1) Introduction

Designing an airplane for efficient commercial transport operation, while meeting requirements of safety and environmental responsibility, is a highly challenging endeavor representing the highest level of technological complexity and engineering sophistication. Effective airplane design requires maintaining synergy between customers’ needs for their intended mission and the engineering processes of aircraft design and development. Outside of major OEMs of the aircraft industry General Aeronautics (GAPL) is one of very few organizations globally with capability of comprehensive aircraft design. The author
brings a lifetime of experience at NASA and The Boeing Company to GAPL’s unique perspective in airplane design based on intimate knowledge of industrial airplane development processes and R&D contributions to them.

Traditional airplane design process has followed a largely linear path through the conceptual, preliminary and detailed design phase. Fine tuning the configuration for delivering the best performance possible has been generally accomplished by optimization procedures introduced at a late stage of the design process. The optimization process attempts to find the best attainable compromise between requirements and constraints, often mutually conflicting, imposed by various engineering disciplines as well as performance demands. In this context it is instructive to consider the essential differences in viewpoints regarding multidisciplinary optimization from the aircraft industry and R&D organizations presented in Table 1. below.

### Table 1

<table>
<thead>
<tr>
<th>R&amp;D</th>
<th>Industry</th>
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<tr>
<td>Collaboration of a few domain experts and optimization authority</td>
<td>Engineering teams executing standardized processes repeatedly</td>
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<tr>
<td>Comprehensive framework encompassing all disciplines involved in aircraft design</td>
<td>Focused problem solving in limited context</td>
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<td>Ab initio configuration design from DOE</td>
<td>Synthesis of configuration design from real configurations data</td>
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<tr>
<td>Generalized exploratory process</td>
<td>Proprietary process for specific purpose integrated into design process</td>
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<td>Focused on final design</td>
<td>Focused on generation of knowledge base for design improvement</td>
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<tr>
<td>Process driven by objective function representing idealized design solution</td>
<td>Process goal is to achieve design for specific performance metric representing business goals</td>
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It is clear from the differences presented above that industrial aircraft design is primarily a product-centric endeavor to achieve targeted performance goals, rather than a search for an idealized configuration. Recent advances in computational architecture enabling distributed collaborative design environments as well as emerging technologies such as Multidisciplinary Design Analysis &
Optimization (MDAO), Model-Based Systems Engineering (MBSE), Artificial Engineering (AI), have pointed towards the possibility of synthesizing product-centric airplane designs from real-world aircraft data all throughout the design process starting from concept definition. This synthesis paradigm has potential for producing an accelerated design and development process that blurs the boundaries of the development phases and thus reduces development cycle time and cost. The need of the next few decades is for a multidisciplinary design process that allows the product design to evolve at levels of sophistication appropriate for any stage in the design process. Synthesis is key to maintaining a multidisciplinary focus from the beginning of the process and ensuring integrity of the design throughout its evolution.

A case in point is the author’s conceptual design of a supersonic business aircraft – the Spike Aerospace S512. The design process from the earliest sketches to the finalized concept configuration, shown below in Figure 1, was underpinned by synthesis considerations to accommodate conflicting performance requirements crucial to designing a supersonic aircraft for commercial use. A couple of these conflicting requirements are

- Conflicting requirements for airplane shape for minimizing sonic boom and minimum wave drag.
- Aerodynamic wing shape design requirements for best performance at low speed (take off and Landing) and high speed (supersonic cruise) conditions.

![Figure 1. Conceptual design of supersonic business jet](image)

2) Paradigm Shift
Newly emerging technologies and the need to accelerate the design development cycle while maintaining comprehensive multidisciplinary integrity of the product at every step of the design process has necessitated a paradigm shift in design methodology towards integrated product development enabled by design synthesis procedures. The crucial need in industry for the next few decades is for design synthesis processes that utilize real aircraft configuration and performance data augmented by the designer’s experience and intuition to implement a product-centric methodology for attaining desired performance goals from the very beginning rather than using optimization as a post processor. The salient features characterizing this paradigm shift are listed below.

