

LM AGS GUIDANCE SOFTWARE
FINAL DESIGN REPORT
FLIGHT PROGRAM 6
(FORMERLY FPX)

Contract No. NAS 9-8166
April 1969

Approved: *T. W. Layton*
T. W. Layton, Chairman
LM AGS Guidance Software
Design Review Board

Approved: *D. L. Meginnity*
D. L. Meginnity
Task Manager

Section I: INTRODUCTION AND SUMMARY

This report documents the final development and design review of the LM AGS Flight Program 6 (formerly FPX) for the Apollo lunar landing or G mission. This effort was performed under subtask 2 of the MSC/TRW ASPO Task 32E which is part of Contract NAS 9-8166.

The documents forming a part of this design report, but provided under separate cover, are:

- A. TRW Report No. 11176-6041-T000, "LM AGS Programmed Equations Document, Flight Program 6", dated April 1969
- B. TRW Report No. 11176-6033-T000, "LM AGS Operating Manual, Flight Program 6", dated April 1969
- C. TRW Report No. 11176-6042-T000, "LM AGS Computer Program Specification, FPX", dated March 1969
- D. TRW Report No. 11176-6050-T000, "Program Verification Test Results, LM AGS Flight Program 6 (formerly FPX)", dated May 1969
- E. TRW Report No. 11176-6049-T000, "Performance Analysis Results Summary, Flight Program 6 (formerly FPX)", dated May 1969

TRW has successfully completed the program verification testing, defined in the Test Plan (Reference 1) as modified at the FPX FACI (Reference 2), and therefore recommends that FP6 be accepted as flight ready. The preliminary FPX program, designated LM AGS FPX S03, ID = 0151, dated 03/03/69, and released under Reference 3, has been approved as the final FP6 program configuration in Reference 4. An absolute deck was also transmitted to GAEC by Reference 4. This deck, in accordance with the TRW/GAEC memo of understanding, contains the final FP6 program merged with the GAEC Load and Verify Program and is designated ID = 0158, dated 04/24/69.

The following conclusions can be obtained as the result of FP6 program verification testing and experience derived from previous program testing:

- 1) All of the LM AGS software functions and interfaces perform as required in the program specification (Item C, above) and in the LM AGS P and I Spec (Reference 5).
- 2) The AGS, when loaded with FP6, and used in accordance with the procedures specified in the Operating Manual (Item B, above) is capable of satisfactorily performing the LM abort mission functions of the Apollo G mission.
- 3) As a result of the program coding, the velocity-to-be-gained magnitude (DEDA address 267 and downlink telemetry word No. 36) may not be a valid output quantity in the CDH guidance mode. However, the CDH solution is correctly computed and these quantities are available for use, after switching to the external Delta V guidance mode, as required for burn execution. The components of the inertial vector velocity-to-be-gained and the corresponding components of the desired pointing direction for the thrust axis (words 40, 41 and 42 on the telemetry downlist) may not be valid when in the CSI or CDH guidance modes. These quantities are correctly computed in the external Delta V guidance mode.

These anomalies do not in any way compromise the flight program's capability to perform the AGS functions on the lunar landing mission. TRW and MSC have agreed to release the program as coded and verified (Reference 4).

The following conclusions can be made as the result of the overall AGS system performance analysis studies, presented in Item E, above.

- 1) The AGS can successfully complete the rendezvous sequence from all of the abort conditions studied. Safe pericyynthion of greater than 30,000 feet above the launch site radius after orbit insertion was obtained in all cases. The mean plus three sigma fuel required to complete the rendezvous after orbit insertion is reasonable for all aborts during coasting, powered descent, and from the lunar surface. In particular, the abort from hover performance criteria of the P and I Spec are met using the specification ASA error model.

The abort from the lunar surface (Case 4) resulted in a larger mean plus three sigma post injection ΔV than the hover abort (Case 1). The results for Case 4 exceeded the post injection ΔV criteria by 19 ft/sec. A major error source in this case is the 1° (3σ) azimuth alignment error used during lunar align. Previous results indicate that this error contributes approximately 50 fps (mean + 3σ) to the total fuel required. TRW is evaluating other major error sources and will keep MSC informed of this continuing analysis. Performance improvements due to alternate radar data sequences are also being examined. For example, Case 4 was repeated with no radar updates pre-CDH and the post injection mean plus 3 sigma ΔV decreased by approximately 30 ft/sec; the total mean + 3 sigma post-injection ΔV of 336 ft/sec satisfies the 349 ft/sec ΔV criteria.

