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APOLLO EXPERIENCE REPORT - THE ROLE OF FLIGHT MISSION RULES IN MISSION PREPARATION AND CONDUCT

by Larry W. Keyser

Lyndon B. Johnson Space Center
Houston, Texas 77058

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16. Abstract

This report describes the development of flight mission rules from the mission development phase through the detailed mission-planning phase and through the testing and training phase. The procedure for review of the rules and the coordination requirements for mission-rule development are presented. The application of the rules to real-time decisionmaking is outlined, and consideration is given to the benefit of training ground controllers and flightcrews in the methods of determining the best response to a nonnominal in-flight situation for which no action has been preplanned. The Flight Mission Rules document is discussed in terms of the purpose and objective thereof and in terms of the definition, the development, and the use of mission rules.

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THE ROLE OF FLIGHT MISSION RULES IN MISSION PREPARATION AND CONDUCT

By Larry W. Keyser
Lyndon B. Johnson Space Center

SUMMARY

The premission preparation of flight mission rules delineates responsibility and authority for the operational conduct of a mission. Because mission success and crew safety often are dependent on clear instructions and precise actions, the questions of who has the authority to act and what the action is to be must be resolved before the mission, whenever possible. The lack of immediate action, when required, because of undefined responsibilities or authority, can be just as disastrous as the wrong action. The effect of flight mission rules was to enable prompt and accurate preplanned action to be taken for 80 percent of the in-flight failures that occurred during the Apollo Program.

Premission coordination of mission rules helps management to observe the development of the planned execution of the mission and to monitor the methods of operation from mission to mission to ensure continuity of operational philosophy between missions. The documentation of responses (as many as are practical) to abnormal in-flight situations is a good operational practice because it forces the entire mission-planning team to coordinate the various efforts. Premission coordination of mission rules also facilitates the training of ground controllers and flightcrews in the methods of determining the best response to a nonnominal in-flight situation for which an action has not been preplanned.

INTRODUCTION

Flight controllers accomplished the operational execution of the flight phase of the Apollo Program. The most important task of flight control was being prepared to make correct real-time decisions consistent with crew safety, mission-objective priorities, and mission-operations/hardware-performance constraints. Sometimes these decisions were made in time-critical situations in which there was no time to review possible actions — only time to respond. The action based on these decisions ranged from a spacecraft switch reconfiguration or a small change in the Flight Plan to an immediate termination of the mission.

A fundamental approach to the successful conduct of a mission in any flight-test program is to be prepared for the loss of significant spacecraft functions and to have alternate courses of action preplanned where possible. The flight mission rules were developed before a mission to arrive at the appropriate corrective actions for potential losses of functions or capabilities.

The primary objective of flight mission rules was to provide guidelines for flight-control and flightcrew personnel to use to expedite the decisionmaking process. These guidelines were based on detailed knowledge of and experience with space vehicle systems, mission-equipment configuration for support of spacecraft systems, constraints, flightcrew procedures, and mission objectives. All these areas were reviewed in detail and were formulated into a series of basic ground rules to increase flightcrew safety and to optimize the chances of completing the mission objectives; flightcrew safety, however, was the overriding factor for all decisions. These decisions or rules were published and distributed to all operational elements.

The Flight Mission Rules Document (FMRD) was the controlled publication that contained the operational policy necessary for the effective control of a mission. Through a review of the FMRD, the Apollo Spacecraft Program Office (ASPO) and other management groups had the opportunity to approve the operational policies for each mission. Such a controlled document allowed preplanned courses of action to be systematically reviewed by the appropriate levels within NASA or to be coordinated throughout various intracenter and intercenter organizations and the respective contractors.

DEFINITION OF MISSION RULES

Flight mission rules are agreements among NASA management, flightcrew personnel, flight operations personnel, personnel from the various program offices, and associated space-vehicle contractors and manufacturers on courses of action to take in nonnominal in-flight situations. The NASA Headquarters specified the requirement for mission rules in a program directive to all organizations that conducted or supported Apollo mission operations. This directive contained the general contents and description of the FMRD and established the responsibilities for the preparation, coordination, and review of the rules. The mission rules included the following.

