Review of the Advantages and Challenges of Strut-Braced and Truss-Braced Aircraft

Dominika Kacik[1], Tomasz Goetzendorf-Grabowski[1]
[1] Warsaw University of Technology, Faculty of Power and Aerospace Engineering, Institute of Aeronautics and Applied Mechanics, Nowowiejska 24, 00-665 Warsaw, Poland

Abstract:

This paper presents the overview of the state of the science regarding the strut-braced wing and truss-braced wing aircraft and the design obstacles that come with these configurations. This study is done as it is believed that designing and developing such aircraft with a usage of multidisciplinary design optimization (MDO) might help address one of the major challenges of the aeronautical industry- reduction of aviation's environmental footprint.

Today, the world is seeking solutions to one of its most pressing challenges—climate change [1]. Various studies show that aviation is responsible for 2-3% of human-made CO2 emissions, with its environmental impact comparable to that of methane produced by the global cattle industry [2]. In line with the European Commission's long-term strategy to achieve carbon neutrality by 2050 [3], interest from both aircraft and engine manufacturers in tackling this problem is steadily increasing.

Enlarging the wing's aspect ratio is an effective method to enhance the aerodynamic efficiency of transport aircraft by reducing lift-induced drag. However, in a traditional cantilever wing, this improvement comes at the cost of a significant increase in structural weight, as the wing must support greater aerodynamic loads. The strut-braced or truss-braced wing design mitigates this issue by reducing the bending moments that the inner-wing structure must bear, thereby minimizing the weight penalty as the aspect ratio is increased [4].

The strut-braced wing (SBW) configuration has been extensively studied by the Virginia Tech Multidisciplinary Aircraft Design Group, which contributed to the Subsonic Ultra Green Aircraft Research (SUGAR) project led by Boeing [5]. This work is part of NASA's N+3 concept studies [6]. These investigations have highlighted the potential of the SBW design, projecting an 8% reduction in fuel consumption compared to a conventional cantilever wing. Similarly, ONERA – the French Aerospace Lab has explored this concept through the ALBATROS research project [7]. The differences between truss-braced wing and strut-braced wing are depicted in Figure 1 and Table 1.

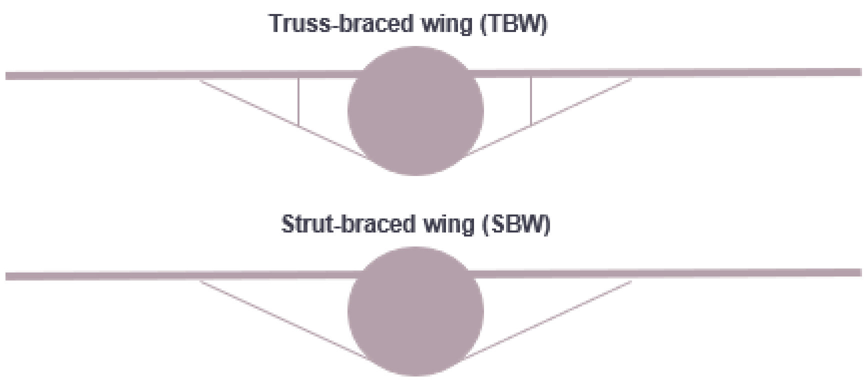

Figure 1 Truss-braced wing and strut-braced wing configurations

Aspect	SBW configuration	TBW configuration
Structural Design	Single external strut from fuselage to wing; simpler load path	Complex truss structure with multiple supports; more intricate load paths
Aerodynamic Performance	Increases aspect ratio, reduces drag, but limited by aeroelastic issues at high speeds	Allows for extremely high aspect ratios, maximizing drag reduction and fuel efficiency
Weight and Flexibility	Lighter and thinner wings but more flexible, prone to aeroelastic problems	Even lighter wings with greater flexibility, but requires careful design to avoid aeroelastic instability
Aeroelasticity Challenges	Susceptible to flutter, gust loading, and aero-servo-elastic coupling due to flexibility	Faces similar challenges, but truss structure helps distribute loads more effectively
Manufacturing Complexity	Simpler design, easier and cheaper to manufacture	More complex design, higher manufacturing complexity and cost
Overall Efficiency	Moderate improvements in fuel efficiency and performance	Superior improvements in fuel efficiency and performance

Table 1. Comparison of SBW and TBW configurations

The increased load-carrying capacity of strut-braced wing (SBW) and truss-braced wing (TBW) designs, along with the multiple load paths provided by the strut or truss structures, enables the inboard wing box to be lighter, thinner, and more flexible. However, this flexibility, combined with the complex load paths, can significantly affect the vehicle's aeroelastic behavior. This may result in issues like excessive gust loading, unacceptable flutter margins, and destabilizing aero-servo-elastic coupling [8].

This paper describes the pros and cons of the mentioned configurations as well as discusses the design challenges that should be taken into account when doing a multidisciplinary design optimization (MDO) study on SBW or TBW aircraft.

[1] D.Kacik, Overview of factors related to aircraft operation associated with a negative impact on the environment, 34th Congress of the International Council of the Aeronautical Sciences ICAS 2024, https://www.icas.org/ICAS_ARCHIVE/ICAS2024/data/papers/ICAS2024_0410_paper.pdf

[2] M. Jarosova, M. Pajdlhauser, Aviation and climate change, 11th International Conference on Air Transport –INAIR 2022, Returning to the Skies, 2022, https://www.sciencedirect.com/science/article/pii/S2352146522006925/pdf?md5=7d8f32c65a9e27262d3aa7d88e8dd41b&pid=1-s2.0-S2352146522006925-main.pdf

[3] European Commission, 2050 long term strategy, https://climate.ec.europa.eu/eu-action/climatestrategies-targets/2050-long-term-strategy_en

[4] G. Carrier and al., Multidisciplinary analysis and design of strut-braced wing concept for medium range aircraft, AIAA Scitech January 2022. 10.2514/6.2022-0726.

[5] X. Carrillo Corcoles and al., Aeroelastic Tailoring of a Strut-Braced Wing for a Medium Range Aircraft, Proceedings of the AIAA SCITECH 2024 Forum Article AIAA 2024-2590 (AIAA SciTech Forum and Exposition, 2024). American Institute of Aeronautics and Astronautics Inc. (AIAA), https://doi.org/10.2514/6.2024-2590

[6] NASA, Subsonic Ultra Green Aircraft Research: Phase IV Final Report – Volume I Mach 0.80 Transonic Truss-Braced Wing HighSpeed Design Report, 2022, https://ntrs.nasa.gov/api/citations/20220016017/downloads/NASA-CR-20220016017%20Volume%201.pdf

[7] M. Meheut and al., Overview of Aerodynamic Design Activities Performed at ONERA to Reduce Aviation's climate impact, 33rd Congress of the International Council of the Aeronautical Sciences ICAS 2022, https://www.icas.org/ICAS_ARCHIVE/ICAS2022/data/papers/ICAS2022_0843_paper.pdf

[8] J.Ran, Aeroelastic Tailoring of Strut-Braced Wings, https://resolver.tudelft.nl/uuid:525970df-c593-40f2-9c59-fb771a774459