It is recommended that MSC reevaluate the ΔV budgets applicable to a variety of abort points.

Section II: PROGRAM REQUIREMENTS

2.1 Basic FP6 Program Requirements

The basic FP6 requirements are to perform the abort guidance and navigation functions for the Apollo lunar landing or G mission, as detailed in the Program Specification (Item C, above). The program requirements along with the AGS systems requirements, have also been documented in the revised LM AGS Performance and Interface Specification (Reference 5). Section 3.2 below lists some of the discrepancies found in the P and I Spec as the result of this design review.

2.2 Program Configuration

The basic program configuration is that of Flight Program 5 (FP5) (References 6 through 9) modified by the incorporation of the aforementioned MSC approved TRW Software Change Proposals (SCP's 43, 50 and 51).

SCP 43 provided an expanded capability radar filter at the cost of deleting the capability for on-board computations of CSI/CDH guidance solutions. The concepts for the radar filter equations are described in Reference 10.

SCP 50 provided for a CSI/CDH capability that is compatible with current mission planning. SCP 50 was incorporated with the following modifications:

- 1) The solution for CSI would be for a CDH maneuver that would occur at one or three halves of an orbital period (Reference 11).
- 2) Time to perifocus (T_{PERG}) and LM apofocus altitude (q_a) computations would be retained (Reference 12).

SCP 51 provided continuously variable orbit insertion targeting.

Confirmation of verbal direction to incorporate SCP's 50 and 51 was provided by MSC in Reference 13.

2.3 Program Interfaces

The program interfaces are identical to those of FP5 with the following exceptions:

Three telemetry downlink words have been reassigned. Word 31 is now the combination of the ullage counter μ_0 and the self test status S_{12} . Word 38 now contains the time between CSI and CDH, T_{AO} , as computed in CSI. Word 39 now contains the absolute time of the next maneuver in the CSI, CDH or TPI modes, T_{ig} .

The approximations used in the improved radar filter mechanization requires that the X-Z plane of the inertial coordinate frame be constrained to a 10^0 region of the CSM orbit plane.

The compensated accelerometer bias values are now available for DEDA readout as decimal quantities, quantized to 0.001 ft/sec which is equivalent to approximately 31 μg .

The ullage counter, μ_0 , and ullage counter constant, K_0^1 , are now DEDA accessible in decimal counts quantized at 1 count which is the equivalent of 2 seconds.

2.4 "G" Mission Definition

Flight Program 6 was verified for the G mission described in Reference 14, which is based on the recent coelliptic flight plan described in Reference 15. Performance analyses were based on the descent trajectory provided subsequent to the FACI (Reference 16) and the abort missions defined at the FACI (Reference 2) and detailed in the MSC memo (Reference 17).

2.5 Verification Testing

The program verification testing is consistent with the TRW Verification Test Plan (Reference 1) as modified at the FACI (Reference 2).

2.6 Performance Analysis

The performance analyses provided under the software contract to be delivered as part of the final program design review were based on the TRW Performance Analysis Plan (Reference 18) as modified at the FACI (Reference 2).

Section III: RECOMMENDATIONS

3.1 Program Acceptance

TRW recommends that FP6 be accepted as flight ready for use on the Apollo lunar landing or G mission.

3.2 Recommended P and I Specification Revisions

In the process of referring to the revised P and I Spec since its release, a number of inconsistencies have been identified which were not discussed in TRW's earlier review (Reference 19). The general areas requiring updating to be compatible with the released FP6 program and performance analysis results are:

1. All coelliptic burns must now be executed in external Delta V.
2. The general wording of the FP6 Program Specification (Item C, above) is more precise with respect to the program modifications and should be incorporated into the revised P and I Spec.
3. The CSM covariance matrix applicable to lunar surface launches should be corrected to be consistent with the original MSC memo 68-FM47-427 from which it was derived.
4. The definition of the lateral velocity output to the crosspointer should be corrected to reflect the FP5 and FP6 computed quantity and sign conventions.

3.3 ΔV Budgets

TRW recommends that MSC review the validity of the existing ΔV budgets for rendezvous with AGS from various abort conditions. Separate budgets should be established from different abort points, such as, abort from hover and abort from the lunar surface.

