial acceleration, guidance-radar look angles, guidance-radar elevation angle, dynamic pressure and angle of attack at staging, Stage I hydraulic-actuator hinge moment, and spacecraft abort criteria. Studies early in the Gemini Program quantitatively established limits in the constraint areas. Maximum or limiting values of some parameters were selected for nominal trajectories such that, if the nominal trajectory remained within these bounds, dispersed trajectories would remain within the true launch-vehicle and guidance-system capabilities.

Although the nominal payload capability for each Gemini Launch Vehicle was of considerable importance, the predicted minimum payload capability was of even greater importance. The minimum payload capability was the weight of the spacecraft that could be put into the desired orbit even under the most disadvantageous launch-vehicle performance. Most disadvantageous was defined for the Gemini Launch Vehicle as the minus 3-sigma payload capability, or that payload capability which would be equaled or exceeded 99.87 percent of the time. This percentage was shifted to 99.4 percent in the latter part of the Gemini Program.

Gemini Launch Vehicle dispersion analyses were initially performed by determining the payload capability effects of dispersions in a large number of key vehicle parameters. The parameter dispersions that were used were the 3-sigma dispersions based upon test data and theoretical analyses. Throughout the Gemini Program, attention was directed to refining estimates of 3-sigma parameter dispersions. Particular attention was given to the parameters with the most significant effects upon trajectory and payload capability performance. From the beginning of the Gemini Program, it was obvious that a very good estimate of the overall 3-sigma dispersion could be determined by considering the variations of a limited number of key parameters. These parameters were those which most affected the shape of the vehicle trajectory in the pitch plane. The following parameters were selected early and used throughout the program for simplicity and continuity:

Stage I	Stage II
Thrust	Thrust
Specific impulse	Specific impulse
Outage	Outage
Dry weight	Dry weight
Usable propellant weight	Usable propellant weight
Pitch programer error	
Pitch gyro drift	
Winds	
Atmospheric density	
Engine-thrust misalinement in pitch.	

Performance improvement program. — Since the inception of the Gemini Program, a vigorous performance improvement program was pursued to meet the ever-increasing requirements of payload capability. Initially, the total weight of the spacecraft, including experiments, was estimated at about 7000 pounds for the long-duration missions and 7250 pounds for the rendezvous missions. It quickly became apparent that these weights would be exceeded. The early spacecraft-weight growth rate was approximately 35 to 40 pounds per month, and not until deletion of the paraglider configuration was some relief obtained. Increase in the size of the spacecraft propellant tanks provided another impetus in the search for higher launch-vehicle payload capability. Ultimately, the spacecraft weights increased to the point where predicted launch-vehicle performance margins relative to the minimum (99.4 percent probability) payload capability were consistently negative. Comparison between actual spacecraft weights and achieved payload capabilities is shown in figure 14-2.

In addition to spacecraft-weight increases, changes in mission requirements had a significant effect on launch-vehicle payload capability. On early flights a 5-hour launch-window requirement was imposed, necessitating large ullage volumes in the propellant tanks to allow for propellant temperature increases. This meant fewer propellants loaded and a reduced payload capability. Optimizing the mixture ratio for the worst case in the window under dispersed propellant temperature conditions also resulted in performance decreases. For certain missions the requirements for high initial apogees and for launch azimuths considerably less or greater than 90° degraded the payload capability. Finally, the requirement to have the launch vehicle steer out as much as 0.55° of wedge angle to increase the availability of spacecraft propellant reduced the probability of achieving the desired insertion conditions. Propellant temperature-conditioning equipment was included in the areospace ground equipment so that launch-vehicle propellants could be chilled to 20° F for oxidizer and 26° F for fuel before loading. This chilling would allow greater propellant masses to be loaded in the fixed tank volumes, thus increasing payload capability. Attention was also given to the performance gain available by reducing the minimum ullages in the propellant tanks from the values used on the Titan II weapon system. Structural studies and engine start tests at reduced ullages were incorporated in the Gemini Propulsion System Test Program.

Early in 1963, the Martin Co. proposed a study of the feasibility of removing the low-

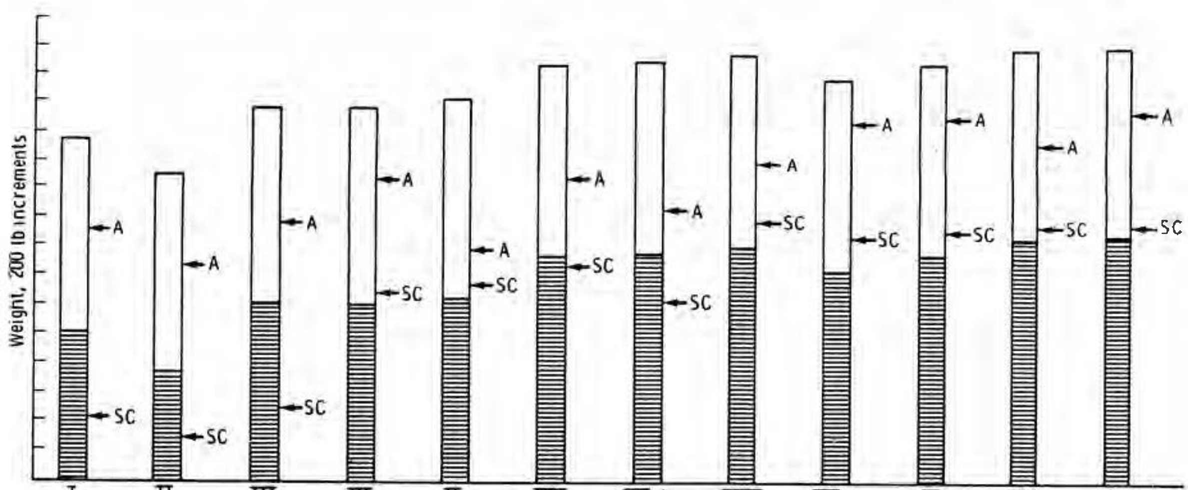


FIGURE 14-2.—Comparison of normalized predicted and achieved payload capabilities.

level propellant shutdown sensors from the shutdown circuits on both launch-vehicle stages. Removing these sensors would eliminate the large possibility of premature shutdowns due to faulty level sensor operation and would also increase payload capability by reducing the amount of trapped propellants. Data from exhaustion shutdowns on the test stand and on the Titan II flights indicated that such shutdowns did not noticeably jeopardize mission success. The shutdown function of the sensors was eliminated, although they were retained for instrumentation purposes and for closed-loop operation if later found desirable.

Changing the Titan II engine target mixture ratios on acceptance tests from 1.93 for Stage I and 1.80 for Stage II to approximately 1.95 and 1.84 would have allowed complete filling of both oxidizer and fuel tanks to ullage limits when the engines were operated in the anticipated flight environment. However, as the mixture ratio increased, the specific impulse decreased for both stages. Some of the other areas investigated were: (1) engine effects, such as heat transfer and combustion stability; (2) possible mission changes; and (3) impact of other potential performance improvement items, such as further reduced minimum ullages and constant temperature propellants. As a result of these studies, the Stage II engine mixture ratio change was eliminated because there was no payload advantage. The Stage I engine target mixture ratio was changed to 1.945, effective for the Gemini IV launch vehicle.

Titan II and launch-vehicle engine performance data were monitored throughout the Gemini Program. By May 1965, sufficient data had been accumulated to indicate that significant changes in the form of biases were likely to occur between acceptance test and flight. This analysis included the results of 10 Stage I flights and 16 Stage II flights. For Gemini IV through X, the biases indicated by the analysis were included in preflight trajectory and performance predictions. When the Stage I thrust bias and specific impulse biases were incorporated into the Gemini IV launch-vehicle preflight predictions, the added efficiency of Stage I resulted in overlofting of the Stage I trajectory. This was disadvantageous for two reasons: first, high-dispersed trajectories could result in pitch look angles which exceeded the existing allowable limits; and second, overlofting caused excessive gravity losses and Stage II pitch maneuvering. Because of these considerations, a new pitch program, developed for Gemini IV, eliminated the over-lofting and resulted in an improvement in the payload capability.

Mission-dependent performance changes.—Correct predictions of trajectory and payload capability also had to be based on differences and changes in the Gemini missions. For example, if the apogee were changed for a specific Gemini mission, it was necessary to adjust the predicted launch-vehicle payload capability accordingly. Similarly, if the launch azimuth and/or yaw steering were changed, the payload capability effects were computed and incorporated in the predicted launch-vehicle capability. For each of the rendezvous missions, it was also necessary to determine payload capabilities for the alternate missions which would be attempted if the primary mission could not be completed.

Flight-test performance.—Obtaining accurate preflight predictions and postflight analyses of vehicle propulsion performance was of great importance throughout the Gemini Program. The launch-vehicle payload capability and trajectory performance were highly dependent on the propulsion parameters of mixture ratio (the major contributor to propellant outage), specific impulse, and thrust for both stages of the vehicle. Propellant outages for Stage I and Stage II were the two largest factors in payload capability dispersion allowances. Postflight analysis of each Gemini Launch Vehicle trajectory was conducted to define the reasons for deviations from nominal and to determine changes to be made in predictions for subsequent vehicles. Table 14–I compares predicted with achieved payload margins for all missions.

Gemini Launch Vehicle Stage I Tank Staging Anomaly

High-speed long-range camera coverage of the Gemini X launch vehicle showed a large orange-red cloud appearing from Stage I shortly after staging and indicating a possible breakup of the stage. A detailed review of the films revealed that the oxidizer tank vented approximately 1.2 seconds after Stage II ignition. A study of Stage II telemetry data revealed no indication of this event. Stage I telemetry was inoperative at this time, having been disabled 0.7 second earlier. A thorough study of the tank rupture isolated the following as the most probable causes: (1) Stage I turning after separation, resulting in the Stage II engine subassembly exhaust impingement and burnthrough of oxidizer tank barrel; (2) breaking of the ablative coating on the oxidizer tank dome, due to dome flexing caused by dome overheating and subsequent structural failure, resulting from high local pressures at Stage II engine start; and (3) dome or tank barrel penetration by transportation section debris. A review of the staging films revealed similar occurrences on seven Titan II flights. The same anomaly occurred during the Gemini XII mission; however, this occurrence was followed by the apparent rupture of the Stage I fuel tank and the breakup of Stage I just forward of the Martin/Aerojet interface. The results of the study and a review of all available Titan II and Gemini flight data showed no detrimental effect on mission success or crew safety due to this event.

