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**INFLIGHT MAINTENANCE OF CREW SKILLS ON LONG DURATION
MANNED MISSIONS**

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ABSTRACT

Manned planetary and Earth orbital missions of the 1970's and 1980's will be long, on the order of one to three years. During this interval, it is probable that the spacecrew will suffer some loss of proficiency, through disuse, in certain skills critical to their safety or to the success of the mission. Inflight training procedures are therefore likely to be needed to moderate or prevent such skill degradation.

Simulation of some space skills, and aircraft pilot regulations for analogous skills, indicate that a significant decay in proficiency may occur if complex skills are not used for intervals of three to six months or more. On typical missions, periods of this duration elapse between the end of preflight training and the performance of critical tasks like Earth entry and landing, the conduct of certain experiments, and planetary landing.

Inflight training, if necessary to maintain skills in the performance of these tasks, will probably use the onboard computer system to simulate vehicles and their environments and responses, to drive displays, and to score results. Ideally, the displays and controls used for an actual mission activity would also be used in a simulation mode to train for that activity. If these facilities are unavailable by edict or by operational constraints, other facilities would need to be provided for training.

In addition to their primary purpose, inflight training facilities could be used to modify existing skills or to help the astronauts acquire new ones to handle contingencies that might occur in the course of the mission. The facilities could also be used to conduct behavioral research.

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Abstract (Contd.)

Skills for the tasks likely to require training should be defined in greater detail. To test the hypothesis of skill degradation, it is recommended that certain former Gemini astronauts be tested in Gemini simulators to measure how their prior skills have deteriorated. Preparations should also be made to perform similar tests in Apollo. Other tests should be conducted to determine the effectiveness and proper utilization of simulators in inflight training. Skill degradation, particularly for Earth entry tasks, should be carefully monitored throughout the AAP program. Tests of inflight training facilities should be conducted in AAP and later Earth-orbit missions. Because these tests require a long time and because their results could have a significant effect on spacecraft design, they should be started at once.

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SUBJECT: Inflight Maintenance of Crew Skills
on Long-Duration Manned Missions
Case 103

DATE: July 30, 1968
FROM: J. R. Birkemeier
TM-68-1031-2

TECHNICAL MEMORANDUM

1.0 INTRODUCTION

Manned missions during the 1970's and 1980's will be much longer than previous ones. Missions to Mars or Venus, for example, will typically require about two years. Earth orbital missions may last from one to five years, or even be open ended. This duration is two orders of magnitude longer than an Apollo lunar landing mission and is a major factor in system design.

The long duration of these missions raises the likelihood that the spacecrew will experience some decline in proficiency, through disuse, in certain skills that are critical to their survival or to the success of the mission. Interference arising from the practice of competing skills may also cause some loss of proficiency. However, as was suggested by Gruman and Schaenman in 1966,⁽¹⁾ it may be possible to use inflight training procedures to slow down or even prevent skill degradation.

This report considers several types of long-duration manned missions: extended Earth orbit, extended lunar landing, Mars and Venus flyby, Mars landing, and combination flyby and landing. The tasks that may require inflight training are determined for each mission type. Alternative methods of providing the facilities to implement this training are then described.

At this time, it is not possible to identify all the crew tasks that will be performed on these missions, nor to determine precisely which skills will be critical or how one skill may interfere with another. Furthermore, it is not definitely known how postulated skills will degrade over long periods of time. However, the author believes that a serious problem exists in this area and bases this report on such an assumption. Several experiments are proposed later to help resolve these issues.

2.0 SKILLS THAT MAY REQUIRE INFLIGHT MAINTENANCE

2.1 Criteria for Selection

The crew tasks involving skills which are most likely to require inflight maintenance can be selected on the basis of four general criteria:

1. they are critical to the safety of the crew or to the success of the mission,
2. they are performed under tight time constraints,
3. they are performed at intervals at least several months in length, and
4. they are not trivial.

The first criterion selects those tasks that, if poorly performed, could result in loss of life, damage to the spacecraft, or excessive expenditure of scarce resources like propellant or unmanned probes. The second criterion eliminates tasks that can be checked out carefully before and after each intermediate step. The third criterion eliminates tasks that are repeated frequently enough to maintain proficiency. The fourth criterion eliminates tasks like a single push of a button or flick of a switch if, although critical to the mission, they are not imbedded in a more complex task such as selecting the right switch from many possible ones for each of a sequence of switching functions.

2.1.1 Skill Degradation with Time

The third criterion is crucial to the studies covered in this report and warrants further discussion.

Prior to a mission, the crew receives intensive training for all phases of the mission and for various contingencies. When the duration of the mission is two weeks or less, skills acquired during training can apparently be retained without significant degradation; at least no such degradation was noted on the longest mission to date, Gemini VII, which lasted 14 days.⁽²⁾ Apollo lunar landing missions will be somewhat shorter in duration, and no requirement for inflight crew training has been defined. Simulation studies performed by Grodsky and his associates at Martin have indeed demonstrated that no significant decay in crew performance need be expected on these missions.⁽³⁾

With the Apollo Applications Program (AAP), longer flights come into the picture. Some of the early AAP missions may last up to two months. Studies reported by Cotterman and Wood indicate that intervals of two or three months may pose problems in skill retention.⁽⁴⁾ Pilots with whom the matter has been discussed have generally concurred in this conclusion. The opinion often expressed is that a significant decay in proficiency may occur during the period from three to six months after a task was last performed.

Some analogies to spacecrew activities can be found in aircraft piloting tasks. In a Vought study, a carrier landing was found to be the most difficult phase of a tactical mission in a high-performance aircraft.⁽⁵⁾ Controlling a spacecraft to a safe landing on the Earth or Mars can be similar in complexity and skill requirements to a carrier landing. To be qualified in a series of high-performance aircraft, a Navy pilot must have flown in the series for at least five hours during the last three months or ten hours during the last six months.⁽⁶⁾ The FAA has imposed a similar restriction on commercial airline pilots, to the effect that a pilot who has not flown for a period of 90 days or more must requalify by making five takeoffs and landings before he may command a passenger flight.⁽⁷⁾

Thus, there is considerable, although indirect, evidence that complex flight skills may deteriorate when they have not been used for periods of three to six months.

2.2 Skills Selected for Inflight Maintenance

With the above four criteria as guidelines, various manned missions have been examined to identify those skills for which inflight training may be required to maintain a satisfactory level of proficiency. These missions are intended to be typical, rather than exhaustive, of those expected to be flown in the 1970's and 1980's. Figure 1 presents timelines for the missions. The time scale shown in this figure is intended to be only representative and should not be interpreted too precisely.

The following paragraphs describe the missions briefly and discuss the crew tasks that they involve.

2.2.1 Extended Earth Orbit Mission

A laboratory with an operating lifetime of one year or more is placed into orbit around the Earth. A team of astronauts occupies the laboratory for several months at a time. During this period, they make observations and conduct experiments in various areas such as astronomy, medicine, behavioral sciences, geology, and Earth resources. In the course of subsequent revisit flights, some crew members return to Earth, while others remain in the laboratory.

Although booster functions during launch are normally performed automatically, the crew monitors the operations and initiates an abort if necessary. On revisit flights, rendezvous

and docking with the orbiting laboratory may involve crew participation, especially in the final maneuvers. However, all these functions would be completed during the first or second day of a flight, and skill degradation would not be likely to occur.

