The Blended Wing Body (BWB) Aircraft Configuration

Prof. Dr.-Ing. Dieter Scholz, MSME

in cooperation with all colleagues from the aeronautical engineering section, Department of Automotive and Aeronautical Engineering, HAW Hamburg

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Die *Blended Wing Body (BWB)*

_Flugzeugkonfiguration_

Prof. Dr.-Ing. Dieter Scholz, MSME

in Zusammenarbeit mit allen Flugzeugbaukollegen des Departments Fahrzeugtechnik und Flugzeugbau
<table>
<thead>
<tr>
<th>Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Introduction</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Projects</strong></td>
</tr>
<tr>
<td><strong>Aero. Disciplines</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Air Transport System</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>AC20.30</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td><strong>Summary</strong></td>
</tr>
</tbody>
</table>
Data for this presentation was obtained from:

- Internet
- Literature
- Diplomarbeiten / Master Thesis
- Team Effort at HAW
- Airbus
- Personal Communication
Introduction
1) Conventional Configuration: "Tube and Wing" or "Tail Aft" (Drachenflugzeug)
2) Blended Wing Body (BWB)
3) Hybrid Flying Wing
4) Flying Wing

The Blended Wing Body aircraft is a blend of the tail aft and the flying wing configurations:
A wide lift producing centre body housing the payload blends into conventional outer wings.
Potential Advantages

BWB target advantages compared to todays advanced aircraft
(from different internet sources)

- reduction in weight: 10 to 15% less per pax
- better L/D: 20 to 25% better
- reduction in fuel consumption: 30% less than today
- reduction in emissions: NOX down 17%
- reduction in noise: only with engines on top
- increase of airport capacity: more than 750 pax per A/C
- reduction in DOC: down 12%

DOC: Direct Operating Costs
BWB Projects
Aerospatiale "Megajet"

Design study, 1995:
- 1000 seats,
- range 6450 NM,
- span 96 m,
- cruise at Mach 0.85.
Boeing BWB-250 ... BWB-550

250-Sitzer  350-Sitzer  450-Sitzer  550-Sitzer

Boeing: study of BWB aircraft family

Today BWBs are not a topic anymore at Boeing for civil transport!
Blended Wing Body systems studies based on BWB-450 as part of the programme Ultra Efficient Engine Technology (UEET): Boundary Layer Ingestion (BLI) inlets with Active Flow Control (AFC).

NASA/CR-2003-212670
2006: Boeing, NASA, U.S. Air Force. 21 ft span wind tunnel and flight test model. Two X-48B are built. Original: 450 seats, range 7000 NM, span 75.3 m, cruise: high subsonic.
BWB Projects

Boeing X-48B - tanker

Air Force Research Laboratory (AFRL)
BWB Projects

Boeing X-48B - tanker

X-48B prototypes were built for Boeing Phantom Works by Cranfield Aerospace Ltd.

The X-48B prototypes have been dynamically scaled to represent a much larger aircraft.
TsAGI (Russia) Integrated Wing Body (IWB)

Best configuration from comparison of four New Large Aircraft configurations based on VELA specification.

Research sponsored by AIRBUS INDUSTRIE

5th Framework Programme of the European Commission: VELA and MOB

1999 - 2002

Very Efficient Large Aircraft (VELA)

Two datum configurations for a flying wing (VELA 1 and VELA 2).

Passenger-carrying aircraft.

Multidisciplinary Optimisation of a BWB (MOB)
Freighter version.
VELA 2
6th Framework Programme of the European Commission: NACRE with PDA (VELA follow on)

WP3: Payload Driven Aircraft (VELA 3)
WP4: Flying scale model for novel aircraft configuration

2003 - 2006

National: LuFo III, K2020

BWB (VELA 2) der Uni Stuttgart
BWB Projects

VELA 3

Engines: Trent 900/15 (116" fan)

750 PAX 3 class VLR
Wing profile: MH-45
(Martin Hepperle)
$t/c = 9.85\%$, low drag, improved max. lift,
low $c_m, c/4$, proven even at Reynolds numbers below 200000.
Body profile: MH-91.

AC 20.30: geometry is based on VELA 2; student project; sponsor: "Förderkreis"
Research: Green Freighter

GF - Grüner Frachter

Entwurf untersuchungen zu umweltfreundlichen und kosteneffektiven Frachtflugzeugen mit unkonventioneller Konfiguration
Aeronautical Disciplines
Requirements:

