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Potential Effects of Blended Wing Bodies on the Air Transportation System

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Flying wings in various layouts (blended wing body, C-wing, tail-less aircraft, etc.) are among the most promising concepts in the foreseeable scenario of air traffic increase and very demanding noise and emission regulations. Published literature shows that these aircraft will exhibit considerable gains in field length and cruise performance with respect to conventional airplanes and could be less harmful in terms of emissions and noise. The objective of this study is to present the beneficial effects that blended wing bodies would have on the air transportation system: specifically, on four relevant aspects of airport capacity, community noise, air space capacity, and emissions.

I. Introduction

MOST air traffic forecasts predict a remarkable increase over the next two decades, in spite of the serious downturn after the year 2000 crisis and the terrorist attack of 11 September 2001. Overall revenue passenger-kilometer goes up at a pace around 5% [1–3], remarkably over the world economic growth. The predicted traffic growth varies from region to region, and Asia-Pacific Rim will become the largest market. Freight traffic is expected to increase at even higher rates. In the next 20 years, this activity will demand around 25,000 new jet airplanes that will have to cope with continued pressure to achieve significant reductions in direct operating cost and environmental impact, particularly because of the fuel price volatility and the new, more demanding, NOx limitations and carbon-trading schemes.

Commercial aviation has been mainly based over the last 50 years on what is currently called the conventional layout. This is characterized by a slender fuselage mated to a high-aspect-ratio wing, with aft-mounted empennage and pod-mounted engines under the wing [4]. A variant with engines attached to the rear fuselage was also developed during the 1950s and is still broadly used in business and regional jets. However, it seems that this primary configuration is approaching an asymptote in range parameter and other performance features. With the current technology level, this asymptote would be slightly above the size of A380 [5].

Within this framework, one of the most promising concepts is the flying wing in its diverse configurations: blended wing body (Fig. 1), C-wing, U-wing (Fig. 2), tail-less aircraft, etc. It is not a fully novel concept, because it was considered by Horten, Northrop, and others [6,7] from the mid-1930s to the mid-1950s, but was abandoned for stability and control problems. The flying wing's principal advantage comes from arranging the passenger and freight cabins in one or more decks that extend spanwise, providing structural, aerodynamic, and payload synergy [8,9], although this layout is hard to engineer. The concept may provide significant fuel savings and hence a lower level of CO_2 production. Moreover, the engines can be located above the wing, and the aircraft does not need high-lift devices in low-speed configuration, which results in a much quieter airplane.

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The introduction of a new aircraft paradigm must be backed up by suitable analysis, albeit of an approximate nature, of the key issues such as aerodynamic configuration, structural arrangement, engine-airframe integration, aircraft stability and control, productivity, airport compatibility, emergency evacuation, passenger acceptance, etc. This explains the great deal of activity carried out by the aircraft industry and numerous researchers throughout the world to perform conceptual design level studies, to address the problems and challenges posed by this concept [8–17]. Most papers deal with very-high-capacity aircraft, up to 1000 passengers, but forecasts are very promising too for medium-capacity airliners in the 300-seat category.

The present paper concentrates on preliminary estimations of flying-wing performance on four relevant items of the air transportation system: airport capacity, community noise, air space capacity, and emissions. For its very nature, the present findings are only approximate but may serve to identify where some key points of the configuration are.

II. Airport Capacity

All aircraft in flight generate wake turbulence, which is arranged in a horseshoe pattern that evolves downstream up to vanishing at very long distance from the aircraft. Such a pattern forms two parallel counter-rotating vortex tubes that concentrate all vorticity originally distributed throughout the wing boundary layer. The swirling effect produced by each vortex tube is very strong and results in a dangerous rolling moment on any aircraft crossing the wake [18,19]. This happens whenever the aircraft is airworthy: i.e., in cruise, approach, takeoff, etc. Although the evolution of the wake also depends on the trailing-edge devices deployed, this effect has not been considered in this preliminary analysis.

Cruise encounters are very rare and less problematic, since the aircraft has time to react and regain control. But in landing and takeoff, the rolling moment produced by the leading aircraft wake turbulence may completely alter the trajectory of the follower aircraft, leading to an accident.

