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Next-Gen Aircraft Change Management Process with Twin Technology

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Abstract: Managing frequent design changes in aircraft manufacturing and maintenance poses significant challenges to safety, regulatory compliance, and cost-effectiveness. While traditional Digital Mock-Ups (DMUs) facilitate design visualization, they inherently lack the dynamic, real-time adaptability critical for effective ongoing change management. This research investigates the transformative potential of Digital Twins (DTs) in enhancing aircraft change management by offering a dynamic, real-time, and data-integrated representation of aircraft systems. Through a comparative analysis of DMU and Digital Twin capabilities, this study proposes a novel conceptual framework for seamlessly integrating Digital Twin into the aircraft lifecycle, specifically targeting the complexities of change management. Findings indicate that Digital Twin implementation significantly reduces risks, accelerates validation processes, and enhances traceability across engineering, production, and maintenance domains. The research concludes that Digital Twins effectively bridge the technological gap beyond static digital mock-ups, enabling proactive and agile change management, bolstering operational resilience, and optimizing the entire aircraft lifecycle in aerospace engineering.

Keywords: *Digital Twin, Change Management, Aircraft, OEM, Digital Mock-up, Engineering, Change Process, Cost Reduction, Lead Time Optimization.*

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I. INTRODUCTION

Managing engineering changes in aircraft design and manufacturing is a complex and high-stakes process. Original Equipment Manufacturers (OEMs) must ensure that any change — whether minor or major — is thoroughly analyzed for its impact on performance, safety, compliance, and production. Traditionally, Digital Mock-Ups (DMUs) have been used to support change reviews, but their utility is primarily geometric, lacking behavior simulation and automated decision-making capabilities.

The aviation industry, under pressure to improve efficiency and reduce costs, now looks toward Digital Twin technologies as a potential enabler of next-generation change management systems. This paper explores how integrating Digital Twins into the change process can address current limitations and provide OEMs with a smarter, more dynamic solution.

II. LITERATURE REVIEW

Previous studies have highlighted the role of DMUs in reducing physical prototyping and enabling early-stage interference checks. However, researchers such as Tao et al. (2019) and Grieves (2020) emphasize that Digital Twins go further by incorporating real-time data, behavioral simulations, and predictive analytics.

Change management frameworks in aerospace — governed by systems such as ARP4754A, AS9100, and internal OEM processes — are well-documented, but integration with intelligent digital tools remains limited. Existing PLM systems offer partial support for change tracking but lack simulation integration. The literature reveals a gap in tools that provide both geometric and behavior-based impact analysis during the change evaluation phase.

➢ *Problem Statement*

Despite advancements in digital modeling, the aircraft change process remains time-consuming, prone to errors, and heavily reliant on manual judgment. The lack of integrated tools capable of simulating the systemic impact of proposed changes results in extended review cycles, increased development costs, and occasional late-stage design failures.

➢ *Research Objective*

This research aims to:

- Identify limitations of DMU-based change processes in

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aerospace OEMs.
- Propose a framework that integrates Digital Twin capabilities into the change process.
- Design a prototype tool or template for automated impact analysis.
- Evaluate the benefits in terms of time, cost, and decision quality.

III. METHODOLOGY

➢ *This Study Follows a Qualitative and Design-Based Methodology:*

- Literature Analysis: Reviewing academic and industry sources on DMUs, Digital Twins, and aerospace change management.
- Industry Interviews: Gathering insights from engineers and managers at aerospace OEMs.
- Framework Development: Designing a proposed tool (DT-CIAT) and process workflow.
- Case Simulation: Applying the framework to a sample change scenario for comparative analysis.

