Redesign of the Gossamer Albatross using a Boxwing

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ABSTRACT

Historically, human powered aircraft (HPA) have been known to have very large wingspans; the main reason being for aerodynamic performance. During low speeds, the predominant type of drag is the induced drag which is a by-product of large wing tip vortices generated at higher lift coefficients. In order to reduce this phenomenon, higher aspect ratio wings are used which is the reason behind the very large wingspans for HPA. Due to its high Oswald efficiency factor, the boxwing configuration is presented as a possible solution to decrease the wingspan while not affecting the aerodynamic performance of the airplane. The new configuration is analyzed through the use of VLAERO+©. The parasitic drag was estimated using empirical methods based on the friction drag of a flat plate. The structural weight changes in the boxwing design were estimated using "area weights" derived from the original Gossamer Albatross. The two aircraft were compared at a cruise velocity of 22 ft./s where the boxwing configuration showed a net drag reduction of approximately 0.36 lb., which can be deduced from a decrease of 0.81 lb. of the induced drag plus an increase of the parasite drag of around 0.45 lb. Therefore, for an aircraft with approximately half the wingspan, easier to handle, and more practical, the drag is essentially reduced by 4.4%.

INTRODUCTION

The majority of existing HPA possess large wingspans, a fact that renders them impractical and difficult to operate. For example, the Gossamer Albatross has a wingspan of 96 ft., greater than that of the Boeing 717, an aircraft carrying more than 100 passengers. Such large wingspans not only affect the aircraft controllability at very low altitudes, but it also makes it handling on the ground difficult and requires that the aircraft be disassembled for storage or, alternatively, the use of large facilities.

The large wingspans have been used to minimize the induced drag, which is the predominant drag component at low speeds. However, other methods for reducing induced drag for a given span are available, such as the use of non-planar wing configurations. The non-planar configuration with the highest efficiency is the boxwing. Therefore, it can be postulated that an HPA could be designed as a boxwing with a significantly lower span but with a similar or better aerodynamic efficiency.

To investigate this hypothesis, the Gossamer Albatross wing will be modified to become a boxwing aircraft (boxplane) and its performance will be evaluated and compared to that of the original Albatross. To isolate the configuration effect, the boxwing's airfoil, fuselage, canard, etc. will be unaltered from the original Albatross and only the single wing will be replaced by two wings, joined at the tips, with roughly half the span.

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METHODOLOGY

Because of the availability of information and data, the Gossamer Albatross (Fig. 1) is used in this study as the baseline for the redesign using the boxwing concept. The aircraft's general dimensions are presented in Table 1.

Figure1. Gossamer Albatross during flight test
https://www.nasa.gov/sites/default/files/images/300796main_ECN-12557_full.jpg

Table 1. Gossamer Albatross general parameters

Wing Span	96 ft.
Wing Area	488 ft.^{2}
Gross Weight	222 lb.
Wing Loading	0.455 lb./ft.^{2}
Aspect Ratio	18.89

The aerodynamic calculations for this study were performed using VLAERO+©, a commercial vortex lattice method (VLM) computer program. The accuracy, limitations and, hence, the applicability of the program for the preliminary design of HPAs, will be first determined in a validation exercise in which the calculated values will be compared to published Gossamer Albatross flight test data.

According to Kroo [9], vortex (induced) drag accounts for about 40% of drag in conventional aircraft and is even more significant at low speeds [9]. The induced drag, for an aircraft of known weight, in level flight, is given by the well known equation

$$D_i = \frac{\left(W/_S\right)^2 S}{1/_2 \rho V^2 \pi A R e} \qquad (1)$$

It can be seen that the induced drag is inversely proportional to velocity, aspect ratio, and efficiency factor. Therefore, it will be more significant for an aircraft operating at low speeds such as HPAs. From the equation, it can easily be understood the reason for resorting to large spans for its minimization.

