Preparation and Verification Method at ETB/FM Test Level for Establishing Satellite IAC Procedures

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***Abstract*—Launch and Early Orbit Phase (LEOP) is the critical final verification stage conducted after launch vehicle (LV) separation and orbit insertion, before normal mission operations. LEOP consists of Initial Activation and Checkout (IAC) and In-Orbit Test (IOT). Within this phase, the spacecraft (S/C) bus IAC is of paramount importance. Traditionally, because a physical LEOP test on the ground has been impossible, verification has been limited to procedural checks at the Electrical Test Bed (ETB) level. However, this occurs early in the development cycle (around the Preliminary Design Review (PDR)), leaving a significant gap during which design changes or unexpected variables can emerge. Furthermore, conventional End-to-End (ETE) tests—which integrate the satellite and ground station (G/S)—often exclude S/C bus IAC procedure as a formal test item. To address these limitations, this paper proposes a robust preparation and verification method at both the ETB and Flight Model (FM) test levels to ensure reliable early operations after launch.**

Keywords*—*LEOP, IAC, IOT, ETB, G/S, ETE, FM

I. Introduction

The LEOP is the most volatile period of a satellite mission, during which the success of the entire project hinges on the flawless execution of IAC procedures. These procedures—including power-on sequences, deployment of critical components, and primary subsystem health checks—must be executed with high precision under strict time constraints. Any procedural error during this initial phase can result in irreversible mission failure.

To guarantee the robustness of IAC, thorough verification at both the ETB and FM stages is crucial. However, achieving a smooth transition between these stages remains a technical challenge. The ETB offers a flexible setting for developing logic and simulating error cases, while the FM incorporates physical constraints and hardware interactions that are challenging to model accurately. Without an optimized verification approach, IAC procedures might fall short of the fidelity needed for the real orbital environment, increasing the risk of unexpected anomalies during LEOP.

This paper presents a systematic approach to optimizing IAC procedures to improve mission reliability during LEOP. The method uses a verification framework that applies an ETB to refine logic in detail and an FM to validate procedural fidelity. By incorporating automated telemetry-based verification, the approach reduces the gap between ground testing and orbital conditions. This optimization enhances the reliability of initial activation sequences and significantly shortens the overall FM-level test timeline.

The paper is organized as follows: Section II outlines the requirements for satellite IAC during LEOP; Sections III and IV describe the proposed scheme and its expected effects, respectively; and Section V concludes with a discussion of the potential impact on future satellite missions.

II. Background

A. Timing for Testing ETB & FM in the Satellite Development Lifecycle

The ETB is used to verify the operational integrity of the spacecraft bus and its subsystems under simulated conditions. Typically, ETB testing begins before the PDR and continues through this phase, which occurs roughly a quarter into the development cycle, to achieve TRL-6. Since TRL-6 mandates system performance verification in a relevant environment, these tests are carried out early to confirm nominal operational procedures [1]. The outcomes are crucial for the PDR, helping establish a solid design foundation and providing the technical confidence needed to progress to the CDR and FM development.

The CDR takes place roughly halfway through the development process to verify that the detailed design meets all system requirements and is ready for fabrication. After a successful CDR, the FM test begins to assess flight hardware performance under conditions similar to those of actual flight, confirming the system's readiness for the mission environment.

The FM test can only begin after meeting these essential requirements:

- Completion and formal approval of all design verification activities and critical subsystem reviews;
- Resolution of all open action items identified during the CDR;
- Confirmation that the flight hardware has successfully passed applicable ETB or prototype verification campaigns.

The FM test can proceed only once these criteria are met. This thorough process ensures that the test outcomes accurately reflect FM performance while reducing the likelihood of design-related issues during the Assembly, Integration, and Test (AIT) phase and LEOP.

B. Inheritance from ETB to FM Test

The ETB test is conducted during the early development stage to evaluate core design ideas and subsystem interfaces. Its main goals are to verify technical feasibility, pinpoint potential risks, and meet TRL requirements before the PDR. Conducted in controlled lab settings, these tests focus on validating interfaces, verifying subsystems, and conducting initial performance assessments instead of testing under full-scale environmental conditions.

In contrast, the FM test is conducted after the CDR to verify that the final hardware can withstand the challenges of LEOP. This stage involves detailed functional assessments and qualification-level environmental tests like vibration, acoustic, thermal vacuum, and electromagnetic compatibility, which simulate real launch and orbital conditions. The functional performance evaluations for the FM are based directly on ETB results, maintaining consistency and traceability in the system verification process.

