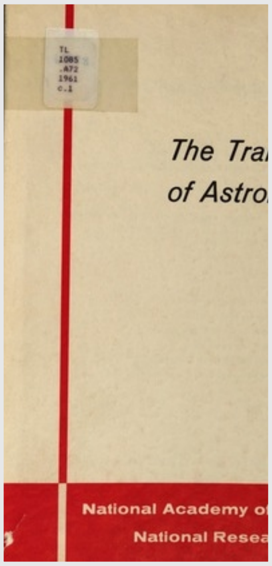

Training of Astronauts: Report of a Working Group Conference, Panel on Psychology, Armed Forces-NRC Committee on Bio-Astronautics

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AUTHORS

Panel on Psychology of the Armed Forces; Committee on Bio-astronautics; National Research Council

The Panel on Psychology of the Armed Forces-NRC Committee on Bio-Astronautics

Dr. Walter F. Grether, Aerospace Medical Laboratory, Wright Air Development Division, Chairman

Dr. Gordon A. Eckstrand, Aerospace Medical Laboratory, Wright Air Development Division, Vice Chairman

Dr. William Bevan, Kansas State University

Dr. John L. Brown, University of Pennsylvania

Dr. Abraham Carp, Lackland Air Force Base

Dr. Paul M. Fitts, University of Michigan

Dr. George D. Hauty, Federal Aviation Administration

Dr. John C. Lilly, Communications Research Institute

Dr. David McK. Rioch, Walter Reed Army Medical Center

Dr. George E. Ruff, University of Pennsylvania

Mr. John W. Senders, Minneapolis-Honeywell Corporation

Dr. Richard Trumbull, Office of Naval Research, Department of the Navy

The Training of Astronauts

Report
of a
Working Group Conference

Panel on Psychology
Armed Forces-NRC Committee on Bio-Astronautics

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PREFACE

This report has been prepared by the Panel on Psychology of the Armed Forces-NRC Committee on Bio-Astronautics. It deals with important psychological problems relating to the training of crew members for effective performance of their duties in space missions. Much has already been accomplished in the training of pilots for the X-15 and Mercury vehicles. Preparations are being made for training of pilots for the Dyna-Soar vehicle, and some study has been directed toward more advanced space-flight programs. This report presents a review and evaluation of past training efforts and offers guidance for future programs of a similar nature.

During its initial organizational meeting at Woods Hole, Massachusetts, in July 1959, the Panel on Psychology decided to hold working group conferences in several important space-flight problem areas. The first of these working group conferences was held at the National Academy of Sciences, Washington, D. C., on 2 and 3 December 1959. This conference considered the problem of selecting personnel for space flight. Dr. Abraham Carp of the Air Force Personnel Laboratory, Lackland AFB, Texas, organized this conference and served as chairman. An earlier report presented the results of this conference. On 29 and 30 August 1960, a second working group conference was held at Woods Hole to review the problems of training personnel for space flight. Dr. Gordon A. Eckstrand of the Air Force Behavioral Sciences Laboratory, Wright-Patterson AFB, organized this conference and served as chairman. This report presents the results of the working group conferences on "Training."

Many scientists contributed to the information, discussion, and recommendations contained in this report. Since their names are listed in the report, they will not be repeated here. I would like, however, to give grateful recognition to Dr. Sam F. Seeley, Executive Secretary of the Committee on Bio-Astronautics, and his staff, for their invaluable assistance to the Panel on Psychology in making the physical and administrative arrangements for the meeting of the working group.

WALTER F. GRETHER
Wright-Patterson Air Force Base, Ohio
Chairman, Panel on Psychology
Armed Forces-NRC Committee on
Bio-Astronautics

INTRODUCTION

Gordon A. Eckstrand
Wright Air Development Division
Air Research and Development Command
Wright-Patterson Air Force Base, Ohio

The Working Group Conference on "Training of Astronauts," sponsored by the Panel on Psychology of the Armed Forces-NRC Committee on Bio-Astronautics, was held on 29-30 August 1960 at Woods Hole, Massachusetts. This conference was the second of two sponsored by the Panel on Psychology for the general purpose of reviewing critical psychological problem areas related to astronautics. The first was the Working Group Conference on "Personnel Selection for Man in Space," held on 2-3 December 1959, a report of which constitutes Part 1 of this document.

In the Working Group Conference on "Training," a small group of knowledgeable people assembled for the purpose of (1) critically reviewing past, present, and planned programs for the training of space crew personnel, (2) suggesting improved concepts, techniques, and procedures for such training based upon the current state-of-the-art, and (3) recommending areas of research and development critical to future advances in this field.

The first day's program was devoted to a review of current programs and concepts in astronaut training, with technical presentations on the X-15, Project Mercury, Dyna-Soar, and SR 49756, an Air Force study dealing with space crew training requirements and concepts of the 1965-75 time period. The morning of the second day was devoted to critiques, comments, and suggestions by each of five invited scientists.[1] The afternoon of the second day was devoted to a general discussion and to the formulation of official working group recommendations.

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[1]See Appendix for complete list of conference participants.

This report contains the technical papers presented on the first day of the conference, the formal comments made by each of the invited scientists, and the working group recommendations as approved by the Panel on Psychology on 31 August 1960.

In addition to the material contained in this report there was, of course, considerable group discussion at various times throughout the conference. It was not felt possible to impose on these discussions the rigid structure which would have been required to obtain a meaningful transcript, without destroying some of their spontaneity and value. For this reason, transcripts of the discussion periods are not included.

SECTION I

Technical Papers Concerning Current Programs and Concepts in Astronaut Training

TRAINING ASPECTS OF THE X-15 PROGRAM

Richard E. Day
NASA Flight Research Center
Edwards, California

Introduction

The NASA Flight Research Center, during its 13-year history, has had the responsibility of extending the envelope of manned flight to ever increasing speed and altitude. In early programs it was necessary to operate with a minimum of training aids in planning and conducting flight projects. More and more training aids have become available, however, and it can be safely said that without some of these aids the X-15 program would be so hazardous as to be impractical. Another reason why training aids are presently of the utmost importance is the financial aspect. With the current ratio of airplane cost to the number of expected flights, the cost per flight is extremely high. Moreover, flights may be relatively infrequent. Thus, for reasons of time-cost, it is essential that the pilot be trained to peak proficiency in order to obtain the maximum amount of research information in the minimum amount of time.

Mission Profile and Pilot Tasks

Before discussing X-15 training developments, perhaps it would be best to show some of the tasks required of the pilot. Figure 1 illustrates a typical-design altitude mission, with various phases of the flight indicated.

The airplane is launched from the B-52 carrier airplane near Wendover, Utah. During the boost phase, the pilot is exposed to as high as 4-g chest-to-back acceleration and, consequently, must resort to a side-located controller. After burnout the pilot will experience several minutes of weightlessness. In this ballistic-flight regime the air is so thin that conventional controls are ineffective and reaction jets must be resorted to. The next phase of flight, the re-entry, is perhaps the most critical from the standpoint of stability, control, heating, structural loads, and the pilot's acceleration environment. After recovery, the airplane is vectored to the dry lake at Edwards for a landing.

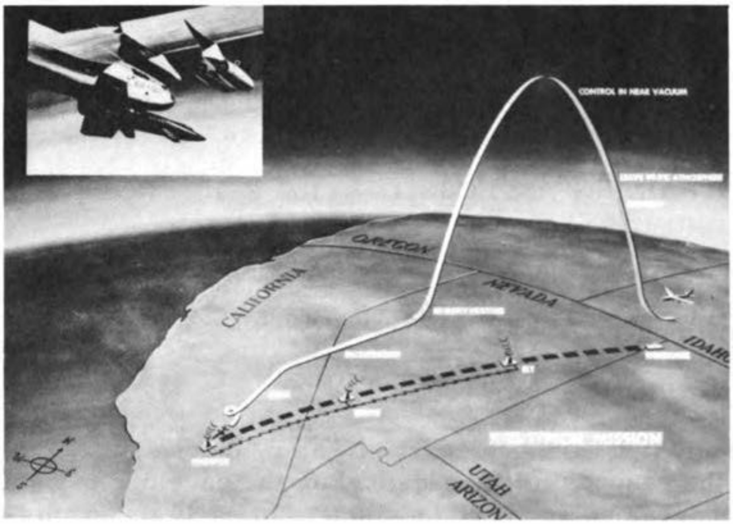

Figure 1

To date, two of the three X-15 aircraft have made a total of 18 flights with the interim engine, and one aircraft has attained a Mach number of 3.3 and an altitude of 107,000 feet.

It appears pertinent at this point to review briefly the qualifications and experience levels of the X-15 pilots. The eight pilots presently on the X-15 roster represent North American Aviation, NASA, the Air Force, and the Navy. The average pilot is 37 years old, has been flying for 16 years, and has spent half of that time in experimental test flying. Each has a Bachelor's degree, and several have advanced degrees. They are all volunteers so that creating motivation is no problem. These pilots have lived with this program since its inception and have made valuable contributions to the design, based upon their experience in previous research-airplane programs.

Training Aids

Prior to the general acceptance of the analog computer, essentially no ground-training devices were employed by NASA in guiding flight testing of research airplanes. Rather, gradual inflight buildup to design conditions was depended upon. However, certain types of control problems are not amenable to this approach, since they are characterized by abrupt and violent instabilities. As early as 1953 and 1954, the X-1 and X-3 research airplanes and some of the Century Series fighters were experiencing violent motions about all three axes during rolling maneuvers. These motions result from what is known as inertial roll coupling and are analogous to the instability of a slow-spinning top or gyroscope. At about this same time the electronic analog computer was coming into its own as a device for solving highly complex, non-linear, differential equations with an adequate degree of accuracy. Since the mechanics of inertial coupling was complex, the use of an analog was obtained to determine the causes and possible solutions to these problems.

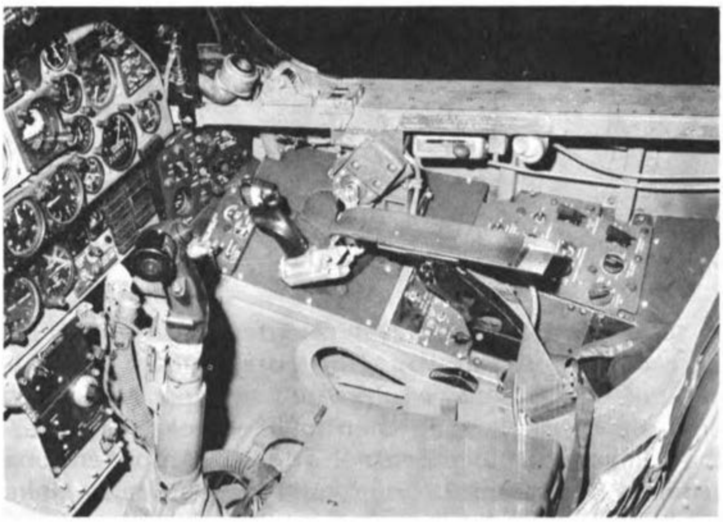

Figure 2

Figure 2 shows the arrangement used in this study. The pilot observes pertinent display information that has been calculated by the computer. His control reactions to this display are then sent back to the computer for interpretation into modified display information. Thus a closed-loop solution is available for real-time operation. It should be mentioned that this procedure has important advantages over the open-loop approach; by including the human operator in the loop, the effects of inadvertent and corrective control-inputs can be evaluated. In addition, actual hardware such as stability-augmentation systems may be included in the loop. From this study a logical training procedure evolved for flight-test guidance in critical stability areas.

To simulate the various phases of the X-15 mission, an extremely elaborate analog and simulator arrangement was mechanized by North American Aviation to study in detail the over-all flight control problem from launch to landing. Figure 3 shows part of the vast analog-computer complex used in the X-15 program.

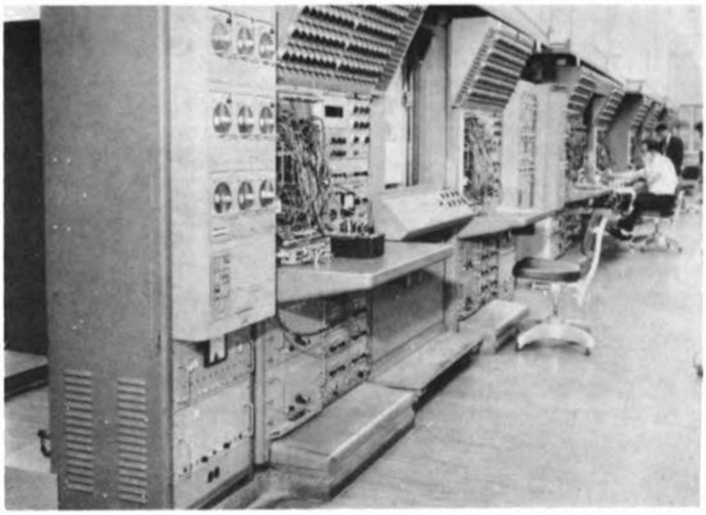

Figure 3

Coupled to the analog is an exact duplicate of the complete control-system hardware, including the pilot's display and cockpit mockup. A photograph of this general equipment is presented in Figure 4, and Figure 5 shows the arrangement of the cockpit. Note, in particular, that there are three control sticks. A conventional center stick is provided for normal flying, and mechanically linked with it on the right is a console stick for control under high acceleration. The control stick on the left is provided for the reaction-control

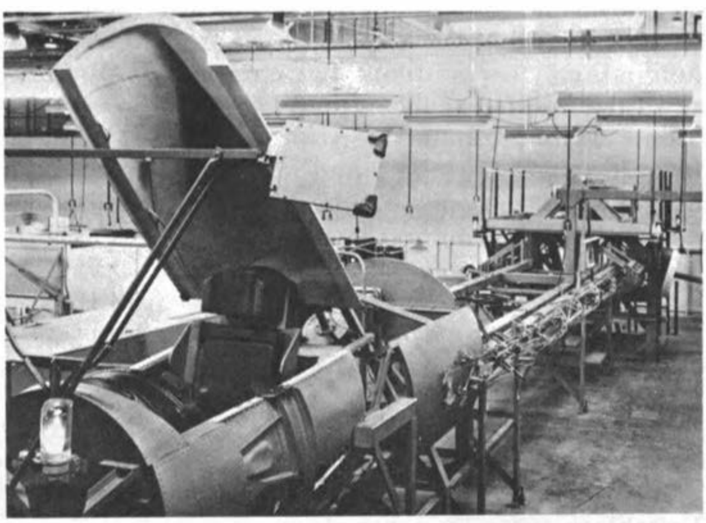

Figure 4

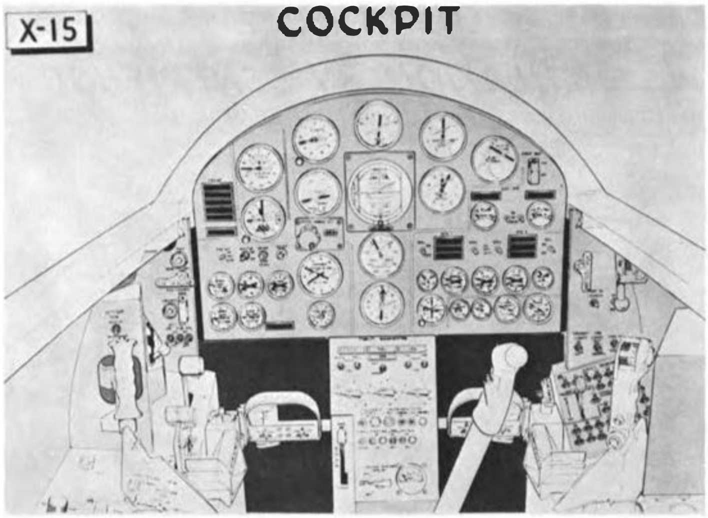

Figure 5

system. The NASA Flight Research Center now has the same analog capabilities. The control simulator will be transferred to the Flight Research Center at the termination of the contractor's flight-demonstration program.

The initial simulator studies examined the control problem in the most critical areas of the flight envelope, such as the trajectory described previously. During the pilot-training program, optimum control techniques and boundaries for re-entry were established through a systematic study of pertinent variables, including the effects of stability-augmentation malfunctions. The role of the simulator in flight planning and flight-to-flight pilot training is discussed subsequently.

Although the relative difficulty of various types of entries could be fairly well established, based on the static-simulator program, it was known that the pilot would be subjected to extreme accelerations for considerable periods of time. Therefore, it was felt that simulation, including acceleration, should be accomplished to determine the validity of the static-simulator results. Accordingly, a cooperative program was conducted by NASA, NAA, and the Navy, utilizing the human centrifuge at Johnsville, Pennsylvania. For the first time, the centrifuge was tied into an analog computer so that closed-loop real-time simulations, including accelerations, would be possible. A simplified sketch of the centrifuge is shown in Figure 6. To orient the acceleration vector properly, gondola rotations are superimposed on the normal rotation of the centrifuge arm.

SIMULATION BY CENTRIFUGE

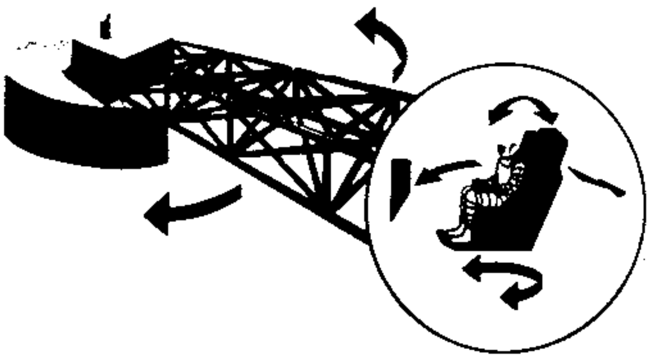

Figure 6

During the early centrifuge tests, the original display arrangement presented a scanning problem under acceleration. Modifications were suggested by the pilots, and the improvements were verified in the centrifuge tests.

The results of the centrifuge program generally substantiated the static-simulator results from the standpoint of pilot capability, and indicated that the pilot could withstand prolonged periods of high acceleration and still perform the task required of him. Now they knew that in the acceleration field of the X-15 they would be able to handle the airplane. One more unknown had been removed for the pilot.

The most recent training aid to be employed in the X-15 program is the Cornell Aeronautical Laboratory variable-stability T-33 airplane. The simulation study, using this airplane, is being conducted at Edwards Air Force Base under contract to the Flight Control Laboratory of the Wright Air Development Division. The stability and control parameters of the T-33 can be varied electronically and mechanically to match the characteristics of the X-15. In addition to simulating conditions of the X-15 at constant Mach number, altitude, and angle of attack, the T-33 is equipped with programming servomechanisms that will permit simulation of stability, control, and, to some extent, the accelerations that will be encountered during X-15 re-entries. A six-week flight program is now being initiated. The program should be completed and results should be available for presentation to the Panel on Psychology at the time of the Working Group conference.

One of the unique features of the X-15 control system is the side-located aerodynamic controller. Inasmuch as little previous experience had been obtained with a console controller of the X-15 type, an installation similar to the X-15 (Figure 7) was made in an

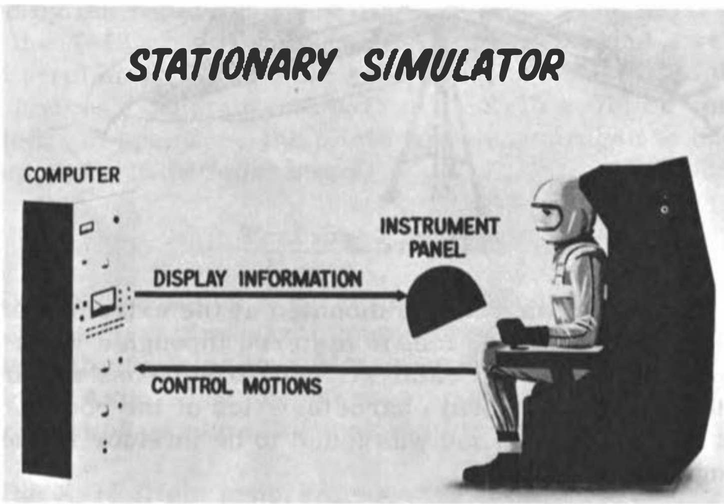

Figure 7

F-107A airplane. The F-107 program enabled pilots to evaluate the inflight characteristics of such a controller. In initial flight tests, pilots favored the center stick because of over-control due to sensitivity of the side stick. However, after a nominal training period, the pilots learned to discipline themselves to smaller control-inputs and eventually favored the side stick in certain flight regimes. The variable-stability T-33, previously mentioned, also has a console controller of the X-15 type.

The portion of the X-15 flight requiring reaction controls is made under conditions of zero-g, and cannot be simulated for any appreciable length of time with ground-based simulators. Consequently, the final phase of simulation training must be made in flight. Reaction-control studies at the Flight Research Center began in 1955 with crude equipment used in conjunction with an analog computer. However, this investigation established several requirements that have been substantiated by many subsequent studies.

The next development in this field was construction of what is known as the "Iron Cross." This simulator, shown in Figure 8, consists of two I-beams mounted on a universal joint at the center

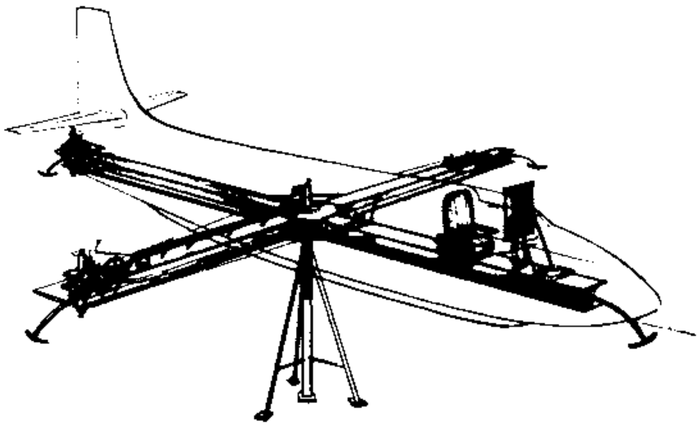

Figure 8

of gravity. To power the rockets mounted at the extremes of the I-beams, hydrogen-peroxide fuel is metered through a valve and is activated by a silver-screen catalyst. The Iron Cross was devised primarily to check operational characteristics of the rockets and control-system hardware, and was found to be inferior to the analog as a training device.

The last matter to be discussed, that of the landing, also requires training, since the X-15 landing characteristics are not conventional. The basic geometry of the airplane is such that considerably steeper landing approaches are encountered with the X-15 than with any previous research airplane. Figure 9 illustrates a typical X-15 landing approach. For comparison, the conventional

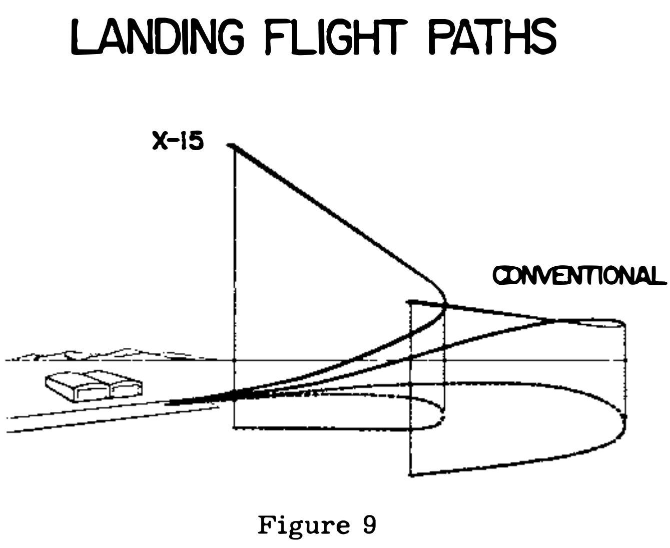

Figure 9

approach path of an operational aircraft is also presented. The differences in glide paths and ground tracks are readily apparent. To train the pilots for the X-15 landing phase, two methods were employed. First, an analog computer was used with an oscilloscope presentation to indicate approach attitude. This gave the pilots and engineers an understanding of the relative importance of the factors affecting the landing flare, but definitely lacked the in-flight realism afforded by the rapid approach of the ground. The most useful training for the X-15 program was obtained by employing a standard F-104A airplane. By suitable scheduling of thrust- and drag-producing devices, the approach path of an X-15 could be very closely simulated. In practice, the pilots were encouraged to build up to the steep paths in rational steps.

