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APOLLO EXPERIENCE REPORT — FLIGHT PLANNING FOR MANNED SPACE OPERATIONS

by John W. O'Neill, J. B. Cotter, and T. W. Holloway

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16. Abstract

The history of flight planning for manned space missions is outlined, and descriptions and examples of the various evolutionary phases of flight data documents from Project Mercury to the Apollo Program are included. Emphasis is given to the Apollo flight plan. Timeline format and content are discussed in relationship to the manner in which they are affected by the types of flight plans and various constraints.

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CONTENTS

FIGURES

ACRONYMS

AOS	acquisition of signal
ASPO	Apollo Spacecraft Program Office
CCB	Configuration Control Board
CPCB	Crew Procedures Change Board
CSM	command-service module
c.s.t.	central standard time
DOI	descent orbit insertion
EVA	extravehicular activity
FAO	flight activities officer
GET	ground elapsed time
LM	lunar module
LOI	lunar orbit insertion
LOS	loss of signal
MCC	Mission Control Center
MCC-H	Mission Control Center, Houston
MCC-1	midcourse correction 1
MOCR	Mission Operations Control Room
MSC	Manned Spacecraft Center
MSFN	Manned Space Flight Network
PTC	passive thermal control
R&D	research and development
RCS	reaction control system
REFSMMAT	reference stable member matrix
S-IVB	Saturn IVB (third) stage

SPS	service propulsion system
TD&E	transposition, docking, and extraction
TEC	transearth coast
TEI	transearth injection
TIG	time of ignition
TLC	translunar coast
TLI	translunar injection

APOLLO EXPERIENCE REPORT

FLIGHT PLANNING FOR MANNED SPACE OPERATIONS

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SUMMARY

The purpose of a flight plan is to organize the activities of a mission in a logical, efficient, and safe manner. During the premission phase, flight plans are developed to support hardware definition, to support the integration of the crew and vehicle, and to provide a basis for crew training and mission simulations. During a mission, the flight planning team supports the Flight Director by monitoring flight plan activities, anticipating problems necessitating the preparation of alternate plans, monitoring overall crew procedures, and modifying the procedures when necessary.

Flight planning has greatly increased in complexity from previous programs to the present missions of the Apollo Program. Using the Apollo 12 final flight plan as an example, this report describes the present state of the flight planning art in detail. The discussion is oriented around a three-way division of the flight plan: introductory information, timeline, and supporting data. The timeline format and content are discussed, and the elements affecting the timeline are described.

Flight plan development and scheduling of crew activities are discussed. Factors that affect scheduling include mission type, launch frequency, crew training and simulations, and flight plan correlation to other onboard data. The interplay of these and other factors are described, and the effect on flight planning data requirements is outlined.

One section of this report is devoted to contingency and alternate flight plans. Contingency flight plans include timelines for situations in which some mission objectives are abandoned to avoid violation of the mission rules. Alternate flight plans are designed for use on nonnominal launch dates.

INTRODUCTION

It has long been accepted that any major project should have a documented plan covering what is to be done, how, when, by whom, the cost, the foreseeable problems, and the alternative solutions to these problems. The plan is the means by which the roles and responsibilities are communicated to the project participants; it is the yardstick by which performance is measured. In recent years, the concept of planning has been expanded and incorporated as a basic element of systems engineering. Just as the entire integrated systems assembly and the interrelated requirements and constraints must be considered in the purely technical functions of systems analysis, design, development, and testing, the planning of the project also must cover the complete range of activities necessary to reach the systems development goal.

The actual execution of a manned space flight certainly must be ranked as one of the largest and most complex projects ever undertaken; and the need for a documented plan is even more critical because of the complex goals, resources, and constraints that must be interrelated. The flight plan for a manned mission, therefore, must be designed to fulfill all the listed planning requirements in regard to the mission personnel and resources. The questions answered in the flight plan are described in the following paragraphs.

What is to be done? What are the mission objectives and what are all the crew and ground-control activities required to perform these objectives?

How? What are the safest, most efficient, and most potentially successful crew and ground procedures for accomplishing the objectives and all prerequisite activities?

When? What are the durations of these activities, and what is the most logical and effective sequence that ensures adequate time for all critical activities?

By whom? What is the procedural relationship of the flight crew and ground-support function? What are the proper division and interaction of the onboard tasks among the crew, taking into account the constraints of the vehicle and space environment?

At what cost? What is the most efficient and safest way to execute the mission in terms of all consumables and resources, such as propellants, electrical power, life-support water and oxygen, photographic film, and crew and mission time available?

What are the foreseeable problems and alternative solutions? What effects accrue from possible inflight hardware problems or slips in the launch schedule, and what are the new or revised flight plans that will maximize what is to be gained from the alternate or contingency mission?

The discussion that follows traces the evolution of flight planning from the first manned flights through the first two Apollo lunar-landing missions. The development, change control, and real-time updating of the flight plans are discussed, and the importance of crew training and mission simulations in validating and modifying the flight plan is illustrated.

The changing relationship between the flight plan and other documentation used by the crew has had a major impact on the flight plan purpose and content. This relationship and the associated changes are presented whenever unique insight is to be gained.

This document was prepared by the Flight Planning Branch of the Crew Procedures Division, Flight Crew Operations Directorate, NASA Manned Spacecraft Center. Contributing authors from the Flight Planning Branch were W. M. Anderson, J. H. Bain,

D. D. Durych, B. E. Ferguson, S. H. Gardner, G. E. Gentry, T. A. Guillory, J. N. Leech, E. B. Pippert, J. W. Radcliff, L. J. Riche, J. V. Rivers, C. L. Stough, and Major G. M. Colton, USAF. Acknowledgment is also made to R. J. Rogers of TRW Inc., Houston Operations, for his contribution to the section on Apollo flight plan formats and samples. J. N. Leech and H. E. Moos, Jr., co-op students from Purdue University, assisted in the final editing process.

BACKGROUND OF FLIGHT PLANNING FOR MANNED SPACE MISSIONS

Purpose of Flight Plans

As the objectives of a flight are determined, the flight plan is the means of operational implementation. Using known systems constraints, crew constraints, and operational requirements, the flight planner schedules the crew activities and the major crew and ground-control interfaces.

This scheduling function is necessary in the premission phase to support development of total operations plans, and it continues through the real-time mission operation to accommodate any necessary changes resulting from actual mission events. Reference flight plans for advanced-program missions can serve as systems-design inputs and evaluation tools.

The role of flight plans in premission support. - During the premission phase, flight plans are developed to support hardware definition and proper integration of crew capability into the vehicle design. Flight plans also provide the basis for crew training and mission simulations as the program moves into the flight phase.

During the mission conceptualization phase, general flight plan studies are often conducted to assist in establishing a realistic program definition and basic program objectives. As the program moves into the hardware design phase, more detailed flight planning is initiated to verify the operational compatibility of proposed spacecraft system designs with mission objectives, to introduce the operational knowledge gained from previous programs into the systems design, and to assure that adequate operating flexibility is provided by the hardware. Studies based on design-reference flight plans include (1) the use of hardware for backup and alternate missions, (2) the use of hardware for emergency situations, (3) proposed experiment-payload analyses, including estimates of crew time available for experimentation, (4) the effects of trajectory and pointing requirements upon the flight plan, and (5) detailed timelines for use in consumables analyses.

Throughout the hardware design process, the flight plan studies also support detailed crew-integration efforts. The fundamental goal of crew integration is to use man effectively in the space environment. The four basic crew-integration functions are (1) determining the operational adequacy of vehicle systems and of the monitoring and control capability required by the crew, (2) identifying and analyzing inflight operations, (3) optimizing the technical and scientific return from missions and the probability of mission success through application of the capabilities of the crew, and (4) planning and conducting flight crew training. Because the flight plan is the outline of crew activities, it is a most useful tool in all these areas.

Where vehicle-systems operational constraints are not compatible with the total mission system (the integrated crew-vehicle/ground-control system), these conflicts are evaluated for vehicle impact and crew-operations impact. When the crew operations are found to be unacceptable, a recommendation for design change is made. The context of the recommended design change reflects the minimum hardware change that is compatible with a safe and sufficient flight activity definition. The latter will have been evaluated against the total flight plan and the associated constraints. In some cases of unacceptable crew operations, the hardware-change impact may be extensive relative to schedules or funds. If the requirement for the flight activity still exists, a complex compromise must be reached to resolve the requirement. In this case, the flight plan becomes the focal point of evaluating the alternatives in crew operations, flight operations, and flight definition.

After the hardware is developed, the flight plan, as a means of integrating subsystem procedural steps into flight activity definitions, becomes a primary reference in vehicle-integrated-test design. In many respects, processing of data elements to generate the flight plan is essentially the same systems-engineering approach used to generate a detailed test objective. Preliminary versions of lunar-mission flight plans were used extensively in developing the test plans for the Apollo command-service module (CSM) and lunar module (LM) full-scale thermal tests in the Space Environmental Simulation Laboratory at the NASA Manned Spacecraft Center (MSC).

The evolution of the flight plan and flight data file on the basis of functional data is shown in figure 1. These data elements do not necessarily correspond to published documents but reflect types of information considered in crew integration and flight planning. Following the evolution from top to bottom, it can be seen that each data category is dependent on the preceding category. Further, each data element within a category has independent goals associated with it. The flight planning data-processing goals are delineated in figure 2.

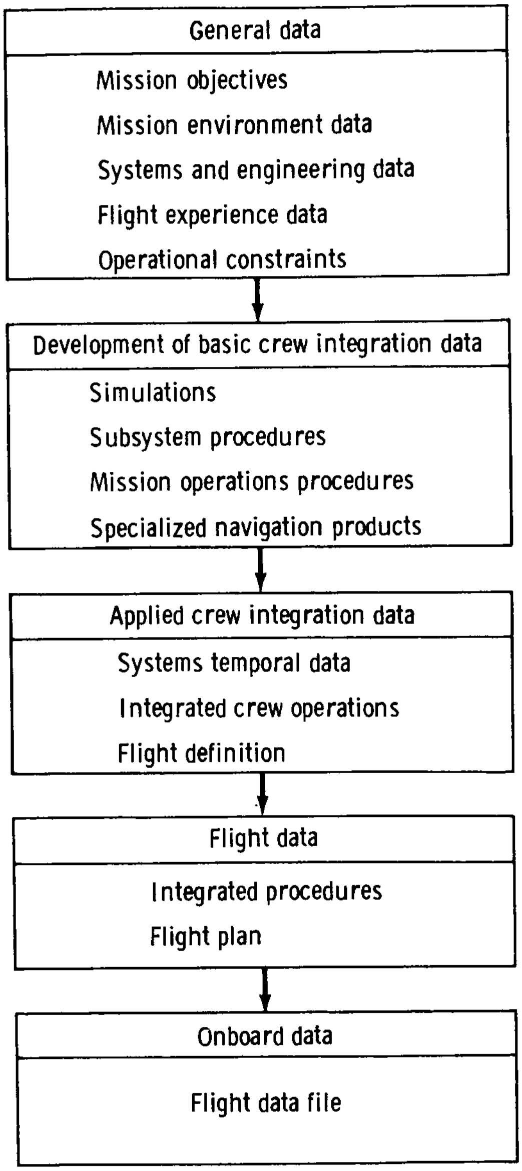


Figure 1. - Technical evolution of flight plan and flight data file.

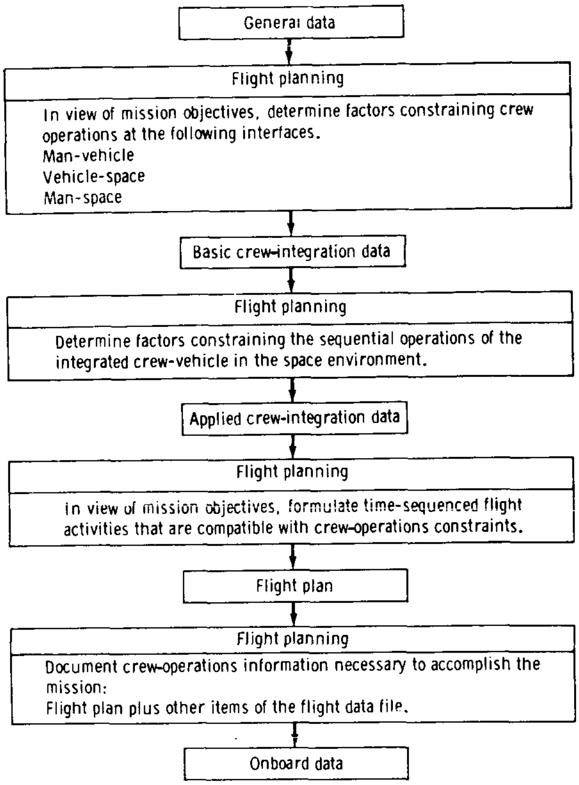


Figure 2. - Flight planning information utilization.

The use and evaluation of flight plans in crew training and mission simulations. - The first real test of the flight plan comes when the crew uses it, or portions thereof, in vehicle simulators and other training exercises. Then, flight planning becomes an even more iterative process. Crew training is the basic laboratory for determining the feasibility of not only the detailed procedures but also the various flight plan phases.

When the crew has progressed from systems training to mission training, the preliminary flight plan becomes the guide. As the crew trains, the flight planner receives feedback from the crew on the continuity, the order, and the feasibility of different parts of the flight plan. During this phase, the flight planner must work with the crew to make sure that they understand some operational constraints that may not be obvious. For example, communications with the ground are required for some engineering tests and experiments This requirement may mean that the test or experiment cannot be performed at the optimum time, based on crew workload, but must be scheduled at a time when a Manned Space Flight Network (MSFN) station will have contact with the spacecraft. On the Apollo 14 mission, the bistatic radar test required not only ground control and monitoring but also specific ground-tracking stations for the processing of data. Also, a part of the flight plan often may seem logical on paper, but a more logical sequence will become apparent when the crew performs the sequence during training exercises.

Initial time allocations for activities in the flight plan are based on experience and judgment; but, when the activity is performed in the simulator or other training facility, the crew may find that the time allotted is more or less than what is required. With this information, the flight planner can add or delete activities of lower priority or reschedule initial events if necessary and possible. Some scheduled activities are found to be very difficult or impossible to perform when the crew simulates the activity. The flight planner must either modify the activity so it can be performed or delete it from the flight plan.

The final preflight tests of the flight plan are the integrated simulations involving the crew in the spacecraft simulators and the ground controllers in the Mission Control Center (MCC). Integrated simulations demonstrate how rapidly the ground can react to crew problems and how well the ground can provide normally required data. By the time the integrated simulations are reached in the training cycle, the crew has trained with the flight plan for a sufficient period of time to reveal the major modifications required. The flight plan should be refined to such a point that no major changes in the crew timeline sequence of activities result from the integrated simulations. The flight plan is, however, polished to final form as a result of integrated simulations.

Flight experience has proven that, unless a major or persistent systems problem occurs, the portions of the mission that are simulated with the crew and the ground controllers are retained as they were planned. However, many of the interactions of activities cannot be determined preflight and, because simulation time is limited and costly, the crew cannot train for all portions of the mission. The flight planner must extrapolate from whatever data he can glean from simulations of other portions of the mission.

Real-time flight planning support. - During a mission, the flight planning and crew procedures team, headed by the Flight Activities Officer (FAO), supports the Flight Director by monitoring flight plan activities as they are performed; by anticipating flight plan problem areas and supervising the preparation of alternate plans; and by monitoring and modifying, as required, overall crew procedures. The flight planning and procedures team also provides attitude information for activities other than major propulsion-system burns. In addition, the FAO and his team coordinate miscellaneous scientific inputs into the flight plan. Working with other flight controllers, the FAO coordinates procedural changes or new systems tests and schedules them in the flight plan.

As spacecraft-systems problems occur, the FAO directs the reordering of the crew activities so the higher priority objectives can be accomplished. The consumables must be monitored, and, if a consumables redline is reached or approached, activities are deleted to allow completion of major objectives. Some problems require not only rescheduling of activities but also reworking of mission procedures. The FAO and his procedures team modify the procedures and provide them to the other flight controllers for review. After all flight controllers have agreed on the proposed procedure of flight plan changes, the FAO prepares an update to be read to the crew.

As indicated by the references to the FAO team, real-time flight plan support requires more than one person. The FAO is located in the main control room, the Mission Operation Control Room (MOCR). Personnel in the MOCR receive detailed support from many mission-operations personnel located in various staff support rooms. The Flight Activities Officer's Staff Support Room is manned by other flight planners, selected experiments personnel, procedures experts, navigation experts, simulator instructors, and specialized clerical personnel. The flight planners assist the FAO in following the mission and monitoring the activities. They suggest operational alternatives, support the preparation of flight plan updates, and assist in tracking the consumables. The experiment-support personnel calculate the attitudes required to support mission activities, coordinate photographic requirements and procedures, provide MSFN-acquisition times and landmark-crossing times, and act as the interface with the ground computers for any flight plan support.

Before the mission, the crew trains daily in the simulators. The simulator instructors, by working with and training the crew, have an excellent opportunity to observe in detail the individual and collective manner in which the crew executes the mission procedures. Therefore, the instructors are most qualified at monitoring the crew procedures during the mission. Another important capability results if experienced simulator operators are available when major procedural changes are proposed in real time. When time allows, the instructors can use the MSC simulators to check the procedure changes during the mission before updating the procedure to the crew.