1. Nominal and nonnominal performance criteria for space vehicle systems and subsystems

2. Trajectory and guidance guidelines

3. Flight-abort criteria

4. Criteria for the real-time selection of alternate missions

5. Mandatory and highly desirable support requirements of the Mission Control Center (MCC), the Spaceflight Tracking and Data Network (STDN), and the Marshall Space Flight Center for real-time flight operations and for subsequent analysis and evaluation

6. Rules about human or medical aspects of manned flight

7. Mission GO/NO-GO criteria based on systems and medical considerations

8. Criteria for extravehicular activity and for deployment of the scientific Apollo lunar surface experiments package

9. Recovery restrictions

10. Launch-window rules on time of lift-off, launch azimuth, recovery, and spacecraft performance limitations

Basically, mission rules were composed of three different types: general rules, flight operations rules, and specific rules. General rules were furnished by the Office of Manned Space Flight (OMSF) to set forth the policy for preparation, coordination, and review of the rules. Flight operations rules, which are guidelines for the creation of the specific rules, are furnished by the Director of Flight Operations and by the Flight Director and his staff to provide direction and policy on a detailed, mission-specific level and to reflect the position of the Flight Operations Directorate (FOD) on the conduct of the mission. The specific rules, remedial courses of action to be followed in specific contingency situations, are compiled by the individual flight controllers, after coordinating data from cognizant personnel according to the general guidelines set forth by the OMSF and the FOD, to cover the failures of spacecraft and ground systems.

Mission rules also include GO/ NO-GO points, which are points in the mission when the decision is made to commit or not to commit the space vehicle and crew to the next, usually more critical, mission phase. A GO decision is made after the status of the space vehicle and crew has been assessed; it is a statement of confidence in the space vehicle and crew to proceed successfully, to complete, or to return safely from the next mission phase. If a NO-GO decision is reached, the next mission phase is not entered and an alternate mission or mission termination results. These GO/ NO-GO decision points are defined by the mission design and by the initiation of a specific or unique phase or event. The GO criteria for the spacecraft systems are summarized in charts by mission phase. The capabilities listed in these charts are the requirements for initiation or continuation of a mission phase or event.

THE ROLE OF MISSION RULES DURING MISSION PREPARATION

Operational preparation for a mission begins with the spacecraft design and the initial commitment to the construction of flight vehicles and launch facilities. The development of mission operations begins after sufficient information on space vehicle design is available. During the Apollo Program, mission preparation was divided into three separate phases: the mission development phase, the detailed planning phase, and the testing and training phase. These phases and an example of mission-rule development are discussed in the following paragraphs.

Mission Development Phase

The mission development phase began approximately 2 years before the first launch of a new flight program. The conceptual guidelines for conducting operational support of the flight were established at the beginning of this phase. Initial program direction began with the mission definition as outlined in the Mission Requirements Document. As the mission became better defined, personnel had an opportunity to analyze the possible effect of various onboard and ground systems failure modes on the mission and to identify additional systems changes and requirements. These analyses lead to the identification of certain guidelines and constraints. These guidelines and constraints were then used as criteria for continuing beyond certain points in the mission and subsequently became the GO/NO-GO criteria for the mission rules. When a constraint or guideline could not be satisfied by a change in the mission design, a mission rule was written to ensure that the constraint or guideline would not be violated. In some cases, the mission profile or spacecraft-system operation had to be changed when a rule could not be written to satisfy existing constraints.

For Apollo, the OMSF rules were used during this phase as basic guidelines for the development of the flight operations rules. Flight operations rules were affected most during this phase. As the mission became more defined, the various constraints and guidelines that were generated often required the addition or modification of a rule. The analyses of these constraints and guidelines, the mission profile, and the mission rules frequently necessitated recommendations to change either ground-based or space vehicle hardware and software.

Detailed Planning Phase

The detailed planning phase for a particular Apollo mission began when the detailed mission objectives were assigned (approximately 6 months before the launch). The detailed objectives were assigned priorities and integrated into the mission time line. This procedure was affected by the mission rules if any of the time-line changes, systems constraints, or operating limits caused a mission rule to be violated. Conversely, if certain objectives were to be achieved, other mission rules had to be written to ensure safe conduct of the mission.

The beginning of the detailed planning phase was characterized by the initial formulation of the specific rules, which were developed to be compatible with other documentation being produced during this phase. These documents included the Spacecraft Operational Data Book (SODB) and other documents relating to trajectory, time lines, and procedures. The specific rules for each specialty area were formulated by the appropriate flight-operations, launch-vehicle, experiment, scientific, medical, recovery, and space-radiation personnel. These rules were based on existing capabilities, requirements, limitations, mission objectives and mission applicability wherein flight crew safety was the overriding factor. The data used for writing the specific rules were derived from flight-test experience, ground-test experience, engineering simulations, training experience, space vehicle and crew-equipment design specifications, and the flight operations rules.