Training Program

The X-15 training program has consisted of two distinct phases. The first phase is a general preparation which has encompassed the training program described previously in the section on Training Aids. The second phase consists of detailed flight planning, with emphasis on pilot training for particular flights.

The X-15 flight program consists of several flights building up to design conditions and various flights for obtaining specific research information. Consequently, each flight is somewhat different and requires separate preparation. Prior to each flight, engineers employ the simulator to study all conceivable aspects of the flight. These aspects are summarized and presented to the pilot. Preparation for a typical flight might be as follows:

1. The pilot "flies" the mission several times on the simulator with no emergency or off-design conditions, in order to assess techniques, timing, and check-points. If the pilot has any suggestions or notes any discrepancies, the flight plan is modified accordingly.

2. The mission is flown with various combinations of the damper system failed. If a failure is critical, methods of recovery are determined or the region in which the failure is critical may be avoided.

3. Inadvertent engine failure and loss of partial power are simulated at critical points along the trajectory to determine which emergency landing site is required and the proper approach for landing.

4. Various display information is failed for critical portions of a mission, and alternate guidance methods available to the pilot are employed for continuing the flight.

5. Because of the uncertainties existing in wind-tunnel data or extrapolated flight data, the stability parameters used in the simulator are varied appreciably from predicted values in order to assess the controllability in new flight regimes and to determine methods of recovery for uncontrollable areas.

6. If the pilot has not flown recently, or if a new emergency landing site may be required, he makes several practice approaches using an F-104 aircraft in the simulated X-15 configuration.

To date, this type of training program has been of great value to the X-15 program. It is felt that a saving in terms of time and additional flights has been achieved. The capacity of the simulator to predict accurately the X-15 characteristics and flight profiles has made possible peak pilot proficiency, research data of increased quality, and improved operational planning.

Conclusions

In conclusion, the role played by various training aids in the development of the X-15 program has been presented. Future flight data obtained in more critical control areas will afford the unique opportunity to assess the true value of these training aids for the X-15 and to establish training requirements for future vehicles.

MAN'S INTEGRATION INTO THE MERCURY CAPSULE[1]

Edward R. Jones
McDonnell Aircraft Corporation
St. Louis, Missouri

Introduction

The role that a man may assume as an occupant of a space vehicle and the potential contribution of this man to the outcome of a mission has been the subject of considerable discussion and speculation. Many strong opinions have been expressed both for and against an active role for an astronaut, usually without reference to the details of specific mission and space vehicle characteristics.

This paper is based upon McDonnell's rapidly accumulating experience with the NASA Mercury capsule. It describes man's integration into the vehicle and his role as an operator of the systems based upon the present stage of hardware development and anticipated mission conditions. The realities of actual vehicle design and fabrication result in a better understanding of the importance of the astronaut's role in assuring mission success.

The primary control of the Mercury capsule is automatic. That is, if everything goes well and if the operator desires, the mission may proceed through launch, boost, orbit, re-entry, and rescue without the astronaut turning a hand, since the automatic systems and the ground environment can control the vehicle. Manual overrides for many of the automatic systems are available to the astronaut and ground monitors. The vehicle is considerably more sophisticated than many realize.

Yet, despite the fact that the primary control is automatic, the presence of a trained operator is very important for the success of the mission through the secondary control that he exercises. This paper will develop further the nature of man's role in the Mercury vehicle.

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[1]This paper was previously presented at the ARS 14th Annual Meeting in Washington, D.C., Nov. 16-19, 1959.

This role for man is a departure from present concepts, but it probably represents a future trend for the integration of man into advanced space and weapon systems.

The Evolution in Thinking Concerning Man's Function

A recent trend of thinking concerning man's function in space flight has relegated him to a passive role. Serious discussions have advocated that man should be anesthetized or tranquilized or rendered passive in some other manner so that he will not interfere with the operation of the vehicle. However, another school of thought has suggested that if man is along, he should be integrated into the system and advantage taken of his versatile capabilities.

The early thinking concerning man's role does not seem to have been based upon consideration of specific vehicles or the operations of its systems. As equipment became available, a more realistic approach evolved. It is now apparent in connection with the Mercury capsule that man, beyond his scientific role, is an essential component who can add considerably to systems effectiveness when he is given adequate instruments and controls, and is trained. Thus there is increased emphasis on the positive contribution the astronaut can make.

Man's Basic Role

Man in the Mercury capsule can function:

1. As a scientific observer of astrophysical, biological, and psychological phenomena associated with orbital flight. This function as a scientific observer is beyond the intent of this discussion and will not be pursued further.

2. To increase the probability of mission success beyond the automatic mode by:

   a. Initiating corrective action for malfunctioning components at the point at which degradation to the mission begins to occur.

   b. Adding flexibility to the mission by analyzing and taking action to counteract unique flight conditions that were not anticipated during the design of the system.

The design philosophy of the Mercury vehicle provides a large number of redundant systems to perform functions that are critical for mission reliability, with man having the potential of operating the system as the need arises.

This redundancy concept is illustrated schematically by a small segment of the mission profile (Figure 1):

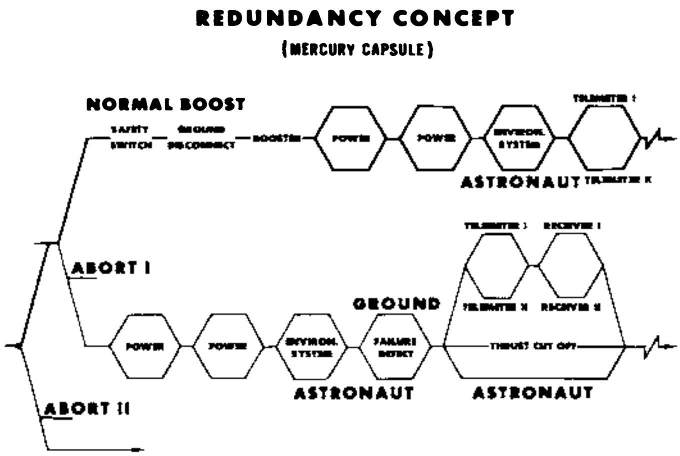

Figure 1

1. Several redundancies are present for each function and there may be automatic switching to the alternate system if a difficulty arises.

2. The astronaut becomes the final back-up, or may, if he desires, perform the function manually in order to add flexibility to the systems operations even though the automatic equipment is operating satisfactorily.

Thus, in terms of vehicle operation, man has been added to the system as a redundant component who can assume a number of functions at his discretion. Manual control is secondary, which is a change in concept from the operation of most present military weapon systems in which manual control tends to be primary. This secondary manual control is critical for the mission and adds significantly to the probability of success. The facilitating effects of man will become even greater with longer missions and when a number of flights are projected, and the total reliability of multiple flights of extended duration must be considered.

Determination of Man's Specific Functions

So far, this discussion has considered in general terms how man may contribute to manned space flight. Now an attempt will be made to suggest how man's specific function may be defined for a vehicle such as the Mercury capsule.

The determination of man's specific function in an automatic system must be based upon a somewhat different approach than that used for vehicles in which man exercises primary control. The determination becomes even more important when the vehicle is not evolutionary, as is the case with most aircraft, but revolutionary in conceptions, as is the Mercury vehicle.

The basis for this determination is a prediction of the components and systems that might malfunction under the expected mission conditions. This defines what man might be expected to do. The failures that could occur can be outlined by design and reliability engineers, giving the following information for each predicted malfunction:

1. The system and component that fails.

2. The effect of the failure on the vehicle operation.

3. The sensory or instrument indication, available to the astronaut that indicate the presence, severity, and nature of the failure.

4. The instrument indications available to the ground crew that dictate the presence, severity, and nature of the failure.

5. The corrective action for the astronaut.

6. The corrective action for the ground monitor.

The failures can be analyzed collectively, using punch cards, tabulating equipment, and appropriate analytical techniques to arrive at:

1. The instruments necessary to detect malfunctions and the controls required to operate the malfunctioning system for both the capsule and the ground monitoring station.

2. The types of trouble-shooting actions required during countdown, boost, and orbital flight by the astronaut and ground crew.

3. General trouble-shooting procedures for specific systems.

4. The characteristics of training devices necessary for proper astronaut training.

5. Possible areas where in-orbit maintenance might be considered.

Analyses such as these represent an early step in determining man's predictable role during a mission. As data become more specific through better definition of the hardware, system tests, and early test flights with animals, the role of man can be specified more definitely. As a general rule, the need for man's integration into the system becomes more obvious as system development proceeds. This is a lesson from the past that has been true for system after system.

Examples of Man's Functions in the Mercury Vehicle

The following are examples of specific functions that man might perform in the Mercury vehicle. They are given as examples, but since they are out of context, care should be exercised in assuming that they are representative of the capsule's operation:

1. Failure Detection and Diagnosis is the primary function that man performs. This can be observed in Figure 2. This function may be quite simple where a button is pressed in response to a light, or extremely complex where involved diagnostic procedures are required to isolate a malfunction and a complex control task is required to correct the difficulty (Figure 3).

2. Attitude Control is the primary continuous control task that the astronaut may elect. It involves control, using reaction jets for three degrees of freedom, with no aerodynamic coupling between axes. The closest comparable task involves elements of both submarine and helicopter control.

3. Location of Position of the Vehicle in Space, using the periscope and window, is the primary navigation task. This has elements similar to present visual navigation except that the earth appears considerably different, and thus unfamiliar geographical landmarks must be learned and used.

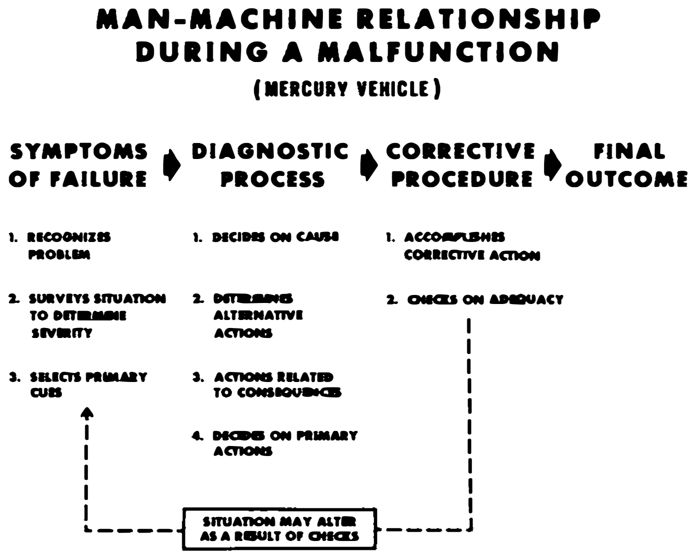

Figure 2

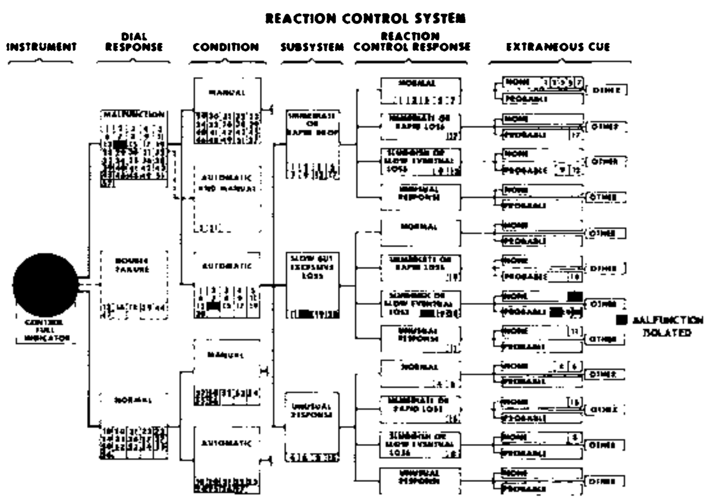

Figure 3

Assuring Man's Contribution to Orbital Flight

Basic systems design must consider man's capabilities and limitations and optimize them in man-machine integration, using techniques such as those discussed previously. Emphasis must be placed on what man does best.

The ground environment must be used effectively to assist the astronaut in controlling the vehicle. This requires considerable coordination and concepts similar to those used between interceptor pilots and GCI or the SAGE environment.

The astronaut must be trained in all aspects of systems operation far beyond the point where apparent progress stops. This involves what is known technically as overlearning. Particular attention must be devoted to diagnosing the state of system operation. The NASA training program has made remarkable progress in this direction.

Summary

In summary, a trained operator has an important function in the Mercury vehicle. Besides his role as a scientific observer, the astronaut can contribute significantly to mission success by operating systems that malfunction and adding flexibility for unanticipated conditions. The value of man becomes obvious as the design and construction of space vehicles proceeds and the realities of space flight and the equipment that will be available become apparent. A trained man properly integrated into a well-designed machine is an unbeatable combination to assure a successful man-in-space program. Longer missions and more complex space vehicles can take even greater advantage of the astronaut to increase the probability of mission success.

PROJECT MERCURY ASTRONAUT TRAINING PROGRAM*

Robert B. Voas
NASA Space Task Group
Langley Field, Virginia

Introduction

This paper presents a general outline of the NASA Project Mercury Astronaut training program. Basic considerations which entered into the development of the program are listed. Six primary training areas are described, together with the training equipment and facilities employed. Problem areas for future training programs are discussed.

Any training program must be based on three factors: (1) the nature of the job for which training is required, (2) the characteristics of the men to be trained, and (3) the facilities and time available in which to do the training. In Project Mercury the astronaut's job involves both flight and non-flight tasks. He is expected to contribute to systems design and to the development of operational procedures through his daily contact with the project engineers. It was considered that, by virtue of the selection process, the astronaut had the skills required to make these contributions; therefore, no training was attempted in connection with the non-flight tasks. The astronaut's in-flight activities can be broken down into six areas: (1) "programming" or monitoring the sequence of vehicle operations during launch, orbit, and re-entry; (2) systems management—the monitoring and operation of the on-board systems, such as the environmental control, the electrical systems, and the communications systems; (3) the vehicle-attitude control; (4) navigation; (5) communications; and (6) research and evaluation. In addition to these in-flight activities, the astronaut has a number of ground

*This report was previously presented at the Symposium on Psychophysiological Aspects of Space Flight held at San Antonio, Texas, May 26-27, 1960. It is to be included in a book entitled "Psychophysiological Aspects of Space Flight" to be published by Columbia University Press.

tasks connected with the flight operations. He has a role in the countdown and preparation of the vehicle; in communications from the ground to the vehicle; and in the recovery program following the flight. It is for these activities associated with the flight itself that a training program was undertaken. More detailed descriptions of the astronaut's tasks are available in papers by Slayton[1] and Jones[2]. It should be noted that the astronaut's job is only one of many jobs associated with space flight for which training is required. Brewer[3] has outlined the overall training requirements for Project Mercury.

The astronaut selection program was designed to select individuals who would require a minimum of training in order to fulfill the Mercury job requirements. Particularly desired were individuals who had sufficient experience in aircraft-development operations to make immediate contributions to the Project Mercury program. On this basis, the following criteria were adopted as the mininum requirements for qualification as a Project Mercury Astronaut:

1. Age - less than 40.
2. Height - less than five ft. 11 in.
3. Excellent physical condition.
4. Bachelor's degree (or equivalent).
5. Graduate of test-pilot school.
6. 1,500 hours flying time.
7. Qualified jet pilot.

Records of 508 Air Force, Navy, Marine, and Army pilots who had graduated from test-pilot school were reviewed and screened on the basis of these requirements. Of these, 110 met the seven basic requirements. Forty-one of these pilots were eliminated through further screening based on recommendations from instructors at the test-pilot schools. The remaining 69 pilots were interviewed and given an opportunity to volunteer for the Project Mercury program. Of these, 37 pilots either declined or were eliminated as a result of the initial job interviews. The remaining 32 who were considered to be qualified in education and experience were given detailed medical examinations and were exposed to the physical stresses expected in the space flight. The nature of these tests has been described in more detail in references 4 and 5. On the basis of the medical examination and the stress tests, the number of candidates was reduced to 18, from which were selected the seven who demonstrated the most outstanding professional background and knowledge in relation to the job requirements. Through this procedure, a group of experienced test pilots with extensive training in engineering, excellent health, and a high motivation in the Mercury Project were selected for the training program. The availability of such individuals makes it possible to utilize self-instruction,to a great extent and thus to minimize the amount of formal group training required.

At the outset, few, if any, facilities were available to support the training program. Both training devices and training manuals have become available in stages throughout the first 12 to 15 months of the training program. The more elaborate and complete training devices were not placed in operation until more than a year after the program was initiated. As a result, the early part of the training program depended upon review of design drawings in vehicle components and on travel to various Mercury production facilities to attend design briefings. Verbal presentations by scientists of the NASA Space Task Group and of the prime contractor were heavily relied upon. In addition, early in the program, extensive use was made of established Armed Forces Aeromedical facilities for familiarizing the astronauts with the conditions of space flight. Thus, the training methods and the order in which topics were presented were, to a great extent, dictated by the resources available at the time the program was initiated.

Since mature, intelligent trainees were selected and since little if any training equipment was available initially, it might have been argued that the astronauts should be allowed to work completely on their own without any group program. There are, however, a number of desirable benefits to be derived from such a program. A planned group program facilitates the scheduling of activities with other organizations. In addition, a structured program permits more efficient use of instructor and student time. It also makes possible progress from one aspect of the operation to the next in an appropriate sequence. Sequence in training activities is important, since learning is simplified if material is presented in a logical order. An organized program also insures completeness in that no major training requirement is overlooked. Finally, since this project represents a first effort of its kind, the use of a group program facilitates the collecting of records and the evaluation both of the astronauts' progress and of the various training activities.

About one-half of the program which has resulted from these considerations is allotted to group activities, and the other half to individually planned activities in each astronaut's area of specialization. A review of the Astronauts' travel records reveals the relative division of their time between group training and other duties associated with the development of the Mercury vehicle. During the 6-month period from July 1 to December 31, 1959, the Astronauts were on travel status almost two months, or one out of every three days. Half of this travel time (28 days) was spent on four group-training activities: a centrifuge program; a trip to Air Force Flight Test Center, Air Force Ballistic Missile Division, and Convair; a weightless flying program; and trips to fly high-performance aircraft during a period when the local field was closed. The other half of their travel time (27 days) was devoted to individual trips to attend project-coordination meetings at McDonnell and the Atlantic Missile Range, or for pressure-suit fittings, couch moldings, and viewing of qualification tests at McDonnell, B. F. Goodrich Company, and their subcontractors' plants. These individual activities, while providing important training benefits, are primarily dictated by the Project Mercury development program requirements and are not considered part of the group training program.

The extent to which the Mercury crew-space area is "customized" to the seven astronauts, and the time required to fit the man to the vehicle, should be noted. Each man has had to travel to B. F. Goodrich Company for a pressure-suit fitting and to a subcontractor for helmet fittings; then to the Air Crew Equipment Laboratory for tests in the suit under heat and lowered pressure; then to McDonnell for couch molding. Usually, he has been required to return to the suit manufacturer for a second fitting, and to McDonnell for final fittings of the couch and studies of his ability to reach the required instruments and controls in the capsule. While the Mercury vehicle is more limited in size than future spacecraft, the cost of space flight and the limited personnel involved will probably always dictate a certain amount of customizing of the crew space. The time required for this activity should not be underestimated.

Training Program

The astronaut training program can be divided into six major topic areas. The primary requirement, of course, is to train the astronaut to operate the vehicle. In addition, it is desirable that he have a good background knowledge of such scientific areas related to space flight as propulsion, trajectories, astronomy, and astrophysics. He must be exposed to and familiarized with the conditions of space flight such as acceleration, weightlessness, heat, vibration, noise, and disorientation. He must prepare himself physically for the stresses he will encounter in space flight. Training is also required for his duties at ground stations before and after his own flight and during the flight of other members of the astronaut team. An aspect of the training which might be overlooked is the maintenance of the flying skill which was an important factor in his original selection for the Mercury program.

Training in Vehicle Operation

Seven training procedures or facilities were used in developing skills in the operation of the Mercury capsule. These included lectures on the Mercury systems and operations; field trips to organizations engaged in the Mercury Project; training manuals; specialty study programs for the individual astronaut; mockup inspections; and training devices. To provide the astronaut with a basic understanding of the Mercury system, its components, and its functions, a lecture program was set up. A short trip was made to McDonnell for a series of lectures on the capsule systems. These systems lectures were then augmented by lectures on operations areas by Space Task Group scientists. This initial series of lectures provided a basis for later self-study, in which use was made of written descriptive material as it became available. Individual lectures have been repeated as required by the developments within Project Mercury. A series of lectures on capsule systems by both Space Task Group and McDonnell personnel have been scheduled to coincide with the delivery and initial operation of the fixed-base Mercury trainer. In these lectures, the same areas are reviewed in an attempt to bring the astronauts up-to-date on each of the systems as they begin their primary procedures training program.

In addition to this lecture program, indoctrination trips have been made to the major facilities concerned with the Project Mercury operations. Two days were spent at each of the following facilities: McDonnell, Cape Canaveral, Marshall Space Flight Center, Edwards Flight Test Center, and Space Technology Laboratories and Air Force Ballistic Missile Division. One day was spent at Rocketdyne Division, North American Aviation, and five days were spent at Convair/Astronautics. At each site there was a tour of the general facilities, together with a viewing of Mercury capsule or booster hardware and lectures by top-level personnel covering their respective aspects of the Mercury operation. The astronauts also had an opportunity to hear of related research vehicles such as the X-15 and Discoverer, and of the technical problems arising in these programs and their significance for Project Mercury.

Obtaining current and comprehensive study materials on a rapidly developing program such as Project Mercury is a major problem. McDonnell has been providing manuals covering Project Mercury systems. The first of these, the Indoctrination Manual, was delivered at the time of an early astronaut visit in May 1959. No attempt was made to keep this manual current, and a first edition of a full systems manual (Familiarization Manual) was issued in September 1959. It quickly became out of date, however, and a new manual, a second edition of the Familiarization Manual, was issued in December of the same year. A first copy of the Capsule Operations Manual (Astronauts' Handbook) was delivered in June 1960. During initial phases of the program, the astronauts have had to depend primarily on capsule specifications and specification control drawings for written information on capsule systems. Copies of these, however, were not always available and they were too large to compile into a single manual.

Valuable aids to the astronauts in keeping abreast of the status of the development program are the regularly issued reports of the Capsule Coordination Group Meetings. At these meetings, the status of each of the capsule systems is reported and any changes are discussed. Miscellaneous reports on boosters and on progress have also been provided to the astronauts by cooperating agencies. Maintaining an up-to-date flow of accurate information on vehicle-development status is a critical problem not only for the Mercury training program, but also, in all probability, for most near-future space-flight applications, since training must proceed during the vehicle-development phase.

Another method employed in the dissemination of information was assignment of a specialty area to each astronaut. These assignments were as follows: M. Scott Carpenter, navigation and navigational aids; Leroy G. Cooper, Redstone booster; John H. Glenn, crew-space layout; Virgil I. Grissom, automatic and manual attitude-control system; Walter M. Schirre, life-support system; Alan B. Shepard, range, tracking, and recovery operations; and Donald K. Slayton, Atlas booster. In connection with his specialty area, each man attends meetings and study groups at which current information on capsule systems is presented. Regular periods are set aside for all the men to meet and report to the group. Another important source of information about the vehicle, particularly in the absence of any elaborate fixed-base trainers, has been the manufacturer's mockup. Each of the men has had an opportunity to familiarize himself with the mockup during visits to McDonnell.