Evolution of Flight Plans Through the Apollo Program

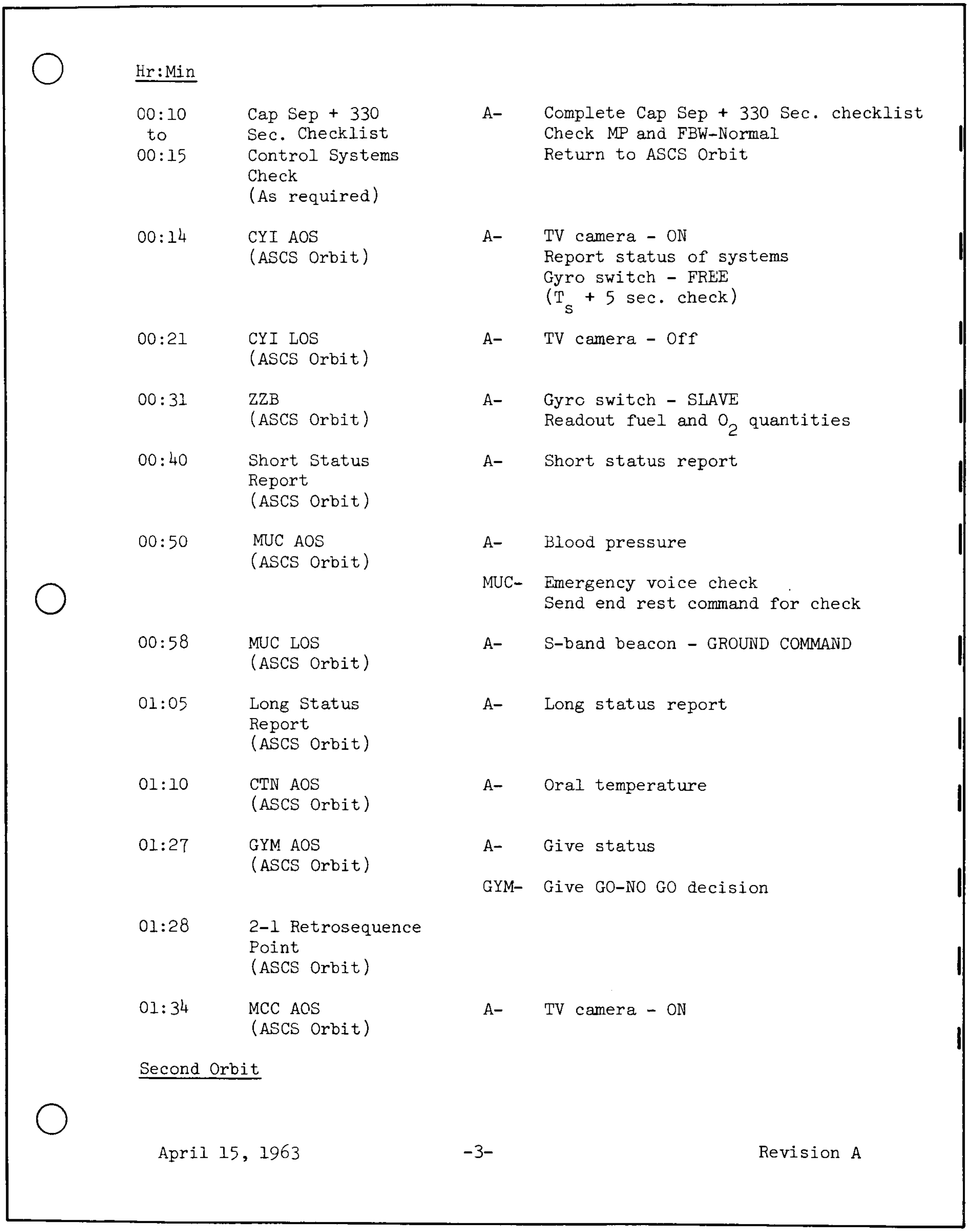
Flight planning, in parallel with the spacecraft and program objectives, has increased in complexity because of the growth in mission duration and spacecraft capability and the increase in the number, complexity, and sophistication of the objectives and vehicle systems.

The flight plans of the early manned missions are considerably different from those of the present, mainly because of the difference in the length of the missions. The short missions of Project Mercury made it more efficient to include in the flight plan, in checklist form, all the details required to accomplish the various objectives. Sample pages of a Project Mercury flight plan are shown in figure 3.

In the Gemini Program, the number of objectives increased as a function of the longer duration of the missions and the increase in the capability of the spacecraft. Some objectives were scientific in nature and others were operational evaluations designed to develop techniques that would be used in the Apollo Program. Constraints, such as trajectory or systems requirements, had to be met, thus resulting in the necessity of performing the objectives over the United States or in the South Atlantic anomaly where the Van Allen radiation belt phenomenon is encountered, or the necessity that the spacecraft be powered up for attitude information. Still other objectives were constrained by the number of crewmen available, because the staggered sleep cycle (in which one crewman slept while the other monitored) was used on several of the Gemini missions. Also, the type of activity that could be performed without awakening a sleeping crewman restricted the objectives that could be accomplished during these periods.

Because the Gemini missions were much longer than those of Project Mercury and had many more objectives, the job of scheduling the objectives and showing enough detail in the flight plan to accomplish the objectives became more complex. The necessary information was too voluminous to be included conveniently in the flight plan itself; therefore, an integrated flight plan and flight data file (crew onboard data) system was developed. The details of activities such as rendezvous, vehicle activation, or extravehicular activity (EVA) were included in a checklist separate from the flight plan. On Gemini missions, the flight plan itself indicated when, not how, an activity was to be performed (fig. 4).

The Apollo flight plans evolved into much more detailed documents than either the Mercury or Gemini flight plans (although procedural data were still carried in the checklists), primarily because, at certain times, two manned vehicles were involved. This increase in the number of vehicles led to an increase in the number of operational and systems constraints to be considered in scheduling activities. In addition, the complexity of the Apollo missions required more detail to assist the crewman in performing

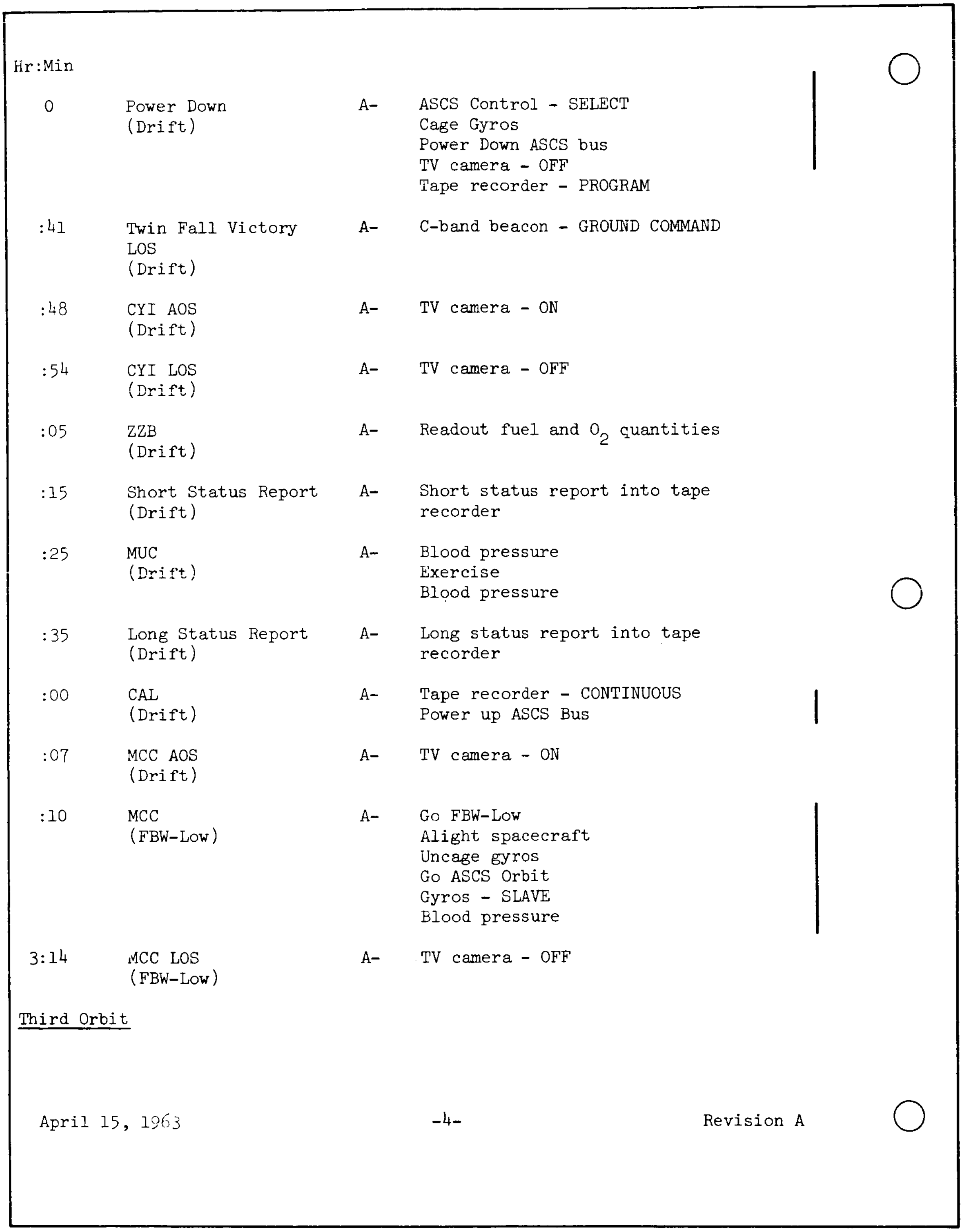


Hr:Min			
00:10 to 00:15	Cap Sep + 330 Sec. Checklist Control Systems Check (As required)	A-	Complete Cap Sep + 330 Sec. checklist Check MP and FBW-Normal Return to ASCS Orbit
00:14	CYI AOS (ASCS Orbit)	A-	TV camera - ON Report status of systems Gyro switch - FREE (T_s + 5 sec. check)
00:21	CYI LOS (ASCS Orbit)	A-	TV camera - Off
00:31	ZZB (ASCS Orbit)	A-	Gyrc switch - SLAVE Readout fuel and O_2 quantities
00:40	Short Status Report (ASCS Orbit)	A-	Short status report
00:50	MUC AOS (ASCS Orbit)	A-	Blood pressure
		MUC-	Emergency voice check Send end rest command for check
00:58	MUC LOS (ASCS Orbit)	A-	S-band beacon - GROUND COMMAND
01:05	Long Status Report (ASCS Orbit)	A-	Long status report
01:10	CTN AOS (ASCS Orbit)	A-	Oral temperature
01:27	GYM AOS (ASCS Orbit)	A-	Give status
		GYM-	Give GO-NO GO decision
01:28	2-1 Retrosequence Point (ASCS Orbit)		
01:34	MCC AOS (ASCS Orbit)	A-	TV camera - ON

Second Orbit

April 15, 1963 -3- Revision A

Figure 3. - Excerpt from detailed timeline of Mercury IX flight plan.

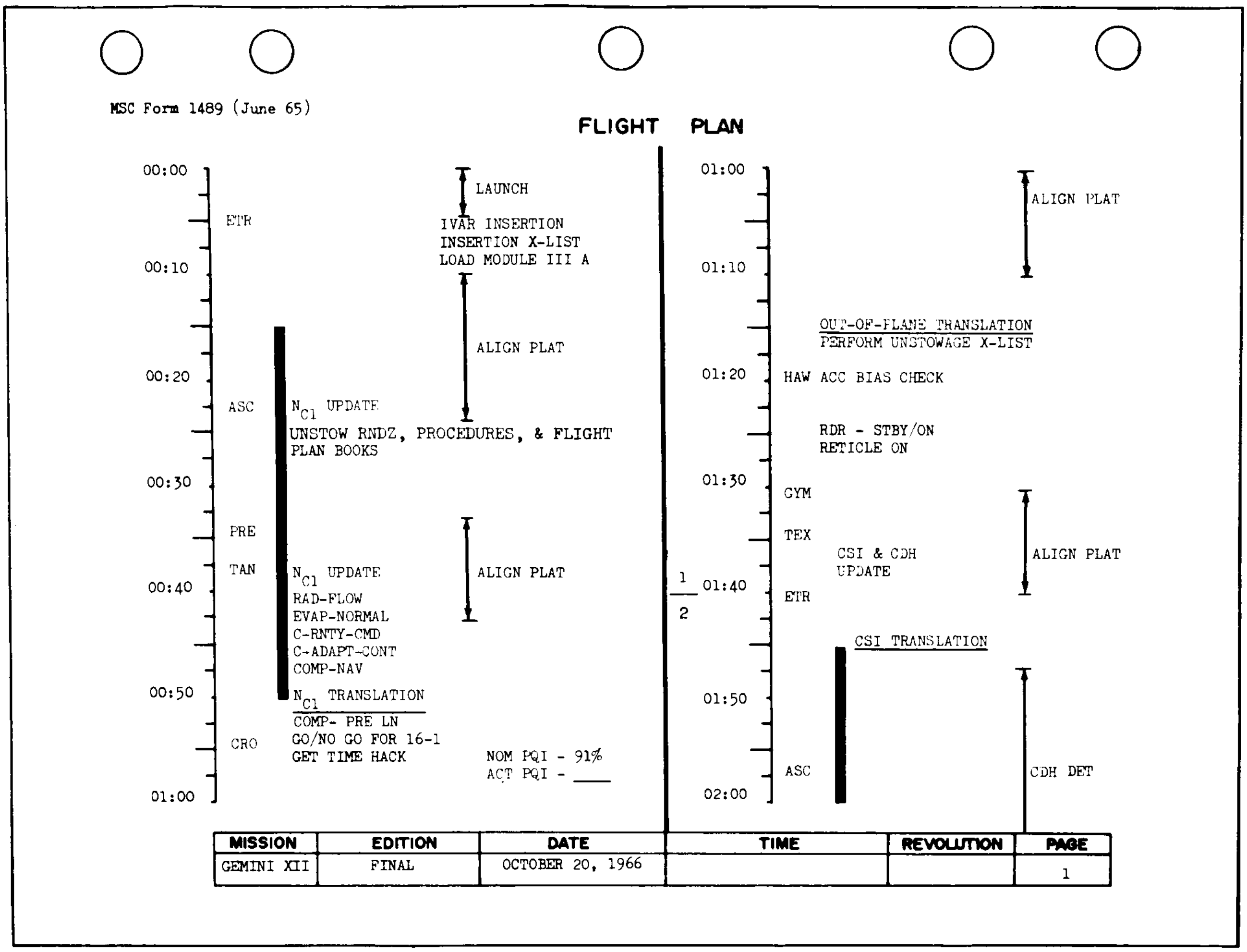


Hr:Min			
0	Power Down (Drift)	A-	ASCS Control - SELECT Cage Gyros Power Down ASCS bus TV camera - OFF Tape recorder - PROGRAM
:41	Twin Fall Victory LOS (Drift)	A-	C-band beacon - GROUND COMMAND
:48	CYI AOS (Drift)	A-	TV camera - ON
:54	CYI LOS (Drift)	A-	TV camera - OFF
:05	ZZB (Drift)	A-	Readout fuel and O_2 quantities
:15	Short Status Report (Drift)	A-	Short status report into tape recorder
:25	MUC (Drift)	A-	Blood pressure Exercise Blood pressure
:35	Long Status Report (Drift)	A-	Long status report into tape recorder
:00	CAL (Drift)	A-	Tape recorder - CONTINUOUS Power up ASCS Bus
:07	MCC AOS (Drift)	A-	TV camera - ON
:10	MCC (FBW-Low)	A-	Go FBW-Low Alight spacecraft Uncage gyros Go ASCS Orbit Gyros - SLAVE Blood pressure
3:14	MCC LOS (FBW-Low)	A-	TV camera - OFF

Third Orbit

April 15, 1963 -4- Revision A

Figure 3. - Concluded.



MSC Form 1489 (June 65)

FLIGHT PLAN

00:00 LAUNCH
ETR
IVAR INSERTION
INSERTION X-LIST
LOAD MODULE III A
00:10
ALIGN PLAT
00:20
ASC N_{C1} UPDATE
UNSTOW RNDZ, PROCEDURES, & FLIGHT PLAN BOOKS
00:30
PRE
TAN N_{C1} UPDATE
ALIGN PLAT
00:40
RAD-FLOW
EVAP-NORMAL
C-RNTY-CMD
C-ADAPT-CONT
COMP-NAV
00:50
N_{C1} TRANSLATION
COMP- PRE LN
CRO GO/NO GO FOR 16-1
GET TIME HACK
NOM PQI - 91%
ACT PQI - ____
01:00

01:00 ALIGN PLAT
01:10
OUT-OF-PLANE TRANSLATION
PERFORM UNSTOWAGE X-LIST
01:20 HAW ACC BIAS CHECK
RDR - STBY/ON
RETICLE ON
01:30
GYM
TEX
CSI & CDH UPDATE
ALIGN PLAT
1/2 01:40
ETR
CSI TRANSLATION
01:50
ASC
CDH DET
02:00

MISSION	EDITION	DATE	TIME	REVOLUTION	PAGE
GEMINI XII	FINAL	OCTOBER 20, 1966			1

Figure 4.- Excerpt from detailed timeline of Gemini XII flight plan.

the mission objectives. Some of the necessary details that were added to the flight plan to assist the crewmen were as follows.

