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SPACECREW TRAINING: A REVIEW OF PROGRESS AND PROSPECTS

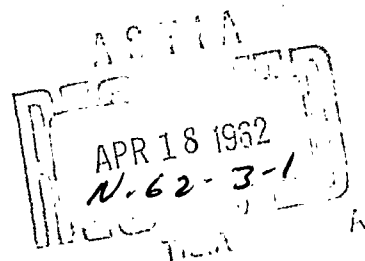
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**BEHAVIORAL SCIENCES LABORATORY
AEROSPACE MEDICAL RESEARCH LABORATORIES**

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**EVALUATION OFFICE
DEPUTY FOR ENGINEERING**

DECEMBER 1961



**AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO**

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ASD TR 61-721	UNCLASSIFIED	Aeronautical Systems Division, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio SPACECREW TRAINING: A REVIEW OF PROGRESS AND PROSPECTS, by G.A. Eckstrand and M. R. Rockway. December 1961. 29p. incl. illus. 16 refs. (Proj. 1710) Unclassified report	UNCLASSIFIED
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DECEMBER 1961

PROJECT No. 1710

**AERONAUTICAL SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
WRIGHT-PATTERSON AIR FORCE BASE, OHIO**

FOREWORD

This report was prepared in support of Project 1710, "Training, Personnel, and Psychological Stress Aspects of Bioastronautics." Dr. Ross L. Morgan is Project Scientist.

This report was prepared as a joint effort by Gordon A. Eckstrand, Training Research Branch, Behavioral Sciences Laboratory of the Aerospace Medical Research Laboratories, and Marty R. Rockway, Evaluation Office, Deputy for Engineering, and presented at the American Rocket Society Space Flight Report to the Nation held in New York City, October 9-12, 1961.

ABSTRACT

This report reviews current progress and future prospects in the field of spacecrew training. Descriptions of all current astronaut training programs are presented, and a number of general conclusions with reference to such training are drawn, based upon the manned space operations which have been conducted to date. In addition to the actual experience which has been gained in training spacecrew personnel, a review is presented of recently completed and current research which is directly relevant to this problem. Several areas in which research should be accelerated are identified.

PUBLICATION REVIEW

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SPACECREW TRAINING: A REVIEW OF PROGRESS AND PROSPECTS

By

Gordon A. Eckstrand and Marty R. Rockway

INTRODUCTION

At the American Rocket Society semiannual meeting in San Diego in June 1959, we presented a paper discussing some of the problems of spacecrew training as a part of a session on the human factors problems associated with the design and operation of a spacecrew holding facility. This paper was later published in *Astronautics* (ref. 5). In this paper we attempted to do four things: (a) to justify the assumption that man will have a very active and important role in future space vehicles and to delineate some of the functions he will perform, (b) to point out the vital importance of intensive, rigorous, thorough training in assuring that man will perform reliably and effectively in space, (c) to discuss the important role of ground-based simulators and trainers in providing the required training, and (d) to emphasize the importance of and logical necessity for considering training plans and facilities as an integral part of any space systems development program. The discussion of these points was largely conceptual in nature. At that time very little experience in training personnel for space flight was available (in fact, the Mercury Astronauts had just been selected), and practically no research on the specific problems of spacecrew training was under-way.

But a great deal has happened since then. The purpose of this paper is to up-date and expand the discussion presented in 1959 by reviewing developments relevant to spacecrew training which have taken place during the past 2-1/2 years. Significant developments are reviewed in three broad areas: (a) changes in attitudes and orientation toward manned space flight, (b) experience in training personnel for space flight, and (c) research on problems of spacecrew training. Before going any further, it is necessary to comment briefly on this imposing objective. It is probably impossible today for anyone in any field of astronautics to be cognizant of everything that is going on related to his field. Certainly, we do not presume to be in this position with respect to training. We have, however, tried to outline the most significant aspects of this field.

CHANGES IN ATTITUDE AND ORIENTATION TOWARD MANNED SPACE FLIGHT

Significant changes in attitude and orientation toward manned space flight have occurred during the past 2-1/2 years. We will briefly discuss four of these changes of particular relevance for spacecrew training.

First, a much more positive attitude exists today toward both the feasibility and desirability of manned space operations than existed in June 1959. This change in attitude appears to have occurred among both the public and the scientific and technical community. Whereas we devoted approximately one-fourth of our paper in 1959 to justifying man's role in space, we feel there is no need to do so today. We do not deny the importance of continued study and quantitative description of man's performance capabilities in space. This is of utmost importance, of course, if we are to continue to improve our capability to integrate men effectively and efficiently into increasingly complex space systems. But it is to say that the question as to whether man has any role in space other than to indulge his curiosity has been effectively answered in the affirmative. The Mercury Project has taught us much during the past few months regarding man's positive role in space. When Alan Shepard reported that "all systems are go" on the MR-3 flight, he was reporting accurately on the status of the human component of the Mercury system as well as the machine components. As we have moved out of the purely discussion phases of this question of man's role in space into the realities of space flight with specific vehicle systems, it has become clear that a trained man properly integrated into a well designed machine is essential in assuring a successful manned space program.

Second, the probability of large-scale manned operations in space has definitely increased. All of us who participated in the spacecrew holding facility session in 1959 seemed to be considering a rather limited type of space operations: we were considering preparations for a space flight rather like those for a polar exploration or an assault on Mt. Everest. In other words, we were considering a very small, select group of astronauts, relatively few missions, etc. In the intervening 2-1/2 years, however, the military has become increasingly aware of the operational indivisibility of air and space, and a great deal of planning, study, and advanced development is currently underway to exploit the military potential of space and to counter any such exploitation by potential aggressors. Therefore, many of us in the training field have turned some of our attention away from the conditioning and training of premium men for exotic missions to the problem of training crews for more "routine" military operations in space. In such operations the concept of a holding facility, while not invalid, would undoubtedly resemble a military operational base more than the sterile biological laboratory which was outlined at the San Diego meeting. The exotic missions will undoubtedly continue, of course, as new concepts and new regimes of space are continually explored, but the large-scale manned operations offer the greater challenge and greater potential payoff to the training specialist.

Third, the importance of rigorous and thorough training of spacecrew personnel has been increasingly recognized during the past few years. The positive accomplishments of the X-15 and Mercury training programs have been verified by actual flight experience and have given substance and reality to what were before only hopes and predictions. This increased recognition of training as an important aspect of system design, development, and operation has resulted in the initiation of a number of training research and study programs which will be described later.

Last, there have been changes in the time tables for the various space systems envisaged for the future. Many of these time tables have been significantly advanced. To take the Apollo Project as an example, current estimates are that with suitable fiscal support a three-man crew can be landed on the moon before 1970, perhaps as early as 1967. Even a year ago, this event was not programmed to occur until after the turn of the decade. Comparable changes have occurred in the time tables of a number of other systems which are in the conceptual or development stages.

These four changes in attitude and orientation toward manned space flight have important implications for spacecrew training. They have, we think, increased the likelihood that spacecrew training on a broad scale will be a national requirement and have advanced the date when this requirement must be met. They have, in addition, served to focus more attention on training problems and have increased the vigor and urgency with which these problems are being attacked. In the remainder of this paper we briefly review past and current spacecrew training experience and research to see where we stand in this field today.

SPACECREW TRAINING EXPERIENCE

Currently the United States is conducting three "spacecrew" training programs. Two of these, the X-15 and Mercury training programs, have already received indirect—but impressive—verification of much of the training employed as a result of successful limited performance missions. The third, Dyna Soar, is still in a preliminary status, although a formal training plan is being prepared at this time.

All three programs are characterized by the fact that they involve a limited number of highly experienced military or civilian test pilots, each of whom has one or more degrees in engineering or the physical sciences. In addition, all personnel are volunteers and all receive some of their training as a result of direct participation in the design and development of the system they are being trained to operate.