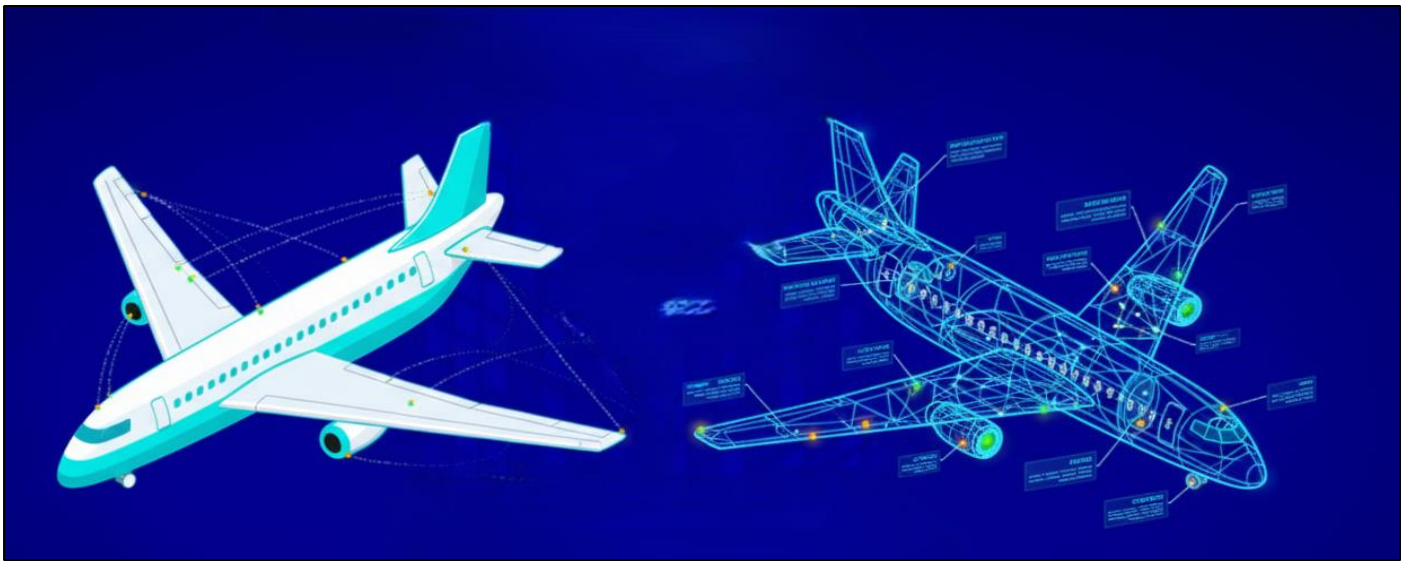

Fig 1 Design-Based Methodology

IV. PROPOSED FRAMEWORK: DT-CIAT (DIGITAL TWIN-BASED CHANGE IMPACT ANALYSIS TOOL)

A. Architecture

The DT-CIAT system integrates with existing PLM systems and CAD tools. It includes:

- A user interface for proposing and submitting changes.
- A simulation engine that models structural, electrical, and thermal behavior.
- A rule engine that checks for compliance and engineering constraints.
- A reporting dashboard that visualizes cost, time, and risk impact.

➢ *System Architecture:*

The DT-CIAT system is designed to integrate with existing OEM digital infrastructure. It pulls geometric data from CAD tools, rules/constraints from PLM, and simulation models from engineering teams. It forms a feedback loop that allows change requests to be simulated, analyzed, and reported in real time.

