presented at:
13th STAB/DGLR Symposium, München (de), 12.-14.11.2002
published in:
Breitsamter, C. Laschka, B. Heinemann, H.-J. Hilbig, R., New Results in Numerical and Experimental Fluid Mechanics IV, Vol. 87, pages 26-33, Springer 2004.
ISBN 3-540-20258-7

Environmental Friendly Transport Aircraft

DR. MARTIN HEPPERLE

German Aerospace Center, Institute of Aerodynamics and Flow Technology,
Lilienthalplatz 7, D-38108 Braunschweig, Germany

Summary

The paper discusses some key elements of aircraft configurations which are intended to meet future requirements of environmental friendly transportation. Increased transport capacity is achieved by enhancing takeoff and landing performance in order to reduce the separation between subsequent flights. Additionally, overall productivity is improved by adapting the configuration to future noise restrictions allowing for extended daily operating times.

1 Introduction

Almost all scenarios for the development of air traffic show that a further growth of transport capacity can be anticipated in the future. Solutions to handle the increased traffic are constrained by economical and environmental issues which may lead to quite different or even completely new aircraft configurations. In the past, it was tried to minimize the environmental impact after the configuration had already been developed mainly based on cost and performance requirements. In the future, environmental issues will have a stronger influence at the component level, but also on the arrangement of the aircraft components and thus on the configurations. Increased transport capacity can be provided by:

1. increasing the number of aircraft,
2. reducing the turn around time at the airport and separation between flights,
3. enlarging the aircraft capacity, and
4. increasing the cruise speed of aircraft.

The first path has been followed in the past by simply using a larger number of available aircraft. It is severely limited by the number of airport slots and by environmental issues. The second possibility seems to offer a small potential for further improvements only. Over the years, the last two solutions have been the subject of conceptual and preliminary design studies which have lead to proposals for new configurations.

Enlarging the capacity of configurations by scaling has been a traditional and quite successful strategy during the history of flight. The latest sample of this method is the Airbus A380, which is scheduled to enter Service in 2008. While refinements in all disciplines have made such a design possible, it seems to be close to the limits of the classical airplane configuration. Therefore new aircraft configurations have been proposed, which promise higher transport capacity at reduced cost.

Figure 1 presents the passenger capacity of a few current and future configurations over their cruise Mach number regime. It can be seen that the direction of most developments is directed into one single direction: either an increase of passenger capacity or an increase in speed. Only the OFW concept tries to extend the operating range in speed as well as capacity.

One of the configurations shown in the graph seems to be rather unspectacular in terms of cruise speed and passenger capacity, but may offer more challenges than expected. This configuration, dubbed "The Green 24 Hour Aircraft" (24HAC) will be discussed in more detail below.

2 The Green 24 Hour Aircraft

Currently, many airports have already reached the limits of their capacity. Increasing the passenger capacity of airplanes helps to limit the number of takeoffs and landings for long range flights, but the huge number of short and medium range flights cannot be reduced easily. Each week, nearly 70% of all flights take less than 5 hours but carry 50% of the travelers (see figure 2, derived from [6]).

One design target of a new configuration design must be to minimize the time between subsequent takeoffs and landings. This can be done by introducing the capability to climb and approach at steeper angles and to select different angles for the flight path depending on the current traffic situation (Figure 4). Thus it is possible to avoid the trailing wakes of preceding aircraft and to reduce the distance between flights. Additional flexibility can be achieved by developing flight control systems suitable for dynamic takeoff and approach patterns. This aim is augmented by a considerable reduction of the perceived noise level so that the aircraft can be operated 24 hours each day. These requirements favor certain design features and can lead to configurations with significant changes compared to current aircraft [9]. The following paragraphs will discuss some of these features and how they affect the configuration.

2.1 Improving the Takeoff and Landing Performance

The performance during these two mission segments can be characterized by two parameters: the climb and sink angle and the flight speed. A steeper angle can be used to adapt the flight pattern to the current traffic density at the airport. By varying flight path angle and speed from flight to flight it is possible to reduce the distance between aircraft without increasing the danger of wake vortex interaction.

As noise scales approximately with velocity to the power of 5, it is desirable to fly as slow as possible. On the other hand, the time spent close to the ground and the area covered by the noise footprint during takeoff should be kept at a minimum. Therefore an assessment of the perceived noise must take place already during the conceptual design phase of new aircraft.

