

16. PRE-GEMINI MEDICAL PREDICTIONS VERSUS GEMINI FLIGHT RESULTS

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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-

tions concerning man's support and response to this environment with the reality of the findings from the actual experience.

The space-flight environment predictions are compared with the actual observations in table 16-III.

The human responses to space flight which were predicted are compared with the observations in table 16-IV. There were more predicted system effects than were observed,

though there were also several effects noted which were not predicted.

General Aspects of the Flight Program

In evaluating the results of flight programs, it is important to realize that man is being exposed to multiple stresses and that it is impossible at the present time to evaluate the stresses singly, either inflight or post-

TABLE 16-I.—*Project Mercury Manned Flights*

Flight	Crew	Launch date	Description	Duration, hr:min
MR-3	Shepard	May 5, 1961	Suborbital	0:15
MR-4	Grissom	July 21, 1961	Suborbital	0:15
MA-6	Glenn	Feb. 20, 1962	Orbital	4:56
MA-7	Carpenter	May 24, 1962	Orbital	4:56
MA-8	Schirra	Oct. 3, 1963	Orbital	9:14
MA-9	Cooper	May 15, 1963	Orbital	34:20

TABLE 16-II.—*Gemini Manned Space Flights*

Gemini mission	Crew	Launch date	Description	Duration, day:hr:min
III	Grissom Young	Mar. 23, 1965	Three revolution manned test	0:04:52
IV	McDivitt White	June 3, 1965	First extended duration and extravehicular activity	4:00:56
V	Cooper Conrad	Aug. 21, 1965	First medium-duration flight	7:22:56
VII	Borman Lovell	Dec. 4, 1965	First long-duration flight	13:18:35
VI-A	Schirra Stafford	Dec. 15, 1965	First rendezvous flight	1:01:53
VIII	Armstrong Scott	Mar. 16, 1966	First rendezvous and docking flight	0:10:41
IX-A	Stafford Cernan	June 3, 1966	Second rendezvous and docking; first extended extravehicular activity	3:01:04
X	Young Collins	July 18, 1966	Third rendezvous and docking; 2 extravehicular activity periods; first docked target-vehicle-propelled high-apogee maneuver	2:22:46
XI	Conrad Gordon	Sept. 12, 1966	First rendezvous and docking initial orbit; 2 extravehicular activity periods; second docked target-vehicle-propelled high-apogee maneuver; tether exercise	2:23:17
XII	Lovell Aldrin	Nov. 11, 1966	Rendezvous and docking; umbilical and 2 standup extravehicular activity periods; tether exercise	3:22:37

TABLE 16-III.—*Space-Flight Environment*

Predicted	Observed
Micrometeorite density	Low micrometeorite density
Loss of cabin pressure-vacuum	5 psi except during extravehicular activity
Loss of suit pressure-vacuum	Space suit, wear unpressurized (pressurized on extravehicular flights)
Toxic atmosphere	100-percent oxygen
Cabin and suit temperature	Minimal variation about comfort zone
Radiation levels	Insignificant
Isolation	None
Physical confinement	Physical restraint
Weightlessness	Weightlessness
Gravity loads	Gravity loads, no problem with performance
Vibration	Minimal vibration
Severe glare	Varying illumination
(a)	Workload higher than expected

* Not predicted.

TABLE 16-IV.—*Human Response to Space Flight*

Predicted	Observed
Dysbarism	None
Disruption of circadian rhythms	None
Decreased g-tolerance	None
Skin infections and breakdown	Dryness, including dandruff
Sleepiness and sleeplessness	Interference (minor)
Reduced visual acuity	None
(a)	Eye irritation
(a)	Nasal stuffiness and hoarseness
Disorientation and motion sickness	None
Pulmonary atelectasis	None
High heart rates	Launch, reentry, extravehicular activity
Cardiac arrhythmias	None
High blood pressure	None
Low blood pressure	None
Fainting postflight	None

* Not predicted.

TABLE 16-IV.—*Human Response to Space Flight—Concluded*

Predicted	Observed
Electromechanical delay in cardiac cycle	None
Reduced cardiovascular response to exercise	None
(a)	Absolute neutrophilia
Reduced blood volume	Moderate
Reduced plasma volume	Minimal
(a)	Decreased red-cell mass
Dehydration	Minimal
Weight loss	Variable
Bone demineralization	Minimal calcium loss
Loss of appetite	Varying caloric intake
Nausea	None
Renal stones	None
Urinary retention	None
Diuresis	None
Muscular incoordination	None
Muscular atrophy	None
(a)	Reduced exercise capacity
Hallucinations	None
Euphoria	None
Impaired psychomotor performance	None
Sedative need	None
Stimulant need	Occasionally before reentry
Infectious disease	None
Fatigue	Minimal

* Not predicted.

flight. Man is exposed to multiple stresses which may be summarized as: full pressure suit, confinement and restraint, 100-percent oxygen and 5-psia atmosphere, changing cabin pressure (launch and reentry), varying cabin and suit temperature, acceleration g-force, weightlessness, vibration, dehydration, flight-plan performance, sleep need, alertness need, changing illumination, and diminished food intake. Some of the stresses can be simulated in ground-based studies but the actual flight situation has never been duplicated, and more data from additional flight programs are necessary before flight

observations can be applied to the ground situation.

It is necessary to provide the capability to monitor the physiologic state of man during flight activities. A great deal of consideration has been given to the definition of a set of physiologic indices which might be easily obtained in the flight situation and which could be meaningfully monitored. Routine parameters have included measurements of voice, two leads for electrocardiogram, respiration, body temperature, and blood pressure (fig. 16-1). Other functions were added for the experiments program, but were not monitored in real time. The monitoring of man's physiologic state in flight is necessary to provide information for real-time decision making concerning the accomplishment of additional flight objectives; to assure the safety of the flight crew; and to obtain experimental data for postflight analysis for

predictions concerning the effects of long-duration flight upon man. The sensors and equipment should not interfere with the comfort and the function of the crew. Whenever possible, the procurement of data should be virtually automatic, requiring little or no action on the part of the crewmen. A great deal has been learned concerning the use of minimal amounts of data obtained at intermittent intervals while a spacecraft is over a tracking station. The extravehicular crewmen have been monitored by means of one lead each of electrocardiogram and of respiration-rate measurement obtained through the space-suit umbilical. Additional physiologic information, such as suit or body temperature and carbon-dioxide levels, could not be obtained due to the limited number of monitoring leads available in the umbilical.

The medical objectives in the manned space-flight program are to provide medical support for man, enabling him to fly safely in order to answer the following questions:

- (1) How long can man be exposed to the space-flight environment without producing significant physiologic or performance decrement?

- (2) What are the causes of the observed changes?

- (3) Are preventive measures or treatment needed, and if so, what are best?

Attainment of these objectives will involve tasks with different orientation. The most urgent task is obviously to provide medical support to assure flight safety through the development of adequate preflight preparation and examination, as well as inflight monitoring. The second is to obtain information on which to base the operational decisions for extending the flight duration in a safe manner. The third task differs from the operational orientation of the first two in that it implies an experimental approach to determine the etiology of the findings observed. Frequently, many things that would contribute to the accomplishment of the last task must be sacrificed in order to attain the overall mission objective. This requires con-



FIGURE 16-1.—Gemini biosensor harness.

stant interplay between the experimental and the operational medical approaches to the missions.

The medical profession requires a team effort by personnel with varied training and backgrounds in order to reach a common objective, the preservation or the restoration of health for mankind. This is no less true in a space-flight environment where a strong team effort is necessary, and a strong engineering interface is imperative. If man is to be properly supported, medical requirements concerning the spacecraft environment and the equipment performance must be supplied very early in the hardware development cycle. A very long leadtime is necessary to meet realistic flight schedules, and ample time must always be left for proper testing of the hardware. Flight-configured hardware should be utilized to collect the baseline physiologic data which will be compared with the inflight data.

Anticipated Problems Compared with Flight Results

The review of a number of aerospace or space medicine texts published since 1951 reveals a large number of anticipated problems involving man and the hardware or vehicle in the space environment. It appears logical to compare the predictions with the actual flight results.

Maintenance of Cabin Pressure

In regard to the vacuum of space, extrapolating from aircraft experience led to a prediction of difficulty with the maintenance of cabin pressure. To date, the spacecraft have maintained a cabin pressure of approximately 5 psia throughout the manned flights. The pressurization feature of the space suits was a backup to the cabin pressure, but was not required except during the planned excursions outside the spacecraft when the cabin was intentionally depressurized. The normal suit pressures have been approximately 3.7 psia.

