

Bridging the OEM–Non-OEM FTI Process Gap: A Risk-Driven Decision-Gate Framework for Flight Test Instrumentation Planning

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Abstract:

This paper discusses the implementation of Flight Test Instrumentation (FTI) under different organizational paradigms, focusing on the stakeholder responsible for delivering the FTI system. When FTI activities are performed by Original Equipment Manufacturers (OEMs), programs typically benefit from long life cycles, broad access to onboard data buses and sensor documentation, and established design and certification privileges such as Design Organization Approval (DOA) or Organization Designation Authorization (ODA) within Federal Aviation Administration (FAA) or European Union Aviation Safety Agency (EASA) frameworks. These conditions generally allow a more streamlined coordination process when obtaining Special Flight Permits, despite the broader certification scope typically involved. In this work, OEM-based FTI processes are used as a reference condition for identifying process gaps and improvement opportunities in non-OEM environments. In contrast, independent flight test service providers typically execute numerous smaller, application-specific projects and often have limited access to Interface Control Documents (ICDs) and aircraft system information. Based on this comparison, the paper proposes a risk-driven decision-gate framework to support early-stage planning and risk identification in non-OEM FTI projects. Two case studies are presented to illustrate these differences: the first one describes an environment in which standardized aircraft bus implementation was confirmed, where design followed ARINC 429 recommendations and enabled direct parameter acquisition for most required parameters, with minimal architectural constraints; the second one details a scenario in which the absence of ICD access required significant FTI architecture adjustments, additional signal conditioning, and indirect data acquisition strategies. The framework consolidates recurrent risk drivers associated with data availability, architecture definition, aircraft access, signal characterization, calibration, logistical support, and certification planning. The proposed framework builds on lessons learned from previous IPEV flight-test research involving aerodynamic modeling, simulation fidelity, optical tracking, and probabilistic safety assessment. The resulting recommendations aim to improve planning efficiency and reduce certification and integration risks in non-OEM flight test environments.

Keywords: Instrumentation Architecture, Risk Mitigation in Flight Test, FTI Project Planning, Decision-Gate Framework, Real-Time Decision Support.

1 Introduction

Flight test activities vary significantly depending on the organization's role within the aerospace ecosystem. In the case of an Original Equipment Manufacturer (OEM), whose primary mission is the development and certification of new aircraft, flight test campaigns are deeply integrated into the design process and benefit from extensive access to system-level information. In contrast, non-OEM organizations—such as flight test service providers, research institutes, or aircraft operators—are typically responsible for evaluating already certified aircraft, expanding operational envelopes, or developing new operational procedures for existing platforms.

Within this context, the Instituto de Pesquisas e Ensaios em Voo (IPEV – *Flight Test and Research Institute*) operates as a non-OEM flight test organization supporting experimental flight test campaigns, applied research, and aircraft evaluation activities for the Brazilian Air Force. Its Flight Test Instrumentation and Telemetry team (EIT) develops, integrates, validates, and operates instrumentation

and telemetry solutions required to acquire reliable flight test data across different aircraft platforms and operational contexts. The constraints commonly faced by EIT—including limited access to aircraft documentation, restricted aircraft availability, architecture adaptation, calibration requirements, and certification constraints—are representative of non-OEM FTI environments and provide practical motivation for the risk-driven framework proposed in this work.

Previous IPEV research has addressed several flight-test applications in which reliable instrumentation, synchronized data acquisition, and robust post-flight or real-time analysis are critical enablers. These studies are mainly part of the Advanced Flight Test Tools (FAEV) project and include flight-test-based aerodynamic modeling and model stitching for high-fidelity flight simulation [1], the assessment of longitudinal/lateral-directional cross-coupling effects using dedicated flight test campaigns [2], the identification of lateral stability variations across the flight envelope [3], and the development and validation of optical tracking systems for external-

store separation analysis (SisTrO II) [4]. Other related works extended this instrumentation-driven approach to probabilistic safety assessment, using SisTrO II data to quantify uncertainty effects in store separation dynamics and support risk-informed decision-making [5], [6]. Together, these contributions demonstrate the increasing dependence of modern flight test activities on reliable, synchronized, and well-planned FTI architectures. However, they also reveal a recurrent challenge in non-OEM environments: the success of advanced analysis, modeling, simulation, and decision-support applications depends strongly on the early feasibility assessment of data availability, aircraft access, instrumentation architecture, calibration, and certification constraints. The present work complements these previous studies by shifting the focus from individual flight-test applications to the underlying FTI planning process, proposing a risk-driven decision-gate framework for non-OEM instrumentation projects.

Accordingly, relevant differences arise in the implementation of FTI [7] processes depending on whether they are conducted within an OEM or a non-OEM environment. In OEM contexts, the entire aircraft development lifecycle is under organizational control, which enables direct access to design data, onboard system architectures, and Interface Control Documents (ICDs). This condition facilitates the identification, acquisition, and synchronization of parameters required for both post-flight analysis and real-time monitoring. Moreover, instrumentation can be integrated during early design and manufacturing stages, allowing the installation of sensors—such as strain gauges and accelerometers—in locations that would not be accessible after aircraft delivery.