3-class seating: 750 pax (22 / 136 / 592)
cargo capacity > 10 t

range: 7500 NM (200 NM to alternate, 30 min. holding, 5% trip fuel allowance)

high density seating: 1040 pax

cruise Mach number: 0.85
\( M_{MO} : 0.89 \)

span < 100 m
Input Parameters for Preliminary Sizing

Estimation of maximum glide ratio $E = L/D$ in normal cruise

$A$ : aspect ratio
$S_{\text{wet}}$ : wetted area
$S_W$ : reference area of the wing
$e$ : Oswald factor; passenger transports: $e \approx 0.85$

from statistics: $k_E = 15.8$

$S_{\text{wet}} / S_W$
- conv. aircraft: 6.0 ... 6.2
- BWB: $\approx 2.4$

$A$
- conv. aircraft: 7.0 ... 10.0
- VELA 2: 5.2

$E_{\text{max}} = 23.2$

$$E_{\text{max}} = k_E \sqrt{\frac{A}{S_{\text{wet}} / S_W}}$$

$$k_E = \frac{1}{2} \sqrt{\frac{\pi e}{c_f}} = 14.9$$

$$c_f = 0.003$$
Preliminary Sizing

Input Parameters for Preliminary Sizing

Estimation of maximum glide ratio $E = L/D$ in normal cruise

TsAGI for AIRBUS
Preliminary Sizing

Input Parameters for Preliminary Sizing

Estimation of maximum lift coefficient take-off and landing

\[ C_{L,max} = C_{L,0} + \frac{\partial C_L}{\partial \alpha} \alpha + \frac{\partial C_L}{\partial \eta_W} \eta_W + \frac{\partial C_L}{\partial \eta_B} \eta_B = 0.73 \]

Wind tunnel measurements of AC 20.30:

\[ C_{L,0} = 0 \]
\[ \frac{\partial C_L}{\partial \eta_W} = 0.22 \]
\[ \frac{\partial C_L}{\partial \eta_B} = 0.43 \]
\[ \frac{\partial C_L}{\partial \alpha} = 2.5 \]
\[ \alpha = 12^\circ \]
\[ \eta_W = 18^\circ \]
\[ \eta_B = 18^\circ \]
Assumptions:

OEW / MTOW = 0.5

LOFTIN: 0.52 (T/W!)  A380: 0.49  VELA 2: 0.55 → 0.48

SFC = 1.4 mg/(Ns)

latest technology assumed (GEnx)

approach speed = 165 kt

mass of pax and luggage

for long distance flying: 97.5 kg per pax

Given:

Wing Area: 1923 m²
VELA 2

Sizing Results:

$L/D$ during 2. segment: 17.0 (higher than conv. due to small lift coefficient and small drag).
$L/D$ during missed approach: 11.0 (normal, because landing gear drag dominates, FAR!)
$V / V_{md} = 1.09$ (normal: $V / V_{md} = 1.0 \ldots 1.316$) $\Rightarrow E = 22.8$
lift coefficient cruise: 0.25
trust to weight ratio: 0.28 (value is slightly high for 4-engined A/C, reason: TOFL and $C_L$)
wning loading: 260 kg/m$^2$ (very low for passenger transport, due to low lift coefficient)
Initial Cruise Altitude (ICA): 38400 ft (= 11.7 km)
load: 83000 kg
MTOW: 501000 kg (VELA 2: 691200 kg)
Wing Area: 1923 m$^2$ (VELA 2: 1923 m$^2$ - forced to fit)
MLW: 366000 kg
OEW: 251000 kg (VELA 2: 380600 kg)
Fuel: 167000 kg (VELA 2: 278200 kg ?)
Thrust: 344 kN (for each of the four engines)
Aerodynamics

AC20.30: CFD with FLUENT

Diplomarbeit: H. Brunswig

![Graph showing lift coefficient vs. angle of attack (α)]
Aerodynamics

AC20.30: CFD with FLUENT

Stalls can easily be handled
Usable lift up to AOA of 12°
At 22° AOA:
  - wings are stalled
  - body continues to produce lift but control surfaces do not deliver control power

Path lines
Aerodynamics

AC20.30: CFD with FLUENT

Gleitzahl

lift to drag ratio, L/D

angle of attack, α

Anstellwinkel

Windkanal 13 m/s
Fluent 13 m/s
Windkanal 20 m/s
Fluent 20 m/s
Aerodynamics

AC20.30: CFD with FLUENT

Engine Integration
Positioning of the CG on the Mean Aerodynamic Chord (MAC) for required static margin is achieved in conventional design by shifting the wing with respect to the fuselage. This approach is not possible in BWB design!

\[ x_{\text{LEMAC}} = x_{\text{fg}} - x_{\text{cg}} + \frac{m_{\text{wg}}}{m_{\text{fg}}} \left( x_{\text{wg}} - x_{\text{cg}} \right) \]
Static Longitudinal Stability for VELA Configurations

![Graph showing static margin vs. sweep of center wing](image)

**Static Margin bei MTOW**

**Static Margin bei MZFW**

**VELA 1**

**VELA 2**
Weight Saving Potential of BWB Configurations

Less bending moments in a flying wing or BWB

Helios - example of an extreme span loader with distributed propulsion (NASA / AeroVironment, Inc.)

