Green Freighter

development of an eco-friendly freighter at HAW Hamburg

DIPL.-ING. KOLJA SEECKT; PROF. DR.-ING. DIETER SCHOLZ, MSME
Department of Automotive and Aeronautical Engineering, Hamburg University of Applied Sciences

Prof. Dr.-Ing. Dieter Scholz graduated in mechanical engineering at Purdue University Lafayette and at University Hannover. He worked at Airbus and TU Hamburg-Harburg and taught at Queen's University Belfast. Since 1999 he has been a professor at Hamburg University of Applied Sciences.

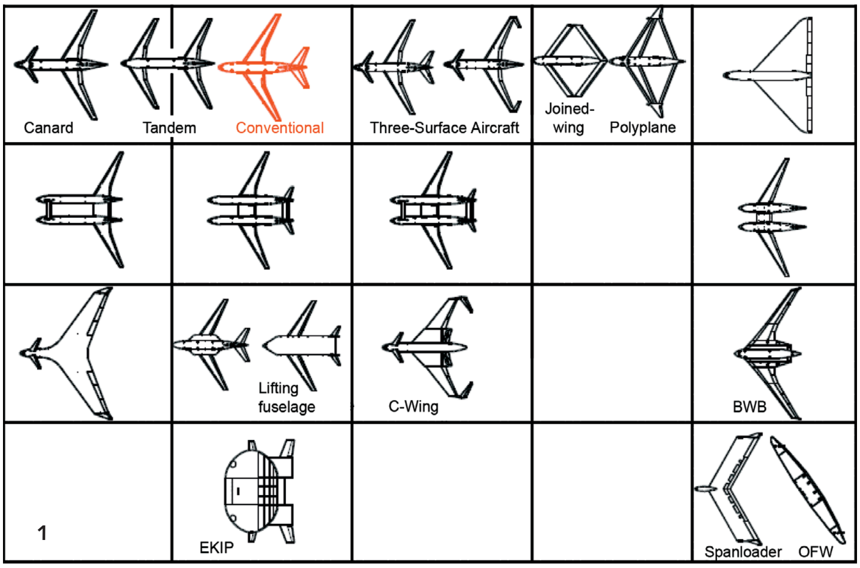
» "Elegant", "quiet", or "green" are not normally catchwords associated with cargo aircraft. In fact, discarded passenger aircraft that have been converted for a second life as a freighter are the first thought to cross one's mind: robust workhorses, often the last of their kind at European airports. But for these aircraft, the air is getting thinner. Nighttime and noise restrictions, rising fuel prices and the coming emission-related taxes are increasing the pressure on logistics companies to operate more modern aircraft. Today, brand new cargo aircraft are already available and in operation. Others, like the Boeing B747-8F or the Airbus A380-800F, are about to follow to meet the fast-growing demand for new freighter aircraft. The size of the world freighter aircraft fleet is expected to double to 4000 aircraft by 2025. This is the tentative date for the entry into service of the Green Freighter, which is the subject and title of a current joint aircraft design research project under HAW leadership on environmentally friendly and economic aircraft operation.

This research includes technical aspects such as low fuel consumption, future fuels (liquid hydrogen [LH_2], synthetic fuels, biofuel), low noise levels, low emissions (CO_2, NO_x, . . .), and low operating costs (zero-pilot operation, little or no environmental control system). The project was launched at the end of 2006 and has a duration of three years. HAW's partners in this project are the Institute of Aircraft Design and Lightweight Structures (IFL) at Technical University of Braunschweig (TUBS), Airbus' Future Projects Office (FPO), and Bishop GmbH. The aim of the project is to research unconventional cargo aircraft configurations and to compare these to conventional ones.