Gemini Launch Vehicle Switchover/Switchback Studies

With the incorporation of a redundant flight control system, a detailed system evaluation was conducted to reassess the vehicle airframe, the switchover logic, and the sensor limits. The evaluation indicated that the initial selection of sensor limits, structural safety factor, and switchover logic did not result in optimum switchover capability. It became apparent that a switchover during Stage I flight from a loss of hydraulic pressure would result in the secondary flight control system being used throughout Stage II flight. This could have resulted in discarding a good, reliable, primary flight control system

TABLE 14–I.—*Predicted and Achieved Gemini Launch Vehicle Payload Capability Margins*

Mission	Payload capability margin			Difference, lb
	Predicted, lb		Achieved, lb	
	Minimum	Nominal		
I	508	1017	1171	154
II	336	1025	1066	41
III	577	1199	1396	197
IV	−62	593	767	174
V	−135	526	374	−152
VII	69	709	786	77
VI–A	265	891	778	−113
VIII	−162	492	471	−22
IX–A	−282	372	638	266
X	−217	416	571	155
XI	−175	497	528	31
XII	−51	619	869	250

during Stage II flight. To alleviate this situation, the capability of switching back to the primary system was incorporated. It was planned that switchback would only be actuated in the event the switchover was initiated by loss of hydraulic pressure and would be activated between staging and guidance enable.

The switchover flight loads during the high maximum dynamic pressure region were found to be in excess of the structural design criteria. Consequently, the concept was optimized by selecting the sensor limits that maximized crew safety. A corresponding hardware change was made to reduce the angular rate switch settings. The structural load-carrying capability was reevaluated in the light of probability considerations, which resulted in a reduced factor of safety for switchover from 1.25 to 1.10. A deliberate flight-test switchover was discussed; however, because of difficulty in initiating the switchover, and the significance of the limited results, it was decided not to perform the test.

Gemini Launch Vehicle Stage II Engine Stability Improvement Program

One of the major concerns in man rating the Titan II vehicle was the possibility of combustion instability during the Stage II start transient. The ground-test history of the original Stage II engine utilizing the production quadlet injector gave rise to certain dynamic combustion stability questions for man-rating requirements. The quadlet injector had a demonstrated instability incident rate of about 2 percent during ground tests. Even though this rate was extremely low, the effect of an instability during manned flight caused concern and resulted in the AF NASA decision to develop a more dynamically stable Stage II injector, one that would be capable of accepting limited pulsing without instability. The development of the new injector required evaluation of several injector types. These injectors were screened by thrust-chamber assembly tests consisting primarily of newly developed bomb pulsing techniques derived to establish instability triggering thresholds. The selected prototype injectors were then tested at the engine level for system compatability. A final candidate injector then underwent a modified qualification test program which was integrated into an engine improvement program verification test series. To provide further assurance of the adequacy of this injector for manned flight, it was flight tested by a Titan IIIC vehicle, and subsequently incorporated into the Gemini VIII launch vehicle.

Gemini Agena Target Vehicle

As with the Gemini Launch Vehicle, the Air Force Space Systems Division was the NASA contractor for the development and procurement of the Gemini Atlas-Agena Target Vehicle system. However, an attempt was made to add the effort to an existing AF NASA organizational arrangement already established for the procurement and launch of the Atlas-Agena combination for other programs. Accordingly, NASA continued to use the Marshall Space Flight Center in the ". . . role of procurement contractor and technical advisor to the Project Office in the development, procurement and launch of Atlas Agena Target Vehicles for the Project Gemini Rendezvous Missions. . . ." The Air Force added the development, procurement, and systems integration of the target-vehicle system to an existing program office charged with procurement and payload integration of Agena vehicles for other NASA programs. In March 1962, the target-vehicle program was initiated by NASA-Defense Purchase Request H–30247 with the details of the objectives and statement of work to be evolved in working sessions.

In January 1963, the Manned Spacecraft Center assumed direct control of the Space Systems Division effort with the withdrawal of Marshall Space Flight Center from the program. At the same time, organizational realinements began at the Space Systems

Division to provide a program office solely concerned with the target-vehicle effort. This objective was not finally achieved on a basis comparable to the Gemini Launch Vehicle office until July 1965. However, certain aspects of the initial organizational arrangement for both procurement and technical development, once established, could never be completely changed.

The objectives of the Air Force program office were evolved as a result of joint working sessions based upon Gemini mission ground rules, objectives, and requirements. The fundamental objective was to modify the basic Agena vehicle to provide the required accuracies, command and control, pilot safety, reliability, and docking capability consistent with the mission to be accomplished.

To simplify the overall Agena vehicle procurement and launch services, the unmodified basic Agena S-01B vehicles and the necessary launch-site level of effort were procured through the existing Space Systems Division Agena Program Office. The modification of the basic Agena to a target vehicle was managed by a separate program office group at the Air Force Space Systems Division.

In March 1962, a contract was issued to the Lockheed Missiles & Space Co. to provide a vehicle to be used as an in-orbit target for rendezvous with a manned spacecraft. The orbiting vehicle could be controlled by commands from the ground or from the manned spacecraft. The vehicle also had to be capable of maneuvering as part of the spacecraft after docking.

In late 1964, a Technical Operating Plan for the Target Vehicle Program had been established, and the responsibility for providing technical surveillance of the Lockheed contract was assigned to the Aerospace Corp. In keeping with the normal relationships and operations of the Space Systems Division and the 6555th Aerospace Test Wing at Cape Kennedy, the target-vehicle launch responsibilities were assigned to the SLV-3 Directorate of the Wing.

Typical Target-Vehicle Chronology

The target vehicle was initially manufactured, assembled, and tested on the standard Agena production line, and certain items unique to the target vehicle necessarily had to be incorporated as part of the initial assembly prior to final modification and systems test. These unique items included the Model 8247 engine manufactured by Bell Aircraft Corp., a 17-inch auxiliary forward equipment rack, additional helium gas capacity, and similar items.

After delivery of the basic vehicle to the Air Force, certain installations required additional modifications by Lockheed because of the peculiar requirements of the target vehicle. The changes were mainly confined to electrical and electronic packages and harnesses. After final assembly, the target vehicle was moved to the final systems test area and completely tested using a simulator for the Target Docking Adapter, when necessary, and for shroud electrical connections.

After airlift to Cape Kennedy the vehicle was inspected, checked, and alined. High-pressure checks, which for safety reasons could not be accomplished at the factory, were completed. The Secondary Propulsion System modules and heat shields were installed and alined. A complete series of interface tests was accomplished, followed by loading of ancillary fluids and gases. (All pyrotechnics, propellants, and batteries were installed at the launch stand.) The vehicle was then erected with the Atlas Target Launch Vehicle. The major remaining tests were the Joint Flight Acceptance Composite Test and the Simultaneous Launch Demonstration. The vehicle was then ready for F—1 day, precount, and final count tests.

For the actual launch of the Gemini Agena Target Vehicle, the role of each contractor included the following:

(1) Lockheed Missiles & Space Co. furnished the Gemini Agena Target Vehicle, and associated reference trajectory, range-safety package, and flight-termination sys-

tem report, and was the integrating contractor for the ascent guidance effort.

(2) General Dynamics Convair furnished the Atlas Launch Vehicle (SLV–3) and the associated flight-termination system report, and flight-test results, and conducted a comprehensive preflight data exchange with the integrating contractor.

(3) TRW Systems furnished ascent guidance equations and associated documentation for the Gemini Atlas-Agena Target Vehicle, and provided Burroughs Corp. with tray-wiring data.

(4) General Electric Co. furnished guidance canisters for the Gemini Atlas-Agena Target Vehicle, and operated the General Electric Model III System at Cape Kennedy during launches and all associated testing.

(5) Burroughs Corp. furnished wired ascent guidance trays for the Gemini Atlas-Agena Target Vehicle, and operated the computers in Guided Missile Computer Facility no. 1 at Cape Kennedy during launches and all associated testing.

Gemini Target Vehicle Project Sure Fire

On October 25, 1965, Gemini Agena Target Vehicle 5002 was launched from the Eastern Test Range as part of the scheduled Gemini VI mission. After separation from the launch vehicle, the engine malfunctioned destructively during the starting sequence, and the target-vehicle pressurization system destroyed the vehicle.

Corrective action requirements were generated based upon the results of the postflight analysis, the propulsion system and vehicle aft rack design review, and the symposium on ignition of hypergolic propellants. The engine design change recommendations were to convert the Gemini-peculiar engine (XLR 81–BA–13) to a thrust-chamber oxidizer-lead start sequence similar to the basic Agena engine (YLR 81–BA–11); to incorporate shock mounting for certain engine electrical control components; and to disable the electronic-gate shutdown capability during ascent maneuver operation. Test requirements were established to verify adequacy of the design changes and to demonstrate flightworthiness of the modified engine configuration. Results of the symposium on hypergolic ignition indicated that one significant test requirement had not been included in the original XLR 81–BA–13 engine development and the associated PERT program. The requirement was engine testing at an altitude which properly simulated the hard-vacuum space environment. An engine modification and a test program were planned, which required reliable ignition demonstration during hard-vacuum simulation tests above 250 000 feet before the Gemini VIII launch date. An Air Force, Aerospace Corp., NASA, and industry team effort spearheaded by a high-level Super-Tiger Team, as well as maximum priorities, were necessary to accomplish and manage the engine modification and test program on an accelerated, maximum-success schedule. The activity was designated Project Sure Fire and was initiated in November 1965.

Testing was initiated immediately on the turbine pump assembly. These tests provided the preliminary engine-transient performance values, defined the initial detailed design-change requirements, verified satisfactory operating characteristics of the proposed modified configurations prior to initiating engine-level testing, and verified expected operating characteristics with various imposed malfunction conditions. A total of 75 turbine pump assembly tests was accomplished between November 1965 and March 1966.

