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TRW NOTE NO. 68-FMT-643

PROJECT APOLLO
TASK MSC/TRW A-163

APOLLO CMC/LGC SOFTWARE
DEVELOPMENT PLAN

30 APRIL 1968

Prepared by
Lang Research
Group

(FORM NO. 6020)	18945 (ACCESSION NUMBER)	(THRU) 2B
	17 (PAGES)	(CODE) 08
	CR-42246 (NASA CR OR TMX OR AD NUMBER)	(CATEGORY)
	AVAILABLE TO NASA AND NASA CONTRACTORS ONLY	

NASA

NASA CR 92246

05932-H494-R0-00

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FOREWORD

The Apollo CMC/LGC Software Development Plan is one of three documents developed under MSC/TRW Task A-163, "Apollo Spacecraft Software Development Management Procedures Study." The other two documents are:

- a) The "Apollo CMC/LGC Software Readiness Verification Plan"
- b) The "Apollo CMC/LGC Software Management Plan"

This document presents the plan for development of CMC/LGC software.

The "Apollo CMC/LGC Software Readiness Verification Plan" presents the plan for verifying flight readiness of the CMC/LGC software after development is completed.

The "Apollo CMC/LGC Software Management Plan" presents MSC procedures for management of the software development and verification activities and for software configuration control.

These three documents were planned to supersede the "Apollo Guidance Software Development and Verification Plan," 4 October 1967, prepared by the Guidance Software Validation Committee for the Guidance Software Control Panel.

Procedures defined in this plan are compatible with S B07-C-001, "Apollo Spacecraft Program Configuration Control Manual," 15 December 1967.

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NOMENCLATURE

CARR	Customer Acceptance Readiness Review
CDR	Critical Design Review
CMC	Command Module Computer
FACI	First Article Configuration Inspection
FRR	Flight Readiness Review
FSB	Flight Software Branch
FSRR	Flight Software Readiness Review
GSOP	Guidance System Operations Manual
LGC	Lunar Module Guidance Computer
MIT	Massachusetts Institute of Technology
MSC	Manned Spacecraft Center
PCR	Program Change Request
SCB	Apollo Spacecraft Software Configuration Control Board

1. INTRODUCTION

1.1 PURPOSE

The purpose of this document is to set forth a practical software program development plan. This plan provides adequate visibility for effective management of the software development which will assure availability of the program for test and flight use in a timely manner. The plan also provides for sound program control and documentation consistent with the needs of program design, development, and qualification testing. The applicable management concepts and procedures for implementing this plan are set forth in Reference 1.

1.2 SCOPE

The spacecraft software development plan presented herein is limited in scope to the Command Module Computer (CMC) and Lunar Module Guidance Computer (LGC) software. It covers the period of activity from the establishment of software requirements through the Customer Acceptance Readiness Review (CARR) where the software is accepted by the Manned Spacecraft Center (MSC) and the development activities are completed. The flight readiness verification activity which follows completion of development is described in Reference 2.

This plan defines the documents, activities and milestones associated with the software development. The CMC/LGC program for each Apollo mission goes through this development cycle. The word program as used in this document, therefore, refers to a single program assembly. The details on the responsibilities and procedures for the implementation of this plan are found in Reference 1.

1.3 SUMMARY

The full span of spacecraft software development from the availability of data defining software requirements through acceptance of the program at the Customer Acceptance Readiness Review (CARR) is depicted in Figure 1-1.

The spacecraft software development begins with the definition of the software requirements. The software requirements provide the basis for the software design specification, which is the detailed specification to which the software is developed. The design specification, the Guidance System Operations Plan (GSOP), is reviewed and approved by MSC. The Critical Design Review (CDR) is the formal milestone associated with design specification approval. Section 2 describes these activities. The coding and development testing of the software follows the development of the design specification. At the completion of this phase of development, the program is ready for qualification testing. The First Article Configuration Inspection (FACI) is the formal milestone marking the end of the coding and development testing phase and approval to begin qualification testing. This phase of software development is discussed in Section 3.

The qualification testing activity following the FACI is designed to verify that the software has been designed in accordance with the paper design as defined in the software design specification. Satisfactory completion of the qualification testing completes the software development. The software is formally accepted by MSC at the time of the CARR. Section 4 discusses these activities.