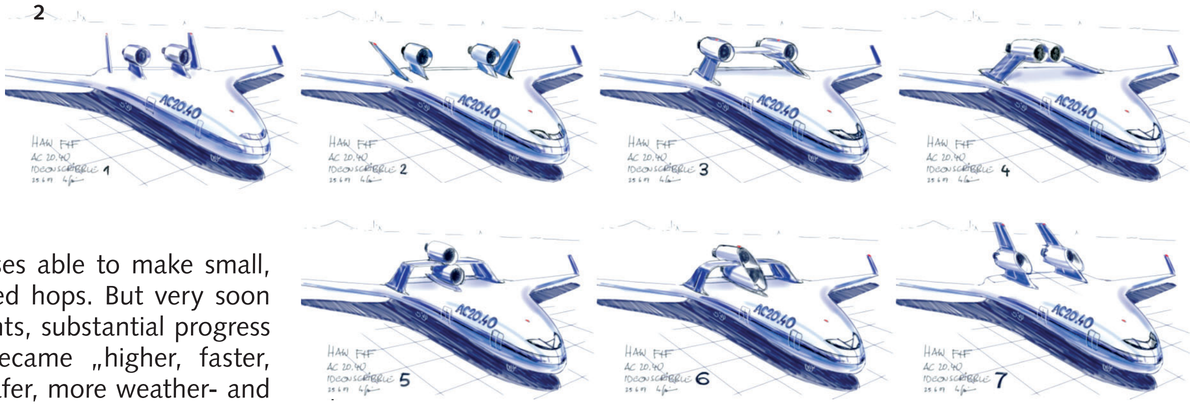
Unconventional Configurations: Practically all of today's transport aircraft have the conventional configuration, or tail-aft as it is also called. It is defined by three main features: a fuselage which accommodates the payload, a wing attached to the fuselage that produces the lift, and an empennage, also called a tailplane or just a tail, at the aft end of the fuselage for stability and control.

Any aircraft configuration that differs from this in one or more features is unconventional. Unconventional aircraft may be grouped as illustrated in **Figure 1**. The first row depicts aircraft with an arrangement of wing(s) and tail(s) other than the described configuration: canard, tandem or biplane, three-surface, joined-wing, and delta-wing. The second row shows aircraft with more than one fuselage: twin- or multi-fuselage. The third row illustrates aircraft merging fuselage and wing: lifting fuselage and blended wing body (BWB). The fourth row displays aircraft with no extra fuselage but only a wing (with or without tails): flying wing, oblique flying wing (OFW), and EKIP (Russian acronym for „ecology and progress"; flying wing with a low aspect ratio; also see http://www.ekip-aviation-concern.com). The columns indicate groups of different arrangements of one, two or three lifting and control surfaces.

But why look at new configurations at all? Today's aircraft are a safe and reliable means of transportation, and over the last couple of years flying has become very cheap, particularly due to the launch of many low-cost airlines. Flying is often not only the fastest and safest way of traveling inside Europe, but also the cheapest. What are the driving factors that justify the huge efforts currently underway to research and develop new aircraft concepts and technologies?



1 Aircraft Configuration matrix [6]



Considering the different types of aircraft that have been built over the course of more than one century, there have been major developments. The first flyers were homemade apparatuses able to make small, more or less controlled hops. But very soon after these initial flights, substantial progress was made. Flying became „higher, faster, further," as well as safer, more weather- and daylight-independent and more comfortable. In short, aviation became a mature technology.

In 1954, 51 years after the Wright brothers' first sustained powered flight in December 1903, the Boeing B707 was rolled out: a modern jet airliner capable of carrying more than 150 passengers on transatlantic routes at a speed of more than Mach 0.8. This aircraft may be regarded as the prototype of most of today's airliners traveling at high subsonic speeds: a pressurized fuselage with a cylindrical midsection and the empennage at its rear end, a tricycle landing gear and a swept wing carrying pylon-mounted jet engines.

In 2005, another 51 years later, the similar-looking Airbus A380 was rolled out. Nothing essential has changed, though there are two main decks and many improvements regarding noise, fuel burn, safety, passenger comfort, etc. But all of these improvements are based on internal advancements. For example, modern turbofan engines have a much higher bypass ratio, which means considerably more air is accelerated by the fan than the amount of air that passes the core engine. This, in combination with modern engine control and new materials, reduces noise, fuel burn, and the production of smoke.

Further improvements to conventional-configuration aircraft are only possible on a small scale and involve large research and development efforts. Furthermore, there are still high aims that need to be achieved in order to tackle the demands of the continual growth in air traffic. Particularly in light of global warming and other current environmental and social demands, the calls are getting louder for sustainable air traffic and green aircraft.