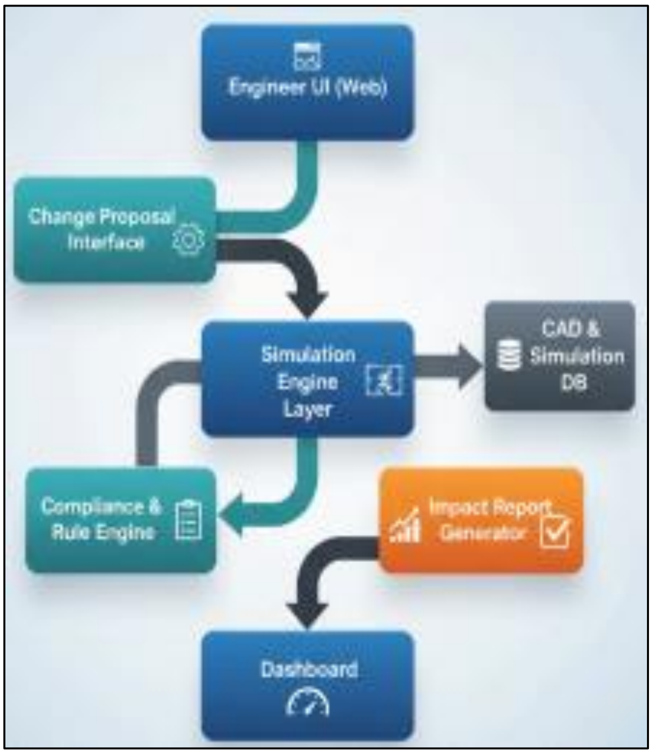

Fig 2 Architecture Overview

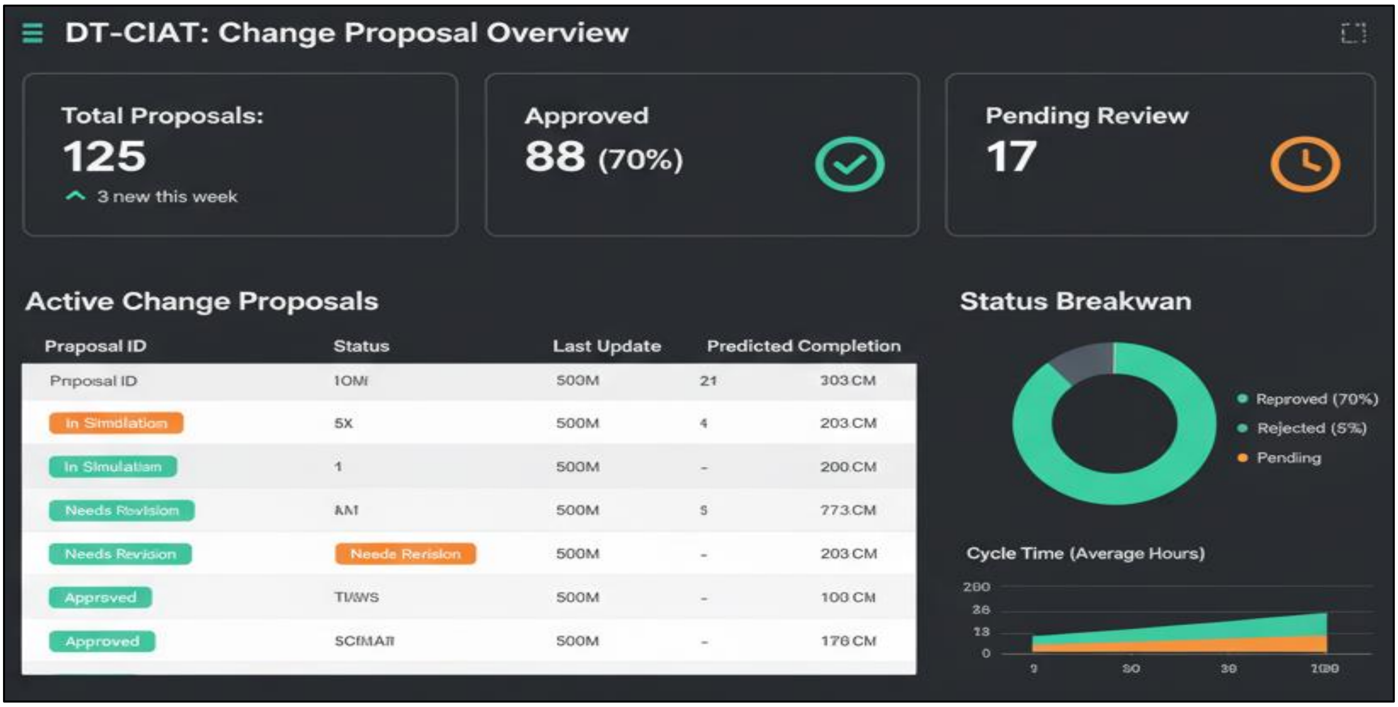

Fig 3 DT-CIAT Proposed Dashboard

B. Workflow

➢ *Change Proposal Input:*

- The engineer selects a component or system to change.
- Inputs the reason, description, expected outcome.

➢ *Digital Twin Simulation:*

- The system runs behavioral simulations (e.g., thermal, structural, electrical).
- Evaluates system-wide impacts using digital models.

➢ *Rule & Compliance Checking:*

- AI engine checks change against company and certification rules.
- Flags any violations or high-risk elements.