From a process-oriented perspective, OEM-based FTI implementations may be regarded as a reference condition approaching an ideal instrumentation environment, characterized by high data availability, strong system integration, and streamlined certification pathways. In contrast, non-OEM FTI projects are typically performed under distinct constraints, including limited access to aircraft documentation, restricted aircraft availability, contractual and warranty limitations, and dependence on external airworthiness authorities for modification approval. These constraints introduce uncertainty into the instrumentation process and often require adaptive solutions that differ substantially from the original test-driven design intent.

Consequently, a fundamental challenge in non-OEM FTI projects is the existence of a process gap when compared to OEM environments. If not properly addressed, these limitations may lead to architectural rework, increased aircraft downtime, reduced data quality, and decreased efficiency in flight test campaigns.

This challenge is particularly relevant in modern flight test contexts that rely on real-time monitoring and decision-support capabilities, such as those pursued in the FAEV project.

Ultimately, the goal of this work is to provide a practical and scalable methodology that enhances planning efficiency and reduces technical and

operational risks in non-OEM FTI projects, while enabling a closer approximation to the level of integration and reliability typically observed in OEM environments.

2 Methodological Approach

The methodological approach adopted in this work is based on a process-oriented comparison between OEM and non-OEM Flight Test Instrumentation (FTI) environments. OEM-based FTI processes are used as a reference condition. The comparison with non-OEM environments enables the identification of process gaps associated with limited documentation, reduced aircraft availability, external approval dependencies, and constrained implementation conditions.

The proposed framework was derived from three complementary sources. The process gap was characterized to materialize the main differences between the types of organizations. Observations were then extracted from two real non-OEM FTI projects, in which different levels of data bus access, aircraft availability, and architecture adaptation were observed. Next, recurrent risk drivers were identified across these contexts, including data availability risk, architecture risk, integration risk, calibration risk, operational scheduling risk, and certification risk.

These risk drivers were then consolidated into a sequence of decision gates, each representing a critical point at which the feasibility of the proposed instrumentation approach should be verified before the project advances to the next phase. This structure is intended to reduce late-stage redesign, improve alignment between measurement requirements and implementation constraints, and support more realistic planning of aircraft access, installation, validation, and approval activities.

3 Characterization of the OEM – Non-OEM FTI Process Gap

3.1 Access to ICD

A relevant difference between OEM and non-OEM FTI processes concerns access to information related to aircraft data bus traffic. Although standards such as ARINC 429 [8] provide guidance on digital data transmission in avionics systems, their implementation may vary significantly across manufacturers and aircraft configurations. The availability of Interface Control Documents (ICDs) and equivalent technical documentation is a key enabler for efficient instrumentation design.

In OEM environments, this issue is typically mitigated by direct access to internal design data, system architectures, and development teams responsible for avionics and control systems. As a result, the identification of relevant parameters, including their labels, encoding, update rates, and conversion factors, can be performed with a high degree of confidence and efficiency. This condition contributes to a near-ideal instrumentation scenario, in which data acquisition architectures can be defined based primarily on test requirements rather than data availability constraints.

In contrast, for non-OEM organizations, access to this information is often limited or uncertain. Detailed

communication data may depend on technical support agreements, warranty conditions, intellectual property restrictions, or specific contractual provisions. Since aircraft and onboard systems are typically delivered for operational use, internal communication protocols are not always included in the original scope of supply, and obtaining this information may require additional negotiation or contractual arrangements.

This limitation represents a primary data availability risk, which directly contributes to the process gap between OEM and non-OEM FTI environments. In practice, non-OEM teams often initiate instrumentation design based on the assumption that the aircraft follows applicable standards, such as ARINC 429, using this assumption as a starting point for data bus investigation and architecture definition [9]. While this approach provides an initial framework for parameter identification, it introduces uncertainty when the actual implementation deviates from the standard, is partially documented, or includes proprietary modifications. Adjustments tend to be time-consuming and may significantly extend the FTI implementation schedule.

This uncertainty affects early-stage requirement validation, as the feasibility of acquiring specific parameters cannot be fully confirmed during initial planning. Consequently, instrumentation design may transition from a test-driven paradigm to a constraint-driven one, where data accessibility becomes a dominant factor. If not properly addressed, this condition may lead to architecture risk, including late-stage redesign, increased integration effort, and reduced instrumentation capability.

Therefore, access to ICDs and equivalent documentation should be treated as a critical decision point in non-OEM FTI planning. Early identification of documentation availability, combined with the definition of fallback acquisition strategies, is essential to mitigate data-related risks and to support the development of robust and reliable instrumentation architectures.

3.2 Warranty and Contractual Constraints

These constraints may shift the FTI planning paradigm from a purely test-driven approach to a constraint-driven—or more specifically, permission-driven—paradigm, in which the primary design driver becomes the avoidance of actions that could affect aircraft warranty conditions, maintenance requirements, or contractual limitations. In this context, the feasibility of a given instrumentation solution is not determined solely by its ability to meet test objectives, but also by its compliance with operational, and legal constraints.