1. Spacecraft attitudes

a. During translunar coast (TLC) and transearth coast (TEC)

(1) Passive thermal control (PTC) attitude

(2) Onboard-computer lunar-navigation-program (P23) starsighting attitudes

(3) Attitudes for television and photographic operations

b. During lunar orbit

(1) Onboard-computer orbital-navigation-program (P22) attitude, time, and landmark references

(2) Lunar-orbit sleep attitude

(3) Communications attitude for high-gain or steerable antennas

(4) Bootstrap-photography attitudes or any other attitude required to perform a specific objective

2. Preferred navigation stars

3. High-gain and steerable antenna angles for communications

4. Photographic information, such as camera location, camera lens, and camera settings, included with photographic objectives

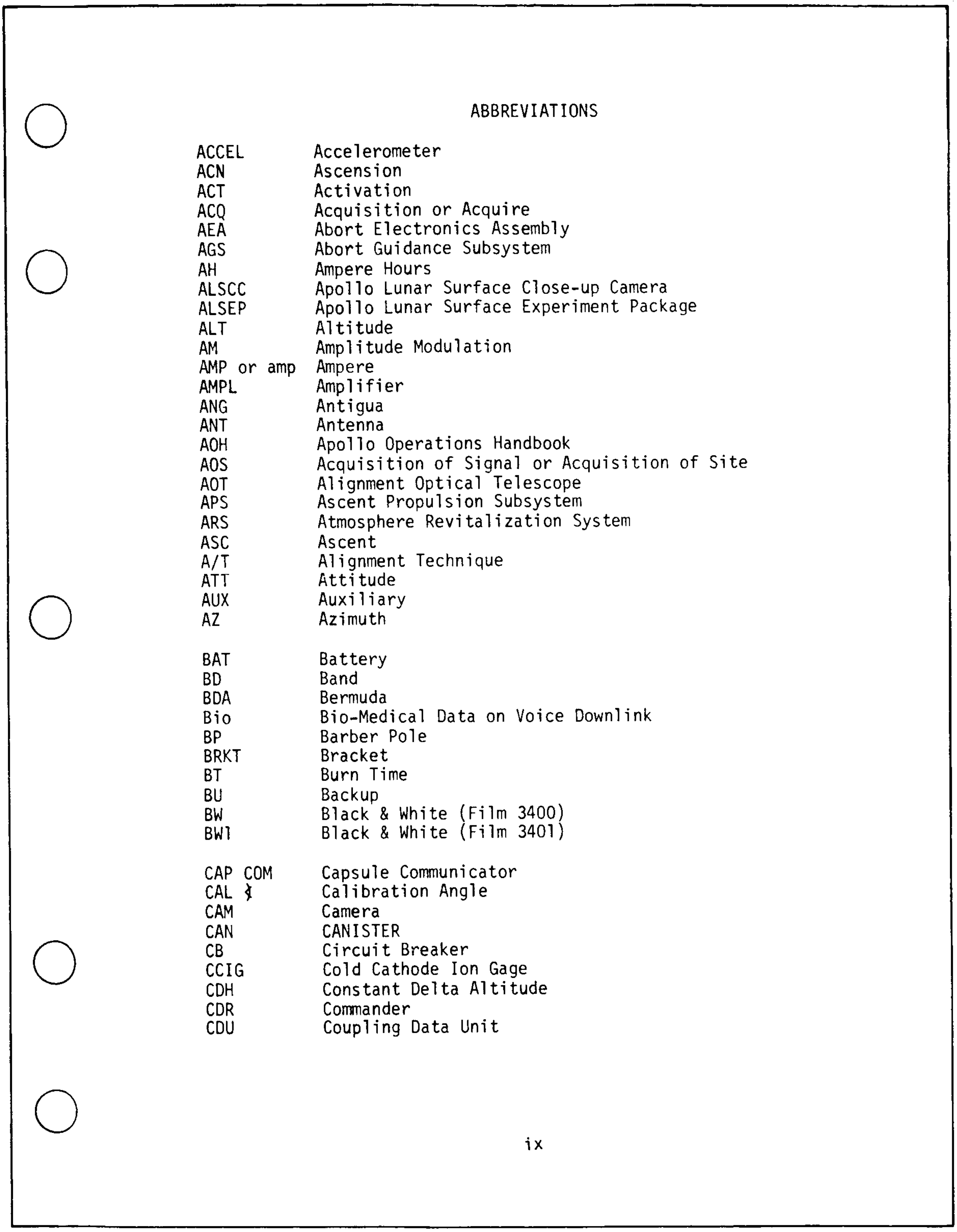
5. Update pads included in the flight plan for those activities requiring updates from MSFN, the exception being maneuver pads

In summary, the early flight plans were self-sufficient; but, as the missions became longer and more complex, it became necessary to construct a general timeline supported by detailed procedures in checklists. This approach reduced the logistics of the flight plan by eliminating the repetition of standard procedures. Detailed and lengthy activities were covered in a separate and specialized book for that mission period.

APOLLO 12 FLIGHT PLAN SAMPLES AND DESCRIPTION

Introductory and Administrative Information

The initial section of the flight plan is a compilation of premission information that identifies the document, status, contents and revisions (if any), abbreviations and symbols used, special considerations, and applicable mission objectives. The document identification, approval, and control are specified by NASA standards, with unique control provisions detailed in the administrative section of the flight plan. The abbreviations and symbols used are often unique to both manned space flight planning and the specific mission being planned. Typical lists of abbreviations and symbol nomenclature from the Apollo 12 flight plan are shown in figures 5 and 6, respectively, to demonstrate the extensive use of acronyms, abbreviations, symbols, and graphical representations. The inclusion of these reference data assists the infrequent user in interpreting a highly specialized, technically and operationally oriented document.



ABBREVIATIONS

ACCEL	Accelerometer
ACN	Ascension
ACT	Activation
ACQ	Acquisition or Acquire
AEA	Abort Electronics Assembly
AGS	Abort Guidance Subsystem
AH	Ampere Hours
ALSCC	Apollo Lunar Surface Close-up Camera
ALSEP	Apollo Lunar Surface Experiment Package
ALT	Altitude
AM	Amplitude Modulation
AMP or amp	Ampere
AMPL	Amplifier
ANG	Antigua
ANT	Antenna
AOH	Apollo Operations Handbook
AOS	Acquisition of Signal or Acquisition of Site
AOT	Alignment Optical Telescope
APS	Ascent Propulsion Subsystem
ARS	Atmosphere Revitalization System
ASC	Ascent
A/T	Alignment Technique
ATT	Attitude
AUX	Auxiliary
AZ	Azimuth
BAT	Battery
BD	Band
BDA	Bermuda
Bio	Bio-Medical Data on Voice Downlink
BP	Barber Pole
BRKT	Bracket
BT	Burn Time
BU	Backup
BW	Black & White (Film 3400)
BW1	Black & White (Film 3401)
CAP COM	Capsule Communicator
CAL ∢	Calibration Angle
CAM	Camera
CAN	CANISTER
CB	Circuit Breaker
CCIG	Cold Cathode Ion Gage
CDH	Constant Delta Altitude
CDR	Commander
CDU	Coupling Data Unit

ix

Figure 5. - Partial abbreviations listing from Apollo 12 final flight plan.

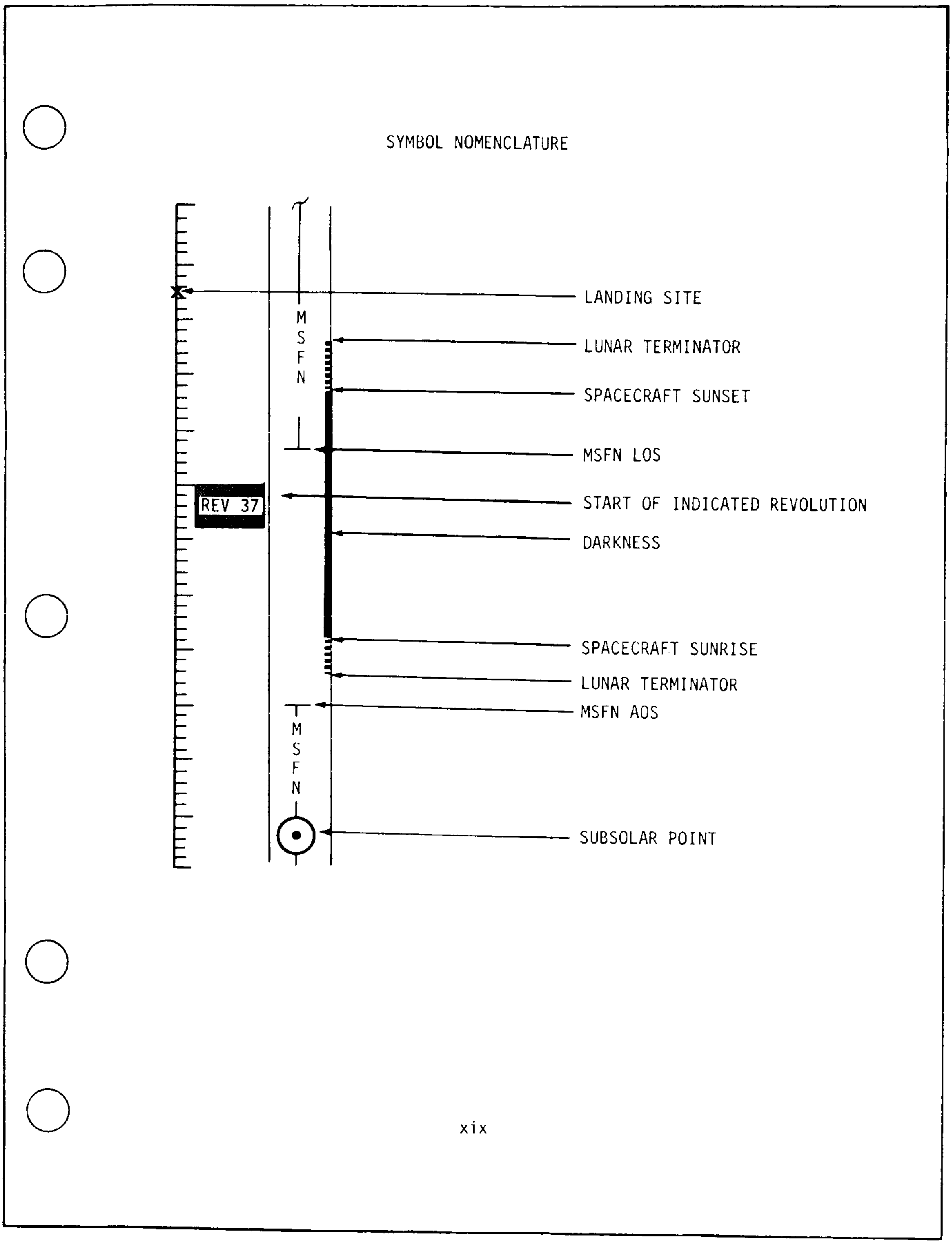


Figure 6. - Symbology description included in Apollo 12 final flight plan.

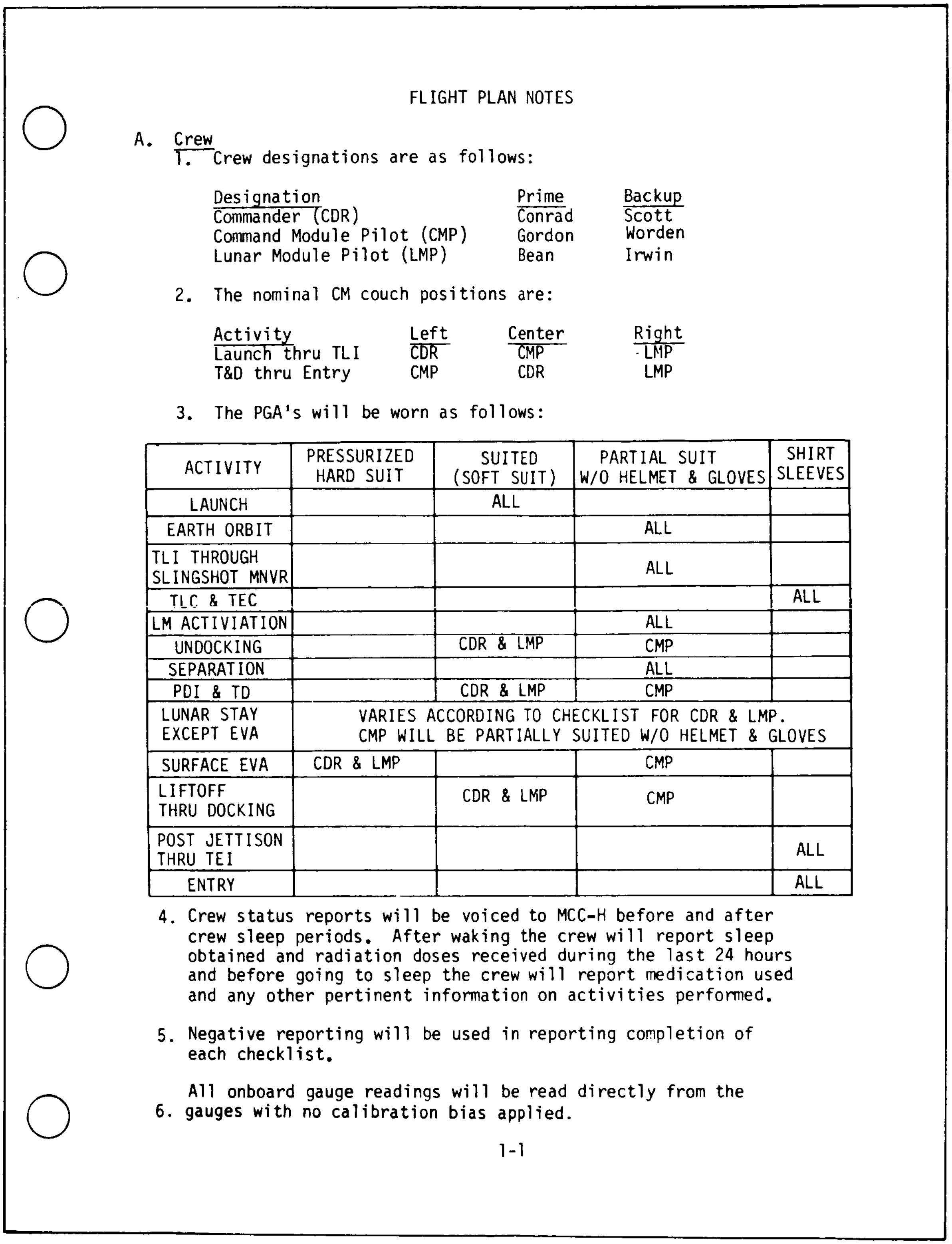
The first section of the flight plan consists of flight planning notes and summary charts of special interest to the mission planning community. The flight plan notes (fig. 7) contain various items related to the detailed timeline that are called out for special attention. Typical items covered are crew designation and positions, pressure-garment protocol, the ground and spacecraft communications interface, and management of the various spacecraft systems. The titles of source documents for the procedures called out in the detailed timeline are also identified in this section. Safety precautions may be spelled out or implied in this section to emphasize safety considerations or to provide rationale for scheduling decisions.

Summary charts of specific functions and activities are generated as a result of flight plan analysis and optimization. Experience has shown that these summaries are frequently applicable to the real-time replanning effort. These summary charts and tables include, but are not limited to, the following items.

1. Graphical communications links
2. Tabularized ground-station coverage
3. Television schedule
4. Spacecraft-systems-management schedules
5. Thrusting-maneuver data
6. Planned navigational corrections

A typical systems-management data item, a lithium hydroxide canister change schedule, is shown in figure 8. As with other summary charts, additional information is provided. An elapsed time between activities and the applicable stowage data are readily available for this particular function. Other summary charts present information such as predicted usage rates for consumables, changes in various orbital parameters, and special remarks.

Mission requirements, which are the basis for the flight planning effort, are related to the activity schedule of the detailed timeline in section 2 of the flight plan. A page from a typical chart of mission objectives, activities, and the corresponding timeline page numbers is shown in figure 9. Successful completion of the related activity, therefore, ensures satisfaction of all mission objectives as required.



FLIGHT PLAN NOTES

A. Crew

1. Crew designations are as follows:

Designation	Prime	Backup
Commander (CDR)	Conrad	Scott
Command Module Pilot (CMP)	Gordon	Worden
Lunar Module Pilot (LMP)	Bean	Irwin

2. The nominal CM couch positions are:

Activity	Left	Center	Right
Launch thru TLI	CDR	CMP	LMP
T&D thru Entry	CMP	CDR	LMP

3. The PGA's will be worn as follows:

ACTIVITY	PRESSURIZED HARD SUIT	SUITED (SOFT SUIT)	PARTIAL SUIT W/O HELMET & GLOVES	SHIRT SLEEVES
LAUNCH		ALL		
EARTH ORBIT			ALL	
TLI THROUGH SLINGSHOT MNVR			ALL	
TLC & TEC				ALL
LM ACTIVIATION			ALL	
UNDOCKING		CDR & LMP	CMP	
SEPARATION			ALL	
PDI & TD		CDR & LMP	CMP	
LUNAR STAY EXCEPT EVA	VARIES ACCORDING TO CHECKLIST FOR CDR & LMP. CMP WILL BE PARTIALLY SUITED W/O HELMET & GLOVES			
SURFACE EVA	CDR & LMP		CMP	
LIFTOFF THRU DOCKING		CDR & LMP	CMP	
POST JETTISON THRU TEI				ALL
ENTRY				ALL

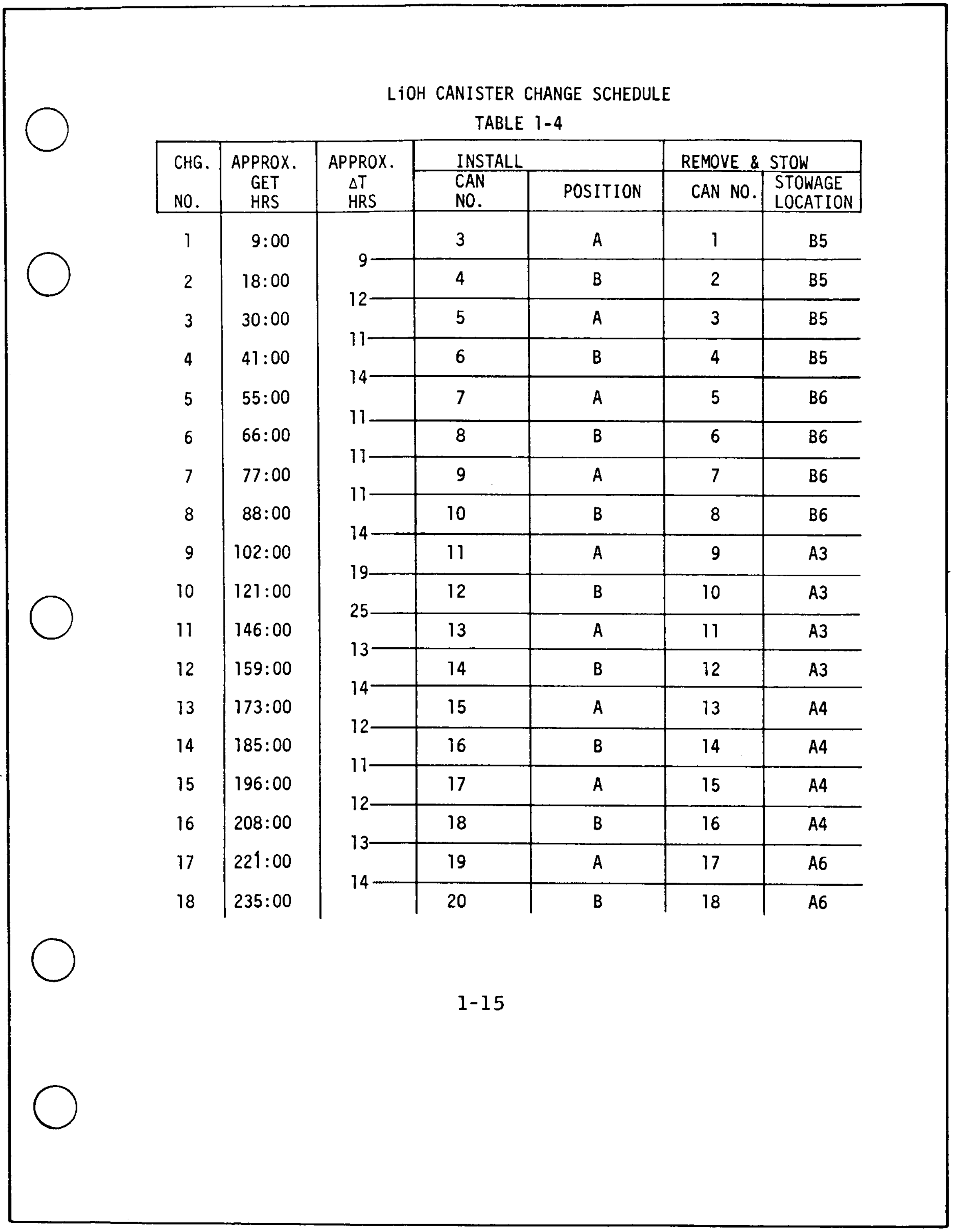
4. Crew status reports will be voiced to MCC-H before and after crew sleep periods. After waking the crew will report sleep obtained and radiation doses received during the last 24 hours and before going to sleep the crew will report medication used and any other pertinent information on activities performed.