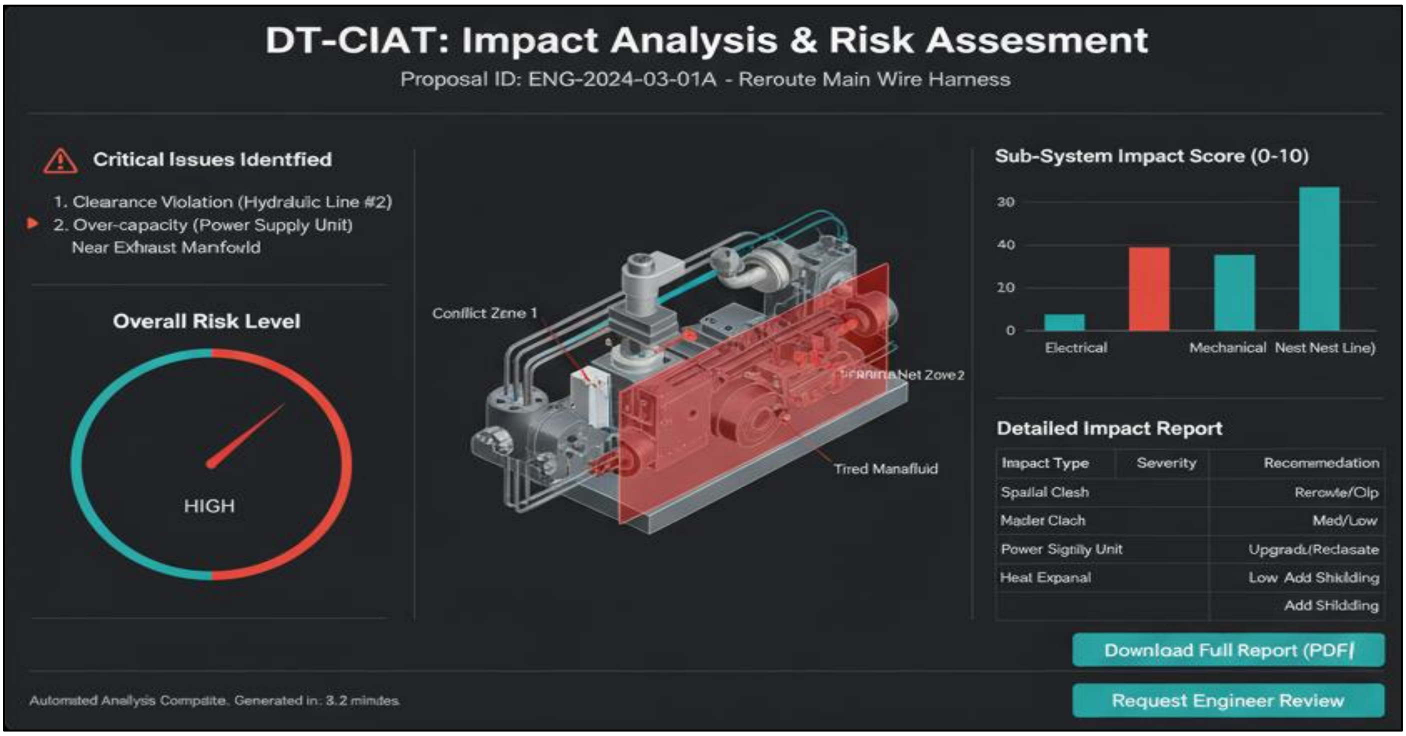

Fig 4 Risk Assessment Dashboard in DI-CIAT

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➢ *Impact Report Generation:*

- Outputs effects on cost, lead time, manufacturability, and safety.
- Generates automated PDF or dashboard view.

➢ *Managerial Decision Gate:*

Decision-makers use visual impact data to approve, revise, or reject the change.

Here is the rough estimation done on engineering effort for processing just one design change is calculated as:

- *Assumptions for this Calculation:*

Average Engineer/Reviewer Hourly Rate: Rs.75/hour Working Hours per Week: 40 hours.