TABLE I summarizes the activities of ETB and FM tests, categorized into Interface Validation, Subsystem Verification, and System Verification. For Interface Validation, both ETB and FM undergo DC, electrical, and RF integrations, while the FM also performs a Thermal Continuity (T/C) check. In Subsystem Verification, ETB executes individual logic tests for the Flight Software (FSW), Electrical Power Subsystem (EPS), GPS, Thermal Control Subsystem (TCS), Attitude and Orbit Control Subsystem (AOCS), and payload(s). Meanwhile, FM carries out Integrated System Tests (ISTs) at the bus and system levels. During System Verification, both ETB and FM perform fault management and End-to-End (ETE) tests, with ETB additionally conducting a Bus Operation Test (BOT) that is not repeated on FM.

This comparison emphasizes how the ETB test aids FM verification by conducting subsystem-level checks and initial performance evaluations, which contribute to overall system-level assessments.

C. *ETB Bus Operation Test*

The ETB BOT is an essential procedure for confirming the functional integrity of the S/C bus before launch [2]. Performed on the ETB, which simulates the spacecraft bus system in a lab environment, this setup enables testing of major subsystems such as FSW, EPS, GPS, TCS, TCRS, and AOCS, and validates operational procedures under both normal and contingency scenarios.

The ETB BOT is performed after subsystem logic tests, as it depends on verified subsystem functionality to execute integrated sequences. However, it is usually performed only once during early development, well before LEOP. As a result, any design changes or unexpected issues that occur after the ETB BOT has been completed cannot be fully managed, reducing its ability to catch late-stage integration problems or intricate interactions with the G/S.

Despite these limitations, the ETB BOT is conducted independently of G/S interaction, allowing isolated testing of onboard sequences and functions. These outcomes enhance operational documentation and aid operator training, thereby reducing risks during LEOP and promoting reliable in-orbit operations.

D. *End-to-End Test*

ETE tests are intended to verify the full integrated operation between the satellite (space segment) and its ground segment (G/S) [3]. Unlike the ETB BOT, which is conducted only on the ETB without G/S involvement, ETE tests evaluate the entire operational chain, including uplink telecommands (TC or CMD), telemetry (TM or TLM) reception, and payload data processing in realistic scenarios. This enables validation of data flows, communication protocols, and operational sequences between the satellite and G/S prior to LEOP.

ETE tests are generally performed using either ETB or FM hardware with the G/S, offering a thorough evaluation of typical integrated operations. The findings help improve operational manuals, confirm G/S software such as the Satellite Operation Subsystem (SOS) [4] and the Direct Ingestion Subsystem (DIS) [5], and aid operator training. As an essential step before shipment, the ETE test on the FM verifies that both the satellite and G/S can function reliably and work together smoothly during normal in-orbit activities.

Focusing on satellite–G/S interoperations and integrated performance, the ETE tests supplement the ETB BOT, which mainly verifies on-board sequences and subsystem functions. Collectively, these verification steps provide a comprehensive assessment of satellite and G/S readiness before the mission begins.

TABLE I. ETB & FM FUNCTIONAL PERFORMANCE TESTS

Target	ETB	FM
Interface Validation	DC Integration	DC Integration
	Electrical Int.	Electrical Integration
	RF Integration	RF Integration
	n/a	T/C Check
Subsystem Verification	Processor (FSW) Test	Bus IST
	EPS Logic Test	
	GPS Logic Test	
	TCS Logic Test	
	AOCS Logic Test	
	Payload Logic Test	System IST
System Verification	Fault Management Test	Fault Management Test
	Bus Operation Test	n/a
	End-to-End Test	End-to-End Test

III. PROPOSED SCHEME

A. *Test Readiness Assessment Criteria*

Before conducting any test, a Test Readiness Review (TRR) is performed to verify if all necessary criteria are satisfied, as summarized in TABLE II [6]. Although the general criteria are discussed in later subsections, as indicated in the table, two particular cases are assessed separately:

- When the subjects evaluated in the ETB BOT and ETE tests are identical.
- When consistent criteria are applied across all test phases.

Regarding specific criteria in TABLE II:

- Criterion #4 (KIP and MIP): Ensures that all components, equipment, and personnel are prepared before the test and that results are formally reviewed afterward.
- Criterion #5 (Calibration): Excluded from this study because both ETB BOT and ETE tests were performed using equipment calibrated at the same location, ensuring environmental consistency.