Onboard and ground-control procedures were developed during this phase in parallel with the mission rules. To aid the development of onboard procedures, the flightcrew was kept apprised of mission rules; to keep the mission rules current, the flight controllers were advised of the latest crew procedures. The rules and procedures had to be compatible to ensure the proper use of spacecraft systems. Ground-control procedures for flight controllers were developed similarly, in parallel with the mission rules. Constant coordination between the flightcrew and the flight controllers was required to keep each group apprised of the current thinking on the various rules and procedures.

Testing and Training Phase

An Apollo mission testing-and-training phase began approximately 90 days before lift-off; at this time, operational testing of the rules was performed in a simulated environment. The flight-control and flightcrew personnel exercised the rules during integrated simulations; the rules were changed when, as a result of simulations, it was determined that a rule was wrong or that a new rule was required. Frequently, simulations resulted in the discovery that a rule could not be implemented because of a lack of time or because of inadequate data. In such cases, the rules were modified to compensate for the delays in data processing or the lack of data. The flightcrew and flight-control procedures were also refined during this phase as the rules were exercised.

As the rules changed, the procedures were changed to make them compatible with the rules; in instances when rules were not changed, the procedures were altered to prevent violation of any rules, guidelines, or constraints.

The rules were reviewed throughout the NASA Lyndon B. Johnson Space Center (JSC) (formerly the Manned Spacecraft Center (MSC)) by personnel in each specialty area and were later reviewed in a NASA-wide review to ensure compatibility among operational elements. These reviews were conducted by the Flight Director in conjunction with the ASPO, the flightcrew, the contractors (as required), the safety office, other mission-support personnel, and the flight controllers from the systems specialty areas.

The rules were influenced at these reviews by any new developments or failures-effects analyses, test-vehicle reports, simulation evaluations, manufacturer reports, and pad-test results. The SODB and other documentation were updated as the rules were changed as a consequence of these reviews. The simulation-review-rewrite-simulation iterative cycle during this phase continued until lift-off and provided the rules their finest critique.

Example of Mission-Rule Development

A good example of the development of a mission rule involves communications with the lunar module (LM) during descent to, and ascent from, the lunar surface during the Apollo 11 mission. After ASPO had outlined the attitude guidelines for the first lunar-landing mission, the mission planners constructed an attitude time line. This time line revealed that during lunar descent and ascent, for landing sites outside ± 20° longitude, the STDN would lose telemetry and tracking coverage of the LM between an altitude of 50 000 and 20 000 feet.

The LM contractors proposed several hardware, software, and procedural changes to the ASPO. One proposed change was to maneuver the spacecraft attitude between 50 000 and 20 000 feet altitude to provide good communications through better antenna pointing. The ASPO decided not to change the LM hardware or software design because of weight, schedule, and cost factors. The flightcrew concurred with the ASPO on no spacecraft changes but also went on record as not favoring an attitude constraint, at least not that long before mission simulations could validate the constraint. The flightcrew believed that "voice only" communications between 50 000 and 20 000 feet altitude were satisfactory for crew safety.

Flight controllers examined the effect that the loss of this telemetry and tracking data would have on crew safety and on mission success; they concluded that it was mandatory to keep all communications. The flight controllers agreed with the flightcrew and with the ASPO on no spacecraft modifications but believed that an attitude constraint was best and should be planned because it might be required.

The flight controllers then submitted their operational constraints to the mission planners; these constraints stated that constant telemetry and tracking coverage were required for the entire descent and ascent phases. The mission planners then examined different attitude profiles for these phases and determined the proper attitude for good, continuous communications at different landing sites.

When the flight controllers wrote the preliminary mission rules for these phases, telemetry and tracking were required to begin and to continue through descent. After the ramifications of various LM failures without communications were discussed with everyone involved, the crewmembers agreed to perform an attitude maneuver to keep continuous communications during ascent or descent, if necessary. The simulations provided a realistic impression of the ascent and descent phases of the mission, and a decision was made that constant telemetry and tracking were not absolutely required; however, ground-based personnel did require adequate data to make each GO/NO-GO decision to continue powered descent. The mission rule concerning loss of LM telemetry for the Apollo 11 mission is given in figure 1.