A total of 37 gas-generator/start-system tests was conducted from November 1965 through March 1966. During these tests, which were conducted at sea level and at a 240 000-foot simulated altitude, reliable gas-generator ignition was achieved throughout the range of predicted flight operating conditions, as well as for conditions normally considered conducive to producing adverse ignition characteristics. In addition, reliable ignitions were demonstrated after a gas-generator/start-system had simulated a 28-day pad hold period and a subsequent 5-day altitude coast storage period.

A pressure switch relay box was designed for the initially proposed configuration, and the development and flightworthiness demonstration tests were conducted on this component in December 1965 and January 1966. Vibration, shock, humidity, acceleration, altitude, and electrical tests were conducted. A relay failure occurred during development vibration tests; and after a subsequent reliability analysis, the relay was removed and the relay box was converted to a junction box.

The proposed engine modification involved the addition of two pressure switches in the engine control circuit to provide the required thrust chamber oxidizer-lead start sequence. Turbine pump assembly test results indicated a high-frequency actuation-deactuation cycling characteristic of the backup oxidizer feed pressure switch during a normal engine-start sequence. Pressure-switch durability and vacuum tests were conducted, with no observed degradation of the microswitch contacts, successfully demonstrating switch operational capability at the Gemini mission altitude for a minimum 5-day period.

Vibration, shock, and hot-fire tests were conducted as part of the engine sea-level flightworthiness demonstration program. Satisfactory structural design of the new and modified component installations was verified. The 42 hot-fire tests demonstrated satisfactory operation and sequencing of the modified engine configuration, and verified successful implementation and checkout of the modified engine test and servicing procedures.

A total of 43 engine flightworthiness tests at simulated altitudes ranging from 257 000 to 453 000 feet, and two checkout firings at 85 000 feet, were conducted. The ignition-confidence, simulated-mission, low-temperature, and malfunction tests at an average simulated altitude of 356 000 feet successfully demonstrated the high-altitude flightworthiness of the modified XLR 81–BA–13 engine. Sufficient confidence in the reliability of the engine ignition had been gained from the 27 Phase I and Phase II altitude tests completed by March 4, 1966, to assure flightworthiness of the Gemini VIII target vehicle and to allow commitment of the modified engine design to flight. Significantly, the postulated target-vehicle flight failure mode was confirmed during the altitude malfunction tests; and showed that a fuel lead on the XLR 81–BA–13 engine would produce hard starts when tested at the proper altitude and that a reasonably high probability of hardware damage existed. Reevaluation of the Gemini VI data indicated that the engine damage incurred during the flight was similar to that observed during the last fuel-lead test. In addition to the successful flightworthiness demonstration of the modified engine, the altitude tests provided data on altitude ignition characteristics over a temperature range from 100° F to below zero.

An unexpected destructive hard start occurred during a checkout firing early in the altitude test program. Post-test data analysis and testing showed that excessive water and alcohol contamination (approximately 85 percent) was introduced into the engine fuel system during the prefire propellant loading operation. The fuel system became contaminated with water during test-cell downtime for instrumentation and hardware repair. An abbreviated isopropyl-alcohol flush procedure was conducted to remove water from the engine; however, the water and alcohol were not completely removed from the facility fuel system, resulting in entry of the contaminated fuel load into the engine. Full-scale and subscale thrust-chamber ignition tests were instituted to evaluate the effects of fuel contamination. Results showed that significant increases in ignition delay and peak pressures occur as the quantities of alcohol and water in the fuel are increased. Further analysis and tests clearly supported the conclusion that the checkout test failure was caused by contaminated fuel.

Further ignition tests investigated thrust-chamber ignition characteristics with fuel, oxidizer, and simultaneous propellant leads over a range of operating temperatures and altitudes (ambient pressures). Considerable data were relatable to the XLR 81–BA–13 engine thrust chamber, and usable as an aid in explaining the differences in ignition characteristics in the main thrust chamber with fuel and oxidizer leads. When subjected to the same test conditions, the XLR 81–BA–13 engine thrust chamber produced significantly different ignition characteristics for a fuel-lead start sequence compared to an oxidizer lead. Therefore, a comparative evaluation of the differences in ignition characteristics was made, based on test data for the full-scale (engine) thrust chamber, the subscale thruster, and the engine gas generator assembly. The hardware design factors which can affect ignition were reviewed; and the dependent conditions existing in the chamber at ignition (such as mixture ratio, density, ignition delay, and ignition chemistry) were recorded or derived as the test variables of altitude, temperature, and propellant lead were changed. The proper pressure and temperature must be generated in the fuel-oxidizer mixture during the induction period just prior to ignition, and a sufficient amount of oxidizer must be present during induction to prevent long ignition delays or quenching of the reaction.

Based on analysis of the design factors and conditions in the full-scale and subscale thrust chambers at ignition, it appeared that the chemistry of the ignition was involved in producing the hard start experienced in the main thrust chamber with the fuel-lead start sequence. When oxidizer was not present in sufficient quantities during the induction period, a suitable oxidation reaction did not occur to overcome the effects that the hard vacuum produces during the propellant pre-flow and/or mixing period. Thus, proper pressures and temperatures were not developed and a long ignition delay resulted, during which secondary reactions probably occurred, producing high energy intermediate compounds. A highly reactable mixture is formed, including the unsymmetrical dimethyl hydrazine (UDMH) fuel which possesses monopropellant characteristics. The resultant mixture becomes the source of the additional energy which produces the hard start when ignition occurs. In the XLR 81–BA–13 thrust chamber, additional damage was incurred because the residence time was such that a reactable mixture accumulated downstream of the throat during the long ignition delay, causing the nozzle overpressure when ignition occurred.

Although the gas generator operates reliably with a fuel lead, this reliability is attributable to: (1) the relatively very large volume of the gas generator turbine manifold assembly, which readily accommodates the energy stored at ignition; and (2) a preignition pressure rise, which indicates that a preigniter probably exists, similar to the main thrust chamber oxidizer-lead start sequence.

The following significant conclusions were derived from Project Sure Fire:

(1) Flightworthiness of the modified XLR 81–BA–13 engine configuration was successfully demonstrated.

(2) An oxidizer-lead start sequence is optimum for the XLR 81–BA–13 engine thrust chamber, and provides low and acceptable ignition shock levels over the range of required operating conditions.

(3) Significant differences exist between oxidizer-lead and fuel-lead ignition characteristics in the XLR 81–BA–13 thrust chamber.

(4) The conclusion indicated by the flight-failure analysis of the Gemini VI target vehicle, that an engine hard start occurred, was proven correct; and the postulation that the engine hard start was due to a fuel-lead start sequence was also correct.

(5) Fuel-lead hard starts yield high probability of damage to the thrust chamber assembly. Reevaluation of Gemini VI data indicates that an oxidizer line break occurred in the same area as that observed during the last fuel-lead test at Arnold Engineering Development Center. No reactions or adverse pressures were detected in any of

the thrust chamber manifold cavities during the fuel-lead starts at Arnold Engineering Development Center. The hard-start reactions occurred in the combustion chamber and divergent nozzle.

(6) The fuel-lead hard-start mechanism appears to involve the chemistry of the reaction during the induction period. Lack of an excess of oxidizer apparently prevents a satisfactory oxidation reaction from occurring relative to that for an oxidizer-lead start sequence. A very long ignition delay occurs, allowing an accumulation of a reactable oxidizer-fuel mixture which probably contains high-energy intermediate compounds formed during this delay.

(7) The XLR 81–BA–13 engine gas generator assembly provides reliable ignition with a fuel-lead start sequence within the range of operating requirements. Low peak pressure and very slow pressure rise rates are always obtained. These characteristics appear to be due to the large volume of the gas generator assembly, to the low potential energy in the chamber at ignition, and, perhaps most important, to a preignition pressure buildup probably attributable to a preigniter oxidizer flow.

(8) Testing at the proper simulated altitude to determine engine ignition reliability is a necessary and extremely important phase of space-flight engine development.

(9) Propellant triple-point (phase) data provide a reliable guideline for defining the minimum altitude test requirements. Further studies on the relation of phase data, propellant injection, and expansion dynamics at hard vacuum, and presence of excess fuel or oxidizer, are recommended in order to advance the state of the art.

(10) Existing ground-test technology is more than sufficient to properly simulate required altitude conditions for medium-size rocket engines.

(11) Sea-level and altitude subscale ignition tests, and full-scale sea-level ignition tests can be a valuable adjunct to full-scale altitude testing. However, full-scale altitude tests must be conducted as final proof that complete simulation of all factors affecting the ignition process for a specific configuration have been demonstrated.

Results of Project Sure Fire were positive and on March 17, 1966, the engine was committed to launch. The engine performed as desired through all phases of the mission, including demonstrations of multiple starts and maneuver capability.

Gemini Target Vehicle Stability During Docked Engine Firing

The target-vehicle control system was originally designed to provide stable flight for an Agena vehicle with a conventional payload. For Gemini, the control system was required to provide stability during Primary Propulsion System firings while in the docked configuration. The original system was designed to filter all Agena body-bending modes greater than 8 cycles per second. The system could be modified by a gain change to handle frequencies as low as 5 cycles per second. However, the docked spacecraft target vehicle had a fundamental body-bending mode with a frequency between 2 and 4 cycles per second. A lead-lag circuit was designed by Lockheed to cope with this mode, and stability studies were performed to check out the modified system.

The fundamental mode in question involved rigid-body motion of the spacecraft target vehicle with a flexible spring, the Target Docking Adapter, connecting them. Preliminary stiffness data showed both in-plane and out-of-plane response when incorporated in the model, and indicated the inability of the modified system to provide stability. A dynamic response test was performed to provide better data for the analysis and resulted in considerably more out-of-plane coupling in the fundamental mode than had been expected. The frequency of this mode was between 2.5 and 3.0 cycles per second, depending on the weight condition. Structural damping varied between 2.0 and

5.0 percent. In the course of evaluating the test data, errors in handling the out-of-plane response were discovered in the model. With the model corrected and with the use of lower bound damping values, the lead-lag modification proposed by Lockheed was shown to provide adequate stability. The modification was flown on the Gemini VIII and subsequent Gemini Agena Target Vehicles.

