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History of Research in Subgravity and Zero-g

at the Air Force Missile Development Center

HOLLOMAN AIR FORCE BASE, NEW MEXICO

1948 - 1958

Historical Division
Office of Information Services
Air Force Missile Development Center
Air Research and Development Command
Holloman Air Force Base, New Mexico

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AIR RESEARCH AND DEVELOPMENT COMMAND
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FOREWORD

Weightlessness, the weird condition of subgravity which man had never before experienced and survived--except for the initial split-second of short-distance free fall--has recently become a major field of serious scientific research. Man now approaches this condition as his fast-climbing fighter flattens out to intercept an enemy bomber, and he may soon experience it for long duration on multimonth interplanetary excursions.

In recent years man has gone to considerable expense and personal risk to fly Keplerian trajectories in high-performance aircraft in order to experience a force of less than normal gravity for fractions of a minute. Recently a Soviet satellite exposed an animal subject to this condition for a period of several days. Gradually a corpus of solid knowledge has formed as a result of these dramatic experiments, and man will go forth into space inhibited less by this psychophysical phenomenon than would otherwise have been the case.

Much of the important basic research in subgravity and zero-g has been performed by men of the Space Biology Branch of the Aeromedical Field Laboratory at the Air Force Missile Development Center. In the following monograph Dr. David Bushnell, of the Center's Historical Office, has traced the history of local contributions to this field of study. He has also

placed this effort into the broader context of subgravity research accomplished elsewhere, especially in the United States, Argentina and the Union of Soviet Socialist Republics.

This forms the third of a series of monographic studies by Dr. Bushnell related to the historical evolution of space biology as a field of study. It maintains the same rigorous professional standards evident in both his _Beginnings of Research in Space Biology at the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, 1946 - 1952_ and his _Major Achievements in Space Biology at the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, 1953 - 1957_, which were published earlier this year. Three additional monographs concerning contributions of the Aeromedical Field Laboratory are scheduled for publication during the summer months of this year.

James Stephen Hanrahan
Center Historian
May 1958

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RESEARCH IN SUBGRAVITY AND ZERO-G

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Among the phenomena to be encountered in manned space flight few if any have inspired as much scientific and popular speculation as that of subgravity,* including both pure weightlessness or zero-gravity and the various fractional states that lie in between zero-gravity and normal gravity conditions. In recent years this has also been a subject of intensive research both in the United States and abroad; and the Space Biology Branch of the Aeromedical Field Laboratory, at the Air Force Missile Development Center, is one of the agencies that have made significant contributions to the research effort. This aspect of the Center's human factors program is less well known than either the rocket-sled experiments of Doctor (Colonel) John Paul Stapp or the program of high-altitude balloon flights culminating in the

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* The term "subgravity" will normally be used in this study to denote all states in which the gravitational force is less than the normal one "g." "Weightlessness" is commonly used in the very same broad sense, but can be confusing. The word literally suggests a complete absence of weight, or zero-gravity, whereas the writer often is referring in fact to a small fractional gravity state--"virtual" weightlessness as it is sometimes expressed.

record Man-High (II) ascent of 19-20 August 1957. Yet the current program of subgravity research has roots at Holloman Air Force Base that go back before the rocket track was even built, and before the first balloon with biological payload was launched.

Subgravity research as a clearly defined field of study had its real beginning just after World War II. It has its primary application in the field of ultimate space flight, where gravitational attraction will still be present but will be normally counterbalanced by other factors, rather than in conventional aviation. Nevertheless, brief exposures to subgravity can and do occur in aircraft flight, so that the problem attracted some slight attention even earlier from specialists in aviation medicine. Moreover, by the end of the war a limited amount of subgravity experimentation had already taken place.

About 1940, the German investigator Heinz von Diringshofen, whose main work concerned human tolerance to multiple g-loads, began exposing test subjects to a few seconds of subgravity simply by putting an aircraft through a vertical dive.[1] Later during the war one other German scientist, Dr. Hubertus Strughold--now at the School of Aviation Medicine, Randolph Field, Texas--staged a particularly memorable experiment to study human orientation when deprived of gravitational cues from the external pressure.

sense. This is only one of the sense mechanisms that supply information on bodily weight and direction, but it is important in flying, where it is activated by the pressure of the aircraft seat on a flier's skin and thus provides the familiar "seat-of-the-pants sensation." In order to simulate a weightless condition as far as this one sense is concerned, Strughold anesthetized his buttocks with novocaine. He then flew a series of acrobatic maneuvers, and in his peculiar condition he found the experience very disagreeable.[2]

The early experiments of Von Diringshofen and Strughold did not lead to any concerted or continuing program of subgravity research in Germany. In the immediate post-war years German scientists contributed some valuable theoretical studies relating to subgravity, as did scientists in other European countries. The first major landmark in actual subgravity experimentation, however, was a series of high-altitude rocket flights with animal subjects started in 1948 by the United States Air Force.[3] The agency immediately in charge was the Aero Medical Laboratory at Wright Field, which then formed part of the Air Materiel Command and which is now a unit of Wright Air Development Center. The vehicle used at first was the German V-2 rocket, of which large numbers had been captured and brought to White Sands Proving Ground in south-central New Mexico to be used in high-altitude research. No less than five V-2 animal flights were

launched from White Sands, and in each case the project obtained a wide variety of support services from Holloman Air Force Base, on the opposite side of the same Tularosa Basin. For all flights except the very first, actual preparation of the nose cone including the animal capsule took place in Holloman laboratory facilities. And when, in 1951, the Aero Medical Laboratory began using the newly-developed Aerobee research rocket for its experiments, launch operations as well were transferred entirely to Holloman.