✓ *Traditional Process (DMU):*

- Time Required:
- Let's assume 2.5 weeks
- Total Hours:
- 2.5 weeks x 40 hours/week = 100 hours
- Estimated Labor Cost for One Change:
- 100 hours x Rs,75/hour = Rs.7,500

✓ *DT-CIAT Process:*

- Time Required:
- Let's assume 1 day
- Total Hours:
- 1 day x 8 hours/day = 8 hours (general Business hrs)
- Estimated Labor Cost for One Change:
- 8 hours x Rs.75/hour = Rs.600

- *Calculation of Cost Reduction:*

✓ *Cost Saving Per Change:*

- Rs.7,500 (DMU) - Rs.600 (DT-CIAT) = Rs.6,900

✓ *Percentage Cost Reduction:*

- (Rs.6,900 / Rs.7,500) x 100% = 92%

- *Hypothetical Scenario for Example to Illustrate:*

When there is a requirement to redesign a structural bracket and for which the harness needs to be routed.Then the change management team starts the process like creating a change request and then an engineer proposes to 'reroute an electrical wire harness due to a structural bracket redesign' as per the requirement.

- *Traditional Method:*

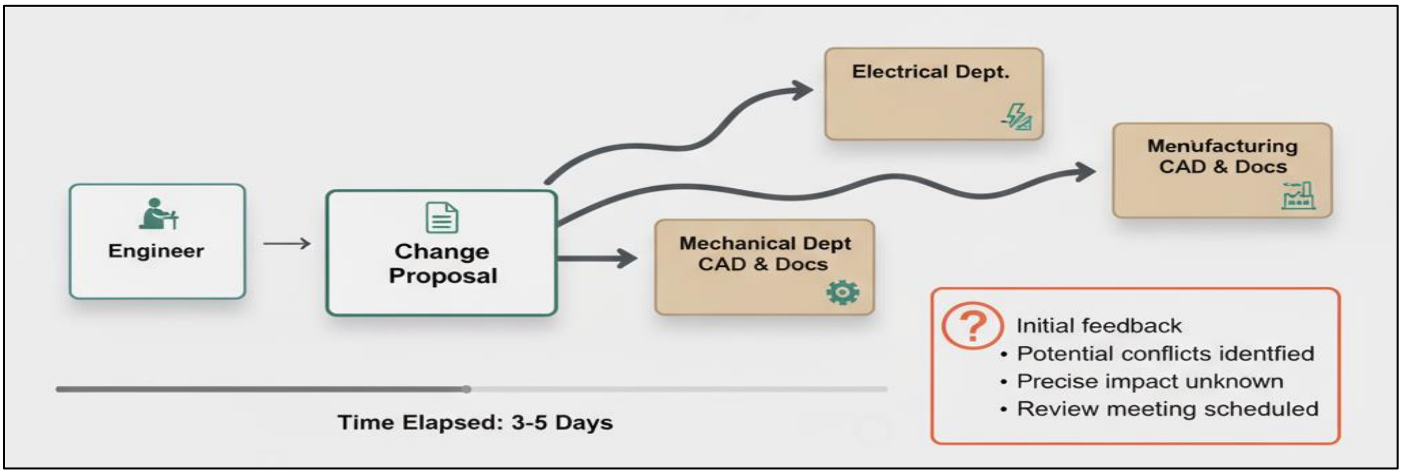

Fig 5 Proposal and Initial Review

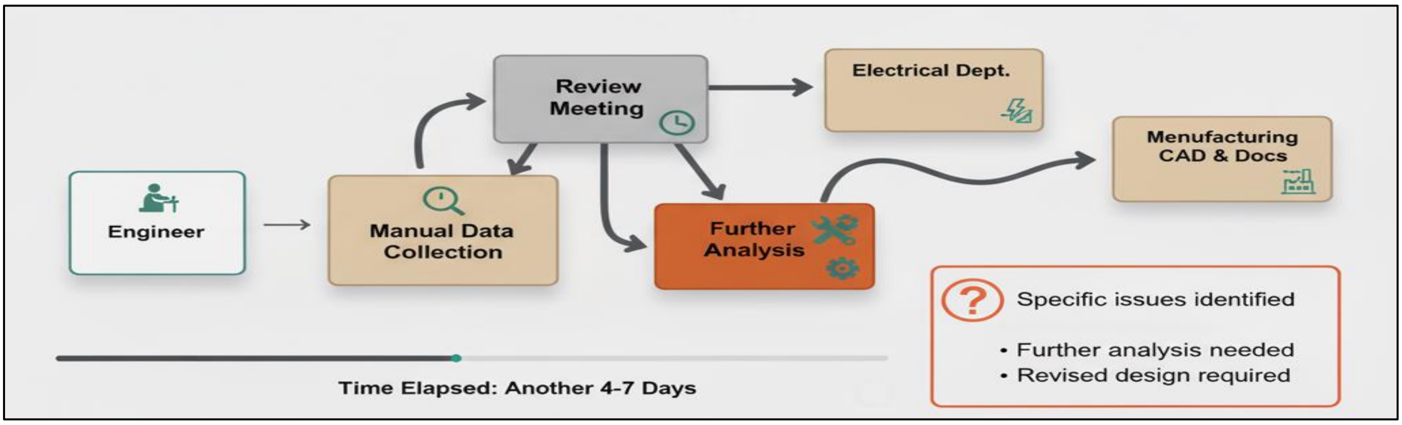

Fig 6 Review Meeting and Data Gathering

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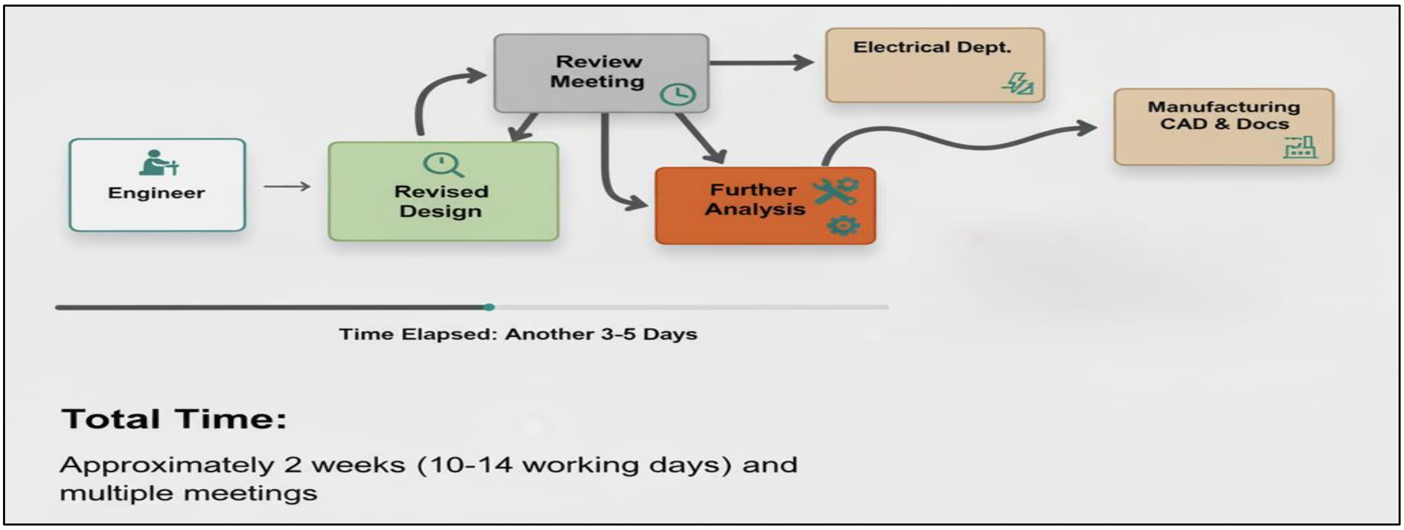