As soon as the modal response of the docked spacecraft target vehicle had been established by studies at the Massachusetts Institute of Technology and the results accepted by the contractors affected, the flight control electronics compensation was established. Previous studies by Lockheed had shown that a modification to the lead-lag shaping network already in existence could handle both the ascent dynamics and the docked dynamics with a minor change in loop gain between two flight modes. The simulation of the vehicle was increased to include the flight control system, and the potential of the revised lead-lag was confirmed.

Lockheed proceeded to mechanize and optimize the lead-lag design with the use of a single-axis digital computer simulation. Hardware components and tolerances were evaluated. The most difficult development item in the change was the perfection of the temperature-stabilized operational amplifier. Actual breadboard parts were tied into the single-axis simulator for temperature tests as well as system performance evaluations. This phase was also used to perfect test procedures and tolerances that would insure proper system performance.

Gemini Target Vehicle Center-of-Gravity Offset Problem

A major problem occurred on the Gemini VIII target vehicle during undocked, in-orbit, Primary Propulsion System powered flight. A significant vehicle yaw-heading error existed; the resulting velocity vector error affected the orbital guidance computations and resulted in adverse orbital ephemeris accuracies when making out-of-plane orbit changes. This yaw-heading error was due to a combination of yaw center-of-gravity offset, slow control-system response time, and vehicle dynamics. The yaw center-of-gravity offset was approximately twice that of the standard Agena due to the added weight resulting from the addition of two running light batteries. The slow control-system response time was caused by the redesign of the flight-control electronics package. The redesign had been required to provide stable control-system operation during the docked mode.

Orbital altitude errors ranged to approximately 120 miles during Primary Propulsion System operation. The errors were much more pronounced when the vehicle was in a $\pm 90^\circ$ configuration and a plane change was attempted. This was due to the offset being in the yaw direction and the velocity component error combining directly with the orbital velocity. These errors greatly exceeded 3-sigma values derived in prior error analyses and on-orbit guidance computations. Various solutions to the center-of-gravity problem were investigated. These consisted of removing batteries, realining the engine, adding ballast, off-loading the Secondary Propulsion System propellants, and preparing correction tables for use in trimming out potential dispersions. A parametric study was performed which related pitch-and-yaw-attitude errors to center-of-gravity offsets for the target vehicle during Primary Propulsion System operation. Attitude errors were determined as a function of firing time, vehicle center-of-gravity offsets, and vehicle weight. Results were plotted as a family of curves to provide programed attitude correction data for desired orbit changes. Average attitude error and actuator position for various times of Primary Propulsion System firings, along with transient attitude and actuator position response curves, were presented.

Atlas SLV-3 Target Launch Vehicle

The basic planning of the Gemini Program directed the use of the Air Force Atlas SLV-3 as the launch vehicle for the Gemini Agena Target Vehicle. The overall development of the Gemini Atlas-Agena Target Vehicle system was assigned to the Air Force Space Systems Division. The target-vehicle program office used the existing internal Space Systems Division management structure for the procurement of the SLV-3 vehicles. The SLV-3 contracts covered necessary services and equipment from General Dynamics/Convair, Rocketdyne, Acoustica, General Electric, Burroughs, and the Aerospace Corp. Seven Atlas SLV-3 vehicles were procured and launched during the Gemini Program.

After final assembly at the factory, the tanks were mated to the engine section; various subassembly kits were installed and tested prior to a final composite test of the complete vehicle. The vehicle was then shipped to Cape Kennedy where the SLV-3 underwent inspection and final installations in the hangar prior to erection. After the vehicle was erected on Launch Complex 14, the principal tests were the SLV-3 Flight Acceptance Composite Tests and the overall Atlas-Agena Target Vehicle system test (Joint Flight Acceptance Composite Test). Finally, an SLV-3 tanking test was accomplished to establish flight readiness of the launch vehicle.

Augmented Target Docking Adapter Program

Program Development

In December 1965, the Manned Spacecraft Center delineated the Air Force Space Systems Division and contractor support requirements for the Augmented Target Docking Adapter mission. The Air Force Space Systems Division was to supply the following hardware: an SLV-3 vehicle, a Gemini target-vehicle shroud, and a Gemini target-vehicle booster adapter. Space Systems Division was also required to perform the software work necessary to place the Augmented Target Docking Adapter into orbit, using only SLV-3 boost capability.

Program Requirements

The Augmented Target Docking Adapter was originally designed as a backup vehicle for the Gemini VII/VI-A rendezvous mission and for the Gemini VIII mission. At first, it was not known if the hard start experienced by the Gemini VI target vehicle could be corrected before the Gemini VIII mission. The Manned Spacecraft Center requested a vehicle that would permit docking even though it would have no maneuver capability. The Augmented Target Docking Adapter consisted of a target-vehicle shroud, a Target Docking Adapter, an equipment section, a Gemini spacecraft Reentry Control System module, and a battery section.

The insertion conditions required a near-circular orbit of 161 nautical miles with dispersions no greater than ± 20 nautical miles and an inclination angle of 28.87°. The steering mode was to be the crossing of the ascending mode. A 2500-pound payload was used for planning.

Gemini Atlas-Agena Target Vehicle Launch History

Gemini VI Mission

Since the Gemini VI mission was to be the first Gemini rendezvous mission, the primary objective was the rendezvous and docking of the Gemini spacecraft with the Gemini Agena Target Vehicle. Another objective involved checkout of the target vehicle while docked, and included commands from the spacecraft to the target vehicle, determination of target-vehicle safety status, and test of target-vehicle attitude maneuver capability. A small Secondary Propulsion System firing in the docked configuration was also planned, although no docked Primary Propulsion System firing was planned. This mission was also the first simultaneous countdown for the launch of two vehicles (the Gemini Atlas-Agena Target Vehicle and, 101 minutes later, the Gemini Launch Vehicle and spacecraft).

The Gemini Atlas-Agena Target Vehicle for the Gemini VI mission was launched at 10 a.m., eastern standard time, October 25, 1965. The ascent portion of the flight was normal until time for the target-vehicle Primary Propulsion System to fire for the insertion maneuver; the engine suffered a hard start and subsequent explosion, and the vehicle failed to achieve orbit.

Gemini VIII Mission

The Gemini Atlas-Agena Target Vehicle for the Gemini VIII mission was launched at 10:03:03 a.m., eastern standard time, March 16, 1966. The ascent phase was very close to nominal with insertion into an orbit 161.4 by 161.7 nautical miles. The insertion parameters were as follows:

Semimajor axis, n. mi.	3603.05
Inclination angle, deg	28.86
Eccentricity	0.0006
Period, min	90.47

Following undocking and reentry of the spacecraft, eight orbital firings were performed by the target-vehicle Primary Propulsion System during Gemini VIII. The duration ranged from the 0.85-second minimum-impulse firing to a 19.6-second plane change, with the majority between 1 and 3 seconds. Of the eight firings, five utilized the short 22-second A-ullage sequence, and the other three used the 7-second C-ullage sequence. Based upon the available data, the Primary Propulsion System performed normally during all eight firings. During the 19.6-second out-of-plane maneuver, a major system anomaly became apparent. The vehicle attitude in yaw was considerably off the intended heading, resulting in a large in-plane velocity component. This same heading offset was also noted on the second out-of-plane maneuver, or inclination-adjust maneuver, and again resulted in a large in-plane velocity component. It was later determined that these errors were caused by a large center-of-gravity offset from the centerline, and by the dynamic response of the guidance and control system being too slow to correct for center-of-gravity errors. It was decided that additional out-of-plane maneuvers would not be made.

An in-plane retrograde maneuver resulted in lowering the apogee to 200 nautical miles, and the results were nearly perfect. The yaw offset was again noted, but the firing was short; slight yaw-heading errors have much less effect on the resulting orbit when the maneuver is performed in-plane. Based upon this success, two more in-plane maneuvers, dwell initiate and dwell terminate, were performed to deplete some of the propellants and to achieve a circular orbit of 220 nautical miles. These maneuvers were very successful and accurate, although the yaw offset was noted during each firing. The center-of-gravity offset problem was the only major system problem during the mission.

Operation of the Secondary Propulsion System was desired until the propellant was depleted; however, because of the excessive control-gas usage during the spacecraft malfunction, only 15 pounds of Attitude Control System gas remained when the first Secondary Propulsion System firing was to be initiated. The operation was planned for 20 seconds to provide the first actual in-orbit operation of the Secondary Propulsion System and to verify control-gas usage rates. The first Secondary Propulsion System Unit II operation occurred over Grand Canary Island in revolution 41. The firing was performed using flight control mode FC–7 to reduce velocity-vector errors caused by center-of-gravity offset. Over the Eastern Test Range during revolution 42, the second operation of the Secondary Propulsion System was performed at the existing heading of −90 . This maneuver was also performed with docked gains to reduce thrust-vector errors caused by center-of-gravity offset. The maneuver appeared nominal, except that 5 pounds of control gas were expended. The target-vehicle orbit after the final Secondary Propulsion System firing was 220 by 222 nautical miles with a 28.867 inclination angle.

During the Gemini VIII mission, 5439 commands to the target vehicle were sent, accepted, and executed. The Gemini Atlas-Agena Target Vehicle was launched within 1 second of the scheduled lift-off time.

Gemini IX Mission

The Gemini Atlas-Agena Target Launch Vehicle for the Gemini IX mission was launched May 17, 1966. A normal countdown and lift-off occurred. After 120.6 seconds of flight, the vehicle experienced a loss-of-pitch control in one booster engine. Tracking film showed that after the loss-of-pitch stability, the vehicle pitched downward in excess of 180 , and changed in azimuth toward the left (northward). Flight control data also indicated that the vehicle pitched downward; extrapolated and integrated data revealed that the vehicle pitched down 216 from the 67 reference at 120.6 seconds. Radar data from the Grand Bahama Island station at 436 seconds, approximately 136 seconds after vernier engine cutoff, placed the vehicle about 103.4 nautical miles from the launch site, headed in a northerly direction at 97 000 feet in altitude, and descending. These data correlated well with a set of radar impact coordinates which placed vehicle impact 107 miles from the launch site in a northeasterly direction. The exact reason for the loss of the engine pitch control is unknown, but the data indicate that a short-to-ground occurred in the circuit for the servoamplifier output-command signal. This short-to-ground may have been caused by cryogenic leakage in the thrust section.