TABLE II. TEST READINESS ASSESSMENT CRITERIA

No.	Description	Subsection
1	Test documentation availability and suitability	III.B, III.C
2	Item under test configuration	III.B
3	Test configuration/set-up	III.D
4	Inspection status report of KIP[a], MIP[b], or both	-
5	Test facility, environmental conditions, test instrumentations, calibration, and maintenance status	-
6	Cleanliness, condition, hazard, and safety	-
7	GSE and infrastructures	III.D
8	Status of non-conformances that affect the item under test, its associated GSE, or the test facility	-
9	Waiver status and deviations	-
10	Personnel qualification and availability	III.D
11	Results from test rehearsal using the test facility with or without the item under test, when relevant	III.C
12	Test pass/fail criteria completeness	III.B
13	Assignment of responsibilities	III.D
14	Test schedule	III.D

a. KIP: Key Inspection Point

b. MIP: Mandatory Inspection Point

- Criterion #6 (Environment): Inherently satisfied as all tests are conducted within a certified clean and safe environment.
- Criteria #8 and #9 (Negative Factors): These represent constraints to confirm test feasibility; however, as they are not mandatory for proceeding with the test, they were excluded from the primary assessment.

B. Test Item Selection

Criterion #1 focuses on documentation, which is crucial to ensure that tests can be performed solely on the provided procedures, even if the test designer is unavailable. While redundant documentation can be omitted, the test plan must be included as it outlines the overall strategy and scope of the test campaign. To avoid confusion, verification requirements should be clearly identified, classified, and broken down into independently verifiable units, as outlined in Criterion #2. Additionally, for each test item, pass/fail criteria must be established to determine when the test is complete, in accordance with Criterion #12.

For integrated test planning, it is important to first clearly define the objectives of the ETB BOT and ETE tests. The S/C bus IAC, confirmed through the ETB BOT, ensures the successful deployment of the Solar Array (S/A), orbit injection, and attitude stabilization, thereby enabling the payload to conduct normal mission operations. Conversely, the ETE tests focus on verifying the ability to exchange control commands, status data, and large volumes of scientific data with the Ground Station (G/S). This involves validating the SOS's capacity to generate and send TCs in the specified format, receive status data in various formats, and transform payload data into mission-specific products.

This combined testing approach aims to complete the full sequence of S/C bus IAC procedures through payload deployment and to verify G/S control and data reception capabilities. The technical requirements for both ETB BOT and ETE tests have been merged into a single set of test steps. The ETE test items from earlier projects are incorporated into the relevant steps of the S/C bus IAC procedures. Their pass/fail criteria provide the objective basis for progressing to the next operational stages.

C. Developing Test Procedures

The test procedure outlines step-by-step instructions to ensure consistent, repeatable execution. The main challenge in the proposed scheme is incorporating the ETE test items into the S/C bus IAC procedures. TABLE III shows the verified S/C bus IAC procedures from the ETB BOT, arranged by test steps. The final column of TABLE III links each step to its relevant ETE test items, with identifiers provided in TABLE IV.

For instance, in test step #1, the OBC automatically initializes the system after LV separation. This involves executing a specific TC sequence called the Relative Timed Command Sequence (RTCS). Therefore, ETE test ID #022 is verified during this step. Since the RTCS is also used in the S/A Deployment Test (SADT) during test step #3, the same verification applies.

In test step #2, the G/S modem conducts uplink sweeping to detect the satellite signal, then performs single- and multi-Real-Time (RT) TC transmission tests (IDs #011 and #012). In test step #5, activating the Virtual Channel Data Unit (VCDU) allows TM downlink, facilitating packet-level ETE tests (IDs #042–#044), which involve packet dwelling, order selection, and sequence changes.

Other test steps related to ETE test items associated with the Software Error Table (SET), Event Log Table (ELT), playback, Minor Cycle Sampling (MCS), Precise Attitude Determination (PAD), and Absolute Timed Command (ATC) functions are omitted here for brevity. Test IDs #015, #033, and #034 (marked in red) have been verified in accordance with IAC procedures under abnormal conditions. Conversely, Test IDs #013 and #014 (marked in blue) involve intentional anomalies, such as disabling standard event logs or injecting abnormal TC arguments, and thus require specialized, exceptional ETE tests.

D. Considerations for Test Resources

The satellite electrical test environment depends on a complete set of resources, including facilities, measurement and simulation tools, qualified staff, a clear schedule, and supporting documentation. These elements create a structured framework that is vital for confirming functional correctness and ensuring satellite reliability before launch.

The proposed scheme aims to re-verify the S/C bus IAC procedures previously validated in the ETB BOT, as part of the established test schedule. The procedures will be carried out twice: once during the ETB ETE test and once during the FM ETE test, leading to a total of three verification instances throughout the development cycle. No additional effort is required to perform these procedures within the current ETE schedule, but personnel who did not participate in the ETB tests will require training in security and safety protocols.