X-15 Program

The X-15, although not a true space vehicle in its present configuration and mission, still poses many of the problems to be faced by the pilot of higher performance systems with a winged re-entry capability. In a typical flight the X-15 is released from a B-52 carrier aircraft at an

altitude of approximately 40,000 feet. It is boosted into a zero-g trajectory established by the pilot. During boost the pilot is exposed to as much as a 4-g transverse acceleration. Following boost cut-off the pilot experiences several minutes of weightlessness during which he maintains his trajectory through the use of aerodynamic or reaction controls as appropriate. During the final phases of flight the pilot effects an aerodynamic recovery and landing.

Much of the training for the X-15 was accomplished on ground-based simulators in conjunction with the system development program. * Most of this training took place in a fixed-based, six-degree-of-freedom, analog computer simulation. This simulator also serves as a preflight briefing device and is used by the pilot to rehearse each mission prior to an actual flight. However, some training was given using the Johnsville centrifuge** in a closed-loop mode. According to the pilots, one of the major benefits of the centrifuge program was that of establishing confidence in their ability to handle the vehicle when exposed to the actual acceleration environment. Another ground-based device used in the X-15 program was the "Iron Cross." This consisted of two I-beams mounted on a universal joint at the center of gravity. It was designed primarily as a vehicle for checking the operational characteristics of the reaction controls although it was felt that it might also have some training potential. However, it was not particularly effective for training.

In addition to the ground-based simulator training, some training was also received in joint operations with ground personnel during ground firing of the engines and ground operation of the various vehicle subsystems. Considerable training benefit was also derived during pilot participation in the development and qualification testing of the pressure suit and associated protective equipment items.

Four different vehicles have provided varying amounts of flight training. The first of these was the F-107 which was used to evaluate the in-flight characteristics of the side-stick controller. The second is the Cornell Aeronautical Laboratory variable stability T-33. The stability and control parameters of this vehicle can be varied mechanically and electronically to approximate those of the X-15. The third flight vehicle is a modified F-104 which, through suitable programming of thrust and drag-producing devices, simulates very closely the landing approach characteristics of the X-15. In practice the pilots were encouraged to build up to the steep approach path in gradual steps. This device is also used for training prior to an actual flight when long periods occur between flights or new emergency landing sites are required. The final flight training vehicle is the X-15 itself. Training for the maximum performance mission is provided through a program of unpowered air drops and a gradual build-up of powered flights to design conditions.

Project Mercury Program

The results of Project Mercury flights provide one of the most dramatic demonstrations to date of the value of a comprehensive training program. This is not to say that the Mercury training program was optimal from the point of view of either efficiency or economy, for undoubtedly it was not. However, the considerable success of the initial flights, with respect to astronaut performance, is convincing validation of the program as a whole. In addition, the success of the program is a powerful argument for using ground-based simulators since these were the primary media for premission training. Because of its central importance to our current knowledge of spacecrew training, we will describe the Mercury training program in some detail.†

* Information on the X-15 training program was obtained from personal contact with project personnel and from references 4, 11, and 16.

** Naval Medical Acceleration Laboratory, Johnsville, Pennsylvania

† Information on the Project Mercury training program was obtained from personal contact with project personnel and from references 3, 6, 7, 12, 13, and 16.

In retrospect the Mercury training program presents a spurious appearance of systematic pre-planning. Actually, it evolved in large part after-the-fact, but fortunately early enough in the system development cycle to be of value. The variety of techniques and devices used attests to both the ingenuity and insight of project personnel as well as to our general ignorance concerning some of the specific requirements for spacecrew training.

The Mercury training program may be categorized either by subject matter content or training method. Both approaches will be used to describe the various phases of the overall program in this paper.

Academic training consisted of readings and lectures in a variety of basic fields such as astronomy, meteorology, astrophysics, geophysics, space trajectories, rocket engines, and physiology. In addition to the lectures on basic astronautics, information concerning the design and operation of the various subsystems was obtained in engineering briefings and coordination meetings. Since each of the astronauts was assigned responsibility for a different aspect of the Mercury program, he also briefed the others on the latest developments in his specialty area. The classroom work was supplemented by a number of field trips to capsule and booster design, development, and test facilities.

Static training was obtained in fixed-base part-trainers and the mission simulator referred to as the Mercury Procedures Trainer. An early part-trainer for practicing retrofire and re-entry maneuvers consisted of an analog computer tied into prototype instruments and hand controller. A later modification of this device was linked to an F-100 flight simulator computer. This trainer was designed for operation using a contour couch while the astronaut was wearing the pressure suit. The major training device of the Mercury program is the Procedures Trainer (figure 1). With this device, it is possible to simulate with rather good fidelity complete mission profiles in real time. The trainer permits practice on both normal and emergency procedures throughout the entire flight regime. As an example of its acceptance and use, Astronaut Shepard flew 10 MR-3 simulated missions in the week prior to the MR-3 flight. Since this trainer evolved with the system, it proved to be a valuable tool during the design and modification of the various capsule subsystems. Another portion of the training program, aimed specifically at orbital flight, involved fast-time practice in celestial navigation. This training took place in the Moorehead Planetarium of the University of North Carolina.* A Link Trainer with a viewing port the same size and shape as that of the Mercury capsule was installed in the planetarium and a series of orbital flights was run. Since each run took only 9 minutes, a large amount of practice could be obtained in a relatively short time.

Dynamic training consisted of a series of experiences in a variety of ground-based devices which involved physical motion as well as exposure to a number of environmental stresses. The first such device is the Air-Lubricated Free Attitude Trainer (ALFA) (figure 2). ALFA contains a capsule couch, hand controller, and periscope viewer. A moving film strip projects an earth image as seen from orbit on the back of a screen which covers one wall of the room housing ALFA. The ALFA platform is free to rotate around three axes and is propelled by air jets in response to movements of the hand controller. In addition, compressed-air retrorockets have been attached to the back of the trainer to permit retrofire practice under dynamic conditions. Another device employed for attitude control training is the Multiaxis Spin Test Inertia Facility (MASTIF) at Lewis Laboratory in Cleveland, Ohio (figure 3). This trainer consists of a seat, hand controller, and flight instruments mounted within a large three-axis gimbal frame. The device can be set in motion for up to 30 rpm around all axes from an external control station. The trainee's task is to reduce all rotations to zero through the control of compressed nitrogen jets mounted on the periphery of the cockpit cage. Although the MASTIF frequently induced nausea, it did serve to convince the astronauts that they could control any probable tumbling maneuver in the actual capsule. The astronauts also took an orientation ride in the rotating room at the Naval School of Aviation Medicine in Pensacola, Florida. This room provides experience with coriolis forces such as might be present when rotating a satellite to create an artificial g-field. It is very unlikely that this experience provided any relevant training for the Mercury missions, although it might well be applicable to some later space systems.