Gemini IX-A Mission

The Gemini IX–A Target Launch Vehicle with the Augmented Target Docking Adapter was launched from Cape Kennedy at 10:00:02 a.m., eastern standard time, June 1, 1966. The Target Launch Vehicle was steered into a predetermined coast ellipse and nodal crossing. The insertion orbital elements were as follows:

Apogee altitude, n. mi.	167.1
Perigee altitude, n. mi.	161.0
Period, min	90.50
Inclination, deg	28.87

Gemini X Mission

The Gemini Atlas-Agena Target Vehicle for the Gemini X mission was launched at 3:49:46 p.m., eastern standard time, July 18, 1966. The insertion parameters were as follows:

Semimajor axis, n. mi.	3603
Inclination angle, deg	28.85
Eccentricity	0.0008
Period, min	90.46

The ascent phase was nominal with insertion into an orbit of 163.4 by 159.0 nautical miles. The largest dispersion noted in the ascent guidance equations was 1.5 sigma. The target vehicle was commanded into docking configuration from the ground. Prior to docking, the Gemini spacecraft had a higher-than-predicted usage of propellants. This altered the flight plan and resulted in more docked time, more reliance on the target vehicle, and more maneuvers using target-vehicle capability.

Gemini XI Mission

The Gemini XI Atlas-Agena Target Vehicle was launched at 8:05:01 a.m., eastern standard time, September 12, 1966. The ascent phase was nominal with insertion into an orbit of 165.7 by 156.3 nautical miles. The insertion parameters were as follows:

Semimajor axis, n. mi.	3602.5
Inclination angle, deg	28.84
Eccentricity	0.0013
Period, min	90.56

The launch was originally scheduled for September 9, 1966; however, it was delayed

1 day due to an oxidizer leak in the Gemini Launch Vehicle. The second scheduled launch on September 10, 1966, was scrubbed at T—140 minutes due to a suspected autopilot malfunction in the Target Launch Vehicle. During the ascent Primary Propulsion System firing, it was determined that the magnitude of the center-of-gravity offset problem encountered during Gemini VIII had been successfully eliminated. The target-vehicle command system responded properly to all ground and spacecraft commands during the mission.

Gemini XII Mission

The Gemini Atlas-Agena Target Vehicle for the Gemini XII mission was launched at 2:07:59 p.m., eastern standard time. November 11, 1966. The ascent phase was nominal with insertion into an orbit of 163.6 by 159.0 nautical miles. This was the most accurate insertion for the target vehicle in the Gemini Program. The insertion parameters were:

Semimajor axis, n. mi.	3603.0
Inclination angle, deg	28.86
Eccentricity	0.0009
Period, min	90.56

The launch was originally scheduled for November 9, 1966; however, the launch was delayed 2 days due to a malfunction in the secondary autopilot of the Gemini Launch Vehicle. During the target-vehicle ascent maneuver, an apparent anomaly occurred 140 seconds after Primary Propulsion System initiation. At this time a 30-psi drop occurred in thrust-chamber pressure for approximately 1 second, then returned to normal for the remaining 42 seconds of the firing. This did not affect the Gemini Atlas-Agena Vehicle insertion conditions. The docked posigrade Primary Propulsion System maneuver originally planned was canceled due to uncertainties about the significance of the chamber-pressure-drop anomaly.

Reference

1. ANON.: Gemini Midprogram Conference, Including Experiment Results. NASA SP-121. 1966.

15. MISSION SUPPORT BY THE DEPARTMENT OF DEFENSE

By ROYCE G. OLSON, *Director, Department of Defense Manned Space Flight Support Office, Patrick Air Force Base, Florida*

Introduction

The Secretary of Defense designated the Commander of the National Range Division, Air Force Systems Command, Lt. General Leighton I. Davis, as the Department of Defense Manager for Manned Space Flight Support Operations. This designation, organizationally under the Joint Chiefs of Staff, emphasized DOD support of the Gemini Program. General Davis was given the responsibility and authority to insure complete and responsive support to NASA's needs. Through the National Range Division, he directed the long-range planning for the design and acquisition of supporting resources such as range ships and aircraft, high-quality communications, and range instrumentation.

The DOD Manager established a small supporting joint staff which was the single point of contact for the final coordination and marshaling of all supporting resources prior to each mission. These officers served as the operational control staff during mission periods when the DOD Manager assumed operational control of all committed DOD resources. The areas of support responsibility included launch, network, recovery, communications, ground medical, meteorological, public affairs, and miscellaneous logistics.

Launch and Network Support

Manned Space Flight Network

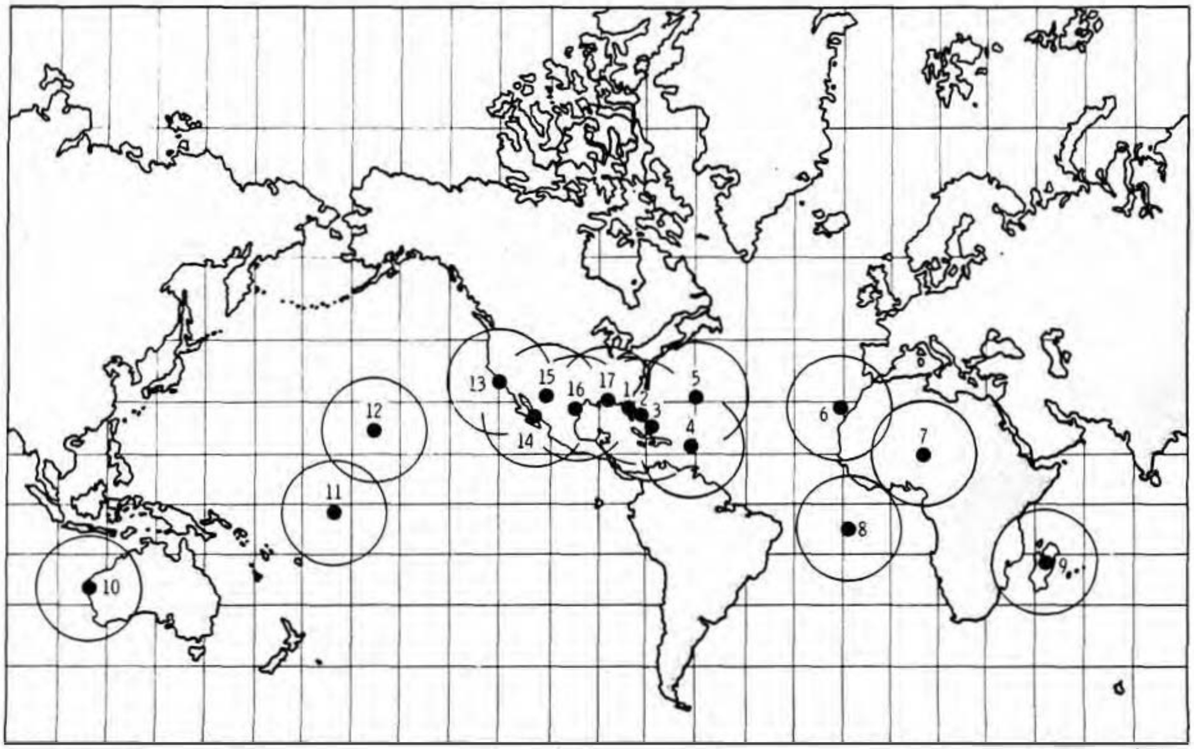
The responsibility of the Manned Space Flight Network during the Gemini Program was to control, to communicate with, and to observe by electronic methods the performance of the spacecraft (systems and occupants) and, on most missions, the Gemini Agena Target Vehicle. The global tracking and reentry network established for Project Mercury and modified for the Gemini Program was a joint NASA/DOD venture. The network was developed by integrating existing DOD range resources with stations established and operated by NASA at strategic sites around the world. In addition, the Australian Weapons Research Establishment operated two stations for NASA. Figure 15–1 shows the location of the tracking sites in the standard configuration for the Gemini rendezvous missions. The locations of the tracking ships varied somewhat as specified by individual mission needs.

DOD Support

DOD support to the Manned Space Flight Network was provided by several agencies.

Eastern Test Range.—The Eastern Test Range (U.S. Air Force) facilities were used in the launch and the orbital phases of the missions. Standard launch-site and instrumentation support were provided as necessary for the launching and performance evaluation of the Gemini Launch Vehicle. The services included propellants, pad safety, range safety, metric and optical tracking, telemetry, and communications, as well as command and control support.

Certain selected facilities at Cape Kennedy and at Eastern Test Range downrange stations also comprised a part of the network for tracking the target vehicle and the spacecraft during orbit and reentry. The facilities included: C-band radars for tracking the spacecraft and target vehicle and S-band radars for tracking the target vehicle; tele-



1. Cape Kennedy	(DOD)	7. Kano, Nigeria	(NASA)	13. Pt. Arguello, Calif.	(DOD)
2. Grand Bahama Island	(DOD)	8. Ascension Island	(DOD)	14. Guaymas, Mexico	(NASA)
3. Grand Turk Island	(DOD)	9. Tananarive, Malagasy	(NASA)	15. White Sands, N. M.	(DOD)
4. Antigua	(DOD)	10. Carnarvon, Australia	(WRE)	16. Corpus Christi, Tex.	(NASA)
5. Bermuda	(NASA)	11. Canton Island	(NASA)	17. Eglin AFB, Fla.	(DOD)
6. Canary Island	(NASA)	12. Kauai, Hawaii	(NASA)		

DOD ships Rose Knot Victor Coastal Sentry Quebec, Range Tracker to be positioned as necessary.
Radar and telemetry aircraft to be positioned as needed.

FIGURE 15-1.—Gemini network stations.

metry recording and display equipment; command and control equipment; ground communications, both voice and teletype; and spacecraft voice communications. The stations designated for orbital support were Cape Kennedy and Grand Bahama, Grand Turk, Antigua, and Ascension Islands.

