Box-Wing Con igurations: A Future Scenario?

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1 Introduction

The aviation industry has witnessed great development in the last 40 to 50 years including but not limited to deeper understandings of aerodynamics, materials, different types of drag affecting aircrafts and efficiency progress regarding internal combustion and jet engines. Ongoing research is taking place in search for the next future airliner configuration with the aim of bringing further improvements in fuel efficiency, reductions in noise and noxious emissions from the engine(s). One of these “future airliner configurations” is the so-called box-wing or joined-wing, where researchers are claiming potentials of reduced structural weight and direct operating costs by lowering or eliminating the induced drag. This improves overall fuel efficiency and therefore makes the configuration interesting to investigate further. [1]

Fig. 1 Joined-wing aircraft concept of "the future". [2]

2 Nomenclature

All nomenclature used in this report will be stated in the following table:

Designation	Denotation	Unit
C_{Di}	Induced Drag Coefficient	-
C_L	Lift coefficient	-
e	Oswald Efficiency Factor	-
AR	Aspect Ratio	-
δ	Induced Drag Factor	-

3 Drag Theory

When aircrafts (airfoils) are moving through a fluid e.g air in this case, lift is produced because of the aircraft’s wing characteristics. The wing enforces a higher airstream velocity above it than below it, resulting in higher pressure beneath than above the wing, creating lift. With a traditional wing configuration, since there is a lower pressure above than beneath the wing, some air will slip from the high pressure side to the low pressure side at the wingtips resulting in vortices and so called induced drag or vortex drag. Since

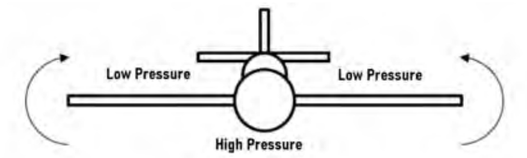

Fig. 2 Vortex flow behaviour for aircraft wing tips when producing lift.

a box-wing has no wingtips the slip of air is greatly reduced which decreases the total drag and therefore improves the lift-to-drag ratio. The overall effect of implementing a box-wing will be improvements in range and endurance, or reductions in fuel consumption. [3]

3.1 Comparison of the induced drag coefficient

The induced drag coefficient is defined as:

$$C_{Di} = \frac{C_L^2}{\pi \cdot e \cdot AR} \quad [4]$$

To compare different results with each other it is most convenient not to use the Oswald Efficiency Factor, but the induced drag factor δ, which has the following relationship with the Oswald Efficiency Factor:

$$\frac{1}{e} = (1+\delta) \quad [3]$$

This leads to the following induced drag coefficient:

$$C_{Di} = \frac{C_L^2}{\pi \cdot AR} \cdot (1+\delta) \quad [3]$$

The ideal lift distribution of an aircraft wing would be a halve ellipse which would have an induced drag factor of 0. Unfortunately these wings are hard to manufacture and expensive to build, so the industry came up with different approaches for decreasing the induced drag factor. One example is the implementation of a dihedral, which reduces δ by 0.029. Another well know optimization is the use of winglets or wingtip fences, the latter can reduce the induced drag factor by up to 0.28 [3].

According to [3] Fig. 7, the box-wing is shown to have the highest reduction of induced drag factor, being equal to -0.32.

Ludwig Prandtl also searched for the most efficient wing system and came up with a biplane configuration. For this reason, the box-wing is sometimes also referred to the Prandtl-wing [5].

4 Discussion and Conclusion

The aim of this paper was to investigate the properties of a possible "future" aircraft, in this case the use of a box-wing. The European Union has concluded a number of challenges for the aviation industry with goals to be fulfilled starting from the year of 2020 [6]. These challenges include goals for increased comfort and safety regarding civil transport while minimizing environmental pollution through less emissions of e.g noxious gasses and a more energy efficient aviation industry. The European Union strives for more available space and comfort, faster boarding times and disembarkation of passengers and luggage partially by minimizing approach and landing separations due to wake vortex turbulence of larger aircrafts. There is also an aim for increased allowed cargo weight for passengers, 30% reduction of Direct Operating Costs and minimized maintenance costs with a 0.85 Mach minimum cruise speed. The level of survivability to accidents especially regarding take-off and landing is a main requirement for the future where e.g design against crash and/or spreading of fire, safer fuel tanks, use of new materials and evacuation systems are of main focus regarding aviation safety according to the European Union.

All these mentioned improvements require the investigation and development of new technologies, regarding the aviation industry. The aerodynamic design for aircrafts is of highest importance for minimizing drag which leads to more efficient aviation and a more successful transport aircraft programme. Noise and noxious emissions during take-off and landing produce the worst impact on people living in the surrounding areas, which calls for improved possible lower velocity take-offs and landings. "In a large transport aircraft during cruise flight, drag is mainly due to friction drag (45-50%), and induced drag (40-45%)" [7]. The opportunity to minimize the induced drag through new aircraft design is possible which would have a great impact on the aviation industry, in this case the box-wing.

Since box-wing configurations use double wings to produce lift, there is a higher total lift to drag ratio if one compares a conventional airliner to a box-wing aircraft with the same wing span. This means that with the use of a box-wing configuration, the use of smaller wings is possible to produce the same amount of lift. The fuselage could also be increased in size while the wing span stays the same. This higher lift leads to the engines not having to be as powerful and could be held smaller which also gives a better fuel efficiency by decreasing the operating fuel consumption, decreasing the pollution as well as the noise.

Since the induced drag stands for almost half of the total drag in today's civil aviation, decreasing it would have a huge impact on the industry.

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