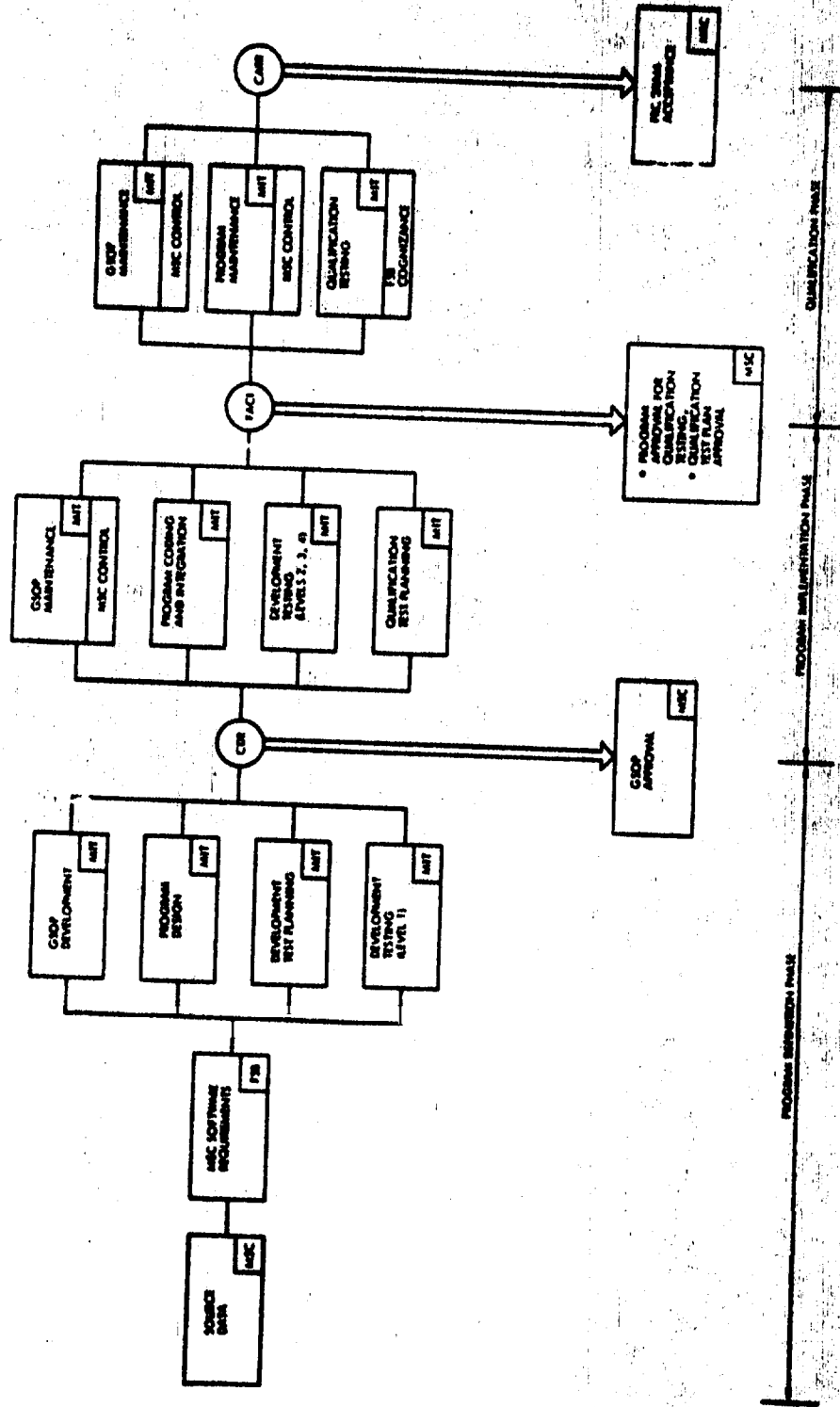


Figure 1-1. CMC/LGC Software Development

2. PROGRAM DEFINITION

A preliminary step to the development of CMC/LGC software is the establishment of requirements by MSC and the preparation of the design specification by Massachusetts Institute of Technology (MIT). These are the principal activities occurring during the program definition phase, as illustrated by Figure 1-1. The activities during this phase are described in this section.

2.1 SOURCE DATA

The fundamental sources of spacecraft software requirements are spacecraft systems specifications, interface control documents, mission requirements, early trajectory documents, and a variety of guidance and navigation study reports. The software requirements are derived from these sources and published separately as an MSC Software Requirements document.

