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Quality Supervision Method for Aerospace Projects

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Abstract—To ensure both the quality and timeliness of aerospace projects conform to engineering standards, this study investigated mature quality supervision methodologies from diverse engineering disciplines for potential applicability in aerospace projects. Based on supervision techniques from the International Federation of Consulting Engineers and international satellite product assurance methods, the study synthesized key insights and lessons from advanced international quality supervision practices. According to the unique attributes of aerospace project development and testing procedures, this study devised a comprehensive framework for quality supervision, encompassing organizational models, workflow processes, and principal supervision components. This framework serves as a referential guide for implementing quality supervision initiatives within the aerospace sector.

Keywords—aerospace; quality management; quality supervision

I. Introduction

At present, aerospace projects, exemplified by commercial spaceflight, are burgeoning both in number and scope. Owing to their inherently high levels of complexity and risk, effective quality supervision is indispensable for fortifying the quality control mechanisms of these initiatives. Established methods, such as international advanced satellite supervision and international consulting engineer supervision, have formed a scientifically rigorous and effective set of quality supervision practices. Given the evolving challenges and responsibilities in aerospace development, it is imperative to assimilate mature experiences and effective practices. The objective is to cultivate more scientific, standardized, and effective modes and methods of quality supervision, thereby optimizing its impact and assuring the successful completion of aerospace projects.

The term "superintendent," originally defined in the construction industry, refers to a third-party organization contracted by Party A to oversee a project. Generally, a superintendent's purview encompasses three controls and one managerial aspect: quality, progress, safety, and capital management. However, in several contemporary projects, supervisory agencies are primarily tasked with quality control, also known as quality supervision. This role necessitates representation of and responsibility toward the end-user or Party A, functioning as an impartial third party with independent oversight. Additionally, the superintendent safeguards the end-user's legitimate rights and interests without undermining those of the contractor, thereby maintaining an equitable stance.

II. International Federation of Consulting Engineers (FIDIC) Supervision Method

A. Overview

The International Federation of Consulting Engineers (FIDIC) is a globally recognized organization that has developed a set of scientifically rigorous and effective methods for quality supervision through long-term practice. These methods have garnered international acclaim and are widely adopted for their influential and well-operated frameworks. The primary characteristics of the FIDIC method of supervision include impartiality, transparency, and fairness, alongside strictness, definitiveness, and legality. Notably, the FIDIC approach places considerable emphasis on the role of engineers. In the context of FIDIC contract conditions, supervision engineers are central to project quality management practices, encompassing responsibilities such as drawing reviews, ongoing supervision, and physical inspections.

The FIDIC method primarily employs a project management approach, accentuating the principles of project management in alignment with the plan–do–check–action (PDCA) cycle. This approach facilitates control over project cost, schedule, and quality. Specifically, in terms of project quality, the FIDIC method initially delineates the objectives within the contractual conditions. It further outlines the foundational principles and procedures for quality supervision, while also defining problem-solving methodologies and apportioning responsibilities between the involved parties for any challenges that may arise throughout the process.

The FIDIC supervision methods for quality supervision of projects are conducted in three major areas:

(1) Formulation of plans: The supervising engineer's quality control is grounded in contract conditions, design documents (inclusive of any modifications), technical specifications, and quality standards. A structured organizational system is established to implement predetermined work procedures. Various effective mechanisms and methods, such as inspections, verifications, sample tests, measurement stations, and on-site reviews, are employed throughout the construction process, providing comprehensive, continuous supervision and management across all elements of the project.

(2) Process inspection: This aspect is formed by two primary dimensions. First, the examination of quality behavior, essentially a review of the contractual commitments pertaining to quality assurance in the construction project. Second, the inspection of the engineering entity itself, executed with focused attention, a well-defined plan, and adequate testing and detection mechanisms.

(3) Completion of identification: Upon the completion of the project, the supervising engineer conducts an evaluation to identify the quality level of the project. This identification process is based on prevailing engineering quality assessment and inspection standards.

B. Analysis

1) Emphasis on Autonomy and Responsibility in FIDIC Quality Supervision: Unlike domestic supervisors who operate under the oversight of the client, FIDIC supervising engineers maintain robust independence throughout the project lifecycle. These engineers exercise their signature rights within the bounds of their designated duties, free from any interference by the owner. Communication concerning design and construction occurs solely via the supervising engineer, rather than directly with the owner. Nonetheless, in cases of issues related to quality, progress, or safety, the owner has the legal prerogative to hold the supervising engineers accountable.