The Aero Medical Laboratory's animal rocket flights were not designed purely for subgravity studies. Their purpose was to expose living subjects to as many as possible of the potential hazards of space flight. In practice, however, a rocket trajectory was too brief to obtain significant exposure to such hazards as primary cosmic radiation, while fairly moderate g-forces were involved both in rocket acceleration and in the opening shock of the parachute recovery system that was designed to carry the capsule safely back to earth. The far-reaching significance of these flights lies rather in the exposure of animals to subgravity lasting for as much as two or three minutes, during the period of coasting and free fall from rocket burnout to the point where the descending capsule again met appreciable atmospheric drag. At that time, no other experimental method could come close to providing as long an exposure. Moreover, for subgravity

research, unlike cosmic radiation studies, two or three minutes was not too short a period for some disturbing symptoms to make themselves felt, if in fact any were likely to occur.

The hero of the first animal rocket flight was a nine-pound rhesus monkey named Albert. He was brought to New Mexico by a team from the Aero Medical Laboratory at Wright Field that included Doctor (Captain and later Lieutenant Colonel) David G. Simons, who now heads the Aeromedical Field Laboratory at Holloman. Albert was carefully instrumented to record both heart and respiratory action. On 18 June 1948 he was finally launched toward space. Unfortunately, his brief trip in a V-2 to an altitude of thirty-seven miles was plagued with a series of operational failures, and no data were obtained. Neither did Albert manage to get back alive: the parachute system failed.

A year later the Wright Field scientists, including Doctor Simons, tried again. On 14 June 1949 Albert (II) reached an altitude of about eighty-three miles. There was still no live recovery, since the parachute system failed again. However, data were successfully recorded throughout the flight and indicated that the second Albert suffered no serious ill effects from weightlessness, cosmic radiation, or any other hazard of space flight.

After two more monkey flights, of which one was marred by unsatisfactory rocket performance and the other essentially

repeated the outcome of the Albert (II) flight, a mouse was chosen as passenger in the fifth and last of the space biology V-2's. The mouse was not instrumented for heart action or breathing since this time the primary objective was to record the conscious reactions of an animal under changing gravity conditions. For this purpose the animal capsule was equipped with a camera system to photograph the mouse at fixed intervals. As usual, the recovery system failed--the mouse did not survive impact. But photographic evidence showed that the mouse retained "normal muscular coordination" throughout the subgravity phase, even though "he no longer had a preference for any particular direction and was as much at ease when inverted as when upright relative to the control starting position."[4]

With the first aeromedical Aerobee firing, on 18 April 1951 from Holloman Air Force Base, project scientists reverted to the pattern of the V-2 monkey flights. The result was quite familiar: physiological data on a monkey's breathing and heart rates were successfully recorded, there was no sign of any gross disturbance in the subject, and the parachute failed again. Finally, with the second Aerobee animal flight of 20 September 1951, the long-awaited breakthrough in parachute recovery was successfully accomplished. An instrumented monkey was safely brought back from peak altitude of 236,000 feet, and so was a grand total of eleven mice that had gone along with

him. Successful recovery was again accomplished on the third and last Aerobee flight of the series, which took place on 21 May 1952. All passengers--two monkeys and two mice--returned safely to earth, and one of the monkeys is still alive and healthy in a Washington, D. C., zoo.

Nine of the second Aerobee's mouse contingent served primarily as cosmic radiation subjects, but all other mice, like the mouse on the last V-2, were studied photographically for their reactions during the subgravity state. One of these had undergone a prior operation removing the vestibular apparatus of the inner ear that is responsive to gravitational forces and helps give both mice and human beings a sense of equilibrium. The mouse was already accustomed to orient himself by vision and touch exclusively and did not seem troubled by loss of gravity during the flight. One of the three normal mice used as subgravity test subjects was also free from any sign of disorientation during exposure to subgravity, apparently because it had a paddle to cling to and retained full possession of tactile as well as visual references. But the two remaining mice did show some signs of disorientation.

Since May 1952 there have been no more rocket experiments with animal subjects either at Holloman Air Force Base or elsewhere in the United States. For a few years, at least, experiments of this type have become a monopoly of the Union

of Soviet Socialist Republics, where the first animal-carrying rocket is said to have been launched in 1951. The Russians preferred dogs as test subjects, and refrained from giving them anesthesia before takeoff. They have also claimed that no dog was ever lost through failure of his breathing equipment or "effect of external factors," but they have not specified how many may have been lost for other reasons.[5] If United States experience is any guide, one is tempted to assume that the Russians must regard parachute failure as an "internal" factor! Be that as it may, the Russian methods and test results generally resembled those of the earlier Air Force animal rocket flights--until, of course, they used a rocket to place a dog in orbit in November 1957.