Because of this interference, aviation authorities have established certain time and distance separations between leading and follower aircraft [20,21]. As it will be shown later, the intensity of the wake turbulence depends on the aircraft weight, wingspan, wing aspect ratio, and speed, but the key variable is weight. Consequently, the aforementioned separation has been imposed in terms of the leading and follower aircraft weights. Table 1 shows the current regulations. Runway capacity is therefore limited by the aerodynamic interference between subsequent aircraft.

New aircraft are evaluated according to these wake interference criteria to check that they will not pose unforeseen problems. This

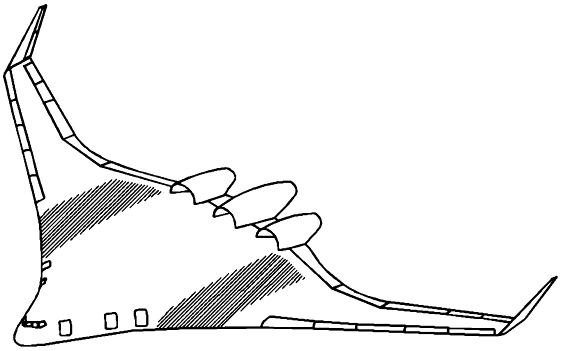

Fig. 1 Perspective view of a blended wing body aircraft.

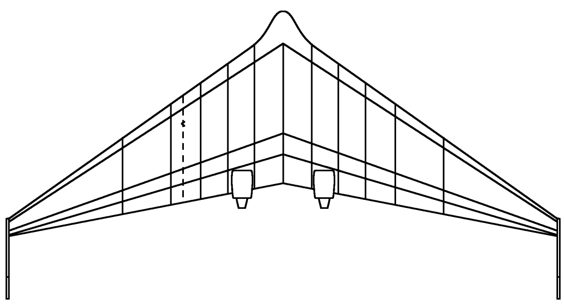

Fig. 2 Plan-view sketch of a flying wing, showing the internal spanwise distribution of passenger and cargo bays, and the location of the mean aerodynamic chord (dashed line) and its quarter-chord point.

occurred in the early 1970s at the advent of wide bodies and, recently, before the entry into service of A380 [22]. And this is expected to happen again in a future with blended wing body (BWB) or other flying wings.

As part of a research project on flying wings, a previous paper has shown that this concept will produce a very mild wake [23]. The maximum tangential velocity induced by the vortex tube, $v_{\theta\max}$, occurs at the edge of the vortex core, which diffuses downstream by viscous effects [24]. Therefore, it depends on the downstream distance x, flying speed V, and overall aircraft circulation Γ_0, as indicated in Eq. (1):

$$v_{\theta\max} = \frac{\Gamma_0}{4\pi r_c} = \frac{20}{\pi}\sqrt{V\Gamma_0/x} \qquad (1)$$

In turn, Γ_0 depends on the aircraft characteristics as

$$\Gamma_0 = \frac{4W}{\pi\rho V b} \qquad (2)$$

where W is aircraft weight, ρ is air density, and b is wingspan.

Interestingly, on considering Eqs. (1) and (2) simultaneously, it is evident that the main variable controlling the wake intensity is the span loading W/b, which is very different for conventional airplanes and flying-wing layouts. On the other hand, in this first-order

Table 1 ICAO aircraft separation in approach to avoid vortex encounters

Leader aircraft	Follower aircraft	Separation, n mile	Time delay, s[a]
Heavy[b]	Heavy	4	106
Heavy	Medium	5	133
Heavy	Light	6	159
Medium[c]	Light	5	133
All other combinations	——	3	79

[a]Approximate speed is 70 m/s.
[b]MTOW > 136,000 kg.
[c]7000 kg < MTOW < 136,000 kg.

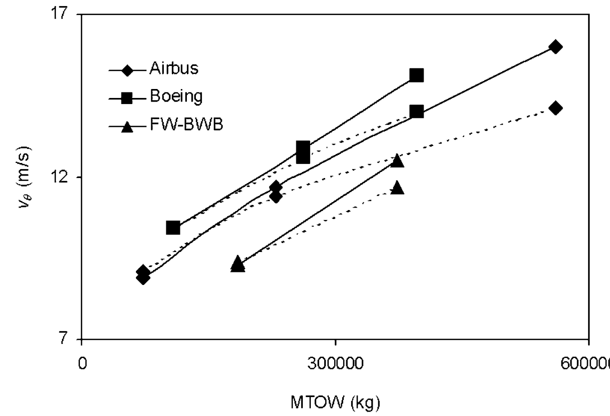

Fig. 3 Maximum induced velocity at a separation distance of 6 nm in takeoff (solid lines) and 5 nm in approach (dashed lines) for the Airbus and Boeing airplanes, and the flying wings analyzed in [26].

approach, the aircraft velocity has almost no impact on the wake characteristics.

