On the maximization of control power in low-speed flight

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There is a substantial literature on the optimization of the deflection of several control surfaces, for example to minimize trim drag in cruise; this is particularly relevant to the blended wing body (BWB), that has the whole span available at the trailing-edge for control and high-lift surfaces, and also a large fraction of the leading-edge.

The present work extends existing knowledge on the subject in two directions: (i) on theoretical side by allowing for the deflections of multiple control surfaces, that gives more options to obtain the desired forces or moments with less risk of flow separation or aeroelastic effects; (ii) on the application side by considering not only minimum drag but also maximum drag (e.g. for fast descent) and maximum control moments for emergencies, such an engine-out condition. These applications are made to a FW, extending the scope of the literature that concentrates mostly on minimum drag for pitch trim in cruise. Thus the present paper is also a contribution to the expanding literature on various aspects of the BWB aircraft.

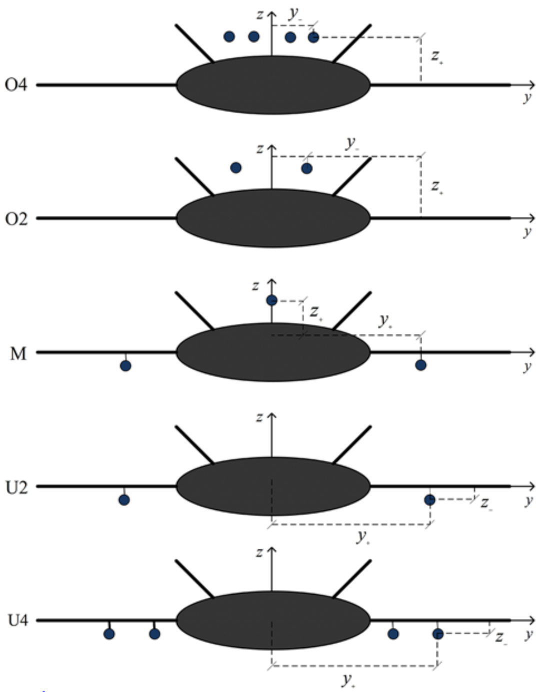

Fig. 1 BWB with five engine configurations: (O4) four engines above the body with twin fins for noise shielding; (O2) two engines above the body; (M) one engine above the body and two un underwing nacelles; (U2) two engines in underwing nacelles; (U4) four engines in underwing

The control limits of a BWB configuration were explored in low-speed flight. The method used can maximize or minimize any component of the aerodynamic forces or moments within the range of possible deflections of each control surface; other components can be left free or constrained, e.g. by equilibrium conditions. Applying this method to a BWB in a low-speed configuration: (i) shows that pitch trim can be obtained with a minimum drag reduction of 10%, which has beneficial effect on climb performance after take-off; (ii) conversely a maximum drag increase of 58% can be obtained with the same angle-of-attack and pitch trim for the steepest descent to land; (iii) the maximum and minimum pitching moment using all control surfaces can be modulated over a much wider range of values than using only the body flap, and similar results concern the broader range of achievable drag at constant lift with pitch trim (Table 1); (iv) the maximum and minimum yawing moment specifies the yaw control authority available in the worst scenario of failure of an outboard engine showing that the use of all available control surfaces is much more effective than rudders alone (Table 2) leaving a greater safety margin; (v) the maximum and minimum rolling moment also benefit from the use of all available control surfaces to achieve a broader range of values.

Table 1 Effect of pitch trim on drag.

Drag (kN)	Deflection of body flap alone	Optimal deflection of all surfaces
Untrimmed drag	43.575 kN	43.575 kN
Drag due to trim: - minimum - maximum	 +25.138 kN + 39.155 kN	 58.769 kN 58.769 kN
Percentage of untrimmed drag - minimum - maximum -ratio	 + 57.69 % + 89.85 % + 1.56	 −9.65 % + 134.87 % −13.98
Total trimmed drag: - minimum - maximum - ratio	 68.713 kN 82.730 kN 1.204	 39.369 kN 102.340 kN 2.600
Deflections of control surfaces - minimum drag - maximum drag	 (–19.84, 0, 0, 0, 0)º (+25, 0, 0, 0, 0)º	 (–8.24, 8.36, 0, 0, +3.13)º (25, 25, 0, 0, –25)º

Table 2 Yaw trim compensate outboard engine failure.

Configuration with outboard engine out	Yawing moment	Percentage of maximum yaw control power need for compensation	
		with optimal controls	with rudders alone
O4- four above centrebody $n=4, y_-=8m$	3.9014×10^{-4}	−1.49 % , +1.59 %	−5.48 % , +7.70 %
O2- two above centrebody $n=2, y_-=15m$	7.8027×10^{-4}	−2.97 % , +3.17 %	−10.97 % , +15.39 %
U4- four underwing $n=4, y_+=35m$	1.7068×10^{-3}	−6.51 % , +6.94 %	−23.99 % , +33.67 %
M – one over centrebody and two underwing $y_+=35m$	2.2758×10^{-3}	−8.69 % , +9.25 %	−31.99 % , +44.90 %
U2- two underwing $n=2, y_+=35m$	3.4137×10^{-3}	−13.0 % , +13.9 %	−47.99 % , +67.35 %

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Related Work:

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Campos, L., & Marques, J. (2015). On the minimization of the cruise drag due to pitch trim", Session: Aircraft Performance, 5th CEAS Air & Space Conference, 7-11 Sept, Delft University of Technology, The Netherlands.