Digital Design Network+
Case Study 1 Individual Report Template

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Team	Group 1
Focus	Better, Faster, With Less
Design Process	Conceptual and detailed design phases via automated shape and topology optimisation.
Tools Used	Open-source Python libraries, Computational Fluid Dynamics (CFD), Finite Element Analysis (FEA)
Links	N/A

Executive Summary

The traditional engineering design process relies heavily on human intuition and legacy heuristics, which inherently restricts the exploratory design space and limits vehicle performance. This case study demonstrates the transition to an automated, generative design paradigm to accelerate the UK engineering sector's transition to a net-zero future under the Digital Design Network Plus (D2N+) initiative. By applying gradient-based algorithms within an open-source Python environment, I optimised drone sub-systems, specifically thermal heat exchangers, aerodynamic aerofoils, and structural wing spars, achieving mathematically optimal designs that drastically improve performance, accelerate development times, and minimise material usage.

Problem

Manual design processes are fundamentally constrained by rigid, preconceived geometric parameters and standardised variables (e.g., specific NACA aerofoil profiles or uniform structural rib thicknesses). Human intuition limits structural complexity, as the human mind cannot efficiently compute optimal load distributions across millions of localised nodes in a complex structural assembly. Consequently, designing via iterative human trial-and-error inevitably leaves significant performance potential unrealised on the table and frequently results in sub-optimal performance coupled with high material waste.

Digital Design Solution

The solution shifts the engineering focus away from manual drafting and toward the rigorous mathematical definition of performance goals and boundary conditions using an automated, generative design architecture. Built entirely within a Python environment utilising modular open-source libraries, the framework deploys gradient descent algorithms to iteratively generate and refine complex geometries. Three specific drone applications were explored:

1) Thermal Shape Optimisation: Redesigning a 2D pipe heat exchanger to maximise perpendicular heat transfer away from high-density sub-systems, modelled using the Steady Incompressible Navier-Stokes and Heat Transfer equations.

2) Aerodynamic Shape Optimisation: Generating bespoke aerofoils mathematically constrained by area and barycentre to minimise drag, maximise lift, or maximise the Lift-to-Drag (L/D) ratio tailored to specific low Reynolds numbers.

3) Topology Optimisation: Maximising the global stiffness (minimising mechanical compliance) of a wing spar bounded by the previously optimised aerodynamic profile, governed by linear elasticity.

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

Better: By actively removing human bias and relying purely on mathematical physics, the generative algorithms produced highly efficient, unconventional geometries. This achieved a 129% increase in average heat flux for thermal components and verifiable optimality for aerodynamic profiles.

Faster: The open-source framework resolved complex multi-physics optimisations rapidly. Bespoke fluid aerofoils utilising 800 active design nodes converged in merely 5 minutes, while a massive 1,200,000-node structural topology domain was fully resolved in just 30 minutes.

With Less: To ensure minimal material usage, a strict 30% volume fraction constraint was mathematically imposed during the wing spar topology optimisation. The algorithm independently deduced an optimal internal I-Beam structure, maximising structural strength while successfully eliminating 70% of the material mass.

Reflections

The deployment of automated generative design fundamentally shifts the modern engineer's role from geometric synthesis to rigorous problem definition and systems integration. The utilisation of an open-source Python stack not only ensures workflow agility but also guarantees absolute traceability, as every iterative geometric update and gradient calculation is mathematically logged.

A key challenge for future R&D is navigating the intersection of high geometric complexity and traditional manufacturing constraints. To fully unlock the sustainability benefits of generative design for mass-market products, optimisation algorithms must embed robust Design for Manufacture (DfM) parameters to ensure that these complex, high-performance structures can be reliably and cost-effectively produced via both additive and subtractive manufacturing methods.

References

Appendix