In the aforementioned work [23], it was reported that a 300-seat category flying wing would generate a wake turbulence (defined as the maximum induced velocity in the wake at a given distance) similar to the one generated by an A320 or B737 of approximately 150 seats. And a large 800-seat BWB would behave like a B757 or B767 in the 200-seat category. This is clearly observed in Fig. 3. The passenger capacity is closely related to the aircraft maximum takeoff weight. But, as indicated before, the flying wings are lighter than conventional airliners. Furthermore, flying wings have a lower span loading. Both facts explain, according to Eqs. (1) and (2), why the induced turbulence is less intense in blended wing bodies.

Consequently, these new aircraft could be allocated in the approach or takeoff sequence with smaller separation than the one corresponding to its actual seating capacity. This would therefore increase the runway capacity by allowing the operation of more and larger aircraft. It has to be noticed that both unconventional designs considered here, the BWB and the flying wing, fall within the new International Civil Aviation Organization (ICAO) letter F wingspan limitation of 80 m. This may imply some limitations on the taxiways to be used, but, in principle, the new concepts will not be subjected to additional operational restrictions.

The number of aircraft movements per hour in a runway can be estimated as

$$N_{\text{ops}} = \frac{3600}{\bar{T}} \qquad (3)$$

where $\bar{T}$, the mean interval between operations, can be computed as

$$\bar{T} = \sum_{i=1}^{4} p_i \sum_{j=1}^{4} p_j T_{ij} \qquad (4)$$

In this expression, p_i and p_j are the fractions of the various aircraft categories (light, medium, heavy and flying wing) for the leader and follower airplane, respectively, and T_{ij} is the corresponding time interval, as shown in Table 1. The procedure agrees well with established airport-capacity predictors [25,26].

Analogously, the number of passengers per hour can be obtained as

$$N_{\text{pax}} = N_{\text{ops}} \sum_{i=1}^{4} p_i N_i \qquad (5)$$

where N_i is the average number of passengers per aircraft in a given category.

Depending on the category mix at any given airport [25,27], a certain number of airplane landings will mean a different number of passengers. For example, North American main hubs receive a large number of commuter airplanes, which results in a lower passenger per aircraft average, as compared to leading European or Asian airports: i.e., Chicago, 82 passengers per aircraft movement, Atlanta 90, Houston 71, London Heathrow 140, Frankfurt 110, or Madrid 107 [28].

For the present study a typical load factor of 70% is considered. Therefore, the input values for Eq. (5) are 15 passengers for light airplanes, 105 for medium, and 220 for heavy airliners.

The analysis performed in the subsequent paragraphs is based upon the following hypothesis: the blended wing bodies will be allowed to operate according to the turbulence they generate (shown in Fig. 3) instead of by their maximum takeoff weight (MTOW) as occurs in conventional aircraft. Thus, when the leading aircraft is a 300-seat-class flying wing, the time separation to the follower aircraft is that of the medium-size category in Table 1. On the other hand, since the vast majority of the flying wings in a foreseeable future would be in the 300-seat category, the average number of passengers per aircraft movement is set at 220, as for the heavy airliners. This avoids any bias in the results.

Therefore, if a number of narrow-body aircraft were replaced by a similar number of 300-seat-class flying wings, the aircraft movements would remain the same, but the airport passenger movements would increase. In another scenario, if medium-size wide bodies were replaced by the aforementioned flying wings, this would imply a higher number of movements (since the time between operations is shorter, as indicated in Table 1) and an equivalent increase in the number of passengers, because the average aircraft capacity would be kept.

Taking all this into account, airports could handle many more aircraft and passengers with their current configurations (provided that neither the ground traffic management nor the terminal facilities are overflowed), without requiring huge investments in new runways and taxiways.