2) FIDIC quality supervision emphasizes the skilled application of standards and specifications for project implementation by technical personnel: FIDIC quality supervision accentuates the skilled utilization of project implementation standards and specifications by technical personnel. In international projects, the executing unit must elucidate the standards for project execution as delineated in the contract terms. In case these conditions are not be explicitly stated, consultations with the owner and consulting engineer are mandatory to define them in advance. During the preparation phase, technical staff are assembled to study the relevant standards and specifications. Subsequently, these personnel are mandated to draft work instructions in alignment with these standards and submit them to consulting engineers ahead of time to ensure ample communication prior to construction.

3) FIDIC quality supervision focuses on the quality control of components related to site personal safety: FIDIC quality supervision is particularly stringent about the quality control of site components that have implications for personal safety. Items such as public platforms, staircase railings, and equipment featuring integrated climbing ladders, though seemingly inconsequential, are subject to rigorous quality control by supervising engineers.

III. International Satellite Supervision Method

A. Overview

International satellite supervision encompasses various activities: technical review, mandatory inspection, production readiness review, test/test readiness review, and on-site surveillance. Specific product assurance supervision activities are categorized as: daily supervision, witnessing (with 100% presence), and monitoring (*via* intermittent presence).

The user outlines product warranty requirements in a contract annex. In response, the supervised entity drafts a product warranty outline that incorporates both the annex content and the user's stipulated requirements. The product warranty requirements mainly include comprehensive product warranty requirements, technical review, reliability assurance, component, material and process assurance, quality assurance, software assurance, technical status management, safety assurance, subcontractor product assurance, launch site product assurance, in-orbit abnormality tracking control plan, and product warranty delivery documents. The product assurance requirements are clearly defined in the form of general specifications for satellite supervision and manufacturing, satellite production, test process and factory, transfer phase, delivery, technical state change control, quality problems to zero, reliability, software, components and other key links, key items satellite supervision and manufacturing of the main content, methods, processes.

1) Technical Review: The technical review in satellite supervision and manufacturing is segmented into five principal phases: product qualification status review (EQSR), preliminary design review (PDR), critical design review (CDR), pre-shipping review (PSR), and launch readiness review (LRR). Specifically, EQSR is undertaken for each individual product during the project's design phase. This review compares and analyzes technical specifications, usage documentation, test data, and test conditions between the product and any predecessor products, ultimately determining the product's qualification status level and test items. The PDR involves the participation of the product assurance supervisory representative as a member of the review committee, who have previously examined the product assurance documents. This representative generates a questionnaire and engages in detailed dialogue with the supervised entity during the PDR meeting. During the PSR phase, the representative's primary responsibilities include addressing non-conformities (NCR), handling requests for production overruns (RFW), and facilitating pending closures.

2) Mandatory inspection points set: During the design phase, the supervisor establishes mandatory inspection points for the project, collaboratively delineating the specific inspection items, programs, and other particulars with the supervisee. This culminates in a document listing the mandatory inspection points. In the case of a satellite project, the user designates three types of mandatory inspection points (MIP): platform critical items, platform qualification products, and payload critical products. These points are identified based on the critical item process control provided by the supervised party. Critical and mandatory inspection points (KIP/MIP) are not only selected but also require acceptance results before proceeding to manufacturing and testing stages. These inspection points are specifically indicated in the production flow charts at the equipment level, as well as in the assembly, final assembly, and test plans at the system level.

For critical products, the MIP in the process can be determined based on their criticality, with critical inspection being performed in-plant and not requiring the involvement of higher-level contractors, whereas the MIPs require end-user involvement.

3) Manufacturing readiness review (MRR). The objective of supervision during the manufacturing readiness stage is threefold: to verify the congruence between the first flying part and the current production status, and to identify the design and production statuses as well as the production conditions. The design status encompasses design drawings, documents, process documents, specifications, and any deviations or concessions. The production status entails preparation elements such as components, materials, standard procurement parts, and designated to-do items. The production status focuses on the preparation of components, materials, procurement standards, to-do items, and the identification and preparation of production processes and key inspection points; production conditions focus on key facilities and equipment, tools (including processing and testing, etc.), and the qualification of key positions.

4) Test/Trial Ready (TRR) Review: The purpose of the test/test readiness reviews set for qualification and critical project products, as well as vital subsystems and large scale test phases of the entire star, is to verify that the test/test status of critical products is consistent with the past findings; the test/test status of the first flight component is consistent with the status through qualification; and the large scale test/test readiness is complete. Research, analyze, and track the key elements of the test/test readiness review including: design status, test/test status, and test/test conditions. In particular, the design status focuses on design documents, product specifications, test/test outline and specifications, deviations and concessions; test/test status focuses on non-conformance (NCR) status, mandatory inspection point (MIP) results, and completion of production process to-dos; test/test conditions focus on test/test site (including environment), test/test equipment (including list and calibration), test/test software (including list and version status), and test/test software. test software (including list and version status), test/test positions (personnel list and qualifications), test/test plans, etc.