* Chapel Hill, North Carolina

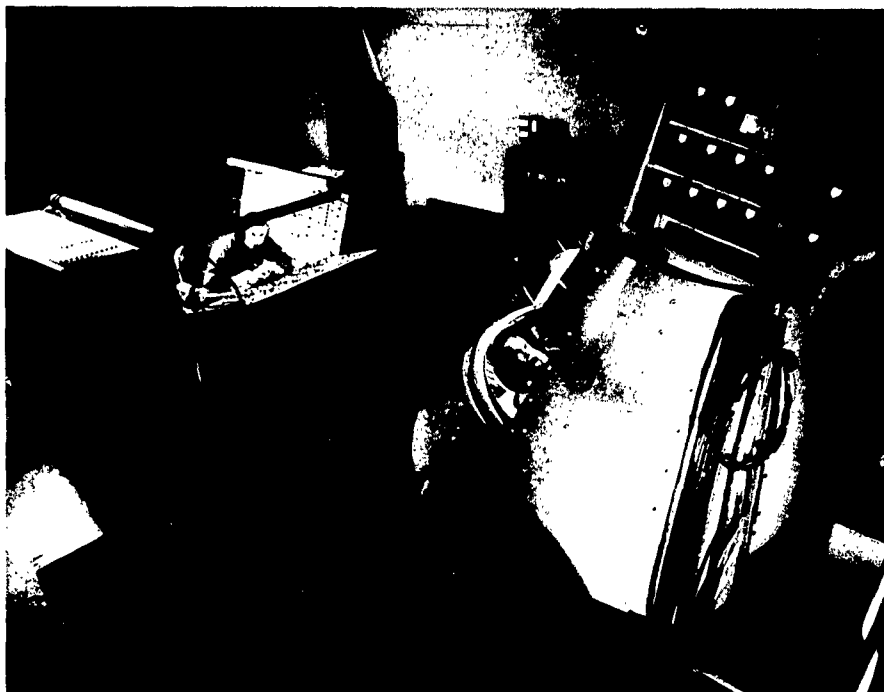


Figure 1. Mercury Procedures Trainer



Figure 2. Air Lubricated Free Attitude(ALFA) Trainer

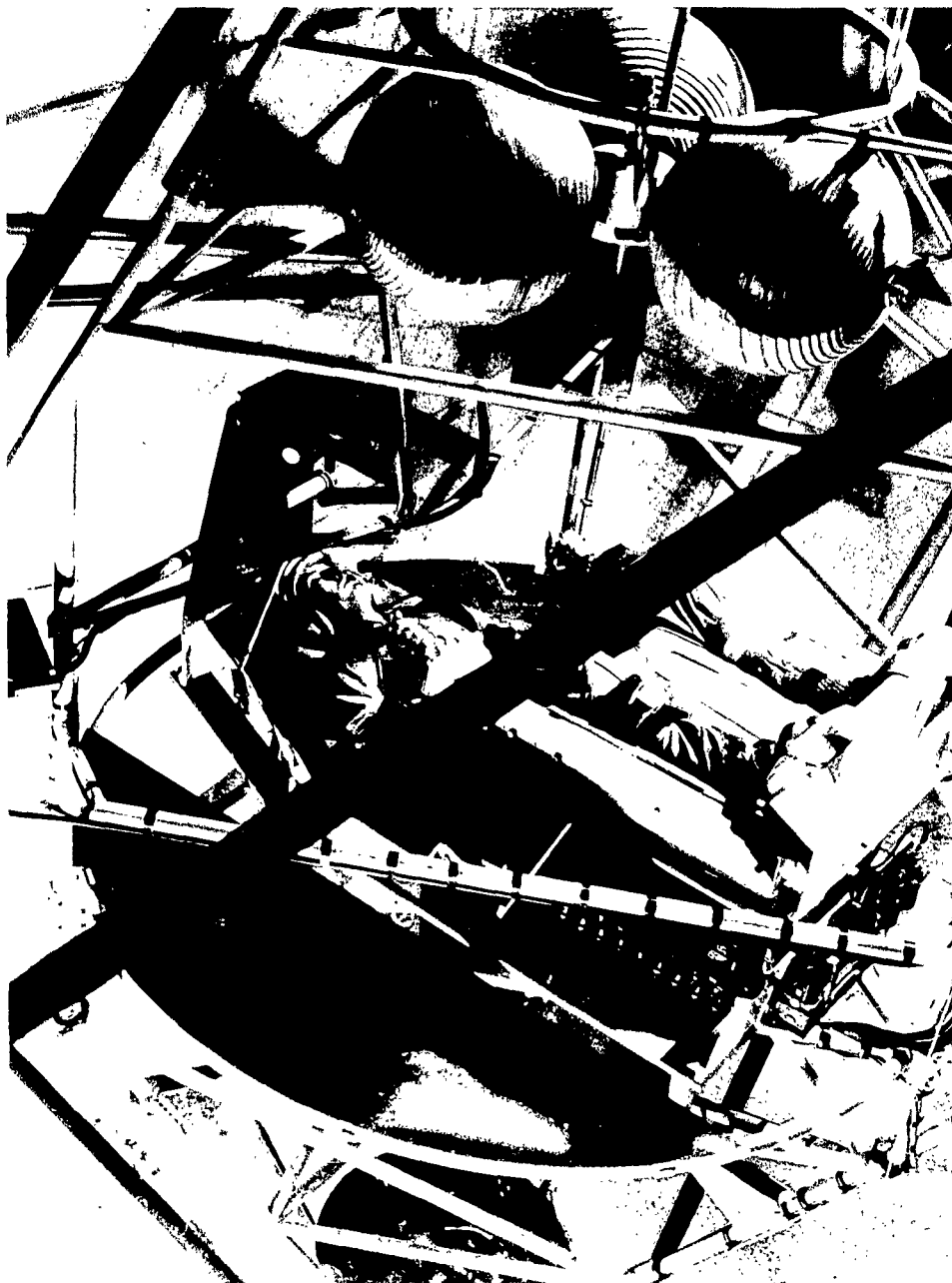


Figure 3. Multiaxis Spin Test Inertia Facility (MASTIF)

In the opinion of the Mercury Astronauts the NADC centrifuge at Johnsville was one of their most valuable training devices (ref. 13). The centrifuge gondola contained a mock-up of the capsule instrument panel and hand controller as well as a complete environmental control system. Runs were made which simulated all normal launch and re-entry profiles and most of the possible abort re-entry profiles. Training included the development of techniques to maintain vision, and to permit breathing and speaking under high g-loads. Practice was also given in controlling the vehicle throughout the range of acceleration loads experienced during re-entry.

Airborne training included weightlessness familiarization using C-131 and KC-135 aircraft at Wright-Patterson Air Force Base, Ohio, and F-100 aircraft at Edwards Air Force Base, California, flying parabolic trajectories. In addition, considerable time was spent in proficiency flights in high-performance jet fighter aircraft. The astronauts felt that the free-floating weightlessness experienced in the cargo aircraft was fun but has little direct application to Mercury. It may, of course, have application to later space operations.* They also felt that weightlessness while restrained, as in fighter aircraft or the Mercury capsule, did not constitute a training problem for persons with their backgrounds of experience. On the other hand, they did feel that the proficiency flights were very valuable for maintaining their ability to make rapid judgments and appropriate responses under conditions where the potential consequences of error were more serious than in a simulated situation. Despite the opinion of the astronauts, there is doubt that such experience contributes directly to their ability to perform adequately in Mercury missions. It is important to realize that a clear distinction can be made between the value of extensive jet flight experience as a criterion of selection and the relevance of further jet experiences as a medium of training. However, since all of the astronauts are rated jet pilots who may return to their previous jobs in the future, proficiency flights undoubtedly do contribute to the maintenance of morale and conventional flying skills.

As part of their familiarization with potential environmental stresses, the astronauts were subjected to ambient temperatures of approximately 250° F while dressed in a ventilated pressure suit. Since no excessive discomfort was experienced, the astronauts' qualms concerning the effects of high heat loads were eliminated. The astronauts also experienced the physiological effects of above normal concentrations of carbon dioxide in their breathing atmosphere. Familiarization with the physiological effects such as increased respiration and pulse rates, flushing, etc., could prove very valuable since the lack of satisfactory partial pressure measuring devices places greater reliance on the astronauts themselves as sensors. In addition, familiarity with these involuntary effects tends to avert the possible panic reaction which might occur when they are experienced for the first time during the course of an actual mission.

Another phase of training was the physical conditioning program. In general, this was an individual responsibility. The only organized activity was some scuba diving with an underwater demolition team. This acted not only as a physical conditioner but also provided some practice in breathing under pressurized conditions with an artificial system and additional familiarity with a water environment. The astronauts felt that this latter factor was desirable since their primary recovery area is water.

Egress training was accomplished using a full-scale model of the Mercury capsule. Since the primary recovery area is water, this training took place under both calm and rough conditions in a hydrodynamics tank at Langley Research Center** and in the Gulf of Mexico. All possible modes of egress including underwater were practiced. Water survival training was conducted in conjunction

* For a discussion of some potential problems in training for weightlessness, see King et al. (ref. 9).