Following the initial familiarization with the Mercury system, the primary training in vehicle operation is being achieved through special training devices developed for the Mercury program. Early training in attitude control was accomplished on the Langley Electronics Associates Computer (Figure 1) which was combined with a

Figure 1. LEAC simulator: a simulator making use of an analog computer on which astronauts were given initial training in attitude control problems.

simulated Mercury attitude display and hand controller. This device was available during the summer of 1959. Later, another analog computer was "cannibalized" from an F-100F simulator and combined with actual Mercury hardware to provide more realistic displays and controls. This MB-3 trainer (Figure 2) also included provision for the Mercury couch and the pressure suit.

In addition to these two fixed-base simulators, three dynamic simulators were used to develop skill in Mercury attitude control. The first of these, the ALFA (Air Lubricated Free Attitude) Simulator (Figure 3) permits the practice of orbit and retrofire attitude-control problems by using external reference through simulated periscope and window displays. A simulated ground track is projected on a large screen which is viewed through a reducing lens to provide the periscope display. This simulator also permits training in the use of earth reference for navigation. The Johnsville Centrifuge (Figure 4) was used as a dynamic trainer for the re-entry

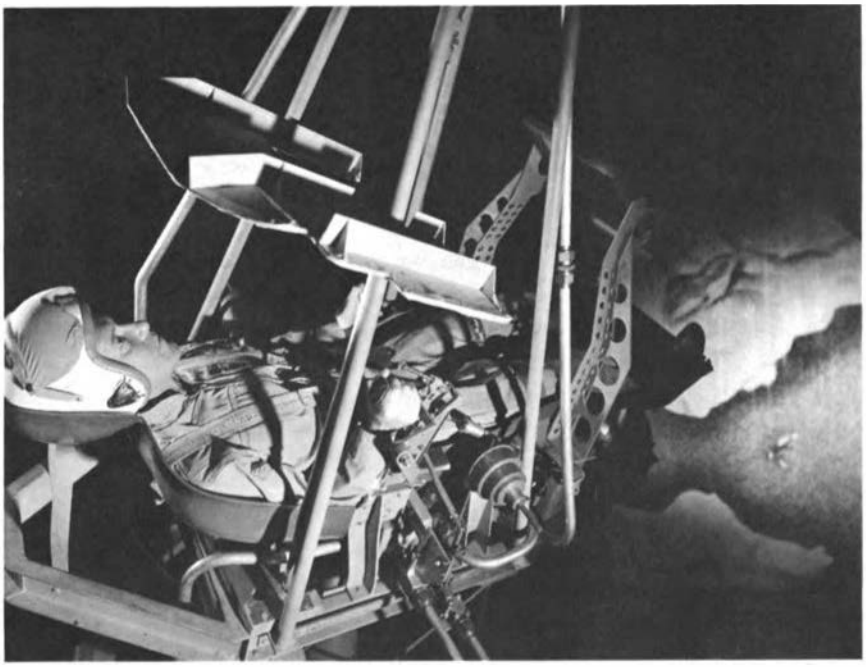

Figure 2. MB-3 simulator: a second stage of fixed-base attitude control simulation which incorporated the astronaut's couch, pressure suit, and Mercury hand controller.

rate-damping task because it adds the acceleration cues to the instruments available in the fixed-base trainers. It also provides some opportunity to practice sequence monitoring and emergency procedures during launch and re-entry. Another dynamic simulation device, used to provide training in recovery from tumbling, was the three-gimbaled MASTIF (Multi-Axis Spin Test Inertia Facility) device at the NASA Lewis Laboratory (Figure 5). In this device, tumbling rates up to 30 rpm in all three axes were simulated, and the astronaut was given experience with damping these rates and bringing the vehicle to a stationary position by using the Mercury rate-indicators and the Mercury-type hand controller.

Figure 3. ALFA simulator: a dynamic simulator making use of an air bearing which provides practice in attitude control during orbit and retrofire phases of mission. External reference is simulated by use of a picture of earth from orbital altitude projected onto circular screen (seen behind trainer). Astronaut views screen through a set of mirrors and a lens which simulates periscope.

Two more elaborate trainers became available in the summer of 1960. These trainers provide practice in sequence monitoring and systems management. The McDonnell Procedures Trainer (Figure 6) is similar to the fixed-base trainers which have become standard in aviation operations. The computer used on the MB-3 has been integrated with this device to provide simulation of the attitude-control problem. External reference through the periscope is simulated by using a cathode-ray tube with a circle to represent the earth. Provision has been made for pressurizing the suit and for some simulation of heat and noise effects. The environmental-control simulator (Figure 7) consists of the actual-flight environmental-control hardware in the capsule mockup. The whole unit can be placed in a decompression chamber in order to simulate the flight pressure levels. This device provides realistic simulation of the environmental-control-system functions and failures. Effective use of these two simulators is predicated upon adequate knowledge of the types of vehicle-systems malfunctions which can occur. A failure-mode analysis by the manufacturer has provided a basis for determining the types of possible malfunction and the

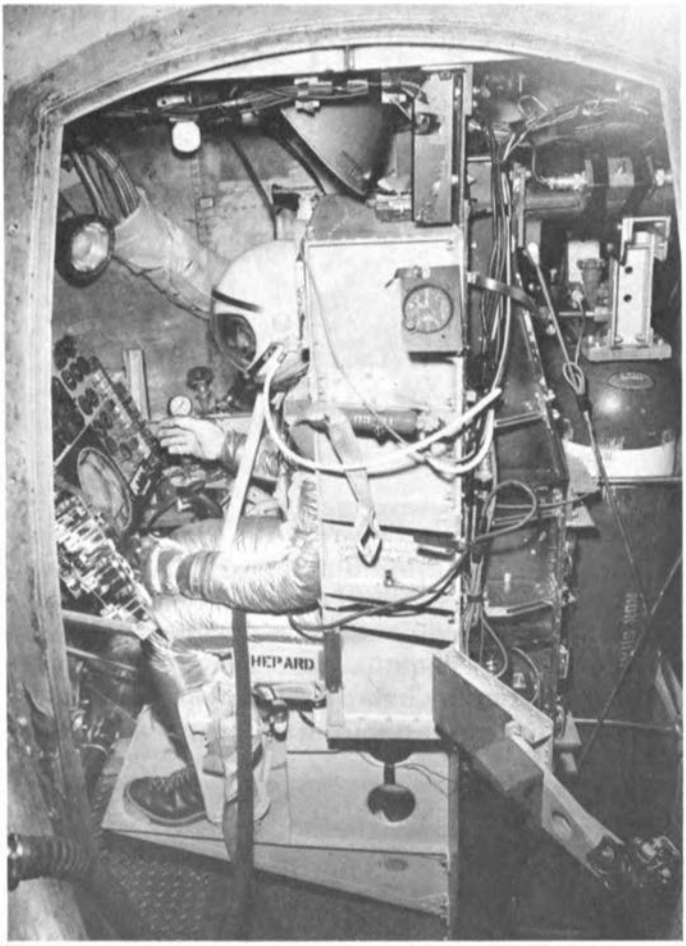

Figure 4. Johnsville centrifuge: centrifuge on which Astronauts were given experience with launch and re-entry acceleration profiles. Note that provisions have been made for use of full-pressure suit and for de-compression of the gondola. Astronauts are also provided with simulation of Mercury instrument panel and hand controller.

requirements for simulating them.[2] A record system on which possible malfunctions are listed on cards, together with methods of simulating them has been set up. On the back of these cards there is space for noting when and under what conditions a failure has been simulated and what action the Astronaut took to correct it. In this way, it is hoped that the experience in the detection and correction of systems-malfunctions can be documented.

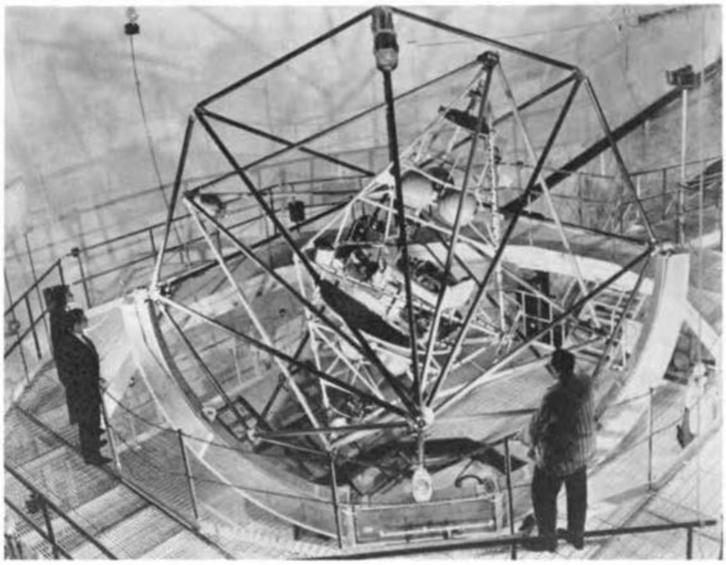

Figure 5. MASTIF simulator: a tumbling device on which astronauts experienced rotational rates up to 30 rpm in three axes. Once a steady rotational rate is achieved, astronaut assumes control and brings trainer to a stop by using instruments and controls similar to those available in Mercury vehicle.

Figure 6. Mercury procedures simulator: a fixed-base trainer which permits practice in management of Mercury systems and attitude control. From instructor's console in foreground, faults can be inserted into any of the Mercury indicators. Astronaut's corrective action is signaled by lights on panel.

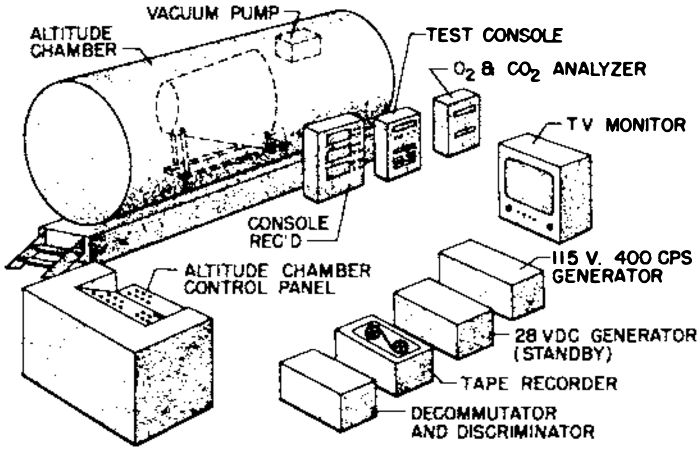

Figure 7. Environmental control system simulator: a device consisting of a mock capsule with a flight-type environmental control system which can be placed within a decompression chamber to simulate the operation of the environmental control system during the Mercury flight.

Training in Space Sciences

In addition to being able to operate the Mercury vehicle, the astronaut will be required to have a good general knowledge of astronomy, astrophysics, meteorology, geophysics, rocket engines, trajectories, and so forth. This basic scientific knowledge will enable him to act as a more acute observer of new phenomena with which he will come in contact during flight. It will also provide a basis for better understanding of the detailed information he must acquire about the Mercury vehicle itself. In order to provide this broad background in sciences related to astronautics, the Training Section of the Langley Research Center set up a lecture program which included the following topics: Elementary Mechanics and Aerodynamics (10 hours); Principles of Guidance and Control (4 hours); Navigation in Space (6 hours); Elements of Communication (2 hours); Space Physics (12 hours). In addition, Dr. W. K. Douglas, Flight Surgeon on the Space Task Group staff presented lectures on physiology totalling eight hours.

Following this initial lecture program, training in specific observational techniques is provided. The first activity of this program was training in the recognition of the primary constellations of the zodiac at the Morehead Planetarium in Chapel Hill, North Carolina. A Link trainer body was modified with a window and headrest to simulate the capsule's external viewing conditions. Using this device, the Astronauts were able to practice the recognition of constellations while the Planetarium was programmed to simulate orbital flight. Future plans call for further training in star recognition, together with methods of observing solar and meteorological events, earth and lunar terrain, and psychological and physiological reactions. These activities will be in support of a primary objective of the Project Mercury program, which is to determine man's capability in a space environment. The training program contributes to this objective in three ways:

1. By establishing base lines, both for the astronaut's performance and his physiological reactions. These base lines can then be compared with psychological and physiological factors in the space-environments.

2. Through the program in basic sciences described above, the Astronaut is given sufficient background with which to appreciate the importance of the observations he can make in the space-environment.

3. Specific training in observational techniques and the use of scientific equipment arms him with the skills with which to collect data of value to sciences.

Thus, the training program attempts to lay the groundwork for the scientific activities of the astronauts, as well as to provide the specific skills which are required to fly the Mercury vehicle.

Familiarization With Conditions of Space Flight

An essential requirement of the training program is to familiarize the astronaut with the novel conditions which man will encounter in space flight. An important part of the program, therefore, has been to provide the trainees with an opportunity to experience eight types of conditions associated with Mercury flights: high acceleration,weightlessness, reduced atmospheric pressure, heat, disorientation, tumbling, high concentration of CO_2, and noise and vibration.

The astronauts experienced acceleration patterns similar to those associated with the launch and re-entry of the Mercury, first at the Wright Air Development Division (WADD) in Dayton, Ohio, and later at the Aviation Medical Acceleration Laboratory at Johnsville, Pennsylvania. During this training, they were able to develop straining techniques which reduced the problem of blackout and chest pain. It was generally the opinion of the astronauts that the centrifuge activity was one of the most valuable parts of the training program.

The astronauts were given an opportunity to experience weightless flying both in a free-floating condition in C-131 and C-135 aircraft and strapped down in the rear cockpit of an F-100F fighter. While the latter is more similar to the Mercury operation, the astronauts, being experienced pilots, felt that there was little or no difference between this experience and their normal flying activities. They also felt, however, that the free-floating state was a novel and enjoyable experience. Since the longer period of weightlessness available in the F-100F aircraft is valuable for collecting medical data, while the C-131 aircraft appears to give the most interesting experiential training, both types of operations appear to be desirable in a training program. The fact that the pilots experienced no unusual sensations during weightlessness when fully restrained was an encouraging finding for the Mercury operation, and supports the desirability of selecting flying personnel for this type of operation.

The astronauts experienced reduced atmospheric pressure while wearing full pressure suits, first at WADD and later at Air Crew Equipment Laboratory (ACEL); in addition to reduced pressure, they also experienced thermal conditions similar to those expected during the Mercury re-entry while wearing a full pressure suit. At the Naval Medical Research Institute (NMRI), they were given an opportunity to become familiar with the body's thermal response, and the effect of moderate heat loads on the body's regulatory mechanisms was demonstrated. At the end of March 1960, the astronauts experienced disorientation in the U. S. Naval School of Aviation Medicine Slowly Revolving Room. As already mentioned, they have also experienced angular rotation up to 30 rpm in all three axes on a gimbaled device with three degrees of freedom at the NASA Lewis Laboratory.

In order to indicate the effects of the high concentration of CO_2 which might result from a failure of the environmental control system, the astronauts were given a three-hour indoctrination period in a sealed chamber at NMRI. In this chamber, they experienced a slow buildup of CO_2 similar to that which they would encounter in the event of failure of the environmental system. None of the men showed any adverse effects of symptoms from this training. As part of the selection program, the astronauts experienced high noise and vibration levels at WADD. During the second

Johnsville centrifuge program, noise recorded in the Mercury test flight was played back into the gondola. Further opportunities to adapt to the high noise levels associated with the Mercury launch will be provided by a sound system connected to the McDonnell Procedures Trainer at Langley Field.

Physical-Fitness Program

To insure that the astronaut's performance does not deteriorate significantly under the various types of stresses discussed in the previous section, it is important that he be in excellent physical condition. Since most of the trainees entered the Project Mercury program in good physical health, a group physical-fitness program, with one exception, has not been instituted. SCUBA training was undertaken because it appeared to have a number of potential benefits for the Project Mercury, in addition to providing physical conditioning. It provides training in breathing control and analysis of breathing habits, and in swimming skill (desirable in view of water landing planned in the Mercury program). Finally, there is, in the buoyancy of water, a partial simulation of weightlessness, particularly if vision is reduced. Aside from this one organized activity, each astronaut has been undertaking a voluntary fitness program tailored to his own needs. This program has included, for most of the astronauts, three basic items. First of all, as of December 1959, they have reduced or completely stopped smoking. This was an individual, voluntary decision; it was not a result of pressure by medical personnel, but of the individual's own assessment of the effect of smoking on tolerance to the stresses to be encountered in flight, particularly acceleration. Some of the members of the team who have a tendency to be overweight have initiated weight-control programs through diet. Nearly all members make it a habit to get some form of daily exercise.

Training in Ground Activities

The extent and the importance of the ground activities of the astronauts are frequently overlooked. Their knowledge of the vehicle and its operation makes them specially qualified for certain ground operations. The training in ground procedures has fallen into three main areas—countdown procedures, ground flight monitoring procedures, and recovery and survival. The astronauts are participating in the development of countdown procedures, and will be training themselves in their own part of the countdown through observation of countdown procedures for the initial unmanned shots, and finally, by participating in the preparation procedures for the actual manned flights.

An important aspect of the astronaut's activities when not actually flying the vehicle will be to aid in ground communications with the Mercury capsule. Since he is fully familiar with the capsule operation and intimately acquainted with the astronaut who will be in the capsule, he makes a particularly effective ground communicator. Procedures for ground monitoring and communicating personnel are presently being developed with the aid of the astronauts. At Langley Field, a ground monitoring station simulator will be tied in with the McDonnell procedures simulator. By using this device, ground-station activities can be practiced and coordinated with capsule-simulator training. The astronauts will also participate in training exercises at the Mercury Control Center at Cape Canaveral. Finally, just prior to manned flights, astronauts not involved in launch activities will be deployed to remote communications stations, where they will have an opportunity for on-site training.

A final area of ground training is in recovery and survival procedures. Study materials such as maps and terrain descriptions of the areas under the Mercury orbits are being obtained. They will be augmented by survival lectures and by field training in survival at sea and in desert areas. Finally, extensive training on egress from the capsule into the water has been given. This was accomplished in two stages, using the Mercury egress trainer (Figure 8). Phase One made use of a wave-motion simulation tank at Langley Field for initial training followed by a Phase-Two program in open water in the Gulf of Mexico.

Maintenance of flight skills. One of the continuing problems in training for space flight is the limited opportunity for actual flight practice and proficiency training. The total flight-time in the Mercury capsule will be no more than four to five hours over a period of three years for each astronaut. A question arises as to whether all the skills required in operating the Mercury vehicle can be maintained purely through ground simulation. One problem with ground simulation relates to its primary benefit. Flying a ground simulator never results in injury to the occupant or damage to the equipment. The penalty for failure is merely the requirement to repeat the exercise. In actual flight operations, failures are penalized far more severely. A major portion of the astronaut's tasks involves high-level decision making. It seems questionable whether skill in making such decisions can be maintained under radically altered motivational conditions. On the assumption that vigilant decision making is best maintained by experience in flight operations, the Mercury Astronauts have been given the opportunity to fly high-performance aircraft. The program in this area is a result of their own interest and initiative and is made possible by the loan and maintenance of two F-102 aircraft by the Air Force.

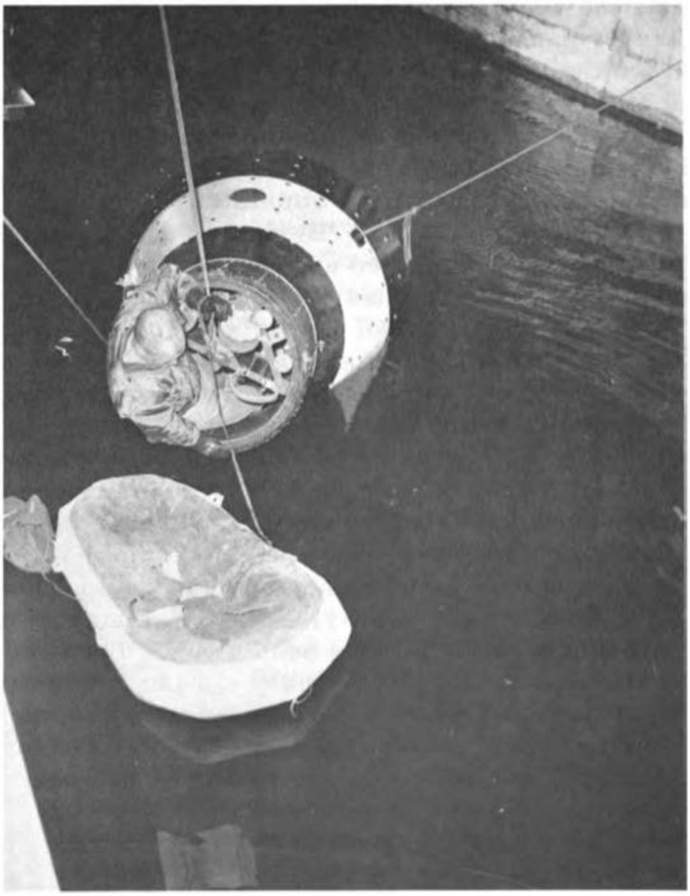

Figure 8. Environmental control system simulator: a device consisting of a mock capsule with a flight-type environmental control system which can be placed within a decompression chamber to simulate the operation of the environmental control system during the Mercury flight.

Implications for Future Programs

In conclusion, the problems relating to future space-flight projects which have been encountered in development of the Mercury program can be reviewed. In developing skills in operation of the vehicle, the difficulty of providing up-to-date information on the systems, when the training must progress concurrently with the development program, has been discussed. Concurrent training and development should tend to be a feature of future space-flight programs, since many of these will be experimental rather than operational.

All spacecraft have in common the problem of systems which must be kept functional for long periods without recourse to ground support. Even in the event of emergency termination of a mission with immediate return to earth, prolonged delay may occur before safe conditions within the atmosphere have been achieved. Thus, emphasis on "systems management" will increase in future space-operations programs. Recognition of malfunctions has always been a part of the pilot's task; usually, however, little in-flight maintenance is attempted. Since aborts are dangerous and, in any event, involve greater delay before return, the astronaut must make more detailed diagnoses of malfunctions and perform more in-flight maintenance. This will require extensive knowledge of the vehicle systems, and training in isolation and correction of malfunctions. In order to provide this training, as many as possible of the numerous malfunctions which can occur in even a relatively simple space vehicle must be identified and simulated. Considerable effort has been devoted to this area in the Mercury training and development program, and it should become an increasingly important feature of future programs.

The physical conditions (heat, acceleration, and so forth) associated with space flight are simulated to permit trainees to adapt to these stressors, in order to reduce the disturbing effects of such stimuli during actual flight. Present measures of the adaptation process are inadequate to provide criteria for training progress. A second purpose of the familiarization program was to give the trainees an opportunity to learn the specific skills required to minimize the effects of these factors on their performance. However, in many cases, the skills required have not been fully identified or validated. For example, in developing straining techniques for meeting increased acceleration, the efficacy of a straining technique has not been fully demonstrated, nor has the technique itself been adequately described. As yet, available data on the effects of combining physical stress factors are inadequate. Therefore, it is difficult to determine the extent to which the increased cost and difficulty of providing multiple-stress-simulation is warranted. In the present program, it has been possible to simulate both reduced atmospheric pressure and acceleration on the centrifuge. Initial experience seems to indicate that this is desirable but not critical. However, further data on the interacting effects of these stresses are required before any final conclusions can be developed.

