FLOW PATH
PRECISION. DIRECTION. IMPACT.

JUMPIN' JACK FLASH

Jack of All Trades, Master of None

How Inspection Structure Can Influence MRO Work Scope, Cost, and Turnaround Time

FLOW PATH CONSULTING LLC
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Executive Summary

Inspection is fundamental to aircraft engine maintenance. Independent inspection, approved technical data, required NDT, qualified personnel, and disciplined quality systems protect airworthiness. This paper asks whether inspection must be isolated from the product to remain independent.

Centralization can improve standardization, utilization, flexibility, and control. It can also separate inspectors from disassembly, as-received condition, repair, assembly, fit/form/function, and test - the lifecycle context that helps turn inspection knowledge into product judgment.

Inspection proficiency is not the same as product mastery.

Flow Path examines three interconnected risks: loss of hardware memory, loss of fit/form/function knowledge, and loss of parallel product flow. None automatically creates an incorrect decision. Each can, however, increase uncertainty, handoffs, queue exposure, and escalation - creating exposure to work-scope expansion, higher cost, and longer elapsed time.

Why this matters now

IATA forecasts LEAP annual shop visits rising from roughly 600-800 in 2025 to more than 5,000 by 2040, while GTF visits rise from about 1,000 to more than 2,000. Capacity expansion is necessary, but flow efficiency and human capability will matter just as much. [1]

Don't optimize the inspection department. Optimize the engine maintenance event.

The Question

What knowledge do we want at the inspection decision point?

The component on the bench came from a module, operated beside other hardware, displayed evidence during teardown, was cleaned and processed, and must ultimately be repaired or accepted, assembled, function, and pass test. The inspection decision is stronger when that lifecycle context remains available.

Three losses to examine

- Hardware Memory - understanding how the component presented during disassembly and before cleaning or stripping changed its appearance.
- Fit, Form & Function Knowledge - understanding interfaces, stack-up, assembly characteristics, clearances, and downstream consequences.
- Parallel Flow - preserving simultaneous module progress rather than unnecessarily converging work into common functional queues.

> ***A specialist sees a part and remembers the engine. A generalist risks seeing only the part.***

Research supports the broader premise that aircraft-engine inspection is more than an accept/reject lookup. A 2022 aerospace industrial-inspection study found that inspectors rely on macrocognitive processes and tacit knowledge when diagnosing engine components. [2]

Why Centralized Inspection Makes Sense

Centralized inspection did not emerge because MROs wanted to create inefficiency. It solves legitimate organizational problems.

- Independence from production
- Consistent application of technical requirements
- Standardized procedures and training
- Flexible manpower allocation
- Department-level utilization and workload balancing
- Quality governance and auditability
- Clear technical authority

There is also a real pooling advantage. A shared inspector pool can absorb workload variability better than dedicated lanes when handoff friction is low. Flow Path's own simulation confirms this: in the control case, central pooling performs better when escalation, movement, and switching burdens are held equal.

The challenge

The engine does not experience departmental utilization. It experiences elapsed time. A local efficiency improvement can therefore coexist with additional movement, waiting, and critical-path exposure elsewhere in the maintenance event.

What This Paper Does Not Advocate

Regulatory and Quality Firewall
This paper does not advocate eliminating independent inspection; reducing required inspection; bypassing approved maintenance data; avoiding required NDT; relaxing airworthiness standards; allowing production schedules or cost to determine serviceability; or replacing qualified NDT personnel with product inspectors.