** Langley Air Force Base, Hampton, Virginia

with egress training. It consisted of spending 1/2 day in one-man life rafts using the various items of survival gear. An additional 3 days was also spent learning desert survival techniques at Stead Air Force Base* against the remote possibility of capsule impact in the West African desert.

The final phase of training was devoted to specific mission preparation to prepare each astronaut for an individual spacecraft, launch complex, and mission. This takes place while the spacecraft is at Cape Canaveral undergoing hangar and pad checkouts. Each astronaut reviews drawings and specifications for his particular vehicle and participates in all system and subsystem checkouts. He also attends all meetings concerned with the checkout and modification of spacecraft. In addition to maintaining familiarity with the hardware, each astronaut receives repeated practice in his particular mission flight plan using the Procedures Trainer. During this time, astronaut performance data is secured for comparison with actual flight results. In addition to individual training, each astronaut also participates in joint exercises with the Mercury Control Center and down range ground personnel involved in his specific flight. During these exercises the Procedures Trainer is tied into the Mercury Control Center and pilot and ground crew standard operating procedures are developed for this particular mission. After the spacecraft is mated with the booster on the pad, the astronaut then participates in all countdowns, checks, and tests. At this time emergency rescue procedures are refined and rescue crews exercised. There are also full-scale training exercises which involve all relevant personnel. During this period the astronaut is placed on a special low-residue diet and specimens collected for comparison with similar postflight specimens. Throughout this final phase the astronaut is subjected to continual medical monitoring to insure that he remains in satisfactory physical condition. Extensive astronaut debriefings are conducted after each flight. While these are not a part of the training program, they serve, along with the pilot performance data, as important sources of feedback as to the adequacy of this program.

Dyna Soar Program

The Dyna Soar system consists of a winged re-entry vehicle (the glider) plus a large booster. Under the present concept, one of the major objectives of the program is to determine the extent and the manner in which man can contribute to space flight. As a consequence, the Dyna Soar pilot will participate to a larger degree than in Project Mercury in the performance of mission functions. In fact, it is planned that the pilot will exercise some control of vehicle attitude and/or flight path throughout the course of a mission from boost to re-entry and landing.

At the time this report was written a preliminary Dyna Soar Aircrew Training Plan had just been prepared and was in the process of review and approval. This document outlined in very general terms the phases of training, subject matter content, and proposed training techniques and equipment. If approved, it was intended that the preliminary plan would become the official training document and would be updated and expanded by the inclusion of training specifics during the evolution of the system program. Despite the preliminary nature of the training plan, and indeed the Dyna Soar development itself, it seems unlikely that the general characteristics of the proposed training program would be subject to serious modification in the future.

The Dyna Soar pilots have not yet been chosen. However, a 7-man team comprised of 4 Air Force and 3 NASA experimental test pilots has been designated the Dyna Soar Pilot Consultant Group. This group provides design engineering inputs and participates in the various simulator and other tests requiring pilot participation during the design and development of the system.

Since information with respect to the sequence and location of training activities is at present classified, the program will be summarized only by broad training areas. Actually, the overall approach to training is very similar to that employed for Project Mercury and also the ones described in a later section of this report under Study Requirement (SR) 49756. The various Dyna Soar training areas are categorized as follows:

* Reno, Nevada

Engineering Theory Indoctrination:

This is fundamentals training in the engineering technology applicable to Dyna Soar. Included are such subjects as rocket propulsion, guidance and control, energy management, etc.

Vehicle Subsystem Familiarization:

Familiarity with the vehicle subsystems will be acquired through study of operational subsystem mock-ups in conjunction with engineering theory indoctrination, observations of various system and subsystem tests, continuous review of performance and design specifications and maintenance manuals, and participation in the preparation and updating of the pilot's handbook.

Ground Simulator Training:

This phase provides actual practice of the job skills and knowledges required to operate the system under both normal and emergency conditions. This training will result both from participation in the various simulator test programs and in specific training exercises. Among the major devices to be used are the Boeing* operational mock-up, the NADC centrifuge, an air-launch simulator located at Air Force Flight Test Center,** and a full mission profile simulator to be located at Air Force Missile Test Center† or an appropriate test site. The full mission simulator will have the capability of tying into the ground facilities to permit integrated team training with critical ground crew personnel.

Flight Training:

Flight training will serve two major functions: to maintain general flying proficiency as in Project Mercury and to provide mission segment training in areas which cannot be simulated so effectively on the ground. During this phase pilots will fly Century series fighter aircraft on routine proficiency flights. They will fly both powered and unpowered missions in the X-15 (if available). They will fly modified high-performance aircraft with cockpit and approach and landing characteristics similar to the Dyna Soar vehicle. And they will also fly variable stability aircraft which simulate Dyna Soar handling qualities during the latter phases of re-entry and terminal glide.

Support Facility Indoctrination:

This will provide familiarity with various relevant facilities including biomedical, launch support, tracking and communication, landing sites, and rescue. During ground launch preparation the pilot will perform final launch practice including ingress, emergency egress, and countdown procedures.

Survival Indoctrination:

This will include refresher training in survival techniques for the escape system and specific air and ground launch routes. Since survival procedures are dependent upon the specific routes to be flown, they must be updated when routes are altered.

Physical Conditioning:

Maintaining physical fitness will be the responsibility of the individual pilot, but such activities will be carried out under competent medical guidance and supervision.

* Boeing Airplane Company, Seattle, Washington

** Edwards Air Force Base, California

† Patrick Air Force Base, Florida

Mercury and X-15 Orientation:

Familiarity with relevant procedures and techniques developed during the X-15 and Mercury programs will be obtained through the media of periodic lectures, films, and launch observations.

Dyna Soar Launch Observations:

Pilots will observe all air and ground launches of the Dyna Soar vehicle and will participate in chase flights.

Vostok Program

The Soviet Union is also conducting a manned space flight program and two manned Vostok flights have been made as of this date. Vostok I, launched 12 April 1961, involved a single orbit of the earth, and Vostok II, launched 6 August 1961, orbited the earth 17 times prior to recovery. Both flights were apparently quite successful. Unfortunately, the Russian Government has released very little information regarding the details of the training program they used and the astronaut performance and reactions during and after the flights. Therefore, it is difficult to assess the value and implications of their experience in the field of spacecrew training. There is an indication also that the Russians have accomplished research on spacecrew training but we have no information on this.

The only information available to the writers concerning the selection and training of the Russian space pilots came from the Russian magazine USSR (ref. 15). The account in this publication shows that there is a great deal of similarity between the Project Mercury selection and training program and that of the Russians. To present as much detail as is available as well as to preserve the "flavor" of the Russian account, the portions of the article in USSR dealing with the astronaut selection and training program are reproduced verbatim:

CHOOSING AND TRAINING THE ASTRONAUT

The first space pilot had to be a man aware of the enormous importance of the assignment. He had to be willing to give all his ability, energy, knowledge—perhaps even his life—to this historic undertaking. Thousands of Soviet citizens of the most varied ages and vocations volunteered.

In the course of a space flight a man is subjected to a complex of such environmental factors as acceleration and weightlessness and to severe nervous and emotional strains that call on all his moral and physical stamina. Along with this, the astronaut must be able to function properly, to orient himself in the complicated flight conditions, and, if necessary, control the spaceship himself. All this requires physical and mental health of an exceedingly high order and a corresponding general background and technical competence. As a group, pilots are most inclined to have this combination of qualities.

In selecting a group to be trained as astronauts a great number of pilots who had volunteered were interviewed. Those considered most promising were given physical and psychological examinations designed to reveal latent deficiencies or low resistance to space flight factors. Biochemical, physiological, electro-physiological, and psychological methods and special functional tests were used to assess the reserve possibilities of the main physiological systems of the applicant. Subjects were examined in a pressure chamber with the air considerably rarefied, under increased pressures, during abrupt changes in barometric pressure, in a centrifuge, etc.

The psychological tests were designed to search out those with especially retentive memories, resourcefulness, instantaneous reaction to changed situations, and precise coordination.

The group selected was then given a course of special instruction that simulated flight conditions and further tested individual reactions.