Cabin Atmosphere

Reduction in cabin pressure to 5 psia, equivalent to a pressure altitude of 27 000 feet, and the further reduction to 3.7 psia in the space suit created some concern about the possible development of dysbarism. Before each mission, the crew was denitrogenated by breathing 100-percent oxygen for 2 hours; this, coupled with the further denitrogenation accomplished in the spacecraft, has proved to be ample protection. There have been no evidences of dysbarism on any of the missions.

Cabin and Suit Temperature

The maintenance of an adequate temperature in the cabin and in the extravehicular pilot's suit was also a matter of concern. The temperatures were generally within the comfort range around 70° F. During one mission, the crew reported being cold when the spacecraft was powered down and rotating. The extravehicular pilots generally have been warm while inside the spacecraft because the extravehicular suit contains additional layers of material.

Micrometeorites

Micrometeorites are a subject heading in every book relating to space flight. They are mentioned as a possible hazard to cabin integrity, to spacecraft window surfaces, and to extravehicular crewmen. No significant micrometeorite or meteorite density has been observed in the flights to date. There has been no evidence of micrometeorite hits on the extravehicular suits; however, a micrometeorite protective layer is provided.

Radiation

The radiation environment of space has been sampled by numerous probes and has been calculated at length. With one exception, the flights have not reached an altitude involving the inner Van Allen belt, but the flights have routinely passed through the

South Atlantic anomaly. The onboard radiation measuring system and the personal dosimeters attached to the crewmen confirmed that the radiation intensity was at the lower end of the calculated range. In a 160-nautical-mile orbit, the crew received approximately 15 millirads of radiation in each 24 hours of exposure. Table 16-V indicates the total doses received on the flights to date.

Light and Darkness

Many predictions were made concerning the effect of the changing light and darkness producing a day and a night every 90 minutes. It was generally predicted that this would totally disrupt the circadian rhythms, producing grave consequences. Certainly no overt effects of the 45 minutes of day and 45 minutes of night were observed on the short missions. As knowledge of sleep in the space-flight environment increased, it was determined best to arrange the work-rest cycles so that sleep occurred at the normal Cape Kennedy sleep time. The spacecraft was artificially darkened by covering the windows, and as far as the crew were concerned, it was

night. The physiological response in heart rate to the regime used on the 14-day flight is shown in figure 16-2.

Gravity Load

During space flight, the increase of gravity load during launch and reentry, and the nullification of gravity load and production of a state of weightlessness during actual flight, were expected to produce detrimental effects. Actually, gravity loads during the missions were well within man's tolerances, with two 7g peaks occurring at launch, and with g-forces varying from 4 to 8.2g at reentry. Much concern was expressed about a decreased tolerance to gravity following weightless flight. No evidence of this has been observed; following 4 days of weightless flight, the Gemini IV crew sustained a peak of 8.2g without adverse effects.

Weightlessness has been the subject of innumerable studies and papers. It has been produced for brief periods in parabolic flight in aircraft, and simulated by water immersion and bedrest. The Gemini Program has produced a fair amount of evidence concerning the effect of the weightless space-flight environment on various body systems.

TABLE 16-V.—Radiation Doses on Gemini Missions*

Mission	Duration, day:hr:min	Mean cumulative dose, mrad	
		Command pilot	Pilot
III.....	0:04:52	<20	42±15
IV.....	4:00:56	42±4.5	50±4.5
V.....	7:22:56	182±18.5	170±17
VI-A.....	1:01:53	25±2	23±2
VIII.....	13:18:35	155±9	170±10
VIII.....	0:10:41	<10	10
IX-A.....	3:01:04	17±1	22±1
X.....	2:22:46	670±6	765±10
XI.....	2:23:17	29±1	26±1
XII.....	3:22:37	<20	<20

* Dosimeters located in helmet, right and left chest, and thigh.

Skin

In spite of the moisture attendant to space-suit operations, the skin has remained in remarkably good condition through flights up to 14 days in duration. Following the 8-day flight, there was some drying of the skin

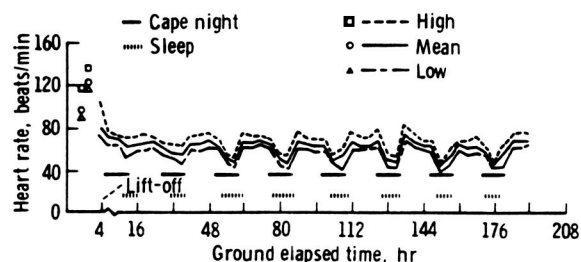


FIGURE 16-2.—Gemini VII pilot heart rate.

noted during the immediate postflight period, but this was easily treated with lotion. There have been no infections, and there has been minimal reaction around the sensor sites. Dandruff has been an occasional problem, but has been easily controlled with preflight and postflight medication.

Central Nervous System

The best indication of central nervous system function has been the excellent performance of the crew on each of the missions. This was graphically illustrated by the demanding performances required during the aborted launch of Gemini VI-A; the rendezvous and the thruster problem on Gemini VIII; the extravehicular activity on Gemini IV, IX-A, X, XI, and XII; and the many accurate spacecraft landings and recoveries.

Psychological tests have not been conducted as distinct entities unrelated to the inflight tasks. Instead, the evaluation of total human performance has provided an indication of adequate central nervous system function. There has been no evidence, either during flight or postflight, of any psychological abnormalities.

The electroencephalogram (fig. 16-3) was utilized to evaluate sleep during the 14-day mission. A total of 54 hours 43 minutes of interpretable data was obtained. Variations in the depth of sleep from Stage 1 to the deep sleep of Stage 4 were noted in flight as in the ground-based data.

Numerous visual observations have been reported by the crews involving inflight sightings and descriptions of ground views. The actual determination of visual acuity has been made in flight, as well as in preflight and



FIGURE 16-3.—Electroencephalogram equipment.

postflight examinations. All of these tests support the statement that vision is not altered during weightless flight.

As previously noted, there has been much conjecture concerning vestibular changes in a weightless environment. There has been no evidence of altered vestibular function during any of the Gemini flights. Preflight and postflight caloric vestibular function studies have shown no change, and special studies of the otolith response have revealed no significant changes. There have been ample motions of the head in flight and during roll rates with the spacecraft. There has been no vertigo nor disorientation noted, even during the extravehicular activity with occasional loss of all visual references. Several crewmen have reported a feeling of fullness in the head similar in character to the fullness experienced when one is turned upside down, allowing the blood to go to the head. However, there has been no sensation of being turned upside down, and the impression is that this sensation results from altered distribution of blood in the weightless state. To clear the record, two of the Mercury pilots developed difficulties involving the labyrinth; the difficulties were in no way related to the space flights. One developed prolonged vertigo as the result of a severe blow over the left ear in a fall, but he has completely recovered with no residual effect. The other crewman developed an inflammation of the labyrinth some 3 years after his 15-minute space flight, and, while he continues to have some hearing loss, there have been no further vestibular symptoms. It is interesting to note this absolute lack of any inflight vestibular symptoms, in spite of the fact that a number of the pilots have developed motion sickness while in the spacecraft on the water.

Eye, Ear, Nose, and Throat

There have been two inflight incidents of rather severe eye irritation. One was the result of exposure to lithium hydroxide in the suit circuit; the cause of the other remains a mystery. In a few instances, some postflight

conjunctival infection has been noted, but has lasted only a few hours and is believed to have been the result of the oxygen environment. During the early portions of the flights, normally the first 2 or 3 days, some nasal stuffiness has been noted. This also is undoubtedly related to the 100-percent oxygen environment and is usually self-limited. On occasion, the condition has been treated locally or by oral medication.

Respiratory System

Preflight and postflight X-rays have failed to reveal any atelectasis. Pulmonary function studies before and after the 14-day mission revealed no alteration. There have been no specific difficulties or symptomatology involving the respiratory system; however, some rather high respiratory rates have been noted during heavy workloads in the extravehicular activity. Even when these rates have exceeded 40 breaths per minute, they have not been accompanied by symptomatology.