5. Negative reporting will be used in reporting completion of each checklist.

6. All onboard gauge readings will be read directly from the gauges with no calibration bias applied.

1-1

Figure 7. - Excerpt from the notes section of Apollo 12 final flight plan.



LiOH CANISTER CHANGE SCHEDULE

TABLE 1-4

CHG. NO.	APPROX. GET HRS	APPROX. ΔT HRS	INSTALL CAN NO.	INSTALL POSITION	REMOVE & STOW CAN NO.	REMOVE & STOW STOWAGE LOCATION
1	9:00		3	A	1	B5
2	18:00	9	4	B	2	B5
3	30:00	12	5	A	3	B5
4	41:00	11	6	B	4	B5
5	55:00	14	7	A	5	B6
6	66:00	11	8	B	6	B6
7	77:00	11	9	A	7	B6
8	88:00	11	10	B	8	B6
9	102:00	14	11	A	9	A3
10	121:00	19	12	B	10	A3
11	146:00	25	13	A	11	A3
12	159:00	13	14	B	12	A3
13	173:00	14	15	A	13	A4
14	185:00	12	16	B	14	A4
15	196:00	11	17	A	15	A4
16	208:00	12	18	B	16	A4
17	221:00	13	19	A	17	A6
18	235:00	14	20	B	18	A6

1-15

Figure 8. - Lithium hydroxide canister change schedule from Apollo 12 final flight plan.

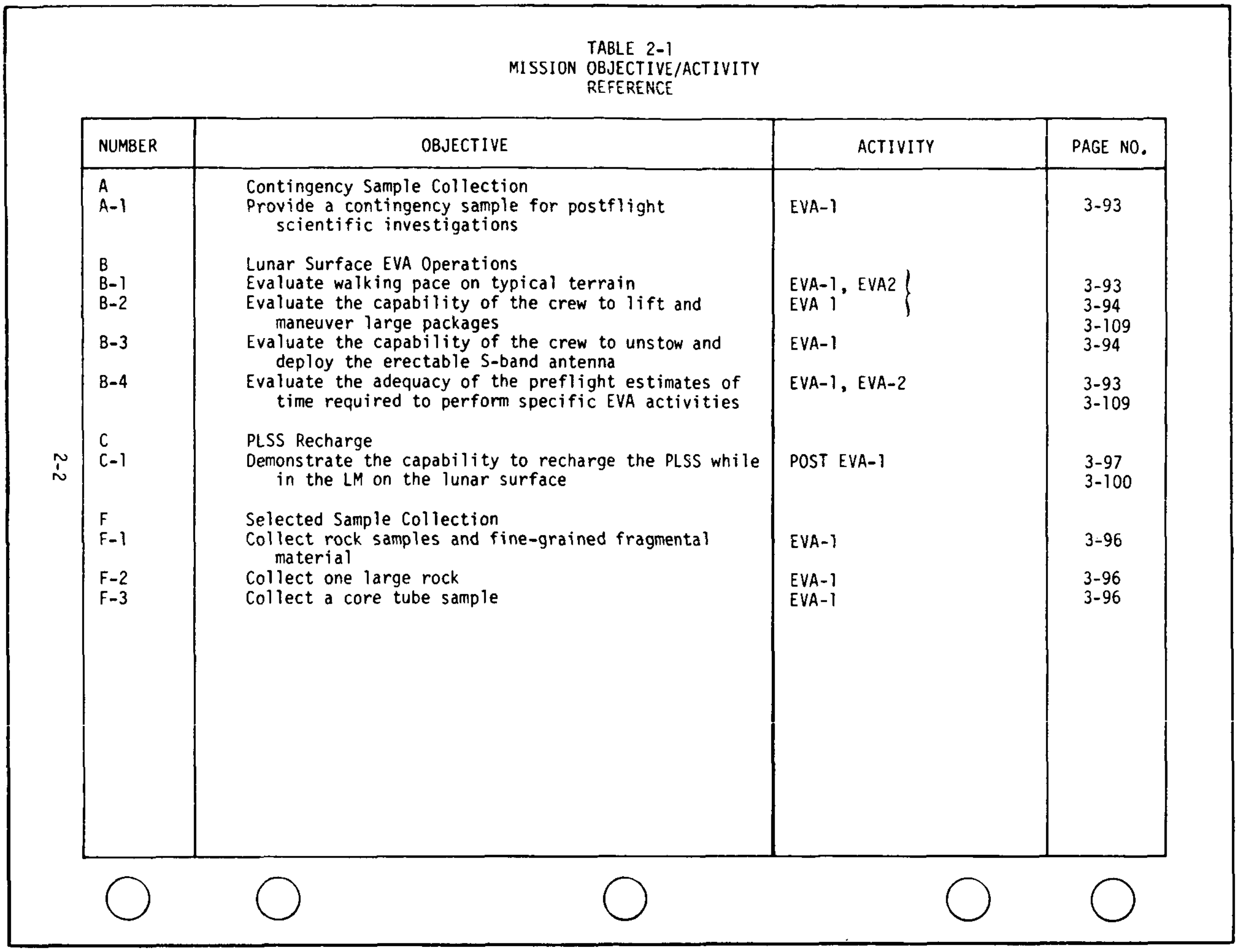


TABLE 2-1
MISSION OBJECTIVE/ACTIVITY
REFERENCE

NUMBER	OBJECTIVE	ACTIVITY	PAGE NO.
A	Contingency Sample Collection		
A-1	Provide a contingency sample for postflight scientific investigations	EVA-1	3-93
B	Lunar Surface EVA Operations		
B-1	Evaluate walking pace on typical terrain	EVA-1, EVA2	3-93
B-2	Evaluate the capability of the crew to lift and maneuver large packages	EVA 1	3-94 3-109
B-3	Evaluate the capability of the crew to unstow and deploy the erectable S-band antenna	EVA-1	3-94
B-4	Evaluate the adequacy of the preflight estimates of time required to perform specific EVA activities	EVA-1, EVA-2	3-93 3-109
C	PLSS Recharge		
C-1	Demonstrate the capability to recharge the PLSS while in the LM on the lunar surface	POST EVA-1	3-97 3-100
F	Selected Sample Collection		
F-1	Collect rock samples and fine-grained fragmental material	EVA-1	3-96
F-2	Collect one large rock	EVA-1	3-96
F-3	Collect a core tube sample	EVA-1	3-96

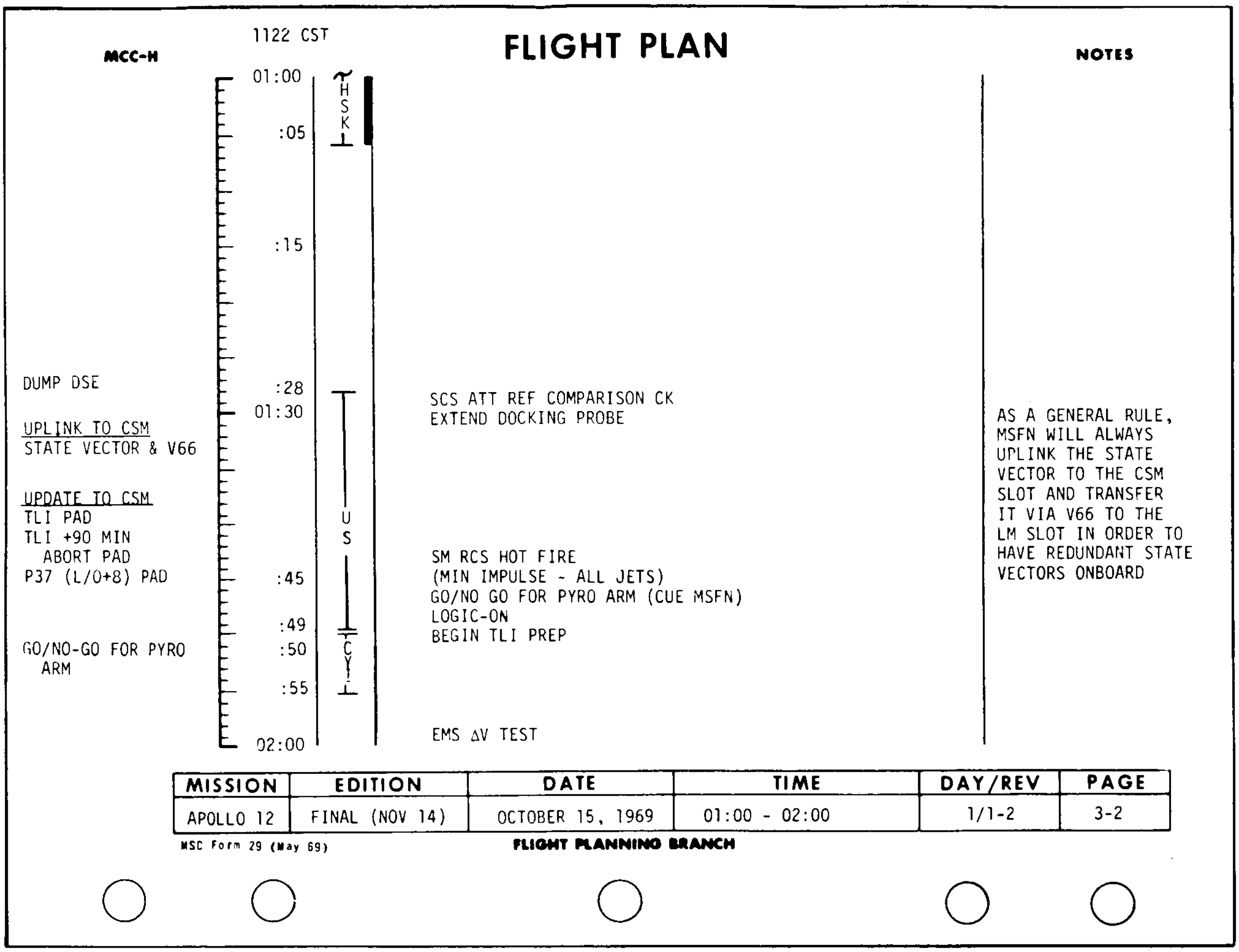
2-2

Figure 9. - Excerpt from mission requirements reference chart of Apollo 12 final flight plan.

Detailed Timeline

The primary product of the premission planning effort is the time-oriented sequence of crew activities called the detailed timeline. Graphical and alphanumeric presentations of trajectory and systems information are integrated with procedural data to provide an astronaut-oriented sequence of mission events. All mission rules and constraints are reflected in the detailed timeline either by implication (such as time relationship) or by statement (such as "Go/No-Go"). The initial planning effort depends greatly on the planner's experience. Then, through detailed review techniques and training simulations, the timeline eventually develops into a complete launch-through-splashdown sequence of activities. The contents of the detailed timeline are described best by reviewing several samples of the final Apollo 12 detailed timeline and the requirements for this information.

The plan for a typical hour in earth orbit is shown in figure 10. To the right of the time column (which shows hours and minutes of ground elapsed time (GET)) is a



MCC-H

FLIGHT PLAN

NOTES

DUMP DSE

UPLINK TO CSM
STATE VECTOR & V66

UPDATE TO CSM
TLI PAD
TLI +90 MIN
ABORT PAD
P37 (L/O+8) PAD

GO/NO-GO FOR PYRO
ARM

SCS ATT REF COMPARISON CK
EXTEND DOCKING PROBE

SM RCS HOT FIRE
(MIN IMPULSE - ALL JETS)
GO/NO GO FOR PYRO ARM (CUE MSFN)
LOGIC-ON
BEGIN TLI PREP

EMS ΔV TEST

AS A GENERAL RULE,
MSFN WILL ALWAYS
UPLINK THE STATE
VECTOR TO THE CSM
SLOT AND TRANSFER
IT VIA V66 TO THE
LM SLOT IN ORDER TO
HAVE REDUNDANT STATE
VECTORS ONBOARD

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE
APOLLO 12	FINAL (NOV 14)	OCTOBER 15, 1969	01:00 - 02:00	1/1-2	3-2

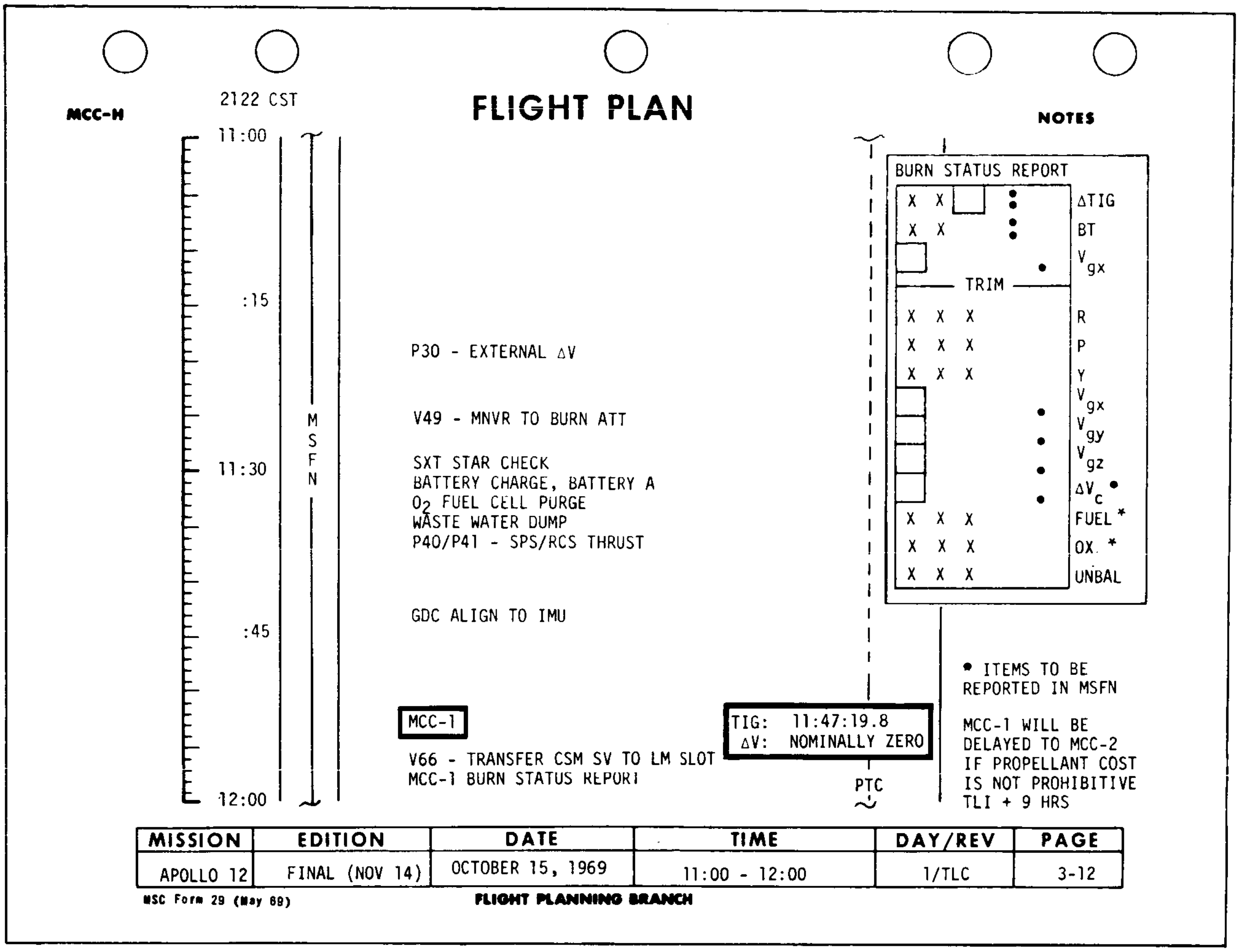
MSC Form 29 (May 69)

FLIGHT PLANNING BRANCH

Figure 10.- Excerpt from earth-orbital detailed timeline of Apollo 12 final flight plan.

narrow column in which applicable trajectory data are presented graphically. In this column, the presence or absence of the solid black strip indicates spacecraft darkness or daylight, respectively, and the lines including a ground-station indicator (e.g., HSK) represent the period of spacecraft-station communications. The far-left column identifies the information that must be provided by MCC to the spacecraft during this period. The large center column contains the crew activities for this period. The far-right column provides information that is neither a ground control nor an astronaut activity but that has been found to aid either or both in using or interpreting the flight plan.