Non-OEM entities must frequently adapt their instrumentation strategies to external constraints imposed by manufacturers and operators. Hence, even technically optimal solutions may be deemed infeasible if they involve intrusive modifications, access to protected interfaces, or changes that could invalidate warranty coverage. If not properly accounted for during the early planning phase, such constraints may lead to delays in approval, redefinition of instrumentation strategies, or partial implementation of the required measurement set.

Consequently, adjustments to the flight test campaign schedule may be required. In some cases, a phased instrumentation approach is adopted, in which a simplified or non-intrusive FTI configuration is implemented while technical support agreements or warranty coverage remain in effect. A more complete instrumentation architecture may then be deployed only after these restrictions are relaxed or expire, enabling full access to the required data sources.

3.3 Aircraft Ownership and Availability

In an OEM environment, the manufacturer usually manages the aircraft directly, which tends to make planning, scheduling, and time allocation for instrumentation activities more manageable. In contrast, non-OEM FTI projects often involve aircraft that remain assigned to their regular operators, such as operational units or flight squadrons. In these cases, any period of aircraft downtime can negatively affect operational readiness.

The FTI team usually receives a list of required parameters, but the available time for inspection, installation, validation, and calibration may not be sufficient to implement the complete instrumentation architecture. Ideally, all requested parameters should be acquired. However, some project steps may not be completed within the available aircraft access window, such as electrical signal validation, sensor calibration, wiring installation, or the manufacturing and installation of dedicated mounting devices.

This limitation introduces a time-driven constraint and an associated operational and scheduling risk, in which aircraft availability becomes a primary driver of instrumentation decisions rather than merely the test requirements.

3.4 FTI Complexity

In an OEM context, aircraft are usually still under development, and flight test campaigns tend to be longer, broader, and more deeply integrated with the aircraft design and certification process. Thus, the FTI system may be required to acquire a very large number of parameters, sometimes reaching hundreds of thousands, depending on the aircraft program and test campaign scope.

In non-OEM environments, flight test campaigns are usually more specific and limited in scope. The number of required parameters is often smaller, since the instrumentation is designed to support a particular test objective, operational assessment, certification activity, or procedure development. However, this narrower scope does not necessarily imply lower complexity. Non-OEM FTI teams often manage multiple projects within the same period and must adapt quickly to different aircraft categories, including transport, fighter, helicopter, and unmanned aerial vehicle aircraft.

In summary, while OEM complexity is primarily associated with scale and system-level integration, non-OEM complexity is driven by variability, reduced planning time, limited aircraft access, and uncertainty in data availability and implementation constraints.

In non-OEM environments, the adoption of flexible architectures capable of accommodating evolving

constraints. Therefore, while OEM and non-OEM FTI projects differ in the nature of their complexity, both require structured approaches to manage it effectively [10]. Non-OEM entities may address variability and uncertainty through risk-aware planning, enabling improved workflow continuity.

3.5 Non-OEM FTI Workflow

The previous constraints can be organized into a typical non-OEM FTI workflow, as shown in Fig. 1. In this workflow, the instrumentation request first leads to defining the required parameters and reviewing available documentation, including manuals, wiring diagrams, ICDs, and sensor information. Based on this review, the FTI team evaluates whether direct bus acquisition is feasible or whether fallback acquisition strategies are required.

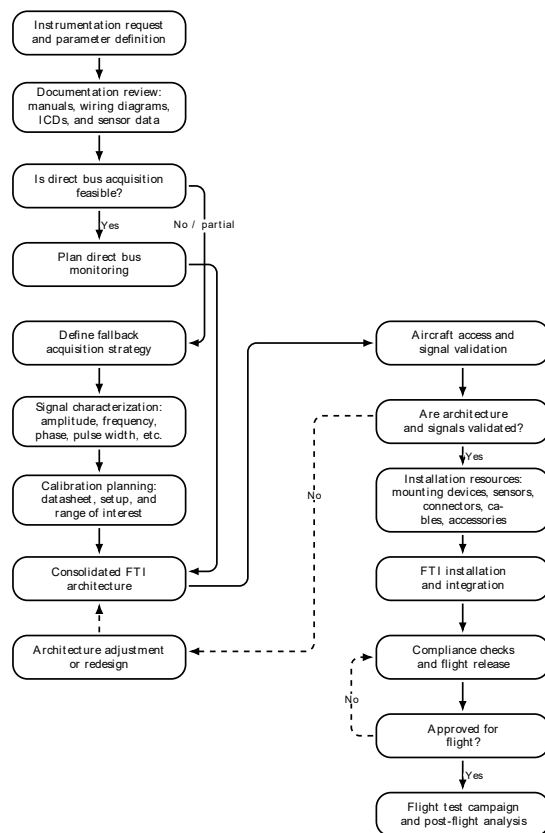


Fig. 1: Typical workflow of a non-OEM Flight Test Instrumentation project.

This initial stage represents a critical step in reducing the process gap between OEM and non-OEM environments, as it directly addresses data availability and feasibility. This phase is primarily associated with data availability and architecture risks, since incomplete or uncertain information may affect subsequent design decisions.