Cardiovascular System

The cardiovascular system was the first of the major body systems to show physiologic change following flight; as a result, it has been extensively investigated by various means (fig. 16-4). As previously reported, the peak heart rates have been observed at launch and at reentry (table 16-VI); the rates normally reached higher levels during the reentry period. The midportions of all the missions have been characterized by more stable heart rates at lower levels with adequate response to physical demands.

The electrocardiogram has been studied in detail throughout the Gemini missions. The only abnormalities of note have been very rare, premature, auricular and ventricular contractions. No significant changes have been detected in the duration of specific segments of the electrocardiogram.

Blood-pressure measurements obtained during the Gemini VII mission revealed that

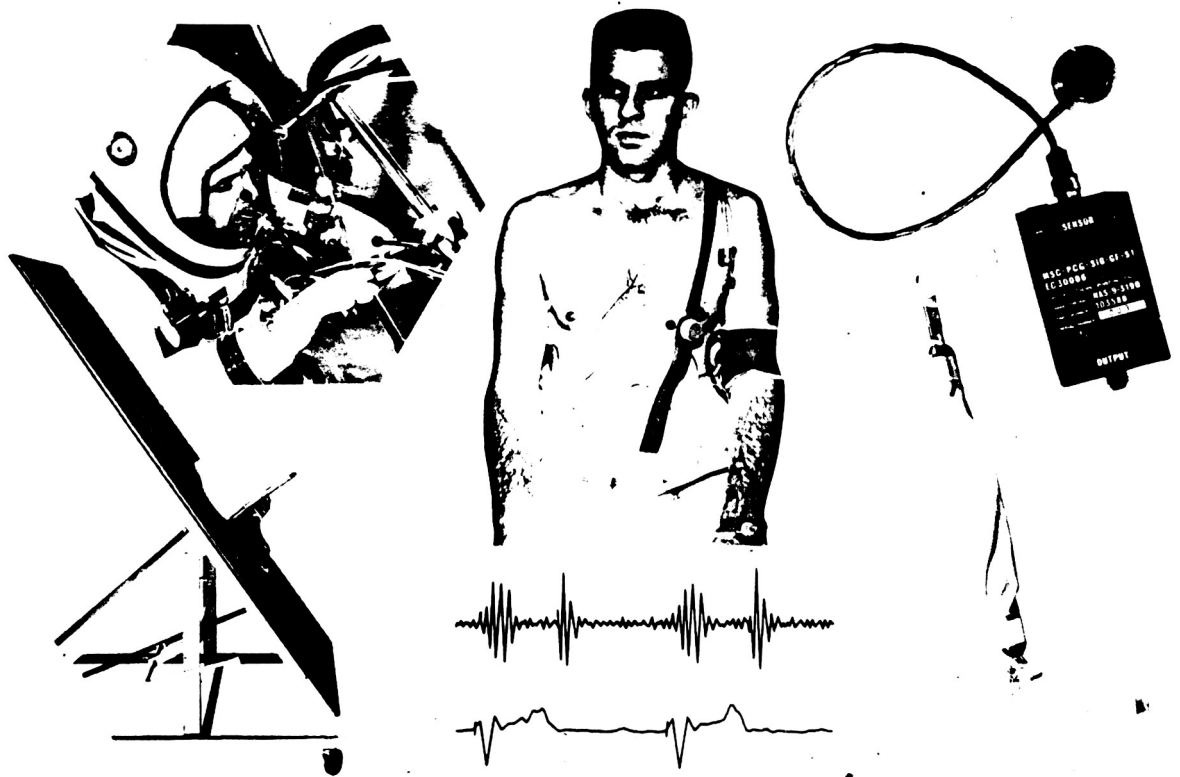


FIGURE 16-4.—Gemini cardiovascular evaluation techniques.

systolic and diastolic values remained within the envelope of normality and showed no significant changes throughout 14 days of flight. As previously reported, this included the pressures taken at the time of reentry.

Some insight into the electrical and mechanical phases of the cardiac cycle was gained during the Gemini flights. The data were derived through synchronous phonocardiographic and electrocardiographic monitoring. In general, wide fluctuations in the duration of the cardiac cycle, but within physiological limits, were observed throughout the missions. Fluctuations in the duration of electromechanical systole correlated closely with changes in heart rate. Stable values were observed for electromechanical delay (onset of ventricular activity, QRS complexes, to onset of first heart sound) throughout the missions, with shorter values observed during the intervals of peak heart rates recorded

during lift-off, reentry, and extravehicular activity. The higher values observed for the duration of systole and for electromechanical delay in certain crewmembers suggest a preponderance of cholinergic influences (vagal tone). An increase in adrenergic reaction (sympathetic tone) was generally observed during lift-off, reentry, and in the few hours preceding reentry.

As a further measure of cardiovascular status, Experiment M003, Inflight Exerciser, determined the heart-rate response to an exercise load consisting of one pull per second for 30 seconds on a bungee device (force at full extension of 12 inches equaled 70 pounds). The responses for one crewman on the Gemini V mission are shown in figure 16-5. The results of the 4-day Gemini IV and the 14-day Gemini VII mission did not differ. This variant of the step test revealed no physical or cardiovascular decrement after

TABLE 16-VI.—*Peak Heart Rates During Launch and Reentry*

Gemini mission	Crewman ^a	Peak rates during launch, beats/min	Peak rates during reentry, beats/min
III	CP	152	165
	P	120	130
IV	CP	148	140
	P	128	125
V	CP	148	170
	P	155	178
VI-A	CP	125	125
	P	150	140
VII	CP	152	180
	P	125	134
VIII	CP	138	130
	P	120	90
IX-A	CP	142	160
	P	120	126
X	CP	120	110
	P	125	90
XI	CP	166	120
	P	154	117
XII	CP	136	142
	P	110	137

^a CP indicates command pilot; P indicates pilot.

as much as 14 days in a space-flight environment.

In contrast to the Project Mercury results, orthostatism resulting from any Gemini mission has not been detectable except by means of passive tilt-table provocation. Typically, the heart-rate and blood-pressure response to a 15-minute, 70° tilt performed postflight are compared with identical preflight testing on the same crewmen. Consistently, such testing has demonstrated a greater increase in heart rate, a greater reduction in pulse pressure, and a greater increase in leg volume, as interpreted from lower limb circumference gages during the preflight tilt (fig. 16-6). The changes observed in these variables may be most significantly illustrated by examining the heart-rate changes observed during preflight and postflight tilt-table studies. When the postflight increases in heart rate during tilt are expressed as percent of the preflight

tilt heart rate for each of the Gemini crews, the postflight increases are from 17 to 105 percent greater than those exhibited preflight. The increasing trend in these values was evident through the 8-day mission. A multiplicity of altered factors, such as better diet, more exercise, desuited periods, and no extravehicular activity, make the improved postflight response to the 14-day mission very difficult to interpret (fig. 16-7).

For purposes of comparison, flight data and data from bedrest studies were viewed in a like manner and show a very similar trend; however, the magnitude of the changes shows marked differences, again illustrating, perhaps, the influence of factors other than those simulated by bedrest.

When the tilt-table tests are considered, postflight leg volume was universally greater than preflight. Postmission observations ranged from 12 to 82 percent increase in volume over premission values.

The Gemini V pilot wore intermittently occlusive lower limb cuffs for the first 4 days of the 8-day mission. The Gemini VII pilot wore the cuffs for the entire 14-day mission; however, his heart-rate increases and pulse-pressure narrowing were greater than for the command pilot; the cuffs seemingly did not alter the variables.

Average resting heart rates have ranged from 18 to 62 percent higher after missions. In spite of higher resting pulse rates, the changes resulting from tilt were still greater. The exception presented by the Gemini VII crew is more apparent. The bedrest data are not remarkable.