The example of nonconformance report for international satellite supervision is presented in Fig. 1.

	Nonconformance report	Project: No.: Date:	☐ deviation ☐ waiver
Identification	Product Name: Product quantity: Product No.: Serial No.: Subsystem: Manufacturer:		☐ major ☐ minor
Phases	☐process inspection ☐acceptance inspection ☐function test ☐fabrication ☐ integration ☐quality test ☐acceptance test ☐launch preparation ☐other		
Test Status	☐acoustic ☐sine-vibration ☐random-vibration ☐shock ☐thermal balance ☐ thermal vacuum ☐ high-temperature soak ☐ thermal cycle ☐ temperature cycle burn-in ☐EMC ☐ other		
Description of observed non conformance (failure)			
Cause of non conformance (failure)- analysis results:			
Description of corrective actions to be taken: ☐ none(us as is) ☐nonstandard repair ☐return to supplier ☐modification application ☐ standard rework ☐re-inspection/extensive test ☐scrap ☐nonconformance application			
Design engineer:	Vice Chief Designer:	CGWIC approval:	
Product assurance:	Project manager:	CGWIC approval:	
Customer: ☐Accept ☐Reject ☐Accept with Proviso Name:________ Signature:________ Date:________			

Fig. 1. Nonconformance report

B. Analysis

1) Emphasis on technical risk as the core, focusing on key features to carry out supervision and manufacturing activities:

In the domain of international satellite supervision and manufacturing, the focal points are control of key items and processes, with technical risk serving as the central concern. Supervision and manufacturing activities revolve around pivotal aspects of satellite development, such as technical reviews, mandatory inspections, and test/test readiness reviews (TRR). Mandatory inspection points are strategically configured in three categories: platform key item products, platform qualification products, and payload key products. The implementation process for these points is meticulously monitored on-site, eliciting questions and action items as necessary.

2) Emphasize the rights of product assurance managers and users: Generic contractual requirements in the annexes of international satellite manufacturing (ISM) emphasize certain key points. First, the product assurance manager (PA) must possess adequate authority for unimpeded access to the contractor's top management, ensuring compliance with output assurance stipulations. Second, it specifies the experience and responsibilities of key project roles, with the Product Assurance Manager directly reporting to a qualified senior leader who is independent of the project. Concurrently, the contract accentuates the critical rights of the user, such as participation rights; witnessing the first part qualification; access to documents; approval of significant technical changes and corrective actions; involvement in failure investigations; conducting independent quality audits in case of failures; and being apprised of pertinent quality information directly related to the contracted item, including data on similar platform models.

3) Strengthen the processing of major non-conformities and the tracking of pending items to close the loop:
The practice of international satellite production supervision and manufacturing necessitates stringent closed-loop requirements. An essential component of these activities is the meticulous handling of non-conformity items (NCR), particularly major non-conforming items, and the diligent tracking of pending items to close the loop. During supervision and manufacturing, any discrepancies in product performance indicators that fail to meet user requirements or contractual obligations are designated as non-conformity items. Throughout each developmental phase, these items are rigorously monitored and managed in accordance with non-conformity project management procedures. Items are categorized based on their significance, and the timeline for resolution is explicitly outlined. Unresolved issues are systematically converted into to-do items, specifying content, deadlines, and subsequent activities. Prior to technical coordination meetings, quarterly reviews, or other such gatherings, these to-do items are addressed and deliberated for resolution.

IV. Aerospace Project Quality Supervision Model

Quality supervision in aerospace projects is facilitated through the creation of an independent, full-time quality supervision team. This team operates in accordance with client requirements and coordinates with ongoing project development activities. Guided by contractual terms, technical documentation, quality standards, and relevant norms, the team focuses on crucial and high-risk elements. It executes independent quality supervision on both the technical and managerial aspects of equipment development and testing. This role serves to bolster quality control without altering the original quality responsibilities of the project team and associated personnel.

Adherence to principles of independence, authority, efficacy, standardization, and timeliness is of paramount importance in quality supervision activities. Quality supervisors primarily engage in frontline and on-site activities, tracking the project's development and testing phases. They identify potential issues and latent risks, promptly mitigating project hazards. These supervisors offer gate-keeping and guidance for the project contractor's effective quality control, contribute to reviews at pivotal junctures such as product delivery and flight testing, and inform quality decisions made by the project authority. Importantly, the quality supervision process operates without direct interference in standard product development, manufacturing, and testing activities, and does not assume responsibility for resolving issues identified during supervision. It neither supplants nor alters the decision-making or quality responsibility of the existing command and designer systems.