Section IV: SCHEDULE

TRW has released FP6 on the schedule defined in the Interim Design Report (Reference 20). The schedule governing the remaining FP6 software activities is as follows:

FP6 Customer Acceptance Readiness Review	13 May 1969
MSC Definition of Final G Mission Constants	13 May 1969
FP6 Updated Sim Flight Procedures	20 May 1969
Release of Constants Update Tape	19 June 1969
Performance Analysis Review	19 June 1969
Software Flight Readiness Review	19 June 1969

Section V: DOCUMENTATION CHANGES

The documents forming a part of this report define the final program configuration, verification testing, program requirements and performance analysis reflecting the released program. This design report also defines the new AGS flight program baseline on which all future software will be based. The final documents listed on the left should be used as the primary reference in place of the preliminary documents listed on the right below.

- | | |
|--|---|
| 1. Program Equations Document
(Item A, above) | 1. TRW Memo No. 7332.9-255,
"Preliminary FPX Flow Chart
and Constants List", dated
3 January 1969 |
| 2. Operating Manual
(Item B, above) | 2. TRW Report No. 11176-6033-
T000, "LM AGS Operating
Manual, Flight Program X
(Preliminary)", dated April
1969(issued February 1969) |
| 3. FPX Computer Program Specification
(Item C, above) | 3. P and I Spec Revised Draft,
dated 4 February 1969 |
| 4. Verification Test Results Summary
(Item D, above) | 4. FPX Verification Test Plan,
dated January 1969 (Ref. 1) |
| 5. Performance Analysis Results
Summary (Item E, above) | 5. FPX Performance Analysis
Test Plan, dated January 1969
(Ref. 18) |

Section VI: SOFTWARE DOCUMENTATION

The documentation supporting the final design review is listed as Items A through E in Section I of this report. In addition, the following documents have been referenced in the Design Report:

- Reference 1: TRW Report No. 11176-6035-T000, "Program Verification Test Plan, LM AGS Flight Program X", dated January 1969
- 2: MSC Document (unnumbered), "Minutes, IM AGS Flight Program X (FPX), First Article Configuration Inspection (FACI)", dated February 24-25, 1969
- 3: TRW Letter No. 7001.16-1965, "Transmittal of Preliminary LM AGS Flight Program X", dated 11 March 1969
- 4: TRW Letter No. 7001.16-2046, "Release of the Final LM AGS Flight Program 6 (Formerly FPX)", dated 30 April 1969
- 5: GAEC Specification No. LSP-500-1A, Draft, "Abort Guidance Section Software GFE Performance and Interface Specification", Revision dated 4 February 1969
- 6: TRW Report No. 11176-6032-T000, "LM AGS Guidance Software Final Design Report, Flight Program 5", dated January 1969
- 7: TRW Report No. 11176-6015-R000, "LM AGS Programmed Equations Document, Flight Program 5", dated January 1969
- 8: TRW Report No. 11176-6021-T000, "LM AGS Computer Program Specification, Flight Program 5", dated January 1969
- 9: TRW Report No. 11176-6022-T000, "LM AGS Operating Manual, Flight Program 5", dated January 1969
- 10: TRW Report No. 05952-6214-T000, "LM AGS Radar Filter Improvement Feasibility Study", dated June 1968
- 11: TRW Letter No. 7001.16-1838, "Evaluation of the New CFP", dated 31 December 1968

- 12: TRW TWX No. 7001.16-1827, "Amendment to SCP 50", dated 20 December 1968
- 13: MSC TWX No. EG43-678-68, "Documentation of Agreements Reached in FPX Design Reviews", dated 20 December 1968
- 14: MSC Internal Note No. 68-FM-106, "Apollo 'G' Mission Spacecraft Reference Trajectory, Vol. 1-5", dated 9 August 1968
- 15: MSC Letter No. 68-FM64-325, "Currently Proposed Rendezvous Profile for Mission G (LLM)", dated 28 October 1968
- 16: MSC Computer Printout, (Updated 69 n.mi. Descent Trajectory Tape), received from MSC (MPAD, J. D. Payne) in March 1969
- 17: MSC Memo No. 69-FM62-56, "Recommended Inputs for AGS FPX Performance Analysis", (no date)
- 18: TRW Report No. 11176-6034-TO00, "Performance Analysis Test Plan, LM AGS Flight Program X", dated January 1969
- 19: TRW Letter No. 7001.16-1895, "TRW's Detailed Comments on the Revised Performance and Interface Specification Draft", dated 13 January 1969
- 20: TRW Report No. 11176-6038-TO-00, "LM AGS Guidance Software Interim Design Report, Flight Program X", dated 1 February 1969