The crew tasks during most of the mission would be associated with the conduct of experiments. Many features of Earth orbital missions tend to minimize the problems that may result from a decay of crew proficiency in performing these tasks. The orbit of the laboratory remains relatively fixed. Consequently, repeated views are possible and additional observations or measurements of terrestrial or celestial features can be made at later times. The repetition of tasks in the course of the mission serves as a kind of training procedure in itself. Frequent and reliable wideband communication with the ground is also available to monitor the crew and advise them on the quality of performance of their tasks. Finally, crew rotations accomplished by revisit flights could insure that at least some members had undergone recent training. Therefore, unless an experiment involving unique skills is deferred until sometime long after launch, no requirement to maintain skills for performance of experiments is foreseen.

Flight-related tasks, such as controlling the attitude of the space station and adjusting its orbital parameters, would be performed frequently and, generally, without great stress. Therefore, these tasks are not likely to require in-flight training.

Earth entry, however, constitutes a potential problem area. The skills needed to control the spacecraft during entry would not be used until the end of a revisit mission, which would probably occur three months or more after launch of the revisit spacecraft. In a low-lift vehicle like Gemini or Apollo, crew tasks involve holding the attitude of the spacecraft until sufficient aerodynamic forces build-up, then controlling roll through a period of high deceleration. Although these functions would normally be performed by automatic systems, the crew must continuously monitor displays of attitude, altitude, velocity, deceleration, and temperature, and must assume control in the event of known or suspected failure of the automatic systems. Later, parachutes and floatation bags must be deployed at the proper times. Even if the control panels in the entry vehicle are similar to those installed in the space station, the entire set of displays needed for entry would not ordinarily have been used before entry. Furthermore, time constraints are more critical during entry than in orbit. Some latitude in the initiation of entry maneuvers exists, and the constant proximity of the Earth allows the mission to be

terminated prematurely if trouble develops. Nevertheless, the factors cited above make Earth entry a very crucial mission phase. If revisit flights occur at regular intervals of about three months, a marginal requirement may exist to provide in-flight training for entry. However, if the interval between successive flights is doubled to obtain longer-duration data, it is much more likely that entry training would become necessary, particularly on the later flights. In either case, the problem could become more serious if multiple launches were used to place the space station into Earth orbit and if the first crew members required several weeks to assemble and check out the modules before they could begin the mission experiments.

2.2.2 Extended Lunar Landing Mission

This mission is similar to the Apollo lunar landing mission. The chief difference of concern here is the longer time spent by the crew on the surface of the moon. A station is set up on the moon and manned for several months at a time. Extensive explorations, tests, and experiments are conducted during this period. When the time comes to leave, the astronauts ascend and rendezvous with an orbiting spacecraft, then return to Earth.

As on an Apollo mission, lunar landing occurs about three days after launch. No skill degradation should be expected during this interval. Therefore, no inflight training need be provided for tasks performed during launch, translunar injection, midcourse, lunar orbit, and lunar descent phases of the mission. Activities of the astronauts on the surface of the moon will probably involve a repeated use of skills. Furthermore, tight time constraints will ordinarily be absent in the performance of these tasks. Therefore, post-launch training for experiment-related skills need not be provided.

Ascent from the lunar surface and rendezvous and docking with the orbiting spacecraft for return to Earth may pose problems in skill retention. On typical missions, periods of two or three months would have elapsed since Earth launch. Therefore a requirement may exist to provide training for the tasks leading up to Earth return.

During the trans-Earth phase of the mission, one or more midcourse corrections would be made. In carrying out these corrections, the astronauts would normally have ample time to verify that the spacecraft is in the proper attitude before applying thrust. Studies being conducted by D. A. Corey⁽⁸⁾ in

Bellcomm show that if the last midcourse correction, which is the most critical in this regard, is accidentally delayed as much as fifteen minutes, the spacecraft is able to enter satisfactorily and land close to its intended destination in most cases. After the correction had been applied, the crew could also monitor the trajectory of the spacecraft to insure its agreement with the intended path. Since time constraints are not severe, midcourse corrections would not be likely to require inflight training.

Because the speed is much greater and the conditions of initial atmospheric encounter are more stringent, Earth entry is a more crucial phase on a lunar mission than on an Earth orbital mission. While many of the control functions required to penetrate the entry corridor can be performed automatically, some involvement of the crew, at least in a back-up capacity, can be expected. Furthermore, if a high-lift entry or landing vehicle is used, manual control would be used during the final phases of approach and touchdown. Lunar missions of two or three months duration, therefore, may require inflight training for Earth entry, and the seriousness of the requirement should increase greatly with longer missions.

2.2.3 Mars Flyby Mission

Several launches may be necessary to deliver all the spacecraft modules to Earth orbit. Over a period of time, typically a month or two, the various modules are assembled and checked out, and the spacecraft is then injected toward Mars. Experimentation is done en route in a variety of space sciences. Prior to encounter, which occurs about four months after Earth departure, the crew members check out, launch, monitor, track, guide, and control unmanned probes to gather data and surface samples. They also carry out observations and measurements of the planet and photograph it as they pass it at close range. During the return to Earth, the crew analyzes the data and samples gathered during the flyby phase. In addition, experiments in various space sciences are conducted.

The assembly and checkout of the spacecraft modules in Earth orbit may be performed by a special crew. The mission crew could then train on the ground until shortly before Earth departure. However, if the mission crew is also required to assemble and check out the spacecraft modules, an additional month or two must be included in the interval between preflight training and the performance of a mission task. Skill degradation might then be more of a problem than if a separate crew had been used for Earth orbital tasks.

Midcourse corrections applied long before encounter are not likely to impose heavily on the crew. The exact time at which firing begins is generally not critical, and the astronaut has ample opportunity to check his actions before and after applying thrust. Special inflight training would therefore not be necessary.

The last correction on the way to Mars, however, may pose some problems. This correction may be delayed until near encounter, especially if a low-altitude pass is planned. It may also be performed differently from the earlier ones; for example, landmarks on Mars may be used as reference points to determine the precise adjustment needed. Furthermore, this correction may be applied in the midst of other activities. However, even with these additional considerations, the final correction would probably not require more complex flight skills than the earlier ones, and would be similarly free of tight time constraints. Therefore, inflight training procedures for these operations would not be necessary.

The planetary encounter phase of the mission, which begins a week or two before the spacecraft passes the planet and continues for a similar interval afterwards, is a period of high crew activity that is likely to pose several problems in skill maintenance. Human errors during encounter could prevent the mission from achieving its major objectives. This is especially true during the few seconds or minutes available for the highest-resolution measurements at periapsis. Landmark sightings would be used to update the navigation data. Unexpected features of the planet may be observed and may result in some deviations from the planned program of tasks. For all these activities, the crew would require inflight training procedures to preserve their familiarity with the various data that they might receive and to retain their ability to evaluate the data and make decisions with regard to the conduct of the mission.