A. Workflow of Quality Supervision

The aerospace project quality supervision organization structure includes quality supervision project management team and quality supervision project technical team.

1) Quality supervision project management team: A project management team is set up based on the requirements of the client's project. The team is responsible for aspects including the overall plan of quality supervision, quality supervision outline, management of relevant supervisors, management of supervision information, and communication and coordination of the supervision process. A project manager is hired as the representative of the supervisory party.

2) Quality supervision project technical team: According to the characteristics of the project, a project technical team composed of experts in various fields and specialties, such as engineering technology experts and quality management experts, is formed to identify and analyze the quality problems and risks of engineering projects and provide suggestions for improvement.

The quality supervision workflow includes three stages—supervision planning, supervision implementation and supervision summary—and in total, nine work steps. The quality supervision workflow and information flow are shown in Fig. 2.

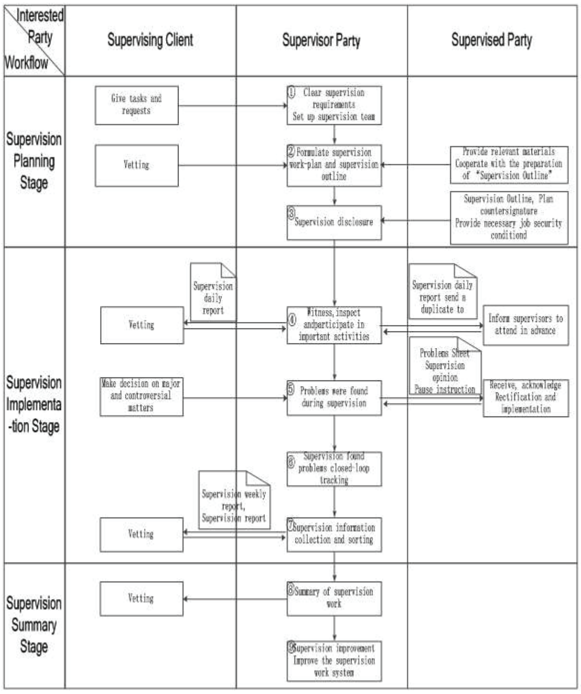

Fig. 2. Quality supervision workflow and information flow

3) Quality supervision planning: Initially, the focus is on elucidating the requirements for quality supervision. A quality supervision team is assembled in accordance with the task's specific attributes and the client's supervisory requisites. Responsibilities are delineated to ensure clarity. Second, technical documents pertaining to quality supervision are developed. These include a comprehensive quality supervision work plan and an outline that elaborates the objectives, organizational responsibilities, work mechanisms, and planned arrangements for the supervision endeavor. Third, a formal handover of the quality supervision outline takes place between the supervisory parties, followed by the joint signing of pertinent documents.

4) Quality supervision implementation: The first phase entails witnessing, inspecting, and participating in crucial activities as dictated by the quality supervision outline. Subsequently, when issues are identified during the process of quality supervision, quality supervisors issue Supervisory Problem Notification Forms. Opinions on key stages of the process are rendered, and immediate feedback concerning significant risks or severe issues is relayed to the client. Thirdly, there is ongoing tracking of the "closed-loop" status of identified issues. Quality supervision personnel monitor the development and execution of problem-solving measures. Simultaneously, they keep track of how problems are resolved or managed in the course of the project's progression. The final aspect involves the collection and organization of supervision information. Management team members are responsible for the timely gathering, structuring, labeling, and archiving of data generated by quality supervision activities.

5) Quality supervision summary. Initially, the quality supervision project team synthesizes the supervision efforts at crucial junctures of the project into a comprehensive report. Concurrently, the quality supervision management team routinely collates, analyzes, and gathers information for dissemination to the commissioning party via daily and weekly reports. Secondly, emphasis is placed on the perpetual enhancement of quality supervision practices. Quality supervisors accumulate experiential insights to refine the existing norms and systems governing project quality supervision.

For discrepancies observed during the quality supervision process, timely dialogue and confirmation with the supervised party are imperative. Quality supervision personnel fill out a "Quality Supervision Problems Notice" and obtain signature confirmation from the supervised entity. The rectification of issues is tracked diligently to ensure loop closure. For graver issues, upon endorsement from the quality supervision project manager, a suspension order can be executed and a veto exercised. The procedural flow for addressing observed issues in quality supervision is depicted in Fig. 3.