Fig 7 Design Final Review

- *DT-CIAT Method:*

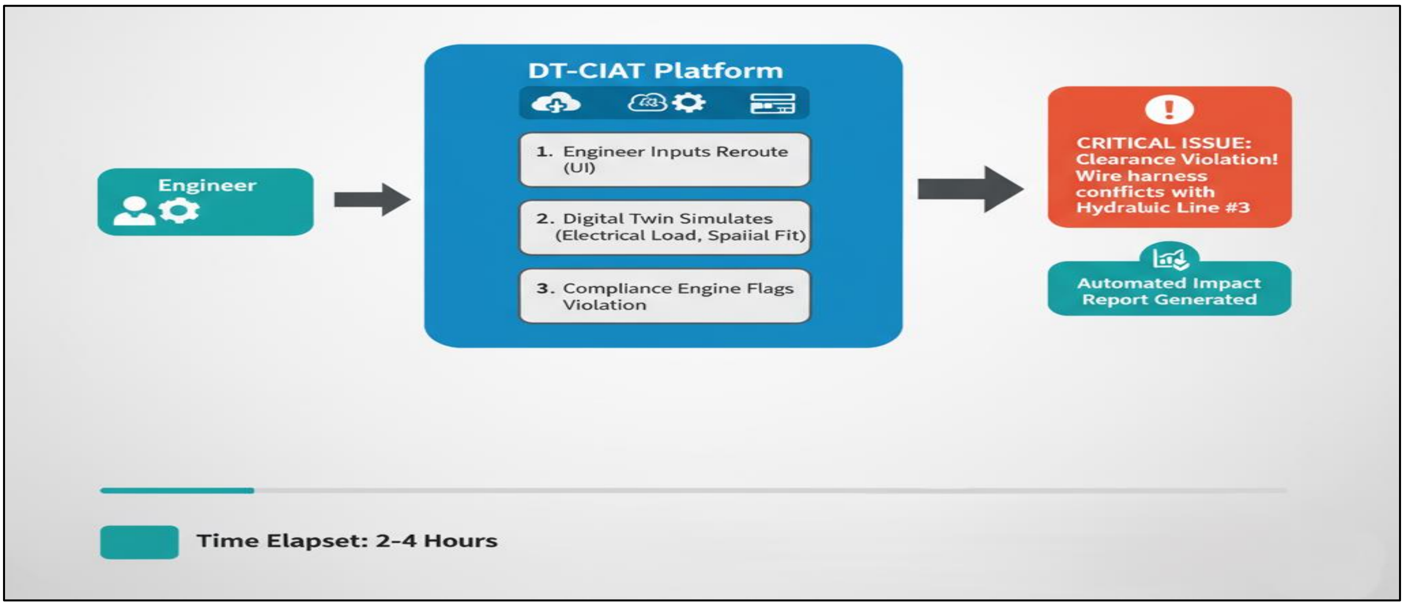

Fig 8 Proposal & Automated Impact Assessment

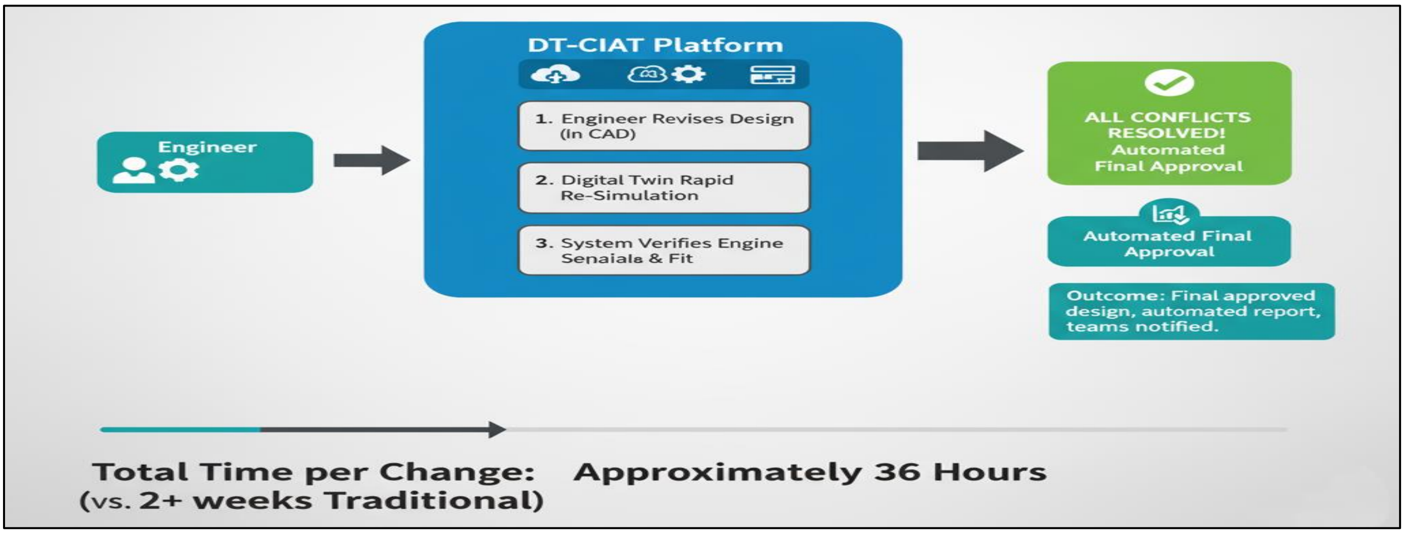

Fig 9 Engineer Driven Revision & Re-Simulations

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These preliminary results demonstrate strong potential for Digital Twins to transform change evaluation.