The increments of aircraft movements and passenger traffic will depend upon the airplane mix and the fraction of heavy- and medium-category aircraft replaced by flying wings. Tables 2 and 3 show the potential benefits of introducing 300-seat-class flying wings at six major hubs in two scenarios.

To better understand the traffic estimations, let us take the John F. Kennedy International Airport (JFK) to describe some clarifying explanations. According to the second column of Table 2, the fraction of aircraft categories are $p_1 = 0.39$, $p_2 = 0.58$, and $p_3 = 0.03$, for heavy, medium, and light airplanes, respectively. When two heavy aircraft approach in sequence, the second must wait 106 s (see Table 1). If the follower is a medium-category airplane, it must wait 133 s, etc. The separation times are thus $T_{11} = 106$ s, $T_{12} = 133$ s, and $T_{13} = 159$ s. Analogously, $T_{21} = T_{22} = 79$ s, $T_{23} = 133$ s, and $T_{31} = T_{32} = T_{33} = 79$ s. The mean time between operations is computed with Eq. (4) to be $\bar{T} = 97.0$ s, which was introduced in Eq. (3), gives 37.1 operations per hour, and appears in the third column. The index of passenger traffic, sixth column, is obtained from Eq. (5) with the aforementioned p_i values and $N_1 = 220$, $N_2 = 105$ and $N_3 = 15$, resulting in 5469 passengers per hour.

In the first scenario, half the medium and half the heavy airplanes are replaced by flying wings. Therefore, the new aircraft fractions are $p_1 = 0.195$ (half of 0.39), $p_2 = 0.29$ (half of 0.58), $p_3 = 0.03$, and $p_4 = 0.485$ (half of $0.39 + 0.58$). With respect to time separations, although the flying wing is a heavy aircraft, according to the former hypothesis, when it is the leading airplane, the separation is that of a medium-category airliner: i.e., $T_{41} = T_{42} = T_{44} = 79$ s, and $T_{43} =$ 133 s. With Eq. (4) the new mean time is $\bar{T} = 87.2$ s and that in Eq. (3) translates into $N_{\rm ops} = 41.3$. This value appears in the fourth column. Introducing $N_4 = 220$ and all former values in Eq. (5) gives 7445 passengers per hour, as shown in the seventh column. These results would imply a moderate increase in the number of movements (11%), but the passenger traffic would increase by 36%.

The procedure can be repeated in a second scenario: 70% of the medium-category airplanes and 30% of heavy aircraft would be replaced by flying wings. Again, the aircraft movements hardly change, but the passenger traffic augments up to 43%.

Traffic gains are even higher in some major hubs, with a maximum of 63% in passenger count for Atlanta Hartsfield in the second scenario. If larger blended wing bodies in the 800-seat class were put into service, passenger counts would increase even further.

Taxiway capacity and aircraft ground traffic should not represent major problems, provided an optimized ground traffic management is set up [29] to properly organize the airport air side. Consequently, the slight increase in the number of movements shown in Tables 2 and 3 could be easily handled. On the other hand, the increase in the number of passengers per aircraft when narrow bodies were replaced by 300-seat flying wings would imply extended emplaning and deplaning operations, but both run simultaneously to other ground servicing tasks. Therefore, doubling the number of passengers per aircraft would mean to pass from some 45 min of turnaround time [30,31] to about 50–60 min [32,33]. Thus, except perhaps in peak hours, gate occupancy would not be much affected by the increase in aircraft passenger load.

Table 2 Airplane operations and passenger traffic increments under the assumption that half the medium and half the heavy airplanes are replaced by flying wings (FW)

Airport	% H/M/L[a]	Index ops/h without FW	Index ops/h with FW	% increase	Index pax/h without FW	Index pax/h with FW	% increase
JFK, New York	39/58/3	37,1	41,3	11,1	5469	7445	36,1
Heathrow, London	33/67/0	38,4	42,4	10,3	5495	7696	40,1
Frankfurt	33/66/1	38,3	41,0	7,2	5436	7385	26,7
CDG, París[b]	18/81,5/0,5	40,9	43,6	6,4	5129	7497	46,2
Hartsfield, Atlanta	14,9/83,3/1,8	41,3	43,2	4,5	4980	7326	47,1
O'Hare, Chicago	11,1/76,2/12,7	40,0	41,4	3,6	4275	6219	45,5

[a]Percentages correspond to the current heavy, medium, and light aircraft mix.
[b]CDG, Paris stands for Charles de Gaulle, Paris.