To date, the observations of the effect of space flight on body systems have shown significant changes involving only the cardiovascular, hematopoietic, and musculoskeletal systems. Even these changes appear adaptive in nature and are measured principally during the readaptive phase to the 1g environment. It appears that adequate information has been obtained to permit anticipation of a nominal lunar mission without being surprised by unforeseen physiologic changes. Medical results from the U.S. space flights

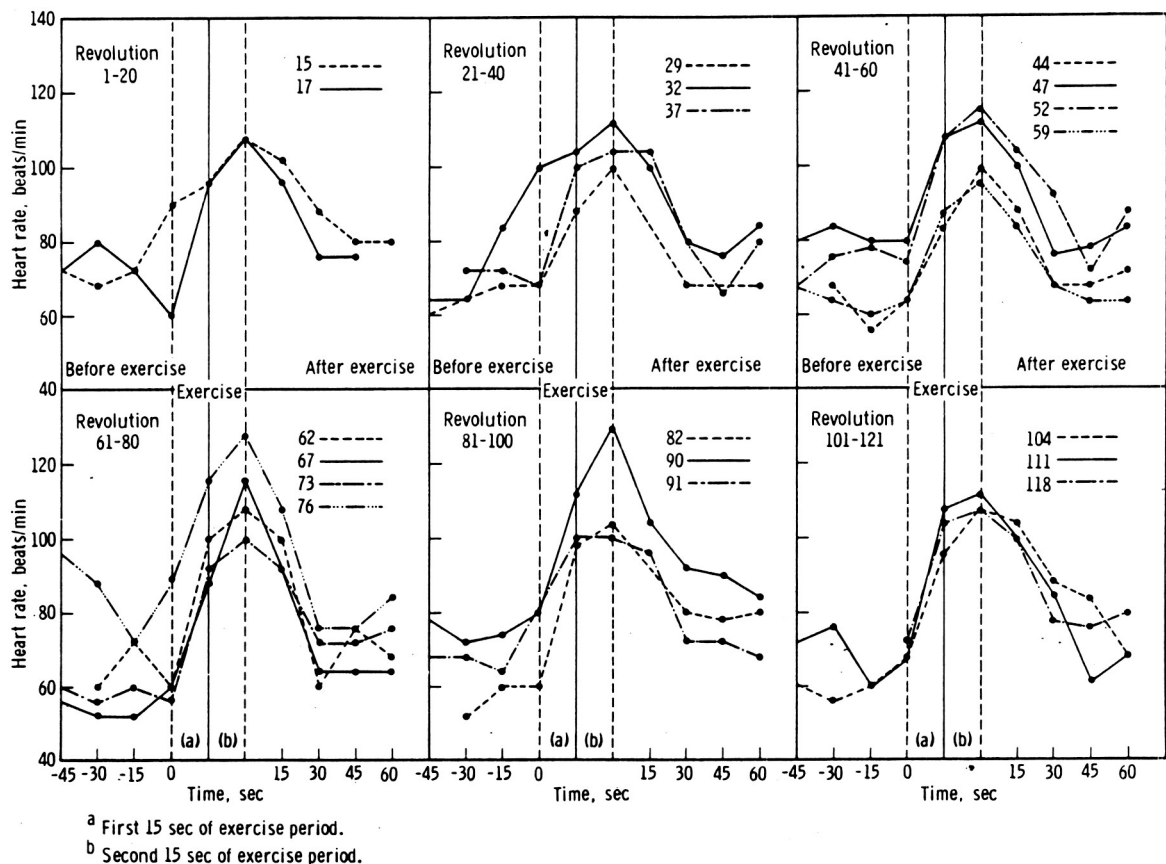


FIGURE 16-5.—Heart-rate response to hungee exercise, Gemini V pilot.

appear to differ from the results reported by the U.S.S.R., where there seems to be a unique problem in the area of vestibular response. In the cardiovascular area, the United States has not confirmed the U.S.S.R. reports of electromechanical delay in cardiac response, and the U.S.S.R. has not confirmed the U.S. findings of decreased red-cell mass.

The Gemini flights have also provided some excellent examples of human variability and have emphasized the necessity for care in making deductions. In making projections based on very limited results in a few people, the current trend is to bank heavily upon comparisons in a given individual; that is, differences between baseline data and responses observed during and after a flight. The crewmen who have flown twice have

shown variability between flights in the same manner as have different men on the same flight. Figure 16-8 shows the heart rates for one crewman during the launch phase of both his Mercury mission and his Gemini mission. The two curves show little correlation and could as easily have come from different individuals. Obviously, confidence in the results and the definition of variability will be improved as more information is gained on future flights. Also, these are gross system findings, and much must still be accomplished in the laboratory and in flight if the mechanisms of the findings are to be understood.

Although physiological adaptation is difficult to define, it might be stated as any alteration or response which favors the survival of an organism in a changed environment. This

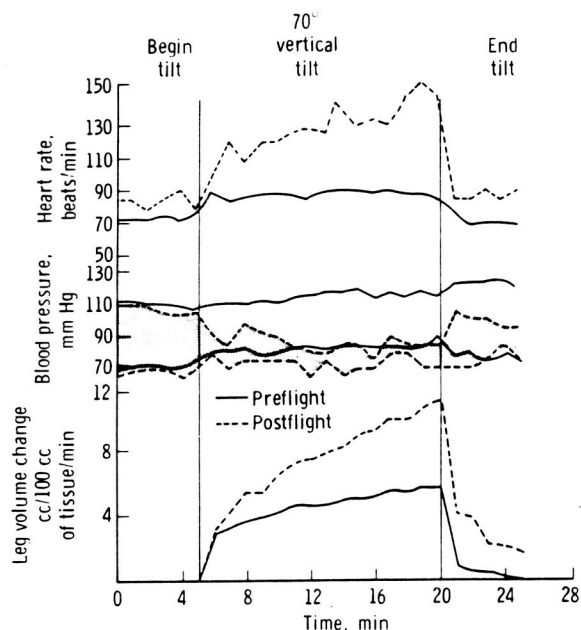


FIGURE 16-6.—Typical tilt-table response.

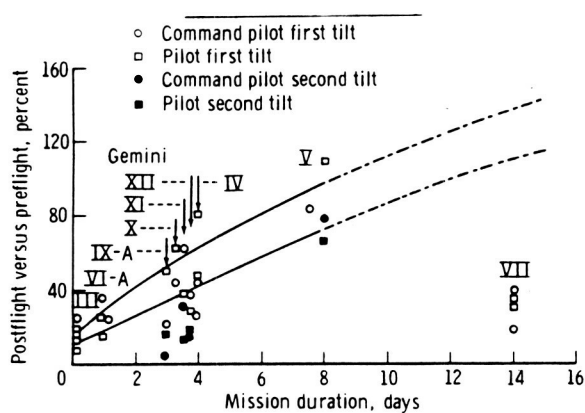


FIGURE 16-7.—Heart-rate tilt response compared with mission duration.

definition implies a useful alteration. In the space-flight situation, man is adapting to a weightless environment into which he has been thrust in a matter of minutes and where he stays a variable time; a second adaptation, required after return to the 1g environment of Earth, can be measured by direct observation. Some of the physiological changes return to normal over an extended time; for instance, the tilt responses have all

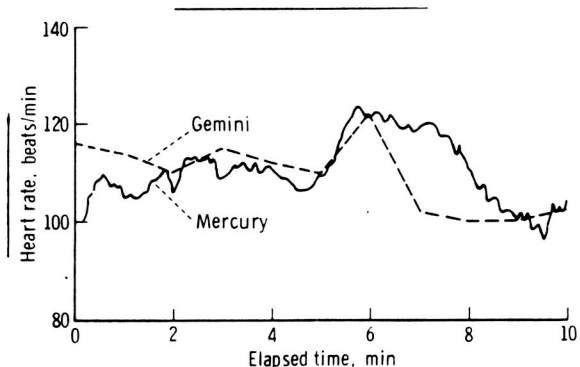


FIGURE 16-8.—Command pilot heart-rate comparisons.

returned to normal within a 50-hour period, regardless of the duration of exposure to the space-flight environment.