The plan for a typical hour of TLC is shown in figure 11. Although the general format has not been changed from that of figure 10, several unique features of the flight plan are displayed. In the notes column, a blocked group of data appears entitled "Burn Status Report." These data are recorded in the flight plan after midcourse correction 1 (MCC-1) has been performed at the time of ignition (TIG), 11:47:19.8 GET. The notes indicate further that only the data followed by an asterisk need be reported by the crew to MCC. The dashed line at the right of the center column is used to indicate that PTC



MCC-H

2122 CST

FLIGHT PLAN

NOTES

11:00

:15

P30 - EXTERNAL ΔV

V49 - MNVR TO BURN ATT

M S F N

11:30

SXT STAR CHECK
BATTERY CHARGE, BATTERY A
O_2 FUEL CELL PURGE
WASTE WATER DUMP
P40/P41 - SPS/RCS THRUST

:45

GDC ALIGN TO IMU

MCC-1

V66 - TRANSFER CSM SV TO LM SLOT
MCC-1 BURN STATUS REPORT

TIG: 11:47:19.8
ΔV: NOMINALLY ZERO

PTC

12:00

BURN STATUS REPORT

X X ☐	:	ΔTIG
X X	:	BT
☐	•	V_{gx}
TRIM		
X X X		R
X X X		P
X X X		Y
☐	•	V_{gx}
☐	•	V_{gy}
☐	•	V_{gz}
☐	•	ΔV_c •
X X X		FUEL *
X X X		OX *
X X X		UNBAL

• ITEMS TO BE REPORTED IN MSFN

MCC-1 WILL BE DELAYED TO MCC-2 IF PROPELLANT COST IS NOT PROHIBITIVE TLI + 9 HRS

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE
APOLLO 12	FINAL (NOV 14)	OCTOBER 15, 1969	11:00 - 12:00	1/TLC	3-12

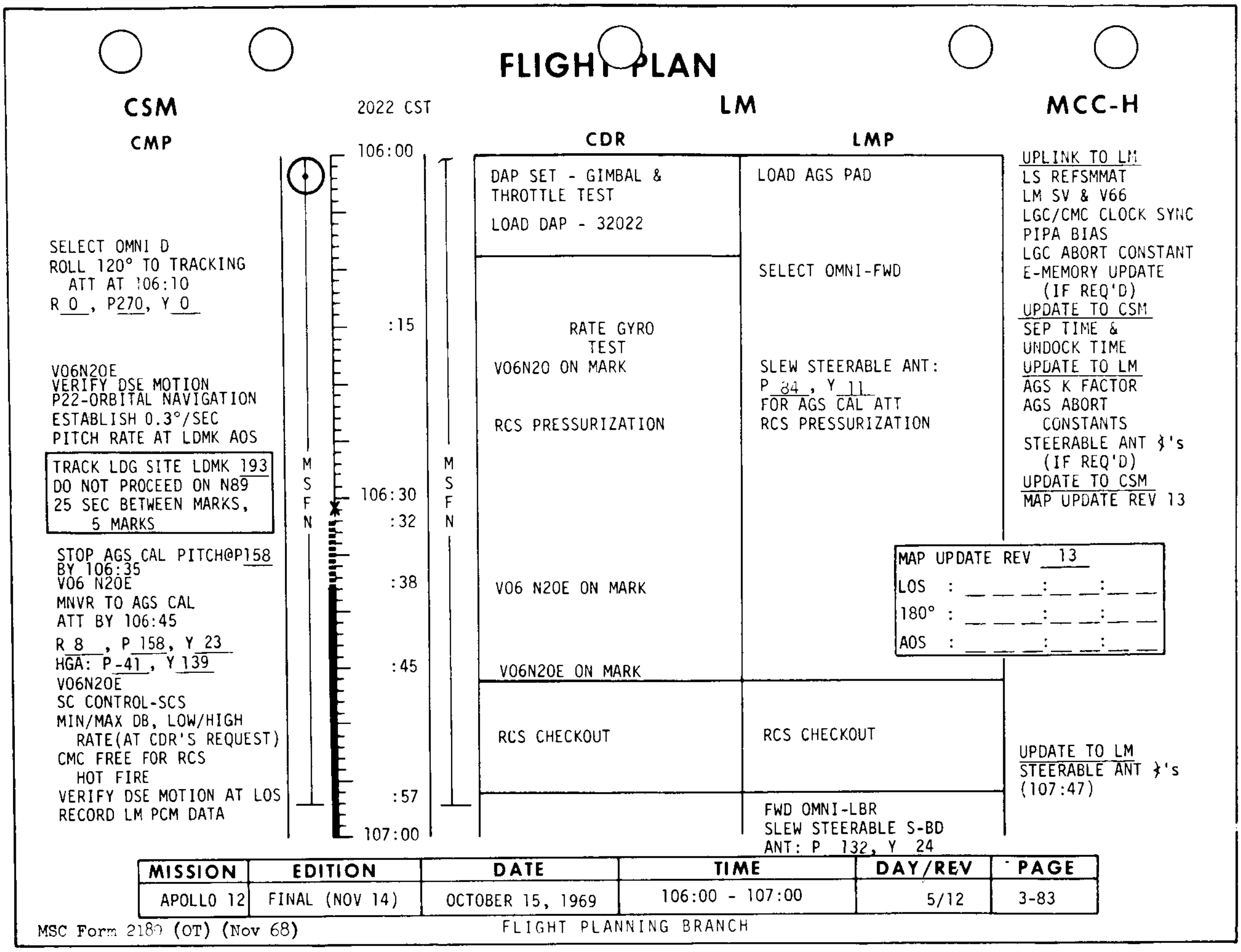
MSC Form 29 (May 69)

FLIGHT PLANNING BRANCH

Figure 11. - Excerpt from TLC period of Apollo 12 final flight plan detailed timeline.

is maintained during this hour if MCC-1 is not required. The rule that will be applied to determine if MCC-1 should be performed is also provided in the notes column. It also should be noted that the initial GET of 11:00 is equal to a central standard time (c. s. t.) of 21:22, if the launch occurred as planned, and that c. s. t. is indicated above 11:00 GET.

Planning for two vehicles more than doubles the information required during each hour of the timeline, and the level of detail presented becomes a controlling factor. A typical plan for 1 hour of operation of two vehicles in lunar orbit is shown in figure 12. Because the vehicles are in a 2-hour orbit at this time, acquisition of signal (AOS), loss of signal (LOS), and the spacecraft day and night cycles become very important and are indicated for both vehicles. Activity timing also increases in importance, and horizontal lines are drawn to indicate the required completion time of specific activities. Graphical presentations of the lunar subsolar point and the landing site are added by a 0.3-inch-diameter dotted circle and a heavy X, respectively. Emphasis is provided for tracking activities by enclosing them in a box similar to astronaut recording pads. An example is the map update in figure 12.



FLIGHT PLAN

CSM

CMP

2022 CST

106:00

SELECT OMNI D
ROLL 120° TO TRACKING
ATT AT 106:10
R 0 , P270, Y 0

:15

V06N20E
VERIFY DSE MOTION
P22-ORBITAL NAVIGATION
ESTABLISH 0.3°/SEC
PITCH RATE AT LDMK AOS

TRACK LDG SITE LDMK 193
DO NOT PROCEED ON N89
25 SEC BETWEEN MARKS,
5 MARKS

MSFN

106:30

:32

STOP AGS CAL PITCH@P158
BY 106:35
V06 N20E
MNVR TO AGS CAL
ATT BY 106:45
R 8 , P 158, Y 23
HGA: P -41 , Y 139
V06N20E
SC CONTROL-SCS
MIN/MAX DB, LOW/HIGH
RATE(AT CDR'S REQUEST)
CMC FREE FOR RCS
HOT FIRE
VERIFY DSE MOTION AT LOS
RECORD LM PCM DATA

:38

:45

:57

107:00

MSFN

LM

CDR

DAP SET - GIMBAL &
THROTTLE TEST
LOAD DAP - 32022

RATE GYRO
TEST
V06N20 ON MARK

RCS PRESSURIZATION

V06 N20E ON MARK

V06N20E ON MARK

RCS CHECKOUT

LMP

LOAD AGS PAD

SELECT OMNI-FWD

SLEW STEERABLE ANT:
P 84 , Y 11
FOR AGS CAL ATT
RCS PRESSURIZATION

RCS CHECKOUT

FWD OMNI-LBR
SLEW STEERABLE S-BD
ANT: P 132, Y 24

MCC-H

UPLINK TO LM
LS REFSMMAT
LM SV & V66
LGC/CMC CLOCK SYNC
PIPA BIAS
LGC ABORT CONSTANT
E-MEMORY UPDATE
(IF REQ'D)
UPDATE TO CSM
SEP TIME &
UNDOCK TIME
UPDATE TO LM
AGS K FACTOR
AGS ABORT
CONSTANTS
STEERABLE ANT }'s
(IF REQ'D)
UPDATE TO CSM
MAP UPDATE REV 13

MAP UPDATE REV 13
LOS : __ __ __:__ __:__ __
180° : __ __ __:__ __:__ __
AOS : __ __ __:__ __:__ __

UPDATE TO LM
STEERABLE ANT }'s
(107:47)

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE
APOLLO 12	FINAL (NOV 14)	OCTOBER 15, 1969	106:00 - 107:00	5/12	3-83

MSC Form 2180 (OT) (Nov 68)

FLIGHT PLANNING BRANCH

Figure 12. - Excerpt from Apollo 12 final flight plan detailed timeline covering simultaneous operation of two vehicles in lunar orbit.

Maneuvers occurring during a particular lunar revolution are presented graphically on separate pages, placed as closely as possible to the associated flight plan pages. The graphical presentation of the maneuver information appearing in figure 12 is shown in figure 13. More complicated maneuvers, such as tracking landmarks, also are presented graphically but in profile. The detailed profile of the landmark-tracking activity in figure 12 is shown in figure 14.

In summary, the detailed timeline represents the way in which the mission is planned to be flown. The unique features of graphical representation permit integration of trajectory data with astronaut activities. The use of acronyms and abbreviations directly associated with training procedures allows the flight planner to present a large volume of information on an 8- by 10-inch page.

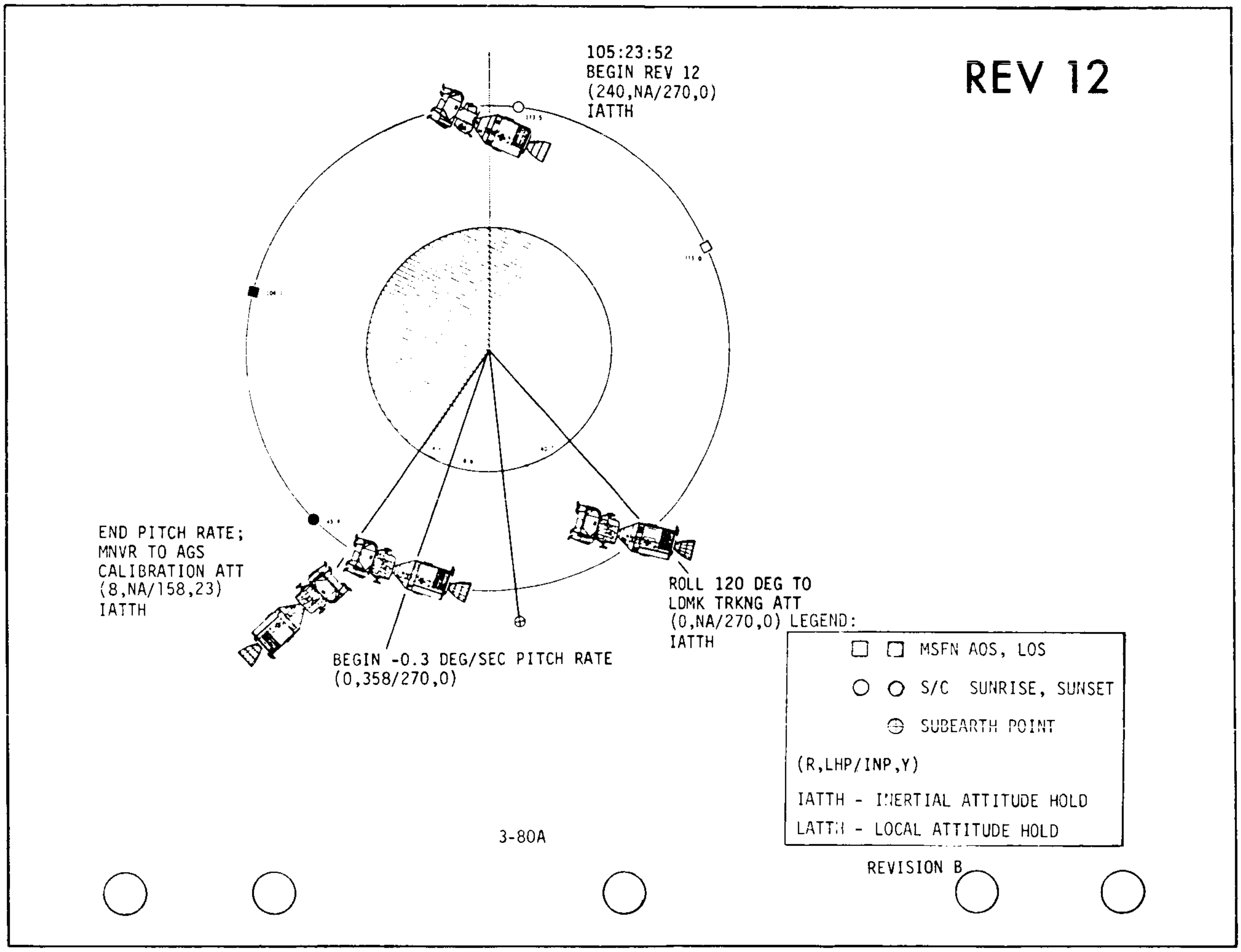


Figure 13. - Example of graphical presentation of spacecraft-maneuvering data in Apollo 12 final flight plan.

During the mission, the spacecraft crew and MCC flight planning team maintain the detailed timeline as the indicated activities are performed. A daily review of what has been accomplished and what is planned for the next day is conducted between the crew and MCC. The detailed timeline is carried on board as part of the flight data file and is one of the major displays in the MCC.

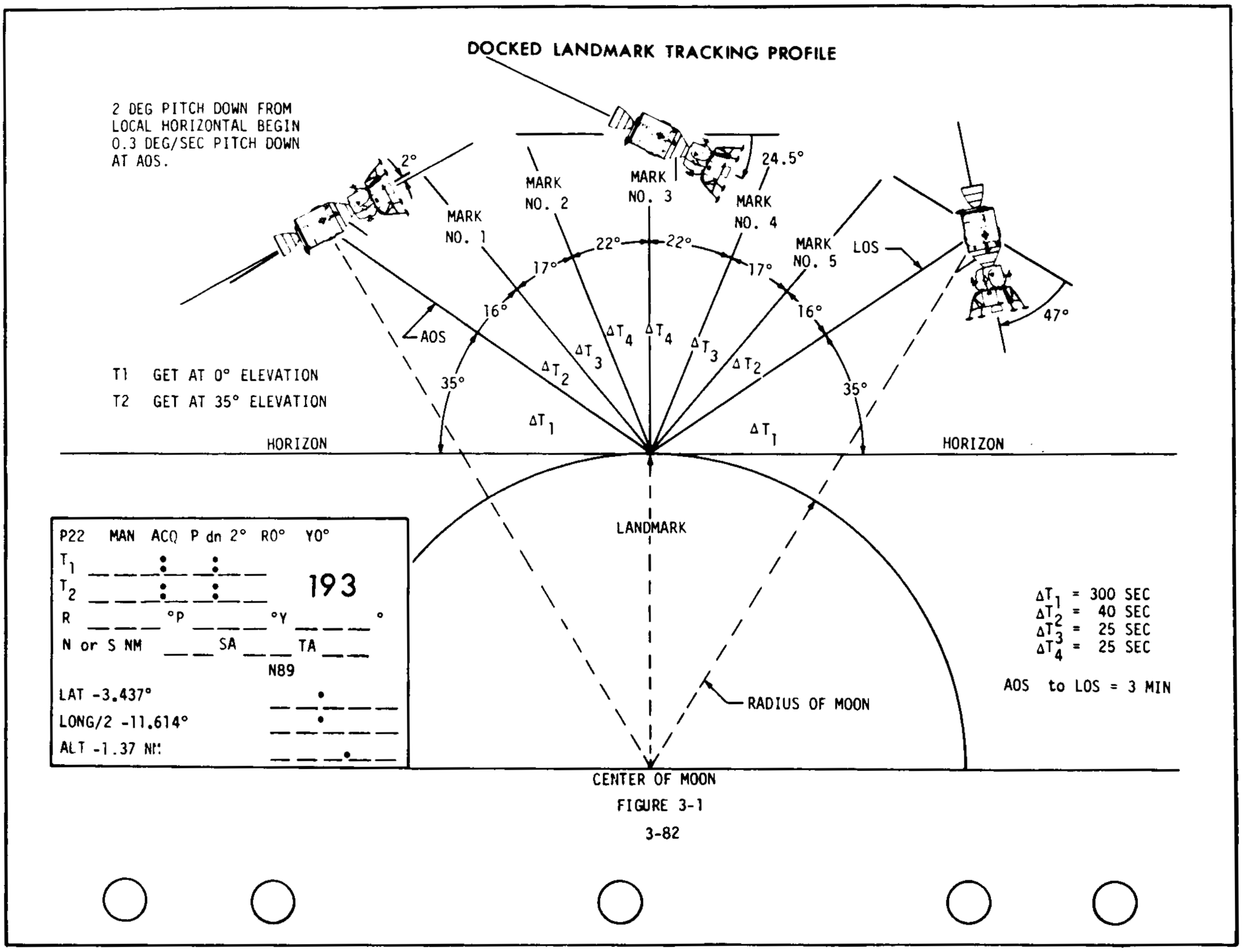


Figure 14. - Graphical presentation of landmark-tracking information from Apollo 12 final flight plan.