The instruction program gave the future astronauts the theoretical background and the skills and habits they would need to use the equipment and instruments in the spaceship's cabin. Study included the fundamentals of rocket and space technology, spaceship, design, related problems of astronomy and geophysics, and space medicine.

THE TRAINING PROGRAM

The training and test program included flight in planes under zero-gravity conditions: training in a replica of the spaceship cabin and on a special device, prolonged stay in a specially equipped soundproof chamber, training in a centrifuge, parachute jumps from planes.

During the training process some problems still pending were solved, specifically those that had to do with feeding the astronaut in flight, his space suit, and the air regeneration system.

On the plane flight reactions to weightlessness and transition from weightlessness to overstrain were studied, together with such problems as maintaining radio communication, taking in water and food, etc.

It was found that all the astronauts in the group bore up well under zero-gravity conditions. For periods of weightlessness lasting up to 40 seconds they could take in liquid, semi-liquid, and solid food; perform such finely coordinated and purposeful movements of the hand as writing; maintain radio communication; read; and orient themselves visually in space.

Training in the replica of the cabin and in the special training device covered general habituation to stays in the actual ship and to the equipment and instrumentation of the cabin and practice in flight tasks. A special stand was made for this purpose, having electronic devices that duplicated the instrument changes that would be taking place during the flight. The pilot acted as he would in space. Unusual—emergency—versions of the flight were simulated for training purposes.

A specially equipped soundproof chamber was used to determine the psychological stability of the astronaut during a prolonged and isolated stay in the close confines of the cabin with external stimuli sharply reduced. During the stay the regimen and feeding process of actual flight were duplicated.

The centrifuge and the thermal chamber tested the astronaut's tolerance for such factors as acceleration and temperature changes and trained him to make the required adjustments. The tests established the fact that the astronaut made a good adjustment. Those who best withstood the tests were singled out.

In air-drop training each of the astronauts had to make several dozen jumps. The physical-training portion of the program consisted of planned lessons and setting-up exercises. The setting-up exercises, aimed at general physical development, were given for an hour daily. The purpose of the physical-training program was to adjust the astronaut to the effects of acceleration, to help him make better use of his body in space, and to strengthen his ability to endure long physical tension.

Physical training combined selected exercises, games, diving, swimming, and exercises on special apparatus, and was carried on under close medical supervision.

The more direct preparation for the flight began when this training program was completed. It included study of flight assignments and maps of the landing area; instruction in navigation, radio communication, etc; a study of emergency supplies and their use after landing, and of the direction-finding systems; training in a centrifuge in a space suit under the anticipated maximum load; training over a long period in a model spaceship using all the lifesaving systems.

Summary of Spacecrew Training Experience

At the time of this writing, there have been, in addition to a number of high-performance X-15 flights, two manned suborbital Mercury flights and two manned orbital Vostok flights. When considered together, they have sampled a wide range of human performance and functions under space flight conditions and have involved durations of space flight in excess of 24 hours. These flights are too recent and, in the case of the Russian flights, too little information is available to permit a careful analysis of the training and human performance data and a formulation of detailed training implications. Nevertheless, the flights to date have "cleared the air" on several issues and a number of general conclusions seem warranted:

- a. All of the manned space flights to date appear to have been very successful. They have demonstrated that with carefully designed programs men can be selected and trained to perform active, complex roles in space, retaining full command of their sensory, motor, and intellectual facilities.
- b. Furthermore, it appears that such training can be accomplished largely if not completely with trainers which are either ground-based or operated within the atmosphere. Economic considerations have long argued that you cannot use space flight to train for space flight. American and Russian experience to date has now given strong indication that you do not have to.
- c. Weightlessness does not appear to present significant training problems when spacecrew personnel are experienced jet pilots and when they remain restrained during space flight.
- d. With carefully selected and trained spacecrew personnel, there appear to be no serious problems associated with isolation, confinement, "breakoff" from the earth, etc., at least for periods up to 24 hours.
- e. The importance, in training program development, of an analysis and coverage of all possible contingencies has been re-emphasized. In those few cases where some particular aspect of astronaut performance has been less than optimal, it is possible with some confidence to trace this to some training omission or deficiency.
- f. The development of an adequate, comprehensive spacecrew training program requires much time and effort. Such programs do not spring from inspired hunches on the part of some individual training officer but are the product of a great deal of planning, analysis, coordination, and plain hard work by many people. The development of a spacecrew training program requires relatively long lead time, application of adequate resources, and strong management support.
- g. With 1-man flights of 1 day or less, there do not appear to be any radically new or extremely difficult training problems. Rather, current experience points up the relevance of currently available concepts and techniques and emphasizes the importance of improving these concepts and techniques and advancing them so as to keep pace with a rapidly developing space flight technology.

SPACECREW TRAINING RESEARCH

In addition to the actual experience which has been gained in training spacecrews during the past 2-1/2 years, it is encouraging to note that some relevant applied research has been initiated also. In a field like spacecrew training, it is difficult to identify specific problems which need to be

solved since these are dependent to a large degree upon the specific characteristics of future space systems for which training will be required. On the other hand, since research is a time-consuming business, one cannot wait until specific space systems are designed before initiating the required supporting research. Waiting would preclude data being available when it is needed. The only solution to this dilemma is to do research at the level of variables which have been abstracted from a number of space system designs and which seem to be most representative and critical. In this way, one can buy time to accomplish research at the price of specificity of problem solution. An added bonus, of course, is that the results achieved by this approach have much wider application than those achieved in solving specific problems. Most of the research summarized below is of this type and is organized around certain general problem areas which are applicable to a wide variety of manned space systems.

Conference on Astronaut Training

Although not properly falling under the heading of either experience or research, there is one conference which should be mentioned in any discussion of significant events in the field of spacecrew training. On the 29th and 30th of August 1960, the Panel on Psychology of the Armed Forces-National Research Council Committee on Bio-Astronautics sponsored a Working Group Conference on the Training of Astronauts (ref. 16). The broad aim of this working group conference was to assemble a small group of experts for the purpose of: (a) critically reviewing past, present, and planned programs for the training of spacecrew personnel, (b) suggesting improved concepts, techniques, and procedures for such training based upon current state-of-the-art, and (c) recommending areas of research and development which are critical to future advances in this field. The first day of the program was devoted to a review of current programs and concepts in astronaut training through technical presentations covering the X-15, Project Mercury, Dyna Soar, and SR 49756, an Air Force study dealing with spacecrew training requirements and concepts of the 1965-75 time period. The second day was devoted to critiques, comments, and suggestions by each of five invited behavioral scientists and to the formulation of specific working group recommendations. This conference represents a significant happening, we feel, not so much because of any particular problem solutions which it achieved, but because it was the first consideration on a national scale of problems specifically associated with spacecrew training. As such, it not only represented the increased recognition accruing to these problems, but became one of the events which served to further crystallize interest and effort in this area.

Study Requirement 49756

Study Requirement 49756 was initiated by the Air Force Systems Command in early 1959 to provide a general forecast of spacecrew training requirements for manned military space systems of the 1965-75 time period. This information was desired to form a sound basis for planning and programming the research and development activities necessary to provide the Air Force with an effective spacecrew training capability when required. It was recognized that much of the information obtained would be tentative in nature and might require modification as new data becomes available. However, the activities necessary to develop an adequate human capability for manned space systems would require at least as much lead time as the activities necessary to develop a hardware capability. Therefore, it was decided to begin the study at this time and to update the findings as required.

The general objective of SR 49756 was to identify the training requirements and to establish the general design characteristics of a complete crew training capability for military manned space systems representative of those likely to exist in 1965-75. Defining an overall spacecrew training program with gross specifications for all techniques, devices, and aids necessary for the efficient acquisition, maintenance, and evaluation of the required human performance was emphasized.

The study objective was elaborated with a series of detailed requirements concerning the desired approach and ground rules. For example, the contractor was instructed to:

- a. Be liberal rather than conservative in the assignment of functions to man.
- b. Consider the need for cross-training in multi-man crews.