From the standpoint of subgravity studies, the unique quality of this last achievement was the length of the exposure obtained, from the final rocket burnout until the death of Laika, the satellite dog, roughly a week after launching. Technically speaking, a minor limitation of this experiment was the presence of fractional g-forces caused by the tumbling of the satellite vehicle. A more obvious limitation for subgravity studies or any other research objective was failure to bring back either the dog itself or a photographic record for later study and observation.[6]

According to results published so far concerning the

Russians' satellite experiment, the effects of rocket acceleration on Laika's heart beat, though tolerable, persisted much longer after acceleration ceased than would have been the case if recovery from the same high g-load had been made in a normal one-g field. Russian scientists attributed this result directly to the influence of a post-acceleration subgravity state. However, there was still no sign of disabling ill effects on the test subject as a result of subgravity exposure. The dog's eyesight allegedly "compensated to a certain degree the disturbance of locomotive power" that was due to subgravity, although under the conditions of the test it is hard to see how this could be anything more than a reasonable hypothesis.[7]

Even before the United States abandoned the field of animal rocket experiments to the Russians, at least for the present, scientists at different Air Force installations had branched out into still another fruitful type of subgravity research, using the airplane as test vehicle. In May 1950 two former German scientists working at the School of Aviation Medicine, Doctors Fritz and Heinz Haber, delivered a paper in which they explained how to achieve over thirty seconds of subgravity in aircraft flight. The method was to fly the plane in a parabolic arc or "Keplerian" trajectory in which centrifugal force would exactly offset the downward pull of gravity and engine thrust would counterbalance air friction. This was not an easy

thing to do, and even with an expert pilot at the controls one could expect absolute weightlessness for only part of the total subgravity trajectory. Nevertheless, the Habers' proposal offered the first method for obtaining a really significant subgravity exposure in manned flight.[8]

During 1951 the new procedure was tested at Edwards Air Force Base in California and at Wright Field in Ohio. At Edwards the noted test pilot Scott Crossfield and the Air Force's Major Charles E. Yeager both flew a number of Keplerian trajectories, the former working on behalf of the National Advisory Committee for Aeronautics. At Wright Field similar experiments were conducted by Dr. E. R. Ballinger. Apparently none of these early experiments achieved more than a few seconds, at most, of true zero-gravity, but total subgravity trajectories were in reasonably close accord with the Habers' predictions. Test results showed a tendency for subjects to overreach with their arms during subgravity. Symptoms of disorientation also appeared in some cases but, on the whole, these flights indicated no major difficulties in orientation as long as the subjects were firmly belted in and had full visual references.[9]

This sudden burst of subgravity flights in the United States was followed by a period of relative inactivity during 1952-1954. Meanwhile, related experiments were being conducted during these same years in Argentina by the Austrian-born

scientist Dr. Harald J. A. von Beckh, who had left Germany for South America shortly after the war. Von Beckh introduced still another animal to the menagerie of subgravity test subjects, the South American water turtle. He had one turtle whose vestibular function had been injured accidentally; and he found that this turtle showed much better coordination and orientation during an aircraft subgravity flight than his normal companions. Like the mouse that had a special vestibular operation before going up in the second aeromedical Aerobee, the turtle had apparently learned to compensate visually for the lack of normal gravitational cues. Even the normal turtles, however, gradually improved their performance after a sufficient number of flights.[10]

In his turtle experiments Von Beckh achieved subgravity exposures up to seven seconds by means of vertical dives. Subsequently he, too, adopted the parabolic flight pattern and shifted from turtles to human subjects. The latter submitted to a series of eye-hand coordination tests, in which they showed the familiar tendency to overreach during subgravity but resembled Von Beckh's turtles in their capacity to improve with later flights. Von Beckh was also much interested to observe that when the plane entered its subgravity arc by a maneuver causing high acceleration forces, the recovery from acceleration-induced blackout took appreciably longer than usual.[11] In a sense this foreshadowed the experience of the Russian satellite dog,

and suggested a special topic for further experimentation. However, Von Beckh cut short his stay in Argentina to take a position in the United States with the Human Factors Division of the Martin Company. Later still, in January 1958, he joined the staff of the Air Force Missile Development Center's Aeromedical Field Laboratory. There he assumed direction of the present subgravity program, which had been started--perhaps it would be better to say reactivated--in 1954.

Later Subgravity Studies at Holloman, 1954 - 1958

The sum total of subgravity research accomplished prior to 1954 still was not great, but it allowed certain tentative conclusions to be drawn. There seemed to be no major respiratory or circulatory hazards resulting from weightlessness, although Dr. David G. Simons at Holloman carefully pointed out that respiratory and circulatory complications might arise as a secondary effect of "emotional and autonomic reactions [which are] essentially the same whether caused by weightlessness, a rough sea, or an obnoxious mother-in-law." Simons generalized further, on the basis of studies up to and including Von Beckh's, that subgravity should normally produce "minimal discoordination and no disorientation...as long as the subject retains tactile and visual references."[12]

What was needed now was a much greater accumulation of detailed test data to verify or revise preliminary conclusions and to reveal still other possible effects of subgravity. Better test instrumentation was also needed, especially to record all the variations of gravity force from true zero-gravity up to a normal one-g state. This would be of great help to any pilot attempting to fly a subgravity trajectory. In addition, most suggestions for future space stations have provided for some form of rotation in order to avoid absolute weightlessness, through the artificial creation of a centrifugal force, but nobody knew exactly how many hundredths of a g must be generated to produce what results. It might also turn out that no rotation at all is needed; but in any case there was an urgent requirement for research data on this and other ramifications of the subgravity question.[13]

By the same token, there was ample reason to establish a formal subgravity program at Holloman within the framework of the Space Biology Branch of the Aeromedical Field Laboratory. Unlike the earlier V-2 and Aerobee flights, the present program is part of the Center's own project workload. The Aeromedical Field Laboratory had been founded in 1951 as a field station for project scientists operating from the Aero Medical Laboratory at Wright Field, but in January 1953 it became a function of the local Center (then known as Holloman Air Development