Selected Supporting Data

The need for supporting data directly associated with the planned-timeline consumables usage is obvious during premission planning. This information also must be available in the event of real-time replanning. This area of the flight plan consists of numerous charts and graphs presenting the predicted results of expending resources during the specific mission. The status of each resource must be planned from launch to splashdown for each activity affecting that resource. The predicted resource-usage data documented in the Apollo flight plan include information about propellants, cyrogenics, battery power, water, oxygen, and life-sustaining capabilities. A summary of the service propulsion system (SPS) propellant usage planned for the Apollo 12 mission is shown in figure 15. Similar summaries and detailed graphs are included for each expended resource. Additional details relating to each resource are supplied where assumptions are made or clarification is required for real-time application.

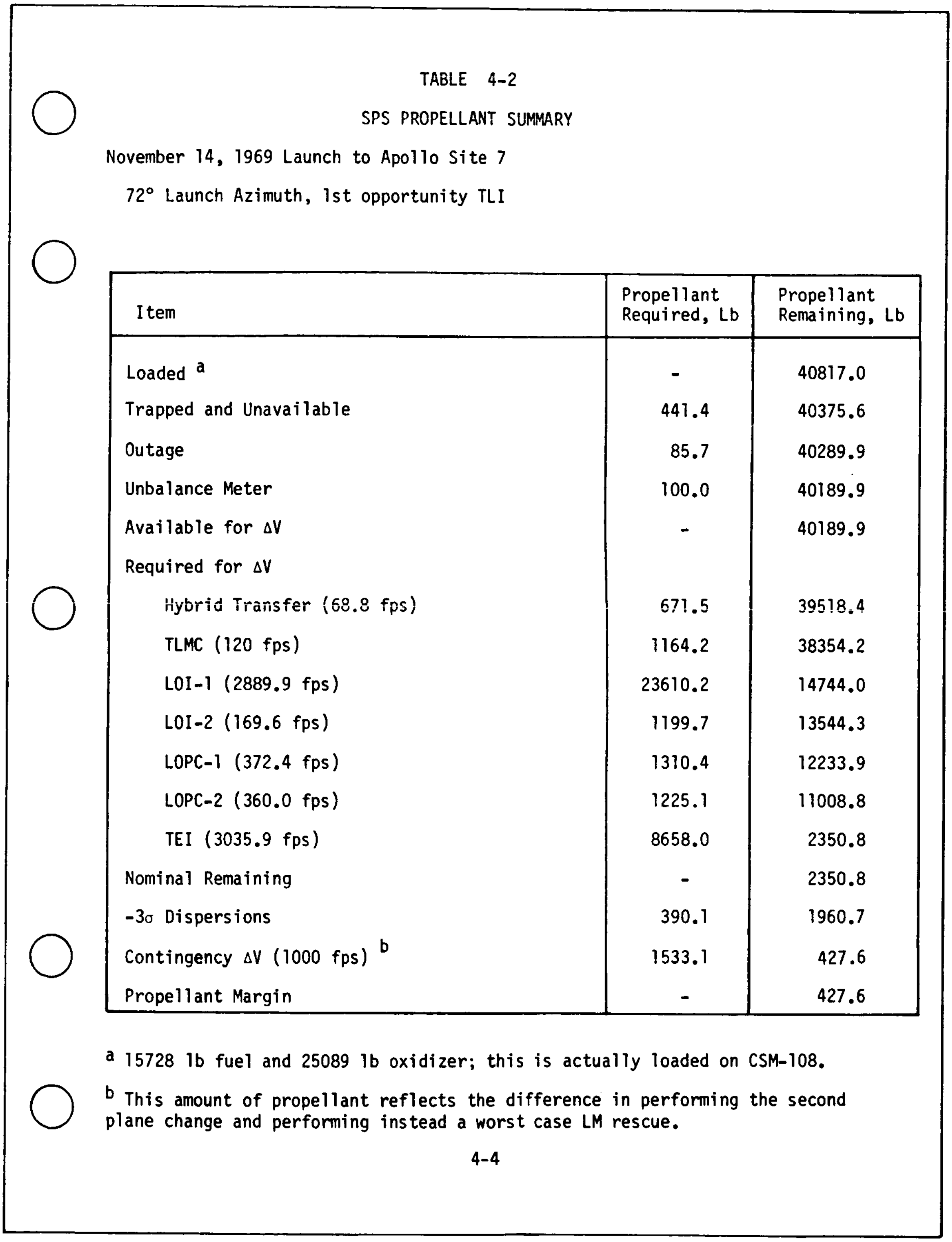


TABLE 4-2

SPS PROPELLANT SUMMARY

November 14, 1969 Launch to Apollo Site 7

72° Launch Azimuth, 1st opportunity TLI

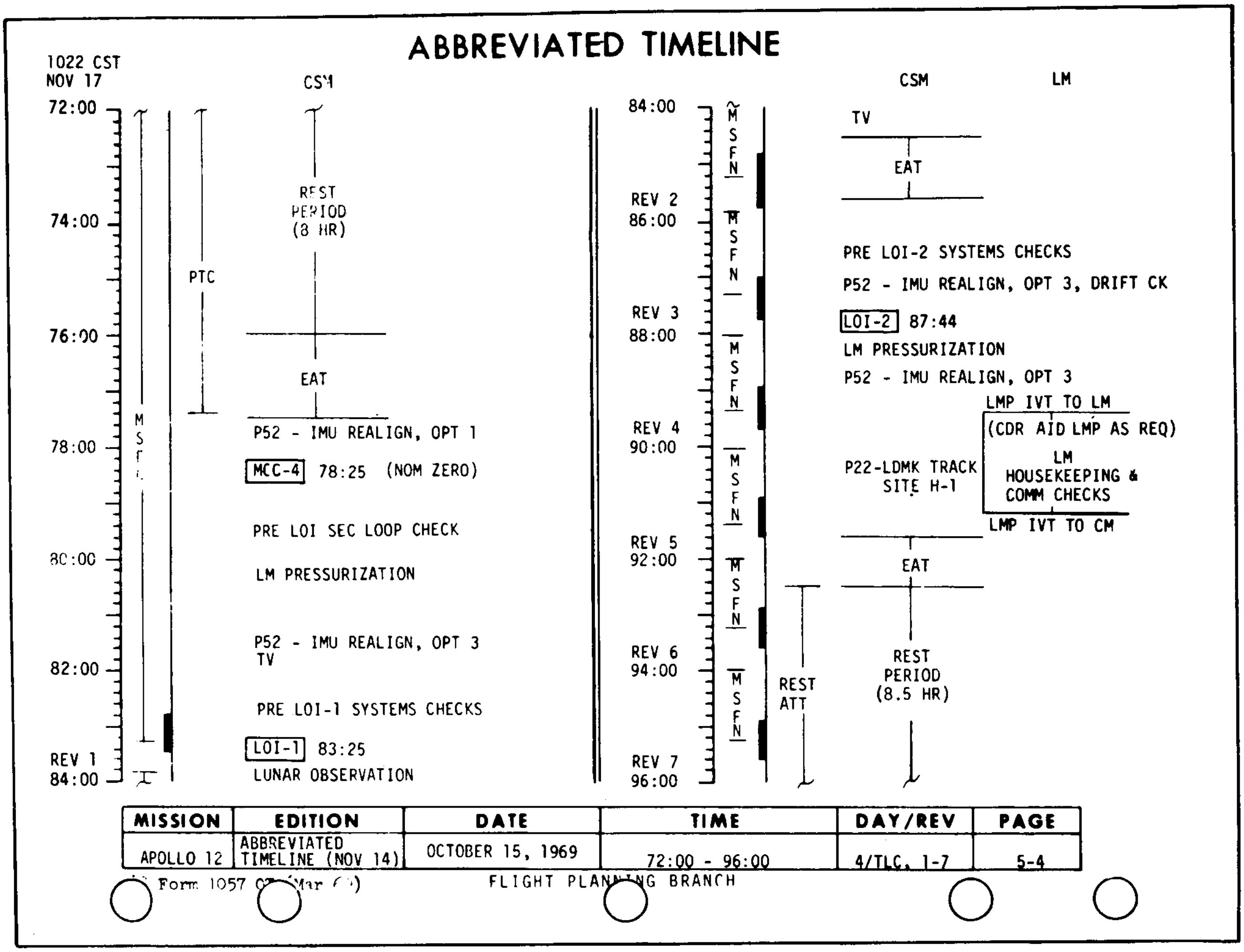
Item	Propellant Required, Lb	Propellant Remaining, Lb
Loaded [a]	-	40817.0
Trapped and Unavailable	441.4	40375.6
Outage	85.7	40289.9
Unbalance Meter	100.0	40189.9
Available for ΔV	-	40189.9
Required for ΔV		
Hybrid Transfer (68.8 fps)	671.5	39518.4
TLMC (120 fps)	1164.2	38354.2
LOI-1 (2889.9 fps)	23610.2	14744.0
LOI-2 (169.6 fps)	1199.7	13544.3
LOPC-1 (372.4 fps)	1310.4	12233.9
LOPC-2 (360.0 fps)	1225.1	11008.8
TEI (3035.9 fps)	8658.0	2350.8
Nominal Remaining	-	2350.8
-3σ Dispersions	390.1	1960.7
Contingency ΔV (1000 fps) [b]	1533.1	427.6
Propellant Margin	-	427.6

[a] 15728 lb fuel and 25089 lb oxidizer; this is actually loaded on CSM-108.

[b] This amount of propellant reflects the difference in performing the second plane change and performing instead a worst case LM rescue.

Figure 15. - Summary of service propulsion system predicted propellant usage from Apollo 12 final flight plan.

An abbreviated timeline is included as supporting data to provide a condensed 24-hr/page schedule for each phase of the mission. The contents of the detailed timeline are combined to form a daily plan that is phase oriented. Gross-level analysis of sleep periods and mission-phase durations are possible with this timeline. A typical page from the Apollo 12 abbreviated timeline is shown in figure 16. A larger view of activities such as sleep periods, eat periods, PTC, and thrusting maneuvers is presented, allowing the mission planner to interrelate these periods.



ABBREVIATED TIMELINE

1022 CST
NOV 17

CSM

72:00
74:00
76:00
78:00
80:00
82:00
REV 1
84:00

PTC
MSFN

REST PERIOD (8 HR)

EAT

P52 - IMU REALIGN, OPT 1

MCC-4 78:25 (NOM ZERO)

PRE LOI SEC LOOP CHECK

LM PRESSURIZATION

P52 - IMU REALIGN, OPT 3
TV

PRE LOI-1 SYSTEMS CHECKS

LOI-1 83:25

LUNAR OBSERVATION

84:00
REV 2
86:00
REV 3
88:00
REV 4
90:00
REV 5
92:00
REV 6
94:00
REV 7
96:00

MSFN

CSM LM

TV

EAT

PRE LOI-2 SYSTEMS CHECKS

P52 - IMU REALIGN, OPT 3, DRIFT CK

LOI-2 87:44

LM PRESSURIZATION

P52 - IMU REALIGN, OPT 3

LMP IVT TO LM

(CDR AID LMP AS REQ)

P22-LDMK TRACK SITE H-1

LM HOUSEKEEPING & COMM CHECKS

LMP IVT TO CM

EAT

REST ATT

REST PERIOD (8.5 HR)

MISSION	EDITION	DATE	TIME	DAY/REV	PAGE
APOLLO 12	ABBREVIATED TIMELINE (NOV 14)	OCTOBER 15, 1969	72:00 - 96:00	4/TLC, 1-7	5-4

Form 1057 (Mar)

FLIGHT PLANNING BRANCH

Figure 16.- Excerpt from abbreviated timeline of Apollo 12 final flight plan.

In outlining the planning approach to alternate missions, the supporting data are selected on the basis of applicability to detailed timeline generation and presented in a summary form. Alternates to the mission plan are presented in this manner and are included as supporting information. The bar chart in figure 17 is one of four alternate-mission summaries that supported the Apollo 12 mission. The assumptions that indicate the alternate-mission applicability, a sequence of events, and a schedule are presented in each chart. In actual use, the chart aids the flight planner in generating a detailed timeline for the selected alternate mission.

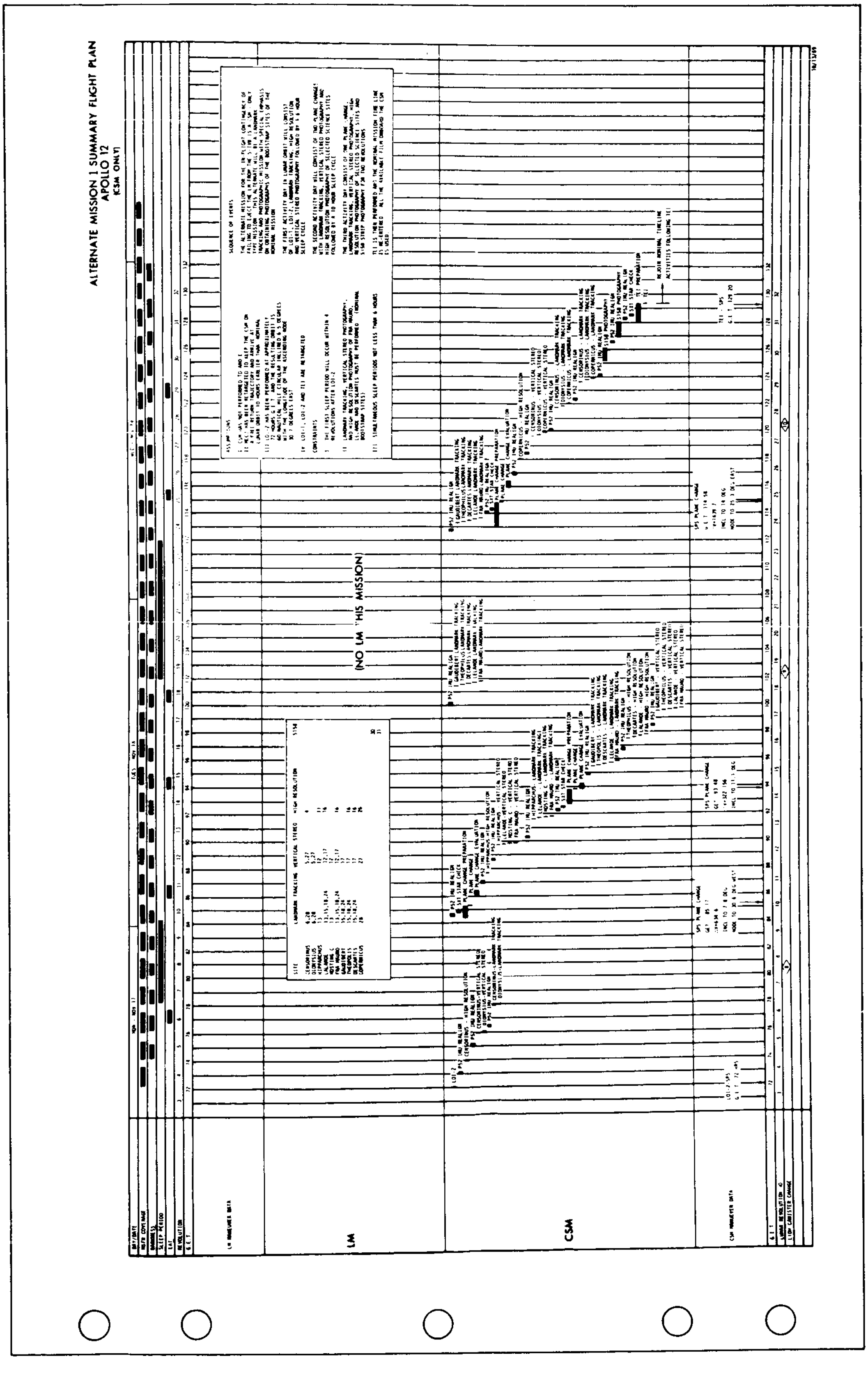


Figure 17. - Alternate mission 1 summary flight plan for Apollo 12 CSM.

FLIGHT PLAN SCHEDULES AND DATA REQUIREMENTS

In discussing the information-management process of actually developing a flight plan to the specifications established in the preceding sections, the following elements must be related.

1. The establishment of flight plan milestones and schedules
2. The gathering, relating, and verifying of all required data
3. The integration of the activity elements, including redesign where required
4. Real-time flight plan development and execution

Because configuration control is a basic element of any systems-engineering method, the manner in which flight plan change control is exercised will be discussed.

Factors Affecting Flight Plan Development Schedules

Effect of mission type on flight plan schedules. - The effect of the mission type (i.e., a research and development (R&D) flight or an operational flight) on flight plan schedules is shown in the following table.

Time before launch, month	Schedule	
	R&D flight	Operational flight
10	Begin partial support (2 men)	--
9	--	--
8	Begin full support (9 men)	Begin partial support (2 men)
7	--	--
6	Reference flight plan	Begin full support (4 to 6 men)
5	--	--
4	Preliminary flight plan	Preliminary flight plan
3	Begin integrated simulation support	--
2	--	Begin integrated simulation support
1	Final flight plan	Final flight plan

When preparing for an R&D flight, it is necessary to start earlier and to apply a more intensive effort and more total man-hours to develop the new procedures techniques and to train the crew properly. The primary difference in an R&D and an operational flight plan schedule is the inclusion of the reference edition. The purpose of this edition is as follows.

1. To establish planning guidelines and base lines for the total procedures and flight planning development effort

2. To establish or confirm the feasibility and practicality of assigned mission requirements

3. To provide a basis for preliminary training

4. To identify operational problems in a time frame that allows them to be solved

The need for these considerations diminishes as the program moves into the operational phase, or, at least, the magnitude of the problems being solved by publishing a reference edition is reduced to a manageable level, and the reference edition is replaced by the experience gained on previous flights. A lower level effort staffed by highly experienced personnel normally is adequate for an operational flight plan, mainly because not as many new and untried activities occur on an operational flight as on an R&D flight.

Effect of launch frequency on flight plan schedules. - Thus far, flight plan schedules have been treated independently from launch schedules. The primary launch schedule effect results from the need to allow enough time after the previous mission so that new information can be factored into the preliminary flight plan early enough for this information to be of use to support crew training. Of course, the obvious factors, such as clerical support, available manpower, and the availability of critical input data, must be taken into account.