- c. Identify techniques for familiarizing or habituating personnel to unique operational conditions.
- d. Define the requirements for on-board training facilities for maintaining little used, but critical, skills on long-duration missions.
- e. Give consideration to the use of all available and planned facilities such as simulators, centrifuges, etc., in any recommended program.
- f. Study the training programs proposed for the X-15, Mercury, and Dyna Soar projects.
- g. Consider the pros and cons of employing an actual space vehicle flight trainer.

The study was conducted on an unfunded basis by four contractors: Douglas,* Chance Vought,** Link,† and North American.‡ The official study period was 7 months in length, extending from November 1959 to June 1960. Each of the four contractors performed a separate study and submitted separate final reports.

The success of a study such as this is largely dependent upon the adequacy of the methodology employed. All of the contractors involved used essentially the same general approach, although there were some individual variations with respect to specific analytic tools, formats, and levels of detail. However, any of the four studies could be selected as a model for future efforts of this nature. To illustrate the systematic progression of the major steps in the overall approach, the following paragraph is quoted from the Douglas report:

The overall approach was essentially a human factors approach which begins with a description of the system and the mission. Considerable effort during this study was devoted to refining system and mission descriptions and abstracting mission requirements. The mission requirements dictated the functions to be performed. Analysis of functions resulted in decisions as to which should be assigned to man and which to machine. The functions assigned to man were then organized in tasks and on the basis of the total list of tasks a position structure evolved. The position structure consisted of the crew positions and their interrelationships. The training program was then built around the position descriptions and was oriented toward imparting the necessary skills to the selected trainees.

Because of the volume of material involved, it is not possible to present anything but a very sketchy summary of the results from SR 49756. A more detailed analysis and summary is available in ASD Technical Report 61-127 (ref. 14). In their reports each of the major contractors described in detail: (a) their particular approach, (b) the representative missions and vehicle systems they had synthesized, (c) the individual crew positions, functions, and tasks, (d) personnel selection factors, (e) the overall training program, and (f) the required training equipment and facilities. We will briefly touch upon each of these areas.

Systems, Missions, and Crew Positions:

The emphasis in this study was not on developing or evaluating systems realistic from an engineering or military point of view. Instead, it was aimed at determining the training requirements implied by the broad spectrum of advanced system and mission concepts under consideration at the time the study was performed. As a consequence of this orientation the

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** Vought Astronautics Division, Dallas, Texas

† Palo Alto, California

‡ Los Angeles Division, Los Angeles, California

contractors differed with respect to the types and numbers of systems which they proposed. However, despite these differences, there was marked similarity with respect to mission coverage and the functions, duties, and tasks to be performed by man. The systems analyzed by North American will be used as an example.

North American described five systems: (a) a recoverable booster with a 4-man crew, (b) a winged re-entry vehicle similar to a 2-man Dyna Soar, (c) a space shuttle system with a 3-man crew, (d) a permanent orbital space station with a crew of 49 and capable of housing up to 100 personnel, and (e) a vacuum landing vehicle similar to the space shuttle with a capability for lunar landing. North American's space force had the greatest variety of missions, functions, and positions. However, on the whole, it did not present any uniquely different training requirements.

Selection Factors:

In general, the initial selection criteria for admission to the training programs for the earlier systems identified by the contractors are very similar to those used in Project Mercury. The experiential requirements are a function of the particular crew position involved. Emphasis is placed upon selecting personnel with relevant experience in earlier systems to man positions in later systems where appropriate. In addition, virtually all of the contractors regarded the training program itself as an important medium for the final selection of personnel to man a given system.

The Overall Training Program:

Although the four contractor training programs differed in details, they were very similar in most major respects. For example, the overall content of any of the programs can be grouped into the following training area format used by Chance Vought:

- a. Academic training
- b. Physiological and psychological conditioning
- c. Simulator training
- d. Transition training
- e. In-flight training

Academic training provides the necessary background for a more thorough understanding of the vehicle, flight procedures, and in-space environment. It covers such basic fundamentals as mathematics, space mechanics, electronics, propulsion and guidance, and navigation. Training in the function and use of personal equipment and escape and survival procedures are also included.

Physiological and psychological conditioning teaches the student the nature and effects of stresses that may be experienced during a mission. It also provides a knowledge of nutrition, prepares him for emergency survival conditions, and contributes in general to his mental and physical conditioning.

Simulator training provides the student the opportunity to practice his job skills in a ground-based synthetic environment, which may include many of the stresses present on an actual mission. During this phase the student also acquires the integrated crew skills which make him an effective team member.

Transition training is used to bridge the gap between ground-based training and actual space flight. It also provides experience in areas which cannot be simulated adequately on the ground.

In-space training, in general, is on-the-job training acquired in actual space operations.

All of the contractor programs placed heavy emphasis on developing performance redundancy through cross-training. Since a cross-trained individual can perform some or all of the tasks associated with crew positions other than his own, he can enhance overall system reliability by assuming the duties of one of the other crew members in case of an emergency or during the off-duty portion of a work-rest cycle. This is one of the unique aspects of space crew training not usually encountered in training for conventional systems.

There were two major points of disagreement among contractors with respect to training programs. The first involved the proposed lengths of the programs and the second the number of students to be trained. Actually, the latter point evolves not from a difference of opinion with regard to training, but from differing assumptions concerning the size and composition of the total space force. Douglas designed for 9-1/2 months while North American proposed programs for as much as 50 months. The greater lengths of the North American programs result from the large amount of academic training prior to specific task training. In fact, academic programs up to 2 years are stated to be essential for the proper preparation of some personnel. Link and Chance Vought each proposed programs which required maximums of 21 and 30 months for completion, respectively. In our opinion, a well designed formal training program of about 2 years in length should be adequate for most conceivable spacecrew positions assuming that appropriate selection criteria are used. Any very precise estimate, however, requires a specification of the skills and knowledge possessed by the trainees when they enter training.

Training Equipment:

The contractors agreed, in general, with respect to training equipment and facilities required to support the various programs. Primary emphasis was placed on the use of ground-based media supplemented by modified high-performance aircraft for both the acquisition and maintenance of proficiency. Only two of the contractors favored some form of in-flight space training, although they did not recommend development of a space vehicle solely for training purposes. However, on-the-job training achieved through the integration of new personnel with veteran crew members on operational missions was accepted practice. The other two contractors specifically rejected the development of an exospheric (space) trainer on the basis of potentially high cost, high hazard, and doubtful training value. All contractors agreed that it would be advantageous from both a training and economic point of view to have a centralized space training facility at which virtually all training would be given.

The specific items of proposed ground training equipment ran from conventional training aids such as films, charts, etc., to extremely complex "full mission" simulators which simulate virtually all tasks and environmental conditions likely to be encountered in space flight. In addition, all contractors suggested a variety of techniques and devices such as centrifuges, heat chambers, zero-g flights, etc., to provide the student with realistic experience with the physical stresses of space flight.

Final Remarks:

Perhaps the most significant outcome of SR 49756 was that no insurmountable problems nor spectacular solutions were identified. This is not to say that all of the information needed to design an optimal training system is already available. Actually, there are many specific problem areas which demand research and development. However, most of these do not represent discontinuities in the state-of-the-art, but only differences in emphasis. Both economic and humane considerations dictate that work on many of the problems of training for space be initiated immediately if we are to have the "best possible" answers when required.

Although some deficiencies in methodology and depth of coverage were apparent in these studies, they still represent the most comprehensive analysis of manned space crew training requirements and problems made to date. These studies are sufficiently valid and cogent to form the basis for timely actions of both a research and a development nature. These studies should be used as a basis for planning actions by all agencies having responsibilities for research, development, or support activities related to manned space systems. The Air Force has been studying

the results of this effort carefully and, at the present time, additional follow-up studies are being planned.