The unmanned probes launched during encounter involve another group of critical crew tasks. These probes would perform specialized tasks such as photographing the planet from orbit, measuring atmospheric characteristics during entry, conducting geophysical analysis on the surface, or returning surface samples to be taken back to Earth in the spacecraft. In the conduct of these operations, the manned spacecraft serves as a mobile launch complex and provides the functions of a mission control center. The crew checks out and, if necessary, repairs the probes, aligns the inertial platforms, and inserts attitude and velocity change data and commands into the probe memories. It is especially imperative that these tasks be performed correctly, since errors in launch or trajectory conditions

may endanger the spacecraft and its crew. After the probes have separated from the spacecraft, the crew tracks them optically and by radar, issues midcourse corrections if necessary, and monitors received data to ascertain the proper operations of the various probe subsystems. Photographs and other data transmitted from the first probes are studied and may be used to alter the intended missions of the probes. Commands are sent to the probes to cause them to deboost into orbit or descend to the planetary surface. The sample return vehicle must be directed to lift off the planet and rendezvous and dock with the spacecraft. The samples themselves must be analyzed quickly to determine if life forms are present. Inflight training will probably be required to maintain proficiency in the performance of these tasks. However, since these activities occur four months after Earth departure, the need for inflight training is not as firm as it would be if a longer interval elapsed.

Earth entry occurs almost two years after Earth departure. Because the approach velocity is higher, the trajectory constraints for Earth entry are more critical on a planetary mission than on a lunar mission. Therefore, inflight training to maintain entry flight skills is even more likely to be required than it would be on a lunar or Earth orbital mission.

2.2.4 Venus Flyby Mission

The Venus flyby is similar to the Mars flyby. The spacecraft passes Venus up to a month earlier than it would Mars, and the entire mission requires about 13 months, against nearly two years for a Mars flyby mission. Variation in probe design and operation and in observation and measurement objectives and techniques would also be expected, because of differences in surface and atmospheric conditions for Venus and Mars.

In general, the flight skills and their inflight training requirements would be about the same as for the Mars flyby mission. The experiment tasks and their training requirements would be grossly similar in that they would involve experiments conducted during midcourse phases, and remote sensing experiments and unmanned probe activities carried out at encounter. The detailed skills, however, may have significant differences. Greater emphasis would be placed on targets of opportunity that might be observed through breaks in the clouds or televised from probes beneath the cloud layer. Samples may be returned from the atmosphere rather than the surface. High temperatures may impose further constraints by limiting the operational lifetime of a landing or low-atmosphere probe. These factors could influence the importance that was attached to retaining proficiency in various skills.

2.2.5 Triple Flyby Mission

This mission starts as a Venus flyby. Instead of returning to Earth directly, the spacecraft passes Mars, then flies by Venus again. Crew functions would be essentially the same as on Venus and Mars flyby missions, but much longer time intervals would be associated with the performance of some tasks. The first Venus flyby occurs about five months after Earth departure. The Mars flyby occurs at least six months after the first Venus flyby, and the second Venus flyby occurs at least four months after the Mars flyby. Earth entry takes place at least four months after the second Venus flyby.

Actually, the minimum times quoted here would not pertain together to any one mission; Earth entry, for example, would not occur until at least two years after Earth departure. All these minimum intervals, however, are of such length that skill degradation may be expected, even for those tasks performed during every flyby phase. Furthermore, the previous section showed that similarity of function does not always imply similarity of required skills. Therefore, whatever inflight training is deemed necessary on the single flyby missions would be even more necessary on the triple flyby because of the longer times involved.

2.2.6 Mars Landing Mission

The Earth departure and interplanetary phases are essentially the same as on a Mars flyby mission, while the operations in the vicinity of Mars resemble those on the Apollo lunar landing mission. Part of the crew remains in the spacecraft in orbit around Mars. Other crew members descend to the planetary surface to conduct explorations, tests, and experiments. About one month later, they ascend and rendezvous with the orbiting spacecraft for the return trip to Earth. As in the case of the planetary flyby missions, a considerable amount of experimentation in various space sciences is carried out en-route to Mars and to Earth.

The landing on Mars is a highly critical phase of the mission. The landing itself is very similar to an Apollo lunar landing, with the crew directly controlling the vehicle during the final portions of flight. Significant differences also exist, however. Aerodynamic forces may be used to decelerate the vehicle as it enters the atmosphere and may also affect the performance of the vehicle during landing. Furthermore, the Martian terrain will probably be less well known than the lunar landing sites. The stranger environment would require that a

Mars landing mission be prepared to handle a wider range of contingencies. Inflight training would probably be required for the flight skills involved in descent and landing on the surface of Mars, and ascent and rendezvous with the orbiting spacecraft. The fact that these events occur five to seven months after Earth departure strengthens the necessity of training for them during the missions.

Earth entry does not take place until at least 14 months after Earth departure. As in the case of the flyby missions, this is a sufficient time interval to allow significant decay in crew skills to occur if inflight training is not provided.

2.2.7 Venus Flyby and Mars Landing

This mission starts as a simple Venus flyby. Instead of returning directly to Earth, the spacecraft goes to Mars, where it enters an orbit around the planet. Landing and subsequent activities, similar to those done on a direct landing mission, are conducted.

Venus flyby occurs five or six months after Earth departure. Mars landing takes place five or six months after Venus flyby. Earth entry occurs about a year and a half after Earth departure. All these time intervals are sufficiently long to arouse concern for skill retention and to warrant inflight training to maintain crew proficiency.

It is possible to reverse the order of the flyby and landing phases of this mission; for example, a Venus flyby may be employed on the return phase of a Mars landing mission, since it allows a lower Earth entry velocity than does a direct return from Mars. Conducting the flyby before the landing, however, has the advantage of using the unmanned probes when passing Venus, so that their mass does not need to be decelerated into Mars orbit and subsequently accelerated for departure from Mars. But in this case the Mars landing, which involves the most difficult and critical skills in the entire mission, is performed about six months later (nearly a year after Earth departure) and degradation of these skills is more likely to occur if inflight training procedures are not adopted.

2.2.8 Summary of Mission-Related Skills

In summary, it is possible to enumerate several areas that may require inflight training to preserve skills related to the flight of the spacecraft or the conduct of experiments on long-duration manned missions. These areas are presented in

Table 1 for the seven missions discussed above. Based on considerations of task complexity and the interval between performances of a task, the firmness of the requirements for inflight training is also indicated. More detailed skill analyses for those mission operations listed in Table 1 as possibly or probably requiring maintenance should be undertaken at an early stage to determine what influence they may have on spacecraft design or operating procedure.

2.2.9 Other Skills

On all space missions, the astronauts must be able to respond correctly to emergency situations like fires, meteoroid punctures, and malfunctions in the life support systems. In Earth orbit, abandonment of the laboratory and boarding of escape vehicles must also be considered. Events of this type are generally recognized as potential hazards and procedures to handle them are already planned into missions. "Fire drills" for various kinds of emergency would be conducted on all missions, and could even be combined on occasion with the inflight training for the tasks mentioned above.

3.0 SKILL MAINTENANCE PROCEDURES

Most skills to be maintained during a mission would not require special training facilities. The crew members could preserve some degree of proficiency simply by reading instruction manuals, watching training films, studying the controls and displays, and reviewing specific procedures. Furthermore, those skills that are needed frequently in the course of a mission would probably not require special equipment for training.