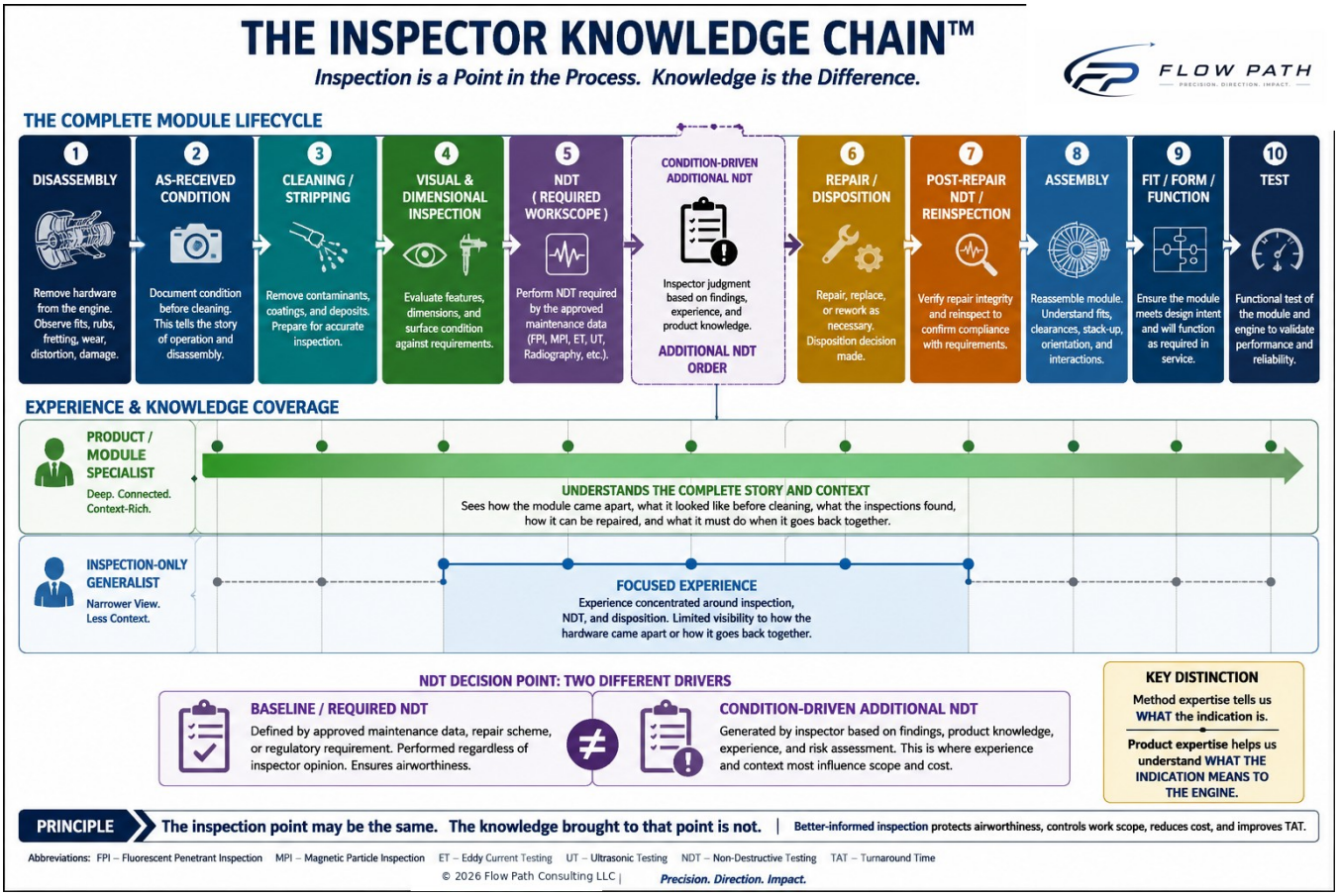
The question is narrower and more useful:

Can inspection remain fully independent while becoming more product-specialized, context-rich, and integrated with the complete maintenance event?

FAA Maintenance Resource Management guidance emphasizes that maintenance personnel work within a complex system and that the effects of individual actions ripple throughout organizations. [3] The intent of this paper is consistent with that systems view: preserve technical authority while improving the information, experience, and flow surrounding the decision.

The Inspector Knowledge Chain™

Inspection is a point in the process. Knowledge is the difference.



The formal inspection point may occur after cleaning and preparation, but the knowledge used at that point can originate across the full lifecycle: disassembly, as-received observation, processing, inspection, NDT, repair, reinspection, assembly, fit/form/function, and test.