In addition to the land-based stations, two Eastern Test Range ships, the *Coastal Sentry Quebec* and the *Rose Knot Victor*, were an integral part of the network. These ships provided telemetry, command and control, and communications coverage. The Eastern Test Range also positioned JC-130 aircraft in the primary Atlantic Ocean recovery area to record terminal spacecraft telemetry, and to relay flight-crew voice communications from the landing area to the Mission Control Center—Houston. The resources of the Eastern Test Range were augmented, on a mission-by-mission basis, by such facilities as the C-band radar at Pretoria, South Africa, and instrumented ships.

Pacific Missile Range.—The Pacific Missile Range (U.S. Navy) facilities provided tracking ship support and voice-relay telemetry aircraft for the Eastern Pacific landing area. Early in the Gemini Program, the Pacific Missile Range operated the Hawaii, Canton Island, and California tracking sites. Later the National Range Division and the Western Test Range were established, and the national range resources were realined. As a result, the operations of the Hawaii and the Canton Island sites were transferred to NASA; and the operation of the California site, to the Western Test Range.

Western Test Range.—The Western Test Range (U.S. Air Force) facilities operated the California tracking site. Although not considered a Gemini network station, the U.S. Navy ship *Range Tracker* participated in the Gemini III through Gemini X missions with radar, telemetry, and communications.

White Sands Missile Range.—The White Sands Missile Range (U.S. Army) facilities provided C-band radar support throughout the Gemini Program.

Air Proving Ground Center.—The Air Proving Ground Center (U.S. Air Force) facilities provided C-band radar support throughout the Gemini Program.

North American Air Defense Command.—The North American Air Defense Command support to manned space flight began with Project Mercury. The ability to skin track and catalog orbiting objects, and to compute impact data and separation distances, was beneficial to the Gemini Program. The North American Air Defense Command assisted NASA Goddard Space Flight Center in computing launch-vehicle impact points; provided ephemeris information on the Gemini Agena Target Vehicles left in orbit; and provided the capability to skin track the spacecraft.

Organization

During the coordinating (premission) phase, management of the DOD portion of the Gemini network was the responsibility of the individual range or organizational commander. In planning DOD network support, the DOD Manager and his staff coordinated with the Manned Space Flight Coordinator who was responsible for planning, arranging, and coordinating the resources of his individual range. The Assistant for Network to the DOD Manager coordinated network plans and operating procedures with the Manned Space Flight Coordinator and with NASA to assure proper integration of the DOD stations with the Manned Space Flight Network.

Twenty-four hours prior to launch, the DOD Manager assumed operational control of all DOD forces supporting the mission. The Assistant for Network was part of the operational staff and provided the DOD Manager with network-readiness reports, and assured that the DOD stations operated in accordance with the plans and procedures specified for that mission.

The entire integrated network during the mission was controlled by the network controllers on the staff of the NASA Flight Director at the Mission Control Center—Houston. They conducted the network countdown, conducted premission simulations and tests, and issued last-minute instructions. They also directed network activities during the flight, as necessary, to assure that the required network support for the mission was provided to the flight controllers. The network controllers were assisted by a joint Goddard Space Flight Center/DOD Network Support Team. This team of specialists in each major category of network instrumentation served as technical advisors to the network controllers.

During Project Mercury, and for the first portion of the Gemini Program, the network-control function was performed solely by DOD. After relocation of the Mission Control Center function from Cape Kennedy to Houston, the network-control staff was augmented by NASA personnel from the Manned Spacecraft Center and from the Goddard Space Flight Center. The network-control function was then brought under the direct control of the Manned Spacecraft Center.

Mission Highlights

Gemini I.—For Gemini I, an unmanned orbital mission, the network was in a proper configuration for the Gemini Program. The ships, *Rose Knot Victor* and *Coastal Sentry*

Quebec, were not required to support this mission.

Gemini II.—Gemini II was unmanned and ballistic, requiring only Eastern Test Range tracking facilities. The *Rose Knot Victor* was located up range under the ground track; the *Coastal Sentry Quebec* was located near the landing point. The Antigua radar tracked the spacecraft through the communications blackout period.

Gemini III.—Gemini III was manned and orbital and was the first exercise of the entire network. The U.S. Navy ship *Range Tracker* was added to the network. The communications from the *Coastal Sentry Quebec* were augmented by the U.S. Navy ship *Kingsport* and the SYNCOM II satellite. This was the first time NASA and DOD recovery communications augmented one another. All radars that had been committed to the spacecraft reentry phase obtained track.

Gemini IV.—Gemini IV was a 4-day, manned, orbital mission and used the same network configuration as Gemini III. An Eastern Test Range subcable break was successfully bypassed by using alternate routes. Telemetry monitoring of launch-vehicle reentry and breakup was available through radar tracking from Patrick Air Force Base and Kennedy Space Center.

Gemini V.—Gemini V was an 8-day, manned, orbital mission and full network support was provided. The North American Air Defense Command successfully tracked and provided impact prediction on the second stage of the launch vehicle.

Gemini VI-A and Gemini VII.—Gemini VI-A and Gemini VII used combined flight plans. Gemini VII was a 14-day manned mission; Gemini VI-A was a 2-day, manned, rendezvous mission. Full network support was provided. The ship *Wheeling* was substituted for the ship *Range Tracker*. No significant network failures occurred during the 14-day mission. The performance of the remote-site data processor was superior to that obtained during previous missions.

Gemini VIII.—Gemini VIII was planned as a 3-day rendezvous mission; however, the mission was terminated during the seventh orbit because of a spacecraft control-system malfunction after docking. The U.S. Navy ship *Kingsport* was added for this mission. Excellent network support was available throughout the spacecraft emergency and the reentry.

Gemini IX-A through Gemini XII.—Gemini IX-A was a 3-day rendezvous mission with the Augmented Target Docking Adapter. Both Gemini X and XI were 3-day rendezvous missions with the Gemini Agena Target Vehicle. Gemini XII was a 4-day rendezvous mission with the Gemini Agena Target Vehicle.

The Gemini IX-A through Gemini XII missions required identical network support. Network tracking was excellent; failures were at a minimum and had no effect on the missions. On Gemini IX-A and X, the Computer Acquisition System allowed the Eastern Test Range radars to acquire and to track the spacecraft on reentry. On Gemini XI, a computer was made available at the Western Test Range, and a vector was sent from the Real Time Computer System at the Eastern Test Range to the California site for acquisition. Tracking data were returned to the Real Time Computer System for computing acquisition information for the Eastern Test Range radars.

Summary of Network Support

Significant progress was realized during the Gemini Program not only in improving basic tracking and data transmission, but also in streamlining operation and test procedures to assure more efficient use of the available equipment. Network problems, such as communications failures, inadequate radar tracking, and difficult troubleshooting that occurred during Project Mercury, were reduced so that a fully operative network became a routine occurrence at launch time and throughout the mission.

Modifications and improvements to the C-band radars provided more accurate tracking, easier acquisition, and more rapid processing of the radar data. Using pulse code modulation, the Telemetry System allowed a much greater volume of spacecraft data to be transmitted and displayed at one time. The Digital Command System allowed more complex and a greater number of commands to be sent to the spacecraft; by computer processing, a fail-safe system was provided to assure that the proper command was, in fact, transmitted. The more extensive use of computers, both on site and at the Mission Control Centers, provided for near real-time transmission, reduction, and display of the volumes of data made available by the network. The Gemini Program provided the first real operational testing of many of these new systems and the improvements of older systems. The Digital Command System and Telemetry System, for instance, are gradually replacing older systems on the national ranges.

The Computer Acquisition System was one result of the Gemini network support developed on the DOD ranges. The reentry profile and the primary landing area of the Gemini spacecraft were such that, to provide adequate radar tracking during reentry for landing-point computation, the radars had to acquire during the blackout period. Without highly accurate acquisition information, this was almost an impossible task; however, the means were devised to solve the problem. Prior to blackout, radar-track data were provided to a central computer that had been programed for reentry. These data could be translated into an accurate driving signal to be fed to the radar which would acquire the spacecraft during blackout. The accuracy of the data enabled the radar to follow the actual spacecraft track and to find the weak beacon signal through the ion shield. By use of computers associated with each radar, data could be fed in both directions, and the radars could operate independently. A lack of equipment at the DOD ranges precluded early implementation of the system. Using the Real Time Computer System at Cape Kennedy, a successful test of the theory was accomplished on the Gemini V mission; further tests were run on subsequent missions. Refinements were made and by the time of the Gemini IX–A mission, data from the White Sands radar, processed by the Real Time Computer System, allowed the Eastern Test Range radars to acquire and track the spacecraft during reentry, proving the advantage of the system. Additional computers will be made available at the DOD ranges to add to the system so that the final configuration can be realized.

The Impact Predictor System was an outgrowth and refinement of a capability that had existed at the Eastern Test Range since the Real Time Computer System became operational. This system used radar data from other DOD ranges and the downrange Eastern Test Range sites. The data were processed by the Real Time Computer System and provided a near real-time plot of the spacecraft ground track during reentry. The spacecraft drag factor and the maneuvering information were not entered in the computer program, but the quantity of available downrange data offset this deficiency in the terminal phase of reentry.

Recovery Support

The primary mission of DOD recovery forces during the Gemini Program was to locate and to retrieve the flight crew and spacecraft, and to deliver them to NASA program managers. This responsibility began with the launch of the spacecraft and ended with the delivery of the recovered spacecraft to NASA.

Planning for the spacecraft-location function assumed that information would be available from several sources. One source in computing a probable landing point was the information obtained from the ground tracking stations. In addition, the spacecraft was equipped with a high-frequency radio beacon which enabled the worldwide DOD high-frequency direction-finding network to provide fixing information. The spacecraft was also equipped with an ultrahigh-frequency radio beacon which could be received by airborne forces. The airborne forces used electronic homing for all Gemini missions. An additional electronic source of information not originally anticipated was shipboard radar. Radar information from ships stationed in the Primary Landing Area was particularly valuable; and a contact in excess of 300 miles was reported by the primary recovery ship during recovery of the Gemini VII spacecraft.