Center), and in October 1953 subgravity studies were specifically included in the Holloman laboratory's mission. In the following year, 1954, work on subgravity actually got underway as Task 78501 of the newly-created Project 7851, Human Factors of Space Flight. Doctor (at that time Major) David G. Simons was project officer of Project 7851, as well as head of the laboratory's Space Biology Branch. Technical Sergeant John T. Conniff was the original task scientist for Task 78501, Subgravity Studies.[14]

For some time, with funds and manpower both limited, the main task activity consisted of planning and preparations for an ultimate test program. Sergeant Conniff's subgravity duties were not so engrossing as to prevent him from continuing as head of the laboratory's Electronics Unit;[15] indeed the latter position was presumably of advantage to him in collecting instrumentation for the subgravity program. Nevertheless, a preliminary aircraft flight took place at least as early as September 1954, using a T-33, to evaluate some of the problems involved in flying a parabolic subgravity trajectory. More flights were made early the following year with an F-89, again mostly for evaluating techniques and instrumentation.[16]

The program was not really intensified until after the assignment of Captain Grover J. D. Schock as task scientist on 1 July 1955. Captain Schock--whose contributions to subgravity research later qualified him as the first known

scientist to receive a Doctor of Philosophy degree in space physiology--initiated subgravity flights in an F-94C aircraft in the fall of 1955, using himself as one of various test subjects. The F-94C became the standard test vehicle for subgravity research, and Task 78501 remained the primary duty of Captain Schock until the beginning of 1958, when Dr. Von Beckh took over as task scientist. Captain Schock then branched out into other lines of activity for the Aeromedical Field Laboratory, but without abandoning his previous interest and participation in the subgravity program. Moreover, he kept one special foothold as task scientist for Task 78530, Psychophysiology of Weightlessness. This was a task of the recently-established Project 7857, Research in Space Bio-Sciences. It is not concerned with the aircraft subgravity flights at Holloman, but with certain research to be done by outside investigators on a contract basis as well as a limited amount of "in-house" effort.[17]

The F-94C flights, which have been the primary activity of Task 78501, are capable of giving subgravity trajectories of more than thirty seconds in duration; and more than one such trajectory or "run" can be scheduled on a single flight. The amount of actual zero-gravity is always considerably less, although the exposures have increased steadily. Early in 1958 the maximum zero-gravity obtainable in a test

trajectory was about twenty-two seconds, and even this exposure was not continuous but was interrupted by momentary lapses into some minute fraction of positive or negative g-force. Nevertheless, the period was long enough for many types of experimentation, and it compared favorably indeed with the two or three seconds of true weightlessness achieved on some of the very earliest parabolic test flights.[18]

This advance is of course due to improvements both in flight techniques and in test instrumentation. One item of instrumentation still in use when Captain Schock joined the program was a golf ball dangling on a string from the aircraft canopy--a gadget that accurately showed when pure weightlessness had been achieved but could not measure degrees of subgravity. The standard aircraft g-meter was not very satisfactory, either, for instrumenting subgravity flights. However, Captain Schock devoted a major part of his attention to the instrumentation problem. More precise methods have since been devised, using a combination of differently-placed accelerometers. Information on the exact g-forces being experienced is constantly relayed to the aircraft pilot by two sensitive microammeters installed in his field of vision, and the same information is carefully synchronized with a film record of the test subject's reactions.[19]

Unfortunately, the subgravity program was also afflicted with more than its share of aircraft trouble. Apart from normal

maintenance problems, the F-94C aircraft used in the program developed such special troubles during subgravity flights as loss of oil pressure, loss of hydraulic fluid, and "sticking" of the trim tab motor. These difficulties, as well as the presence of extra equipment mounted inside the aircraft, caused a good bit of worry to flying safety and maintenance officers, and required suspension of tests on several occasions. But in the end all the difficulties were shown to be of little importance or else were corrected. Both Lockheed, the aircraft manufacturer, and Pratt-Whitney, the engine manufacturer, were extremely helpful in finding solutions. Moreover, the difficulties over hydraulic fluid and oil pressure suggested some profitable investigations on the behavior of fluids under subgravity conditions, shaking them or forcing them from a squeeze bottle in subgravity flight.[20]

Still another problem that arose was that standard microphones in the F-94 (and earlier in the F-89) were unable to transmit clear messages between pilot and test subject during subgravity. This led to research on the problem and installation of a more satisfactory type of microphone. As a result, Captain Schock is now able to conclude, "Voice communications in future space vehicles should present no problem."[21]

It is worth noting that so many materiel problems of subgravity flight were discovered in the course of human factors

research. Nevertheless, the main interest of the subgravity program does not lie in the effects of subgravity on aircraft parts and equipment but in the reactions of human test subjects. And it is well to note, first of all, that not all human subjects reacted the same way. Some have positively enjoyed the gravity-free state, while others have on occasion felt extreme motion sickness with nausea and vomiting. Among the former can be included Sergeant Conniff, the original task scientist, and Captain Druey P. Parks, who has participated in this as in all other programs of the Space Biology Branch. Among those who have suffered varying amounts of discomfort, Captain Schock definitely includes himself. It is perhaps significant that one who professes no distaste for subgravity is Captain Joseph W. Kittinger, Jr., better known as the test pilot for the Man-High (I) balloon flight, who piloted a great many subgravity trajectories at Holloman before his recent transfer to Wright Air Development Center. In his case it is likely that a broad previous flying career helped prepare him for the experience, although no number of flying hours is any guarantee in itself against feeling ill at ease during a subgravity exposure.[22]

The apparent existence of wide variations in human tolerance suggests that one criterion for selection of crews in space travel may well be a comparison of monitored responses during experimental subgravity exposures. However, still more

information is needed on these varying personal sensations. The sickness felt by some may be related to the rapidly changing g-forces encountered in a complete test flight, including the high acceleration and deceleration that sometimes mark the plane's entry to and exit from the subgravity parabola. In that case the same symptoms might not be associated with long-duration, continuous subgravity exposures. On the other hand, those who easily endure thirty seconds of subgravity might conceivably do less well with a three-minute--or three-month--dose of the same thing. Laika's experience is encouraging in this respect, but hardly conclusive.