The equilibrium of the forces during climb and glide can be written in the form

$$\sin\theta = \frac{T}{W} - \underbrace{\frac{\rho_\infty}{2}\cdot v_\infty^2 \cdot \frac{S}{W} C_{D0}}_{\frac{\text{zero lift drag}}{\text{weight}}} - \underbrace{\frac{W}{S}\cdot\frac{2\cdot k\cdot\cos^2\theta}{\rho_\infty\cdot v_\infty^2}}_{\frac{\text{induced drag}}{\text{weight}}} \quad . \tag{1}$$

A differentiation of (1) leads to the maximum climb angle $\theta_{\max}$ and the following expression for the associated flight speed [2]:

$$v_{\infty,\theta_{\max}} = \sqrt{\frac{2}{\rho_\infty}\sqrt{\frac{k}{C_{D0}}}\frac{W}{S}\cos\theta_{\max}} \ , \quad \text{where} \quad C_L = \sqrt{\frac{C_{D0}}{k}} \ . \tag{2}$$

Figure 3 illustrates how the operating point during climb can be controlled by a variation of the design variables. The climb angle can be increased by:

- increasing the ratio of T/W (favoring twin jets),
- increasing the aspect ratio Λ, or
- increasing the ratio L/D, reduction of C_{D0}.

The desired reduction of flight speed can be achieved by the following measures:

- reduction of the wing loading W/S (not affecting the climb angle), or
- increasing the usable lift coefficient C_L.

A simple numerical study shows that the T/W ratio is the most powerful driver to increase the climb angle. The most important driver for a reduction of the flight speed is the wing loading W/S.

A high thrust to weight ratio favors twin jet configurations, due to the FAR takeoff requirements, which result in 50% reserve power compared to 33% for an aircraft equipped with four engines.

The usual methods to adapt the cruise design for takeoff and landing are a reduction of the wing loading by enlarging the lifting area and an increase in lift coefficient by cambering of the airfoil sections. This can be achieved with a slotted high lift system, which typically consists of three elements at least (slat, main wing, flap). Drawbacks of such a slotted multi-element flap system are mechanical complexity, weight, costs and a rather high noise level.

The actually usable lift coefficient can also be raised by altering the wing planform (e.g. reduced sweep angle). Additionally, the chord length could be increased in order to maintain the absolute wing thickness, mass and cruise performance. This would also have the beneficial effect of increasing the wing area, thus lowering W/S and helping to recover any lift loss which occurs when the slotted high lift system is replaced by a single element system. Segmented full span ailerons provide means to adapt the lift and drag distribution to the current flight condition.

2.2 Reducing the Noise during Takeoff and Landing

In order to extend daily operating hours, the noise during takeoff and landing must be reduced considerably (-10 … -20 dB). During these two flight segments different sources are responsible for the noise generation:

takeoff:

- engine noise (fan noise and jet noise, depending on BPR),
- airframe noise (landing gear, high lift systems),

landing:

- airframe noise (landing gear, high lift systems),
- engine noise (mainly fan noise).

Engine noise is dominant during takeoff and is composed mainly of fan and jet noise. The high frequency fan noise can be reduced by improving the absorption inside the nacelle and by using longer inlets to achieve a shielding effect – for a new configuration an additional shielding effect could be achieved by positioning the engine inlet above the wing or by embedding the engines in the rear fuselage [8]. In the latter case the long and curved inlet ducts must be carefully optimized to keep pressure losses low and to limit flow distortion at the fan entry. Also maintenance costs of such buried engines will be higher than on conventional arrangements.

Jet noise levels can be lowered by increasing the bypass ratio (thus reducing the jet velocity) and by modifying the structure of the jet shear layer (e.g. by chevrons or mixers). While ultra high bypass ratio engines offer great benefits in noise (Figure 5) as well as propulsive efficiency, their development requires the addition of a gearbox. Such a geared engine could also be used to raise the turbine RPM towards the higher frequency range, where the human ear is less sensitive.

The takeoff and landing configuration of a conventional aircraft is characterized by slotted high lift systems. Minimizing the number of high lift elements and their track systems can lead to a considerable reduction of noise and weight. The weight savings (≈2-3% of the wing weight) can be spent in a larger wing area to achieve the same lift capability with a plain flap droop nose system. Any drag penalty during cruise due to the larger wing area can be compensated by adapting the flight altitude [5].