When bus acquisition is feasible, the project may proceed toward direct bus monitoring and architecture consolidation. When it is not feasible, or only partially feasible, alternative strategies must be considered, such as sensor-level tapping, additional sensors, indirect measurements, or video-based acquisition.

These alternatives introduce additional tasks, including signal characterization, calibration planning, and verification of the range of interest for the test objective, increasing implementation complexity and integration effort.

After the preliminary architecture is consolidated, aircraft access is required to validate the selected signals. If the architecture or signals cannot be validated, the project enters a redesign loop before proceeding to installation. This step is particularly relevant in non-OEM environments, where incomplete documentation or limited aircraft access may reveal constraints only during implementation. This iterative loop reflects the impact of uncertainty and highlights the importance of early validation to mitigate rework and schedule delays. Once the architecture is validated, the project proceeds to installation, compliance checks, flight release, and campaign execution.

This workflow provides the basis for the decision-gate framework proposed in this work, in which each stage corresponds to a verification point aimed at reducing uncertainty before progressing to subsequent phases.

3.6 Certification and Special Flight Permits

FTI installation is generally treated as a modification to the aircraft configuration and must therefore be evaluated before the aircraft is released for flight. Depending on the scope and complexity of the instrumentation system, this approval process may require significant time and coordination. In non-OEM environments, this step represents a critical certification and approval risk, since the FTI team often depends on external organizations or authorities to complete the required evaluations.

After installation, the aircraft is subject to several verification activities, such as inspections of non-native equipment, electromagnetic compatibility and interference assessments, maintenance record reviews, weight and balance evaluations, and conformity checks. These activities often involve maintenance organizations, engineering teams, airworthiness authorities, or other external stakeholders. As a result, the time required to return the aircraft to flight condition may increase considerably.

The evaluation of modifications affecting aircraft airworthiness is typically a responsibility of the competent aviation authority. However, manufacturers or approved design organizations may hold delegated privileges that allow them to perform certain design-approval or compliance-verification activities. In the European context, this may occur through a Design Organization Approval (DOA) under EASA rules [11]. In the United States, similar delegated functions may be performed through an Organization Designation Authorization (ODA) under the FAA framework [12], [13].

Consequently, depending on the scope of the modification and the privileges granted by the competent authority, an OEM or an approved design organization may be able to manage the approval of certain FTI-related modifications through an established internal process, streamlining the release

for flight. In contrast, the dependence on external airworthiness or certification channels for non-OEM FTI organizations may increase the time required for approval, since the process relies on their availability, review cycle, and requirements.

4 Case Studies

The case studies intend to highlight recurrent risk drivers and practical constraints that motivated the decision-gate framework proposed in this work.

4.1 Case Study A – Architecture Redesign Due to Limited Data Bus Information

During the preliminary aircraft survey, it was observed that the required parameters could not be directly identified in accordance with the expected data bus standards. In addition, the available time window was not sufficient to develop a dedicated decoding library from scratch. Therefore, the initial assumption that the required parameters could be acquired directly from the aircraft data bus was not confirmed.

From the standpoint of the proposed methodology, this situation represents the materialization of a data availability risk, since the lack of sufficient bus documentation prevented the direct confirmation of parameter encoding, update rates, and conversion factors. It also triggered an architecture risk, because the initial bus-based acquisition strategy could no longer be maintained without significant additional effort.

As a consequence, a new FTI architecture had to be defined, and instead of acquiring the required information from the data bus, the team decided to collect data closer to the original sensors. Although this approach allowed the campaign to proceed, it increased the number of intervention points in the aircraft because the relevant sensors were distributed across multiple locations. Consequently, additional time had to be allocated to the instrumentation phase for access, installation, validation, signal characterization, calibration, and troubleshooting.

This change affected significantly the overall flight test campaign schedule. Since the aircraft was assigned to an operational unit, the operator had to be consulted, and operational activities had to be replanned to accommodate the additional instrumentation work. This case illustrates how limited access to data bus documentation can lead to architectural rework, increase aircraft downtime, and require coordination beyond the FTI team.

4.2 Case Study B – Mixed Data Acquisition Supported by Standardized Bus Implementation

Preliminary survey allowed to confirm that the relevant data bus followed the ARINC 429 standard and that most of the required parameters could be properly identified. This early verification significantly reduced the uncertainty associated with the FTI architecture, as the team confirmed the availability of most required parameters, their identifiers, and the feasibility of direct bus monitoring.

From the perspective of the proposed methodology, this case represents a condition in which the data

availability risk was substantially reduced at an early stage. However, it also shows that compliance with a standardized bus implementation does not, by itself, fully validate the instrumentation architecture. Parameter availability must still be assessed against the specific requirements of the flight test objective, including update rate, a usually critical aspect.

However, the parameter list was only partially available at the required acquisition frequency. In particular, some engine parameters were either unavailable at the required update rate or unsuitable for the intended analysis when acquired directly from the data bus. As a result, although the initial bus-based architecture remained valid for most parameters, complementary acquisition paths had to be implemented for selected engine data.