In general, the tasks cited in the previous section as being likely to require inflight training involve complex skills that could not be maintained by bookwork alone. Actually practicing the tasks involving these skills is the best way to retain proficiency but may be too expensive or even impossible. For example, firing a high-thrust rocket or operating the reaction control system for training purposes may consume a prohibitive amount of propellant, both to carry out the training exercise and to correct the spacecraft attitude and trajectory afterwards. Furthermore, although an aircraft pilot can make realistic practice landings on cloud banks, no analogous opportunity exists for an astronaut wishing to practice Mars landing or an Earth entry while he is in space. Therefore, some alternative training means is necessary.

3.1 Use of Simulators

Simulators have been successful in training crews to perform complex tasks.⁽⁹⁾ Full mission simulators duplicate as closely as practical the situations and environment that may be experienced on the actual flight, and are the next best thing to actual flight practice. The effectiveness of simulator training was demonstrated quite clearly during the Gemini program, and the discrepancies between the simulations and actual spacecraft systems had no noticeable effect on orbital performance.⁽²⁾ The Apollo program is also making extensive use of simulations of the Command Module and the Lunar Module to train the astronauts in all phases of the mission, and a similar demonstration of the effectiveness of this training when the actual flights occur may well be anticipated. Moreover, commercial airlines, facing increased operating costs and a shortage of qualified instructors, are shifting more training operations from flight to simulation.⁽¹⁰⁾ With these precedents well established, it appears desirable to consider simulators in more detail to determine their possible application to inflight training.

3.1.1 General Simulator Characteristics

The basic functions of the spaceborne simulator would be similar to those of the ground-based simulator, and would center on a control station with computer-driven displays. In most ground-based simulators, however, weight, size, and power are secondary considerations, while these factors would be far more critical in a spaceborne simulator.

One particular difficulty lies in the simulation of visual, "out the window" displays. Landing a vehicle on Mars or on the Earth may be expected to impose a heavy workload on the astronaut. As a recent accident with the M2-F2 lifting body demonstrates, pilot concentration, familiarity with the landing area, and good altitude information are key items here.⁽¹¹⁾ In training for such landings, a credible simulation of the three-dimensional real world would be highly desirable, if not essential. Perception of distance is also important during the touchdown phase of a Mars landing and during the rendezvous for Earth return. Providing realistic visual simulations has been a long-standing problem, but progress is being made in the use of television and films in large ground-based installations.⁽¹²⁾ It remains to be seen whether these techniques can be adapted to spaceborne applications.

The difficulty in obtaining completely satisfactory visual simulations points up an area in which further study is needed. The skills that involve out-the-window views should be analyzed to determine their importance to the conduct of the mission and their degradation in time. If these skills are shown to be important and to degrade significantly, mission planners would have a choice between providing adequate visual simulation for inflight training and not relying on the crew to perform certain tasks properly. An unwillingness to accept the latter alternative could influence mission plans; for example, landing on Mars before flying by Venus to reduce the effects of landing skill degradation. It could also spur the development of out-the-window simulators for spaceborne applications. Because of the far-reaching consequences, studies in this area should be initiated early.

3.1.2 Crew Considerations

The type of inflight training and the degree of proficiency required would not generally be the same for all crew members. The mission commander, and probably his immediate backup, would be highly qualified pilots. During the mission, they would train primarily to preserve the skills that they already had acquired and that they knew they would need to keep ready for use at a later time. There would also be some members of the crew, particularly when more than three men are involved, who were not primarily pilots and who had much less flight experience than the others. On Earth orbital missions, they may never have been in space before. These astronauts might also train to enlarge their skills, as well as maintain whatever proficiency they had already acquired, to provide a backup to the primary flight crew. Since they are backups to crew members who are themselves backups to an automatic system for most flight operations, their training would be less critical and would not impose as stringent requirements for proficiency as would be the case for the mission commander.

3.1.3 Availability of Time for Training

Finding time for inflight training should pose no problems to the astronauts. On interplanetary missions, long intervals occur during which the crew members are engaged in tasks of relatively low scheduling priority. On all missions, some time could be found during which other activities could be interrupted if necessary to allow the astronauts to engage in training exercises for future events.

3.1.4 Compatibility With Preflight Training

In breadth and depth, inflight training should be as similar to preflight training as possible. When an astronaut begins training for a space mission, he concentrates on the average or nominal conditions which he can expect to encounter. After he has become familiar with these, he is introduced to more difficult situations, such as might result from unusual flight conditions, equipment malfunctions and failures, changes in mission plan, etc. Eventually he is able to manage the most complicated aspects of the planned mission and a number of contingencies as well. Inflight training should enable him to preserve all the skills he has acquired in the performance of primary tasks, backup functions, and emergency procedures.

The implementation of inflight training should also be as similar to that of preflight training as possible. If the spaceborne simulation is kept harmonious with that on the ground, inflight training can more readily provide a reinforcement of learning already acquired. Because of limitations of weight, size, and power, the spaceborne simulation is likely to be a subset of the ground-based simulation. This point could be an important consideration, and could result in designing the ground-based simulator to be compatible, for training purposes, with the spaceborne.

3.2 Hardware and Software Considerations

3.2.1 Inflight Training Stations

The basic function of the simulator is to accept inputs from the astronaut, use these inputs to control or modify a computational program, and present outputs to the astronaut. Figure 2 shows these functions in a generalized block diagram. The astronaut controls and displays, and visual simulator if needed, comprise a training station aboard the spacecraft.

The station used for training for a task could be the same station that will be used in the performance of that task on the actual mission. This approach would tend to make training more realistic by letting the astronauts practice with the same controls and displays as they would use during the actual mission phases to come. One disadvantage is that the station would be functionally disconnected from the actual mission operations during training. However, since training exercises would be conducted only during periods of low mission activity, a few essential displays (meters, lights, etc.) to monitor on-board systems could be exactly or functionally duplicated elsewhere in the spacecraft, as they may well be anyway to provide

a backup to the primary mission station. Another disadvantage is that additional failure modes may arise, since the controls and displays at the station must be switched between the real world in which the mission is taking place and the simulated world of the training operations. Some of this switching capability, however, may already be available. Automatic or semi-automatic testing and checkout will probably be incorporated into the design of many spacecraft systems, and may require an operating mode in which test stimuli are applied to the systems. The astronaut might even be considered as another system aboard the spacecraft, and his training could be treated as part of the testing performed from time to time in the course of the mission. It is possible, therefore, that mission stations could be used for training operations as well as their primary functions, with little or no additional hardware required.

A second alternative would be to conduct training exercises at a station other than the one to be used during the actual mission. Using a different station would minimize the possibility of interference with routine mission operations and reduce the likelihood of damaging mission-critical equipment. By eliminating the need for switching the primary station between training and actual mission modes, the use of a different station would also remove a number of potential failure situations and make it less likely that a malfunction that occurs during training could jeopardize the overall mission. The station would not necessarily be installed exclusively or even principally for training; it could be intended as a backup for the primary station, and may even be identical to the primary station. In that event, training functions could be implemented with little or no additional hardware.

If neither the primary nor a backup station is available, an additional station designed expressly for training purposes must be considered. Some degree of modularity could be observed in the design of this station so that, by replacing the appropriate modules, the same station could be used to simulate several mission stations on the spacecraft. Devices like visual simulators, which would be used only for training, could be more readily installed at a special station and would be less likely to affect the design or interfere with the operation of the primary and backup stations. This advantage compensates to some extent for the weight penalty that an additional station causes.