Table 3 Same as in Table 2, except that 70% of medium and 30% of heavy airplanes are replaced by flying wings

Airport	% H/M/L	Index ops/h without FW	Index ops/h with FW	% increase	Index pax/h without FW	Index pax/h with FW	% increase
JFK, New York	39/58/3	37,1	40,4	8,8	5469	7828	43,1
Heathrow, London	33/67/0	38,4	41,7	8,4	5495	8199	49,2
Frankfurt	33/66/1	38, 3	42,4	10,9	5436	8283	52,4
CDG, París	18/81,5/0,5	40,9	43,1	5,4	5129	8232	60,5
Hartsfield, Atlanta	14,9/83,3/1,8	41,3	43,2	4,5	4980	8094	62,5
O'Hare, Chicago	11,1/76,2/12,7	40,0	41,2	3,0	4275	6904	61,5

III. Community Noise

For the present research only the noise in approach has been considered. Although takeoff noise is typically stronger, it is mainly influenced by engine technology and the engine-airframe integration, both out of the scope of the present research. Most published designs show the engines located over the upper wing, near the trailing edge, which shields fan noise. Moreover, in common takeoff and climbing maneuvers, the aircraft is able operate at reduced thrust and to follow a certain flight path to generate the minimum disturbance to the surrounding community. On the contrary, the approach phase takes place following a rather rigid safety protocol imposed by the navigation aids at the airport (i.e., typically the instrument landing system) and has almost no degree of freedom to avoid the specific path to the runway threshold. Continuous approaches and steep descent arrivals are being studied to reduce the noise footprint [34,35] but are not yet fully approved and imply higher risks for aborted landings [36].

Most of the noise in approach comes from the airframe, so it is well suited for understanding the impact of the aircraft configuration [37].

In the present study, the noise generated by the airplane has been computed by means of the Engineering Sciences Data Unit (ESDU) method [38]. This method determines the effective perceived noise level by estimating the contribution of several parts of the airframe during final approach and landing. It has the capability of discriminating among noise sources and frequencies. All spectral characteristics are obtained analytically from empirical data or are assumed to be similar to those of known sources. The airframe is decomposed on wing, flaps, slats, horizontal and vertical tailplanes, and main and nose landing gears. The noise produced by the fuselage is considered negligible. The accuracy claimed by the method is in the order of 1 to 3 dB.

The ESDU method is capable of providing sound pressure levels in any point close to the flight path: in particular, at the ICAO references. Therefore, according to ICAO Annex 16 [39], a reference point at 2000 m before the runway threshold, named the approach reference point, has been chosen to determine the approach noise. This reference point is otherwise at 2300 m from the touchdown point, which would correspond to maintaining the 3 deg instrument-landing-system glide slope until touchdown, as it is also shown in Fig. 4. At this point, the aircraft flies at around 120 m above the ground.

To check consistency and trend of the results, the sound pressure level produced by the airplane, when it is above the approach reference point, has been computed at two additional points: one slightly closer to the runway (coded as point 1 in Fig. 4) and another slightly farther (point 3).

Figure 5 presents the noise produced by the B777-200 and the 300-seat class flying wing [17], at the aforementioned points. The results show that the flying wing is clearly less noisy than the conventional airliner: around 7 to 10 dB in sound pressure level, at all frequencies. For the flying wing the maximum value of 69.0 dB corresponds to a frequency of approximately 100 Hz. The actual effective perceived noise level, integrating over the audible range of frequencies [38], is 79.6 dB. This value compares very positively with respect to 88.2 dB for the B777-200.

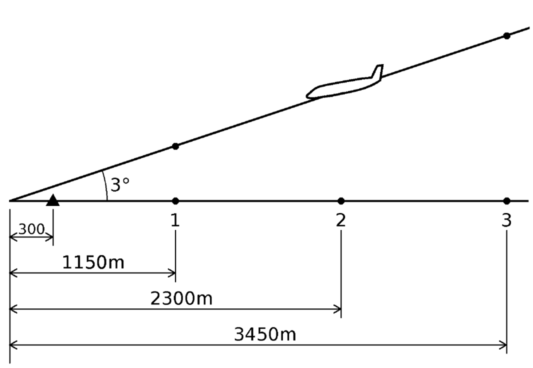

Fig. 4 Glide path of an airplane in IFR final approach. Points 1 to 3 represent the noise measuring points in the present study; ▲ is the runway threshold. The distances shown are from the straight touchdown point.