THE ROLE OF MISSION RULES IN FLIGHT

The in-flight application of the mission rules to nonnominal situations actually began before lift-off. Some of the rules applied to failures during the prelaunch countdown of space vehicle instrumentation that might be required for making GO/NO-GO decisions later in the mission. Other rules applied to the MCC capability to support the mission. Consumables-loading redlines were also exercised during the prelaunch period. Failures of flight instrumentation or ground-support equipment during the countdown could have caused a hold or a scrub of the launch. All the failures or anomalies that could have possibly caused a hold or a scrub should have been documented in the FMRD.

NASA - Manned Spacecraft Center

MISSION RULES

SECTION 20 - COMMUNICATIONS AND INSTRUMENTATION

REV	ITEM	CONDITION/MALFUNCTION	PHASE	RULING	CUES/NOTES/COMMENTS
				SPECIFIC	
	20-55	LOSS OF LM TM			REF MAL PROC
		A. LOSS OF LBR ONLY	ALL	A. CONTINUE MISSION	COMM 6
		B. LOSS OF HBR ONLY	DOCKED	B.1. CONTINUE MISSION	MFSN REPORTS
			UNDOCKED	2. RETURN TO VICINITY OF CSM NO GO FOR DOI	LOSS OF PCM
			DESCENT ORBIT	3. RETURN TO VICINITY OF CSM NO GO FOR PDI	
			POWERED DESCENT	4.(A) PDI TO LO GATE - ABORT RETURN TO VICINITY OF CSM	
				(B) LO GATE TO TD - CONTINUE MISSION	
			LUNAR STAY	5. CONTINUE MISSION	
		C. LOSS OF ALL TM	DOCKED	C.1. CONTINUE MISSION	
			ALL	2. RETURN TO VICINITY OF CSM NO GO FOR TD	
			POWERED DESCENT	3.(A) PDI TO LO GATE - ABORT-DOCK ASAP	
				(B) LO GATE TO TD - CONTINUE MISSION	
			LUNAR STAY	4. LM LIFTOFF NEXT LAUNCH OPPORTUNITY	
	20-56	LOSS OF CRITICAL INSTRUMENTION			
			DOCKED	DO NOT UNDOCK	
			UNDOCKED	DOCK ASAP	
		RULES 20-57 THROUGH 20-59 ARE RESERVED.			

MISSION	REV	DATE	SECTION	GROUP	PAGE
APOLLO 11	FNL	5/16/69	COMM & INST	LM INST - SPECIFIC	20-10

Figure 1.- Mission rules 20-55 and 20-56 for the Apollo 11 mission.

Any decision involving these failures or anomalies was preplanned and automatic; if these failures or anomalies had not been documented, a decision, based on the philosophy used to develop the rules that were documented, was made at that time. After lift-off, the instrumentation and ground-support rules no longer applied.

Throughout the Apollo Program, approximately 80 percent of all problems encountered in flight, both large and small, had been analyzed previously and a course of action documented before the flight. This analysis allowed the choice of a best course of action subsequent to most failures to be essentially automatic. The remaining 20 percent of the problems were solved readily in flight by using the same decisionmaking logic used to develop mission rules before the mission; this procedure, however, is not as desirable as having mission rules available, because little or no time exists for a review-simulation-rewrite cycle to validate the rule and the procedures involved.

The implementation of a mission rule begins with the recognition of an abnormal condition by the flightcrew or by the flight-control team. Once identified, if the failure is time critical and catastrophic, an immediate flight abort is required; if time allows and if the failure is not catastrophic, a search is made to isolate the problem source. This is accomplished by flightcrew observations during the execution of systems malfunction procedures, by flight-control real-time observations of the malfunction procedures, by analyses of taped records of telemetry and voice playbacks, by trend analyses, by analyses of premission testing and data, and by a comparison of previous-mission data. If the identification of the problem source reveals an impending catastrophic failure, an attempt is made to circumvent the problem by procedural changes in the use of the systems. An immediate termination of the flight may be required if the failure is still imminent. If the failure is not imminent, continuation of the remainder of the flight depends on the number of mission objectives remaining to be accomplished. The mission rules, the nominal Flight Plan, and any preplanned alternate mission plans must be examined to determine an acceptable course of action for the accomplishment of the mission objectives, with crew safety kept as the paramount issue. In some cases, after this examination, the scheduled nominal mission is permitted to continue; in other cases, an alternate mission is chosen.

CONCLUDING REMARKS

The flight mission rules proved to be a very effective tool in planning and executing Apollo missions in a safe manner. The rules enabled prompt and accurate preplanned action to be taken for approximately 80 percent of the in-flight failures that occurred. The experience gained in developing these rules enabled the ground and flight personnel to determine rapidly and effectively corrective actions for the remainder of the failures.

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