The possibility of training at a station other than the one to be used during the actual mission phase points up an important design consideration: the various stations on the spacecraft should be as much alike as possible. Observance

of this principle could simplify crew training in general by reducing the peculiarities of each station with which an astronaut would need to become familiar. The Air Force, in fact, is following a similar policy in its newest fighter aircraft. However, caution must be exercised in designing the various spacecraft stations to prevent the negative-transfer effects that may occur if similar stimuli require different crew responses at different stations or different times during the mission.

The modular configurations typical of large space vehicles may impose some restraints on the implementation of training requirements. In training for the Mars landing, for example, the crew may be able to assume their stations within the landing module and so experience a most realistic interaction with its controls and displays. On the other hand, it is also possible that the landing module will be secured during most of the interplanetary phase of the mission and so will be unavailable for training procedures. In the latter case, a simulated station in the main spacecraft would appear to be mandatory. A similar situation may exist with regard to the Earth entry vehicle if a special module is involved and is not boarded by the crew until shortly before entry. In cases where spacecraft modules are inaccessible for training, it may be possible to settle for training exercises of reduced complexity and comprehensiveness during most of the mission, and to introduce a period of high-level, intensive training involving the module immediately before its use on the mission. The checkout of the module itself could be a part of the training exercise. Problems of this nature would be eased if the control stations in the entry module were as similar as possible to those in the main mission module.

3.2.2 Computer System Considerations

The points just made regarding the use of various spacecraft stations for training generally apply to the computer system as well. A computer, however, has more flexibility and versatility than the displays and controls with which it operates. Furthermore, the functions of one computer can be simulated on another computer much more readily than, say, one set of displays can be simulated with another set. Therefore, although it is generally desirable to use the same equipment for training as will be used during the actual mission, there may be less urgency to apply this principle to the computer system.

The modular configuration of the spacecraft may significantly influence the design of the computer system and its programs. Modules intended for operation apart from the rest of

the spacecraft, such as those used for landing on the moon, Mars, or the Earth, would generally have their own independent computers. These computers may be interchangeable for reliability purposes. It is also possible that each computer would be tailored to the specific needs of the module in which it was installed and may even have its program in a fixed memory to protect it from accidental damage during the mission. Some interconnections among the various modular computers may exist, either for data transfer during the proper mission phase or for checkout purposes.

The specific methods that may be used to implement in-flight training on the spacecraft computer system are governed by two factors: the availability of the computers at various times during the mission, and the extent to which these computers can accommodate the additional requirements of inflight training. (The additional requirements are considered in more detail later.) On planetary missions, for example, the computer used in the operation of the unmanned probes would likely be in the main mission module, be large enough to handle the additional functions required for training during the midcourse phase, and be available when needed. If the mission computer is available but has insufficient resources for the additional functions involved in training, another computer would be needed to provide these functions. The Earth entry module, for example, may have a rather small computer that could not accommodate more functions. The additional functions required for training would then need to be handled by another computer. If the mission computer is not available for training purposes, one or more other computers could substitute for it, by either duplicating or simulating its function, as well as providing the additional functions needed for training. This could be the case if modules were not available except when needed on the actual mission.

Computing resources other than those normally used during the mission may be available for training purposes. A spare computer, which might be aboard the spacecraft primarily as a backup to the main module computer, could possibly be used in training applications, either to simulate other modular computers or to replace the main module computer in training. It may also be possible to exploit redundant features of the computers; for example, if the main module computer has a duplex memory for reliability purposes, operating the computer in simplex mode may allow the redundant half of the memory to be used for simulation. One difficulty with both these approaches is that a failure that would cause the spare computer or redundant memory to be pressed into service could also eliminate or greatly restrict the capability of the computer to support in-flight training.

The various factors cited above show clearly that the configuration of the spacecraft and its systems, particularly the computer system, can have a pronounced effect on the manner in which inflight training is implemented. Conversely, the need to provide inflight training imposes constraints on the design and operation of spacecraft modules and systems, although configuration decisions cannot be based solely on training requirements.

3.2.3 Additional Computer Requirements

The spacecraft computer system may be loaded more heavily during a training exercise than during the corresponding phase of the actual mission. With regard to Earth entry, for example, the computer system would perform essentially the same tasks on both these occasions as far as entry functions are concerned. In addition, during training, the computer system must simulate the environment, dynamics, and trajectory of the entry vehicle. Concurrently, the computer system must attend to guidance, navigation, flight control, systems monitoring, communication, and other functions relating to real-world events. Inflight training, therefore, can impose more stringent requirements on the computer system than the corresponding phases of the actual mission.

The additional computer capability that is needed specifically to implement inflight training requirements can be considered from three aspects: the simulation of the vehicles and their environments and trajectories, the control of input-output and program execution, and supplementary function. These topics are considered in more detail in the following paragraphs.

3.2.3.1 Vehicle Simulation

The vehicles to be simulated on the various missions can be grouped into four general types:

1. Earth entry and landing vehicle.
2. Mars entry and landing vehicle.
3. Moon or Mars ascent and rendezvous vehicle.
4. Unmanned planetary probes.

The total computer resources needed to simulate any one of these vehicles depend on a number of factors that cannot be determined at this time, such as vehicle design and computer

characteristics. It is possible, nevertheless, to make gross estimates of these requirements, at least to indicate which areas impose the most severe demands on the computer system.

Earth entry vehicles have been extensively studied with a wide variety of programs. A Bellcomm simulation of an Apollo Command Module (CM) with three degrees of translational freedom and roll angle control uses about 50K words of storage on the UNIVAC 1108. However, this program is not intended for real time simulation. The crew training simulator at Manned Spacecraft Center uses three computers with a total memory of 88K words to simulate the Apollo CM in six degrees of freedom in real time. On the other hand, glide vehicles like the X-15, which is a more complex aerodynamic body than the Apollo CM, have been simulated in real time with about 4000 words of memory. The first two simulations cited achieve a high degree of sophistication and produce results that are in close agreement with other simulations, while the third one includes a number of simplifying assumptions. For inflight training purposes, the complexity of the simulation could probably be reduced appreciably, so that a memory of roughly 4000 words should be adequate to simulate the atmospheric and gravitational environment of the vehicle, the response of its systems to environmental stimuli, and its dynamic performance and trajectory.

Computers with cycle times up to 5 microseconds have been used satisfactorily in the real time simulations cited above. Spaceborne computers during the 1970's and 1980's are likely to be an order of magnitude faster than these computers. Therefore the spaceborne simulation computer should have no particular problem in providing solutions at an acceptable rate.

If the Earth entry vehicle is a lifting body, it would have gliding capability and could be controlled to touchdown. In that case, a visual simulation of the landing area may be needed for training. If a satisfactory simulation could be obtained by positioning models or photographs, the computer would require only a small amount of additional processing to provide control signals. However, a display generated on a cathode ray tube could lead to great increases in memory requirements and processor utilization, particularly if frequent updating is demanded. A relatively simple display consisting of lines on a plane may be generated without significant effect on computer requirements if the display device has a vectoring capability. On the other hand, a complex display involving detailed terrain features, levels of intensity, and points hidden

by surfaces could make prohibitive demands on computer time. These points serve to underscore the need, cited before, to investigate the visual simulation problem more carefully and determine what level of complexity is actually required for training.