A factor in space flight not yet adequately simulated for training purposes is weightlessness. Short periods of weightlessness have been included in the present program, as indicated previously. True weightlessness, however, cannot be achieved for periods long enough to be adequate for training purposes. On the other hand, ground simulation methods using water seem to be too cumbersome and unrealistic to be fully acceptable substitutes. At the present time, this lack of adequate simulation does not seem to be critical, since the effects of weightlessness on performance appear to be minor and transitory. Should early space flights uncover more significant problems, greater efforts will be justified in developing weightlessness-simulation methods.

Finally, it seems important to reiterate the requirements for reproducing adequate motivational conditions in the training program. The basic task of the astronaut is to make critical decisions under adverse conditions. The results of the decisions he makes involve not just minor discomforts or annoyances, but major loss of equipment and even survival. Performance of this task requires a vigilance and decision-making capability difficult to achieve under the artificial conditions of ground simulation. It appears probable that training in ground devices should be augmented with flight operations to provide realistic operational conditions.

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SOME IMPLICATIONS OF PROJECT MERCURY EXPERIENCE FOR FUTURE ASTRONAUT TRAINING PROGRAMS

Robert B. Voas
NASA Space Task Group
Langley Field, Virginia

Project Mercury is a research and development program, designed to put man into space and to study the effects of a space environment on man's physiology and performance. Because Project Mercury is a development activity, the training program for the astronauts has a number of special features and problems which are not applicable to training programs for vehicles which have reached the operational stage. During the developmental program, the vehicle operator has an important role in the design and test of the vehicle. His training activities, therefore, go hand in hand with his contribution to the vehicle development. He also encounters special problems such as keeping up-to-date with the rapidly changing vehicle design. In general, training programs for test pilots to be used with research and development aircraft involve only small numbers of individuals. In contrast, a training program for an operational vehicle normally involves much larger numbers of students. The full time of the trainees can be devoted to the training program itself, and providing up-to-date information is made simpler by the fact that the vehicle design is essentially frozen. In considering the implications of the Mercury training for future training programs, the distinction between these two types of training requirements should be kept in mind.

Experience with the Mercury program to date has suggested the following:

1. Man's primary role in the operation of space vehicles will be to increase system reliability. The most unique feature of space vehicles appears to be the requirement that they operate continuously for relatively extended periods of time without access to ground maintenance capability. Not only must they operate successfully for extended periods to accomplish their mission, but in the face of a serious malfunction, they must have backup systems which can operate successfully for somewhat shorter but still lengthy periods in order to return the man safely to the surface of the earth. Because

of the limitations in the present state of the art of engineering, insuring this type of reliability is difficult, perhaps impossible, without man. The astronaut can make his greatest contribution by detecting malfunctions and correcting them. Thus, the vehicle operator must take on much of the maintenance function that has formerly been delegated to ground crews. It appears likely that for long-term flights this will become a more critical and difficult area of training than the more traditional tasks of the vehicle operator, such as attitude control, power management, and communications.

2. As a result of the point made above, it is obvious that the operator's knowledge of the vehicle he flies will have to be more detailed and more comprehensive than has been traditionally required. It is important also that the nature of the knowledge of the vehicle is fully understood. It is not the knowledge of the design or the design specifications which is essential. It is in the knowledge of how the vehicle operates, what types of malfunctions can occur, how to distinguish important from unimportant failures, etc. It is, then, operational information which is essential to the astronaut. This point is made here because this type of information is often most difficult to derive. Generally, the design engineer does not approach the problem in such a way as to be able to provide operational information. Handbooks often reflect design data rather than operational data; they describe how systems are wired, rather than how they function. This distinction, then, between operational information and design information is a critical one, and must be understood in determining the proper type of information for training programs.

3. Another corollary of the role of man in insuring reliability is that he will often have to make use of less-than-optimal controls. Man's efficiency in controlling attitude, as an example, can often be improved by "rate aiding" or "quickening" or by power-boosting the controls, etc. However, each of these auxiliary systems is dependent upon power and electrical or mechanical components, which can malfunction. To the extent that man is dependent upon electronics or other complex systems in order to make his inputs, his total contribution to reliability will be reduced, because of the unreliability of these components. The astronaut adds most to reliability by using simple, direct mechanical linkage controls which are not dependent upon power or upon the function of electronic systems. In the past, when the single operator could be supported by a large ground crew, it was often desirable to optimize his performance for the critical moments of flight at the cost of greatly increasing maintenance complexity. For space flight, where the operator must also do the maintenance, the trade-off may

well be in favor of using the simpler mechanical systems which require less maintenance and are more reliable, even at the cost of somewhat reduced proficiency in task performance. Less-than-optimal controls will require more training to reach the same criterion levels.

4. A result of the increased requirement for knowledge of the vehicle and the probability that controls will be less than optimal is that the most important prerequisite for operators of space vehicles will be high levels of skill. Popular interest has been caught by the physical tests and medical examinations given to the astronauts. This side of the selection and training programs has been highly publicized and attracted much attention. It goes without saying that an individual who takes part in this type of activity must have a high level of physical fitness. However, the critical problems of meeting the physical requirements for space flight are not in selecting individuals of very special or peculiar qualities; but rather, through adequate bio-engineering, developing methods of supporting and protecting the individual during space flight. Thus, while selection for physical health and physical training cannot be neglected or overlooked, the critical problem in space-flight programs will be selection for demonstrated skills and knowledge, and training to develop the highest level of capability in both these areas.

5. Another indication of our Mercury experience is that the flight simulator will become a more and more significant research, development, and training tool. For some time, it has been the policy to use computer simulation of attitude-control problems in the design and development of attitude-control systems. This procedure will probably be extended into other areas of vehicle operation such as the problems of monitoring on-board systems. Furthermore, the trainer is an extremely useful device for developing operational procedures. In the near future, opportunities for in-flight training will be greatly reduced. Not only will initial training be dependent on the simulator a great deal more than formerly, but in addition, space-flight opportunities will be so limited that a major dependence must be put on these devices for proficiency maintenance.

6. Since man's principal function will be to take over in the event of malfunction, a critical factor in the development of training programs, training manuals, and training devices will be to identify the types of malfunctions which may occur with the primary systems, to determine what symptoms are available for detecting these malfunctions, and what corrective actions can be taken. Determining this information at an early stage in the design is difficult.

In the case of Mercury, we did not have such information available during initial portions of the training program. As a result, our manuals do not provide a full description of the various malfunctions which may occur. Nor does our fixed-base simulator permit the simulation of many malfunctions with which the astronaut may have to deal. As a result of work done at McDonnell, a preliminary analysis of the types of malfunctions which may occur is available today. However, in such a development program as Mercury, so many changes occur during the course of the program that much of the original analysis is now out-of-date. Obtaining this type of information should be somewhat simpler for operational training programs than for research and development programs.

7. A final and perhaps most critical problem in research and development programs is that of obtaining up-to-date information on the vehicle configuration. Mentioned above was the difficulty in determining the types of malfunctions that may occur and their symptoms, due to the tendency of changes in the vehicle design to keep out-moding the information submitted to analysis. One of the most difficult problems in the Mercury Training Program has been providing the astronauts with up-to-date information. Part of this has been achieved through assigning them individual responsibilities for specific areas of information, and providing them with time to attend engineering meetings, to make trips to manufacturers' facilities, and to launch sites to keep up-to-date in their respective areas. The information they gather in this way is brought back to the rest of the astronauts and shared at weekly meetings. In operational-training programs, this problem should be somewhat relieved, since the vehicle configuration will be fixed and time will be available to prepare adequate and comprehensive manuals. The requirement for thorough knowledge of the system will not be changed, but the information on the vehicle system should be much more readily available.

DYNA-SOAR PILOT TRAINING

Lt. Col. Burt Rowen
Maj. Robert M. White

AIR FORCE FLIGHT TEST CENTER
Air Research and Development Command
Edwards AFB, California

The selection of Dyna-Soar I pilots requires a program for their familiarization and training in all the aspects of flight from the familiar supersonic regime to flight at hypersonic and orbital velocity. The requirements of the stronaut embarking in near-space-flight are many and varied, and have been discussed at length in general terms by many authors. The purpose of this program will be to present specific tasks, within present knowledge and known facilities, to satisfy the objective of preparing selected pilots to flight-test the Dyna-Soar I.

To proceed in an orderly manner, a category will be assigned each broad area pilots will investigate, or in which the pilots will be investigated. Detailed discussion of each category will offer the tasks the pilots will be expected to complete. In addition, many factors necessary for training will involve knowledge and equipment not presently available. This will form a basis for a discussion of requirements to fulfill this and other space programs.

Selection

Selection is the obvious first category to examine. What kind of persons, who are they, and what are the criteria to be used in their selection? The aptitudes and skills involved require knowledges and understandings in: (a) proficiency and experience as pilots of high-speed, high-performance jet or rocket aircraft; (b) detailed engineering understanding of the operation and maintenance of the power plant, controls, and environment-conditioning equipment of the spacecraft; (c) medical and physiological training in human performance and functioning, with particular emphasis on survival and efficiency in the spacecraft; (d) detailed understanding of the operation and maintenance of all communications and scientific and military observational equipment; and (e) detailed understanding of the mission plan in relation to navigational and astronomical frames of reference.

Graduate test pilots have engineering and scientific training, interest, and curiosity, and are very experienced in high-performance aircraft. Therefore, the selection should logically be made from this group. To be more specific, pilots should be selected from among those of the Flight Test Operations Division, Air Force Flight Test Center, Edwards Air Force Base, California. The premise here is that these pilots have completed most of the basic screening and selection by: (a) being accepted for and completing the Test Pilot School; (b) being accepted for assignment in Flight Test Operations at Edwards AFB because of high standing in their school classes; class standing determined by flying ability, scholastic achievement, and attitude; and (c) experience in performance, stability, and control-testing in new aircraft, this experience not being readily obtainable at any other Center of the ARDC. Equal excellence is expected from those NASA pilots to be selected by their organization.

Each pilot will be from among the type discussed and will have at least a Bachelor's degree in one of the Engineering Sciences. Several other factors, such as height-weight relations and age, are not to be exactly delineated within the province of this proposal, and are left open. Such factors are significant and must be resolved on the basis of payload and cabin requirements, and clinical judgment.

In conclusion for this category, two points must be stressed: (a) personnel must be selected immediately so they can be identified with the project from its present blueprint-stage to flight-test; and (b) selection must be considered a continuous process since the progress of the training program will provide for further selection and attrition.

Clinical Screening

The first phase of selecting DS-I pilots should be their medical evaluation. This can be determined by screening at the USAF Aerospace Medical Center, Brooks AFB, Texas. This screening is similar to the medical examining program of the X-15 pilots and Mercury Astronauts. The results of the screening would be twofold; first, to identify any physical deficiency that would give cause for elimination, and second, to reveal minor shortcomings such as obesity, less-than-best current physical condition, etc. This will provide data for implementing a programmed and scheduled activity to maintain good physical condition. A program of physical training is recommended, and can be handled adequately with existing facilities of the Air Force Flight Test Center.

Stress Testing

Psycho-physiological screening and stress testing have been received with mixed feelings by experienced pilots when they are used to determine whether they are suited to fly very-high-performance aircraft. Some of these feelings are shared, since the test pilot has proved his adaptability to new soul- and mind-disturbing situations. The test pilot performs with instrumentation recording every action. He talks to contractors about their aircraft (and they are concerned about many hundreds of thousands of dollars), and every word he speaks is weighed for its accuracy, competence, and technical value. He has coped with aircraft responses and motion not previously predicted in analytic and wind-tunnel studies. These factors and others that a pilot routinely encounters in flight-test operations have added up to a clinical screening which in the past was used to help determine which persons were chosen for such projects as the X-series rocket aircraft. In addition to all this was the evidence of desire—of motivation—which is absolutely essential for a project of radical departure such as DS-I. With highly experienced test pilots, it appears easier to determine a desire for radical departures in flight-test programs. However, since some of the pilots chosen as candidates will acquire their basic experience as test pilots (discussed in a later section) in the build-up to DS-I, it will be difficult to determine desire or motivation. For this reason, it is recommended that psycho-physiological screening and associated stress testing be made a category to which the DS-I pilots must willingly submit prior to other specifics of a training program. Selected pilots should have no difficulty completing this process. Psychiatric and physiologic process will provide DS-I pilots a keen insight into the aeromedical research efforts to define human requirements for space flight.

Flight-Test Program

Flight-test programs in the Century series or other aircraft must be an essential part of training for DS-I. The problems of retainability, reassignment, and selection of new pilots require programs that include supersonic flight, resulting in recorded data on performance, stability, and control, and written reports. Additional experience must be offered in qualitative stability and control to allow interpretation of aircraft stability and control systems that instrumented data cannot reveal. In this manner we guarantee the experienced test pilot for DS-I.

A projection of fighter-aircraft programs for the next three years does not show sufficient promise to gain a great amount of flight-training time. If this is correct, it should be considered necessary to instrument a high-performance aircraft to allow DS-I pilots to gather and analyze flight-test data. They should also be provided the opportunity to cross-evaluate aircraft of the United States Navy and aircraft of special nature, such as variable-stability. Acquisition of a high-performance, variable-stability-and-control aircraft will provide a valuable tool in DS-I and other programs for stability and control, landing, and visibility problems.

Briefing on DS-I

A proper introduction would be a comprehensive briefing on the DS-I. This would be provided by various groups—Air Force, NASA and Contractors—and would require several days, since each subject would be presented in detail. Subject areas will include: (a) a general briefing to define the concept of DS-I; (b) the aerodynamic design and energy management; (c) vehicle secondary power and sub-system; (d) crew station and environment; (e) boosters; (f) range (AMR & global), radar tracking, telemetry, and communications requirements; and (g) flight test programs.

Preliminary Required Reading in Basic Rocket and Astronaut Theory

With a detailed briefing on DS-I complete, many questions will be posed regarding the basic knowledge, the terms used, and their definitions. An immediate required-reading program will be instituted to provide DS-I pilots with the background to better identify and evaluate future tasks in the training program.

Detailed study will be required covering nozzle and thrust chamber theory and design, heat transfer, liquid and solid propellants, secondary power systems, guidance, tracking, communications, orbital flight paths, and possible military and scientific application for space vehicles.

Test-Pilot School

A proposal must be made to present some formal courses in theory, to provide DS-I pilots with advanced knowledge in astronautics. It would be advisable to provide instruction that would apply directly to the program. For example, a course should be offered on aerodynamics of lifting surfaces at hypersonic velocity near orbital altitudes. The subject matter should be presented using the contractor's design, his estimates on C1 max, L/D max, C1 optimum, their effects on orbital altitude and energy management, and boundary conditions due to turbulent or laminar flow, aero-dynamic heating, and dynamic pressure.

Other formal courses can be offered and are being planned by the USAF Test Pilot School, where it is felt that the best talent and facilities are available for formal theoretical instruction.

TDY with Primary DS-I Contractor

Initial training of DS-I pilots will begin with a schedule of TDY assignments for two or three pilots for thirty-day periods at the contractor's facility. They will be assigned to and work with the DS-I Engineering Design Group. This is considered essential for three reasons: (a) to identify DS-I pilots to the contractor from the beginning; (b) to obtain detailed information in all systems, such as cockpit, hydraulics, electric, secondary power, heat and vent, etc.; and (c) to provide influence and input in the design of these systems, particularly since USAF and NASA pilot experience will probably be greater than that of contractor pilots. It is probable that there will be no contractor-pilot participation, particularly for the launch operations at Cape Canaveral.

Continued TDY at the contractor's plant must be emphasized to maintain impetus and direction of this USAF-guided flight-test program.

Static Simulators

Static simulators have provided the means for engineers and pilots to evaluate aircraft stability, control, control systems, displays, and aircraft and control responses. DS-I pilots will be scheduled for static simulator practice for training and as necessary to evaluate controls and displays. In the past, it has been necessary to schedule this activity at the contractor's plant pending availability of the computer and pilot. The best arrangement to allow the pilots maximum utilization of static-simulator training would be to provide an analog computer in six degrees of freedom at the Air Force Flight Test Center. This additionally provides AFFTC engineers with a tool to do much needed flight research for the DS-I and other supersonic and hypersonic aircraft programs. A properly equipped computer laboratory is considered essential and is recommended for early integration if the Air Force Flight Test Center is to offer training for future space activity.

Dynamic Simulation

Dynamic simulation in the form of centrifuge programs will be a scheduled activity as the DS-I program progresses. As with the static simulator, the dynamic simulation will allow realistic evaluation of controls, stability, displays, and crew accommodations. At present only one facility exists that is adequate for closed-loop dynamic simulation, at Johnsville, Pennsylvania. This facility has a loaded schedule and thus is not available in sufficient frequency. Moreover it is not convenient to the West Coast. The infrequency of its availability leads to the necessity for pilots carrying on a program without the realism of full-pressure suits. The computer laboratory has old and dated equipment, resulting in many delays during the conduct of a program. This generates some degree of pilot distrust. A national requirement exists for a dynamic simulator located on the West Coast in support of the DS and other manned space programs. This centrifuge simulator should provide sophistication to allow flying in all "g" profiles, dynamic closed-loop simulation by tie-in to the computer laboratory previously recommended, and the creation of an environment in the gondola, or one in which the gondola may be placed (i. e., artificial atmosphere, visibility simulation, external cues, realistic personal equipment evaluation, etc.) to achieve a realistic simulation of the space mission. Thus we would have a much needed facility for the best possible non-flight training of pilots for DS-I and future space vehicles.

Land and Sea Survival Training

The booster flight-test phase of DS-I requires extensive operation over both land and oceans. Emergency recovery in other than a proposed landing area presents the pilot with the task of survival. Survival training on land will be offered DS-I pilots at the AFFTC, where a survival-training course began late in 1960. Survival at sea will be included, and it is anticipated that coordination with the AF Air Rescue service and the U. S. Navy will offer the best lessons in this subject.

Pressure-Suit and Environment Training

Early in the program, each pilot will acquire a full-pressure suit. These suits are in a continuing process of development, and it is expected that DS-I pilots will assist in their development while becoming used to wearing them for several hours and developing a tolerance for confinement, restricted visibility and mobility, uncomfortable variation of temperature and humidity, and change in internal suit pressures because of variation in cabin pressure. Much of the environment-conditioning will be accomplished by scheduling in special chambers at the AFFTC. Adaptation to these conditions while performing vital flight tasks is necessary and will be accomplished in conjunction with centrifuge programs and in two-place aircraft in flight. It is recommended that a two-place aircraft such as the TF-102 used to support the X-15 human factors program be considered a continued requirement to support the DS-I program.

Astronautic Symposia

With the science of astronautics in ascendancy, many professional societies such as the IAS and the American Rocket Society hold symposia at which papers are presented by distinguished men in the field of aeronautics. Often these symposia are held in conjunction with the ARDC or the Office of Scientific Research. The value of material presented in these meetings increases markedly with the large number of classified sessions. It is intended that DS-I pilots will attend these meetings to acquire knowledge and current thinking in astronautics, to lend prestige to themselves, the AFFTC, the ARDC, and the USAF. The intent in this case is neither exploitation of the pilots as public figures nor of the program as such. The public relations activity concerning the program and the individuals involved is conducted conservatively and sensibly, with due regard for the national interest in this venture and for the importance of the program in advancing space research.

Cape Canaveral and Atlantic Missile Range

The most significant portion of the flight-test program will be conducted from Cape Canaveral to islands of the Atlantic Missile Range. A briefing tour and inspection of Cape Canaveral will be participated in by all DS-I pilots. It is planned to have the tour coincide with a launch operation so that the preparation, countdown and launch of a Jupiter, Thor, Atlas, or Titan may be observed. A knowledge of operation at Cape Canaveral is required since, for one example, a DS-I pilot must make or approve a decision on the method and division of responsibility between himself and the Range Safety Officer in the event of emergency on or shortly after leaving the launch pad. Pilots will be scheduled for additional visits during each unmanned DS-I launch. The initial tour of the Cape will be followed by a flight along the islands of the Atlantic Missile Range to learn visually the geography, size, and shape of the islands, and particularly the planned and emergency recovery sites. Visual identification is extremely significant since the pilot will have no external vision until after re-entry. In the event of loss of tracking and communication failure, the pilot may have only visual means to identify position and selection of the intended recovery area. It is proposed that high-altitude flights (35,000 to 45,000 feet) will be provided for training in identifying the islands along the Atlantic Missile Range.

Projects X-15 and Mercury

The X-15 program and the Mercury project will provide a great amount of information beneficial to DS-I. DS-I pilots will be briefed on the X-15 program periodically at the AFFTC and will pilot chase aircraft on X-15 missions. This will provide a background on dead-stick landing problems, air launch procedures, and knowledge of the X-15 High Range. Air launch, use of High Range, and dead-stick landings are all elements of the initial DS-I flight-test program. Periodic briefings on Project Mercury will be arranged with the NASA so its progress and problems, where compatible with DS-I, will become useful knowledge.

Additional areas for training suggest themselves, such as dead-stick landing practice in aircraft configured to the visibility and L/D of the DS-I, and possible rocket flights. These are valid anticipations, and may be firm requirements as the program progresses. Additional categories, not included in this proposal, will be suggested or become obvious with further thought and coordination. They can be accepted or rejected after careful evaluation. Care must be used to provide training subjects that will have direct benefit to the pilot preparing for the DS-I program. As the number of pilots assigned to the DS program increases, areas of primary responsibility will be assigned to individual pilots. This system has proved successful in the Mercury project and it is anticipated as a guarantee of success in the DS program. The assignment of a test pilot early in the development of a new manned weapon system has always led to a practical, usable application of technological knowledge.

The foregoing has been presented as a guide to the ARDC position regarding training of test pilots for the Dyna-Soar program.

SR 49756—A PRELIMINARY FORECAST OF A SPACE CREW TRAINING PROGRAM FOR THE 1965-1975 TIME PERIOD[1]

Marty R. Rockway
Wright Air Development Division
Air Research and Development Command
Wright-Patterson AF Base, Ohio

Introduction

This paper presents an abbreviated summary of the objectives, approach, and results of ARDC Study Requirement 49756, "Advanced Design Trainer." This study was originally conceived as a means of providing the Air Force with a general forecast of flight crew training requirements for manned military space systems likely to exist during the next decade and a half. Such information was desired to form a sound basis for the planning of research and development activities related to space-vehicle crew training. It was recognized, of course, that much of the information obtained from such a venture would be tentative in nature and would require considerable modification, elaboration, and refinement as new data became available. However, it was felt that the activities associated with the development of a human performance capability for manned space systems require at least as much "lead time" as do the activities associated with the development of a hardware capability. Therefore, it was decided to take the first steps now and to update the findings as required.

The study was conducted on a "no-cost" basis by four contractors (Douglas, Chance Vought, Link, and North American) selected from approximately twelve who submitted proposals. The

[1]SR 49756 was officially initiated by Hq ARDC and managed by Mr. Roy Flanigan of the Advanced Systems Planning Office, Directorate of Advanced Systems Technology, Wright Air Development Division. Technical assistance throughout the course of the study, from contractor selection to final evaluation, was provided by personnel from several WADD Laboratories. However, the bulk of such support was supplied by personnel of the Training Psychology Branch of the Behavioral Sciences Laboratory.

official study period was seven months in length, extending from November 1959 to June 1960. Each of the four contractors performed a separate study and submitted separate final reports. However, virtually all of the unsuccessful bidders and several other contractors participated as subcontractors with one or the other of the major participants.

Objective and Requirements

The objective of SR 49756, as set forth in the official Statement of Desired Work, is ... "to establish the phases of training required and the general design characteristics of a complete crew-training capability for military manned space systems representative of those likely to exist in the 1965-1975 time period. Primary emphasis will be directed toward the characteristics of an over-all flight crew training program with gross specifications for all techniques, devices and aids necessary for the efficient acquisition, maintenance, and evaluation of the required human performance. Where appropriate, alternative techniques, devices and aids will be suggested."