Blood

Significant increases have been observed in white-blood-cell counts manifested as an absolute neutrophilia following most flights. This condition has always returned to normal within 24 hours. Hematologic data derived from Gemini missions of 4, 8, and 14 days demonstrated a hemolytic process originating during flight. Specific data points include red-cell mass deficits of 12, 20, and 19 percent (command pilot) following the Gemini IV, V, and VII missions, respectively (fig. 16-9). The 12-percent Gemini IV data point is probably inaccurate. This 4-day point was calculated from RISA-125 plasma volume and peripheral hematocrit data, a method predicted on a constant relationship between peripheral and total-body hematocrit. Subsequent direct measurements showed that alteration of the peripheral/total-body hematocrit ratios do occur, thereby introducing an obvious error into the calculations. Based upon the direct measurements, the Gemini IV calculated red-cell mass deficits were reexamined and found to more closely approximate 5 percent. Other hematologic tests corroborated this disparity; however, to date, no satisfactory explanation of the phenomenon exists. Complete interpretation of

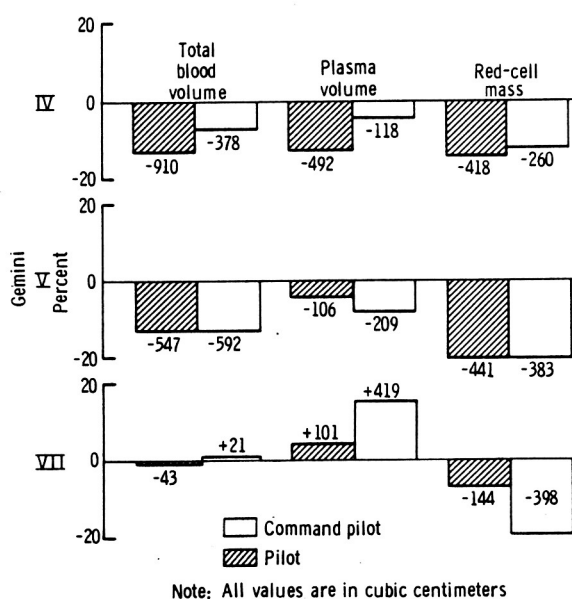


FIGURE 16-9.—Blood-volume studies for Gemini IV, V, and VII.

the red-cell mass deficit noted in the command pilot of the Gemini VII also required special consideration. It appears that no significant progression of the hemolysis occurs after the eighth day in orbit; however, this may be more apparent than real. Analysis of the related mean corpuscular volume values shows a significant increase in this parameter during the 14-day space-flight interval. If each individual erythrocyte increased in volume, a measurement of the total red-cell volume (red-cell mass) would not accurately reflect the actual loss of erythrocytes. Correcting for the postflight corpuscular volume shift, a 29-percent circulating red-cell deficit is derived. The latter figure more accurately describes the hemolytic event; therefore, it is possible that the true extent of the hemolytic process has not yet been determined.

Possible causative factors of the red-cell loss are hyperoxia (166-mm oxygen at the alveolar membrane), lack of inert diluent gas (nitrogen), relative immobility of the crew, dietary factors, and weightlessness. Only increased oxygen tension, immobility, and dietary factors are well known to influence the red cell. Dietary considerations may be

of considerable importance; however, at this point no definite incriminations can be levied against the flight diet. A program to define certain diet levels of lipid soluble vitamins has recently been initiated. Specifically, alpha-tocopherol is an important antilipid oxidant and is essential in protecting the lipid at the red-cell plasma membrane. Immobility is effective in reducing red-cell mass by curtailing erythrocyte production; however, all flight observations support hemolysis as the significant event. Although not demonstrated by any previous studies, it is possible that weightlessness is a contributing factor in the hemolysis observed. Altered hemodynamics, resulting in hemostasis, could result in the premature demise of the cell. The role of a diluent gas (nitrogen) is not well understood; however, some investigators have shown significant reduction in hematologic and neurologic toxicity in animals exposed to high oxygen pressure when an inert gas is present. Therefore, the absence of an inert atmospheric diluent could be significant at the hyperoxic levels encountered within the Gemini spacecraft.

Of all the mechanisms previously stated, oxygen has the greatest proven potential as a hemolytic agent. Basically, two modes of oxygen toxicity are described. It has been demonstrated that red-cell plasma membrane lipids undergo peroxidation when exposed to conditions of hyperoxia. It has also been demonstrated that the lipid peroxides thus formed are detrimental to the cell. Specifically, lipid peroxides are known to affect enzyme systems essential for normal red-cell function. It is also possible that peroxidation of the erythrocyte plasma membrane lipids changes this tissue to curtail erythrocyte survival. The second mode of oxygen toxicity expression may be more direct, for inferential evidence is available showing a direct inhibitory effect on some glycolytic enzymes. Oxygen has several documented deleterious effects on red-cell plasma membranes and metabolic functions; any combination of these effects could be operative within a Gemini spacecraft.

Biochemical

The analysis of urine and plasma has been used as an indication of crew physiological status preflight, in flight, and postflight. Analyses of the results obtained on all three phases were performed on the 14-day Gemini VII flight, and essentially complete analyses were performed on the preflight and postflight phases of the 3-day Gemini IX-A mission.

The first attempt at accumulation of in-flight data was essentially a shakedown and provided an *n* of 2, which for biological data is insignificant. Some of the data are presented, but interpretation is dependent upon more refined techniques and upon accumulation of a sufficient number of observations to establish variabilities and trends. The high degree of individual variation should be noted. The Gemini VII pilot and command pilot did not always respond qualitatively or quantitatively in the same way.

The biochemical determinations are grouped into several profiles, each of which provides information concerning the effect of space flight on one or more of the physiological systems. The first profile, water and electrolyte balance, is related to an examination of the weight loss which occurs during flight and the mechanisms involved in this loss. To this end, the levels of sodium, potassium, and chloride in the plasma were measured preflight and postflight, and the rates of excretion of these electrolytes in the urine were observed in all three phases of the study. Total plasma protein concentration measured both preflight and postflight was used as an indication of possible dehydration. Water intake and urine output were measured to determine whether the primary loss of weight was due to sweat and insensible losses or to changes in renal function. The vasopressin (antidiuretic hormone) and aldosterone hormones were measured in the urine in an attempt to establish the functional contribution of baroreceptors in a zero-gravity condition.

As may be expected, since one of the prime functions of the homeostatic mechanisms of

the body is to maintain the composition of blood and extracellular fluid as nearly constant as possible, significant changes in plasma were not observed. As seen in figure 16-10, 48-hour pooled samples of flight urine indicate a slight reduction in the output of sodium during flight. As indicated by the hashed bars, this is associated with some increase in aldosterone excretion. Postflight, there is a marked retention of sodium. As expected, chloride excretion parallels the sodium excretion. Potassium excretion during flight (fig. 16-11) appears depressed, and in all but the command pilot of Gemini VII, it was depressed immediately postflight. This depression could be observed in total 24-hour output and in minute output. This anti-diuretic hormone appeared elevated in only the first postflight sample of the Gemini VII pilot. The crudities of this biological assay may account for the inability to observe any gross changes. The retention of electrolytes is very closely associated with the retention of water postflight.

The second profile involves the estimation of the physiological cost of maintaining a given level of performance during space flight. This could be considered a measure of the effects of stress during space flight. Two groups of hormones were assayed: the first, 17-hydroxycorticosteroids, provides a measure of long-term stress responses; the second, catecholamines, provides a measure of short-term or emergency responses. The results obtained with the catecholamine determina-

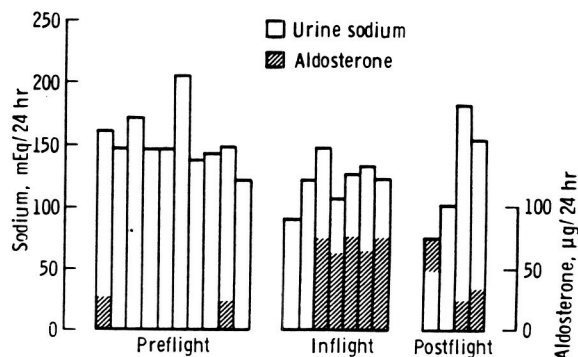


FIGURE 16-10.—Urine sodium and aldosterone, Gemini VII command pilot.

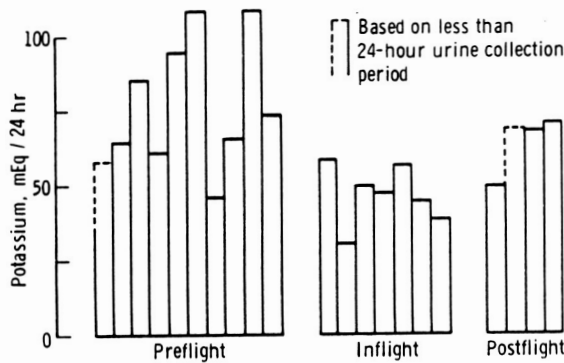


FIGURE 16-11.—Urine potassium, Gemini VII pilot.

tions are anomalous and changes observed could be considered well within the error of the methodology. As seen in figure 16-12, the 17-hydroxycorticosteroid levels are depressed during the flight. An elevation immediately postflight may be related to the stress of reentry and recovery. Although there may be considerable speculation regarding the low inflight steroids, it must be reemphasized that these results are from a single flight, and much more data will be essential before a valid evaluation is possible.