The effect of crew training, simulations, and integrated simulations on flight plan schedules. - The flight planning schedule must be compatible with the training schedule to provide the crew and training-support personnel with a procedural and timeline base line. With this compatibility, not only is the crew assured of training with the proper data, but an effective validation of the flight plan and procedures data is provided. Ideally, schedules would be arranged to allow training simulations between the publishing of the reference edition and the preliminary edition, and integrated simulations with MCC in the loop between the preliminary and final editions. Simulations after the final edition would be for proficiency only. Also ideally, flight plan and procedures inputs from simulations should be available before the final flight plan is published.

Support to and from other onboard data. - As explained previously, support from other detailed procedures is required for the flight in the form of checklists to provide the crew with the total spectrum of data required to fly the mission. The flight planner must be thoroughly familiar with these detailed procedures to perform his job of total integration of activities. Therefore, detailed procedures development must precede the flight plan development. On the other hand, some onboard data are mission dependent and are closely related to the flight plan. In these cases, the flight plan development must precede the onboard-data development. This varying interrelationship of procedures and flight plans can be handled only by well-defined and close-working relationships between the flight planning and procedures-development groups.

Data Requirements

Systems-operation data and systems constraints. - To design a flight plan that is operationally usable for performing a mission, operational data are required for the various systems. Mission objectives require various systems to be used in varying modes; therefore, an understanding of how the systems can be used is required to determine if the objective is feasible and compatible and could be scheduled in the flight plan. The following is an example of how a systems operation can affect the flight plan. On the Apollo 12 mission, a new program was added to the onboard computer that provided the capability to program a given spacecraft pitch rate automatically. However, in examining the operation of this new capability, a systems anomaly was found. The anomaly was that the automatic-pitch-rate program was economical, with respect to propellant, only in the heads-up orientation (0° roll) and was not suitable for use heads down (180° roll). Thus, the attitudes in which this new capability could be used were constrained by these operational data. The operational performance data were also useful in pointing out that this pitch-rate capability could be modified so as to be useful in attitude orientations other than 0° roll without prohibitive propellant consumption.

Systems constraints affect the scheduling of activities in a flight plan. For example, fuel-cell purges of hydrogen are constrained by a requirement to have the hydrogen-purge-line heaters on at least 20 minutes before a purge to avoid freezing and blocking of the purge line. Therefore, it is necessary to have constraints of this type in the flight plan to assist the crewmen and to avoid any systems problems that would result from neglecting the constraint.

Mission requirements. - Mission requirements are usually the first planning-data inputs available on a mission and generally give an initial indication of what objectives are being considered. Usually, a rough draft of the mission-requirements document is distributed for review and comment on the feasibility of the various objectives. After this review, some objectives usually are deleted or modified. The mission requirements define some of the constraints of each objective, such as trajectory requirements, spacecraft-systems requirements, telemetry (high bit rate), and attitude requirements. These constraints must be known to schedule activities in the flight plan and to determine compatibility. In addition, the mission-requirements document lists the objectives in order of priority, which assists the definition of the scheduling sequence for activities in the flight plan and provides a critical input to scheduling trade-offs. A priority list also is required in real time to determine which objectives are to be performed if the mission is to be altered by a real-time problem.

Trajectory data. - Trajectory data are (as a whole) one of the basic requirements of a flight plan because the trajectory, with definition of the major propulsion events, forms the basic framework of the mission and because many of the mission objectives are trajectory dependent and cannot be scheduled until a trajectory is available. Once a trajectory is generated, some of the activities, such as major burns, are scheduled in the flight plan automatically, thus outlining the flight plan for the scheduling of the remaining activities. Some of the types of trajectory data that are required for the flight plan to satisfy trajectory-dependent objectives are as follows.

1. Tracking-station coverage

2. Shadow timeline (when the spacecraft is in the shadow of the earth or moon)

3. Spacecraft ground-tracking information

4. Burn data

Trajectory data also are required for some flight-data-file items (such as lunar maps, star charts, procedures books for rendezvous and lunar descent or ascent, and checklists) that require time references to critical trajectory events. Trajectory data required in addition to those already mentioned for the flight plan are as follows.

1. Reference stable member matrix (REFSMMAT) for use on star charts

2. Position of the earth and moon with respect to the spacecraft during TLC and TEC, for use on star charts

3. Lunar module descent parameters

Trajectory data also are required to generate spacecraft attitudes for performing certain activities such as landmark tracking and high-resolution photography.

Because so many factors are dependent upon the trajectory, both in the flight plan and in the flight data file, changes to the trajectory data have a more drastic effect on the flight plan and flight data file than any other type of data change.

DEVELOPMENT OF THE FLIGHT PLAN TIMELINE CONTENT

Each successive program and, to a degree, each operational phase within the program require the development of a timeline format and the inclusion of varying timeline-content data to meet the increased requirements in mission and spacecraft-operation complexity. A history of the evolution of the timeline and of changes in concept has been presented, and it is reasonable to assume that the content and format of the timeline will continue to evolve to meet future requirements. The variable factors, the methodology, and the general guidelines based on experience that have gone into the makeup of the timeline for past Apollo missions are presented in this section.

The timeline is a real-time operational document and it is required to accomplish the following basic functions.

1. Identifying or calling out applicable crew procedures for accomplishing scheduled activities

2. Being of sufficient content and detail to permit a precise consumables analysis

3. Scheduling all activities to enable the crew to fly the mission and accomplish the objectives

4. Identifying ground-interface requirements that affect crew activities

5. Supporting the preparation of the flight data file

6. Supporting premission training and simulations

7. Supporting real-time mission control

The first six of these items also can be used as a set of criteria for the flight planner to test and verify that any formulated timeline meets the intended function.

Abbreviated Timeline as a Worksheet

It has been the experience of the flight planners at MSC that it is desirable first to lay out the mission highlights and sequence of events on an abbreviated timeline to a condensed time scale. The abbreviated timeline (fig. 16) generally is laid out with 24 or more hr/page. It is used as a working paper to provide overall mission visibility and conflict detection for integrating crew work/rest cycles and major mission events and for scheduling recurrent events such as systems checks and canister changes. This flight planning worksheet can be constructed independently of detailed trajectory data and is prepared commensurate with the amount of supporting data available at the time of planning. It can be used to support a wide variety of initial premission planning, such as consumables-analysis feasibility studies and the premission activities discussed in the section entitled "Background of Flight Planning for Manned Space Missions." It also is used to incorporate changes for relocating trajectory events for more efficient crew integration or event scheduling. The abbreviated timeline is also valuable in giving a mission overview at mission reviews and mission presentations to management.

After an abbreviated timeline has been completed, reviewed, and generally approved by the crew and mission-operations personnel, the flight planner is ready to proceed with integrating the trajectory, the mission requirements, and the crew activities into a detailed timeline.

Detailed Timeline Format and Content

The flight planner has to consider six general areas when deciding upon the content or the amount of information to be presented in the timeline. Each of these areas has to be understood and evaluated separately and collectively to determine the effects of the type of flight plan on timeline content. However, in all cases, the level of content should be sufficient to meet the timeline functional criteria.

1. Mission phase. A mission phase is defined for discussion purposes as a time interval in the trajectory when the spacecraft is either in powered (propulsive) or coasting flight (including lunar stay). Lunar module powered descent, TLC, and orbital flight between maneuvers are examples of mission phases. A powered-flight phase, being trajectory related, is usually fixed in time, and the flight planner must schedule

all activities around these phases and the associated times. If a given mission has long periods of coasting flight between powered phases, these periods are ideal for scheduling experiments and system tests. In each phase, however, the flight planner must schedule those housekeeping and periodic systems checks necessary to maintain spacecraft-systems condition or readiness.

2. Crew activities. Certain periods of the mission require a higher density of crew-activity scheduling than others. One example of high-density scheduling is the LM activation and checkout before undocking in lunar orbit. Preparation starts at a time before undocking as determined from premission simulations, overall activities for the workday, and work/rest requirements. Each crewman is engaged in portions of the integrated procedure leading up to undocking. These periods often require as much mission-related supporting-content data on the timeline as possible, such as attitude information for rotational maneuvers, antenna-pointing angles, navigation stars, and digital-autopilot data loads. Activities for each crewman usually are shown in column form on the timeline, with 1 hr/page.

Coasting flight phases generally are periods of light crew activity. For these periods, the timeline usually is formatted with 2 to 4 hr/page.

3. Onboard data requirements. The timeline normally makes reference to the crew procedure for accomplishing the scheduled activity. The crew then refers to the appropriate checklist in the flight data file for the total procedure. However, at times, it is desirable to add the procedural steps in the body of the timeline. In the Apollo Program, the timeline has served as an index to the flight data file, and there have been few instances where procedural steps have been included in the content.

The flight planner must be fully cognizant of the total flight data file and must continually monitor it to perform the following functions.

a. Ascertaining that procedures are available for each scheduled activity documented either in the flight data file or within the timeline

b. Ensuring that the timeline and the flight-data-file elements are in agreement and are completely compatible

c. Avoiding duplication of premission planning and development effort

d. Ensuring that supporting graphics are available for celestial and land navigational activities

e. Ensuring that procedures are available for various contingency situations that may arise during flight

4. Mission test objectives. All missions are designed to fulfill a given set of mission requirements or objectives. The first few flights of a new spacecraft design are flown to obtain operational data for the purpose of evaluating and verifying onboard systems. These missions, referred to as development-type missions, contain a large number of systems-test objectives. Later, as the program reaches the operational phase, these systems-test objectives are replaced by experiment objectives. Systems

tests and experiments have individual timeline-content requirements that must be tailored to the specific objective.

Each time a systems test or experiment is scheduled, it is desirable to include in the flight plan a reference to descriptive information on the objective, for the use of management or sponsor personnel. Often a systems test or experiment will require an onboard log to record update-support data or to record parameters not available on telemetry. It is often desirable to add these logs to the body of the timeline.

5. Ground-interface requirements. The ground interface involves scheduling ground-support functions to support the flight activities. The ground support may be in the form of verbal updates, real-time systems commands, or the recording of telemetered data. Timelines for later Apollo missions have added an "MCC-H" (Mission Control Center, Houston) column for scheduling ground-interface activities.

6. Mission-unique details. Mission-unique details are a function of the individual format requirements unique to each mission and relate to supporting data added to the timeline. These data may be reminders to the crew of a procedural step, listings of specific targets during a scheduled target-of-opportunity photographic session, distance from the earth during TLC, and so forth. Because this information is tailored to assist the crew, no set rules for formulation exist.

Final Abbreviated Timeline

The final abbreviated timeline is prepared after the main timeline has been completed and is a precise and updated version of the timeline worksheets used as a first step in the flight planning process (fig. 16). The format and level of content of the abbreviated timeline are usually the same regardless of the type of mission. The purpose is to present, for management, a synopsis of the mission and mission activities.

Interaction of Detailed Flight Planning, Trajectory Refinement, Procedures Development, and Crew Training

The data required to support mission planning at any point in the cycle are functions of the state of procedure development and the phase of crew training.

Trajectory interaction. - When the flight plan is first compiled on the basis of the preliminary mission requirements, the trajectory data regarding MSFN acquisition and daylight/darkness are all that are required. As the detailed procedures are developed to support the flight plan, the need for data increases. For many procedures, systems data are required that define systems limits for monitoring the systems as the procedure is performed. For example, as the reaction control system (RCS) is pressurized in flight, the pressure and temperature limits defining a safe, fully operable system are required to monitor the system. The measurements are monitored through the pressurization sequence and, at the end of the procedure, the crew can know the general condition of the RCS.

During the development of the procedures for some phases, detailed trajectory data are needed to provide realistic trajectory-monitoring procedures. For example, during launch, data on velocity and attitude as functions of time are required to monitor the boost trajectory. Trajectory limits for phases of the trajectory are needed to provide the crew with the information for abort procedures or the taking of alternative action.

As the procedures are developed, the flight planner must have more information on attitudes, landmarks, and other details. The most efficient maneuvering rates must be determined. The time required to perform activities based on landmark availability or star availability becomes more critical. Consumables budgets are needed to decide whether all the activities can be performed.

Crew constraints. - When the flight plan is first developed, crew constraints are of prime concern. The obvious constraints are work/rest cycles, eat periods, interior spacecraft mobility, and the number of crewmen required for a given task. Other crew constraints become obvious during crew training. For example, in certain situations, a crewman cannot don his suit without the aid of another crewman. All these crew constraints are important factors in determining the scope of the mission workload, the amount of time that can be allotted for activities, and the time when major events can occur.

The work/rest cycle plays an important part in the structure of the mission. Because changes in mission events or in the crew's anticipated work/rest pattern often occur in real time, the premission planning must allow for considerable flexibility. On the first lunar-landing mission, the planned lunar-surface exploration activities were to have occurred after a sleep period scheduled between touchdown and the EVA. It was anticipated that the crew's good condition and the general situation might lead to EVA ahead of schedule, and alternate lunar-surface timelines were prepared that would allow adequate rest after EVA. In fact, the crew did perform the EVA before the rest period.

Other constraints must also be considered. Because food preparation and eating in zero gravity require techniques different from those on earth, sufficient time must be allotted for meal periods. Mobility is important when planning EVA or dual-vehicle transfer operations. The ability of a crewman to move about the lunar surface and to carry tools determines the sequence and timing of geological and other scientific experiments. In summary, while making use of the full and unique capabilities of man in space, the constraints that help define his role must be observed.

Relationship to crew training. - After the first detailed version has been completed, the further development of a timeline depends to a great extent on crew training. Although the activity schedule appears efficient and reasonable on paper, the schedule may prove to have undesirable features when the crew begins training in a simulated environment. An example is the development of the LM activation checklist. The flight planner prepares a schedule of activities in the timeline and allots a reasonable amount of time to perform them. The crew then trains with the timeline and checklist and rearranges the activities to improve the flow from one activity to the next and to refine the time requirements for the activities. The time needed for this critical function has decreased on each subsequent mission.

By training with the flight plan and procedures, the crew often determines that more data are necessary in certain areas and that, in other areas, all the data available in the flight plan or flight data file are not needed. Crew training has the greatest impact on data requirements and format, because the procedures and mission simulators provide the most direct means of assessing the adequacy and utility of the flight planning data.

Simulation verification of operational data. - When simulation of critical mission phases begins, most of the data requirements are fulfilled and the data are available. The types of nonprocedural data that can be checked are attitudes, star availability, the transformation between inertial alinements, antenna angles, burn parameters, and consumables predictions.

The data are verified by simulating the activities in detail and then monitoring the performance as it would be done in flight. During the debriefings after the simulations, any problem areas can be discussed, discrepancies can be reviewed and resolved, and alternatives can be proposed. Because most of the activities are simulated more than once, the data can be doublechecked and new data can be verified.

Once the crew has trained on the individual phases of the mission, integrated mission simulations are started. The integrated simulations are the best preflight method of verifying the operational data in the flight plan. These simulations involve everyone who has a part in supporting the mission in real time. From these simulations, the flight planner receives corrections and changes to eliminate trouble spots and errors. From all these inputs comes the final version of the timeline that will be used during the mission.

REAL-TIME OPERATIONS IN THE MISSION CONTROL CENTER

The real-time operations with respect to the timeline involve making any changes or updates that are necessary as a result of events in the actual mission. If everything went precisely as planned, the timeline would require no corrections during the mission; however, some changes have always been necessary in practice.

An example of a real-time change is the effect of performing lunar orbit insertion (LOI) at a time other than the time planned. During the early lunar missions, the LOI targeting program of the Real Time Computer Complex was constrained only to target LOI to begin over a particular point on the lunar surface. As a result, the LOI time always differed by several minutes from the premission-planned time. This difference required that all lunar-orbit activities be performed based on the difference in the LOI time. In later missions, the LOI targeting program was changed to include the preferred time of LOI in targeting the LOI burn. The LOI burn could then be targeted as close as possible to the premission-planned time.

Other types of timeline changes result in problems such as equipment failures. In the case of a problem that arises during an activity, the flight planner first tries to develop a work-around procedure. If the problem cannot be solved without affecting the schedule of activities, the flight planner develops an alternate timeline that will accomplish everything that is required. If no way exists to accomplish all the activities, he consults the affected parties as represented in the MCC to generate a priority listing of the activities. This listing is then used to reschedule the activities to accomplish as many of the highest priority activities as possible. A procedural problem occurred during the first lunar mission, when the procedures for starting PTC resulted in excessive pitch and yaw deviations, while rolling to achieve the desired thermal effect. A new procedure had to be developed and implemented in real time. An example of an operational problem that affected the scheduling of activities was the rescheduling of lunar-landing-site photography because of trajectory dispersions. Consequently, the photography had to be incorporated in the critical revolution before the transearth-injection burn. In the case of an equipment failure, activities might be deleted that could not be performed or the timeline might be revised so that the sequence would be performed differently to work around the failure.

The flight planner also attempts to keep the timeline completely updated to correspond to actual events and times, so that the timeline can support any subsequent analysis and can be used in planning the next mission.

CONTINGENCY AND ALTERNATE FLIGHT PLAN DEVELOPMENT

The flight planner must be prepared to meet the eventualities of problems occurring after launch that alter or compromise mission objectives and of problems before launch that delay the mission. For this purpose, contingency and alternate flight plans are developed before the mission.

Contingency Flight Plan Development

A contingency flight plan is a preplanned, nonnominal timeline in which it is assumed that a mission-rule violation prevents the accomplishment of some of the planned objectives.

Purpose of contingency flight plans. - The purpose of a contingency flight plan is to aid in the accomplishment of as many mission objectives as possible and in the implementation of new objectives, considering the nature of assumed mission problems. As such, the contingency flight plan is a guide for premission evolution of engineering, scientific, and management requirements into agreed objectives and priorities based on the assumed nonnominal mission. Therefore, the real-time flight planning effort is minimized and spacecraft and crew utilization is maximized.

Development of contingency flight plans. - The contingency flight plan evolves primarily from the nominal flight plan with specific-trajectory data, crew inputs, and test objectives intermeshing in the development of the nonnominal portions just as in the production of the nominal timeline. Additionally, the following requirements must be considered.