The objective quoted above was further elaborated in the following requirements, which are also contained in the official Statement of Desired Work:

> "A. The contractor will survey all relevant Governmental and civilian sources for information concerning the possible characteristics of manned military space vehicles in the 1965-1975 time period. On the basis of this information, he will select and synthesize (one or more) plausible representative systems for study. The contractor will perform the necessary mission analyses to determine the in-flight characteristics of the selected systems. In view of the absence of firm data, it will be necessary to make many assumptions concerning the specific details of these systems, their missions, and the nature of man's contribution to their capability. With respect to the human participation in space flight, liberal, rather than conservative judgment will be used in the assignment of system functions to man.
>
> "B. After identification of the system(s), mission(s) and both routine and emergency human performance requirements, the contractor will design a complete program for achieving, maintaining, and assessing the adequacy of the desired crew capability. All of the procedures

and media for training the crew members should be specified in as much detail as possible. The need for cross-training in crews with more than one member is to be indicated along with the methods to be employed in familiarizing or habituating personnel with some of the unique conditions which may be encountered during operational missions. In addition, consideration is to be given to the desirability of incorporating facilities within the operational vehicle itself for the maintenance of little used but highly critical skills. This latter consideration may be extremely important in the case of relatively long-term missions. Naturally, the contractor will be involved to some extent with questions of crew selection and human engineering. However, at the present time it is felt that his activities in these areas should largely be restricted to exploring their implications for training.

"C. All presently available and planned training facilities such as ground simulation equipment, centrifuges, pressure chambers, mock-ups, and high performance flight vehicles will be considered for use in any recommended program. In addition, during this program it is important that the contractor make a thorough study of related efforts in the X-15, Mercury, and Dyna-Soar programs.

"D. The contractor is to determine gross capital and operating costs in terms of money, manpower, special facilities and training of the individual phases of the proposed program as well as the complete-crew training program. Consideration will be given to cost and benefits associated with a space flight trainer compared to a calculated risk program of omitting the flight phase and training space-flight personnel entirely in ground simulators."

Approach

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. In general, however, it may be said that almost any of the four studies might be selected as a model for future efforts of this nature. To illustrate the systematic progression of the major steps in the over-all approach, the following paragraph is quoted from Volume I of the Douglas report:

"The over-all 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 into 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 inter-relationships. The training program was then built around the position descriptions and was oriented toward imparting the necessary skills to the selected trainees."

This section contains a relatively brief summary of selected portions of the contractors' final reports. The brevity is enforced primarily by the tremendous amount of material involved. For example, the three-volume Chance Vought report alone contains approximately 900 pages. In addition, much of the material in the various reports has been classified. All but one or two pages of the North American report carry a classification of Secret; therefore, their study will receive only very sketchy treatment. Despite these restrictions on detail, however, it is felt that some useful and interesting information may be transmitted concerning general concepts and issues.

Missions and Vehicle Systems

Douglas selected one composite mission and one composite vehicle system which they felt incorporated virtually all of the relevant functions and tasks likely to be required of man during the time period in question. They were very explicit in pointing out that their system was not intended to be "realistic" with respect to engineering and military considerations.[2] However, they did feel that it represented a legitimate model for the derivation of training requirements and training program development.

Mission (Douglas). A low-altitude (250-300 mi) orbital mission was selected. The vehicle remains in orbit thirty days prior

[2] That is, the mission characteristics as such were reasonable, but they might not all be included in a single vehicle system.

to re-entry and landing. The mission includes the following functions:

1. Reconnaissance and surveillance.
2. Defensive and offensive employment of weapons.
3. Electronic countermeasures.
4. Rendezvous with other vehicles.
5. Boarding and inspection of other vehicles.

Vehicle System (Douglas). A composite system with a four-man crew and consisting of an expendable booster, a satellite, and a winged return vehicle was synthesized. The satellite is a collapsible toroid which is boosted into orbit with the return vehicle while in a folded condition. After attaining orbit, the wedge-shaped sections of the satellite unfold in the fashion of a circular fan to form the final toroidal structure. The satellite is capable of berthing two return vehicles to permit crew transfer and logistic support.

Link identified two representative missions and systems. The first covered the time period 1965-1970 and the second the period 1970-1975. As a result of time pressures only the first mission (Mission A) was used as the model for the derivation of training requirements and training program development.

Vehicle System and Mission (Link). The mission and vehicle characteristics are as follows:

1. Prime mission—Reconnaissance, including global surveillance and early warning.
2. Secondary mission—Satellite inspection.
3. Space operating region—Low-altitude earth orbit (about 300 N. M.)
4. Booster—four- or five-stage Saturn.
5. Payload—30,000 to 60,000 pounds.
6. Mission duration—Up to thirty days.
7. Logistic support—None, except for possible rescue.
8. Maneuverability—Limited number of orbital plan changes and orbital altitude corrections.
9. Crew size—Four.

Chance Vought identified four different space-vehicle systems which they felt were typical of those likely to exist within the selected time period.

Vehicle Systems and Missions (Chance Vought). The four typical systems were identified as:

1. Typical System No. 1—A low altitude orbital vehicle with a one-man crew similar to Dyna-Soar I. Capable of one to nine orbits. Primary mission is reconnaissance.

2. Typical System No. 2—A more advanced vehicle with a three-man crew and a complete orbital mission capability. Missions are offensive, defensive, and support, with durations up to three weeks.

3. Typical System No. 3—An orbital space station with a five-man crew. System is assembled in space. Missions are offensive, defensive, and scientific.

4. Typical System No. 4—A lifting/ballistic vehicle with a three-man crew and a capability for a soft lunar landing and return to earth. Mission duration approximately seven days.

North American synthesized an integrated space force consisting of five classes of vehicles. Each vehicle system is assigned particular mission functions, but taken as a group they probably include the total spectrum of space-crew performance requirements for the predictable future.

Vehicle Systems and Missions (North American). The five vehicle systems considered are as follows:

1. Recoverable Booster Support System (RBSS)—A high-performance "aircraft".

2. Winged Re-entry Vehicle (WRV)—Similar to Dyna-Soar with two-man crew. Performs a variety of missions including logistic support for space force.

3. Space Shuttle Vehicle (SSV)—A pure space system with a three-man crew and no re-entry capability. Missions are offensive, defensive, and support. Serves as control center for assembly of System 4.

4. Permanent Orbital Station (POS)—A large orbiting station which is assembled in space. Serves a number of functions including command, staging, and supply for other vehicles in space force.

5. Vacuum Landing Vehicle (VLV)—Similar to System 3 with a capability for lunar landings.

Crew Positions, Functions, and Tasks.

Douglas proposed a four-man crew with all tasks associated with a single sub-system assigned to one man. The four crew positions are as follows:

1. Pilot—Senior crew member and over-all coordinator and system monitor. Responsible for all activities and functions of propulsion and flight-control systems including preventive maintenance. Should be rated jet pilot.

2. Navigator—Responsible for guidance during all phases of flight. During normal operations will be in close contact with earthbound telemetering stations. Performs preventive maintenance on subsystems for which he is responsible. Background includes training in navigation, air launch missiles and electronic maintenance.

3. Maintenance Technician—Responsible for life-support subsystem. Also prime maintenance officer for both preventive and corrective maintenance. Supervisor of all maintenance carried out by other crew members. Background includes training and/or experience equivalent to a B.S. in engineering, with experience in system analysis and troubleshooting and repair.

4. Reconnaissance Operator—Responsible for all communications, data-sensing, and data-processing activities. This includes contacts with earth, other space vehicles, enemy communication monitoring and jamming. Background should include training and/or experience in radio operator duties, reconnaissance and photo interpretation, optics, map reading photography, radar and IR sensing.

Link's four-man crew is not specifically identified with respect to specialized positions, since Link advocates "complete cross-training" for all crew members. However, it appears that the designations for the illustrative task-groupings might be satisfied by titles such as pilot, co-pilot, navigator, and maintenance man. In fact, Link indicates that such a specialty breakdown would be highly desirable if information from early flights obviates the need for such heavy emphasis on cross-training. Individual crew members are responsible for the functions and tasks associated with operation and maintenance of the various subsystems in a manner not too different from that indicated in the previous section. With respect to background selection factors all four crew members should be rated pilots with a science degree or equivalent. Two of the crew members should have a minimum of 1,500 flying hours, with at least 600 hours logged in high-performance jet aircraft, and be graduates of a military test-pilot school. The other two crew members should have a minimum of 800 flying hours, with at least 300 hours in high-performance jet aircraft.

Chance Vought identified a total of twelve different space-crew positions to man their four typical systems. These are described following the system titles in the next four subsections. With respect to background, all crew members are expected to have a degree in some field of engineering or science and some special training in connection with aviation, system operation, or system maintenance.

Typical System No. 1 has only one crew position, the pilot. His tasks fall under the categories which include program selection; manual emergency control; making decisions over automated systems and providing manual operation as required; inserting corrections as needed; selecting and activating sensors; data interpretation; and data transmission.

Typical System No. 2 has the following three crew positions:

1. Pilot-Vehicle Commander—Primarily responsible for all decisions affecting mission success, for piloting the vehicle and monitoring all vehicle subsystem operations, and for monitoring the imminence I. R. Detect and Elint displays.

2. Co-Pilot-Navigator—Primarily responsible for assuming the pilot's functions when necessary, for directing the vehicle as required for intercept, bombing, etc., and for acting as a substitute for the flight intelligence officer during the latter's off-duty periods. He will be secondarily trained to assist the flight intelligence officer in performing maintenance and repair functions.

3. Flight Intelligence Officer—Primarily responsible for operating and interpreting data received from the sensor equipment such as radar, photographic, I. R. mapper, electronic order of battle (Elint) equipment and other auxiliary aids. Secondarily, this crewman will be trained to service, troubleshoot, and repair all vehicle subsystems and equipment.

Typical System No. 3 has the following five crew positions:

1. Station Commander—Is a first pilot on Typical System No. 2 and will serve as commander of the space station and crew. Responsible for all ultimate decisions affecting mission success.

Alternate duties include mission programming, directing crew activities, record keeping, control of space-to-earth communications, periodic monitoring of imminence evaluators, and other command functions as required.

2. Vice-Commander—Is a co-pilot of Typical System No. 2 and will serve as vice-commander of the space station. Alternate duties include that of navigator of Typical System No. 2 and substituting for the commander during the latter's off-duty periods or in cases of emergency.

3. Flight Intelligence Officer—Primarily responsible for operating and interpreting data received from the sensor equipment such as radar, photographic, I.R. mapping, Elint and other auxiliary aids. Secondarily, he is responsible for the performance of support and preventive maintenance functions on station subsystems and equipment; e.g., periodic and timely charging of CO_2 absorbers, O_2 re-supply, proper storage of food and water, periodic servicing of equipment and components as required, etc. During missions when hardware and/or biological tests are being performed or when crew members are being trained, this crewman will be required to perform other supplemental tasks as required.

4. Assistant Flight Intelligence Officer—Will be trained to relieve the flight intelligence officer and the station engineer during their off-duty periods. He will also perform limited maintenance and repair tasks in addition to those tasks associated with research and development testing and space-crew training.

5. Station Engineer—Primarily responsible for performing all engineering functions associated with subsystem monitoring and troubleshooting, and repairing the vehicle, its subsystems and equipment.

Typical System No. 4 has the following three crew members, all of which are veterans of Typical System No. 2:

1. Pilot—Acts as first pilot and vehicle commander of the parent vehicle throughout all phases of the mission. Also responsible for control of the Lunar module during descent, landing, ascent, and rendezvous with the parent vehicle in Lunar orbit. Secondarily, serves as flight engineer during the off-duty periods of the latter.

2. Flight Engineer—Monitors all vehicle subsystem operations and performs preventative maintenance, troubleshooting, and

repair tasks as required. In addition, serves as co-pilot and substitutes for the pilot during off-duty periods of the latter.

3. Space Navigator—Responsible for verifying, computing and/or otherwise determining the necessary guidance data for directing the vehicle from earth to the moon and return. Also serves as navigator of the Lunar module during descent, ascent, and rendezvous with the parent vehicle. Secondarily, serves as flight intelligence officer in the utilization of the vehicle's sensor equipment.

North American's descriptions of crew positions, functions, and tasks are not summarized since all such information was classified secret in their report.

Personnel Selection Factors

Although the identification of selection criteria per se was not a primary goal of this study, it is obvious that such factors must be considered in the derivation of training requirements and the design of training programs. That is, what needs to be trained (i.e., the training requirements) may be considered as the difference between the human performance capabilities required by the system and those already possessed by the potential trainees.[3] In addition, assuming that this difference represents "trainable" attributes, then the particular training format and collection of techniques, media, etc. employed also depend in part upon the other training-relevant characteristics of the available trainees (e.g., intelligence, adaptability, etc.).

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 employed in Project Mercury. The experimental factors are a function of the particular crew position involved, and great emphasis is placed upon selecting personnel with relevant experience in earlier systems to man positions in later systems where appropriate. In addition, virtually all contractors regard the training program itself as an important selection medium.

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[3] Of course, some of this difference may also be reduced by techniques other than training; e.g., the use of performance guides.

Because of the requirements introduced by long-duration missions and multiman crews, specific attention is devoted to selection for these factors. Douglas, for example, states:

> "Since crew integrity is probably more vital than ever before, stringent conditions for crew selection and crew maintenance have been established. A very careful selection procedure will be followed at the end of basic training, resulting in the formation of compatible, well-rounded crews which will then proceed to take advanced training. Each crew will be considered an entity and treated as such at crucial times. For instance, at the last moment before launch, if one crew member is ill, the entire crew will be cancelled and an alternate crew sent. If at any time a crew member drops out of the program for any reason, the crew will be taken out of the operational situation, a rigorous selection process initiated, and extensive retraining given."

The Over-All Training Program

This section represents the major product of the SR, so it will receive fuller treatment than the previous ones. However, in order to provide somewhat greater depth, it is necessary to sacrifice coverage to some extent. That is, most of the space is devoted to a summary of the program of one contractor (Chance Vought) and the programs of the other contractors are treated very briefly. The selection of the Chance Vought program for detailed consideration is not intended to imply an evaluation of its merit with respect to the other three programs involved. Indeed, the major characteristics of all of the programs were very similar, so that any of the four might have been selected for illustrative purposes.

Chance Vought designed a training syllabus for each of the twelve crew positions required to man the four typical systems. The total estimated training time in calendar months required to complete each syllabus is contained in Table 1. The relatively short time-periods for some of the syllabi following the listing for Typical System No. 2 result from the fact that they are designed for the "retraining" of veterans of System No. 2 who are transitioning to the later system. There is considerable similarity among the various syllabi even though specific subject matter content and training activity may differ from one position classification to another. Each training syllabus is divided into five major phases as follows:

1. Academic training.
2. Physiological and psychological conditioning.
3. Simulator training.
4. Transition training.
5. In-space training.

TABLE 1

The Estimated Training Time in Calendar Months* for Each Crew Position of the Four Typical Systems

Typical System No. 1	
Pilot	30 months
Typical System No. 2	
Pilot	30 months
Co-Pilot-Navigator	30 months
Flt. Intell. O.	24 months
Typical System No. 3	
Station Commander	12 months
Vice Commander	12 months
Flt. Intell. O.	12 months
Asst. Flt. Intell. O.	12 months
Station Engineer	24 months
Typical System No. 4	
Pilot	18 months
Co-Pilot-Engineer	18 months
Navigator	18 months

*This includes holidays, vacation, etc.

In subsequent subsections the syllabus for each position will be summarized and the major training media employed to support the various phases of training will be indicated. The syllabi will be listed by system, position, and phase. The syllabus for the pilot of Typical System No. 1 will be described most completely since it will be used as a reference point for the syllabi to follow.

Typical System No. 1. This system has only one crew member, the pilot. The total training time for all phases of training has been estimated at 2,530 hours.

Academic Training—The objective of this phase is to provide the student with the necessary background for a more thorough understanding of the vehicle, its operation, flight procedures, and the in-space environment. The subjects covered are primarily those related to basic fundamentals such as mathematics, electronics, space mechanics, propulsion and guidance, vehicle design and construction, navigation, etc. Included in this phase is training in the function and use of personal equipment, escape procedures, customs and habits of major world cultures, and oral and sign language. The latter two courses are intended to provide the astronaut with information and skill that may be useful as an aid to survival. It is recognized that trainees will enter the program with different backgrounds. Therefore, it is suggested that some pre-testing be employed to identify those areas in which the trainee already has adequate facility. These may be deleted from this program.

A variety of training media are suggested for this phase. In addition to the more general aids and techniques for fundamentals and subsystems training, the following items will be employed: (1) Systems Demonstration Trainer[4], (2) Space Flight and Procedures Trainer[5], and (3) Egress Trainer[6]. The estimated total time for this phase is 1,096 hours.

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[4] This classification includes such training media as charts, animated panels, mock-ups, cutaways, etc.

[5] This is a fixed-based trainer similar to the conventional aircraft flight simulator. It provides training on virtually all of the normal and emergency task activities associated with system operation but does not incorporate physical motion, external vision, or "environmental" stresses.

[6] A device with the same general internal and external configuration and center of buoyancy as the vehicle escape capsule. Similar in concept to the analagous device used in Project Mercury.

Physiological and Psychological Conditioning—The objective of this phase is to teach the student the nature and effects of stresses he may experience in flight, provide him with a knowledge of nutrition, prepare him for emergency survival on the earth's surface, and provide optimal mental and physical conditioning. This phase includes study and experience with noise, vibration, acceleration, internal atmospheric environments, temperature, and weightlessness. Relevant available information concerning the long- and short-term effects of radiation and the effects of meteoroids will be included, and a comprehensive coverage of nutrition will be emphasized to assist in the formation of proper diet habits during daily living as well as during flights. The effects of isolation under conditions of activity will be discussed. Study of the principles of emergency survival will precede actual survival training. Such training will include a consideration of survival in all areas of the world. The program of physical training will include calisthenics, sports, and other activities. The major equipment supports for this phase will include (1) Space Flight and Environment Simulator[7], (2) centrifuge[8] and rocket sled, (3) water tank device[9], (4) isolation chamber, and (5) disorientation device[10]. The estimated total time for this phase is 936 hours.

Simulator Training—The purpose of this phase is to provide training and/or practice in: (1) the procedures and flight techniques to be followed during the pre-launch boost, orbital, re-entry, glide, and landing phases of the mission (using the Space Flight and Procedures Simulator); (2) the application of boost and re-entry procedures, the flying of complete simulated missions including many combined stresses, long duration missions, isolation, etc. (using the Space Flight and Environment Simulator); and (3) the control of the vehicle during boost and re-entry while experiencing representative acceleration forces (using a centrifuge). The estimated total

[7] A moving platform (gimbaled) full-mission trainer which incorporates all of the essential environmental parameters, except linear acceleration and weightlessness. It also provides visual simulation of the external environment.

[8] The suggested cabin is gimbaled and has an internal configuration similar to that of the vehicle cockpit. It also incorporates the environmental stresses and task-performance capabilities associated with the boost and re-entry phases of flight.

[9] Similar to that employed in Project Mercury.

[10] Similar to those employed in Project Mercury.

time for this phase is 334 hours. This includes 124 hours in the Space Flight and Procedures Simulator, 150 hours in the Space Flight and Environment Simulator, and 60 hours of centrifuge training.

Transition Training—The objective of this phase is to: (1) provide transition between simulator training and space flight; (2) provide experience in areas not simulated and extend experience in areas which cannot be simulated adequately; and (3) acquaint trainees with the facilities, personnel, and procedures pertaining to launch and recovery.

This phase involves flight training within the earth's atmosphere as well as pre-flight, launch, and post-flight procedures. A modified high-performance jet aircraft with cockpit configuration and control characteristics similar to those of the actual space vehicle will be used for much of the flight training. In addition a Typical System No. 1 vehicle will be modified as required for air drops. Extensive practice in approach and landing procedures will be given. Keplerian trajectories will be flown during which tasks may be practiced under short-term weightlessness. Training in launch and recovery techniques will include tours of launch and landing facilities, familiarization with ground crew duties and carrying out procedures with the ground crews as an integrated team. The estimated total time for this phase is 164 hours.

In-Space Training—This will be acquired in actual operations. (Chance Vought feels that the cost and hazards of a boost-glide training flight for this system are equivalent to those for an operational flight.) Therefore, flights solely for the purpose of training are not recommended.

Typical System No. 2. In general, the syllabi for the three crew positions in this system are similar to the syllabus described for Typical System No. 1. However, some modification of the System No. 1 program was required. For example, the following additions were made:

1. Academic—Training in command functions, record keeping, first-aid administration, and inter-crew relationships.
2. Physiological and Psychological Conditioning—In-flight exercise.
3. Simulator Training—Bombing, satellite intercept, reconnaissance, vehicle maintenance, and extra-vehicular functions.
4. Transition Training—No change.

5. In-Space Training—According to Chance Vought, further research is required to determine the necessary training aids and simulator configurations.

The estimated total training hours for each crew member is 2,806 for the pilots, 2,896 for the co-pilot, and 2,564 for the flight intelligence officer. Requirements were established for training a minimum of two crewmen for each essential flight task in order to preclude the loss of the specific capability during work-rest cycles or emergencies.

Pilot Syllabus.

Academic Training—Similar to same phases for Typical System No. 1 with the addition of the following:

1. Propulsion System—Troubleshooting, maintenance and repair in sufficient detail to acquaint the pilot with general procedures and to develop an appreciation of the problems involved.
2. Navigation—Rendezvous with objects in space.
3. Others—Additional information on subsystems, personnel facilities, and command functions and records.

The total estimated time for this phase is 1,202 hours.

Physiological and Psychological Conditioning—Same as for System No. 1 with the addition of in-flight exercise. The estimated total time for this phase is 986 hours.

Simulator Training—Differs from that of System No. 1 to the extent dictated by differences in crew functions and missions. The multi-man crew and long-duration missions indicate a requirement for multi-place simulators with near-total-mission simulation including living quarters, life-support systems, etc. The crews must be seasoned to function as members of teams for long periods. (Under their discussion of a selection program Chance Vought suggests simulator missions of one week to thirty days in length to serve both for training and selection purposes.) The estimated total time for this phase is 454 hours.

Transition Training—Same considerations applicable as for System No. 1 except that it may be possible in some cases to send an inexperienced crew member along with two veterans for his first flight. Thus, since two men are trained in all tasks, he will be backed up by a veteran.

Co-Pilot Syllabus.

Academic Training—Same as for pilot, except that first-aid administration is added and material is modified in areas of troubleshooting and maintenance, and navigation training. The estimated total time for this phase is 1,262 hours.

Physiological and Psychological—Same as for pilot.

Simulator Training—Same as pilot, except for additional training in navigation, extra-vehicular operations and maintenance.

Transition Training—Same as pilot except that less air-drop training is given.

In-Space Training—Same as pilot except for specialized co-pilot functions.

Flight Intelligence Officer Syllabus.

Academic Training—Same as co-pilot except that navigation and command functions and records are deleted and less time is devoted to the study of space mechanics. The estimated total time for this phase is 1,162 hours.

Physiological and Psychological Conditioning—Same as pilot, with addition of food preparation to nutrition study. The estimated total time for this phase is 996 hours.

Simulator Training—Differs from that of other two crew members in that emphasis is on own specialties including greater emphasis on maintenance and repair functions. Although the flight intelligence officer has no function to perform during boost he must be conditioned to acceleration profiles on centrifuge simulator.

Transition Training—Since this crew member will not control the vehicle, he will receive weightlessness training in multi-engine jet aircraft of the C-135 type. During this training he will perform such tasks as troubleshooting, sensor operation, etc. Launch and recovery training same as for pilot. Will be passenger during air drops.