The third profile constitutes a continuing evaluation of the effects of space flight on bone demineralization. Calcium, magnesium, phosphate, and hydroxyproline are measured in plasma and in urine obtained preflight, in flight, and postflight. This is an attempt to determine whether the status, or the changes in the status, of bone mineral are accompanied by alterations in plasma calcium and hydroxyproline, and by alterations in urinary excretion of calcium, phosphate, magnesium, and hydroxyproline. The amino acid, hydroxyproline, is unique to collagen, and it was presumed that an increased excretion of hydroxyproline might accompany demineralization along with dissolution of a bone matrix (fig. 16-13). The first postflight plasma samples following the 14-day flight show a marked increase in the bound hydroxyproline, while larger quantities of calcium were excreted later in the flight than during the early phases of the flight. This is consistent with a change in bone structure.

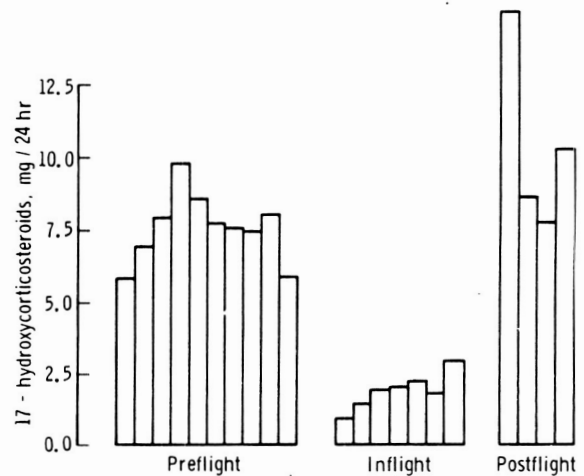


FIGURE 16-12.—Urine 17-hydroxycorticosteroids, Gemini VII command pilot.

The fourth group may be related to protein metabolism and tissue status. When total nitrogen was related to intake during flight, a negative balance was noted.

Gastrointestinal System

The design and fabrication of foods for consumption during space flights have imposed unique technological considerations. The volume of space food per man-day has varied in the Gemini missions from 130 to 162 cubic inches (2131 to 2656 cc). Current menus are made up of approximately 50 to 60 percent rehydratables (foods requiring the

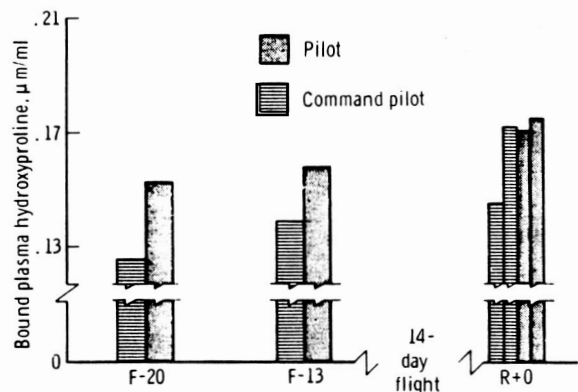


FIGURE 16-13.—Bound plasma hydroxyproline, Gemini VII.

addition of water prior to ingestion); therefore, food packaging is required that permits a method for rehydration and for dispensing food in zero gravity. The remaining foods are bite size; that is, food items which are ingested in one bite and rehydrated in the mouth. About 50 percent of the rehydratable and the bite-size foods are freeze-dried products; the remaining are other types of dried or low-moisture foods, some of which are compressed. A typical menu (table 16-VII) has an approximate calorie distribution of 17 percent protein, 32 percent fat, and 51 percent carbohydrate. Total calories provided and eaten per day varied from flight to flight. Food consumption during Gemini IV, V, and VII is summarized in figures 16-14 to 16-16. Food consumption during Gemini IV and VII was very good, but weight loss on the short-duration Gemini IV mission was definitely substantial. The anorexia of the Gemini V crew is unexplained, although many hypotheses could be presented. Although weight loss has occurred on all missions, it has not increased with mission duration (table 16-VIII). Obviously, more calories and water must be consumed in flight to maintain body weight at preflight levels.

Gastrointestinal-tract function on all missions has been normal, and no evidence exists of excess nutrient losses due to poor food

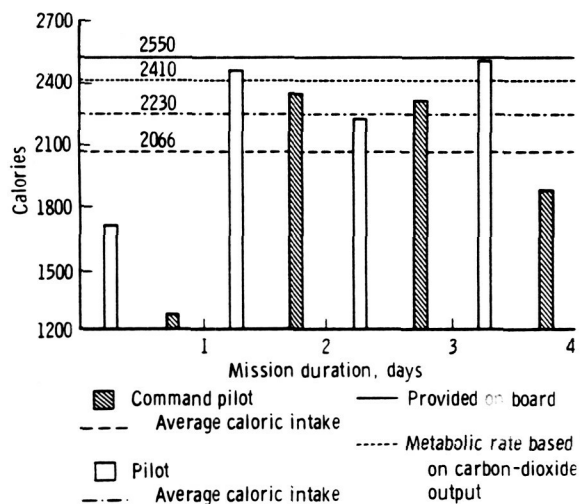


FIGURE 16-14.—Caloric intake on Gemini IV.

TABLE 16-VII.—*Typical Gemini Menu*

[Days 2, 6, 10, and 14]

Meal A:	Calories
Grapefruit drink	83
Chicken and gravy	92
Beef sandwiches	268
Applesauce	165
Peanut cubes	297
	<u>905</u>
Meal B:	
Orange-grapefruit drink	83
Beef pot roast	119
Bacon and egg bites	206
Chocolate pudding	307
Strawberry cereal cubes	114
	<u>829</u>
Meal C:	
Potato soup	220
Shrimp cocktail	119
Date fruitcake	262
Orange drink	83
	<u>684</u>
Total calories	<u>2418</u>

TABLE 16-VIII.—*Flight Crew Weight Loss to the Nearest Half Pound*

Gemini mission	Command pilot weight loss, lb	Pilot weight loss, lb
III	3	3.5
IV	4.5	8.5
V	7.5	8.5
VI-A	2.5	8
VII	10	6
VIII	(*)	(*)
IX-A	5.5	13.5
X	3.0	3.0
XI	2.5	0
XII	6.5	7

* Not available.

digestibility during flight. Before the missions, the crews ate a low-residue diet; on all flights beginning with the Gemini V mission, an oral and usually a suppository laxative were used within 2 days of launch. On the shorter extravehicular missions, this pre-flight preparation has generally allowed the crew to avoid defecation in flight.

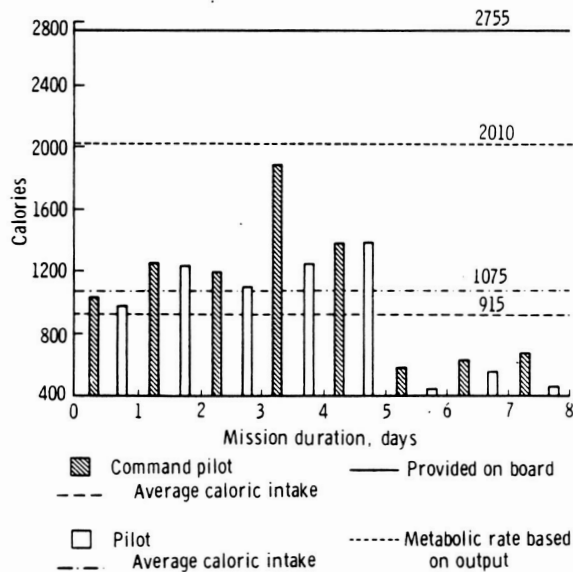


FIGURE 16-15.—Caloric intake on Gemini V.

Genitourinary System

There have been no difficulties involving the genital system. Urination has occurred normally both in flight and postflight, and there has been no evidence of renal calculi.

Musculoskeletal System

Here, again, interpretation of the information gathered to date on bone and muscle metabolism as affected by space flight must be cautious due to the very few subjects observed under varying dietary intakes and exposed to multiple flight stresses.

In figures 16-17 and 16-18, the bone demineralization (percent change in density) which occurred in the os calcis (heel) and phalanx 5-2 (little finger) during space flight is compared with the demineralization which occurred under equivalent periods of bedrest and analogous intakes of calcium. As compared with bedrest, the changes were definitely less in the 14-day flight where calcium intake approached 1000 mg per day and the crew routinely exercised. The phalanx changes are remarkable because significant

differences in density have not been observed during 30 days of complete bedrest when calcium intake of over 500 mg per day has been adequate.