The simulation of a Mars landing module involves aerodynamic forces for braking and large thrust forces for touch-down. From the standpoint of computer requirements, the Mars entry phase could be comparable to an Earth entry. The touch-down phase would probably require six degrees of freedom which, with the transformation of thrust forces into the desired coordinates, could involve a large amount of computation and effectively double the memory needed (8000 words). Furthermore, a high solution rate (up to 25 per second) may be needed to insure good control characteristics. Visual simulation of the landing area may require more detail and better depth sensation than for an Earth entry vehicle and, if it is needed, could prove to be a very serious problem.

The simulation of a lunar or Mars ascent and rendezvous vehicle involves different computer requirements during its two phases of flight. Even with a relatively complex thrust simulation, the ascent phase should require 1000-2000 words of computer memory. During the rendezvous and docking phase, the orbiting spacecraft must be included in the simulation, mathematically and perhaps visually. The mathematical portion should not exceed 2000 words of memory, but the visual requirement remains to be determined, although it should be far less complex and less stringent than the visual simulations already discussed for other vehicles.

The simulation of the unmanned probes involves two distinct areas. Before launch from the spacecraft, the probe subsystems and their response to checkout stimuli and initialization signals from the spacecraft systems are of major interest. After launch, the trajectory of the probes and their data output become important. The trajectory of the spacecraft must also be included in the simulation. Moreover, two or more probes may be in flight and transmitting data simultaneously. Computer requirements to simulate probe operations can vary considerably over this range of possibilities and can be assessed with far less confidence than those previously discussed. A minimum of 2000 words may be necessary for probes of moderate complexity, with solution rates of five or ten per second before launch and one or two per second after launch. Since the various probes launched during an encounter could share such features as spacecraft and planetary positions, a larger program, say 4000

words long, could probably simulate several probes at the same time. The simulation of high-speed data return from the probes may increase these requirements substantially, and may even make it necessary or desirable to use special equipment for this purpose.

3.2.3.2 Control of Input-Output and Program Execution

The control of input-output operations and program execution depends strongly on the configuration of the spacecraft computer system and on the manner in which inflight training functions are implemented. If the same computer and program are used for training as will be used during the corresponding mission phase, means must be provided to switch the inputs and outputs of the program between the real and simulated worlds as needed. However, unless training involves peculiar devices with special input-output problems, the addition of this switching capability should have only trivial effects on the computer requirements. If training is implemented on a computer other than the one to be used in the actual mission phase, or if separate programs are used, the need to switch between the real and simulated worlds would not exist.

The organization and design of the software can be greatly influenced by inflight training requirements. Many mathematical and logical functions are essentially the same during a training operation as during the actual mission phase. Considerable differences exist, however, in input-output operations and in overall program control. The program used during an actual mission phase receives inputs from sensors in the spacecraft and from the Earth communication system. Similarly, commands generated by the mission program for automatic control of the spacecraft are sent to the proper actuators. The program used for training, however, receives its inputs from a simulation of the spacecraft and sends its output commands to the simulation. During typical phases, furthermore, the mission program steps through its various segments in a continuous fashion and treats time monotonically. The training program, however, needs greater flexibility of execution to permit starting the simulated run wherever desired, bypassing portions of the flight not of interest at that moment, and interrupting the run to study or emphasize a point. A fast-time capability may also be desirable to enable the astronaut to complete low-activity phases more quickly and to improve his response to various situations.

The control of program execution may introduce some problems when training exercises are carried out as an additional task on an already active computer. In a time-shared system, the training program, while important, would normally be of secondary priority in comparison with the real-world activities of the computer. Consequently, the training program may be interrupted more frequently and for longer periods than would be the case during the corresponding actual mission phase. It is likely that a time-shared computer, as the main module computer will probably be, would already have a fairly complex executive program, so that no significant additions to it would be needed to handle inflight training.

3.2.3.3 Supplementary Functions

The most important supplementary function is the introduction of errors, malfunctions, and failures into the training procedures. When the same computer and program are used for inflight training and the actual mission phase, the extent to which errors would be included would probably be limited, to minimize the likelihood of interfering with normal operations of the program. More elaborate techniques, however, could be introduced when a second or different computer is involved. The partial or complete failure of the computer itself may be one of the faults simulated.

Another supplementary function would be the gathering of data on the astronauts' performance for immediate or subsequent analysis. The data for each astronaut would be used to determine his proficiency at a point in time, identify areas in which his performance was below standard and in need of improvement, and determine whether he is maintaining, losing, or advancing his skills in the course of the mission. If it became necessary or desirable to reassign the crew members to certain tasks, this information could also be used to select the most capable member to perform a particular task.

Unless rather elaborate failure simulations or statistical processes are included, these supplementary functions should not add more than a few hundred words to the program in which they are incorporated. Furthermore, the execution time of the programs should not be significantly affected by the inclusion of these features.

3.2.3.4 Summary

The simulation of vehicles and their environments imposes the heaviest training load on the spacecraft computer system. The Mars landing vehicle has the largest memory requirement, about 8K words. Other vehicles would typically require 4K

words, to simulate an Earth entry vehicle, a Mars or lunar ascent and rendezvous vehicle, or a series of unmanned planetary probes.

The largest memory requirements for each mission would occur if all the vehicle simulations for that mission were stored in the computer memory at the same time, regardless of when they would actually be used during the mission. This could be the case, for example, with a fixed-memory computer. Then the vehicle simulations would require:

- 4K words on extended Earth orbit missions,
- 8K words on extended lunar landing missions,
- 8K words on planetary flyby missions,
- 20K words on planetary landing missions.

Memory requirements of this magnitude are not likely to be a problem for the computers expected to be available during the time of these missions.

The simulation of vehicle environment however, particularly out-the-window views and data relating to unmanned probes, may greatly increase the computer resources needed. These areas involve a number of questions that cannot be answered at this time and may likely require special equipment to provide the desired capability.

In addition, a number of points have been discussed in areas of input-output, program execution, and supplementary training functions. These points, while not significantly affecting program size or execution time, must be considered in software design and management.

3.2.4 Other Uses for Training Facilities

Just as equipment and facilities installed primarily for other purposes could be used for inflight training, so could training facilities be used for purposes other than retaining or upgrading previously acquired skills. One such application would be the modification of existing skills or the acquisition of new skills to handle contingencies that might arise in the course of the mission. The illness or death of an astronaut or a serious degradation in his skills might require a reassignment of tasks among the remaining members of the crew. Structural damage or irreparable system failures may necessitate major changes in the conduct of the mission; e.g., a damaged heat shield may impose

radical constraints on the attitude to be held during Earth entry, in order to minimize ablation in the damaged area. It is also possible that errors in mathematical formulation or software implementation will be discovered while the mission is in progress and will result in changes in certain procedures or techniques. In all the instances cited here, something happens during the mission to force the crew to carry out various tasks differently from the manner for which they trained before the mission. Training facilities aboard the spacecraft could greatly assist the astronauts in revising their skills or in acquiring whatever new skills are necessary to meet the situation.

Another application for the inflight training facilities is the field of behavioral research. The availability of a simulator provides an opportunity to display shifting situations to the astronaut, to measure his response to them, and to score his performance. A typical experimental area, as cited by Hoffman and Kontaratos,⁽¹³⁾ might be the use of onboard computers to evaluate psychomotor functions (gross and fine movements, continuous and discrete processes) and cognitive processes (attention, vigilance, problem solving, learning and retention). Studies of this nature could be conducted with little or no additional hardware.