Since the aircraft was proprietary and was already outside the warranty period, the FTI team had more flexibility to perform modifications and define additional intervention points. For the engine parameters, data acquisition had to be performed closer to the sensors, which required additional signal conditioning and specific installation work. This solution increased the complexity of the instrumentation architecture when compared with a purely bus-based approach, but it avoided a complete redesign of the system.

Overall, the early confirmation of ARINC 429 implementation allowed the team to preserve most of the original architecture and reduced aircraft downtime compared with cases in which bus documentation or parameter identification is unavailable. Since almost all required parameters could be obtained from the data bus, the additional work was limited to specific engine parameters. This case illustrates that even when the standard bus implementation is confirmed, the sampling frequency, parameter quality, and test objectives must still be evaluated before the FTI architecture is considered fully validated.

In terms of the decision-gate framework, the case highlights the importance of the data source mapping, architecture definition, and signal characterization and calibration gates. Early verification of bus implementation reduced uncertainty and prevented major rework, while the identification of insufficient update rates for selected parameters supported a controlled transition to complementary acquisition paths. This reinforces the need for risk-driven planning. Table I summarizes the main characteristics of the two case studies.

5 Proposed Reference Framework for Non-OEM FTI Planning

The proposed framework seeks to reduce the gap between OEM and non-OEM FTI environments. While OEM-based processes may be regarded as a reference condition due to their higher level of data availability, system integration, and approval maturity, non-OEM projects must approximate this condition through structured planning, early risk identification, and progressive validation of instrumentation feasibility.

TABLE I: Summary of risk drivers in the case studies

Aspect	Case A	Case B
Bus documentation	Limited/unavailable	Standard implementation confirmed
Main risk	Data availability / architecture redesign	Update rate / partial acquisition
Acquisition strategy	Sensor-level tapping	Mixed bus + sensor acquisition
Main impact	Redesign and additional downtime	Limited complementary work

To support this planning process, this paper proposes a reference framework based on sequential decision gates. Each gate represents a critical point at which the FTI team should verify whether the available information, aircraft access, technical resources, and approval conditions are sufficient to proceed with the proposed instrumentation architecture. The framework is intended to be applied during the initial planning phase, before aircraft downtime is formally allocated or flight test campaign dates are fixed. Table II presents the proposed decision-gate framework for non-OEM FTI planning.

The first decision gate concerns the definition of measurement requirements. The initial parameter list is often derived from the test plan or requests from flight test engineers. However, not all requested parameters are equally relevant to the test objective. Treating all parameters as equally mandatory may result in excessive architectural complexity and unrealistic implementation schedules. For this reason, parameters should be classified by criticality. A minimum viable instrumentation set should be defined early to ensure the campaign can proceed if secondary parameters cannot be acquired within the available time or certification constraints.

The second decision gate concerns data source mapping. When ICDs or equivalent technical documentation are available, the FTI team can identify bus labels, transmission rates, conversion factors, and parameter encoding with greater confidence. In contrast, when documentation is unavailable or incomplete, the team may need to infer parameter location and meaning through signal analysis, aircraft manuals, maintenance documentation, or direct measurement. This increases engineering effort and may require fallback strategies, such as acquiring analog signals closer to sensors, installing independent sensors, or recording cockpit displays as a last-resort source of information. This gate primarily addresses data availability risk and supports early mitigation of potential architecture redesign.

The third decision gate addresses aircraft availability. Non-OEM FTI teams often depend on aircraft that remain assigned to operational units. For this reason, the aircraft may be available only for short inspection, installation, or validation windows. This constraint affects the feasibility of signal verification, mechanical installation, electromagnetic compatibility checks, calibration, troubleshooting, and maintenance release. Aircraft availability should therefore be treated as a design constraint, not merely as a scheduling issue. This gate is associated with operational and scheduling risk, since insufficient access may prevent the complete validation or implementation of the intended architecture.

The fourth decision gate concerns the definition of the instrumentation architecture. The preferred solution is usually direct acquisition from existing aircraft data buses or accessible signal interfaces. However, this option may not be feasible when the required parameters are unavailable, undocumented, transmitted at insufficient frequency, or protected by warranty and maintenance restrictions. In such cases, the FTI architecture should include alternative acquisition paths, and each should be evaluated based on accuracy, sampling rate, synchronization, installation complexity, certification impact, and reversibility. This gate is central to managing architecture and integration risk.

The fifth decision gate concerns signal characterization and calibration. When the architecture requires sensor-level tapping, the FTI team must determine how the measured quantity is represented electrically. Depending on the sensor and interface, the information may be carried by amplitude, frequency, phase, pulse width, or another signal characteristic. This step is essential to avoid incorrect conversion from electrical signals to engineering units. It is also necessary to identify the range of interest for the flight test campaign, since the full-scale sensor range may not be relevant to the specific test objective. This gate mitigates calibration and data quality risks, especially when fallback acquisition strategies are adopted.