In-Space Training—Same as pilot except will perform in own capacity.

Typical System No. 3. Retraining of veterans of Typical System No. 2 to serve as station commander, vice-commander, flight or assistant flight intelligence officer for this system will require approximately 12 calendar months. (Should non-veterans be trained, the baseline requirements are the same as those for comparable positions in System No. 2.) The total retraining time in hours for each of the five crew positions is station commander 1,048, vice commander 1,048, flight intelligence officer 1,058, assistant flight intelligence officer 1,118, and station engineer 2,578.

Station Commander Syllabus. Except for refresher training all academic subjects are deleted except for internal power systems, vehicle design, and command functions and records. The latter course is expanded to include research and development test scheduling and records. In the area of physiological and psychological conditioning all subjects are deleted except physical exercise, although some refresher training may be necessary, particularly in the areas of acceleration and emergency survival. Simulator training will include that necessary to retain proficiency as pilot of System No. 2. The simulator training required for System No. 3 includes extra-vehicular operations, space survival, escape and rescue, and station assembly. A space-station simulator and devices to provide training in extra-vehicular operations (including personal propulsion and station assembly) are required. Since this crew member is a qualified pilot of System No. 2, transition training is deleted. In-space training would involve functioning as station commander on a regular military mission for at least one month.

Vice-Commander Syllabus. Same as for station commander.

Flight Intelligence Officer Syllabus. Same as for vice-commander, except that simulator training in vehicle maintenance and a thirty-day apprenticeship as an assistant flight intelligence officer on a military mission are added.

Assistant Flight Intelligence Officer Syllabus. Academic training is the same as for station commander, except that first-aid administration is added and command functions and records are deleted. Transition training is deleted and other training is similar to that for flight intelligence officer.

Station Engineer Syllabus. Academic training is similar to that for the co-pilot of System No. 2, with minor exceptions. For example, command functions and records and navigation are deleted and vehicle design is modified to include space-station data. Conditioning is like that for the flight intelligence officer of System

No. 2, with the addition of food preparation to the study of nutrition. Simulator training is similar to that for the flight intelligence officer, with greater emphasis of maintenance, pre-launch and reconnaissance training. Transition training is like that given the flight intelligence officer of System No. 2, and in-space training involves service as station engineer on a one-month military mission after graduation.

Typical System No. 4. All of the three crew members of this system are veterans of System No. 2. Therefore, except for refresher training, all academic subjects are deleted except for internal power systems, navigation, vehicle design and construction, and Lunar geography. Transition training for the pilot might include a facsimile of the Lunar landing module, properly modified as to thrust requirements, for air-drop training. Extensive training in near-total simulators is recommended for the space navigator due to the precision with which the navigation must be performed, particularly for earth re-entry from cis-lunar trajectories. At least two crewmen will be trained for each task. The total retraining times in hours for each crew position is pilot 1,372, flight engineer 1,357, and space navigator 1,420.

Douglas proposed a training program consisting of 49 training courses of one to five weeks in length, structured so as to require approximately 38 weeks for their total presentation. The total period is divided into a 16-week basic program and 23-week advanced program. The basic courses are designed to provide the general information and background in military space subjects required as a foundation for specialization in specific systems. The advanced courses are specific to the mission and vehicle system and are designed to develop operational proficiency for the four crew positions identified. It is assumed that the proficiency provided by the courses will be sufficient for operational effectiveness on the first flight, anticipating that a certain amount of on-the-job learning is tolerable for all positions except that of pilot. Therefore, Douglas suggests that pilots be given additional training as necessary in boosted orbital flight before being certified as proficient. A nominal one flight in an X-15 or Dyna-Soar-type vehicle is tentatively recommended.

Basic training consists of three major subject areas: (1) space environment, (2) basic system training, and (3) various mission profiles. These items are discussed broadly enough to be applicable to all available space systems. Three other subjects included in basic training are: (1) survival and general emergency procedures, (2) space medicine, and (3) group dynamics.

Advanced training consists of two major activities: (1) Training individual crew members for all phases of flight and modes of operation at their stations called procedures training; and (2) Integration of the various crew members into a homogeneous and efficient team referred to as crew integration training.

Link proposes a training program organized along a mission-phase progression from pre-launch to re-entry and landing. The emphasis is on highly programmed training in which instructors play a specialized and non-traditional role. That is, the instructor deals primarily with specialized individual problems and not with the routine aspects of training. Such training is designed to maintain the mission relevance with respect to content, to provide a basis for standardizing proficiency levels, to provide reliable training, and to provide a means of systematic observations, criticism, and dependable change in the program when required. A whole-part-whole approach is recommended, in which the student passes through the mission-training phases, and at various points combines and integrates new materials with those already learned. A typical training session might involve the use of a tape-recorded lecture interspersed with slides, films, etc. shown by an assistant instructor. The taped lesson is pre-programmed and pre-tested, and is designed to cover all questions which might be asked during a session. Where appropriate, such a technique might provide the initial orientation for procedural training, using equipment supports. All four crewmen will receive complete cross-training in piloting and other operator skills. They will be partially cross-trained on maintenance tasks, with two crewmen trained to handle each half of the equipment. (Link provisionally rejects the use of an actual space-vehicle trainer on the basis of high cost and uncertain value.) The estimated time for completion of this program, not counting absence resulting from illness, leave, etc., is approximately 21 months.

North American presents an "evolutionary" training program in which personnel from earlier systems are transitioned to later ones in a manner similar to that described by Chance Vought. Their general program is characterized by a large amount of academic training prior to specific task training. In fact, academic programs up to two years in length are indicated to be essential for the proper preparation of certain personnel. North American classifies training requirements into three categories—proficiency, experiential, and survival. Considerable emphasis is placed on long-duration, integrated-crew training and training for assembly in space. The various individual training programs range in length from 11 to 50 months.

Training Facilities and Equipment

There is considerable agreement among the recommendations of the various contractors with respect to training facilities and equipment required to support the suggested training programs. In general, primary emphasis is placed on the use of ground-based media supplemented by modified high-performance aircraft for both the acquisition and maintenance of proficiency. Only one contractor team (North American) suggested the use of an actual space vehicle strictly for training, although the integration of "green" personnel with veteran crew members on operational missions for training purposes was accepted practice. Most contractors recommended, either directly or by implication, the use of a central facility at which virtually all training would be given. All contractors considered the requirements for proficiency evaluation throughout training, and for an on-board "training" capability for the maintenance of little-used skills on long-duration missions; but, in general, they did not provide much detail with respect to these questions.

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

Concluding Remarks

Perhaps the most significant outcome of this study is that no insurmountable problems or spectacular solutions were identified. This is not to say that all of the information needed to design an optimal training system is already available, for it is not. Actually, there are many specific problem areas which demand research and/or development. However, most of these do not represent discontinuities in the state-of-the-art, but only differences in emphasis. However, it is obvious that both economic and humane considerations dictate that work on many of the problems of training for space should be initiated immediately if we are to have the "best possible" answers when required.

Although some deficiencies in terms of methodology and depth of coverage are apparent in these studies, they still represent the most comprehensive analysis of manned space-crew training requirements and problems made to date. It is felt that these studies are sufficiently valid and cogent to form the basis for timely actions in both research and development. It is recommended that these studies be utilized as a basis for planning actions by all agencies having responsibilities for research, development, or support activities related to manned space systems.

SECTION II

Comments by Invited Scientists

Jack A. Adams
Aviation Psychology Laboratory
University of Illinois

There have been physical scientists who have decried man in space as unnecessary for the next few years because unmanned vehicles are sufficient for the pressing research objectives that must be accomplished. This view is sound for many research topics, of course, but man's versatile capabilities make him a valuable component of a space system for which there are no machine substitutes. The remarkable advances that have been made in computer and control technology give a large capability to completely automatic unmanned space systems and, indeed, machines surpass the human operator along many dimensions. Machines can be speedy, powerful, and precise, but they tend to be dumb, inflexible brutes. Man's virtues do not always include speed, power, and precision, but he is far from being a dumb brute. Properly chosen and trained, he is resourceful and versatile, with distinctive capabilities in data storage, interpretation, and decision-making. Furthermore, there is the attractive likelihood that the human operator can give the space vehicle an acceptable level of reliability by keeping it working for prolonged periods of time. With no breakthrough in reliability of complex equipment foreseeable, and with space vehicles having an astounding complexity of hardware, the human operator's ability to diagnose malfunctions and perform in-flight repairs may justify him on sound engineering grounds alone. A WADC Technical Note by Westbrook[2] nicely emphasizes the improvements in reliability that result when a human operator can control and repair a vehicle on an earth-moon round trip. Westbrook assumed a mission-time of about ten days in a vehicle requiring continuous attitude control about three axes. He estimated that the probability of success for an automatic control system on an earth-to-moon voyage and return had a prohibitively low value of .22. If, however, a crewman provided a standby control capability, the reliability rose to .70. And, if it was further assumed that three spare parts for the control system are made available, and the crewman could diagnose a failure of the control system and repair it, the reliability became a very acceptable .93.

Dr. Jones, in his paper, has listed many of these merits of man in space, and we need not labor them any more. The issue for this conference is training and how we can best make the astronaut a proficient responder as a scientist, controller, and in-flight diagnostician and repairman of system ills so that reliability and mission success are optimized. The important thing is that he will not have these capabilities unless he is properly trained, and that is the topic of our meeting.

I would like to restrict my discussion of ground training programs for astronauts to certain aspects of the design and use of simulators for the crewmen of space vehicles. This seems of fundamental importance to me because it is evident that a simulator will be the primary training device in which crewmen will gain their proficiency for the space flight. Too, it seems more important to worry about simulator design and use at this time, not only because of its first-order significance in a training program, but because basic decisions about simulator design and use must be made at the very onset of system development if the simulator is to be completed one to two years before the actual space mission. Less advanced planning is necessary for relatively inexpensive and simple academic programs with their textbooks, charts, and mock-ups which can be rather quickly structured from the know-how of established educational technology.

For all of the complexity of modern flight simulators, they have had a limited role in training crewmen of conventional aircraft. Comparatively little use has been made of flight simulators for the original learning of flight skills. Rather, their most prominent use has been in transition-training for new aircraft where trainees have had experience in flying related types of aircraft. As transition devices, the simulator played an important role as a procedures trainer for learning normal and emergency response sequences and the physical layout of a crew station. Present-day flight simulators also have simulation for learning some of the aerodynamic characteristics of a new aircraft, although the growing popularity of simple cockpit-procedures trainers which lack aerodynamic simulation suggests that some people do not think that simulated instrument flying is a large contribution of simulators. Simulators have had an undeniably important role but the important thing is that, typically, they have been conceived as transition devices to provide just enough training so that a crewman could perform his initial flights safely enough to proceed with his airborne training where most of his proficiency would be developed. Simulators also have some usefulness for the refresher practice of emergency procedures which could not be practiced in the air, or for refresher training of navigational and procedural sequences which could be practiced in the air but which were not practiced often enough for proficiency. These latter uses of simulators for the maintenance of flying proficiency always seemed peripheral to the primary conception of them as transition-training devices, and I always believed this to be somewhat unfortunate.

The limited uses of flight simulators never gave them a simplified hardware. They are major electronic devices which need as much maintenance attention as an aircraft. Still, many relevant classes of cues for crew response were absent because it was implicitly assumed that a man's past experience in other aircraft gave him some response-proficiency to these cues, or that he could learn the response to them once he had developed sufficient skill in the transition-training to become airborne in the new aircraft. Actually, for many flying problems this assumption proved weak because the cues were never available enough on training flights for the responses to be learned. ECM training is an example.

It is this transition use, it seems to me, which promoted a limited conception and utilization of flight simulators, and which no longer makes sense for simulators of space vehicles. We must now see simulators as the training device in which a space crewman is presented with all relevant contingencies and cue classes in order that he might learn all response modes to a very high level of proficiency. While I believe there is merit in a more comprehensive simulator of this type, even for conventional aircraft, and mission simulators have been recommended on occasion, we have gotten by without them, although no one knows how well. This is no longer possible. A sophisticated, undeniably complex simulator appears mandatory for space vehicles. The astronaut training problem requires us to shift our thinking away from techniques used with air crews of conventional aircraft, and it seems that a different design rationale for simulators is suggested.

A Proposed Direction for Space Simulators

I would like to focus my initial remarks around the training devices of Project Mercury, criticize what has been done, and finally outline a course of action for simulators of future vehicles having design similar to, or more ambitious than, the Mercury capsule.

My general impression of the simulation equipment for the astronaut program is that we have no central mission training device. Instead, we have what seems to be a rather hastily assembled collection of training devices—a substantial number of part-trainers where each performs a specialized job. Dr. Voas' paper on the

Project Mercury training program listed no less than eight different simulators, one planetarium, three kinds of aircraft for familiarization with zero G-forces, and an F-102 aircraft for the maintenance of vigilant decision-making powers. Parenthetically, I could go along with this array of trainers except the flying of F-102's for maintaining competent decision-making powers. Frankly, I cannot see how decision-making, or any other type of response for that matter, in the F-102 can transfer significantly to the comparatively unique responding required of the astronaut in the Mercury vehicle. I would think that he could profit more by spending this time in the McDonnell Procedures Trainer and practicing some of the decisions associated with emergency sequences. From what I have heard and seen of the Mercury capsule and mission, the astronaut's task is actually more like a radar observer's job than a pilot's. When more time is available to match human abilities and task requirements we might possibly come up with something like a SAC Radar Observer as the key crewman of a future space vehicle. I do not mean these remarks on the Project Mercury training devices in any way to be critical of the human-factors personnel associated with the program. I fully appreciate that it is a crash project propelled by national urgencies. With more time available for long-range programs I am confident they would do things differently.

With my sentiments leaning towards a mission simulator, let me broadly sketch what I think it should include. The big problem, as always, is specifying how much to simulate, and after that decision is made, the problem is how well to simulate it—the old fidelity-of-simulation problem. We are interested in developing skills in the simulator that will have maximum positive transfer to the operation of the space vehicle, and we are charged with delineating relevant stimulus and control dimensions. The first step, which is obvious, will have to be some kind of task-analysis documenting the environmental conditions, and the events and controls associated with responding. Which ones of all of these should be selected for simulation—which are critical for response association and transfer—will be difficult to say. I tend to think that we should be liberal in our simulation because of the tremendous reliance on the simulator for developing in-flight proficiency, but by this I do not mean that we should try to simulate everything. We should not necessarily have a big mission simulator with a full crew, which tumbles and whirls around in a centrifuge while stars streak by overhead and the surface of a planet rushes beneath. Instead, we should have an integrated mission simulator with all crew stations, in which cues of known significance for responding are simulated. This is easier to say than to do, and it would depend greatly upon the vehicle and its mission, but I interpret my statement to imply the simulation of any event, internal or external to the vehicle, to which the task-analysis shows that responses are linked and where transfer can be shown or reasonably assumed. However, I would temper this statement by saying that the simulator should be a fixed trainer, with tumbling, vibration, heat, and acceleration variables omitted on the grounds that their relevance for transfer of training is too imperfectly understood at this time. The cost of having these variables in a crew simulator is so great that including them on a pure hunch basis is probably unwarranted. We do not know that the original learning of responses to instrument indications under conditions of tumbling or acceleration, for example, gives any more transfer to the criterion space-vehicle than if learned in a fixed trainer. Transfer-of-training studies of shift in response from a fixed trainer to a tumbling one, or from a fixed trainer to a centrifuge, would be revealing. It may turn out that the important thing is proper simulation of control and display characteristics, with tumbling and acceleration forces being trivial determinants of transfer. Some task variables, such as those defining proprioceptive feedback for a control system, have surprisingly little influence on transfer. Learned responses are conditioned to internal bodily cues such as proprioceptive stimuli, and these are undoubtedly different under conditons of acceleration forces and tumbling, but we know so little about their role in transfer that we probably shouldn't include them at tremendous cost until our scientific knowledge is more secure. While I suggest some liberalism in simulation, the philosophy should be accompanied by a sense of scientific conservation lest we succumb to vulgar urges for face validity.

As for the venerable topic of fidelity of simulation (how realistically a chosen task variable should be simulated), I think that it is receding in importance. It is more important to know what to simulate so that the proper cues are available for response acquisition than to worry about how much a variable can be degraded without impairing the amount of positive transfer. Cost considerations have dictated our interests in fidelity of simulation, but I don't think that application of our present knowledge in this area can much alter the budget of a space program. I expect that simulator designers will strive for the highest possible fidelity with the hope of maximizing transfer. This approach might cost more but I don't see how it can hurt the training value of the device.

The type of mission-training device I envision is far more complex than those used today for the training of aircrews of conventional aircraft. In some detail, I think the simulator should at least have:

1. Full capability for presenting the cues of all normal and emergency procedures. Moreover, the crewman should be able to practice decisions associated with emergencies, such as diagnosis and selection of alternate courses of action. There is more to emergencies than pressing buttons and flicking switches, as Dr. Jones has mentioned.

2. Simulation of dynamic display indications and controls.

3. Simulation of external visual cues if it can be shown that crew responses are made to them. This might include the earth, or whatever planet is passing beneath the vehicle. Although navigation may be fully automatic, we can expect that a crewman will be taking periodic navigational checks as a reliability safeguard, and will use the stars as reference.

4. All crew stations so that the entire crew (assuming advanced vehicles for the moment) can practice as a unit. I do not mean this for the development of crew coordination and team spirit, whatever they are. Crew coordination frequently has been discussed as a benefit of integrated team training but I have never fully understood what this term means. As far as I am concerned, the principal value of crew training is that the responses of one man can provide the cues for responses by another, and if we are looking to simulate relative cue classes then we can argue for a crew simulator. A good example is the aircrew responses that will be based on communications with ground stations, which should be part of the crew simulator too.

I certainly cannot see a crew always practicing together. There are many aspects of a mission where only one crew member is busy and it would be wasteful to have the others sit around while just he is practicing. Therefore, I think a crew simulator should have a disconnect capability where the various stations can be used separately whenever this is required. Crew simulators have never been developed with any degree of completeness. Certain preliminary attempts have been made, such as the wedding of the B-52 simulator and the ultrasonic radar trainer. These have been discussed in a recent WADC Technical Report on a conference on integrated air crew training[1]. I think that a space flight might be the time to start the first design and development of a complete, well-conceived crew-mission simulator. My position is not meant to be a denial of part-task simulators but only that part trainers should be a supplement to, not a substitute for, a crew-mission simulator. There will always be numerous devices and aids contributing to teaching and familiarization, and properly so, but I am suggesting that they complement a major mission for the integrated practice of time-based mission sequences.

(The following addendum was prepared by Dr. Adams subsequent to the conference in order to clarify and supplement some of his remarks at the conference. -Ed.)

Part trainers, such as cockpit-procedures trainers, are useful training devices and much can be learned with them. However, two recent experiments at the University of Illinois have defined distinct limitations for cockpit-procedures trainers when they are used to teach a discrete procedural response sequence which must be time-shared with continuous flight control activities. It was found, both for original learning and for relearning after forgetting, that mere practice of procedures, unaccompanied by the concurrent, time-shared responses, results in less than full proficiency. Top proficiency in procedures is gained only by following the part-task practice with whole-task practice where all response elements are present. Our interpretation of these data is that a cockpit-procedures trainer can be used unequivocally for training procedural sequences which do not have to be time-shared with other response classes; procedures which have to be time-shared must be followed by some whole-task practice to achieve top performance. For space vehicles this whole-task practice would most likely be in a major, whole-task mission simulator. This, to me, is further justification for a whole-task mission simulator because part trainers alone cannot do the whole training job. Part trainers may often have a cost advantage, but this is accompanied by penalties in the proficiency of certain types of complex responding when part trainers are used by themselves.

References

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Judson S. Brown
Department of Psychology
University of Florida

I would like to say at the outset that I have been very favorably impressed by the work that has been done by the human engineers and psychologists in the programs we have heard discussed. I'm also impressed by what I have heard concerning the current attitudes of manufacturers toward human-factors problems. These favorable attitudes were simply non-existent during much of World War II when those of us who were in the military program encountered considerable resistance to suggestions of this kind. At that time, few believed that psychologists could be of any help in the matter of equipment design, so this sounds to me as though progress has been made.

The specific comments I have to make, like those of Dr. Adams, are not to be construed as criticisms of any one particular person or group of persons, but rather as reflections of my own somewhat wistful feelings that we might do something else, or perhaps do what has been done with a little different attitude and a little different approach to the problem. Specifically, I am concerned over the relative lack of, reference to, and use of psychological concepts in the work that has been done. By and large, the people who spoke to us yesterday did not use psychological terms or psychological words. They talked about acceleration and G-forces and other physical principles, but not about psychology. Hence, I feel that more attention might be given to the question of which psychological principles are involved in the matters under discussion, with particular reference to the performance of space-vehicle skills and to the training of the operators. Now let me give some specific examples of what I mean. First, it seems to me that we now know enough, or should know enough, about the task characteristics of the Mercury Project, to be able at this time to start making some intelligent guesses about how capsule occupants can be most effectively trained. No statements, to my knowledge, were made yesterday about the psychological nature of the operator's task. It was not described as a rote-learning task, as a motor-skills task, as a paired-associates task, or as a task in which the operator must memorize long lists of discrete steps. This is what I mean by my saying that we might rely more on psychological descriptions in the hope that this will facilitate the use of some of the information we have already accumulated as psychologists, not as human engineers. Perhaps, therefore, we should look at these tasks in more psychological ways, and should describe them, as Dr. Miller has urged, in more behavioral terms. Conceivably, we can then do more about the training problem in the sense that we can extrapolate from existing psychological knowledge. For instance, if the list that has to be memorized, let us say, in paired-associates or in rote-learning fashion is more than 50 items, then we know that it will be difficult to learn and that certain kinds of learning procedures will be better than others. Perhaps memory drums and very simple comparable training devices would be helpful devices for teaching sequences of this kind to space vehicle operators. The teaching-machine-like devices that were used at Lowry Field by the psychologist might very effectively be used now in the training of astronaut skills, on the assumption that these skills are clearly identifiable and can be programmed on these machines. We need to know, therefore, how long the lists are, how much discrimination of subtle change is required, how many of the stimulus variables that impinge upon the operator are of a peripheral nature and hence may involve moving the head (which may be difficult under high-G forces), and so on. I gathered from Dr. Jones that most of the cues to which the operator must respond in a monitoring task are quite distinctive. If so, then stimulus distinctiveness has already been developed and the training task becomes a much simpler one of setting up linkages between clearly discriminable cues and the to-be-performed responses.