The Holloman subgravity flights have also featured a variety of sensomotor performance tests. These indicate that subgravity need not seriously impair a subject's ability to touch his nose with his finger tip, mark x's in a row of squares, or perform other similar operations--provided always that he retains a visual frame of reference, and provided also, of course, that he has not first become violently ill with motion sickness. This conclusion closely parallels those tentatively drawn from the earlier test programs of Ballinger, Von Beckh and others. Neither does eating peanut brittle offer major problems during weightless trajectory, as long as the food is first well masticated and then forced to the back of the mouth where the swallowing reflex goes into action

without regard to gravity. Drinking seems to require use of a squeeze bottle, cups and glasses being quite useless during weightlessness. Water must be forced to the back of the mouth by the tongue, but again the swallowing reflex is unimpaired.[23]

A somewhat different variety of experiment has demonstrated that human subjects, deprived of normal visual references, will perceive oculogravic illusions such as "apparent linear motion of a fixed 'target' during a ballistic [Keplerian] trajectory." For these tests both the subject's head and the "target"--a small luminous cross--were placed under a large and ominous-looking black hood. However, the illusion occurred mainly during the periods of increased g-forces on entering and leaving the subgravity parabola; it did not occur during the weightless phase itself, except for certain oscillations of the target attributed to the plane's failure to maintain an even weightless state. Hence the illusion would seem to be a result of linear acceleration and deceleration, rather than a necessary condition of weightlessness.[24]

When Dr. Von Beckh joined the Holloman program, he brought with him as a carryover from his work in Argentina a special interest in the effects of subgravity on ease of recovery from acceleration-induced blackout or greyout. At Holloman he has initiated flights designed to produce subgravity either just after or just before exposure to a force of roughly four g's,

with a peak of five or six. This procedure duplicates the type of conditions to be met in take-off and re-entry of manned space vehicles. The test series has only recently started, but when further advanced it should yield important research data.[25]

Nor have animal subjects been forgotten in the Holloman test flights. The current pet of subgravity research---at least in the Free World---is the familiar cat, which is of interest for its highly developed vestibular function. It is actually more reliant on this function for balance and orientation than are human beings. The cat is also noted for its reflex ability to land squarely on all fours even after being dropped upside down, and tests were conducted to determine how this righting reflex operates during subgravity. Judging by the test results, it does not work very well. In order to examine the matter more closely, Captain Schock obtained certain cats that had undergone operations removing the vestibular apparatus wholly or partially. When these cats were tested in the same manner, it appeared that animals still having even partial vestibular function were confused. On the other hand, animals wholly deprived of this function and accustomed to do without it remained fully oriented and in possession of normal reflex responses unless their eyes were covered. This last observation confirmed once again the critical importance of visual orientation.[26]

Although the test program has centered primarily around subgravity trajectories flown in jet aircraft, other tests

have been performed in simulated subgravity conditions at ground level. Some of the reactions of a human subject immersed in water are similar to those encountered in a subgravity state; for instance, external pressure on the skin is so evenly distributed around the body surface when under water that this pressure is perceptible barely if at all, just as in a weightless condition. Accordingly, in the spring of 1957 Captain Schock staged a series of experiments at the indoor pool of the El Paso Young Men's Christian Association, with the subject on a rotating seat in eight feet of water and blindfolded. Later in the same year underwater experiments were conducted in the pool of the New Mexico School for the Visually Handicapped in Alamogordo. Such tests have demonstrated an impairment of orientation somewhat like that experienced in aircraft experiments where the subject lacks normal visual cues. In one type of underwater experiment, subjects were tilted as much as twenty-two degrees before perceiving the tilt. The underwater tests have also made a definite contribution to the methodology of subgravity research, and offer the advantage of more prolonged exposure to test conditions than a comparable aircraft trajectory.[27]

The Aeromedical Field Laboratory has worked in close cooperation not merely with the owners of indoor pools but also with Air Force and private researchers interested in subgravity studies. The School of Aviation Medicine, in particular, has

been conducting an active subgravity program at Randolph Air Force Base, Texas. Under the principal direction of Dr. Siegfried J. Gerathewohl, this program in its present form dates from 1955; it, too, has been centered around subgravity test parabolas flown in jet aircraft. The general categories of testing and research have been much the same as in the Holloman program, but in some respects work at Randolph has pointed the way while in other respects--notably instrumentation--the Holloman program has been generally more advanced. Fortunately, there has been little if any sign of the rivalry that has sometimes marred relationships between research programs of the Aeromedical Field Laboratory and related efforts of the Aero Medical Laboratory at Wright Field. There has in fact been a mutually profitable exchange of data and ideas, and though a spokesman for the School of Aviation Medicine has admitted that some overlapping research effort exists in subgravity studies he went on to explain that this was actually "necessary because of the importance of the role that subgravity states will play in the immediate future."[28]