The sixth decision gate concerns logistical support assessment. Even when the instrumentation architecture is technically feasible, the project may be delayed if mounting devices, connectors, sensors, cables, tooling, signal-conditioning modules, or specialized support are not available before aircraft downtime begins. This issue is particularly relevant when the flight test provider does not usually operate the aircraft type. Therefore, required parts, manufacturing needs, and support resources should be identified early and coordinated with the aircraft operator, OEM, or third-party suppliers before the installation window.

The seventh decision gate concerns certification and approval planning. In non-OEM environments, the FTI team may not hold delegated design or airworthiness privileges, which can increase dependency on external certification authorities. Early engagement with these stakeholders helps identify the required evidence, such as installation drawings, electrical load analyses, electromagnetic compatibility assessments, weight-and-balance updates, maintenance records, and safety evaluations. This gate addresses certification and approval risk and helps prevent late-stage delays in flight release.

TABLE II: Decision-gate framework for non-OEM FTI planning

Phase	Key Question	Main Risk	Recommended Mitigation	Gate Output
Requirement definition	Which parameters are essential to the test objective?	Overly ambitious or unstable parameter list	Classify parameters as mandatory, desirable, or optional; define the minimum viable instrumentation set	Prioritized parameter list and minimum viable instrumentation baseline
Data source mapping	Is ICD access available for the required parameters?	Unknown bus labels, encoding rules, update rates, synchronization, or conversion factors	Request ICDs and technical documentation early; identify fallback acquisition strategies	Data source map, documentation status, and fallback acquisition plan
Aircraft availability	When and for how long can the aircraft be accessed?	Delays caused by operational commitments or insufficient ground time	Coordinate inspection, validation, installation, and troubleshooting windows before the campaign	Aircraft access plan and validated ground-time allocation
Architecture definition	Can the required data be acquired directly from existing aircraft systems?	Rework after installation due to inaccessible, undocumented, low-rate, or unsuitable parameters	Define alternative signal paths, including analog acquisition, external sensors, or indirect measurement	Preliminary FTI architecture and alternative acquisition paths
Signal characterization and calibration	If sensor-level tapping is required, how is the measured quantity represented electrically?	Incorrect conversion from electrical signal to engineering units; increased calibration effort; delayed validation	Obtain sensor datasheets, characterize the signal in the aircraft, and map the range of interest before installation	Signal characterization plan and calibration strategy
Logistical support assessment	Are mounting devices, spare parts, connectors, tooling, and specialized support available for the aircraft type?	Delays during installation due to missing parts, manufacturing lead times, or unavailable accessories	Identify required parts and support resources early; coordinate with the operator, OEM, or suppliers before aircraft downtime; manufacture mounting devices in advance	Installation resource checklist and support coordination plan
Certification planning	Which authority or organization approves the modification and flight release?	Delay in special permit, maintenance release, or airworthiness approval	Engage certification and maintenance stakeholders early; prepare evidence for safety and compliance assessment	Certification evidence package and approval path definition
Campaign execution	Are all required parameters available at the necessary quality and frequency?	Reduced test efficiency or inability to meet test objectives	Establish a minimum viable instrumentation baseline and define contingency procedures for missing parameters	Flight-ready instrumentation configuration and contingency plan

The final decision gate concerns campaign execution. Even with careful planning, some parameters may become unavailable due to technical, operational, or certification constraints. Therefore, the FTI plan should define which parameters are indispensable for flight release and which are necessary only for expanded analysis. This distinction allows the campaign team to make informed decisions when partial instrumentation capability is achieved. It also reduces the risk of delaying the entire campaign because of parameters that are desirable but not essential to the primary test objective.

The proposed framework supports the early validation of measurement requirements against practical implementation constraints. Rather than treating the

required parameter list as an isolated input, the framework evaluates each parameter in relation to the mentioned constraints. Overall, the proposed framework encourages non-OEM FTI teams to progressively validate each measurement requirement against them.

This supports earlier identification of rework risks and improves alignment between flight test objectives, instrumentation capability, and aircraft release schedules.

6 Process Comparison and Discussion

6.1 Comparative Analysis of OEM and non-OEM FTI Environments

The comparison between OEM and non-OEM FTI environments shows that each context presents

different strengths, constraints, and risk drivers. Table III summarizes the main differences identified between OEM and non-OEM FTI environments. The comparison indicates that non-OEM FTI planning must explicitly address uncertainty at each stage to approximate, as far as practicable, the integration and reliability typically achieved in OEM-based processes.