Electrical functional performance tests use Electrical Ground Support Equipment (EGSE) and test-aid devices. These test aids are straightforward tools designed to monitor particular signals or diagnose faults; since they are always accessible, they are not discussed further. Specialized EGSE required for the S/C bus IAC verification includes the Solar

TABLE III. S/C BUS IAC PROCEDURES IN ETB BOT

Step	Description	ETE Test ID
0	Prepare all necessary conditions and resources required to initiate the test.	n/a
1	Verify that the satellite initialization is executed in the pre-defined RTCS.	022
2	Acquire a communication link.	011, 012
3	Perform on-ground/-board SADT.	022
4	Change the TLM downlink rate to high.	041
5	Enable high-rate VCDUs.	042-044
6	Dump CODA[c], SET, ELT, etc.	014
7	Playback mass memory.	051
8	Perform AOCS sensors & actuators' activation and checkout	-
9	Enable the update flag for orbit parameters and upload KPD[d] to update them.	031, 032
10	Enable GPS data processing and the storage of its raw data.	053
11	Transit to sun-pointing sub-mode.	-
12	Enable MCS to measure throughput.	052
13	Enable storage for PAD raw data and the orbit parameter update flag.	054
14	Upload and activate the Guidance Profile File (GPF) for the payload to perform the mission.	054
15	Upload mission operation ATC.	021, 060
16	Turn off all power to the test equipment.	n/a

[c] CODA: Contingency Operation Data Area
[d] KPD: Key Parameters Database

Array Simulator (SAS), battery, and Satellite Dynamics Simulator (SDS).

- SAS and Battery: Emulate power conditions during sunlight and eclipse periods to enable realistic verification of energy management.
- SDS: Reproduces orbital and attitude effects on all spacecraft bus functions, including power, communication, and control systems.

The Test Leading Engineers (TLEs) for ETB BOT and ETE tests may vary depending on the specific objectives. For ETB BOT, TLEs are usually mission design and operations engineers, while for ETE tests, TLEs handle satellite–G/S interface control. Close cooperation among TLEs is essential, and extra support from mechanical assemblers and engineers is needed for the FM test.

IV. Expected Effects

A. Reducing Development Period

From a development resources standpoint, the proposed plan notably shortens the overall development timeline. Although the duration of individual test phases remains the same, efficiency improves by reusing verified test scripts from the ETB BOT in the ETE testing environment. This method provides multiple benefits:

- Resource Optimization: Eliminates the need to develop independent ETE test scripts.
- Error Minimization: Reduces procedural errors during test execution, thereby streamlining fault investigation processes.
- Early Validation: The spacecraft bus IAC procedures verified during the ETB BOT are rehearsed in the ETE environment with G/S interoperation approximately five to six months prior to LEOP.

Holding these rehearsals earlier allows developers and operators to develop effective communication and coordination protocols. This proactive strategy minimizes and possibly eliminates the need for separate full-scale LEOP rehearsals, thereby streamlining the mission preparation process.

TABLE IV. ETE Test Items

Test ID	Description
011	Send TISL[e] initialization hardware special CMD.
012	Send multiple RT CMDs in a single CLTU[f].
013	Send individual event log enable/disable CMD.
014	Send abnormal RT CMD and dump SET & ELT.
015	Send SGM[g]-P/R selection CMD.
021	Send ATC and dump CSA.
022	Send RTCS and dump SCSA.
031	Send KPD upload and dump SDRAM.
032	Send SDRAM upload and dump SDRAM.
033	Send SGM upload and dump SGM.
034	Send NVM[h] upload and dump SDRAM.
041	Send TLM downlink rate change and mass memory initialization CMD.
042	Send packet dwell CMD.
043	Send packet order selection CMD.
044	Send packet sequence change CMD.
051	Send playback CMDs.
052	Send MCS playback CMD.
053	Send GPS raw data playback CMD.
054	Send PAD raw data playback CMD after finishing orbit maneuvering.
060	Integrated mission operation.
070	Encryption processing and management.

e. TISL: Transponder Input Selection Logic
f. CLTU: Communications Link Transmission Unit
g. SGM: Safe-Guard Memory
h. NVM: Non-Volatile Memory

B. G/S Interoperability

The main goal of the proposed scheme is to enable two extra tests that confirm the S/C bus IAC procedures via direct G/S communication. These tests are conducted right after the ETB BOT and again following the FM environmental tests, before the LEOP rehearsal.