2.2 MSC SOFTWARE REQUIREMENTS

MSC divisions must, from their own source documents, provide to the Flight Software Branch (FSB) their contributions to the total software requirements. These are integrated into the MSC Software Requirements document, which is provided to the contractor to guide the preparation of the software design specification.

The requirements document contains the functional, performance, and operational requirements necessary for the development of guidance, navigation and control equations and the establishment of operating modes and logic. It must specify interface requirements with other spacecraft subsystems and with the RTCC, or reference other authoritative sources for these requirements. The contractor must also be furnished the specifications of the vehicle and vehicle subsystems which interface with the software and dictate its characteristics.

2.3 GSOP DEVELOPMENT

The Apollo CMC/LGC software development and qualification are based on a detailed design specification prepared by the contractor, approved by MSC at the CDR and, thereafter, placed under configuration

control. For CMC and LGC software, the design specification is known as the Guidance System Operation Plan (GSOP). The GSOP contains all requirements for program modes, functions, interfaces, and the equations and logic to be programmed to satisfy the requirements and defines the operational procedures. The GSOP specifies kinds of display, their units, and number of digits. The GSOP includes or references all pertinent data on constants, including their scaling and units along with range of validity of constants. In addition, similar attention to the accuracy of computation is required.

Upon receipt of the MSC Software Requirements, the contractor begins the development and verification of the equations to be programmed. The equations are verified using engineering simulations of the spacecraft computer and other spacecraft systems.

The complete flight program for the CMC or LGC is built up from individual functional routines and callable programs. The selection of routines and callable programs for a particular flight program is based upon the MSC functional and operational requirements for that program and is reflected in the GSOP. Requirements for their integration into a complete flight program exhibiting the required functional capabilities and operational nodes are also presented in the GSOP.

2.4 PROGRAM DESIGN

The development of the CMC/LGC program begins officially after an approved design specification has been established at the CDR. However, the initial coding of equations and development of subroutines begins during the program definition phase and is carried on in parallel with GSOP development. Initial plans for program organization timing and executive control are also established.

2.5 DEVELOPMENT TEST PLANNING

In parallel with GSOP preparation, the contractor begins planning the various levels of software tests to be carried out during the program implementation phase. These tests are sequential in four specific levels.

Level 1 tests use engineering language simulations to perform a formulation validation of the equations in the GSOP that are to be imple-

mented in the guidance computer. The results of these tests are used to evaluate the results of level 2 tests using flight computer language.

Level 2 tests are tests on guidance computer coding of flight program subroutines (such as orbital integration) and, where appropriate, comparisons with corresponding level 1 runs are made. These runs are made on the software contractor's bit-by-bit simulation facility.

Level 3 tests verify collections of subroutines at the level of astronaut callable programs (e. g., steering, cutoff, guidance error signal, and average-g navigation) all working together to provide guidance for a powered-flight burn. All paths through each P-program are checked out. The runs are made on both bit-by-bit and hybrid simulations.

Level 4 tests represent the top level of development testing. These tests involve mission sequencing (e. g., prethrust, IMU alignment, and thrusting programs running in sequence). While there is no requirement that all tests be made on the same configuration program, applicability of data to the proposed program must be established to the satisfaction of MSC.

There is no formally documented plan for level 1 or level 2 testing. However, level 3 and level 4 test plans are presented to MSC for review.

2.6 DEVELOPMENT TESTING (LEVEL 1)

Level 1 testing is conducted as an integral part of the equations development portion of GSOP development. It uses an engineering simulation to provide data for subsequent verification of coding.

2.7 CRITICAL DESIGN REVIEW

The Critical Design Review, which is discussed in detail in Reference 1, is the final element of the program definition phase. The GSOP draft, basic program design concepts, and preliminary development test plans are reviewed by MSC. The resulting approved GSOP is the design specification for the software program under development.

GSOP approval and agreement that the contractor should continue development as proposed are based on MSC review of the program concepts, level 1 test results, and preliminary development test plans provided by the software contractor.

3. PROGRAM IMPLEMENTATION

The implementation of the CMC/LGC program begins officially after an approved design specification has been established at the CDR. This phase of program development continues until the First Article Configuration Inspection (FACI). The activities during this phase are described in the following sections and illustrated by Figure 1-1.

3.1 GSOP MAINTENANCE

During the program implementation phase, changes in the software design requirements may become necessary as the mission requirements and spacecraft data become more clearly defined. Such changes must be reflected in the GSOP. Since the GSOP is under configuration control following the CDR, it can be changed only with the approval of the SCB in accordance with the procedure described in Reference 1.