Assuming that the Reynolds number and speed do not change between the two aircraft, the coefficient of friction should remain the same. Therefore, Eq. 2 from Raymer [14] is used to estimate the parasitic drag component due the increase in wetted area of the boxwing configuration.

$$C_{D0} = C_{fe}\frac{S_{wet}}{S_{ref}} \qquad (2)$$

In order to estimate the weight of the new aircraft configuration for analysis, an "area weight" was obtained by dividing the total weight by the structural area of the Albatross.

RESULTS

A boxwing of roughly half the span of the Albatross with the same airfoil, root chord, fuselage and taper ratio was modeled in VLAERO+©. The height between the two wings corresponds to the original Albatross fuselage height. The general dimensions of this new aircraft are presented in Table 2.

Table 2. Boxplane general parameters

Wing Span	45 ft.
Wing Area	458 ft.^{2}
Root Chord	6.375 lb.
Taper Ratio	0.6
Aspect Ratio	4.42
Vertical Separation	7.62 ft.

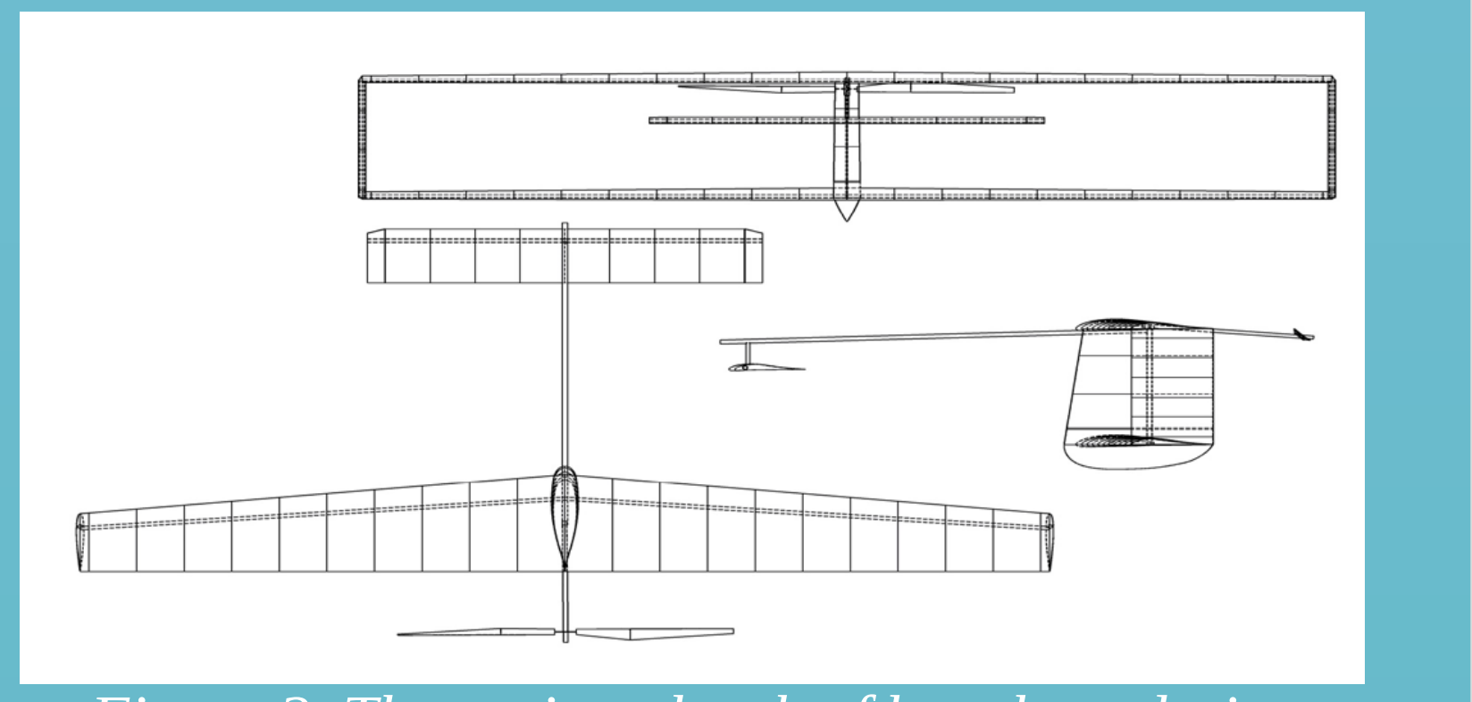

Figure 2. Three-view sketch of boxplane design

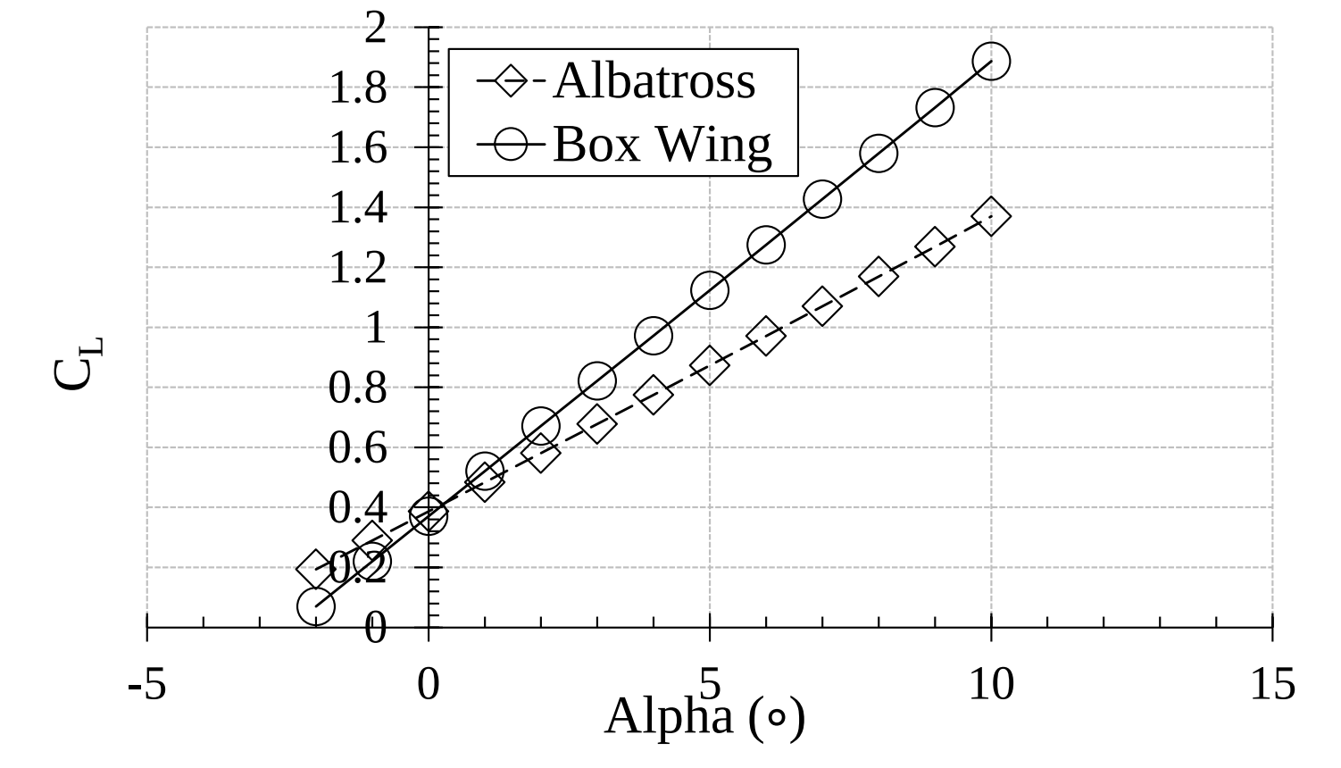