A common question in technical discussions is why LEOP rehearsals often lack direct interoperability. This issue usually results from physical and organizational limitations:

- Co-located Development: When the satellite and G/S are developed within the same organization, integrated tests can be conducted in close proximity. In such cases, LEOP rehearsals often utilize a satellite simulator or TM replay functions.
- Dispersed Development: When the satellite and G/S are developed by different organizations, co-location for testing is frequently infeasible.

Under these conditions, the scheme employs a transportable G/S deployed to the ETB or FM site via an Ethernet network. ETE tests are performed at this stage, eliminating the need for a separate, resource-intensive integration campaign focused solely on G/S interoperability.

C. Early LEOP Rehearsal and Training

As discussed earlier, the proposed scheme enables LEOP rehearsals and operator training to occur much earlier in the document cycle. Typically, the first LEOP rehearsal happens five to six months before launch. However, the ETB ETE test is performed at the end of the ETB testing phase, well ahead of the CDR milestone, effectively shifting the functional rehearsal timeline forward by nearly two years.

This method enables developers and operators to get early, practical experience with the G/S software tools needed for real mission operations. It also provides sufficient lead time to detect and fix critical issues in G/S operations, thereby supporting essential updates and enhancements to software such as SOS and DIS.

D. Repeated Tests and Practices

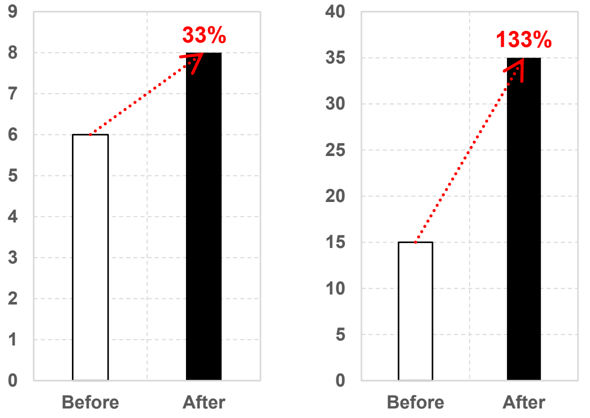
Fig. 1 compares the verification and rehearsal instances and the total duration between the conventional approach (Before) and the proposed scheme (After).

In the traditional method, the S/C bus IAC procedures are checked or practiced six times: once during the ETB BOT and five times in LEOP rehearsals. The new scheme adds an extra verification and rehearsal during the ETB ETE test, bringing the total to eight instances, which is a 33% increase.

From a temporal perspective, the benefit is even more significant:

- ETB BOT and ETE Tests: Typically span ten days each.
- LEOP Rehearsal: Lasts one to two days, with only about one day allocated to spacecraft bus IAC procedures.

As a result, the total time allocated for verifying and rehearsing the S/C bus IAC procedures grows by about 133%.



(a) Instances (times) (b) Duration (days)

Fig. 1. Test Instances (times) & Duration (days) for S/C Bus IAC

E. Early Identification and Intervention

The main benefit of the proposed scheme is that it enables earlier and more frequent verification and rehearsal activities. By conducting LEOP rehearsal tasks during the ETB test phase—normally done only five to six months before launch—developers and operators have the chance to engage in activities that mimic real operations at a much earlier stage.

This proactive integration yields several benefits:

- Operational Feedback Loop: Allows developers to incorporate operational considerations directly into spacecraft procedures.
- Requirement Refinement: Enables operators to identify and communicate project-specific design nuances and additional G/S software requirements.
- Infrastructure Readiness: Provides the opportunity to pre-configure G/S equipment and prepare mission facilities well in advance.

Since human error is inevitable, problems identified in one test may not be completely resolved in subsequent tests or operations. Multiple testing rounds enable the integration of corrective actions that were initially overlooked. Additionally, the proposed approach facilitates the verification and rehearsal of design changes and new requirements introduced after the ETB BOT, ensuring the mission baseline remains reliable through launch.

V. Conclusion

This paper introduces a method for verifying S/C bus IAC procedures at the ETB and FM levels, thereby ensuring mission preparedness during the early launch stages. It uses ECSS TRR criteria and integrates ETB BOT with ETE tests into a seamless workflow, promoting uniform and reproducible execution in both normal and abnormal conditions. This strategy confirms vital satellite functions, G/S operations, and payload data management.

The proposed scheme greatly improves LEOP preparation by reusing verified ETB BOT scripts for ETE tests. This approach shortens development cycles and enables rehearsals up to 2 years earlier than conventional schedules allow. Key advantages include enhanced G/S interoperability, a 133% longer verification period, and earlier detection of operational risks. As a result, operator skills improve, and launch procedure reliability increases. Future efforts will expand this framework to cover full-scale mission scenarios and post-LEOP contingencies, further boosting operational readiness for upcoming missions.

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