In 2001, the major European stakeholders in aviation, including the European Commission, national ministries, research agencies, and aircraft and engine manufacturers, formulated a vision for the European air transport system: Vision 2020. Vision 2020 sets several goals to be achieved by 2020 in order to reach the two top-level objectives of „Responding to Society's Needs" and „Securing Europe's Global Leadership in Aeronautics."

Some of the direct goals are the reduction of accidents in air transport by a factor of 5, the ability to handle 16 million flights per year, and a 30% reduction in the cost of air transport. Other aims include a reduction of passenger waiting times at the gate to less than 15 min for short-haul and less than 30 min for long-haul flights and an improvement in punctuality. As a result, less than 5% of all flights should be delayed by 15 min or more. Last but not least, there are plans to reduce noise emissions by 50%, while CO_2 and NO_x emissions should be lowered by 50% and 80% respectively.

The development over the last decades shows that these goals cannot be achieved solely through evolutionary improvements to conventional configurations. For example, many airports have reached their maximum possible number of departing and arriving flights. The only way for many of these airports to further increase their amount of passengers is to increase the number of passengers per flight. Hence, larger aircraft are needed, but regarding size, the A380 almost sets an upper limit for conventional aircraft due to rather simple physical reasons.

When scaling up a body of any shape, the body's volume rises to the power of 3 while its surface rises only to the power of 2; this basic principle is called the square-cube law. If, for example, a cube with an edge length of 1 is scaled up to an edge length of 2, its volume rises from 1 to 8 ($2 \times 2 \times 2$), while its 6 surface areas only rise from 1 to 4 (2×2). Therefore, the weight-related pressure on the base area rises from 1 (1/1) to 2 (8/4). Transposed to aircraft design, the square-cube law says that the simple geometrical scale-up of an aircraft leads to an increased wing loading, which of course cannot rise arbitrarily for physical reasons. Some unconventional aircraft configurations, like the blended wing body, offer more potential to realize larger aircraft.

The Blended Wing Body Configuration: The blended wing body's fuselage is shaped like an airfoil and therefore contributes to the overall lift of the aircraft. Furthermore, the fuselage and wing merge smoothly into each other. The BWB's main benefits compared to the conventional ›

Dipl.-Ing. Kolja Seeckt graduated in 2006 in aeronautical engineering at Hamburg University of Applied Sciences, started working at Airbus in the same year and has been a postgraduate at the KTH in Stockholm since 2007. In 2006 he joined the Green Freighter project as a scientific assistant.

2 Sketches of different possible engine arrangements on the planned new model of HAW's AC20.40 [4]

configuration are a lighter airframe structure and improved aerodynamics.

Regarding hydrogen-powered aircraft, the BWB offers further advantages as it provides a huge internal volume. As described below, hydrogen requires about four times the storage volume for the same amount of energy as kerosene does. Conventional aircraft using gaseous fuel, such as the Tupolev Tu-155, have to sacrifice valuable volume inside their fuselage, or the hydrogen has to be carried in voluminous tanks located above the passenger compartment or in external tanks beneath the wings, as in the case of the Cryoplane project. This increases both the wetted area and the friction drag of the aircraft.

A large number of institutions are currently carrying out studies which deal with BWB aircraft design. Two of these are HAW's AC20.30 student project and the X-48B of Boeing, NASA, and the U.S. Air Force Research Laboratory (AFRL), see **Figures 2** and **3**. In general, the BWB appears to be the most probable next leap in aircraft design. However, the BWB configuration still poses some challenges that need to be solved before such an aircraft may enter into service:

- Stability and control
- Emergency passenger evacuation
- No outside-view for many/all passengers
- Maneuver accelerations at outboard seats
- Cabin pressurization
- Airport infrastructure
- Certification

Why an Unconventional Freighter Aircraft? As mentioned in the beginning, the global freighter market is a very fast-growing aircraft market. Both Boeing and Airbus expect the world freighter aircraft fleet to more than double to about 4000 aircraft by 2025 [1], [2]. Up until now, many freighter aircraft have been converted passenger aircraft. They are converted after being decommissioned as passenger aircraft, or they are newly manufactured aircraft that were originally designed as passenger versions and have been trimmed down for use as a freighter. These aircraft often bear features, safety margins, and equipment which are not needed for freighter use but have to be paid for and carried on each flight. This shows that there is a general need for dedicated freighter aircraft. Furthermore, there are inevitable facts like depleting crude oil resources and the need to reduce global emissions of CO_2 and other pollutants which also apply to air traffic. Noise reduction is another key requirement, especially for cargo aircraft, as they are most often used during the night and have to face increasing noise restrictions.