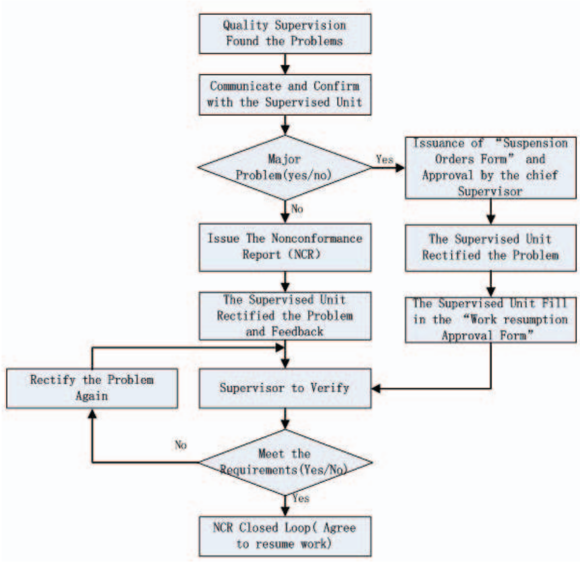

Fig. 3. Processing of detected problems

B. Methods of Quality Supervision

Based on foreign best practices in quality supervision, the aerospace project's quality supervision approach employs a blend of witnessing and routine inspection. This strategy accentuates pivotal projects, key products, and essential procedural stages. Scientifically and logically designated control points for supervision are explained thoroughly to personnel from the supervised project's product contractor unit. This ensures precise pressure compaction at factory gatekeeping and product quality acceptance stages, thereby augmenting the relevance and effectiveness of the quality supervision endeavor.

The quality supervision process primarily involves witnessing, inspecting, and participating in pivotal activities. Witnessing involves the observation, review, recording, and validation of pertinent documents, records, and artifacts related to the project's execution by quality supervisors. Various witnessing methodologies such as document witnessing, on-site witnessing, and stop witnessing are employed. Criteria for setting a witnessing point include the importance and complexity of the supervised process, the challenges in quality control, the degree of technical risk, and the severity of outcomes should a deviation occur. Specifically, a Record Point (R point) is a predetermined quality supervision control point where supervisors verify relevant documents, records, or reports of the supervised products. A Witness Point (W point) is another pre-set quality supervision control point where the supervisor observes and verifies the processes, nodes, or outcomes of the supervised products. A Hold Point (H point) is a stage at which the supervisor witnesses and signs off before the transition to the subsequent node, process, or phase. When establishing these control points, comprehensive consideration should be accorded to the supervised products and processes in terms of their importance, complexity, quality control challenges, technical risk levels, and the gravity of potential deviations.

Inspection comprises either regular or sporadic on-site oversight activities conducted by quality supervisory personnel for the supervised products. Participation in critical activities signifies that quality supervisors engage in vital processes, significant activities, and key meetings within the supervised projects as required. This engagement facilitates an understanding of the project's progress and supports the effective realization of quality supervision objectives.

C. Key Links and Priorities of Quality Supervision

1) Project Product Development and Production: Aerospace project quality supervision aims to assess various phases of project design, production, testing, and evaluation, as well as quality-related activities in the early stages. This assessment includes confirming quality compliance through zeroing early-stage quality issues, managing technical state changes, and validating subsystem acceptance documents.

2) Design Process: Quality supervision examines multiple facets including the rationality of design plans, design reviews and verification, the completeness of design input and output information, and the selection and verification of new technologies, materials, equipment, and processes. Further, it scrutinizes key features, the design process, product inheritance, design changes, and test coverage analysis.

3) Reliability Supervision: Focus is placed on the development and execution of a reliability work plan and design analysis. This includes verification tests for reliability, control measures for key items, and a review of pending matters to ensure that reliability indices meet the specified requirements.

4) Product Delivery Stage: Quality supervision ensures compliance in several aspects, such as delivery procedures, organizational management, and product data packages. It verifies the consistency of final inspection results and evaluates the alignment of product resumes and certificates with established requirements. Additionally, quality supervision reviews deviation or exception licenses, assesses exception releases, identifies quality issues, and reviews pending matters pertinent to product delivery.

V. CONCLUSION

In summary, through the comprehensive analysis and amalgamation of supervision approaches from the FIDIC as well as international satellite supervision protocols, a foundational model applicable to quality supervision of aerospace projects is proposed. This model includes the organizational structure, incorporating both a project management team and a technical team. It describes the supervisory workflow, mechanisms for collaborative work, and key supervisory methods, thereby clarifying crucial aspects and priorities. This seminal work can potentially serve as a robust framework for the effective implementation of quality supervision in aerospace projects.

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