Long-Term Retention

One of the unique and inescapable aspects of manned space flight is the long duration during which crews will be in the operational environment. Among other things, this means that they will be separated from formal programs and facilities for refresher or maintenance-of-proficiency training. Such long-duration missions as those involved in extended orbital flight or interplanetary operations could present some serious problems in maintaining high levels of proficiency of little-used but critical crew skills. Even though studies of human retention have been popular with psychologists since before the beginning of the century, very little experimental data directly applicable to this problem is available. Most of the research has involved relatively short retention intervals, and only in rare cases have tasks been used which are sufficiently analogous to those which will be performed by spacecrews to permit generalization with any degree of confidence. Within the past several years, however, a number of studies have been undertaken which are quite relevant to the problem of long-term retention in space operations. Adams and his coworkers at the University of Illinois have conducted a series of studies to determine how various flying skills are affected by intervals of no practice of up to 10 months (ref. 8). More recently, our Laboratory has initiated work with Dr. Briggs at Ohio State University directed toward investigating the retention of learned skills over relatively long periods of time without actual task performance. The task in this research consists of a time-shared, three-dimensional tracking system with variable task dynamics and a procedural task which can be varied in terms of its temporal and spatial characteristics. Preliminary research indicates, not surprisingly, that retention is directly related to amount of training and inversely related to the length of the retention interval. More important, however, the results indicate that retention is directly related to degree of task integration or redundancy and that there seems to be a second-order interaction between task redundancy and retention interval. Briefly, this latter relationship indicates that the retention interval affects performance much more sharply for the tasks of low redundancy than for those of high redundancy. We are continuing this research in an effort to isolate general task dimensions which are highly correlated with retention as well as to develop techniques particularly suited to sustain or promote the retention of these particular kinds of tasks. Techniques to be used both during original training and during the interval between original training and time when performance is required are being considered. We should be able to provide some solutions to the long-term retention problem within the next few years.

Crew Training for Long-Duration Flights

Also related to the extended duration of space missions is the problem of preparing crews to perform mission functions efficiently for long periods under the confining and rigorous conditions of a space capsule. For several years, our Laboratory has been conducting research at Lockheed-Georgia Company* directed at studying the performance of crews on simulated long-duration space flights. This research is conducted in a simulated space capsule which provides five crew positions as well as small leisure and bunking areas. The crew positions provide a variety of tasks intended to assess several different aspects of human performance. A number of preliminary studies were run to evaluate the performance tasks, establish procedures, and work out a suitable work-rest schedule for extended missions. Following these studies, two long-term crew confinement studies were run using military personnel (two Air Force B-52 crews). These crews were tested on a work-rest schedule of 4 hours work and 2 hours rest (4:2 schedule) over a 360-hour (15-day) period while continuously confined to the simulated vehicle. During the work periods, each crew member manned a work station continuously. He had tasks to perform at all times during the period, although the workload did vary during the 4 hours. Under this schedule 6 men, with appropriate cross-training, can cover 4 positions continuously. The primary results of these studies were that: (a) individual subjects showed considerable variability in the course of a day's performance; (b) there were wide differences among the performance levels of different crewmen; and

* A Division of Lockheed Aircraft Corporation, Marietta, Georgia

(c) some subjects showed continued improvement in performance over the entire 15-day mission (ref. 1). The general conclusion drawn from this series of studies at Lockheed is that, with a minimum amount of selection, current crews can be found who will maintain acceptable human performance capability on a 4:2 schedule of work and rest for as long as 15 days and probably for somewhat longer. We are currently preparing for a study in which a 30-day mission will be simulated but in this study we intend to use a 4:4 rather than a 4:2 work-rest schedule. With a 4:4 schedule, of course, two crew members are required for each crew position that must be continuously manned. We have switched to a 4:4 schedule because it seems more realistic for missions as long as 30 days, and because it seems adequate for manned systems currently under consideration.

As mentioned previously, these studies imply that no radical departures will be required from current methods of selecting and training air crews solely as a result of long-duration space flights. The specific crew skills to be trained will change, but our current concepts and methods of molding efficient aircrews seem to be adequate for the job of training spacecrews. The task at hand, then, seems to be that of developing ways of making the current procedures more efficient and accomplishing more of the required training in ground simulators, since space missions conducted solely for the purpose of crew training will have to be held to an absolute minimum.

We are currently conducting research at Castle Air Force Base* with the assistance of Bell Aerosystems** to determine to what extent it is feasible to conduct training for complete aircrews on the ground using an integrated ground simulation facility. The research involves the training of B-52 crews using individual crew position trainers which have been electronically linked to permit realistic training missions for the whole crew to be conducted on the ground. Studies have been completed with crews undergoing transition training. Studies now in progress will determine whether the training of combat-ready crews in an integrated ground simulation facility increases the operational capability of these crews. It is never possible in an operational setting to gather quantitative data of laboratory quality. However, preliminary results from the first studies strongly indicate that substantial full crew training can be accomplished in an integrated ground simulation facility (ref. 10). The key element is probably the capability which such a simulation facility provides for practicing, in real time, operational missions which involve all crew members in a realistic way. A continuation of such positive results will do much to establish the feasibility of and to determine optimal procedures for accomplishing a major part of integrated spacecrew training on the ground.

Training for Performance Under Task Stress

The sizes of spacecrews will be kept to an absolute minimum for a long time. It will not be economically feasible to man space vehicles in such a way that the peak task loads which are possible can be handled on a routine basis. For this reason, the human component in advanced aerospace systems may occasionally be subjected to extremely high task activity demands during the course of a mission. Such demands may be imposed, for example, by the compounding of critical subsystem malfunctions, all of which require virtually immediate attention, or by the exigencies of a rapidly changing tactical situation which superimpose a substantial increase in information handling requirements on an already heavily loaded operator.

Our Laboratory has recently initiated a research contract with HRB-Singer, Inc.[†] to develop training principles for optimizing the human operator's ability to perform efficiently in multitask situations under high levels of speed and load stress. Many studies have been done on the effects of various stresses on human performance and some work is available on selecting people to perform well under stress. Very little has been accomplished on training as a means of overcoming the undesirable effects of stress. However, data obtained for other purposes demonstrate the value

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† State College, Pennsylvania

of "training" per se, and suggest that, even under relatively unsystematic practice conditions, subjects may learn "tricks of the trade" which enable them to adapt to increasing task demands. Our current program has not as yet progressed far enough to produce much more than a plan of attack on the problem, but we hope to turn out some valuable data during the next several years.

Human Performance Capability in Space

Within the past several years an increasing number of studies has been directed toward determining man's capability to perform various kinds of tasks in space. These studies are directed toward providing, on a firm empirical basis, the behavioral sciences data required for making intelligent decisions about the assignment of functions to men in space systems. This trend toward increased research on human performance capability under the conditions and environments of space operations is encouraging. However, there is also a discouraging side to the picture. Most of the research to develop reference data on human performance capability suffers, in our opinion, from the data being gathered using casually selected, relatively untrained subjects. In fact, many of the studies are carefully designed to preclude the occurrence of any learning, since it is regarded as an annoying source of variance. This deficiency is also present in much of the current work on human performance in space. With data collected in this manner, we continually underestimate the contribution that carefully selected and trained men can make to system performance and reliability. Actually, decisions about whether or not to automate can best be made when human performance data are available for various levels of training and various degrees of personnel selectivity. Only in this way can human performance factors be entered into trade-offs with other systems factors in a meaningful and efficient way. It would indeed be a most encouraging and healthy development if there were to be a rapprochement between personnel and training research and human performance research in the field of bioastronautics. Without this our ability to contribute effectively to the early stages of space system design cannot be significantly improved.

The above opinions notwithstanding a number of valuable research programs on human performance capability in space have been initiated. We will describe two of these programs being conducted in our own Laboratory.