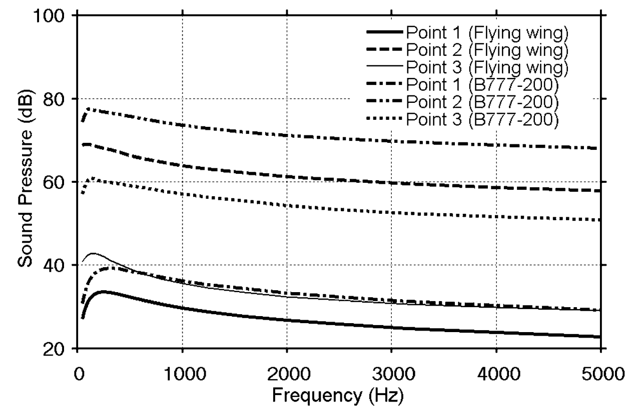

Fig. 5 Comparison of noise produced at three reference points during final approach by B777-200 and a flying wing of similar capacity.

IV. Airspace Capacity

The present section details some considerations on the suitable flight levels for the flying wings, taking into account its specific design features.

Aircraft are always in dynamic equilibrium in flight among aerodynamic, propulsive, inertia forces, and weight. Particularly, in cruise, lift equals weight:

$$W_{\mathrm{cr}} = L = \frac{\gamma p_{\mathrm{cr}} M_{\mathrm{cr}}^2 C_{L\mathrm{cr}} S}{2} \tag{6}$$

where p_{cr} is altitude pressure, M_{cr} is cruise Mach number, $C_{L\mathrm{cr}}$ is cruise lift coefficient, S is wing gross area, and $\gamma = 1.4$ is the air specific heats ratio.

Since the aircraft must also fly in optimum range conditions, this implies [40,41]

$$C_{L\mathrm{cr}} = \sqrt{\beta C_{D0} \pi A \varphi} \tag{7}$$

where β is a parameter related to the Mach number dependence of the specific fuel consumption (around 0.6 for high bypass ratio turbofans), C_{D0} is the non-lift-dependent term of the aerodynamic drag (practically constant below the drag rise Mach number), A is the wing aspect ratio, and φ is the induced drag efficiency factor (close to 1).

Equations (6) and (7) together yield

$$p_{\mathrm{cr}} = \frac{2}{\gamma} \frac{W_{\mathrm{cr}}/S}{M_{\mathrm{cr}}^2 \sqrt{\beta C_{D0} \pi A \varphi}} \tag{8}$$

Flying wings are expected to fly at the same Mach number than the conventional airliners and will have about the same $\beta \pi A \varphi$ product, but with a lower C_{D0} and a much lower wing loading. This would mean that to be efficient, the flying wing will have to fly at higher altitudes than conventional airplanes, as shown in Fig. 6. Therefore, the introduction of such aircraft would imply a double benefit from the airspace view point: using unused flight levels around 13,000–15,000 m (43,000–50,000 ft) and freeing lower congested flight levels (9000–11,000 m, 30,000–36,000 ft).

Quantifying the increase in aircraft movements in a given airspace is beyond the possibilities of the present research, for the large amount of variables intervening in this situation; but the positive effects are evident.

V. Emissions

According to results reported in literature [5,8,16,17,42], the flying wings exhibit important reductions in fuel consumption as

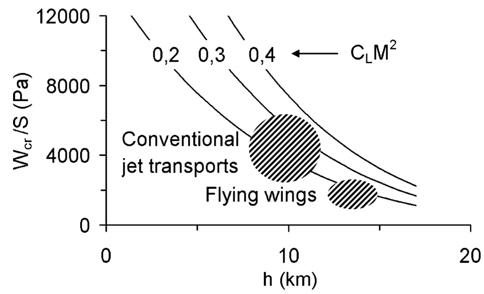

Fig. 6 Wing loading versus cruise conditions for flying wings and conventional airliners.

compared to conventional commercial aircraft. This is mainly due to a more compact and cleaner aerodynamic configuration and to a lighter airframe, which benefit from the wing-loading alleviation effect of its span-loading passenger and cargo distribution.