TABLE III: Comparison between OEM and non-OEM FTI environments

Aspect	OEM FTI Environment	Non-OEM FTI Environment
Aircraft design data	Broad internal access to design data and system architecture	Limited, contractual, or indirect access to aircraft information
ICD availability	Usually available internally	May be unavailable, incomplete, proprietary, or costly
Aircraft ownership	Controlled by the manufacturer	Shared with the operator, squadron, or external organization
Project duration	Long development and certification campaigns	Shorter, application-specific campaigns
Parameter scope	Very large parameter set, often integrated with aircraft development needs	Narrower, test-driven parameter set, often constrained by feasibility
Sensor installation	Integrated during design or manufacturing	Constrained by certified configuration, access limitations, and reversibility requirements
Certification path	May use established internal processes or DOA/ODA privileges, depending on the scope and authority	Usually depends on external authority
Aircraft availability	Planned within the development program	Limited by operational commitments and mission readiness
Main complexity driver	Scale, integration depth, and configuration control	Variability, incomplete information, limited access, and approval constraints
Rework risk	Lower, due to information availability and early integration	Higher, due to late discovery of constraints or unvalidated assumptions
Supply chain and logistics	Established internal support and dedicated resources	Dependent on operator, OEM, or third-party suppliers
Main strength	System-level design control and integration maturity	Adaptability, operational flexibility, and cross-platform experience

6.2 Early Risk Identification and Requirement Definition

The results indicate that several engineering challenges commonly faced by non-OEM FTI teams could be reduced if instrumentation constraints were considered earlier in the project life cycle. In many cases, rework does not result from inadequate technical decisions, but from incomplete information during the initial planning phase. For example, the absence of ICDs, limited aircraft access, unclear warranty restrictions, insufficient knowledge of certification requirements, or unavailable installation resources may lead to architectural decisions that later require revision.

These conditions correspond to recurrent risk drivers that should be identified during the earliest decision gates, particularly requirement definition, data source mapping, aircraft availability assessment, and certification planning. Hence, measurement requirement should be validated not only against the test objectives, but also against data accessibility, acquisition feasibility, implementation constraints, and approval conditions.

For this reason, FTI specialists should be involved as early as possible, especially during requirement definition and contractual discussions. Their participation can help identify whether the requested parameters are technically accessible, whether specific documentation should be included in the contract, whether additional aircraft access windows

are necessary, and whether the proposed instrumentation architecture may affect warranty, maintenance, or airworthiness conditions.

Early involvement does not mean that every specialist must participate in every phase of the project, since excessive participation may increase planning complexity and slow the process. A more efficient approach is to define decision gates at which specific expertise is required. For example, FTI engineers should support parameter feasibility analysis, maintenance specialists should assess installation and aircraft release constraints, and certification representatives should be consulted when the modification may affect airworthiness approval. It is also advisable that FTI personnel have background knowledge in these subjects, whether through experience or specialized training, to foster compliance-driven professionals.

This approach supports the early alignment between measurement needs, implementation feasibility, and operational constraints.

6.3 Signal Characterization and Calibration as a Rework Driver

The case studies also indicate that changing the acquisition strategy from data bus monitoring to sensor-level tapping introduces additional engineering tasks that must be considered during planning. When parameters are acquired from an aircraft data bus, the information is usually already transmitted as encoded digital data and can be converted to engineering units using labels, identifiers, update rates, and conversion factors. In contrast, when data are acquired from analog signals, the FTI team must first characterize how the measured quantity is represented by the electrical signal [14].

This characterization is not always straightforward, depending on the sensor and interface. Accordingly, sensor datasheets, calibration procedures, and interface documentation are important inputs to the FTI design process, which can be challenging in aviation applications, especially for legacy sensors installed in older aircraft, where documentation may be incomplete, difficult to access, or no longer readily available.

The calibration phase is also affected by this architecture change. The full-scale range of a sensor is not always relevant to a specific flight test campaign. Therefore, the FTI team must identify the range of interest for the test objective and accurately map this range from electrical signal values to engineering units. This mapping is essential to ensure that the acquired data are meaningful for analysis. Thus, although sensor-level acquisition may provide greater control over sampling rates and update rates, it introduces additional overhead in signal characterization, calibration setup, and validation.

6.4 Systems Engineering Considerations

The challenges identified in the comparison and case studies can also be interpreted as systems engineering concerns [15]. FTI requirements should not be treated only as a list of desired parameters. As discussed throughout this work, they should also include information about data source feasibility,

acquisition frequency, accuracy, synchronization, installation constraints, calibration needs, aircraft availability, and approval conditions.

If these aspects are not considered during requirement definition, the resulting FTI architecture may become difficult or impossible to implement within the available schedule. For example, a parameter may be relevant to the flight test objective but unavailable on the selected data bus, transmitted at an insufficient update rate, or accessible only through a sensor that requires additional characterization and calibration. In such cases, the technical requirement must be balanced against the practical feasibility of acquiring the data.

Therefore, the FTI system should be treated as part of the broader flight test system. This system includes the aircraft, test objectives, instrumentation hardware, data acquisition architecture, maintenance personnel, certification stakeholders, aircraft operator, data analysts, and campaign schedule. Considering these elements together improves the alignment between measurement requirements and feasible implementation strategies.

From the perspective of the proposed decision-gate framework, this systems engineering approach supports the progressive validation of requirements against implementation constraints. Each gate provides a structured point at which assumptions can be verified before the project advances. This reduces the likelihood of late-stage redesign and helps non-OEM FTI teams approximate the level of process maturity observed in OEM environments.

