

MATERIAL COMPOSITION OPTIMIZATION IN AIRCRAFT WING DESIGN FOR REDUCED LIFECYCLE ENVIRONMENTAL IMPACT

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Abstract

Material selection is a fundamental aspect of aircraft structural design, where engineers must balance competing requirements such as stiffness, weight, cost, and environmental impact. Conventional approaches typically rely on discrete material databases and manual screening procedures, which can limit the exploration of large and highly coupled material property spaces. Recent advances in machine learning offer new opportunities to address this limitation by enabling continuous representations of material properties and more efficient optimization strategies.

This work presents a data-driven framework for aircraft wing material selection that integrates Variational Autoencoders (VAEs) with multi-objective gradient-based optimization. The VAE is trained on material property data extracted from the Granta CES EduPack database, allowing the model to learn a compact latent representation of high-dimensional material characteristics. By embedding materials into a continuous latent space, the approach converts the inherently discrete problem of material database exploration into a continuous design problem. This latent representation captures the underlying correlations between material properties and enables interpolation between existing materials, allowing the identification of new candidate materials consistent with the statistical structure of the dataset.

Within this latent space, a multi-objective optimization framework is implemented to identify materials that balance multiple structural and environmental objectives. The optimization simultaneously considers key engineering properties such as density, elastic modulus, and yield strength, as well as sustainability-related metrics including energy and cost. Gradient-based optimization techniques are employed to efficiently navigate the latent design space and identify Pareto-efficient solutions, enabling systematic exploration of trade-offs between structural performance and environmental impact.

To evaluate the engineering relevance of the optimized materials, several widely used aerospace materials are used as baseline references. The optimized material

candidates obtained through latent-space optimization are subsequently integrated into an aeroelastic wing model developed using OpenAeroStruct. This integration enables direct assessment of the impact of optimized materials on aircraft structural and aerodynamic performance, including wing mass, aeroelastic deformation, and aerodynamic efficiency.

The results demonstrate that the proposed methodology enables efficient exploration of high-dimensional material design spaces while remaining fully compatible with physics-based aircraft design tools. By leveraging latent representations learned from data, the framework provides a systematic approach for identifying promising material candidates that simultaneously improve structural performance and reduce environmental impact.

Overall, this study illustrates how combining generative machine learning models with multi-objective optimization can enhance material selection processes within multidisciplinary aircraft design environments, providing a pathway toward more efficient and sustainable aerospace structures.