In addition to the current subgravity flights at Holloman and Randolph Field, there is at least one more active program of a similar nature now going on. It is in Soviet Russia, and though the Russians do not seem to have publicized aircraft subgravity flights to the same extent as their animal rocket experiments, they claim to have exposed human subjects to about

the same period of weightlessness--forty seconds--that has been achieved by similar research in the United States.[29]

There has been no direct exchange of information between Holloman and Soviet researchers in this field. However, the cooperation of various outside institutions in the United States has been enlisted for the Holloman subgravity program on a contract basis. Researchers at the University of Illinois assisted Captain Schock's study of the vestibular mechanism in cats, performing the special vestibular operations on cats used in Holloman subgravity flights. They have also been working on techniques for attaching a recording device directly to the vestibular portion of the eighth cranial nerve. The Yellow Springs Instrument Company developed an airborne galvanic skin resistance meter, to permit continuous recording of resistance to electric impulses under stress in subgravity experiments. This instrument is at present being fitted at Holloman with the necessary in-flight recording apparatus. Cornell Aeronautical Laboratories, finally, made a theoretical study under contract of animal experiments that might be performed both in test vehicles now available for subgravity research and in more advanced vehicles that may become available for such studies later on. Additional contracts related to subgravity research have recently been initiated; the efforts mentioned, however, antedate the launching of even the first Russian

satellite, and have been substantially or wholly completed.[30]

The same Russian satellite hastened the end of an Air Force-wide austerity drive that was unleashed in the first quarter of fiscal year 1958 and which unfortunately had administered a temporary setback to the Holloman subgravity program. The Air Force Missile Development Center was ordered to slash expenditures, and research projects generally had to suffer more than missile development. Subgravity studies suffered more than most: a directive issued on 27 August 1957 ordered "cessation of work" effective immediately. The "cessation" was soon clarified to refer only to work that cost money, such as the F-94C flights, which were calculated to use up sixty-three dollars an hour in operating expense without counting maintenance and overhead. Captain Schock in his official role as task scientist could still go swimming, and could plan and theorize to his heart's content. His specially-treated cats arrived from the University of Illinois right in the middle of the austerity drive, but he was able to toss them up and down in the laboratory, taking observations on how they fell; these observations could be compared later with the results of in-flight experiments, as soon as an aircraft was again made available.[31]

Subgravity contracts outstanding were scaled down slightly at the same time, but this occurred under a command-wide order

for five percent reduction in expenditure on effort-type contracts. All Center research programs were similarly affected, and the impact on subgravity studies was barely noticeable compared with the suspension of F-94C flights. Moreover, on 1 October 1957 austerity was relaxed by Center decision to the point of authorizing a small number of test flights, for the specific purpose of having the cats flown at last. Later still, with the appearance of the Russian satellites, austerity was abandoned altogether. By the start of 1958 the subgravity program was back in full swing, although time lost could never be wholly regained.[32]

The Present Outlook for Experimentation in Subgravity Conditions

In the spring of 1958 Captain Schock put forward a "philosophy of weightlessness research" in the following terms:[33]

> To date investigations of the biological effects of weightlessness have been confined almost entirely to observations on the effects of weightlessness on orientation and coordination of animal and human subjects. There is a definite need for this type of research. However, only short periods of weightlessness have been obtained in jet flights and rocket flights. The use of Ballistic Missiles and Bio-Satellites affords a chance for experimentation into the effects of prolonged weightlessness.
>
> Using these methods, biological research should be channelled away from an observation experimentation to a [more strictly] experimental approach. Specifically, investigations should be undertaken

into recording the effects of weightlessness on the utricular mechanism, possible loss of reflexes, and greatly enlarged recordings of physiological data when these parameters are controlled by the autonomic nervous systems. The effects of prolonged sensory deprivation---and true weightlessness can be considered a sensory-starved environment--must be energetically investigated. The use of water or other appropriately diluted solutions affords an excellent method of investigating the effects of sensory deprivation.

The psychology of exposure to weightlessness has been little investigated. Past research has attempted to record incidences of "motion sickness" without really tying down the etiology. Perhaps this is autonomically controlled, but perhaps it is psychologically induced.

The effects of pre-weightlessness accelerations and post-weightlessness accelerations have been little considered in the past. The profile of a Bio-Satellite launching reveals that immediately after burnout any biological system in the nose cone is subjected to weightlessness immediately after a rather large acceleration. What the consequences of this may be is unknown. Conversely during re-entry the effects of high accelerations subsequent to prolonged exposure to weightlessness are purely conjectural. Simulating these conditions is difficult using either the centrifuge or deceleration tracks. It is in these problem areas that future zero gravity research must be directed.