- Linear/sequential design process **To** Holistic product centric design
- Piecemeal design **To** Integrated design
- Evolutionary design process in discrete stages **To** Systemic approach treating airplane as a system of systems
- Optimization driven by quest for ideal configuration **To** Product synthesis driven by actual performance data for **real** airplane configurations

The essential goal of the synthesis paradigm of airplane design is to parametrically combine known configurations and their associated performance data (empirical, legacy, from existing airplanes, analytic, test, etc.) to produce an airplane configuration with performance values that closely match product and mission requirements. The paradigm is conceptually illustrated in Figure 2. below.
3) Synthesis

Formal optimization procedures require computational analysis of a large number of configurations at each level of the optimization cycle. Considering the large number of cases, often in hundreds, that have to be analyzed in each engineering discipline, the associated computational cost in time as well as money is enormous. Synthesis offers an alternate paradigm for taking full advantage of the designer’s knowledge, experience and intuition, existing airplane data, available experimental data, and previous calculations to define an airplane that comes close to producing the desired performance while eliminating the bulk of the computational cost of traditional optimization. Conceptual differences between mathematical frameworks of optimization and synthesis paradigms are summarized in the schematic in Figure 3.
Airplane Configuration Design: Alternate Paradigms

Optimization

Configuration Synthesis

In the author’s implementation of the design synthesis mathematical framework the desired performance goal is specified in terms of performance parameters designated over some range of flight conditions, i.e., a performance index denoted \( P_i \). The mathematical procedure combines known configurations defined by the design parameters \( G_i \) to define a resulting configuration \( G_d \) that corresponds to a target performance vector \( P_d \). Further details about the underlying mathematical principles can be found in Reference [1] by the author, et al. The procedure works for single- or multi-disciplinary design environments. The synthesis procedure has several advantages in addition to reduced computational expense for analysis. If the individual configurations satisfy required constraints then the parametrically combined configuration will also satisfy the constraints. Therefore, the synthesized configuration will not represent an “impractical” design. The synthesis procedure does not require the expensive calculation of sensitivities for each design parameter variation as would be required by optimization. A schematic diagram illustrating implementation of a synthesis-based airplane design procedure is presented in Figure 4.
4) Concluding Remarks and Way Forward

Frameworks for design synthesis processes are still at early stages of development. A substantial amount of rigorous mathematical and computational research is needed for implementation of consistent and robust systems for routine airplane design in the synthesis paradigm. General Aeronautics is actively developing a mathematical framework for performance index based synthesis of airplane designs. Advances in emerging technologies in the areas of collaborative computational environment, Model Based Systems Engineering (MBSE), Digital Twin, Artificial Intelligence (AI), and Machine Learning (ML) are expected to make tremendous impact on design synthesis capability for airplanes in the next few decades. General Aeronautics is playing a key role towards this end by partnering with technology
leaders in these fields including ANSYS and Dassault Systemes to advance and adapt these technologies for airplane design.

Reference


About General Aeronautics Private Limited

General Aeronautics Pvt Ltd. is a leading aviation product and engineering service provider in India that specializes in design, development, integration and support solutions for manned aircraft and unmanned air vehicle systems for civilian and military aviation sectors internationally. General Aeronautics is one of a select few companies globally and the only one of its kind in India with capability to undertake comprehensive design of aircraft and offer solutions from concept to realization. Our multidisciplinary engineering and optimization services range from new aircraft development to improvement of existing aircraft according to customer requirements and specifications. Our versatile product range of unmanned aerial systems spans civilian, military, agricultural and humanitarian applications.

We provide a vertically integrated range of end-to-end design and optimization services to OEMs and Tier-1 partners covering discrete work packages to full turnkey solutions at complete aircraft system level down to subsystem and component levels. The engineering team, with several hundred man-years of experience in design and development of aerial systems, represents the highest global standards of aircraft engineering and innovative talent. Team members bring in expertise backed by a proven global record of contributions towards advancing the state of art of aerospace vehicle design and development.