4.0 CONCLUSIONS AND RECOMMENDATIONS

This report has presented an analysis of typical manned missions to determine the crew tasks for which inflight training may be required. The tasks most likely to require inflight training are those needed (1) to control the flight of manned vehicles during Mars landing, lunar or Mars ascent and rendezvous, and Earth entry, and (2) to check out, launch and direct unmanned probes and conduct planetary experiments.

The facilities needed to provide an inflight training capability would involve a control station with computer-driven displays. If it is available, the actual mission station may be used for training. Alternatively, a backup station or a station expressly intended for training may be used. The simulation of various vehicles in training exercises is well within the capabilities of future spaceborne computers, but the simulation of out-the-window views and data relating to unmanned probes may pose special problems.

Since a requirement to provide inflight training could seriously affect spacecraft design, studies and experiments should be undertaken to determine whether skill degradation is

indeed crucial on long-duration missions. The various skills involved in the performance of critical tasks need to be specified in more detail. Performance measures and degradation tolerances for these skills should also be defined, either by selecting from those already in existence or by devising new ones.

Several tests can and should be started now to assess the long-term decay of previously acquired skills. The Gemini mission simulator is currently being reconfigured by Conduction for the MOL program. However, if this equipment is still available, Gemini astronauts could fly simulated missions and compare their performance with that of 1965 and 1966. These tests could be especially meaningful if the astronauts involved in them were not actively engaged in Apollo training. If the astronauts themselves are not available, development and test engineers or others with extensive experience in the simulators might be substituted. However, enough differences exist between the astronauts and these engineers in matters of training, motivation, and experience, so that great care should be observed in drawing conclusions from such tests.

Data should be accumulated on the astronauts now undergoing training for Apollo missions. Some data, relating principally to the expenditure of propellant in conducting various maneuvers, is already being collected, but more detailed data should also be retained. Such data could be used later to compare the astronauts' performance during the mission with that during preflight training. This comparison could lead to quantitative assessments of the effectiveness of simulation training in preparing the crew for their mission tasks. In addition, Apollo astronauts could be divided into two groups, one of which would practice critical tasks periodically after a mission, while the other would not. The performance of these two groups could then be compared at various times following their missions. If the astronauts are not available, pilots could probably be substituted to collect the necessary data. Nevertheless, because the results of tests of this nature can be of long-reaching importance in attaining the nation's manned spaceflight goals, the astronauts' time should be budgeted to allow their participation as much as possible.

Tests similar to those conducted by Grodsky and his associates at Martin⁽³⁾ should be carried out over longer periods of time. Data should be collected and analyzed to determine whether the period of three to six months or some other interval is crucial for skill retention. If it can be shown that the period of three to six months is not crucial, many activities that have been designated as possibly requiring inflight training (MAYBE in Table 1) could be eliminated from further consideration.

The effectiveness of inflight training in maintaining critical skills should also be demonstrated by tests. The questions that need answers are: (1) How much do simulators help in retaining those skills identified as likely to degrade in time? (2) What level of detail in inflight training is needed for various tasks? (3) How often should training exercises be performed? Answers to these questions could be even more meaningful in tradeoff studies if they included the complexity of the onboard simulation and the training procedures as parameters.

As mentioned by Hoffman and Kontaratos,⁽¹³⁾ the Integrated Medical Behavioral Laboratory Measurement System (IMBLMS) is undergoing final definition and could be used during AAP and later Earth-orbit missions to conduct a number of tests to qualify man for longer-duration missions. Furthermore, Johnston and Ringland,⁽¹⁴⁾ although concerned more with the physiological aspects of performance degradation after prolonged periods of weightlessness, propose both ground-based and inflight experiments to study this degradation in more detail and assume (p. 95) that onboard simulators will be available.

The urgency of starting these studies now should not be minimized. The proposed tests intend to measure long-term effects, and necessarily require a long time to accumulate sufficient data. The results of these tests, moreover, could have significant bearing on the design of spacecraft and associated systems. It was pointed out, for example, that a common layout of controls and displays among various crew stations would generally be desirable. Another area of great concern in the design of a spacecraft is the apportionment of functions between the crew and the automated systems. Cost and reliability are key factors in tradeoff studies, and both can be seriously affected by skill degradation and inflight training considerations. These far-reaching consequences underscore the importance of resolving the problem areas cited in this report.

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Attachments
References
Figures 1-2
Table 1