Subgravity studies at the Aeromedical Field Laboratory are at present attempting to meet many of the objectives stated by Captain Schock. As indicated above, pre- and post-weightlessness accelerations are the subject of a series of test flights being conducted by Dr. Von Beckh. Similarly, in order to continue study of "the effects of sensory deprivation" on a body under water, the laboratory is preparing a small tank or pool of its

own. This facility will measure just twelve feet wide by twelve feet deep and will be equipped for heating; thus the water can be maintained at skin temperature, the better to produce "a sensory-starved environment."[34]

But there is also a definite need for more advanced test vehicles. The F-94C still has not outlived its usefulness; nevertheless, substantially longer intervals of subgravity could be achieved either in century-series fighters or in certain types of missiles. One obvious step would be to progress from the F-94 to the F-100, which has been the standard chase aircraft on the Holloman range since 1956. In fact plans already exist to use this aircraft type in the subgravity program. But the two-seat F-100F, which would be required for the test flights, is in rather short supply. The first one reached Holloman only in the fall of 1957, with photographic chase as its primary mission, and because of modifications needed for subgravity work none has been made available as yet for subgravity studies.[35]

For animal experiments the Aerobee is again a possibility, offering up to three and a half minutes of subgravity, although a later model would be involved than the one used previously for biological research at Holloman. Better still would be a long-range ballistic missile, but the "ultimate" test vehicle for subgravity research with either animal or human

subjects is the biological satellite. Only the satellite can provide a test environment that is truly "space-equivalent" in duration of exposure as well as in the mere presence of weightlessness.[36]

Naturally, any test program involving intermediate or intercontinental ballistic missiles or satellite vehicles must involve more than one research organization. In any program of this sort, however, the Aeromedical Field Laboratory can be expected to take part. There is currently an "in-house" effort under Captain Schock directed toward the use of ballistic missiles in aeromedical research. Similarly, the laboratory's present chief, Doctor (Lieutenant Colonel) David G. Simons, is head of the interservice Biosatellite Coordinating Committee. Several other members of the laboratory staff, including Captain Schock, belong to the same committee, and Captain Schock is currently devoting much of his time to this work. Among other things, he is initiating a series of research contracts between the Air Force Missile Development Center and outside scientists in support of the biosatellite program. One such contract, for example, will be designed to provide a satellite experiment on possible degeneration of muscle tone in animals as a result of prolonged exposure to weightlessness.[37]

There are, of course, more reasons than a background in subgravity studies for the prominent role of the Aeromedical

Field Laboratory in biosatellite planning. The Holloman laboratory has also been engaged in active research (as in Project Man-High) on sealed cabin environment and on recovery of biological capsules. In all these fields it has much to contribute toward a successful biosatellite program and toward man's ultimate conquest of space. Its contributions, moreover, will be the fitting culmination of a record of achievement that began in 1948 when Holloman Air Force Base provided essential support to the very first United States experiments in weightlessness and space biology.

NOTES

1. Interview, Dr. Harald J. A. von Beckh, Task Scientist, Subgravity Studies, Aeromedical Field Laboratory, by Dr. David Bushnell, AFMDC Historian, 17 February 1958.

2. Grover J. D. Schock, Sensory Reactions Related to Weightlessness and Their Implications to Space Flight (AFMDC Technical Report 58-6, February 1958), pp. 2-3.

3. A more detailed account of these flights, as well as the sources of information used, will be found in The Beginnings of Research in Space Biology at the Air Force Missile Development Center, Holloman Air Force Base, New Mexico, 1946-1952 (AFMDC Historical Division, January 1958).

4. Quoted from James P. Henry, et al., "Animal Studies of the Subgravity State during Rocket Flight," Journal of Aviation Medicine, Vol. 23, p. 428 (October 1952).

5. A. Blagonravov, article in Vestnik Akademii Nauk SSSR, June 1957, summarized in Air Intelligence Information Report IR-6440-57, 19 August 1957; Prof. Pokorovski [sic], Study of the Vital Activity of Animals During Rocket Flights into the Upper Atmosphere (Library Translation No. 625, Royal Aircraft Establishment, Farnborough, January 1957).

6. Interview, Capt. Grover J. D. Schock, Asst. Chief, Space Biology Branch, Aeromedical Field Laboratory, by Dr. Bushnell, 19 May 1958.

7. New York Times, 12 January and 2 May 1958.

8. Fritz Haber and Heinz Haber, "Possible Methods of Producing the Gravity-Free State for Medical Research," Journal of Aviation Medicine, Vol. 21, pp. 395-400 (1950).

9. Brig. Gen. Edward J. Kendricks, et al., Medical Problems of Space Flight (special report, USAF School of Aviation Medicine, Randolph Field, August 1955), p. 18.

10. Harald J. A. von Beckh, Fisiología del Vuelo (Buenos

Aires, 1955), pp. 103-107, and "Experiments with Animals and Human Subjects under Sub and Zero Gravity Conditions...," Journal of Aviation Medicine, Vol. 25, pp. 235-241 (June 1954).

11. Ibid.

12. David G. Simons, "Review of Biological Effects of Subgravity and Weightlessness," Jet Propulsion, May 1955, pp. 210-211.

13. Cf. Management Report (ARDC Form 111), Human Factors of Space Flight, 24 January 1956.

14. Beginnings of Research in Space Biology, pp. 22-23; R & D Project Card (DD Form 613), Human Factors of Space Flight 12 October 1954; Historical Branch, AFMDC, manuscript in preparation on administrative factors and problems involved in research.

15. For an example of his other work, see Lt. Druey P. Parks, T/Sgt. John T. Conniff, and A/2c John A. Goldsmith, Ground-to-Air Operation of Aero Medical Field Laboratory VHF Handi-Talkie (HADC Technical Note 55-1).

16. Project 7851, "Monthly Historical Report," 8 October 1954, and Weekly Test Status Report, 22 February, 1 and 8 March 1955.

17. Management Report, Human Factors of Space Flight, 1 October 1955; Holloman Rocketeer, 24 January 1958; Aeromedical Field Laboratory, "Historical Data...1 January through 31 March 1958," p. 9; Test Report on Sub-Gravity Studies, Number 1, 11 October 1955; interview, Capt. Schock by Dr. Bushnell, 19 May 1958.