3 Boeing X-48B unmanned blended wing body demonstrator [3]

On the other hand, unconventional configurations, and first and foremost the blended wing body, reveal great prospects for economic and very effective future aircraft operation. Nonetheless, there are still challenges, especially for passenger versions, like the rectangular pressure vessel and maneuver loads on passengers on the outboard seats. Some of these key issues play little or no role for freighter aircraft. Consequently, the Green Freighter may be regarded as a means of developing a knowledge base regarding these aspects, just like the Boeing/NASA X-48B, which is also intended as a step towards a BWB freighter aircraft.

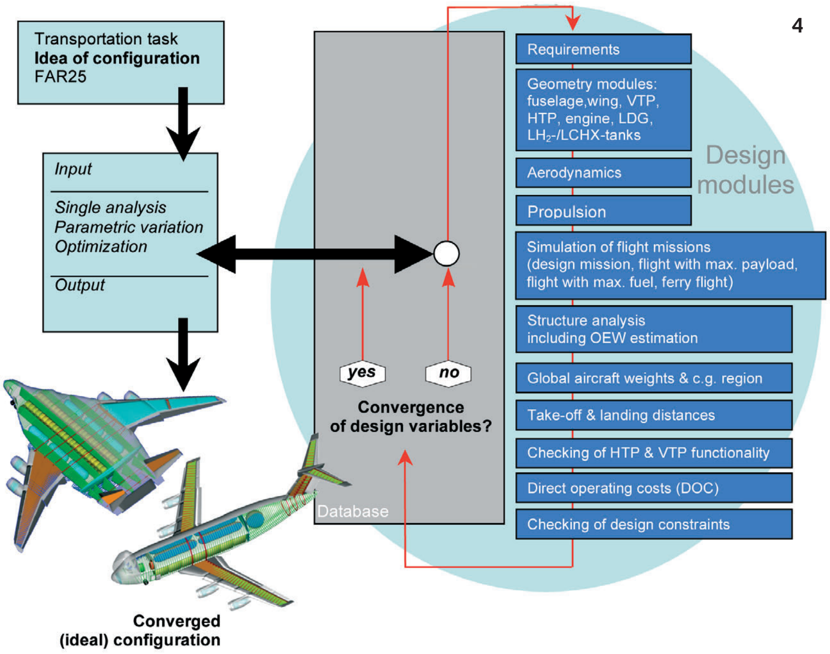
Selection of Reference Aircraft: As already mentioned, the blended wing body configuration is well suited for large aircraft. Moreover, for use as a transport aircraft, a certain size is more than just a possibility-it's a must. In order to accommodate a passenger cabin or a cargo deck, the fuselage must have a minimum thickness and be of at least passenger or cargo deck height plus some extra space for installations and structure. Of course, this is true for every fuselage on every aircraft, but in the case of the BWB, the fuselage is shaped like an airfoil and therefore has to extend to the front and especially to the rear. As a result, high freight like cargo pallets or passengers will increase the length of the BWB, whereby the length relates directly to the wing span if a desired aspect ratio is to be obtained. Ultimately, civil and military transport blended wing bodies need to and will be large aircraft. Previous investigations at the Institute of Aircraft Design and Lightweight Structures at Technical University of Braunschweig revealed a minimum size for transport BWBs in the 50 t payload class.

In April 2007, the project partners agreed on key requirements regarding range, payload, and a design cruise speed of 4800 nm (9000 km), 109 t, and Mach 0.84. These values roughly equate to the Boeing B777F, which therefore represents the conventional reference aircraft. It was decided that the comparative unconventional aircraft shall be two blended wing body aircraft, one meeting the same requirements as the conventional freighter and one using propeller engines and hence cruising at a lower speed of about Mach 0.5. The cruise speeds for both configurations are only starting figures that may and will be optimized later. Additional features will include single-engine cruise, zero-pilot operation, and the application of a hydrogen and hydrogen-biofuel hybrid propulsion system.