Figure 3. C_L slope with respect to angle of attack

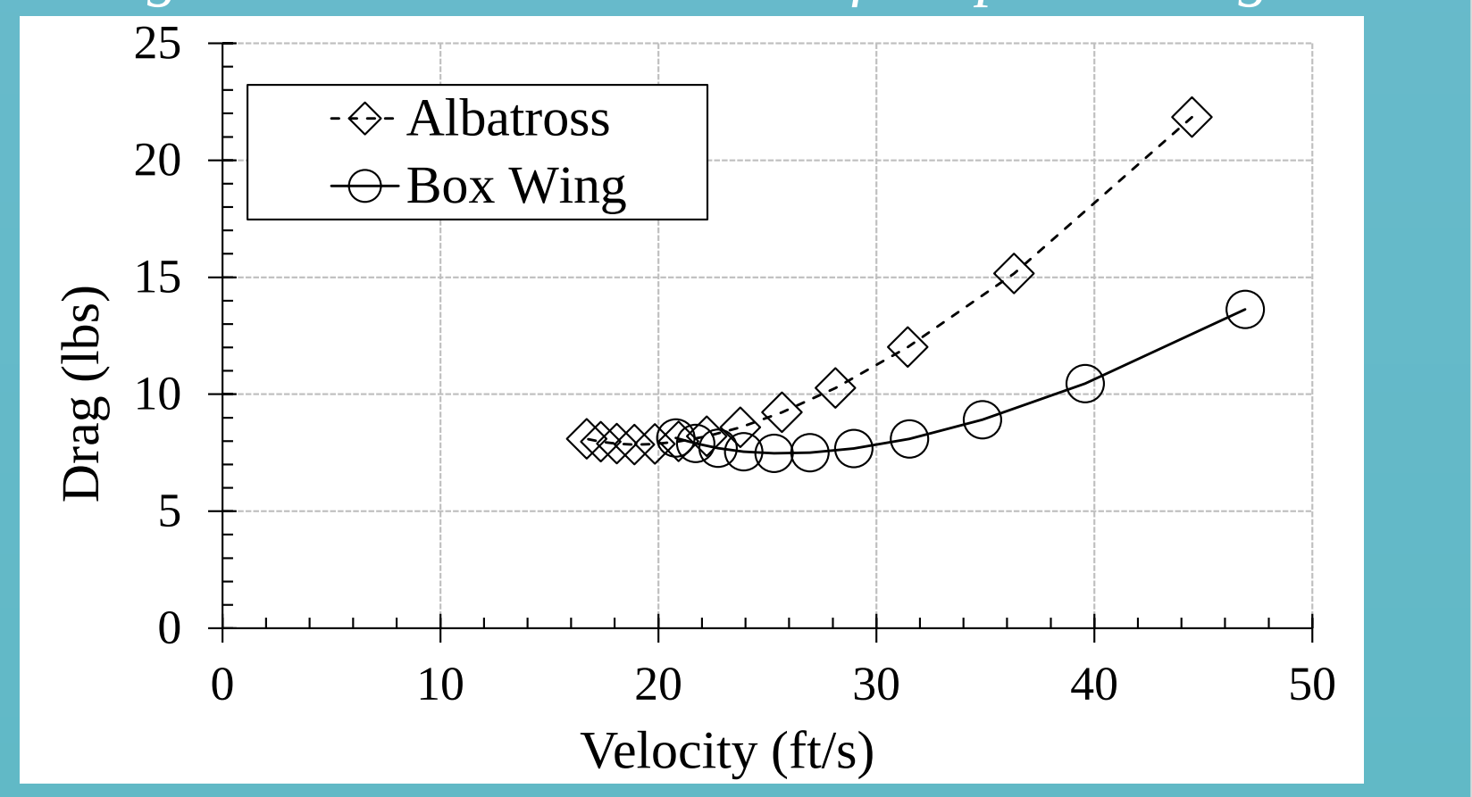

Figure 4. Total drag vs. velocity

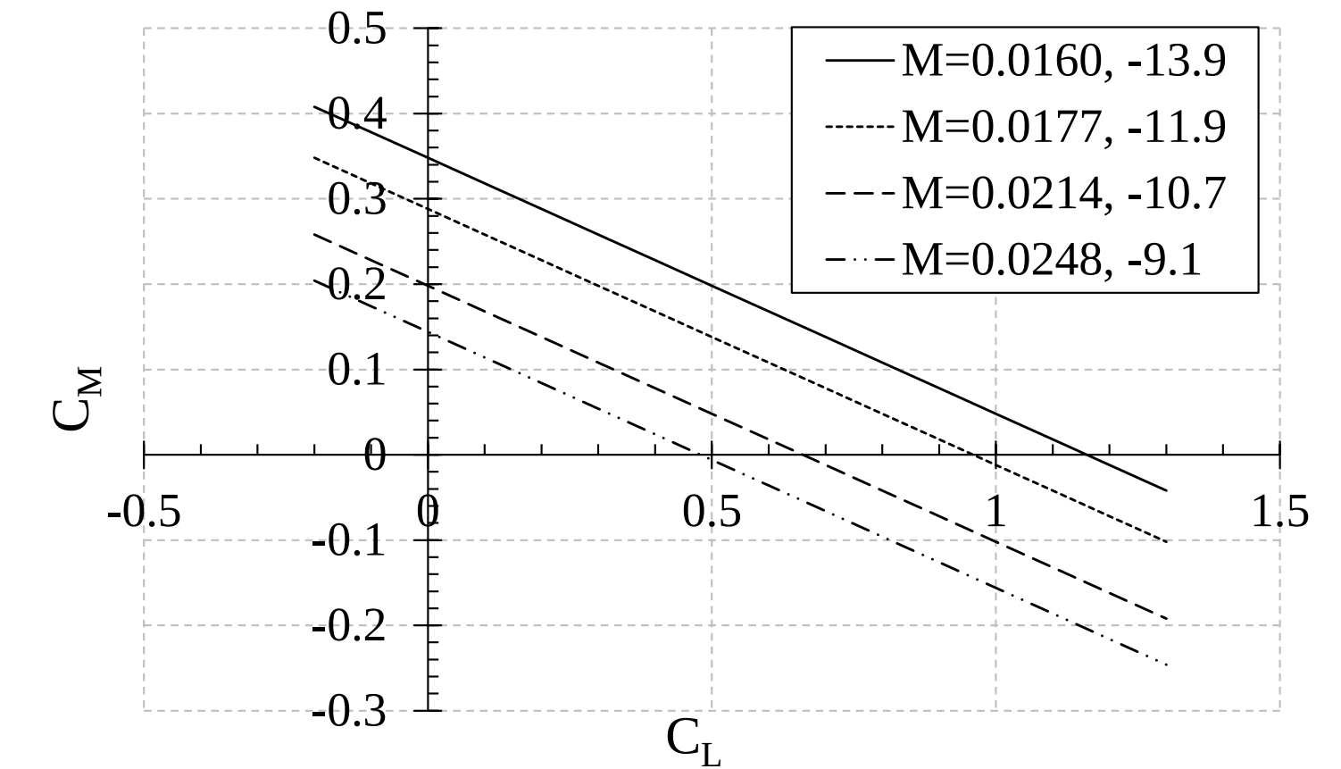

Figure 5. C_M vs. C_L for boxplane

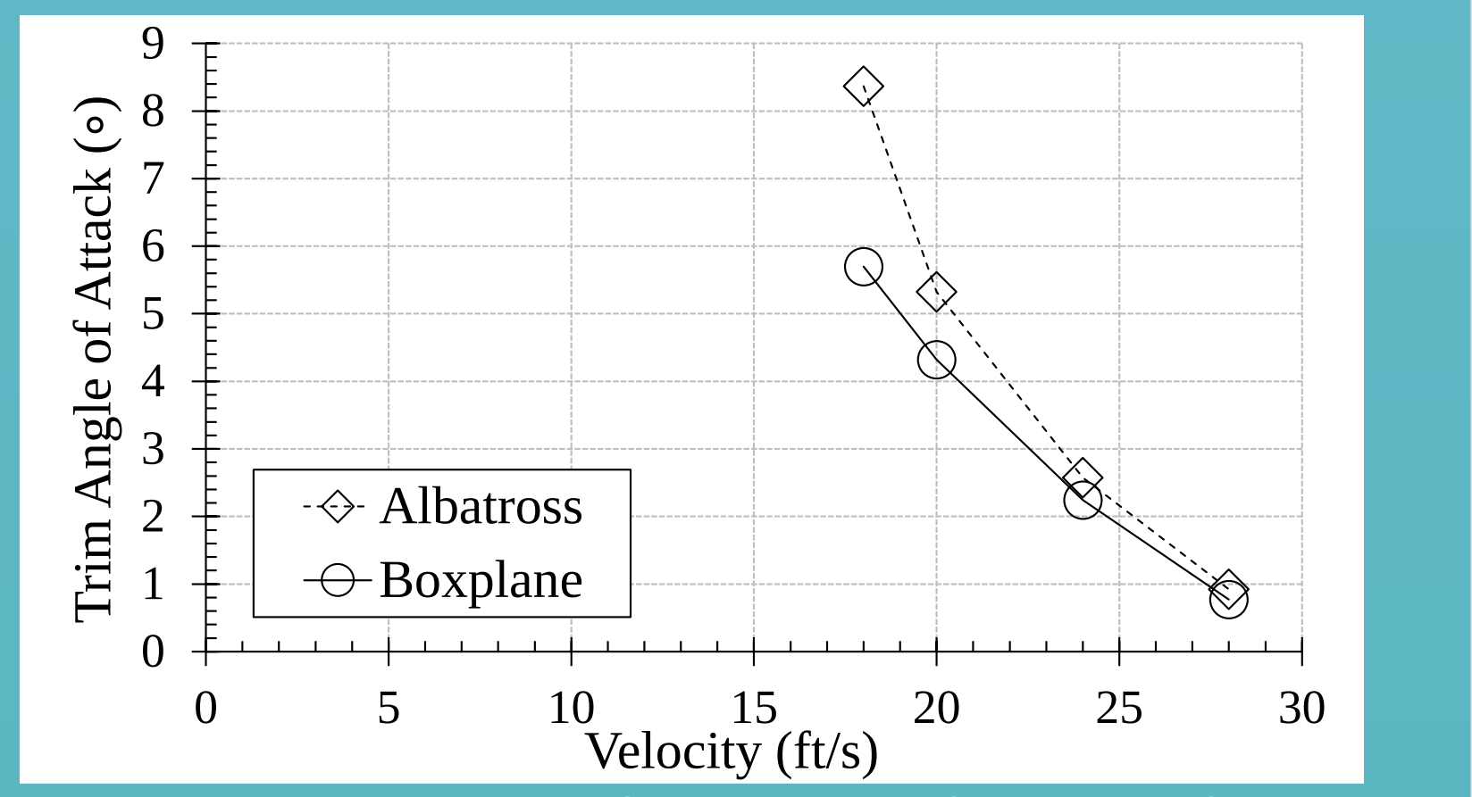

Figure 6. Trim angles of attack as a function of velocity

- In Fig. 3 the boxplane has a higher slope which provides insight on the improved aerodynamic performance since, for any given airspeed, the boxwing configuration will require a smaller angle of attack.
- In Fig. 4 It can be seen that the boxplane results in no drag penalty at 22 ft./s and in significant drag improvements for higher speeds.
- Lines in Fig. 5 represents a particular flight Mach number and its corresponding canard deflection necessary for trim . The graph shows negative C_{MCL}'s with positive moment coefficients at zero lift for all cases, providing the necessary condition for longitudinal static stability.
- In Fig. 5 the boxplane consistently requires a lower angle of attack for trim at every speed; therefore, for the same level flight condition, the boxplane will be at a lower angle of attack, resulting in a faster aircraft.

The boxwing, did not result in any significant weight penalty and, for a normal cruise speed of 22 ft./s resulted in no net drag increase. The parasite drag increased by 0.45 lb., something that was more than compensated by a reduction of 0.81 lb. in the induced drag, giving a net drag reduction of approximately 0.36 lb. or 4.4%. At slightly higher speeds the boxplane displayed even higher total drag reductions.

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