One possible candidate for a low noise high lift system could consist of a clean leading edge and a full span single slotted flap. If required, a simple droop nose could be added. A comparison of achievable maximum lift coefficients indicates, that such a plain wing would require about 40% more chord length when compared to a slotted configuration (Figure 6).

Additional noise is generated by extended landing gears and open cavities like wheel wells. Modern aircraft already cover their wheel wells while the gear is extended, but further improvements can be made. Struts can be streamlined and covers can be added to the wheels and any cavities. The length of the main landing gear can be reduced by attaching it to the fuselage and by moving the engines away from their typical location under the wing. Moving the engines to the tail can results in a shorter rear fuselage so that the landing gear can be shorter without reducing the required rotation angle.

2.3 Selecting Elements for a new Configuration

Based on the requirements and effects discussed above, several design options for a new configuration can be identified. By combining these elements, various configurations can then be developed and analyzed (Figure 7).

Lifting surfaces:

- increased wing span b and aspect ratio Λ to improve L/D,
- increased wing area S to reduce the wing loading W/S, and
- simple high lift system without slats,
- laminar flow technology to reduce cruise drag.

Landing gear:

- short and few legs, add fairings, covers and close all open cavities.

Engines:

- twin jets (high T/W ratio due to “one engine out” takeoff requirement),
- shielded fan face (inlet shape, placement above wings or fuselages, buried engines),
- low jet velocity (increased BPR, geared fan),
- improve absorption and reduce mechanical noises.

3 Conclusions

Currently, several European research programs explore single aspects of environmental friendly aircraft (e.g. noise, airport operations, engine technology, aerodynamics, etc.). Their findings can partially be applied to the current fleet of conventional aircraft in terms of changed operating procedures and retrofit solutions in certain areas. Only a combination of these results together with some specific elements of aircraft configurations may lead to new aircraft configurations with reduced environmental impact. These will also have the additional benefit of reduced operating costs. In the long term, the huge transport volume of short- and medium range flights can only be handled by introducing new technologies together with a revised arrangement of aircraft components. For these specific missions, this does not necessarily mean a completely new configuration like a flying wing aircraft, but a clever arrangement and sizing of the key components.

Future work will focus on the modeling of these key elements at preliminary aircraft design level, the development of the most promising configurations and the assessment and comparison of the complete aircraft configurations. This will also include new models for the modeling of airframe and engine noise and suitable additions to cost models. Additional work should address the cost for manufacturing and operating such aircraft.

4 Symbols and Abbreviations

BWB	Blended Wing Body
BPR	bypass ratio (UHBR = ultra high bypass ratio)
OFW	Oblique Flying Wing
IWFC	Integrated Wing Fuselage Configuration
SST	Supersonic Transport
SC	Sonic Cruiser

Symbol	*Description*	*Unit*
D	Drag Force	N
L	Lift Force	N
M	Mach number	-
S	wing area	m^2
T	engine thrust	N
W	aircraft weight	N
b	wing span	m
k	k-Factor	-

Symbol	*Description*	*Unit*
v_∞	aircraft speed	m/s
C_D	drag coefficient	-
C_{D0}	C_D at $C_L=0$	-
C_L	lift coefficient	-
θ	climb angle	°
ρ_∞	density of air	kg/m^3
Λ, AR	aspect ratio (b^2/S)	-

5 References

[1] Ira H. Abbott, Albert E. Doenhoff. "Theory of Wing Sections", Dover Publications, New York, 1959.

[2] John D. Anderson, Jr. "Aircraft Performance and Design". McGraw-Hill, ISBN 0-07-001971-1, 1999.

[3] J. E. Green. "Greener by Design – the technology challenge", The Aeronautical Journal, Vol. 106 No. 1056, February 2002.

[4] Jeffrey J. Berton. "Noise Reduction Potential of Large, Over-the-Wing Mounted, Advanced Turbofan Engines", 14th International Symposium on Airbreathing Engines, Florence, Italy, 1999.

[5] Martin J. Hepperle. "The Sonic Cruiser – A Concept Analysis", International Symposium "Aviation Technologies of the XXI Century: New Aircraft Concepts and Flight Simulation", ILA-2002, Berlin, 7-8 May, 2002.

[6] Lufthansa Flight Plan, 2002-2003.