Liquid Hydrogen as a Fuel: First of all, hydrogen is not a real fuel in the classic definition of an energy source; in fact, it is an energy carrier comparable to a battery. Energy must be employed first to obtain hydrogen in a pure state, e.g., by means of electrolysis. This process is very energy demanding, and only a fraction of the energy previously spent can be retrieved afterwards. Nowadays, hydrogen is most often produced from natural gas because this process is much cheaper than electrolysis.

If environmentally produced, hydrogen offers the potential of extremely low emissions (zero CO_2 and very low NO_x) by lean combustion. As an alternative to kerosene, H_2 needs to be cooled down to -253 °C in order to be stored in liquid form (LH_2). Based on the same energy content, LH_2 has only one-third of the mass of kerosene but four times greater volume. Safety analyses have shown that H_2 is at least as safe as conventional hydrocarbon fuels. One of its biggest advantages is its gaseous state. In the event of a leakage and/or fire, it evaporates quickly and does not form a (burning) carpet.

Tools: The central tool in the Green Freighter project is the multidisciplinary aircraft design tool known as PrADO (Preliminary Aircraft Design and Optimization) developed by the IFL. The tool is an arrangement of subroutines that acquire and share information by means of a common data management system, see **Figure 4**. Starting with an initial description of the aircraft, the sequential design process covers all major topics that are relevant to describe the aircraft's behavior. Major modules cover the aircraft and component geometry, the aerodynamics, the flight mission simulation and the structural analysis, including weight prediction. The design process continues iteratively until convergence is achieved. The new features appearing during the Green Freighter project will be accounted for by new design modules which are being developed by the different partners in the form of subroutines. In connection with this, it will not only be possible to model an aircraft burning only one type of fuel but also different hybrid propulsion systems using, e.g., hydrogen and a kerosene-like fuel at the same time or sequentially as defined in different defueling scenarios. In addition to PrADO, HAW spread sheets are being used for the preliminary sizing of the comparative conventional aircraft. These initial aircraft descriptions will be the basis for the input entered into PrADO and will then be optimized in the same manner as described above.



4 Preliminary Aircraft Design and Optimization Program PrADO for evaluation of kerosene-/LH_2-freighters [5]

Current State: There are currently several student projects being undertaken at HAW, mostly dealing with general issues of cargo, environmental aspects of air traffic, and the installation and use of PrADO. More projects will follow soon. The topics of upcoming projects will include the improvement of an initial aircraft layout in PrADO and the calculation of propeller efficiency within PrADO. «

References

[1] Airbus S.A.S. Corporate Information: Global Market Forecast 2006-2025 [online]. 2006 [cited 2007-07-16]. Available from Word Wide Web: <http://www.airbus.com/en/corporate/gmf/index.html>.

[2] Boeing. Current Market Outlook 2007 [online]. 2007 [cited 2007-07-16]. Available from Word Wide Web: <http://www.boeing.com/commercial/cmo/freighter.html>.

[3] Boeing Media. X48-B [online]. Boeing image, negative number: SMF06_F_KOEH_X48B-0900a, digitized date: 2006-10-27 [cited 2007-08-02]. Registration required. Available from Word Wide Web: <http://www.boeingmedia.com>.

[4] Granzeier, Werner. Varianten der Triebwerksintegration eines Blended Wing Body [online]. In Scholz, Dieter. Klausur Flugzeugentwurf SS 2007. 2007 [cited 2007-07-31]. Available from Word Wide Web: <http://www.fzt.haw-hamburg.de/pers/Scholz/KlausurFE.html>.

[5] Heinze, Wolfgang. Methodisches Entwerfen von Verkehrsflugzeugen [online]. n.d. [cited 2007-07-31]. Available from Word Wide Web: <http://www.ifl.tu-bs.de/wolfgang.html>.

[6] Thramer, Bernd. Rumpf - Aspekte beim Flugzeugentwurf [online]. Hamburg University of Applied Sciences, Department of Automotive and Aeronautical Engineering, Aircraft Design Lecture Notes, 2004 [cited 2007-07-31]. Password required. Available from Word Wide Web: <http://www.fzt.haw-hamburg.de/pers/Scholz/skriptFEs/Rumpf.pdf>.

All students who are interested in projects related to the Green Freighter are welcome to have a look at http://www.fzt.haw-hamburg.de/pers/Scholz/ArbeitenAngeboten.html or to contact Prof. Scholz or Kolja Seeckt directly.