Location planning also provided for visual search if electronic means failed. The spacecraft was provided with a sea dye marker to aid in daytime visual location and with a high-intensity blinking light for nighttime search. During the later missions, the location task was simplified when the spacecraft, descending on the main parachute, was visually sighted.

Retrieval of the flight crew was accomplished by helicopter on all but two missions. The Gemini VI–A and Gemini IX–A flight crews elected to remain in the spacecraft for pickup by the recovery ship. Spacecraft retrieval was accomplished by the primary recovery ship on all missions except Gemini VIII, which landed in the West Pacific Secondary Landing Area. In this case, the swimmers were deployed from an aircraft on the scene at spacecraft landing. The team attached the flotation collar to the spacecraft, and the recovery was made by the destroyer supporting the area.

During Gemini II and Gemini III, control of DOD recovery forces by the DOD Manager was accomplished from the Mission Control Center—Cape Kennedy. For all subsequent missions, the DOD Manager and his staff operated from the Recovery Control Center, Houston.

An early problem in the command and control area was the lack of real-time voice information from the recovery scene. For Gemini IV, procedures were developed whereby the flight-crew air-to-ground voice circuit could be used for on-scene recovery operations and could be relayed to the Recovery Control Center; this procedure was followed for all subsequent missions.

The use of functionally descriptive call signs for the recovery forces was instituted during Gemini VI–A and VII. This procedure aided the clarity of recovery force communications and was used in all subsequent missions.

Recovery Areas

Since recovery planning was concerned with all conceivable landing situations, the most effective approach was to orient the planning about certain geographical areas. These were the Launch Site, Launch Abort, Contingency, Secondary, and Primary Areas. All except the Contingency Area were considered planned landing areas.

Launch Site Area.—The Launch Site Area (fig. 15–2) was that area where a landing would occur following an abort in the late stages of the countdown or during early flight. For planning purposes, the area was centered on Launch Complex 19 at Cape Kennedy and extended 3 miles toward the Banana River and 41 miles seaward, with the major axis along the launch azimuth. The actual positioning of launch-site forces was oriented about a much smaller area, with the size and location determined by the launch azimuth and local winds.

The typical launch-site recovery force included four CH–3C amphibious helicopters,

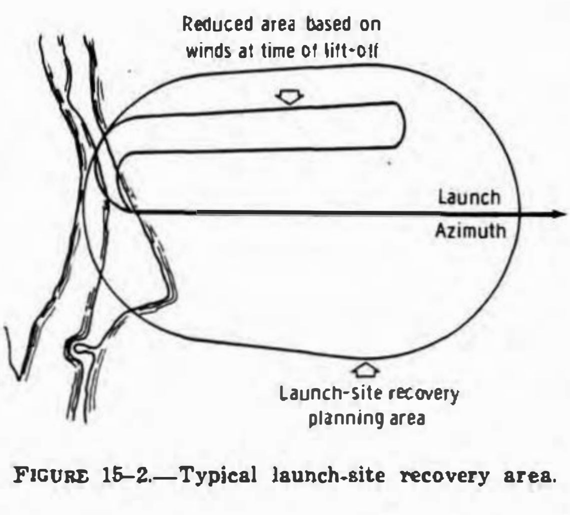


FIGURE 15–2.—Typical launch-site recovery area.

four lighter amphibious resupply cargo (LARC) vehicles, two M–113 personnel carriers, two landing vehicle tracked recovery (LVTR), two rescue boats, and one salvage vessel for in-port standby. The launch-site recovery forces were not required to effect an actual recovery during Gemini.

Launch Abort Area.—The Launch Abort Area was along the launch ground track between Cape Kennedy and the west coast of Africa. An abort might have occurred in this area during the launch phase of flight prior to Earth-orbital insertion. The recovery force posture in the Launch Abort Area underwent considerable change during the Gemini Program as confidence in the launch vehicle and spacecraft systems increased. For example, the on-station launch-abort recovery force for Gemini III consisted of eight destroyers, one fleet oiler, one fleet tug, and nine fixed-wing aircraft. The on-station launch-abort force for Gemini XII was reduced to three destroyers, one aircraft carrier, one fleet oiler, and four fixed-wing aircraft. The launch-abort recovery forces were not required to make an actual recovery during Gemini.

Contingency Recovery Area.—The Contingency Recovery Area comprised the area along the spacecraft ground tracks outside the planned landing areas. Forces supporting this area consisted of Air Force Aerospace Rescue and Recovery Service aircraft deployed to various worldwide staging bases. These forces were capable of reaching any point along the spacecraft ground track within 18 hours. There were no actual contingency-area recoveries during Gemini.

Secondary Landing Areas.—The Secondary Landing Areas which were established for the long-duration missions consisted of four circular zones. Each zone had a radius of 240 nautical miles. The zones were located in the West Atlantic, East Atlantic, West Pacific, and Mid-Pacific. Each zone was supported by a destroyer or a fleet oiler and, in some cases, by a destroyer and an oiler in company. In addition, Air Force Aerospace Rescue and Recovery Service aircraft were positioned adjacent to these zones. Target points were selected in each zone for each time the ground track passed through the zone. These target points were then covered by the supporting ship. The aircraft were on 30-minute strip alert and ready for an immediate takeoff.

The Atlantic zones were covered by the ships and aircraft which had also provided Launch Abort Area coverage during the launch phase of the mission. The East Atlantic Secondary Landing Area was normally supported by a destroyer and a fleet oiler. For Gemini XII, the ship access-time requirement for this area was increased, and sufficient coverage was provided by a fleet oiler equipped with communications and recovery equipment as well as medical personnel.

The value of Secondary Landing Areas and assigned forces was significantly demonstrated on the Gemini V and VIII missions. During the early part of Gemini V mission, the spacecraft developed electrical power-source difficulties. For several revolutions after the problem developed, the spacecraft did not pass through the Primary Landing Area. However, the spacecraft did pass through the Mid-Pacific Secondary Landing Area where air and surface forces were ready to provide support if necessary. The problem was eventually corrected, and the mission was completed as planned.

The value of the Secondary Landing Areas was even more evident during the Gemini VIII flight. Following a successful rendezvous-and-docking maneuver, the docked vehicles developed severe gyrations. The crew was forced to take emergency action which resulted in a low-fuel state in the Reentry Control System. In accordance with preplanned mission rules, the decision was made in this case to land the spacecraft in the West Pacific Secondary Landing Area. The support ship and seven aircraft were alerted, and the first aircraft on the scene sighted the spacecraft descending on the main parachute. The aircraft deployed the swimmers to attach the flotation collar to the spacecraft and to report the condition of the flight crew.

The destroyer arrived on the scene and retrieved the spacecraft and flight crew. Recovery was completed 3 hours 10 minutes after landing.

Primary Landing Area.—The Primary Landing Area was located in the West Atlantic, and the primary recovery ship was assigned to this area. An Amphibious Assault Ship was the primary recovery ship for Gemini X and Gemini XI. A support aircraft carrier was used for this function in all other missions.

The addition of the Amphibious Assault Ship has provided DOD planners more flexibility in scheduling support for manned space-flight missions. This type of ship operates more economically and does not require a rescue destroyer in company. The aircraft carrier has proved to be an effective primary recovery ship, since it serves as a launch and recovery platform for helicopters and provides excellent facilities for postmission evaluation of the flight crew. Helicopters are used in the Primary Recovery Area for the electronic location of the spacecraft and for the transport of the swim teams to and from the spacecraft. During most of the missions, separate helicopters were used for each of these functions. In Gemini XII, the functions were combined by placing the swim teams aboard the search helicopters. This satisfactory arrangement proved economical and operational.

Fixed-wing aircraft were utilized for airborne control of aircraft in the recovery area and for providing a commentary of recovery operations between the recovery forces and shore installations. This information was relayed to the Mission Control Center—Houston in real time through relay aircraft. The relay aircraft provided network support prior to landing and provided recovery support after landing until the flight crew were retrieved.

Beginning with Gemini VI–A and VII, live television broadcasts and recovery operations in the Primary Landing Area were provided. Recovery of the flight crew and spacecraft was televised for all subsequent missions except Gemini VIII. The Gemini VI–A and VII missions established the DOD capability to provide recovery support for a dual mission.

Planned Versus Actual Statistics

Table 15–I presents a compilation of the total DOD resources dedicated to each Gemini mission. The general trend toward reduction of forces as the program progressed is shown.

The second column of table 15–II indicates the distance between the planned target point and the actual landing point of the spacecraft for each Gemini mission. This table also shows the time interval between the spacecraft landing and the arrival of the flight crew aboard ship. Column 4 shows the access time established by NASA for the applicable recovery area; the access time is the principal criterion established for recovery-force operations. This is the elapsed time from spacecraft landing until first-level medical care can be provided the flight crew. Thus, a comparison of the times in columns 3 and 4 provides an indication of recovery-force performance.

Communications

Communications support by DOD forces evolved from a simple network for supporting a ballistic missile launch to complex communications networks of ships, aircraft, ground stations, and worldwide recovery bases and forces for supporting orbital space flights.