[7] Mark A. Potsdam, Mark A. Page, Robert H. Liebeck. "Blended Wing Body Analysis and Design", AIAA-97-2317, 1997.

[8] Steven F. Yaros et al. "Synergistic Airframe-Propulsion Interactions and Integrations", NASA TM-1998-207644, 1998.

[9] Nicolas E. Antoine, Ilan M. Kroo. "Aircraft Optimization for minimal Environmental Impact", 9th AIAA/ISSMO Symposium on Multidisciplinary Analysis and Optimization, September 2002, Atlanta.

6 Pictures

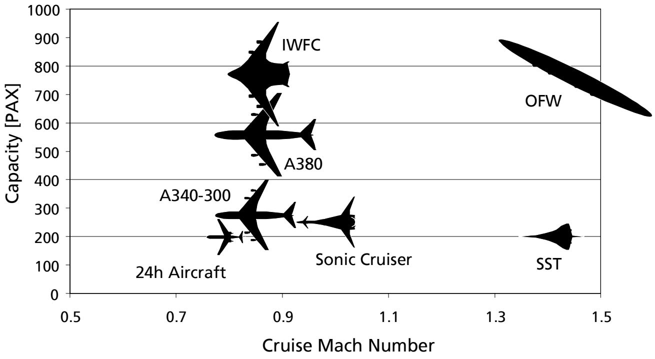

Figure 1 Comparison of various aircraft configurations in terms of their passenger capacity over cruise speed.

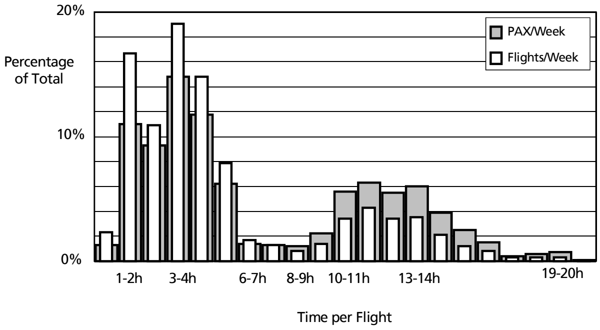

Figure 2 Distribution of number of flights and passengers versus overall flight time.

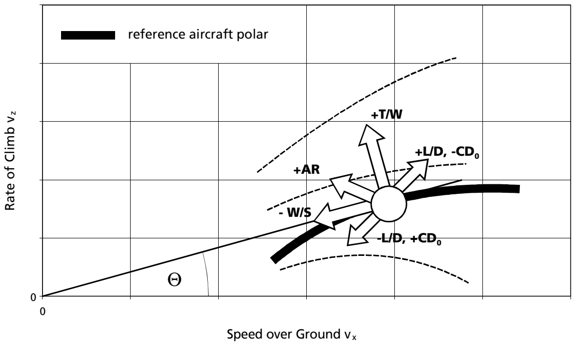

Figure 3 Effect of a variation of parameters on climb performance.

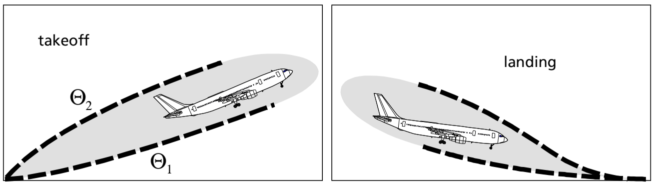

Figure 4 Improved takeoff and landing performance allows for adaptation of the flight path according to the current traffic density.

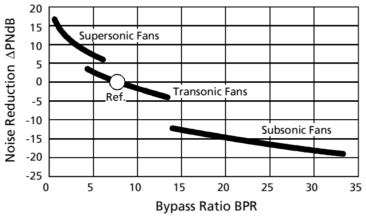

Figure 5 Potential of noise reduction by increasing the bypass ratio.

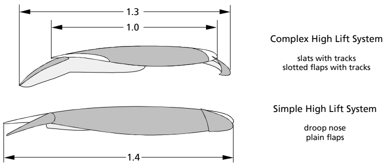

Figure 6 Two high lift systems having similar maximum lift capabilities.

a) UHBR engines, upper surface blowing.

b) fan shielded by wings, high wing.

c) fan shielded by wings, low wing.

d) buried engines, low wing.

Figure 7 Several possible configurations for a *Green 24h Aircraft*.