As a second example of my feeling that we might profitably utilize psychological principles more directly, I want to refer back to a part of yesterday's discussion that was initiated by Dr. Ericksen. This was the discussion of apprehension, anxiety, panic-button pressing, and the like. Although some of these terms are psychological, little heed was paid in our discussion to the psychological principles underlying these emotional phenomena. We might, for example, be able to structure our interpretations of these matters in terms of the principles that are said to apply to conditioned fear, conditioned anxiety, and the like. Clearly, some kind of emotional reaction is involved here. Usually the psychologist is willing to grant, I think, that some degree of emotional excitement is necessary for optimal performance, and I suspect that emotionality will always be present in the astronaut's situation. These situations are inherently stress-inducing and it is doubtful whether, even after prolonged practice, an operator will become so relaxed, unexcited, and confident that he goes to sleep. Thus we need not worry about providing the necessary <u>minimal</u> amount of apprehension required to motivate an operator. What we do have to worry about is that apprehension or fear in substantial degree may be disorganizing and hence a deterrent to the efficient performance of complex tasks. As we discussed these matters yesterday, it became clear to me that one of the major aims of complex simulation procedures is to reduce or to control these high-level interfering apprehensions or anxieties. Psychology may have something to offer here because we do know something about how to get rid of fears. Perhaps we can overcome the astronaut's fears by the application of the training principles or deconditioning principles that are believed to hold for animals and men. If we can identify the fear-or-apprehension-arousing conditions or stimuli in the astronaut's environment, we can then make positive recommendations. For example, some years ago Guthrie suggested that bad habits, including overly strong emotionality, can be eliminated by a graded series of exposures to the anxiety-arousing stimulus. Thus, anxieties aroused with respect to the experiencing of large degrees of acceleration, say, might be "adapted out" or extinguished by the administration of a carefully graded sequence of exposures to increasing G-forces in the human centrifuge. In effect, this is the classic principle of presenting the stimulus and not permitting the response to occur. It may be, of course, that experienced jet pilots are already completely adapted to the feel of high-G stress and are no longer either surprised or frightened, or made apprehensive, by these experiences. Other procedures that might be followed in attempting to decondition these apprehensions can be derived from studies such as those of Solomon and Wynne. Thus, one might try to keep the individual in the presence of fear-arousing cues for a long time, and if he discovers that the situation is really quite safe and he does not get hurt, his anticipatory anxiety should tend to diminish. Another thing to remember in this connection is that, according to some theories of the motivating effects of anxiety, if tendencies to make incorrect or wrong responses are dominant, then these will be activated by the apprehensions and performance will be impaired. This suggests that the individual should be thoroughly trained to make the correct responses. If then he becomes apprehensive, the probability of his making the wrong responses under stress would be reduced. So I feel that, by paying a little more attention to psychological principles, a great deal more could be done to develop efficient training procedures that would lead to optimal anxiety or apprehension levels and to the reduction of apprehensions that are in the nature of interfering processes.

With respect to the problem of the identification of fear-arousing cues, I see no major difficulty. Certainly almost any unknown, unexpected, strange happening is anxiety-arousing. At least, this had been my own experience in riding in aircraft, and I have frequently observed similar reactions in fellow passengers. I think one should go through the astronaut's task in an effort to identify all those events that might lead him to become anxious or apprehensive. Anxiety can be aroused, incidentally, not only by the coming-on of unexpected stimuli, but also by the cessation of ongoing ones. If there is a constant humming noise and this suddenly stops, the astronaut must know whether this is to be expected or whether it indicates some malfunctioning.

I also have the strong feeling that the proper administrative organization of the astronaut's life could help reduce his fears, particularly, let us say, by making absolutely certain that his family is taken care of in case of disaster. I suspect that most pilots carry little more than a $10,000 GI Insurance policy. I think, therefore, that better provisions should be made for the astronaut so that he will be absolutely certain that if he dies his family will be well taken care of. I think that this might also tend to reduce any interfering anxieties he might have.

A further point related to what seems to me to be the relative neglect of psychological principles and available information is the fact that not enough has been done to identify and describe the specific perceptual and motor tasks required of the astronaut, as I think I indicated. I think it would be nice to know, for example, whether the attitude of the space vehicle can indeed be controlled by simple, mechanical controls of the kind described by Dr. Voas. He pointed out that a skilled pilot would have to be used because the controls, that is the over-riding controls, must be simple mechanical ones in order to reduce weight. But do we indeed know that he can control the vehicle in this manner, or does he have to have aids such as are provided by quickening, servo mechanisms, and the like? This kind of analysis of the task is needed, it seems to me; at least more is needed than I was able to pick up from the descriptions provided. It is absolutely essential, therefore, for us to have clear and detailed knowledge concerning the nature of the complex tasks that must be performed by the astronaut. Once this information is available, we can then presumably proceed in a more intelligent manner toward the design and execution of training procedures.

I'm also somewhat surprised to find that insufficient attention has apparently been paid to the design of the equipment that must be operated by the pilot of the Mercury capsule. I recognize the difficulties here, but my impression from looking at the panel of the Mercury capsule is that it has not been engineered in accordance with the best-known principles of human engineering. The dials in the picture that has been given me look like old-fashioned altimeter dials with all their confusing numbers and multiple pointers. I know, of course, that it is difficult to arrange things in the most efficient way for human operation. The engineer has to get the instrument in the right place for mechanical and other reasons. Nevertheless, I continue to hope that psychologists can—and this of course is the perennial recommendation—get into the design program at an early enough phase so that they can have some voice in the design and layout of the equipment. I notice also, from looking at the pictures of the Mercury capsule cockpit, that there are a number of switches all of which are exactly the same shape and placed side by side. I also detect a number of handles, all of them exactly the same shape and all side by side. I believe that this poses a real danger, since the astronaut may pull the wrong handle or throw the wrong switch at some critical moment simply because the switch handles and other controls are not coded for touch. It seems to me that this type of design is extremely important, and should be looked into more than it has been up to now.

I also wish to say that the task of the Mercury capsule operator, as it has been pictured to us here, strikes me as being beyond any known individual's capacity. I tried to point this out yesterday, and I think it still holds true that the operator must have a tremendous capability if he is going to do anything like what has been suggested he might be required to do—controlling the vehicle, servicing the equipment, monitoring it, counting meteorites, measuring his own blood pressure, and heaven knows what else. It seems to me there is clearly an operator overload here, and I would suggest, therefore, that considerable attention be given to the problem of simplifying the operator's task. Methods of obtaining this simplification are well known to the members of this Conference. Checklists can be used to prevent overload of memory, logical sequences for the checking and operation of components can be drawn up, critical instruments can be grouped in the central visual field, and so on. Because of the difficulty of the task, the training problem becomes of substantial importance, and that is what we are discussing in this Conference. It appears to me that the astronaut has so much to do that I do not see how he can ever learn to do it if he is to do all of the things mentioned above, including the maintenance. The maintenance, I suppose, is more of a hope than a reality at present. I gather, for instance, that if a sensitive meter should break, it would be impossible for the astronaut to repair it, and spare instruments cannot be taken along. Certainly the "black-box" conception of maintenance can scarcely be applied to the astronaut capsule. In any event, my point remains that the task, as sketched, seems to be terribly complicated, and although I think it

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is quite reasonable to suppose, as Dr. Jones and Dr. Voas have, that the operator will play an important role, I think that his task must be kept within manageable limits.

Insofar as personnel requirements are concerned, it has been frequently mentioned that skilled pilots must be used for the Mercury, the X-15, and the Dyna-Soar projects. Clearly, the use of skilled pilots seems to be of much less importance for the Mercury than for the other two. This has been pointed out by someone else; I believe it was Dr. Adams. As he noted, there is a serious question whether positive transfer will occur from pilot training to Mercury capsule operation. Certainly, few of the pilot's specific motor skills would be expected to transfer to the new situation. Moreover, I do not feel that the pilot's experience in decision-making would transfer in a useful way from jet flights to capsule flights. The decision whether to abort a jet flight depends upon a great deal of specific information about fuel, range, flight angle, and so on. None of this information is directly applicable to the capsule situation. I fail to see, therefore, how such information would be of much help to the astronaut. As a matter of fact, it is even possible that negative transfer would occur, since the visual cues upon which the jet pilot depends are quite different from the kinds of cues that would be presented to the astronaut during capsule flights. Moreover, the G-forces are different, the auditory cues are different, the vibrations are different, and the somaesthetic cues are different.

Finally, I think a little more attention—and again I'm emphasizing the psychological part—might be given to motivation and to the information that we have about motivation. We've heard it stated that these astronauts are highly motivated, and the lure of glory and fame is probably there as an incentive. But after the first few flights, particularly if we should be unfortunate enough to have an accident, it may take something more to keep these people on the job. Just what these motivational aids would be, I'm not yet certain. Perhaps double flight-pay would help, but whatever it is, it is clear that these people will have to go through long and arduous training programs. There is some question, therefore, whether, after a year or two when the operator is no longer the first man in space, he will be motivated to sit there in the hot, cramped compartment and go flying around the world with a fair probability of not coming back at all. Certainly serious attention should be given to this problem of the maintenance of the astronaut's motivation for the performance of an arduous and dangerous task.

S. C. Ericksen
Department of Psychology
Vanderbilt University

When I read Dr. Jones' paper, it was my reaction that he had identified and presented the basic question when he asked whether the Astronaut will be a passive observer or an active controller. After a day and a half of discussion, I am still inclined to leave this question in the same, top priority, position. To what degree should the training program be oriented toward an astronaut who is responsible for making fine perceptual discriminations, critical conceptual decisions, and actively manipulating the capsule controls? The paper by Dr. Rockway provided a meaningful summary of a significant but more distant psychological problem of crew training for extended space flights. However, it is my opinion that we should first direct our attention to the specific training problem of preparing the first Astronaut for his first lob flight where, for approximately 5.2 minutes, he will experience zero-G plus and, of course, the critical experiences involved in the launch, re-entry, and pick-up. This initial Redstone flight should clear up considerable confusion and answer many questions which will permit us then to proceed with a realistic program of astronaut training. In the absence of the first flight feedback, we should recognize the fact quite honestly that many of our decisions about training will be based on traditions, assumptions, and generalizations from other types of training programs.

I could not help but read and compare these reports dealing with various projections of astronaut training against the background of more familiar Air Force, Army, and the Naval training traditions. Many of these once-active training programs are now matters of historical interest. Nevertheless, I can see a continuing problem, quite general in scope, which is still part of our thinking when we plan training programs. I am referring to the familiar drift toward the use of a liberal arts, general education curriculum as the appropriate model for use in military training. I think we should pause and be more discriminating since the liberal arts pattern is geared for a criterion-free existence. That is, in its extreme form it is a leisure class type of education to prepare one for a life of appreciating, understanding, and contemplating outer space but not flying through it. In its normal civilian setting, the liberal arts concept is one thing, but it is not the best preparation for the practical and technical realities facing the astronaut. I can be more specific and identify three characteristic deficiencies in this liberal arts model which I can see creeping in as a background shadow in the reports that I have read.

1. Face validity and "logical" assumptions. Since the outcome of a liberal arts education cannot easily be validated, we are free to make curricular and instructional decisions on a basis of deductive thinking, cultural habits, and "good judgments." Gross over-generalizations are often made concerning the educational value of a particular discipline and we can use the "calculus complex" to illustrate this state of affairs. The calculus course is fast taking on broad educational benefits analogous to the disciplining values once ascribed to Latin and mathematics. The calculus may or may not be the appropriate prerequisite for the kind of information that a psychologist or a General or an astronaut might need. The training program, must, sooner or later, be specifically, purposefully, and effectively based on the task-analysis of the astronaut's job. In the absence of such data, we should include a given course of instruction because there appears a good probability that the astronaut will need this information. In the present setting, we cannot afford the luxury of "good" assumptions and "logical" deductions.

2. Emphasis on original learning. The second weakness in the liberal arts model is its traditional stress on original learning with the passive assumption of transfer of learning. Most of us have accepted the convention that an instructor has done his job well when he can show that his students have reached a high level of achievement by the time of the final examination. It is clearly apparent that the teaching and testing for transfer of learning would be a difficult and awkward thing to accomplish. However, in the military training situation we cannot simply hope for transfer effects, but we must make the direct effort to teach for maximum generalization and carry-over from the classroom to the operational situation. Dr. Jones' presentation of the IBM job analysis of capsule failures could be used as an example of a good idea which should be reflected in the astronaut training program. I agree, but would further suggest that such a decision should be critically evaluated in terms of the demonstrated transfer-value of this type of training sequence. A well-polished and carefully rationalized curriculum might easily lull us into a false sense of security and program accomplishment. This happens because we gradually, though not intentionally, shift our focus to training as an end rather than as the transfer means toward operational effectiveness.

3. Over-conceptualizing. Most instruction is done with words and it is easy, very easy, to climb gradually up the abstraction ladder in order to cover more and more material within a limited period of time. We should constantly remind ourselves that the lectures and the manuals represent symbolic and conceptual substitutes for the real world of situational decision-making. Concepts are the result of the abstraction process and while a concept may stand for a great deal in general, it represents nothing in particular. And it is this "particular" that can be the difference between success and failure on a given mission. However, we have a problem here because, in the absence of specific information, we are forced to be somewhat general. Concepts are better than nothing, and we need to use concepts when we do not have the percepts. A self-critical training program will be constantly searching for the appropriate balance between the general, conceptual level of training and the specific, rote-type, instruction.

Now let us put aside this more general analysis given in terms of the liberal arts model, and consider three additional points that refer specifically to the astronaut training program.

1. Decision-making in a perceptually distorted environment. This, I think, is the Great Unknown. The unpredictable stresses and distortions during launch, zero-G, and re-entry represent life and death problems about which our laboratory research to date may represent only partial protection. There is already available considerable single-variable research on the individual effects of heat, cold, acceleration, anoxia, etc., and even some observations of weightlessness. In looking at this research I am impressed by the need to be more concerned about the interaction effects which might more closely approximate the prevailing state of affairs in space flight. And I would most certainly add that we should recognize the additional variables of anxiety and fear and fatigue. These conditions could easily be masking variables, i.e., they could eliminate or depress the effects of a careful training regimen, but one which has been accomplished in a relaxed, cognitive environment. I would encourage a stronger effort with multiple-variable research, with particular attention to affective factors and their interaction effects.

Nice, clean, objective variables live a long, long time, even though they may not remain as important as variables which are fuzzy and for which we do not have reliable quantitative measures. Many university faculty members, for example, still define a well-educated person in terms of his ability to spell, and the IQ concept seems to be culturally fixed. We must be careful that our training program is not molded and shaped by the immediate rewards which are available when working with concrete and "get-at-able" variables. In our self-conscious attempts to be scientific, we may feel a little restrained and uneasy when talking about attitudes and fears and anxieties, etc. But it seems to me that in something as critically important as astronaut training, we should "leave no hypothesis unturned" in our search for the crucial factors contributing to successful operational performance. It might be that the molar-personality psychologist, with his skills and understanding (however gross), may make a significant contribution in parallel with the more familiar efforts of experimental psychologists working with the traditional molecular variables of temperature, acceleration, cockpit preparations, etc.

2. The perceptual anchor. Orbital flying does not mean sensory isolation, but the astronaut will be working in a highly conceptualized environment, in the sense that he must maintain his orientation and respond to dials and lights with only minimal reference to the external earth and space environment. I think we should know more about whether the astronaut may or may not need a perceptual anchor, i.e., some specific and continuing tie-in between his cognitive processes and the external environment. I am wondering what might be the capsule counterpart of "the needle and the ball" which was stressed so much in pilot training for conventional aircraft. It is quite possible that this orienting operation would serve as the common denominator and continuing reference point which would help integrate the otherwise isolated and independent activities involved in maintaining normal operation of the capsule. Simply knowing the time of day may have a generalized catalytic effect on the astronaut's psychological efficiency.

3. The establishing of the priority rank in trainable astronaut skills. By the end of this two-day conference we will have discussed a great many factors which should be considered in astronaut training. I think it is well to make as detailed an inventory as we possibly can. The task is not complete, however, until someone has grouped, regrouped, and then established a tentative priority rank of the training objectives. Yesterday I made a comment about physical training in which I questioned its importance, i.e., how much time in the training schedule should be devoted to physical conditioning? This illustrates the type of value judgment that someone must make in order to prevent a scrambling chaos in establishing the astronaut training schedule. We need to encourage a more critical distinction between the "nice-to-know" and the "need-to-know" aspects of the training program. I think that Bob Voas has shown a keen sensitivity to this problem in the paper that he

read to us yesterday and in the document that was mailed out earlier. It is important that some person or group of persons take the initiative to make the value judgments as to what are the "first-things-first" in the training program. I am repeating, but there needs to be constant vigilance against the inevitable backsliding toward the easy-to-train skills as opposed to the necessary-to-train skills. Exactly which items in this training inventory should be identified as ones to be thoroughly overlearned to a point of automatic, but highly proficient, performance, under conditions of perceptual distortion and personal stress?

I feel that the whole problem of simulation devices and training equipment is a crucial factor in the training of astronauts. I was tempted to focus exclusively on this topic but I will abbreviate my comments by referring to an unpublished document, "Principles Governing the Development of Special Training Equipment."[1] This report was prepared prior to our concern about astronaut training. The following principles still have merit in helping to define the astronaut training program:

I. Purpose of This Report

The purpose of this report is to provide some general guidelines for policy decisions relative to the development and use of complex, high-cost, special training equipment. These principles reflect the accumulated experience of many persons who have worked with a wide variety of training equipment in many different military programs. The principles are given further support by the research and development in the areas of human engineering, learning theory, educational procedures, and military training.

II. Establishing the Requirements for Training Equipment

1. The critical decisions about the functional characteristics of training equipment should be made in the early development stage when the military operational requirements are being identified and specified. We should recognize the principle of developmental continuity which extends from the blueprint to the final operational stage. This continuity might well reside in a single monitoring agency.

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[1] S. C. Ericksen, L. Mead, and H. Wilcoxon. Principles Governing the Development of Special Training Equipment. A report prepared by a Special Working Group, named above, for the Department of Defense, Advisory Panel on Personnel and Training Research.

2. It is important that the development for future training activities and development of training equipment necessary for those programs should take place concurrently. This principle is of particular importance in the design, development, and use of new weapon systems which may demand maximum accuracy and precision from the human component.

3. Human-factor specialists must be intimately involved in the decisions affecting the research and development procedures which are prerequisite to the adoption of special training equipment. These decisions are becoming increasingly complex, technical, and scientific, and require close cooperation between the hardware and the human-factor specialists.

4. A monitoring agency should be wary of the "face validity" pitfall. The apparent mechanical similarity between the new training equipment and the operational task is insufficient grounds for evaluative conclusions.

5. The first step in determining the functional requirements of a training device is to complete a thorough, detailed, and specific job-analysis of the situation for which training is required. Such an analysis should be aimed at determining the critical human requirements, namely, those which the average trainee will not already possess and which, if absent, are likely to impair the success of the military mission.

6. The job-analysis of the operating situation should first indicate whether or not the required knowledge and skills can be achieved by using already available programs, by current or obsolete operating equipment, or by locally fabricated training aids, etc.

7. It is often possible to teach certain part-task skills with a simple training device, and such training may offer important economies in training time and cost of equipment. It is often more economical to develop and use several such special training devices than to attempt to do all the training with the more complex devices.

III. Specifying the Functional Characteristics of Training Equipment

8. Optimum simplicity of electronic and mechanical design with minimum operating and maintenance requirements should be sought in the development of training devices. In practice, some compromise with precise realism can often be made in order to gain simplicity and utility without materially reducing the training value of the device.

9. Where certain skills involve a large intellectual component, training often can be accomplished by the use of relatively simple, inexpensive devices such as diagrams, working models, or visual aids which have little direct physical similarity to the actual operating equipment.

10. Those skills requiring team-sharing or action should be practiced in the context in which they will be exercised, and this type of training may require complex and expensive equipment in order to simulate adequately the operational task for which training is desired. Increasing fidelity of simulation is usually desirable as team training is approached.

11. Training devices can often be superior to the operational equipment for training purposes, quite apart from considerations of relative economy. Hence, the most careful attention should be given to ways of capitalizing upon the fact that a device is a trainer, and not the real thing. There are many ways in which this can be done, two of which are suggested below as concrete illustrations.

(a) Sometimes, especially in the earlier stages of training, simulators can be used deliberately to depart from realism in order to simplify, abstract, slow down, or exaggerate certain features of the task. In other cases, especially in the later phases of training, they can be used to introduce critical complexities, distractions, and stresses which are encountered in the operational equipment too rarely to provide for either initial training or maintenance of proficiency. Overtraining in a more demanding version of the task can be used to diagnose human weaknesses and to provide a margin of safety.

(b) A related feature of synthetic trainers is the excellent opportunity they afford for training in detecting and responding to emergencies, many of which cannot, with safety, be practiced on the real equipment.

12. Attention should be given to the unique opportunities often possible in trainers for providing the trainee with knowledge of results, both during the performance of his task and immediately upon final completion of it. Learning cannot occur without some form of knowledge of results, or "feedback" to the learner, and the sooner this occurs after responses are made, the better for learning.

IV. Development of Training Equipment

13. The suggestion made in Principle No. 1 is again confirmed, in that a single, continuing military agency should maintain monitoring responsibility throughout all phases of the development sequence, from initial requirements to the final training evaluation of the special equipment.

14. The developed device will achieve its purpose if, in order to operate it, the trainee is required to execute the behavior which was specified in the original job analysis and if he is provided with realistic knowledge of achievement. Trainers and simulators with such "built-in" specifications will thereby also be useful for several purposes—the measurement and maintenance of operational proficiency, the determination of systems proficiency, the development of new tactics and procedures, and the selection of special crews.

V. Utilization and Evaluation of Training Equipment

15. The evaluation of training equipment should be made in terms of the extent to which the device meets the training objectives which were specified when the decision to develop the device was made. The training requirements are the determiners of what is to be simulated by the physical device. A special training device can, of course, "fail" by being used in a situation for which it was not specifically designed.

16. A utilization manual (or manuals) should be developed (in addition to the installation and maintenance manuals) and should accompany the training equipment to its installation site.

17. Special and complex training devices of extreme cost and high operational importance should be subjected to a utilization and evaluation study. Such a project would answer questions pertaining to the rate and amount of learning of trainees, the range of individual differences in trainee performance, the reliability of operation of the whole device or its components (e.g., course generators or scoring systems), the optimal schedules of practice, and the appropriate stage of training for use.

18. During the life of the equipment, representatives of the monitoring agency should collect periodic in-the-field experience on the part of the using agencies. This "utilizing experience" should be made available for the assistance of other users, modification of the device, or decision to consider the device obsolescent.

VI. Research Support for Training Equipment

We need a better understanding of the basic methodological and theoretical problems which are prerequisite to attacking the more immediate questions of military training. For example, research is needed to identify new and improved procedures and techniques for executing an accurate and functional job-analysis, and assessing the critical human-factor components in the operating task. When this essential criterion information is available, it will be possible to conduct the more pragmatic research projects designed to indicate the best way to develop and use simulators and other types of training equipment. Sometimes, of course, it is necessary to make many pre-research, short-cut decisions, but research remains the one sure way to develop a military training program which can (1) most efficiently bring personnel to the required levels of performance skill, (2) enable them to maintain this proficiency in the absence of direct experience with operating equipment, and (3) enable them to carry over these learned skills into the use of modified or new military equipment with a minimum sacrifice of accuracy.

The results of these training-equipment research projects should be stated in constructive and positive terms, namely, to point to specific ways of improving training by use of special devices, to discover ways of saving training time or money, or to increase levels of military proficiency. Further basic and applied research on transfer of training will improve the scientific basis for practical advances in all aspects of training, as well as in the design and utilization of special training equipment.

Robert B. Miller
Product Development Laboratory
International Business Machine Corp.

To come quickly to the point, I want to speak about man performing procedures in highly automated systems operations in highly complex environments. His roles will, because of automation, be largely confined to those of detector of emergency conditions and unprogrammed (or partially programmed) contingencies, and as take-over in the event of machine failure. His response may be a function of reinstatement of previously learned procedures, or in improvisations, or a combination of both. The possibilities for contingencies are enormous. Delays in perceiving and identifying a state of affairs are dangerous, and errors in selecting and executing a mode of response are likely to be fatal. Our idealized objective, therefore, is to provide a 100 per cent error-free human capability for a huge variety of only partly expected situations and situational contexts. (The problems of attitudes, motivations and emotional stress, although at least as serious as those of skills, I am choosing to disregard in this discussion.)

The first portion of this paper will discuss in turn the significance of "behavior models", some training concepts, techniques for rehearsal of infrequently practiced individual skills, and some human engineering provisions for such skills during actual performance. In addition, I hope to make some comments about skills in improvisation.