6.5 Planning Paradigms in Non-OEM FTI Projects

The comparison also suggests that non-OEM FTI projects may be driven by different planning paradigms, depending on the dominant constraint. In an ideal test-oriented paradigm, the instrumentation architecture is primarily driven by the parameters required to satisfy the flight test objectives. This approach is technically desirable and represents the condition most closely aligned with OEM-based processes, but it assumes that the required data are accessible, that aircraft downtime is sufficient, and that the approval process does not impose major restrictions.

In a time-oriented paradigm, the main driver is aircraft availability. This situation is common when the aircraft remains assigned to an operational unit and can only be released for short inspection, installation, or validation windows. Under this paradigm, the FTI team may need to prioritize a minimum viable instrumentation configuration and postpone secondary parameters to later flights or future campaigns. This paradigm is mainly associated with operational and scheduling risk.

In a permission-oriented paradigm, the main driver is approval, warranty, or maintenance restriction. In this case, the preferred technical solution may not be acceptable if it affects warranty conditions, requires intrusive intervention, or increases the complexity of the airworthiness release. The FTI architecture must then be adapted to remain compatible with

contractual, maintenance, or certification constraints. This paradigm is mainly associated with certification, approval, and stakeholder-management risks.

These paradigms are not mutually exclusive. A single non-OEM FTI project may involve test-driven, time-driven, and permission-driven decisions at different stages. Recognizing which paradigm is dominant at each decision point helps the FTI team communicate trade-offs more clearly with flight test engineers, aircraft operators, maintenance organizations, and approval authorities.

These paradigms help explain why non-OEM FTI planning must be treated as a risk-driven process. Each gate provides an opportunity to identify whether the project is primarily limited by measurement requirements, aircraft availability, or approval constraints, and to adjust the instrumentation strategy accordingly.

6.6 Collaboration and Lessons Learned

The results also show that collaboration among FTI teams can reduce repeated effort and improve planning maturity. Since non-OEM organizations often face similar challenges across different aircraft types, technical forums, user communities, and professional networks can support the exchange of lessons learned, acquisition strategies, and best practices.

This collaboration is especially valuable when dealing with limited documentation, legacy sensors, data bus interpretation, signal conditioning, calibration procedures, and post-flight analysis workflows. Even when aircraft configurations differ, the underlying engineering problems are often similar. Sharing experience can help teams anticipate risks that may otherwise be discovered only during aircraft access or installation. In this sense, accumulated lessons learned help teams partially reduce the process gap relative to OEM environments, where internal design knowledge and previous program experience are more readily available.

However, collaborative knowledge should not replace project-specific validation. Each aircraft configuration, sensor installation, maintenance condition, and approval context may introduce unique constraints. Therefore, lessons learned from previous projects should be used as planning inputs, while final decisions should still be confirmed through documentation review, aircraft inspection, signal validation, and certification assessment.

7 Limitations

Although the proposed framework is supported by a process-oriented comparison and practical observations from two real projects, the analysis remains primarily qualitative. The case studies were selected to illustrate representative constraints and risk drivers commonly encountered in non-OEM environments, rather than to provide a statistically validated assessment of FTI project performance.

In addition, the proposed decision-gate framework has not yet been quantitatively validated across a broad set of flight test campaigns. Thus, its effectiveness should be interpreted as a practical planning aid and risk-identification tool, rather than as

a predictive model for estimating schedule impact, rework probability, or certification delay.

Future applications of the framework should include quantitative metrics, such as aircraft downtime, number of redesign iterations, percentage of parameters successfully acquired, calibration effort, approval duration, and impact on campaign efficiency. Such data would support further refinement of the decision gates and provide a stronger basis for evaluating the framework's effectiveness in non-OEM FTI planning.

8 Conclusions

This paper compared OEM and non-OEM Flight Test Instrumentation environments from a process-oriented perspective. OEM-based FTI processes were used as a reference condition for identifying process gaps and improvement opportunities in non-OEM environments.

Non-OEM FTI projects usually involve narrower parameter sets, their complexity stems from uncertainty, platform variability, and the need to adapt instrumentation strategies under time and information constraints. Therefore, non-OEM complexity is driven less by instrumentation scale and more by risk drivers such as data availability, architecture feasibility, calibration effort, operational scheduling, logistics, and certification constraints.

The case studies illustrated how early access to documentation and aircraft itself can reduce architectural uncertainty and aircraft downtime, while incomplete documentation may require sensor-level acquisition, additional signal conditioning, calibration effort, and redesign. They also showed that even when standardized bus implementation is confirmed, parameters must still be evaluated according to update rate, for example. These findings reinforce the need to validate measurement requirements against implementation constraints before the instrumentation architecture is considered mature.

Based on these findings, the paper proposed a decision-gate framework to support early-stage planning and risk identification in non-OEM FTI projects. By applying these gates before aircraft downtime is allocated, FTI teams can improve planning efficiency, reduce rework, and better align instrumentation capability with flight test objectives.

Future work may include applying the proposed framework to additional flight test campaigns, refining the decision gates based on quantitative schedule and rework data, and developing more detailed guidance for documentation requirements, sensor-level calibration, and non-OEM certification planning. Additional work may also explore the integration of the proposed framework with real-time decision-support architectures, strengthening the link between instrumentation planning, data quality assurance, and operational decision-making.

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