One series of studies is underway in an attempt to define human operator performance in accomplishing orbital rendezvous. The studies are being performed with the motion dynamics of free-floating, orbital man programmed on an analog computer facility and with the target satellite displayed on a large cathode-ray tube. The subject's task is to manipulate available thrust to achieve a safe rendezvous once he has been injected into orbit within 5 miles of the target satellite. Criteria of success include impact versus no impact, fuel expended, time, and impact velocity. This program of research is just beginning but preliminary results indicate that, when coplanar orbits are involved and when thrust direction is fixed relative to the vehicle, man can learn to make successful transfer orbits and soft landings without excessively long periods of training. One of the big problems, however, has been finding the best instructions and methods of training. The subject's task is relatively difficult in that it presents problems which lie outside his normal realm of experience. One interesting result is that there appears to be good transfer of training from one initial injection condition to another, indicating that what is being learned is a generalized skill rather than one which is highly specific to the training conditions. This conclusion, however, has not been verified by controlled experimentation. Although it is realized that these studies are being performed in an abstracted and simplified experimental context, they should contribute a great deal to defining the nature of the human skill involved in orbital rendezvous and the nature and amount of training required to develop high levels of proficiency. In subsequent studies a number of variables expected to have a significant effect on performance will be investigated. An attempt will be made to develop a simulated task environment that is more realistic than the one currently in use.

Another series of studies, somewhat related to the first, has to do with defining man's visual capabilities in space. In space flight man will be required to perform certain visual tasks in the environment exterior to his space vehicle. Since the unstructured visual field of space will deprive man of many familiar cues, relatively little transfer of perceptual skill can be expected. From the results of a series of studies just completed in a simulated space visual environment, some inferences can be made about man's ability to make the visual judgments involved in performing

terminal navigation and rendezvous with another space vehicle without the aid of artificial displays (ref. 2). With no training, man, with considerable precision, can perceive under certain conditions whether an object is approaching or departing. As the luminance of the object is reduced below 0.1 foot-lambert, his ability to make these perceptual judgments decreases rapidly. Also, as the angular size of the stimulus is reduced, his performance deteriorates. His ability to perceive movement in depth extends over a reasonably large range of absolute rates of movement. However, an untrained man is quite poor at making absolute estimates of closure rates when the rate of change of angular subtense of the stimulus is the only perceptual cue. Large variable and mean constant errors are evident in the data obtained from the performance of such a task. Future research is planned to determine the extent to which intensive training and simple visual aids will improve the accuracy and reliability of human visual performance in space.

Mission Simulators

On the basis of current research and experience, it seems safe to say that much of the training of spacecrews will have to be accomplished with full-scale, mission simulators in which it will be possible to practice in real time and with considerable fidelity various mission profiles with all relevant contingencies present. We do not deny the value of part-task trainers or simulators but only emphasize that they should be supplemental to, and not a substitute for, a full-mission simulator. Only in a mission simulator will it be possible for a spacecrewman to integrate and order what he has learned into the associative structure of his operational task skills. The type of mission simulator we envision is more complex than those used today for the training of aircrews of conventional aircraft. They must be more complex primarily because they must train to operational levels of proficiency, whereas current aircraft simulators are largely transition devices to provide just enough training so that a crewman can safely initiate airborne practice. The primary psychological problems involved in designing such mission simulators are concerned with decisions about what must be simulated in the trainer and what can be safely left out. Procedures and techniques of analysis are available for making such decisions in areas associated with the tasks performed by the crewmen. The major unresolved problem, and it is a difficult one on which to do research, is the extent to which environmental conditions associated with a mission must be included in the mission simulator to produce high transfer of training. On the basis of present knowledge, we can say that, where such environments provide cues of known significance for responding which must be integrated with other task behaviors, they should be simulated. On the other hand, where they merely provide a context in which task performance occurs or do not involve cue-response patterns that must be integrated with other task behaviors, adaptation or familiarization training may safely be carried out in part trainers. Further information in this area is definitely needed. Our Laboratory has recently initiated research on one aspect of this overall problem. The research we have undertaken is aimed at determining the need for, and characteristics of, motion simulation in ground training systems for advanced aerospace vehicles. The initial studies are being carried out by the Grumman Aircraft Engineering Company* and are directed at a specific class of motion, i. e., random buffet. Additional studies are planned to provide a sound empirical basis for decisions about the inclusion of motion characteristics in future training simulators.

Automated Training Techniques

No review of research relevant to spacecrew training would be complete without some mention of the work going on in the area variously referred to as auto-instructional devices, automated training devices, or teaching machines. Perhaps no single development in applied psychology since the selection test has created such interest. Without doubt, this growing technology has implications for improving human performance. Since 1958 studies in this field have appeared at an increasing rate and the number of devices and instructional programs available, either experimentally or commercially, is increasing almost daily.

We will not attempt to summarize the vast amount of work which is going on, but it may be worthwhile to point out the relevance of this concept to some of the problems of spacecrew training.

* Bethpage, New York

Any general increase in training efficiency would tend to benefit spacecrew training, but the further development and refinement of automated training technology will be of particular benefit in maintaining crew proficiency on long-duration space missions, a problem to which reference has already been made. On long-duration missions the crew is separated from contact with formal instructional programs and facilities and any required training must of necessity be accomplished with a self-contained, automatic, instructorless training system carried aboard the vehicle. Such training systems would be more desirable if they could be a part of or integrated with existing vehicle subsystems, of course.

No particular technical problems are foreseen in developing such on-board instruction subsystems. However, additional research is needed in two areas so that such developments may be based on empirically verified principles. First, additional studies are needed on the automated training of procedural and continuous motor skills since the vast majority of current work is directed toward verbal knowledge. Second, studies are needed to determine the optimal characteristics and scheduling of auto-instructional programs intended primarily for the maintenance of high levels of proficiency as opposed to initial acquisition.

CONCLUDING REMARKS

Much progress has been made in the field of spacecrew training during the past 2-1/2 years. A review of the current state-of-the-art gives reason for optimism. Certainly, as far as one can predict now, the field of training presents no insurmountable problems and requires no breakthroughs or spectacular solutions to support manned space operations. Based upon current progress and prospects, we can conclude that adequate training systems can be designed for future manned systems, assuming that the required administrative and management support is provided.

On the other hand, a continuation and even expansion of current applied programs will pay significant dividends. Even though we feel quite confident about being able to accomplish the training required by space systems currently under development or study, we must strive to increase the efficiency and economy with which it can be accomplished. The fact that we have, without serious consequences, been somewhat inefficient in our preliminary space training ventures should not mislead us. We must bear in mind that we will not always have this luxury. Some day we will be dealing with larger numbers of trainees, tighter schedules, lower personnel selectivity, etc. Likewise, researchers must be alert to identify and provide timely solutions to new training problems introduced as a result of advances in space technology. For these reasons, state-of-the-art work in spacecrew training must be continued.

Although we can look at the overall field of spacecrew training with confidence, not all areas within this field are progressing equally. Perhaps several examples of this nature should be singled out for special mention. In-flight maintenance is one such area. This area of human performance in space probably makes the widest departure from precedent. Yet relatively little progress has been made in defining the problem areas much less in providing solutions. Some good work on this problem is needed, but such work will require the cooperative efforts of system engineers, subsystem specialists, personnel and training experts, and maintenance and reliability specialists. The second area requiring augmentation is training of decision-making skills of spacecrew personnel. The long-duration missions and the difficulties of normal chain-of-command action enforces a relatively great degree of autonomy upon space crews. As a consequence, and because of the extreme criticalness of space missions, personnel must have a very high order of skill in making complex and difficult decisions. Hypotheses concerning optimal conditions for training decision-making skills can be derived from studies of the decision-making process and some existing management simulation and training programs. However, these need to be related to and tested in the context of space operations. Third, relatively little effort has been devoted to the study of so-called exotic techniques for developing and sustaining human-performance capability. Examples of such techniques are hypnosis to facilitate learning, retention, and performance and psychopharmacological techniques. We are not suggesting these techniques as palliatives or opiates to enable man to "withstand the rigors of space flight" but to optimize human

performance on tasks and under conditions anticipated for space flight. The cost of many space systems will be so large as to make even small increases in individual human reliability worthwhile. It seems desirable to investigate new techniques for achieving these increases.

We hope that the areas mentioned will receive increased attention from training research personnel in the near future.

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