The Knowledge Brought to the Bench

Product / Module Specialist

Repeated exposure to the same module builds pattern recognition and hardware memory. The specialist understands where the component lives, what interfaces with it, how it comes apart, typical deterioration, repair routes, and what the assembly team will encounter later.

Inspection-Only Generalist

The generalist can be highly proficient in inspection requirements and may provide valuable flexibility across workloads. The risk is not incompetence. The risk is narrower lifecycle exposure and weaker product context when conditions fall outside routine patterns.

The inspection point may be the same. The knowledge brought to that point is not.

Hardware Memory

Preserve the as-received story; inspect the properly prepared part.

A component's as-received condition can carry information about rubs, fretting, deposits, discoloration, relative movement, thermal distress, erosion, and contact relationships. Cleaning and stripping may alter or remove some of that evidence.

That does not mean formal visual inspection should be performed on dirty hardware. Research involving 50 industry practitioners and 1,200 observations found average inspection accuracy of 66.8% on dirty blades versus 86.8% on clean blades. [4]

> ***Clean the part for formal inspection. Preserve the as-received information for diagnosis.***

The practical answer is preservation of context: teardown observations, photographs, condition documentation, and direct communication between disassembly, inspection, repair, and assembly. The objective is not to choose between dirty and clean information. It is to avoid losing either.

Product Mastery

Why disassembly and assembly experience matter

Consider two qualified people. One primarily inspects turbine components. The other has experience disassembling the turbine, observing its condition, inspecting its hardware, understanding repair, and reassembling the module. Both may use the same approved technical data. Their product context is different.

- Disassembly teaches how hardware behaves after operating together.
- Assembly teaches fits, clearances, stack-up, mating surfaces, orientation, accessibility, and functional relationships.
- Repair exposure teaches what conditions are recoverable and how processing changes the part.
- Test feedback closes the loop between a piece-part decision and module/engine performance.

Research comparing occupational groups reinforces the broader point that useful product knowledge is distributed across the maintenance system. One small visual-tactile blade study found different serviceability-decision performance among assembly operators, engineers, and inspectors, but the authors explicitly characterized the expertise-group finding as tentative. [5] A larger related study found piece-part accuracy much closer across all three groups. [6]

What the evidence supports

Assembly experience does not replace inspection expertise. Inspection expertise does not replace product knowledge. The strongest system captures both.

NDT: Two Types of Expertise

Required NDT

Where approved maintenance data, a repair scheme, or another controlling requirement specifies FPI, MPI, eddy current, ultrasonic, radiography, or another approved NDT method, that inspection is baseline work. It is performed.

Condition-Driven Additional NDT

A separate category begins when an observed condition generates additional NDT beyond the baseline path. That additional inspection may be completely justified. The management question is what caused the escalation and what the escalation causes downstream.

> ***Method expertise tells us what the indication is. Product expertise helps us understand what the indication means to the engine.***

Qualified NDT specialists and product/module specialists provide different knowledge. Neither substitutes for the other. The opportunity is to connect them without creating unnecessary handoffs or repeated queues.

When "Always" Replaces "Why"

Mature MRO systems accumulate recurring inspection orders. Many begin for good technical reasons. The risk appears when the original reason disappears but the order survives.

- "We always dimensional these."
- "We always send those for NDT."
- "Engineering always reviews this condition."
- "We always reject those."
- "We always replace that hardware."