1. The type and number of failures or mission-rule violations that in turn specify the number of parts or phases into which a mission can be logically divided

2. Candidate or contingency objectives

3. The flexibility of the spacecraft, crew, experimental and photographic equipment, and trajectory, which would enable accomplishment of these objectives

Because numerous failures could perturb the nominal timeline, the number of contingency flight plans must be limited in regard to unspecified or general problems that prevent the continuation into the next planned phase. For example, in the case of translunar injection (TLI), "no TLI" encompasses a large number of problems that could define a "No-Go" for TLI (S-IVB failure, failure of two CSM fuel cells, improper orbit, etc.). The mission as planned cannot continue; however, a minimum number of contingency flight plans can be developed to provide a wide range of earth-orbital missions. The possible alternatives available for a typical lunar-landing mission, considering the broad failures shown, are traced graphically in figure 18. It is possible to limit the number of contingency cases further by defining contingency objectives, selecting priorities for these, and considering the constraints of existing onboard photographic and scientific equipment. Those contingency missions in which little operational or scientific knowledge can be obtained with spacecraft and onboard equipment are eliminated from consideration. For example, a lunar-landing mission consisting of experimentation designed for operation exclusively in the lunar environment would be of little use as an earth-orbital mission, which, consequently, would have low priority as a

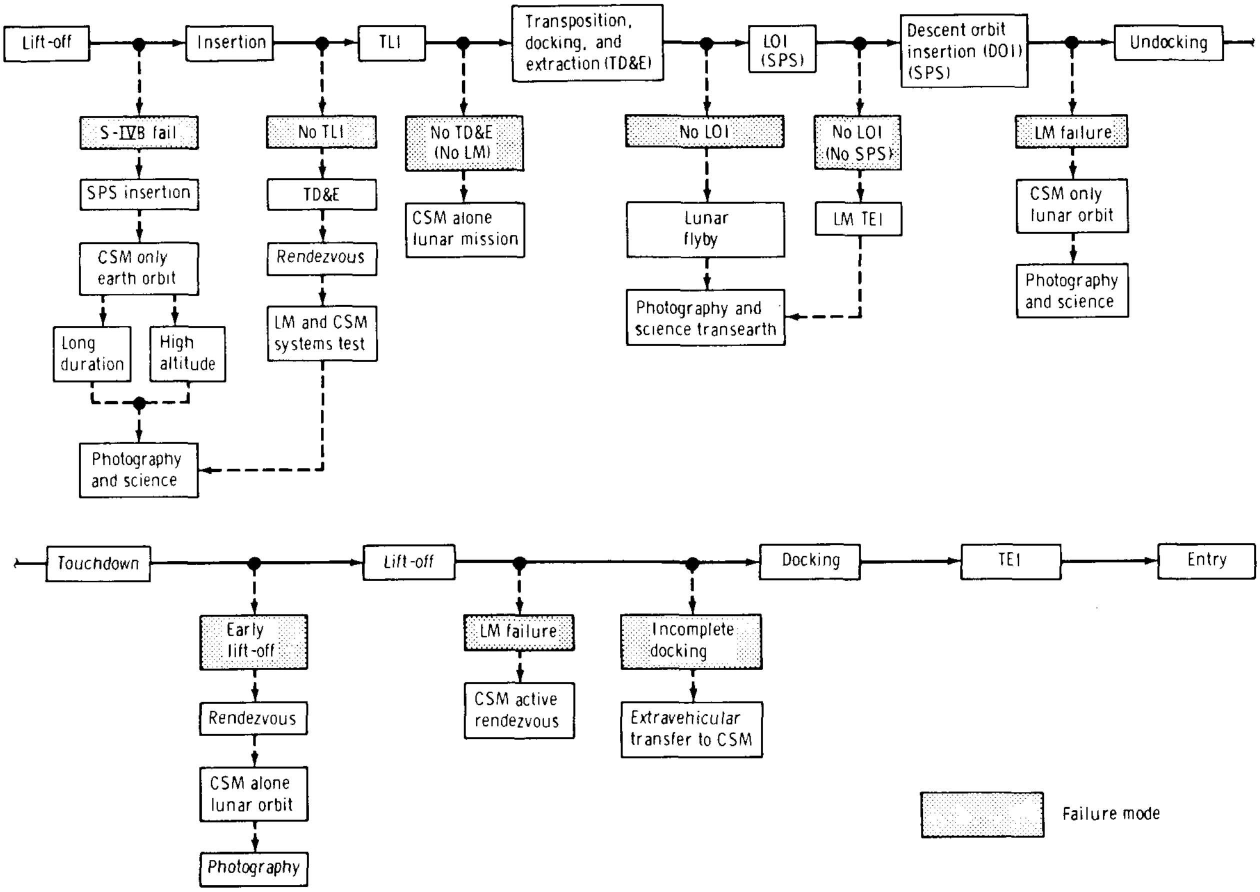


Figure 18.- Contingency flight plan breakdown.

contingency case. Alternatively, a lunar-orbit photographic mission would be considered for a contingency earth-orbital mission. In the latter case, however, camera constraints, film type, and so on would have to be considered, as would the trajectory requirements for photographing targets of interest.

In summary, a contingency flight plan is developed through the following steps (somewhat oversimplified for the purposes of this report).

1. On the basis of the nominal timeline, candidate contingency situations are defined by assumed failures.

2. Based on this definition of contingency situations, situations are selected that possibly can support the planned objectives and into which new objectives can be implemented.

3. Trajectory data and a work/rest cycle are incorporated into the timelines; timelines and objectives that are incompatible or made useless by trajectory constraints are eliminated.

4. Contingency timelines or objectives that are not within the capability of existing spacecraft, crew, and equipment operation are eliminated.

5. Priorities of each objective are defined and scheduled accordingly in the contingency timeline.

Contingency flight plan format. - The typical format presently used on Apollo missions is illustrated in figure 19. In this capsule form, easily interpreted general flight plan data and much of the data found in the nominal flight plan are provided. The advantage of this format over the typical hour-per-page format is the compressed scale and condensation of activities, which enable a quick overview of the plan. Although this format is less informative and instructive than the detailed timeline, the capsule form is sufficient as a guide to the use of the checklist and activity sequence. The chief disadvantage of the hour-per-page format is the cumbersome size (number of pages), complicated by the fact that several contingency flight plans must be produced, printed, and carried on board. For this reason, the graphical form is often preferred by the crew even at the expense of detail.

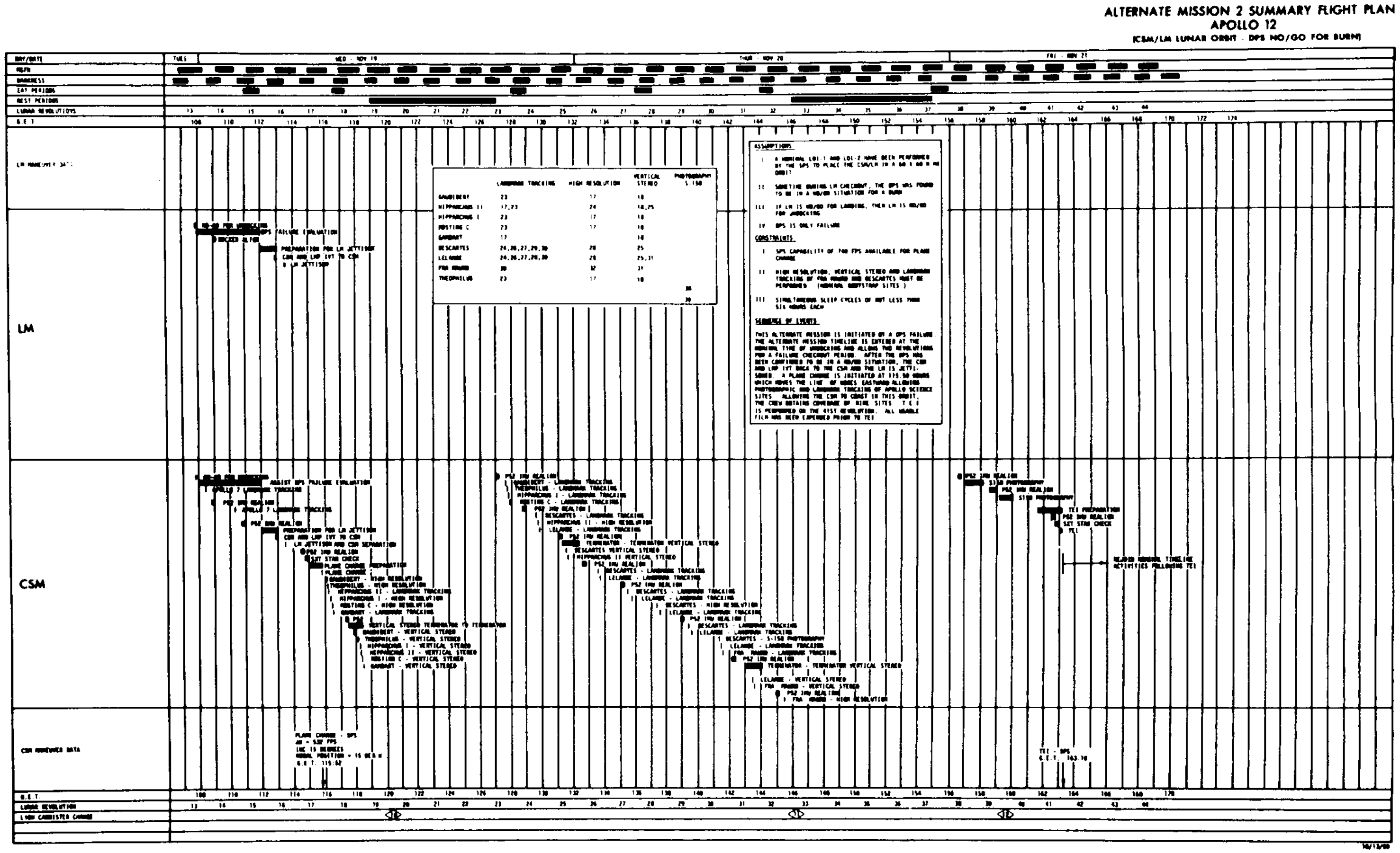


Figure 19. - Typical Apollo mission contingency flight plan format.

Alternate Flight Plan Development

An alternate flight plan is a preplanned timeline that is identical to the nominal timeline except for trajectory effects resulting from different launch opportunities.

The purpose of an alternate flight plan is to provide a detailed timeline in the event that the prime launch day is delayed. Alternate launch opportunities are predetermined to ensure the accomplishment of the same mission objectives as called for in the prime mission plan.

The alternate flight plan evolves exactly the same way as the nominal flight plan. First, trajectory data are run for a selected number of launch opportunities limited by spacecraft turnaround time and other nontrajectory constraints. From these runs, a few launch opportunities (usually two) are chosen that satisfy the prime-launch-day mission objectives. For a lunar-landing mission, for example, the landing-site availability, lighting conditions, and other moon/earth-geometry conditions are considered in selecting the launch day. For earth-orbital missions, the number of launch days is unlimited except for spacecraft turnaround and specific experiment conditions. In this case, however, only a few (usually two) launch opportunities are chosen because of the workload involved with developing each plan.

The final alternate flight plan differs little from the nominal flight plan, except that the launch day, launch time, day/night times, MSFN coverage, crew activities, and so on are modified slightly. Depending upon the number of launch opportunities, the same formats used in the nominal or contingency flight plans are used.

FLIGHT PLAN CHANGE CONTROL

An inherent part of any well-managed hardware-development program is the establishment of design-freeze milestones and methods of hardware configuration control. It is difficult to imagine an item of hardware that could not be improved upon in some way; but, in the development schedule, a termination point for the period of wide design latitude must be selected. After that freeze point is reached, any further changes that are proposed must receive adequate management scrutiny to ensure that the value of the change in the product justifies the cost of implementation.

Mission planning and procedures development have even more latitude and undoubtedly are even more open to continual optimization than hardware development. The trade-off on mission plan and procedures changes is the gain in the probability of crew safety and mission success compared with the implementation cost in terms of consumables reserves, the effect on other mission objectives, or the effects on crew and ground-control preparation and training. Only the operational effects of mission plan and procedures changes will be discussed, because the costs and program-schedule impacts, which can be significant in extreme cases, are outside the scope of this report.

Candidate Change Evaluation

Any changes to the mission plan or procedures that clearly enhance crew safety are implemented whenever feasible. As for the handling of other categories of changes, a complicating factor is the fact that many of the changes are the type that become evident only after the mission planning and simulation schedules are quite far advanced. The two primary reasons for this situation for the first six manned Apollo flights were the following.

1. The elapsed time between missions was minimal. Detailed assessment of all data and experience gained from one completed mission and agreement on the proposed changes in the following mission could not be done before the planning-and-procedures-development cycle for the next mission was well underway to meet the launch schedule. Inadequate time was available to develop backup procedures for all possible contingencies because of the number of changes being worked against nominal procedures. (Over 1000 changes were considered for implementation in the 30 days preceding the Apollo 11 launch.)

2. As was pointed out previously, the primary sources of mission plan and procedures refinements are the simulations, particularly the integrated simulations that combine flight crew and flight controller training. Changes inevitably result as the simulation cycle progresses to the point that training experience indicates improvements that definitely are desirable.

As mission planning and crew training mature, an increasing factor in the cost of implementing a change is the possible negative effect on crew training. A change that, in itself, is worthwhile in terms of the direct benefit and cost trade-off may have to be discarded or not implemented until a subsequent mission because critical procedures or sequences are changed that have been well established through training, and inadequate time or justification exists for training in a new mode of operation.

Flight Plan Configuration-Control Process

Up to this point, changes have been discussed with respect to the mission plan and procedures (i.e., trajectories, communications plans, crew mission procedures, and systems procedures). The flight plan encompasses all these areas of possible change because it is a time-sequenced summary of all crew and ground-control activities. It is, therefore, imperative that the flight plan change-control system start with change-control systems for the flight plan data sources. The evolution in flight plan change control from Project Mercury through the present phase of the Apollo Program followed the expected trend as operations management moved from relatively small and closely knit NASA and contractor groups to the large and diverse organizations required to perform a lunar-landing operation. Flight plan configuration control was no longer possible through small and somewhat-informal meetings of key program management and operations personnel as it was in Project Mercury and, to a large extent, during the Gemini Program. It was necessary to develop formal-operations change-control groups as well as hardware-configuration-control groups to manage the Apollo Program effectively.

The major MSC operations change-control boards of the Apollo Program, the interrelationships among them, and the relationships of these boards to the Apollo Spacecraft Program Office (ASPO) Configuration Control Board (CCB) (the highest level MSC Apollo board) are shown in figure 20.

Obviously, the change-control milestones for all mission-operations data sources must be coordinated carefully and maintained for systematic development of the final mission-operations documents such as the flight plan. In fact, flight plan development is normally the critical path.

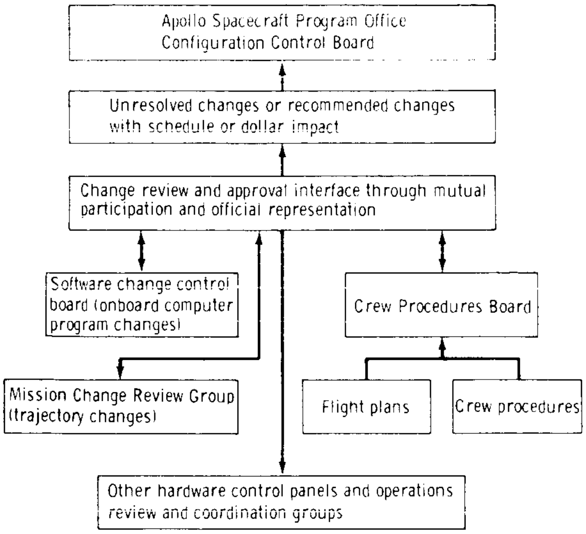


Figure 20. - Apollo operations change-control boards at MSC.

Configuration control of the flight plan is a function of the Crew Procedures Control Board (CPCB), as shown in figure 20, and commences in the Apollo Program with the preliminary flight plan issue 3 months before launch. All proposed changes to the preliminary flight plan or to the final flight plan (normally scheduled for 1 month before launch) must be submitted to the CPCB by way of a crew-procedures change request if the changes fall in any of the following categories.

1. Items that impose additional crew training or that effect crew procedures

2. Items that effect the accomplishment of mission objectives

3. Items that result in a significant RCS or electrical power system budget change

4. Items that result in moving major activities to a different activity day in the flight plan

5. Items that require a change to the flight data file (the crew's onboard data package)

The Chief of the Flight Planning Branch determines which proposed changes fall into these categories. Changes that have definite operational merit and can be implemented but that introduce cost or schedule effect or alter the accomplishment of mandatory mission objectives are referred to the ASPO CCB with a CPCB recommendation. The originators of changes disapproved by the CPCB have the option of carrying the change proposal to the ASPO CCB as a means of appeal.

CONCLUDING REMARKS

The development of flight plans can be summarized accurately as the final integration process for crew procedures and activities on manned space missions. Through the close, critical interface of this integration process and the training of the crew for a specific mission, maximum feedback is obtained on the efficiency and feasibility of the astronauts' planned activities. Therefore, the ultimate goals of the flight plan are twofold: (1) an overall sequence of crew activities that accomplishes the mission objectives and maximizes scientific, technical, and operational return commensurate with crew safety and (2) a crew trained to execute the plan and to handle nonnominal situations. Continued support is required for the flight plan and procedures throughout the mission operations to deal with any real-time variations.

The flight planning development techniques and organizational relationships that have evolved from Project Mercury, Gemini Program, and Apollo Program experience have proven successful in terms of the results accomplished. With regard to future manned space programs, it is obvious that improvements in the flight plan development process must be evaluated and implemented continually where necessary to keep pace with the demands of the Skylab Program and the shuttle and space-station era. It is probable that the present general techniques and management approach to flight planning and flight-data-file development will be paralleled in the future, and the improvements will be in the introduction of interactive computer systems to facilitate the task and decisions of the operations personnel specializing in these areas.

Regardless of the detailed techniques and computer aids that may be used in the future, the flight planner must continue to interface directly with a large number of people and force the integration of their varied ideas and objectives, and occasionally their emotions, into a logical and most effective timeline. Communication remains the key element in the flight planning process.

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