3.2 PROGRAM CODING AND INTEGRATION

The development of the CMC/LGC program is accomplished in a step-by-step manner beginning with the coding of the basic subroutines. These subroutines are then integrated into functional units (the P-programs and R-routines).

The final step in the CMC/LGC program development is the integration of the various functional units to perform the sequences required by the various mission phases.

During the program implementation phase, flow charts of all the subroutines, R-routines, and P-programs are generated and published. These flow charts are designed to provide an accurate description of the program and its design and organization. In addition, current program listings are made available to MSC for review at regular intervals. A list of program constants is a part of this output.

3.3 DEVELOPMENT TESTING (LEVELS 2, 3, 4)

Development tests are conducted at various levels of program coding and integration to verify compliance with the design requirements.

Level 2 testing is conducted to verify coding of the basic equations and subroutines. The contractor uses level 1 test results as a baseline for evaluation of level 2 testing.

Level 3 testing is conducted to verify functional routines and P-programs.

Level 4 testing verifies the integration of the P-programs into mission sequences. Upon successful completion of these tests, the program is ready for qualification testing. The results of all development tests are provided to MSC as they become available.

3.4 QUALIFICATION TEST PLANNING

During the program implementation phase, the software contractor prepares a Qualification Test Plan for MSC approval at the FACI. The test plan provides for overall mission phase testing, including at least one end-to-end run using current vehicle and mission planning information. The test plan document contains the descriptions, purpose, data acquisition and application plans, and schedules for all qualification test runs.

3.5 FIRST ARTICLE CONFIGURATION INSPECTION

The program implementation phase officially ends at the FACI. At the FACI, MSC reviews the development activity and the development testing results and, if satisfactory, official approval to begin the qualification testing is given.

The Qualification Test Plan is also reviewed at the FACI and officially approved by MSC.

4. PROGRAM QUALIFICATION

The FACI review of the software contractor's development work and test planning activity results in a program acceptable to MSC for qualification testing and an approved Qualification Test Plan. The period from FACI to CARR is devoted primarily to qualification testing of this program. This and other activities occurring during this period are described in this section and illustrated by Figure 1-1.

4.1 GSOP MAINTENANCE

During the period of program qualification, the GSOP remains under configuration control by the Apollo Spacecraft Software Configuration Control Board (SCB) and is maintained current as described in Section 3.1.

If, during the period of program implementation and qualification, there have been significant GSOP revisions, the document should be revised by the contractor to include all revisions. This final GSOP is delivered to MSC subsequent to the CARR.

4.2 PROGRAM MAINTENANCE

During the program qualification phase, the configuration of the program assembly is controlled by FSB. The purpose is to assure that due consideration is given to retest requirements to qualify program changes and to assure the applicability of all qualification test results to the final program assembly at the end of the qualification phase.

4.3 QUALIFICATION TESTING

The Qualification Test Plan calls for the testing of all programs and operational sequences specified in the GSOP to verify that the software has been designed in accordance with specifications.

Qualification testing is performed on the program assembly accepted by MSC at the FACI and maintained as described in Section 4.2. The testing is done by MIT on the MIT hybrid and all digital simulators. These tests, which represent refinements of levels 3 and 4 development tests as discussed in Section 3.4, are performed under the strict supervision of MSC.

The basis for MSC evaluation and acceptance of the program is qualification test results. Test results are delivered to MSC for review as they become available. The results are reviewed for adequacy and acceptability prior to the CARR.

4.4 CUSTOMER ACCEPTANCE READINESS REVIEW

The CARR is held following the completion of qualification testing and the analysis of qualification test results by MSC. These tests have verified the capability of the program to perform all operations specified in the GSOP.

Information considered at the CARR must be adequate to assure that there are no unresolved differences between the software design specifications and the program itself.

Actions and decisions taken at the CARR or instigated at the CARR complete the CMC/LGC software development program. The evidence of completion is as follows:

- a) An MSC approved final GSOP
- b) An MSC approved and accepted computer program consistent with the final GSOP

REFERENCES

1. "Apollo CMC/LCC Software Management Plan, TRW Note No. 68-FMT-645, 30 April 1968.
2. "Apollo CMC/LCC Software Readiness Verification Plan, TRW Note 68-FMT-644, 30 April 1968.