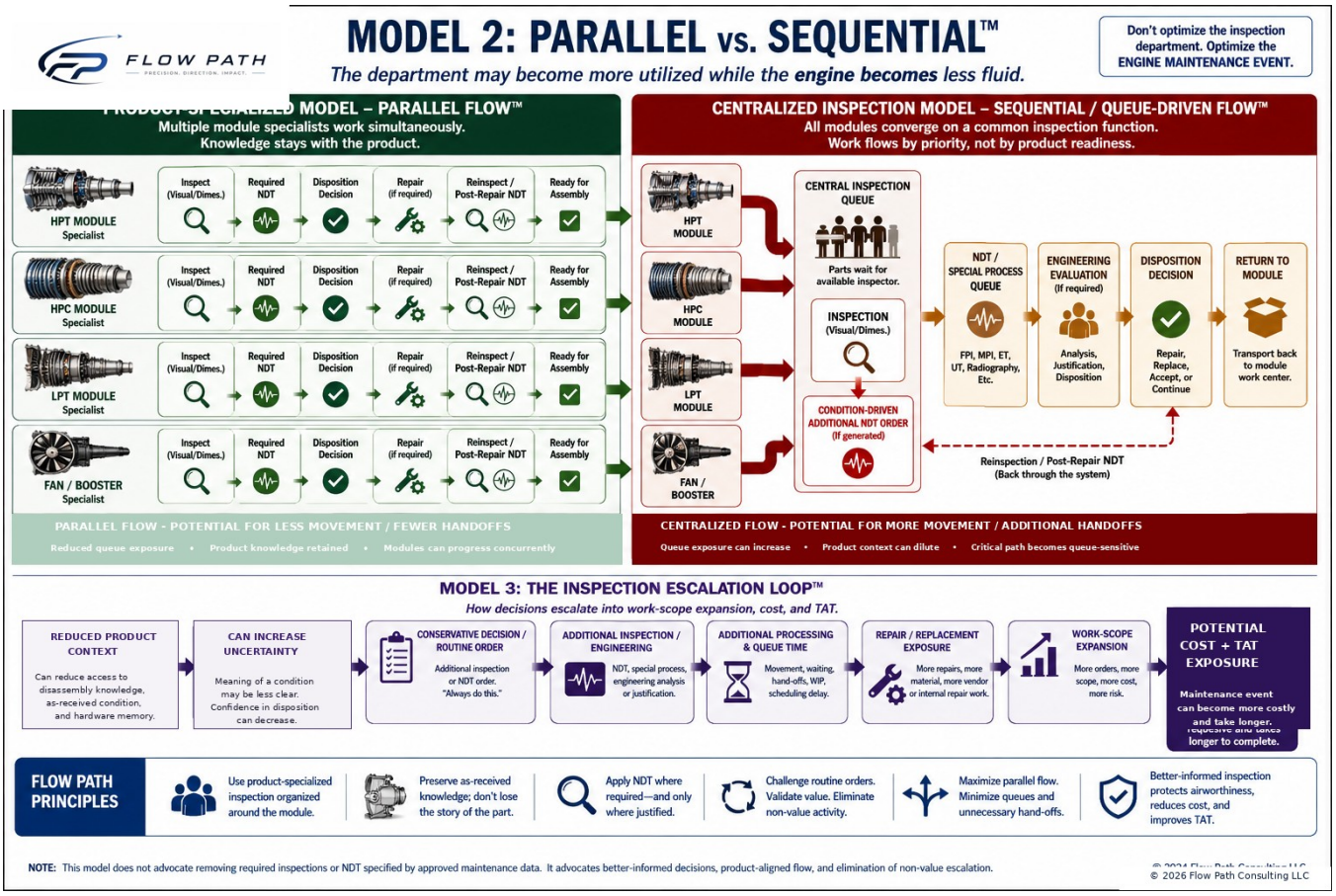
A recurring order should periodically be challenged against current technical data, actual finding rate, repair capability, cost, elapsed time, and continued technical justification. The management question is simple: When was the last time this recurring order was technically revalidated?

> ***Routine is useful until routine replaces judgment.***

Aircraft-engine inspection research also recognizes the economic side of decision error: false positives can increase maintenance cost or commit hardware to needless repair activity. [7][8]

Parallel vs. Sequential™

The department may become more utilized while the engine becomes less fluid.