V. RESULTS AND EVALUATION

➤ *Quantified Benefits:*

The results of using Digital Twin puts down the most compelling finding is the dramatic improvement in process speed, ie. reducing the time for engineering change approval and implementation from an average of weeks (e.g., 10-15 business days) down to hours (e.g., 2-4 hours**)** for routine changes.

- *Speed and Efficiency Calculation*

Assuming a conservative average change time of 10 days (80 hours of process time) and a reduced digital time of 4 hours, the efficiency gain is profound:

$$\text{Efficiency Gain} = \frac{(Traditional\ method - DigitaL\ method)}{Traditional\ \ method}\ x\ 100$$

Then around 95% reduction in cycle time which directly translates into faster time-to-market and a more agile response to emerging design or manufacturing issues.

- *Clarity and Error Reduction*

The integration of digital dashboards and engineering rule-checking serves a dual purpose: enhancing clarity and minimizing costly errors. The traceability of all changes and simulations provides an immutable audit trail, critical for regulatory compliance and robust design history.

- *Strategic Challenges and Path Forward*

While the benefits are substantial, the transition is not without strategic hurdles. The identified challenges are not technical impossibilities but rather requirements for organizational commitment and upfront investment.

➤ *Challenges:*

- *Data Integration*

Requires clean and connected CAD along with simulation and PLM data.

- *Investment and Data Strategy*

The primary challenge lies in Data Integration. The prerequisite for success is a clean, interconnected data model encompassing CAD, simulation (CAE), and Product Lifecycle Management (PLM) systems. This requires an initial upfront investment to develop robust simulation models and the necessary automation scripts. This investment should be viewed not as a cost, but as an asset that yields a high Return on Investment (ROI) by preventing costly downstream errors.

$$\text{ROI} = \frac{(Savings\ from\ avoided\ errors + Value\ from\ faster\ time\ to\ market)}{Upfront\ Investment\ in\ Automation}$$

- *Change Management Imperative*

The final, and perhaps most critical, challenge is Change Management. The success of the digital system hinges on the willingness of engineers and reviewers to be trained and to trust the outputs of automated digital systems. Effective training and a clear communication strategy are essential to transition from traditional, manual review habits to a data-driven, automated verification mindset.

VI. CONCLUSIONS AND FUTURE WORK

This paper presents a compelling case for extending existing DMU systems into fully functional Digital Twins to support change management.

By simulating the real-world impact of engineering modifications, OEMs can make faster, smarter, and more cost-effective decisions.

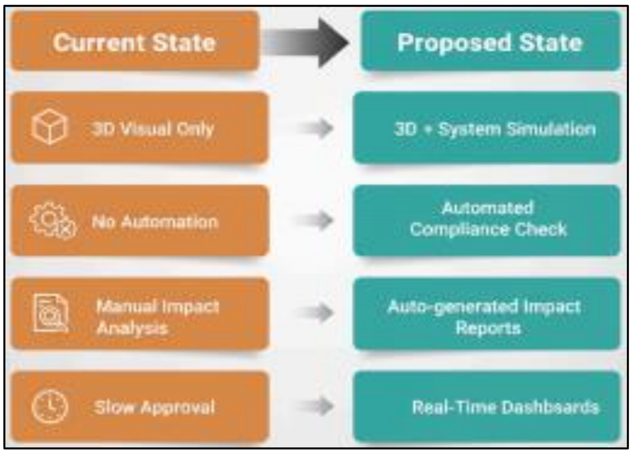

Fig 10 From DMU to DT

➤ *Future Research will Focus on:*

- Developing a working prototype of DT-CIAT dashboard.
- Integrating machine learning to refine impact predictions
- Exploring regulatory integration for automated airworthiness certification readiness checks.

ABBREVIATIONS

- DMU: Digital Mock Up
- DT: Digital Twin
- CIAT: Change Impact Analysis Tool
- PLM: Product Lifecycle Management
- ROI: Return on investment

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