18. Schock, Test Report on Subgravity Studies, Number 5, 30 July 1957; Management Report, Task 78501, 28 October 1957; interview, Capt. Grover J. D. Schock by Dr. Bushnell, 12 May 1958.

19. Grover J. D. Schock and David G. Simons, A Technique for Instrumenting Subgravity Flights (AFMDC Technical Note 58-4, February 1958).

20. Management Report, Task 78501, 28 October 1957; Schock, Test Report on Subgravity Studies, Number 1, 11 October 1955, and Number 2, 24 February 1956.

21. Management Report, Task 78501, 28 October 1957.

22. Interview, Capt. Schock by Dr. Bushnell, 5 December 1957; Interview, Capt. Joseph W. Kittinger, Jr., Flight Test Division, AFMDC, by Dr. Bushnell, 12 December 1957; R & D Project Card, Human Factors of Space Flight, 19 September 1957, p. 7; Management Report, Task 78501, 28 October 1957.

23. Management Report, Task 78501, 28 October 1957; Aeromedical Field Laboratory, "Historical Data...1 January through 31 March 1958," p. 6.

24. Management Report, Task 78501, 28 October 1957; Grover J. D. Schock, *Apparent Motion of a Fixed Luminous Target During Subgravity Trajectories.* (AFMDC Technical Note 58-3, February 1958).

25. Von Beckh, briefing of AFMDC staff, 22 April 1958.

26. Management Report, Task 78501, 28 October 1957; Aeromedical Field Laboratory, "Historical Data...1 October through 31 December 1957," p. 11.

27. Management Report, Task 78501, 28 October 1957; Aeromedical Field Laboratory, "Historical Data...1 April through 30 June 1957," p. 9; interview, Capt. Schock by Dr. Bushnell, 17 October 1957; Grover J. D. Schock, *Sensory Reactions Related to Weightlessness*, p. 7.

28. 1st ind., Lt. Roy E. Johnston, Asst. Adjutant, Hq., School of Aviation Medicine, 21 March 1956, to basic ltr., DCS/Operations, Hq., HADC, subj.: "Transmittal of ARDC Form 111;" continuation sheet 6 of RDB Project Card, Human Factors of Space Flight, 6 May 1954; Management Report, Human Factors of Space Flight, 24 January 1956; Siegfried J. Gerathewohl, *et al.*, *Producing the Weightless State in Jet Aircraft* (School of Aviation Medicine Report 57-143, August 1957); School of Aviation Medicine, Randolph AFB, *Historical Report*, Vol. 21, pp. 18-19 (1 July-31 December 1955), Vol. 22, pp. 36-37 (1 January-30 June 1956), Vol. 23, pp. 31-32 (1 July-31 December 1956), Vol. 24, pp. 100-101 (1 January-30 June 1957), and Vol. 25, p. 54 (1 July-31 December 1957).

29. *Baltimore Sun*, 14 January 1958.

30. Management Report, Task 78501, 28 October 1957; Aeromedical Field Laboratory, "Historical Data...1 July through 30 September 1957," p. 19, and "Historical Data...1 January through 31 March 1958," pp. 7-8; interviews, Capt. Schock by Dr. Bushnell, 5 December 1957 and 15 May 1958.

31. DF, Col. Richard C. Gibson, DCS/Operations, HADC, to Directorate of R & D, subj.: "Cessation of Work Under Task No. 78501...," 27 August 1957; Historical Branch, AFMDC, "The Effect of Fiscal Year 1958 Expenditure Limitations At Air Force Missile Development Center: Preliminary Report," 22 October 1957.

32. Historical Branch, "Effect of Fiscal Year 1958 Expenditure Limitations;" Aeromedical Field Laboratory, "Historical Data...1 October through 31 December 1957," p. 11; interview, Capt. Schock by Dr. Bushnell, 5 December 1957.

33. Disposition Form, Capt. Schock to Dr. [James S.] Hanrahan and Dr. Bushnell, subj.: "Philosophy of Weightlessness Research," 13 May 1958.

34. Aeromedical Field Laboratory, "Historical Data...1 January through 31 March 1958," p. 7.

35. Historical Branch, History of Flight Support, Holloman Air Development Center, 1946-1957, pp. 55-57, 60; interview, Capt. Jack H. Patterson, Aircraft Allocations Officer, AFMDC, by Dr. Bushnell, 18 December 1957; interview, Capt. Schock by Dr. Bushnell, 19 May 1958.

36. Management Report, Human Factors of Space Flight, 1 October 1955; R & D Project Card, Human Factors of Space Flight, 19 September 1957 (with annexes); interview, Capt. Schock by Dr. Bushnell, 19 May 1958.

37. Aeromedical Field Laboratory, "Historical Data...1 January through 31 March 1958," pp. 8-9; interview, Capt. Schock by Dr. Bushnell, 19 May 1958.

GLOSSARY

AFB	Air Force Base
AFMDC	Air Force Missile Development Center
ARDC	Air Research and Development Command
DCS/	Deputy Chief of Staff for
DD	Department of Defense
DF	Disposition Form
HADC	Holloman Air Development Center (redesignated Air Force Missile Development Center as of 1 September 1957)
HAFB	Holloman Air Force Base
Hq.	Headquarters
Ind.	Indorsement
Ltr.	Letter
R & D	Research and Development
RDB	Research and Development Board
Subj.	Subject
USAF	United States Air Force
WADC	Wright Air Development Center, Wright-Patterson Air Force Base, Ohio

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