Necessary Specialization vs. Unnecessary Handoffs

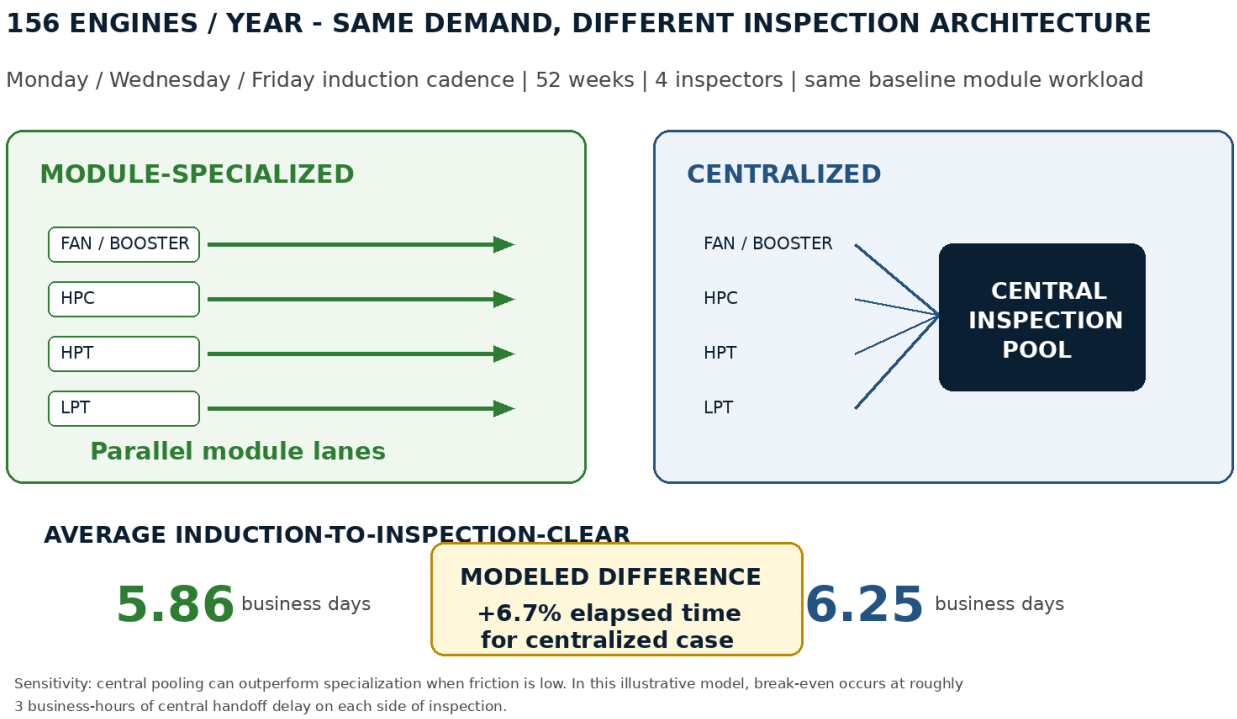
Some work must move to specialized equipment and qualified personnel. NDT, plating, coatings, machining, heat treatment, and engineering evaluation may legitimately sit outside the module area. That is not the argument.

> ***Specialized processes are necessary. Unnecessary sequential handoffs are not.***

The question is whether the organizational architecture preserves parallel module progress or repeatedly routes independent product streams through common queues. GE Aerospace's Celma value-stream work makes the distinction between cycle time and lead time explicit: lead time includes the time doing the work plus queue time waiting for work to be done. [9]

When HPT, HPC, LPT, and Fan/Booster hardware can progress simultaneously, module readiness can develop in parallel. When they converge on shared functional queues, the engine's critical path becomes increasingly sensitive to arrival batching, movement, prioritization, and rework loops.

156 Engines: Same Demand, Different Architecture



Flow Path modeled three engine inductions per week - Monday, Wednesday, and Friday - for 52 weeks, or 156 engines. Both architectures used the same four inspectors, the same baseline module inspection workload, the same business week, and the same required-NDT delay assumptions.

Important

The simulation is illustrative, not an empirical industry dataset. Its purpose is to test the mechanism and identify the conditions under which pooling efficiency is overcome by movement, handoffs, product switching, and escalation.