All fuel burned during flight is converted into carbon dioxide, with small amounts of carbon monoxide or unburned hydrocarbons. The percentage of these lasts depends on engine rating and flying conditions, but engines are currently designed to perform very efficiently under any circumstance [43,44]. NOx is another harmful pollutant, but mainly depends upon engine technology and very little on the aircraft configuration itself. Thence, only CO_2 will be considered for the present preliminary analysis.

Fuel consumption can be directly converted into carbon dioxide production, through the corresponding chemical reaction factor, once the chemical composition of fuel is known [45]. For an average Jet-A, each kilogram of fuel results in 3.15 kg of CO_2 [46].

Following a scheme similar to the ICAO carbon-emission calculator [47] the reduction of CO_2 can be estimated at two different levels [48]: globally, depending on the replacement fraction of conventional airliners by more efficient flying wings, and in terms of passenger kilometers for those long-haul routes that would be performed with the new aircraft type instead the classical one. A flying-wing configuration is around 20% more efficient in terms of lift-to-drag ratio than conventional airplanes, which directly translates into the same amount of fuel savings [17,37]. The CO_2 reduction capability is evident.

Furthermore, the architectural arrangement of the flying wing allows an easier incorporation of laminar flow control (LFC) technologies over the wing, and even higher fuel savings could be achieved. For example, by applying LFC over easily laminarized areas (around 30% of the upper and lower wetted surfaces), a fully loaded 300-seat class flying wing could burn just 14.6 $g/pax \cdot km$ [17] in a 10,000 km flight. This is equivalent to 46.0 $g/pax \cdot km$ of CO_2, which is around 40% lower than the equivalent conventional wide bodies [8,16,17].

Just to show the very high efficiency achieved, let us compare the former value with that of a very familiar case. A modern, compact, efficient car produces around 130 $g/pax \cdot km$. With an average load of three occupants, this means 43.4 $g/pax \cdot km$ of CO_2, just below the former figure. But the car runs at a speed of 100–120 km/h instead of 850–900 km/h for the aircraft.

VI. Conclusions

The flying wing is one of the most promising new aircraft concepts regarding the ever-increasing air traffic demand and a very constrained environmental scenario. Its introduction in the air transportation system could produce several beneficial effects:

1) With only a very moderate increase in aircraft movements, major airports could handle between 40 and 60% more passengers, without requiring expensive investments in additional runways. Aircraft ground traffic should not be significantly affected by such increase in airport capacity. Gate occupancy might be a problem, but not as much for the increase in the number of passengers or in the turnaround time, as for the larger wingspan that could require airport terminal rearrangements.

2) The noise generated by a flying wing approaching the airport would be about 7–10 dB lower than their conventional counterparts, which would translate into improved community living standard.

3) Because of their specific characteristics (in particular, the drag polar parameters and wing loading), the flying wings would use very high flight levels (between 40,000 and 50,000 ft), thus freeing lower congested levels for conventional aircraft flights.

4) CO_2 emission levels, in terms of $g/pax \cdot km$, would be around 20% lower than that of conventional wide bodies. By applying LFC technology over easily laminarized areas the savings could be around 40%. Just for comparison purposes with a very familiar vehicle, a blended wing body would generate the same CO_2 than a modern, compact, efficient car, but moving at high subsonic speed against a mere 100 km/h.

In spite of the many advantages claimed by researchers on the topic, the concept is still in its childhood, and extensive research is required in a variety of areas:

1) Design sizing and optimization tools for unconventional configurations, incorporating emerging technologies (LFC, vectored thrust, composite primary structure, etc.).

2) Complex structural arrangement in the centerbody to accommodate the cabin and withstand pressurization loads and in the outer wing to allow wing tip folding on ground.

3) New engine concepts and new engine-airframe integration possibilities to increase overall efficiency, shield fan noise, and exploit LFC benefits in the upper wing.

4) Impact of high level flight on pollutant production and on radiation received by passengers and crew. Airport compatibility in terms of door sill height, aircraft ground servicing, and wingspan requirements for taxi and gate/finger layout.

5) Emergency evacuation: namely, exit location and operation and slide deployment.

Integrating all design aspects is a formidable challenge, but once achieved it could contribute to alleviating the capacity and environmental problems of the air transportation system.

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