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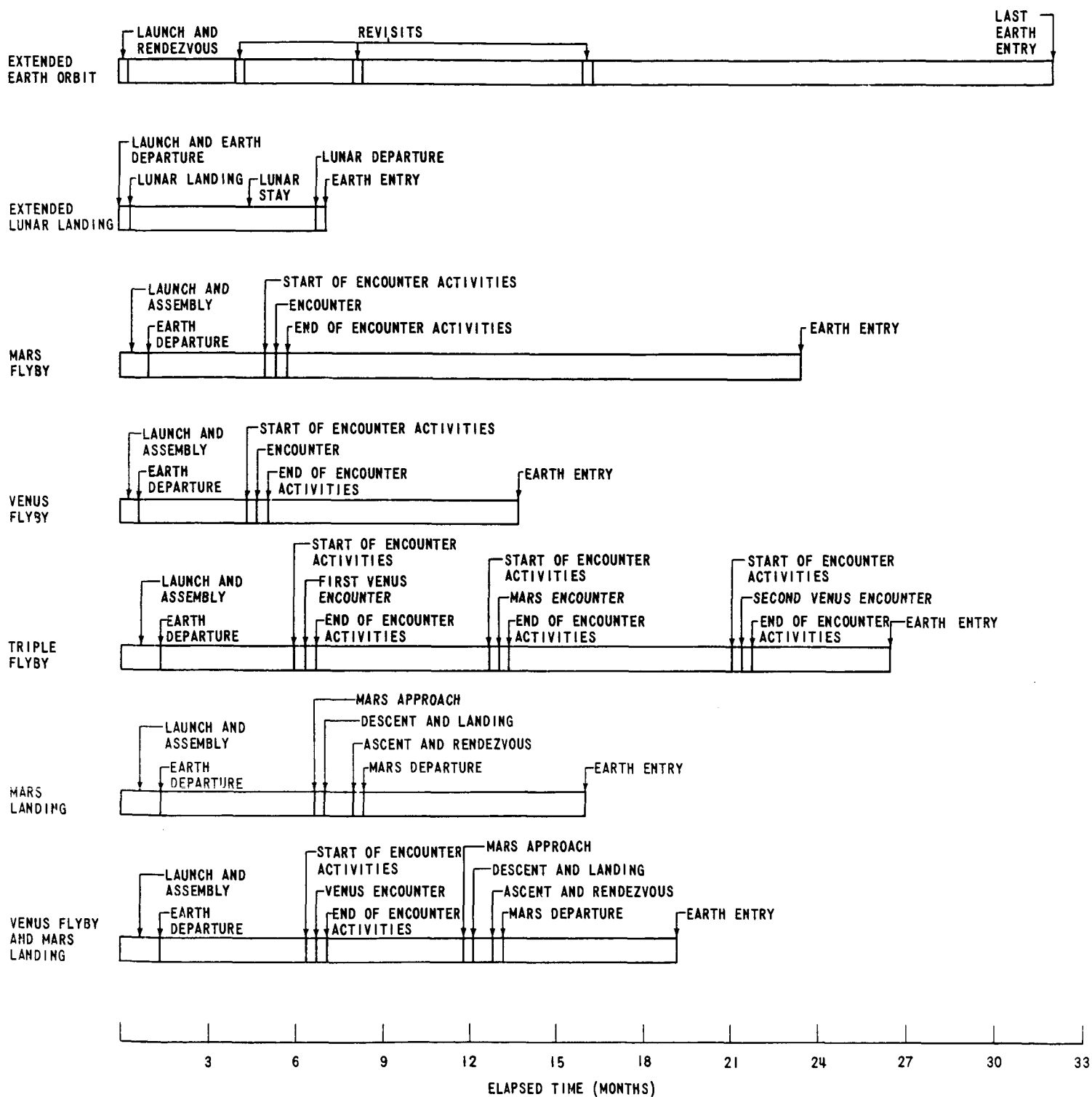
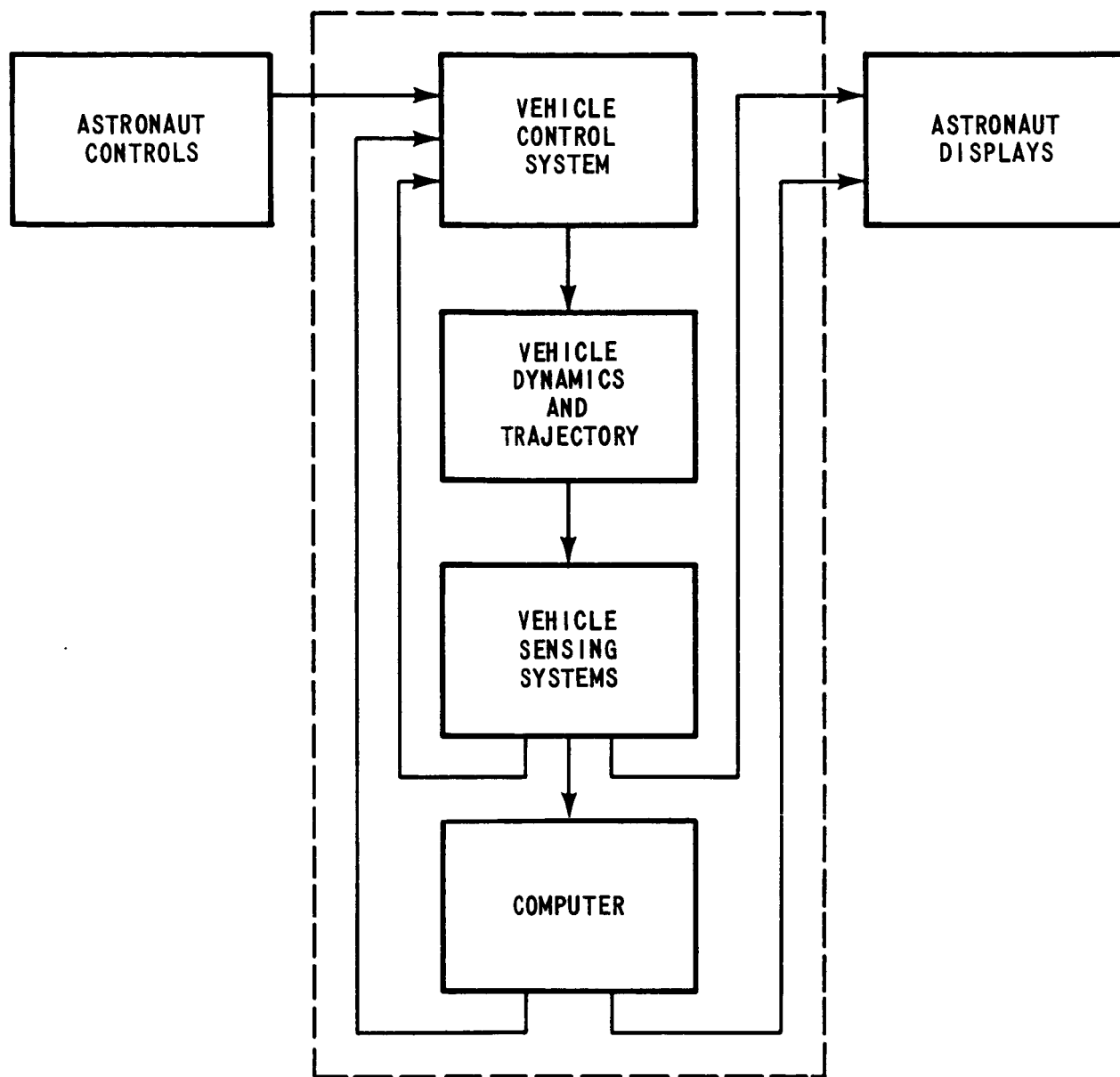


FIGURE 1 - TIME LINES FOR TYPICAL MISSIONS



DASHED LINES ENCLOSE REAL-TIME FUNCTIONS
THAT MUST BE SIMULATED FOR INFLIGHT
TRAINING

FIGURE 2 - GENERALIZED BLOCK DIAGRAM FOR
VEHICLE SIMULATION

Mission phases and activities	Extended Earth orbit	Extended lunar landing	Mars flyby	Venus flyby	Triple flyby	Mars landing	Venus flyby, Mars landing
Earth orbit Launch and insertion Space vehicle assembly Experiments Transplanetary injection (1)	NO NO NO N.A.	NO N.A. N.A. NO	NO NO N.A. NO	NO NO N.A. NO	NO NO N.A. NO	NO NO N.A. NO	NO NO N.A. NO
Interplanetary (1) Midcourse corrections Experiments	N.A. N.A.	NO N.A.	NO NO	NO NO	NO NO	NO NO	NO NO
Planetary (1),(2) Probe operations Final trajectory correction Deboost and capture Descent and landing Experiments Ascent and rendezvous Transplanetary injection	N.A. N.A. N.A. N.A. N.A. N.A. N.A.	N.A. NO NO NO NO MAYBE MAYBE	MAYBE MAYBE N.A. N.A. MAYBE N.A. N.A.	MAYBE MAYBE N.A. N.A. MAYBE N.A. N.A.	MAYBE MAYBE N.A. N.A. MAYBE N.A. N.A.	MAYBE MAYBE MAYBE YES MAYBE YES MAYBE	MAYBE MAYBE MAYBE YES MAYBE YES MAYBE
Interplanetary (1),(2) Midcourse corrections Experiments	N.A. N.A.	NO N.A.	NO MAYBE	NO MAYBE	NO MAYBE	NO MAYBE	NO MAYBE
Earth return Final trajectory correction Entry and landing	NO MAYBE	MAYBE MAYBE	MAYBE YES	MAYBE YES	MAYBE YES	MAYBE YES	MAYBE YES

Notes: (1) For brevity of presentation, the moon is considered a planet in this table.

(2) This phase occurs more than once on triple flyby mission and on Venus flyby and Mars landing mission.

(3) "Fire drills" for various emergencies would be conducted on all missions, and are not cited specifically here.

TABLE I

MISSION ACTIVITIES THAT MAY REQUIRE INFLIGHT TRAINING FACILITIES