In 1960, the Air Force Eastern Test Range was committed to support the first flight of the manned spacecraft program, Mercury-Redstone 1 mission. Cape Kennedy (Cape Canaveral) and Grand Bahama Island, Eastern Test Range stations, were the primary ground stations providing tracking and telemetry support. Other stations were being established to form a worldwide tracking network. The network included airborne platforms for automatic voice relay from a manned spacecraft to the Mission Control Center by means of high-frequency/single-sideband radio and selected ground stations. The DOD communications responsibilities increased as missions progressed from suborbital to orbital. The responsibilities involved the Eastern Test Range, the

TABLE 15–I.—*DOD Support of Gemini Missions*

Mission	Launch date	Duration, hr:min	Personnel	Aircraft	Recovery ship	Ship making spacecraft recovery	Ocean
I (unmanned)	Apr. 8, 1964	[a]5:00	6 176	None	None		
II (unmanned)	Jan 19, 1965	0:18	6 562	67	16	USS *Lake Champlain*[b]	Atlantic
III	Mar. 23, 1965	4:53	10 185	82	27	USS *Intrepid*[b]	Atlantic
IV	June 3, 1965	97:56	10 349	134	26	USS *Wasp*[b]	Atlantic
V	Aug. 21, 1965	190:55	10 265	114	19	USS *Lake Champlain*[b]	Atlantic
VI	Oct. 25, 1965	[c]0:00	10 125	125	16		
VII	Dec. 4, 1965	330:35	10 125	125	16	USS *Wasp*[b]	Atlantic
VI–A	Dec. 15, 1965	25:51	10125	125	16	USS *Wasp*[b]	Atlantic
VIII	Mar. 16, 1966	10:41	9 665	96	18	USS *Mason*[d]	Pacific
IX–A[e]	June 3, 1966	72:21	11 301	92	15	USS *Wasp*[b]	Atlantic
X	July 18, 1966	70:47	9 072	78	13	USS *Guadalcanal*[f]	Atlantic
XI	Sept. 12, 1966	71:17	8 963	73	13	USS *Guam*[f]	Atlantic
XII	Nov. 11, 1966	94:35	9 775	65	12	USS *Wasp*[b]	Atlantic

[a] Tracking time, no recovery intended.
[b] Aircraft carrier.
[c] Mission aborted.
[d] Destroyer. Mission terminated in Secondary Landing Area. USS *Boxer* was planned recovery carrier.
[e] Gemini IX aborted May 17 due to failure of target vehicle.
[f] Amphibious Assault Ship (helicopter carrier).

TABLE 15-II.—*Gemini Recovery Operations*

Mission	Landing distance from target point, n. mi.	Time from landing to flight crew aboard recovery ship, min	Maximum ship access time, hr	Remarks
I		Unmanned		No recovery intended
II	14	Unmanned		
III	60	70	4	
IV	44	57	4	
V	91	89	4	
VI–A	7	66	4	Crew remained in spacecraft
VII	6.4	33	4	
VIII	1.1	190	6	Landing in West Pacific Zone
IX–A	0.38	52	4	Crew remained in spacecraft
X	3.4	28	4	
XI	2.65	24	4	
XII	2.6	30	4	

Eglin Gulf Test Range, the White Sands Missile Range, and the Pacific Missile Range, as well as associated ships and aircraft integrated into one network under a DOD-designated network controller. The Air Force Western Test Range, organized in 1965, includes Vandenberg Air Force Base, Calif.; Hawaii; Eniwetok; and ships and aircraft supporting the Pacific area.

During the Mercury and Gemini manned space flights, many new theories, different support and response, and mechanics of accomplishing the missions were developed by DOD. The transmission of high-speed radar data for manned missions; the use of airborne platforms for tracking, telemetry, and automatic voice relay; and the procedures for integrating the DOD Service and National Ranges with the NASA stations were improved.

While much consideration was accorded a buildup of networks to support the orbital portion of a flight, action was also taken to provide the worldwide deployed recovery forces with communications systems that were adequate, responsive, and reliable. The complete resources of DOD were made available through the facilities of the Defense Communications Agency, Unified and Specified Commands, as well as through the resources of the separate commands. Progression was evident in the method of providing teletype communications (written copy) service. Early in Project Mercury, the facilities of the Army, Navy, and Air Force were used to provide teletype information to the forces and bases under the command of each of the services. To gain operational control, to improve response time, and to insure real-time reaction, the Army (Fort Detrick, Md.) was given the responsibility for the automatic relay-switching center, interconnecting the recovery staff of the DOD Manager with the deployed recovery forces. Voice communications links were also made available from the Defense Communications Agency, commercial carriers, ranges, and military commands. Recovery communications support increased; and a vast network of dedicated, common-user circuits connecting the worldwide deployed forces on a near real-time basis was available for Gemini XII. This system was capable of supporting as many as 131 aircraft, 28 surface vessels, 30 land-based sites, and 5 major recovery control centers. Each recovery force was given a complete test prior to each mission to assure readiness to support nominal as well as nonnominal missions.

Under the direction of the DOD Manager's Assistant for Communications, the DOD communications assets were activated and tested approximately 7 days prior to flight. The assets were tested for station-to-station alinement procedures, alternate and diverse routing, and equipment and manpower readiness. For orbital support, the NASA and DOD tracking/telemetry stations integrated the communication functions systems for network simulations about 15 days prior to flight.

In addition to insuring that necessary circuitry was available and ready to support the mission, key individuals were deployed by the Assistant for Communications to key communications locations. These individuals were to provide quick response to unforeseen situations, to assist field commanders with any communications problem that could not be resolved locally, and to insure that DOD forces conformed to documented and last-minute communication needs as a single and integrated system. Possible improvements to communications equipment, terminal locations, and procedures were constantly studied to assure that the best possible support was available to manned spacecraft missions.

Meteorology

The short duration of the Project Mercury missions allowed confirmation of acceptable weather conditions in the recovery areas. In the planning stage of the Gemini Program, however, it became apparent that weather conditions in the planned recovery areas would have to be monitored continuously in order to determine the suitability of recovery areas. As a result, the National Range Division staff meteorologist was designated the Assistant for Meteorology to the DOD Manager.

Special weather observations were made from DOD ships in the recovery areas and from weather reconnaissance aircraft. Both Air Force and Navy aircraft were used for Gemini weather reconnaissance and were specially equipped for hurricane and typhoon reconnaissance. Each of the four recovery zones for the Gemini missions was supported by one reconnaissance flight each day as needed.

Special weather support, using balloon and meteorological rocket-equipped instrumentation, was provided at selected locations with high-level atmospheric data for postflight analysis.

Bioastronautics

The Bioastronautics Operational Support Unit at Cape Kennedy was completed in time to support the launch of Gemini III on March 23, 1965.

Bioastronautics at the Air Force Eastern Test Range is one of the many complex assignments of a DOD organization. The Director of Bioastronautics is responsible for providing assistance to NASA as required in prelaunch evaluation of the flight crew, biomedical monitoring during orbital flight, medical support for recovery operations, and postflight evaluation.

Medical support for the early Jupiter flights that carried animal life was provided by a joint-services team of three officers designated as the Aero-Medical Consultant Staff. In November 1959, NASA requested DOD to provide the medical support team for Project Mercury. The DOD representative for Project Mercury support appointed his Staff Surgeon to the newly established position of Assistant for Bioastronautics to manage these support activities. The function of this new office was to organize a worldwide DOD medical support capability and to deploy people and materiel as requested by NASA. This first Assistant for Bioastronautics was responsible to the 6550th U.S. Air Force Hospital at Patrick Air Force Base and to the Air Force Missile Test Center commander. In January 1962, the Assistant for Bioastronautics was designated an additional duty position for the redesignated Deputy for Bioastronautics, Air Force Eastern Test Range. In March 1963, the Office of the Deputy for Bioastronautics was selected by the Surgeon General of the U.S. Air Force to provide primary training that would satisfy the requirements for the third year of residency training in aerospace medicine.

Public Affairs

The Director of Information of the Air Force Eastern Test Range was designated as the Assistant for Public Affairs to the DOD Manager under the DOD/NASA agreement. The areas of responsibility of the Assistant for Public Affairs began at Cape Kennedy and extended to Hawaii and to Europe.

The operation of the press sites, including fiscal management and technical organization, was also the responsibility of the Assistant for Public Affairs. The news pools at Cape Kennedy during a launch and those at sea were operated under established rules.

DOD information desks were established in the two major NASA news centers approximately 5 days before the mission and were manned until the day after spacecraft recovery. Beginning 2 hours before mission lift-off and continuing through recovery, DOD public affairs consoles in the recovery control centers were operated 24 hours a day. Manpower assistance was provided by other military commands and departments under the supervision of the Assistant for Public Affairs. Of the 10 100 newsmen accredited during the Gemini Program, nearly 7000 operated in the Cape Kennedy area, and the remainder, in Houston.

16. PRE-GEMINI MEDICAL PREDICTIONS VERSUS GEMINI FLIGHT RESULTS

By CHARLES A. BERRY, *M.D., Director of Medical Research and Operations, NASA Manned Spacecraft Center;* and ALLEN D. CATTERSON, *M.D., Office of Medical Research Operations, NASA Manned Spacecraft Center*

Summary

The Mercury and Gemini space flights provided approximately 2000 man-hours of weightless exposure for evaluating predicted effects of space flights versus actual findings. In general, the environmental hazards and the effects on man appear to be of less magnitude than originally anticipated. The principal physiologic changes noted were orthostatism for some 50 hours postflight as measured with a tilt table, reduced red-cell mass (5 to 20 percent), and reduced X-ray density (calcium) in the os calcis and the small finger. No abnormal psychological reactions have been observed, and no vestibular disturbances have occurred that were related to flight. Drugs have been prescribed for inflight use. The role of the physician in supporting normal space flight is complex, requiring the practice of clinical medicine, research, and diplomacy. Although much remains to be learned, it appears that if man is properly supported, his limitations will not be a barrier to the exploration of the universe.

Introduction

Prior to the first exposure of man to orbital space flight, the biomedical community expressed considerable concern over man's capability not only to perform in such an environment but even to survive in it. Since weightlessness was the one unknown factor which could not be exactly duplicated in a laboratory on the ground, numerous investigators and various committees predicted some effect on almost every body system. It is understandable that detrimental effects were the ones listed, as these could have been limiting factors in manned space flight. In some respects, the medical community becomes its own worst enemy in the attempt to protect man against the hazards of new and unknown environments. Frequently, the physician dwells upon the possible individual system decrements, and forgets the tremendous capability of the body to maintain a state of homeostasis in many environments. Following the first manned space flights, some of these anxieties were reduced, although most observers believed the evidence was insufficient to reject any of the dire predictions.

Predicted and Observed Environment and Human Responses

The successful and safely conducted Mercury and Gemini Programs have provided the first significant knowledge concerning man's capability to cope with the environment of space. In these programs, 19 men have flown 26 man-flights for a total weightless experience of approximately 2000 man-hours. Three individuals have flown as the single crewman in Mercury and as one of the two crewmen in the Gemini spacecraft; four individuals have flown twice in the Gemini spacecraft. The flight programs are summarized in tables 16-I and 16-II. This flight experience only scratches the surface of detailed space exploration, but should provide a sound basis for comparing the predic-