In all instances the data for the bones examined indicate a negative change, and the calcium-balance data collected on Gemini VII verify a negative balance trend. None of the changes are pathological, but indicate that further research is needed and that ameliorative methods for use during long-duration flights need to be examined.

The detailed 14-day inflight balance study revealed some loss in protein nitrogen.

Exercise Capacity Tests

Previous investigations have shown that a limitation of optimal cardiovascular and respiratory function exists when a heart rate of 180 beats per minute is reached during a gradually increased workload. With this in mind, an exercise capacity test was incorporated into the Gemini operational preflight and postflight procedures in order to determine whether changes occur in crew physiologic reaction to work.

The tests have been performed by the crewmembers of the Gemini VII mission and by the pilots of the Gemini IX-A, X, XI, and XII missions. All but one of the tested crewmen exhibited a decrease in exercise capacity as monitored by heart rate, and a concomitant reduction in oxygen consumption to a quantitated workload. These findings are graphically demonstrated in figure 16-19.

Additionally, the heart-rate/workload information collected preflight has been of value as a very rough index of the metabolic rate of crewmen during extravehicular activity. It is realized that many other stresses above and beyond the simple imposition of workload can and do affect heart rate. The heart rate as measured during extravehicular activity is not considered an exact index of the workload being performed, but rather as a reflection of total physiological and psychological strain.

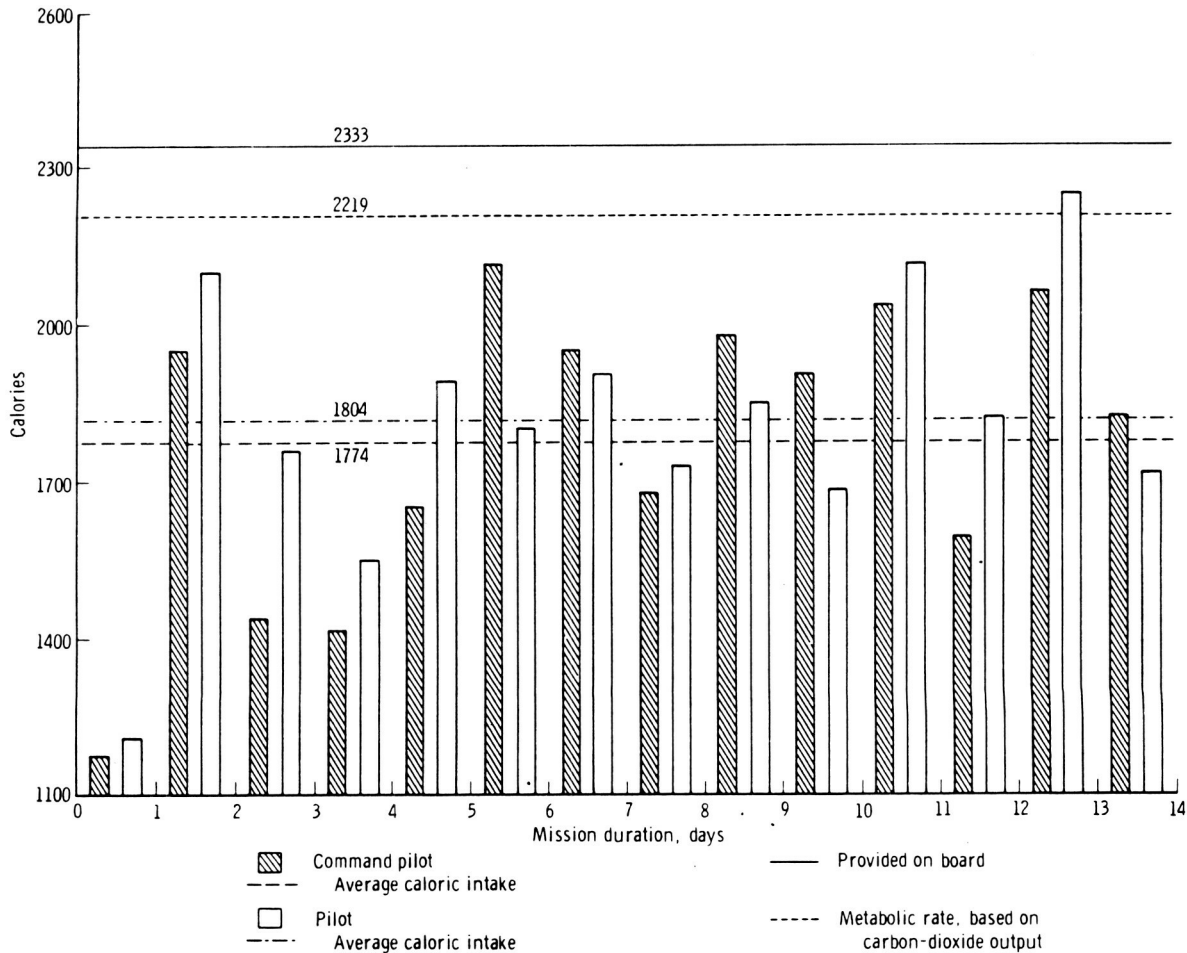


FIGURE 16-16.—Caloric intake on Gemini VII.

Inflight Metabolic Data

Metabolic measurement during U.S. space flights has been limited to the determinations of the total carbon-dioxide production by the chemical analysis of the spent lithium-hydroxide canister. This method is of value only in establishing the average heat-production rate for crewmen during space flight. Figure 16-20 shows close agreement between metabolic data from the U.S.S.R. and the American space flights. The higher metabolic rates observed during the Mercury flights are explained by the fact that these were short-duration flights in which the crewmen did not sleep.

Other Observations Concerning Weightless Flight

The crews have never slept well on the first night in space, and many factors other than weightlessness may be active in limiting the sleep obtained, regardless of flight duration. All crewmembers have reported a tendency to sleep with the arms folded at chest height and the fingers interlocked. The legs also tend to assume a slightly elevated position. On return to the 1g environment, the crews are aware of the readaptation period because they are aware for a short time that the arms and legs have weight and require effort to move. There has been some postflight muscle stiffness following the prolonged missions.

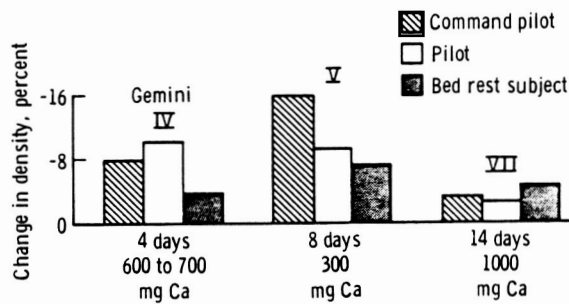


FIGURE 16-17.—Loss of os calcis density on Gemini IV, V, and VII missions.

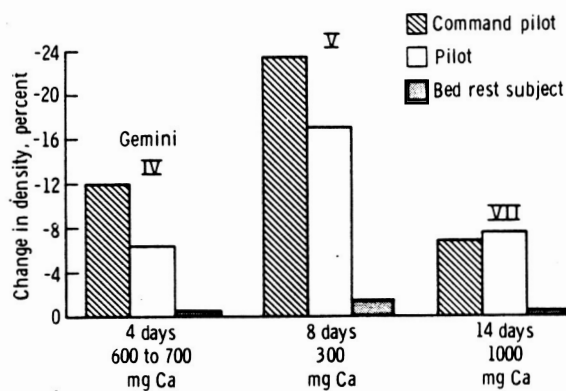


FIGURE 16-18.—Change in density of hand phalanx on Gemini IV, V, and VII missions.

that may be more associated with the confinement of the spacecraft than with weightlessness.

The amount of inflight exercise by the crew has varied even on the long-duration flights. On the 14-day mission, there were three 10-minute exercise periods programed and completed per day. On the short-duration flights with great demands upon the crew for rendezvous and extravehicular activity, no specific conditioning exercises have been conducted. There appears to be a need for a definite exercise regime on long-duration flights.