What the Simulation Actually Found

Control case

When escalation rates, handoff times, and switching penalties were held equal, the centralized four-inspector pool performed better. This is the expected queue-pooling advantage and is important: centralization is not automatically inefficient.

Illustrative MRO-context case

When the centralized architecture included additional movement/handoff exposure, a modest product-switching penalty, and a higher illustrative rate of condition-driven escalation, average induction-to-all-modules-inspection-clear increased from 5.86 business days in the module-specialized model to 6.25 days in the centralized model - approximately 6.7% longer in this modeled scenario.

Sensitivity

Under the current illustrative assumptions, the architectures reached approximate break-even at about three business-hours of central handoff delay on each side of inspection. Below that point, pooling can win. Above it, non-touch elapsed time begins to overwhelm the pooling advantage.

> ***Centralization becomes vulnerable when friction overwhelms pooling.***

The correct management response is therefore not ideological decentralization. It is measurement: how much movement, waiting, switching, reinspection, and escalation does the actual shop create?

The Inspection Escalation Loop™ and CIE

A finding may require only minutes to document but can create a much larger downstream chain. Reduced product context can increase uncertainty, which can trigger additional inspection, NDT, engineering, processing, queues, and potential work-scope, cost, and TAT exposure:

> ***Reduced context -> can increase uncertainty -> can trigger additional inspection / NDT / engineering -> added processing & queues -> potential repair / replacement -> potential work-scope, cost & TAT exposure***

Cost of Inspection Escalation™ - CIE

CIE is a system-level diagnostic: the incremental cost and elapsed-time consequence generated by inspection-driven activity beyond the established baseline workscope. It is intended to make downstream consequences visible, not to score individual inspectors.

- CIE-$: incremental inspection labor, NDT/special process, engineering, repair, material, handling, reinspection, and outside processing.
- CIE-T: incremental queue time, vendor turnaround, transportation, engineering wait, repair wait, reinspection wait, assembly waiting, and critical-path impact.

> ***A five-minute decision can create a five-day consequence.***

> **Guardrail**
> **CIE measures the process - not the inspector. It is a system-level diagnostic and must never become an individual performance metric that discourages legitimate technical escalation.**

The Better Model

Preserve independence. Restore context. Protect flow.

1. Product Specialization

Develop inspectors around defined modules and product families while maintaining common qualification and governance standards.

2. Lifecycle Exposure

Build structured experience across disassembly, inspection, repair, assembly, and test.

3. Preserve As-Received Knowledge

Capture meaningful pre-clean condition through photographs, teardown observations, and direct communication.

4. Integrate NDT Expertise

Connect qualified NDT method expertise with product/module knowledge.

5. Govern Recurring Orders

Challenge recurring inspection and NDT orders against finding rate, technical justification, cost, and elapsed-time consequence.

6. Maximize Parallel Flow

Organize resources around product readiness where practical and minimize unnecessary movement, queues, and handoffs.

FAA human-factors guidance favors system-level approaches rather than simply blaming individuals for process outcomes. [10] That is the intent here: improve the system surrounding inspection judgment.

Flow Path Principles

Independence does not require isolation.

Standardization does not require generalization.

Compliance does not require abandoning flow.

Inspection proficiency is not the same as product mastery.

The Jack of all trades has value. Flexibility, standardization, and independence matter. But aircraft-engine MRO is ultimately a product business. The strongest inspection capability combines technical requirements with hardware memory, product specialization, qualified NDT, disassembly and assembly knowledge, repair experience, and system-level flow awareness.

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Don't optimize the inspection department. Optimize the engine maintenance event.

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References and Notes

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Simulation Disclosure

The Flow Path throughput simulation is a conceptual operations model intended to test sensitivity to inspection architecture. It is not a validated representation of any specific MRO facility. Before using its quantitative results for a customer or facility decision, calibrate it with actual shop data for module release timing, touch labor, inspector staffing, transport/handoff time, inspection-order frequency, NDT queue time, reinspection, engineering delay, and engine/module readiness.