Models of Behavior for Training

At present training is largely a haphazard pouring of information, subject matter, and exercises into the student. To him is left the implicit task of ordering what he learns into the associative structures of his criterion task-skills. Consider now, however, the programmer of a computer who spends many hours (and sometimes months) in converting a problem statement into a set of computational objectives, in preparing general and detailed flow charts and finally in converting these into a detailed set of machine instructions. Contrast this procedure with the way we go about preparing and administering the content and organization of training—the programming of the human mechanism.

The large range of skills and knowledges required of the astronaut, and the reliability required of these skills and knowledges, prohibits the wasteful and risky methods of training with which we have been content.

The alternative is for the training officer and his staff to prepare a comprehensive and detailed set of task requirements in terms of cues, stimulus patterns and stimulus contexts which the astronaut must detect, recognize, and interpret, and to these cues specify appropriate responses and response patterns. Then, with the aid of a particular kind of psychologist, the training officer will prepare detailed behavior models of the information necessary and sufficient for performing the required tasks. He will include models of decision-making operations which I will have to leave described elsewhere. The training officer will also include the mnemonics—the recall aids and recall alternatives calculated to increase probability of recall even under unfavorable operational and psychological conditions. In short, he will construct a behavioral model of the required performance, and include even the internal imagery, conceptualization, and remembering structures for this performance.

Again with the aid of a very special kind of psychologist, he will rearrange the foregoing content into a pattern of sequences for most efficient learning with the same care that a surgeon removes and transplants living tissue. And the training officer will exercise the same care in avoiding irrelevance in training that the engineer, working in the microvolt range, exercises in avoiding the generation of electrical noise in an electronic circuit. He will undertake to program the human as carefully and as precisely (almost) as the computer expert programs a computer for an elaborate intelligence and information-retrieval system.

Our first, and perhaps major, resource in getting reliable performance will be the precision and knowledgeability of the training officer in designing the behavior model of the total assembly of task-skills required of the astronaut. Let me take this important occasion to be blunt. The principal obstacle to the acquisition and practice of this art is likely to be misguided motivations by the professional in training; to be blunter still, in human static inertia.

Reliability Through Redundant Habits

Now I would like to suggest some ways by which we can think about what I have called "behavioral models." I will start with some extremes. We can teach a man to troubleshoot a piece of equipment by teaching him the principles of operation of the equipment, its construction and the interactions of parts, and then let him deduce the implications of symptoms and work out for himself a logical search strategy for localizing to the malfunction. We do not program him for any specific contingency. He has maximum flexibility in coping with troubles, but perhaps questionable reliability in solving some particular trouble because of unscheduled recall routes. (A recall route, by the way, is the train of associations between the inciting work-stimulus and the task-response.) In contrast, we could lay out every symptom the equipment might possibly show, and specify a detailed procedure for localizing the trouble from any possible symptom. Here we could conceivably get high reliability for every anticipated trouble, but little flexibility in generalizing to unanticipated symptoms.

Let us not argue the relative merits of either of these training methods here. The examples were cited only to suggest that given task behaviors may be elicited by various behavior models, associative routes, and bodies of information that have been learned. (We would also have different job aids.)

I would like to offer three general modes for performing virtually any task. Within each mode there will be variations, of course.

Automatized Behavior. We can teach perceptual-motor behaviors in such a way as to make them "automatic." That is, they are performed without conscious mediation—without thinking. This is accomplished most readily by frequent and rapid repetition of the stimulus-response relationship. The steering of a vehicle by a skilled operator is largely of this character. The task supports, including the inciting stimulus and the operator's intention, are sufficient for the motor responses to be unreeled. Any procedural task can be automatized, or at least portions of it in the form of what computer people call "sub-routines." Fitts, George Miller, and others have mentioned this analogy. In the case both of overt verbal and various other muscle responses, the making of one response can be in itself practically the sufficient stimulus for making the next response in the series, and quite without conceptualization. We know some of the conditions for generating this habit mode. In operations it has both advantages and disadvantages which can be deduced from its nature; it is both stimulus-bound and response-bound. (I am sure that trains of conceptualization also become automatized in the sense that originally supporting mnemonic responses drop out.)

Verbalized Procedures. We may, through a proper training regimen, get overt responses to task stimuli by requiring the operator literally to verbalize the stimulus and the response, and requiring this verbalization to occur between the task stimulus and the overt task response. This is the way we all characteristically begin to learn a procedure anyway. In any event, we can require that the operator continue to be able to recall the procedure verbally as well as perform it in other modes (such as the automatic). These verbal habits, which act as surrogates of the overt stimulus-response, are then a redundant set of habits to the automatized habits. If the latter fail, they may be supported and instated by the former.

Conceptualization. This is indeed a general and perhaps somewhat abstruse category. An example of one kind of conceptualization would be imagery recall of the stimulus-response trains that make up a task procedure. Another example is the conceptualization, by imagery or other means, of the cause-effect relations between one stimulus and another in a task-environment, or between cause and effect in a sequence of events where a logical search strategy is required. Still another example is the conceptualization of process-linkages between a task-stimulus and the responses on controls that interact with that stimulus. An example here would be the imagery of the fuel-line linkages in an aircraft in order to redirect fuel flow in an emergency leak, and to do so without unbalancing the aircraft. In general, useful conceptualizations for task performance are likely to be made up of ideas of process-sequences and process-relationships.

This conceptual mode, although in many cases unreliable in itself for any specific occasion in guiding task behavior, can be a powerful mnemonic when learned in conjunction with one or more of the other modes of behavior, as cited above.

These are examples of how we can build redundant habit-systems not only for learning but for remembering what responses are required for what task situations. Within each mode we may devise variations, and apply them to any task, although probably with diminishing returns beyond two or three habit "overlays" for a given task. In any event, we should see that the diminishing-returns curve characteristic in relating practice to learning and recall applies to repetitive practice in the same mode of behavior; it need not apply when we superimpose modes of response. By this means we may bring training time for the total job within bounds, as well as obtain the gains in reliability of recall that we require. In engineering language, we are duplexing and triplexing the equipment for a function.

Apart from redundancy in habit structures, several other suggestions may be offered for reliability in performance. The operator is most likely to be at a loss for what to do at the first moments of being confronted by a situation which demands that he initiate a new order of activity. "Now what am I supposed to do here?" is the nature of the question. Once he has begun to put into effect some of the responses in a procedure he has once learned, the making of the responses themselves provides contest or "set," which increases the probability that subsequent responses (which have been interassociated during learning and previous practice) will be recalled. What are the words to the "Star-Spangled Banner?" Once one gets started on the first line, one can probably keep on going. This suggests that during training considerable practice should be given to recognizing and identifying cues that should initiate a task or sequence of tasks, and considerable overlearning of the beginning overt responses to the task-inciting cue. In other words, get a strong habit association between the title of the poem and the first line of the poem.

And just as a seasoned speaker or actor tends to overlearn—that is, "memorize cold"—the first paragraph of a speech or first few lines in a scene, the group of stimulus-response and response-response units which begin a task-sequence should be very highly practiced. One reason is that they do not have the associational support that responses later in the task-sequence have. Another reason is that the beginning responses in the task-sequence may have to compete with other stimuli and responses engaging the operator's attention.

Rehearsal of Skills

Some suggestions may be made about the effective use of exercising skills when they have been inactive for extended periods of time—days, weeks, or months as the case may be. If we go along with the idea of habit redundancy, we would want to insure that the student was capable in the various alternative habit modes intended to increase his reliability of performance. We would have to test for the exercise of these modes, even though only one mode might be sufficient for performing the task-requirements adequately. Fire hoses are tested even when not used for putting out a fire.

If the skill has grown rusty, we want to minimize relearning time and the risk of setting up habits incompatible with original learning. So we do our best to reinstate task-response context, urging the operator to perform at least his motor responses at the full operational speed of which he was capable at the last exercising.

We urge him to go full speed ahead, and disregard the errors on his first trial. In several trials he may be up to original speed and accuracy. Where he is not, special corrective practice may be given. The training alternative is to have him proceed slowly and carefully on trial one. This means he will be performing it in quite a different context of responses than that in which he performed when his skill was at its peak some months ago. By preventing these old interassociations from occurring, we may force the student largely to retrace his original learning steps. (This recommendation, by the way, is based on a logically derived hypothesis. It was tested by one subject in a piano-playing situation where a particular repertory had not been rehearsed for 15 years. So we should have more data on this one!)

Another recommendation for rehearsal practice of skills is that the full range of task-inciting cues likely to be encountered in operations be presented to the operator. This includes perceptual noise and time-shared tasks.

Human Engineering

The major range of human engineering effort is, of course, directed toward the reduction of human-error probability. I would like to add a few considerations to the conventional list.

Provide Mnemonic Aids for Cues that Initiate a Task-Requirement

In other words, provide cues of a symbolic or graphic nature that start the operator answering the question: "What do I do to this set of circumstances?" The inciting task-stimulus may be coded in such a way as to suggest the mode of response, especially where a safety measure must be taken preliminary to performing the rest of the task. The hammer dangling on a chain below the glassed-in-fire alarm switch is an example. The hammer is far more informative than a lever which might be turned in order to break the glass. Our purpose is to get the operator on the right track, which often consists in little more than getting him to make the first correct overt response in a response series.

Reduce the Need to Perform Task-Elements Solely from Self-Initiated Cues

The classic example of this failure is the pilot who flies a complete combat mission, successfully dropping his bombs on the target but forgetting to pull the arming wire on the bombs. He had to remember to do this "any time over enemy territory." This is a self-initiated cue, and is the most unreliable kind of cue, especially under stress. Better to routinize the act and tie it into some response that does have an environmental stimulus. Any response not required to be made to an overt stimulus is in a degree unreliable, and is less unreliable to the extent that it has to occur directly after the operator has perceived its stimulus. What was the submarine that was lost because someone forgot to close the intake hatches during submerging? The airplane lost because of someone forgetting to reset the altimeter scale when we had altimeter scales? The man who died because the cleaning woman forgot to remove a solution of cyanide cleaning fluid from the operating room and it got pumped into his veins instead of a stimulant? The letter in the pocket that doesn't get mailed? And so forth.

There is a psychological parallel to this principle. Avoid the requirement of important responses that follow what the operator perceives as the consummatory response in the task-cycle. Some housewives chronically forget to turn off the burner on the stove after removing the pan and its heated contents. The habit should be: turn off the burner, then remove the pan. The driver in a hurry to get to a destination is relatively likely to forget pulling up his parking brake unless the habit is highly automatized with associated responses. If one turns on his lights during the daytime (such as when driving through fog or through a tunnel), there is a substantial probability of getting out of the car at the end of the trip and forgetting to turn off the lights. In this case there is, of course, absence of the dramatic cues associated with headlights on in the darkness. But I am sure we could find instances where this tendency to forget immediately about additional task-requirements after the "consummatory response" is made can have fatal rather than trivial consequences. Neglecting to secure an air lock after returning from an adventurous foray from the space craft is one example.

Short-Term Memory Aids

By "short" I refer to the retention of pieces of information during a task-cycle or some portion of it. Your responding to this sentence as a single pattern of thought requires that you retain some impression of the individual words until I have completed the sentence. Problem-solving and decision-making inevitably require this human buffering capability. The human being is remarkably successful with short-term storage of what is to him "meaningful" information, which means that it is likely to be highly redundant to previously experienced messages. But with highly symbolic data—such as digits in a telephone number, for example—where redundancy is low and a pattern is not cumulative, the human has rather severe limitations. He is better off when he can make "notes" for himself, so he will not forget. Provision for simplifying short-term memory requirements in critical tasks will materially increase reliability of such performances. Moreover, assistance may be provided by attention to task design, training, and human engineering of the task-environment.

Long-Term Retention

This refers to what is hoped to be permanent retention of the information which constitutes knowledges and procedural abilities. Despite our ingenuity in task-design and in training, there are limits to how much can be reliably learned in short periods of time and retained over long periods of time. Ready access to externally stored information is desirable. Books, charts, maps, tables ordinarily require extensive search for which time may not be available, and for any particular task-occasion information on paper has too much "irrelevance and noise" that "clutter" the finding and assimilation of the information being sought.

We need, therefore, to develop machine capability for storing, abstracting, selecting, sorting, compiling, and displaying information on command in milli-seconds. High-density storage and efficient methods of machine-processing will be reducing weight and space requirements in relatively few years, we hope. We have to learn how this information should be indexed so as to be compatible with the operator's learning and using the indexing arrangement. This is indeed a challenging task for those interested in man-machine interface problems, but a pressing one for the traveller who will be far from the Library of Congress and who will not have time to pore through even the Encyclopedia Britannica on how to restore a disturbed hydroponic balance in his ship. This problem is all the more fascinating since information retrieval is quite continuous with the concept of automated teaching. And with this thought we come full circle to another solution of the problem of training for reliability.

In summary of these highly condensed observations, I have proposed that concentrated effort be spent on the preparation of detailed behavior models of performance requirements for the Astronaut's job, and on carefully translating these behavior models into training content and organization, taking care to avoid irrelevance to clutter and dilute the effectiveness of learning and recall. I have particularly emphasized the importance of redundant habit modes—alternative recall routes to task performance from the inciting task-stimulus. Some of these modes of habit have been rather clumsily called automated response, verbalized procedures and conceptualization of mechanisms and processes. Some informal human-engineering suggestions have been made about the special problems of remembering self-initiated cues, the limitations of short-term memory, and a recommendation that we attend to the possibilities of mechanical information storage and retrieval for use in-flight and on-location.

I cannot say that I have said very much new in this presentation. I have disinterred some old reports from my archives of the past decade and summarized their contents. For your interest, I have immodestly prepared a list of some of them.

I see that time does not permit discussion of training for improvisation and invention. Perhaps we can discuss this relevant but contentious topic on another occasion.

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Joseph M. Notterman
Department of Psychology
Princeton University

I would like to begin by saying that I have been very much impressed by the tremendous job that has been done by the people who have been involved in the X-15, the Mercury, and now the Dyna-Soar. I feel somewhat uncomfortable about making a critique and recommendations when I really am so impressed with the very competent job done by these people. This is a feeling which I am sure other members of the consultant group share.

There are two impressions I have concerning the training of Astronauts which are not in the way of recommendations, and certainly not in the way of critique, but are characteristics of the situation which have, as far as I can see, influenced much of what I've heard here yesterday and today. I think, first of all, we must recognize that, in a sense, the training problem that we are facing is an easy one; because the astronauts are on a full-time basis and under full-time supervision. We are not dealing with urgencies dictated by maintaining a daily schedule of training and we are not dealing with large numbers of trainees, at least at present. From what I have seen and heard, we will have well-trained astronauts. We may perhaps, be, inefficient in our approach to astronaut training; but this is relatively a trivial consideration in view of the fact that we do have them on a full-time basis and that they are under full-time supervision. We may feel some professional repugnance at the thought of inefficiencies creeping into a training program, but I believe that in a sense, perhaps we are gilding the training lily a bit in some of the things we have been concerned about around this table. On the other hand, the fact that we're "able to be inefficient" in these preliminary ventures should not mislead us. We must bear in mind that some day we will not have this luxury—that we will be dealing with larger numbers of trainees. Such criticisms as I've heard today are addressed to the future programs, really; to the fact that eventually we do have to become much more efficient than we have been. By that time, let us hope, we'll have learned some lessons from the present program.

The second characteristic that I think runs through the discussion and is background to the training problem is the fact that the training of these astronauts, of necessity, has to go hand in hand with the development of the actual gear. Many of the niceties I have heard and much of the finger-wagging I have seen is again addressed to future systems. The people who have been working on the X-15 and Mercury capsule undoubtedly are very much aware of the fact that one should plan ahead in the development of training devices, and not wait until a vehicle is completed or half-way completed before coming along with the consideration of training devices. But they can't help themselves.

Having made these two general comments, let me join the others of the group and get a little "picky." First, I think we need to distinguish more carefully between those simulators which are used for joint development and training and those which are used for training alone. This is more than a semantics problem. It is possible, as you all know, that you might want to include stimulus cues in a training device which do not exist in the real situation, merely to help the trainee learn a response that much sooner. Training devices exist which have these features. There are also problems of knowledge of results which are inherent in the training device; i.e., you want to have knowledge of results in the training device which perhaps does not exist in the actual situation, or which, in real life, comes to the operator only after—long after—the given response has been made. Therefore, we cannot say, "Well, it's more efficient always to use the same simulator both for engineering development and for training." Specific consideration must be given to the training device as a training device. Again, this is directed toward future development.

The second point I want to make is that we must begin to systematize the content of the training program. Up to now, this has been difficult. This has been touched upon, I think, by everyone. How much engineering detail or how much calculus do the astronauts really require? Shouldn't we emphasize—and I think Dr. Voas made this point yesterday—shouldn't we emphasize the functional rather than the textbook or hardware-oriented relation between the error cue and the corrective action?

The third point—we should go easy with the automatic programming approach. I will yield to no one in my enthusiasm for teaching machines, but are we ready in the astronaut training project for the kind of programming which a teaching machine requires? This touches on the problem of flexibility, a point that was mentioned yesterday in connection with training of ground crews and astronauts in the communications area.

The fourth point—concerns the time lag between the development of a training procedure and the development of the hardware. If we are to take advantage of the lessons we have learned from the X-15 and the Mercury in the development of Dyna-Soar and future vehicles, then it becomes clear, of course, that psychologists must participate in the original, or initial, engineering design. Everyone knows this; it's just a case of making sure that we have the appropriate administrative details worked out to accomplish it. Parenthetically, I wonder how much of the Dyna-Soar training program that we heard yesterday, which is hypothetical at the moment, has been discussed in detail with the training people who had experience in the X-15 and in the Project Mercury? I'm sure there have been exchanges of opinion, but this can't be on a casual basis. I think there must be continuing monitoring of the earlier programs.

The fifth point—I think that psychologists interested in the training of astronauts should help to formulate the animal research program which I understand is currently underway at Holloman. Perhaps they do; I don't know that such participation has been invited or offered. There are many problems in transfer of training (for example, the question of whether acceleration experience is important, the question of retention of skills under conditions of inactivity and of long duration of weightlessness) which can be at least partially, if not completely, answered by judicious experimental design in the animal realm. Again, this might be merely an administrative matter. This is a case of maintaining a well-developed channel of communication with those doing the animal work, and participating with them in the design of experiments.

And, finally, although I agree with Jack Adams concerning the need for a full-scale mission trainer, it is also true that there is another end to the continuum. I think that we must not lose sight of the part-task trainer. Again this is something we all know, but in our tendency to reach out for more and more complex simulation, the tendency to see an impressive piece of hardware built for psychologists by engineers, we tend to forget that our transfer of training experiments tell us to go easy here—that sometimes you can get quite a bit out of a gadget that costs you relatively little. I think that, in terms of economy of time as well as economy of money, it would certainly pay to try to do things first with part-task trainers and then see if you have to go over to the "hi-fi" type of simulation.

SECTION III

Recommendations of the Working Group on Training of Astronauts

Recommendations

The following recommendations were formulated by the Working Group on Training of Astronauts at the conclusion of the conference. They were approved by the Panel on Psychology at a meeting on 31 August 1960.

1. Early Emphasis on Training and Training Equipment During System Development

In order to assure the timely development of a satisfactory space-crew training program, it is mandatory that the importance of training devices and training data be recognized early and that provisions be made for their development as an integral part of the space systems. It is recommended that government requests for proposals on space systems and resultant contracts require the contractor to plan, design, and develop necessary training equipment, and to produce other data necessary for training. It is further recommended that the responsible government agency have human-factors personnel to assist in the evaluation and monitorship of these aspects of system design and development, and that their judgments be reflected both in contractor selection and in contract monitorship.

2. Feedback from Current Space-Flight Programs to Training Programs of Future Systems

The training experience being obtained from on-going manned space-flight programs should be systematically collected and made available to personnel responsible for future training programs. In addition, this information should have an impact on vehicle design and personnel selection in future manned space efforts. Specifically, information in the following areas would be of value: (a) the methods used and the problems encountered in defining the astronauts' task for training purposes, (b) changes in training program or hardware due to training experience or vehicle modifications, and (c) the relative effectiveness of the various phases of the training program.

3. Research on Importance of Including Environmental Conditions in Simulation for Training

Research should be undertaken using existing facilities in order to help determine the extent to which unusual environmental conditions (e.g., vibration, acceleration) must be incorporated into training equipment in order to produce high transfer of training to performance in actual space flight.

4. Training Requirements for In-Flight Maintenance

Studies should be undertaken to identify the in-flight maintenance training requirements for space vehicle systems of the 1965-1975 period. Such studies should take into account expected changes in the state-of-the-art with respect to replaceable modules, auto-fault location, self-repair, improvised repair, etc. Consideration should also be given to the implications of the environmental conditions under which in-flight maintenance tasks have to be performed. Special attention should be given to the use of job aids to support the required human performance.

5. Reduction of Anxiety Reactions Through Training

One of the goals of a program to train space crew personnel should be the reduction of emotional anxiety reactions that might impair performance in space vehicles. Studies should be undertaken to identify (a) conditions that evoke emotional responses and (b) techniques for habituating or reducing their anxiety-provoking potentialities.

6. Distinction Between Simulators for Developmental and Training Purposes

During the planning phases of a program, the procurement of simulation devices for both training and development purposes should be considered. This distinction in function must be recognized since, in many cases, separate devices will be required because of different complexity requirements and availability needs. However, even when such separation is desirable, the training simulator may have uses as a developmental tool, particularly in the procedures and operational concept area and as a final check on human engineering. In addition, the developmental device may be useful for some training purposes with little alteration in characteristics, as in the case of the Mercury Environmental System "Trainer."

7. Large Dynamic Simulation Facility for Training

A large dynamic simulator, capable of combining acceleration with a variety of other environmental stresses, is being discussed by numerous groups in DOD and NASA as a possible national facility. Included in this facility would be computers to provide closed-loop simulation of space-vehicle operators' flight tasks. In addition to its usefulness for various types of human factors testing and research, such a facility would also have great value for (a) training future astronauts in their duties under the stresses of space flight; and (b) for research on problems associated with such training. It is essential that this facility, if built, include those features which are required for most effective training simulation.

8. Performance Measurements During Preparatory Training and In-Space Flight

In order to evaluate the effects of space flight upon performance, it is mandatory that adequate and complete human performance data at all significant stages of the mission profile be gathered, evaluated, and published. Specifically, this includes the ability to compare simulated mission performance with actual human performance in space flight. It is recommended that vigorous attempts be made to collect such data systematically in all current and planned manned space-flight programs.

APPENDIX

Conference Participants

Members of the Panel on Psychology

Dr. Walter F. Grether, Wright Air Development Division
Dr. Gordon A. Eckstrand, Wright Air Development Division
Dr. William Bevan, Kansas State University
Dr. John L. Brown, University of Pennsylvania
Dr. Abraham Carp, Wright Air Development Division
Dr. George T. Hauty, Federal Aviation Agency
Dr. George E. Ruff, University of Pennsylvania
Mr. John W. Senders, Minneapolis-Honeywell Corporation
Dr. Richard Trumbull, Office of Naval Research

Invited Scientists

Dr. Jack A. Adams, University of Illinois
Dr. Judson S. Brown, University of Florida
Dr. Stanford C. Ericksen, Vanderbilt University
Dr. Robert B. Miller, International Business Machines
Dr. Joseph M. Notterman, Princeton University

Technical Participants

Mr. Richard E. Day, National Aeronautics and Space Administration
Dr. Edward Jones, McDonnell Aircraft
Dr. Marty R. Rockway, Wright Air Development Division
Lt. Col. Burt Rowen, Air Force Flight Test Center
Dr. Robert Voas, National Aeronautics and Space Administration

Guests of the Panel on Psychology

Dr. Glen Finch, National Academy of Sciences
Dr. Henry Imns, U. S. Naval School of Aviation Medicine
Mr. Ray Stout, Wright Air Development Division