Crew Performance

Strange reactions to the isolation and the monotony of space flight were originally predicted. Hallucinations and a feeling of separation from the world, described as the break-

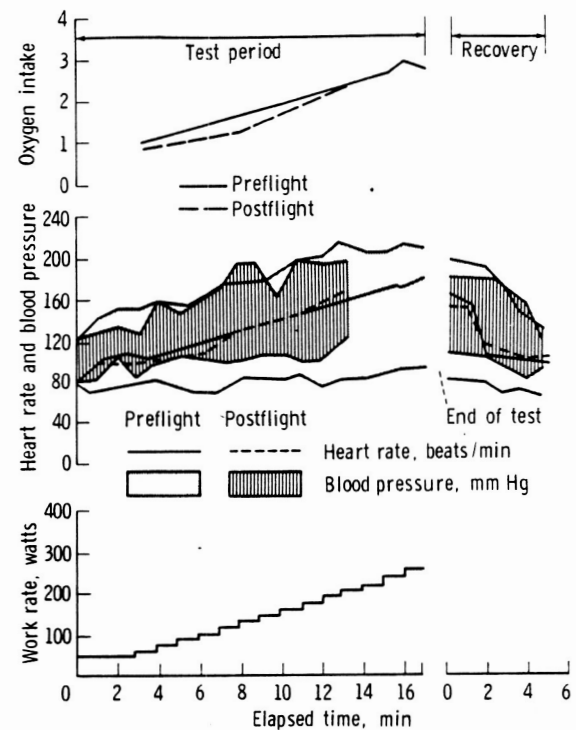


FIGURE 16-19.—Preflight and postflight exercise capacity test results, Gemini IX-A.

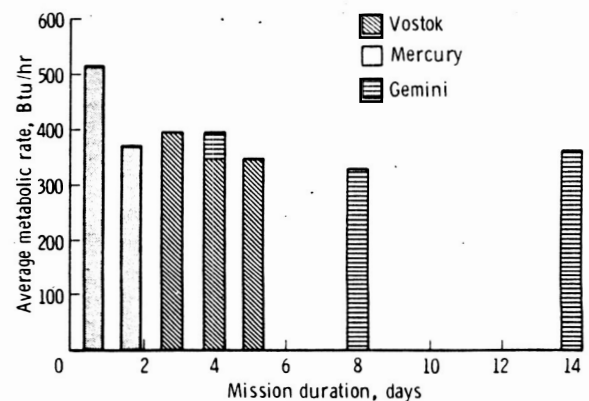


FIGURE 16-20.—Average metabolic rates during actual space flight.

off phenomenon, had also been predicted, along with space euphoria. The experience to date has shown no evidence of the presence of any of these responses. There have been no abnormal psychological reactions of any sort, and the flights have been far from monoto-

nous. In the single-man flights of the Mercury series, there was always ample ground contact and certainly no feeling of isolation or monotony. In the two-man Gemini flights, the same was true; and of course there has always been a companion crewman, thus avoiding isolation. The crews have exhibited remarkable psychomotor performance capabilities, and by performing a number of demanding tasks under stress they have demonstrated a high level of central nervous system function.

Drugs

A number of predictions were made that man would require the assistance of drugs to cope with the space-flight environment. In particular, sedation prior to launch and stimulation prior to reentry have been mentioned. As a result of the early planning for space flight, a drug kit was made available for inflight prescription. The crews have been pretested to each of the drugs carried; thus, the individual reaction to the particular drug is known. Aspirin and APC's have been used in flight for occasional mild headache and for relief of muscular discomfort prior to sleep. Dextroamphetamine sulfate has been taken on several occasions by fatigued crewmen prior to reentry. A decongestant has been used to relieve nasal congestion and alleviate the necessity for frequent clearing of the ears prior to reentry. The anti-motion-sickness medication has been taken in one instance prior to reentry to reduce motion sickness resulting from motion of the spacecraft in the water. An inhibitor of gastrointestinal propulsion has been prescribed when necessary to assist in avoiding inflight defecation. No difficulty has been experienced in the use of these medications which have produced the desired and expected effects. None of the injectors has been used in flight.

Inflight Disease

Preventive medicine enthusiasts have predicted the possible development of infectious

disease in flight as a result of preflight exposure and the lack of symptoms or signs which can be detected in a preflight examination.

Quarantine of the crews for a period of time preflight has been discussed, and has been rejected as impractical in the missions to date. The immediate preflight period is very demanding of crew participation, and efforts have been directed at screening the contacts insofar as possible to reduce crew exposure to possible viral and bacterial infections, particularly the upper respiratory type. A number of short-lived flulike syndromes have developed in the immediate preflight period, as well as one exposure to mumps and one incident of betahemolytic streptococcal pharyngitis. Each situation has been handled without affecting the scheduled launch and, in retrospect, the policy of modified quarantine has worked well. Stricter measures may have to be adopted as longer flights are contemplated.

Fatigue

It was predicted that markedly fatigued flight crews would result from the discomfort of flight in a suited condition, a confined spacecraft, and inadequate rest. In reviewing the flight program to date, it appears that the crews obtained less sleep than in similar circumstances on the ground, but were not unduly fatigued. Intermittent periods of fatigue have resulted from the demanding mission requirements and from the fascination of the crew with the unique opportunity to view the universe. This has been cyclic in nature and on the long-duration flights has always been followed by periods of more restful sleep. No interference with performance has been noted due to inflight fatigue.

Medical Support

In preparing for the medical support of manned space flights, the possibility of in-

jury at the time of launch and recovery was carefully evaluated. A detailed plan of support involving medical and surgical specialists in the launch and recovery areas was evolved and modified as the program progressed. In retrospect, it might appear that the support of surgeons, anesthesiologists, and supporting teams in these areas has been overdone in view of the results. This is always a difficult area to evaluate, however, because none of the support is needed unless a disaster occurs. The best that can be said at the moment is that this support will be critically reviewed in the light of the experience to date and rendered more realistic in the demands placed on highly trained medical personnel.

When originally established, the preflight and postflight examinations were aimed at identifying gross changes in man resulting from exposure to the space-flight environment. The examinations have been tailored along standard clinical lines, and, although these techniques have been satisfactory, little in the way of change has been noted. The procedures have been modified to include more dynamic tests, such as bicycle ergometry, and to reduce the emphasis on those static tests which showed little or no change. Increased use of dynamic testing should continue in the support of future manned space-flight programs.

Concluding Remarks

There has been increased scientific interest in the effect of the space-flight environment on man. The scientific requirements for additional information on man's function must be evaluated in regard to operational and mission requirements and the effect upon future manned space flight. The input of the crews and the operations planners must be weighed along with the basic medical and scientific requirements, and a realistic plan must be established to provide needed medical answers at the proper time and allow projections of man's further exposure. This has been one of the most difficult tasks in the

medical support area. The entire manned space-flight program has required the strictest cooperation and understanding between physician and engineer, and it is believed that this has been accomplished. The medical management of the diverse personnel necessary to provide proper medical support for manned space missions has provided experiences of great value to future progress.

In reviewing the flights, the orderly plan of doubling man's flight duration, and observing the results in relation to the next step, has been successful and effective. There is no reason to alter this plan in determining the next increments in manned space flight.

In general, the space environment has been much better than predicted. Additionally, man has been far more capable in this environment than predicted, and weightlessness and the accompanying stresses have had less effect than predicted. While all these items are extremely encouraging and are the medical legacy of the Gemini Program, it is important to concentrate on some of the possible problems of very long-duration future flights, and the application of Gemini knowledge. Consideration must be given to the following: (1) obtaining additional information on normal baseline reactions to stress in order to predict crew response; (2) determining psychological implications of long-duration confinement and crew interrelations; (3) solving the difficult logistics of food and water supply and of waste management; and (4) providing easy, noninterfering physiologic monitoring.

The first steps into space have provided a rich background on which to build. In addition to the information provided for planning future space activities, benefits to general medicine must accrue as smaller and better bioinstrumentation with wider applicability to ground-based medicine is developed; as normal values are defined for various physiologic responses in man; and as ground-based research is conducted, such as bedrest studies. These results should yield a large amount of information applicable to

hospitalized patients. It has been observed how the human body can adapt to a new and hostile situation and then readapt in a surprisingly effective manner to the normal 1g Earth environment. Continued observation of these changes will help determine whether the space environment may be utilized for any form of therapy in the future. The space-

flight environment will certainly prove to be a vital laboratory, allowing study of the basic physiology of body systems, such as the vestibular system. Even incidental findings, such as the red-cell membrane changes which are markedly applicable to hyperbaric applications in medicine, may be of benefit to general scientific and medical research.