Digital Design Network+
Case Study 1 Individual Report Template

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Focus	Better, Faster
Design Process	The project targeted the acceleration of the end-to-end design cycle for unmanned aerial vehicles (UAVs) in challenging environments, specifically Mars. This involved automating the transition from high-level requirements to optimised geometry, virtual verification through high-fidelity simulation, and agentic analysis of flight telemetry.
Tools Used	The solution utilised Python with open-source libraries for Navier-Stokes and Linear Elasticity solvers. High-fidelity simulation was conducted via NVIDIA Isaac Sim (Omniverse) and the Pegasus Simulator plugin. Gemini LLM was used for test generation and agentic analysis, while the Invention Morphology Explorer was developed as a patent-centric knowledge app.
Links	

Executive Summary

This project addresses the inefficiencies of traditional drone design cycles, which often rely on manual iterations, rigid geometric parameters (such as standard aerofoils), and late-stage physical verification. By utilising a case study based on the NASA Mars Helicopter[1], [2], our team developed a digital framework that integrates automated shape optimisation, LLM-driven requirements verification, and high-fidelity surrogate modelling.

The resulting workflow allows for the rapid generation of unconventional, high-performance geometries and the automated analysis of flight telemetry using AI agents. This shifts the design paradigm from manual trial and error to a goal-oriented, automated process where requirements are verified virtually at every stage, significantly reducing the time required to reach a flight-ready status.

Problem

Current drone design for challenging environments is hindered by three main bottlenecks. Firstly, manual geometric constraints limit performance because designers often rely on preconceived parameters, such as uniform rib thicknesses, which ignore optimal load distributions. Secondly, the verification process is document-heavy, requiring engineers to manually interpret requirements and create test procedures that often cannot be executed until a physical prototype exists. Finally, high-fidelity simulations produce dense 60Hz telemetry data that is slow and tedious for human engineers to analyse, leading to inefficient tuning loops for flight controllers.

Digital Design Solution

Our solution integrates four distinct digital modules into a unified workflow. We utilised automated topology and shape optimisation using Python-based solvers to generate aerofoils and wing spars based on performance goals rather than legacy templates. We then implemented LLM-driven requirements engineering where natural language requirements are processed to automatically generate and execute test scripts within the simulator.

The framework also includes an Invention Morphology Explorer, which is a patent-centric knowledge system that helps designers explore bionic mechanisms from thousands of existing patents. Finally, we deployed agentic simulation and analysis using a high-fidelity surrogate model in NVIDIA Isaac Sim. AI agents, specifically a Data Analyst and an Aerospace Engineer, were used to autonomously analyse flight telemetry, identify instabilities, and suggest specific PID tuning adjustments.

How it makes Digital Design Better, Faster and/or With Less

The solution makes design better by using optimisation algorithms to unlock novel geometries, such as a 129 per cent increase in average heat flux for heat exchangers and aerofoil shapes that maximise lift-to-drag ratios beyond human intuition. It makes the process faster by accelerating the verification phase through LLM-generated test procedures. Furthermore, the agentic analysis loop automates the interpretation of complex flight data, allowing for rapid iterations of the flight controller. The approach achieves this with less by reducing the need for expensive physical prototypes in the early stages and minimising the manual labour required for patent research and data analysis through the use of open-source tools and automated AI agents.

Reflections

The primary challenge identified during this activity is the trust gap in automated systems, specifically regarding how to ensure LLM-generated tests are rigorous and not just trivial passes. Future research and development should focus on establishing standardised benchmarks for AI-generated verification. Additionally, while the tools are powerful, the data flow between them remains a challenge. Creating a seamless digital thread that connects a patent insight directly to a simulation parameter is a key priority. Adoption in industry will likely require clearer value propositions regarding the reliability of these unconventional, algorithmically generated designs.

References

[1] C. Dull, L. Wagner, L. Young, and W. Johnson, 'Hover and Forward Flight Performance Modeling of the Ingenuity Mars Helicopter'.

[2] H. Zhao, Z. Ding, G. Leng, and J. Li, 'Flight dynamics modeling and analysis for a Mars helicopter', *Chin. J. Aeronaut.*, vol. 36, no. 9, pp. 221–230, Sep. 2023, doi: 10.1016/j.cja.2023.05.007.

Appendix

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