BWB study with distributed propulsion (Virginia Polytechnic)
VELA 2 - Basic Structural Layout

- Inner Shell made out of four quasi-cylindrical segments
- Intermediate double shell contour at the Leading Edge
- Regular double shell contour cut by frame parallel to Leading Edge

Parameters:
- Frame height: 898.4 mm
- Frame height: 600 mm
- R = 6000 mm
- Min. frame height: 200 mm
VELA 2 - Cabin

Ribs
VELA 2 - Wing Integration
VELA 2 - Doors

Door cut-outs

Side door integration
## Mass Prediction

### VELA 2

<table>
<thead>
<tr>
<th>Weight Chapter</th>
<th>F. Bansa (kg)</th>
<th>T. Kumar Turai (kg)</th>
<th>T. Kumar Turai (FEM) (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 Structure</td>
<td>234669</td>
<td>253529</td>
<td>210070</td>
</tr>
<tr>
<td>20 Power Units</td>
<td>37731</td>
<td>36603</td>
<td>-&gt;</td>
</tr>
<tr>
<td>30/40 Systems</td>
<td>19795</td>
<td>23302</td>
<td>-&gt;</td>
</tr>
<tr>
<td>50 Furnishings</td>
<td>35313</td>
<td>27588</td>
<td>-&gt;</td>
</tr>
<tr>
<td>60 Operator Items</td>
<td>35313</td>
<td>39578</td>
<td>-&gt;</td>
</tr>
<tr>
<td>OWE</td>
<td>362820</td>
<td>380600</td>
<td>337141</td>
</tr>
<tr>
<td>OWE/MTOW</td>
<td>0.525</td>
<td>0.551</td>
<td>0.488</td>
</tr>
<tr>
<td>Loftin</td>
<td>0.521</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marckwardt</td>
<td>0.462</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A380-800</td>
<td>0.501</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A340-600</td>
<td>0.475</td>
<td></td>
<td></td>
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</tbody>
</table>

Taken for Preliminary Sizing: 0.500

**Result:** The BWB design does not significantly improve the OWE/MTOW ratio!

**Latest News:** One-shell layout can lead to OWE/MTWO = 0.44 ... 0.46!
VELA 2 - System Installation Areas

Steps in system integration:
1.) System diagram
2.) Sizing
3.) Routing & ducting
VELA 2 - ATA 21 - Positioning of the Mixing Unit

Steps in system integration:
1.) System diagram
2.) Sizing
3.) Routing & ducting

Air Generation Unit is positioned in the transition wing.

Alternative position (above cabin) of the Mixing Unit eliminates riser ducts.

Ducts for recirculation air.
Air circulation. **Recirculation requires ducts.**

**Low pressure air connector** and duct to mixing unit.

**Duct for emergency air.**
VELA 3 - Landing Gear Integration

Twin tandem (Bogie) nose landing gear.
Two retraction mechanisms.

Two twin tri-tandem (6-wheel) main landing gears on each side.
Special retraction mechanism.

MLG wheel spacing only 11.4 m due to rib location
(requirement: wheel spacing < 16 m)

Rule of Thumb: 30 t / MLG wheel
=> max. MTOW: 720 t
Air Transport System
A cargo loading vehicle drives in between the MLGs. Cargo loading from below with lifting system. 

Catering from the right.

Water / waste servicing on trailing edge left side.
Ground Handling

VELA 2

Cargo loading from the right.

Catering from the right.

Boarding through three bridges.

Fuel truck under right wing.

Towing truck.
This modification of VELA 1 allows also evacuation after ditching (into the water) through over wing doors.

VELA 1, 2, 3 standard configuration can not be certified, because doors will be submerged.
Wake Turbulence - Fundamentals

Wing tip vortices cause induced drag, $D_i$.

Wake turbulence cause a danger to following aircraft.

The initial strength of the wake turbulence is based on basic aircraft parameters:

$$P_{wake} = D_i V = \frac{2g^2}{\pi A e} \frac{m(m/S)}{\rho V}$$

Decay of wake turbulence from a conventional wing and a C-wing.

C-Wing-BWB:
Wake Turbulence - Comparison

\[
\frac{P_{\text{wake,BWB}}}{P_{\text{wake,A380}}} \approx \frac{A_{A380}}{A_{\text{BWB}}} \cdot \frac{m_{\text{MTO,BWB}}}{m_{\text{MTO,A380}}} \cdot \left(\frac{m}{S}\right)_{\text{BWB}} = \frac{7.53}{4.83} \cdot \frac{700}{560} \cdot \frac{341}{663} = 1.00
\]

with BWB-Data from VELA 3. Result: no major problems expected.

Wake Turbulence - Separation

**IFR Minimum Separation Rules on Approach (nm)**

<table>
<thead>
<tr>
<th>Leading aircraft type(^a)</th>
<th>Small</th>
<th>Large</th>
<th>Heavy</th>
</tr>
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<tbody>
<tr>
<td>Small</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Large</td>
<td>4.0</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Heavy</td>
<td>6.0</td>
<td>5.0</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Source: FAA [1978]

\(^a\) Small: aircraft weighing no more than 12,500 lb. (5,625 kg)
Large: aircraft weighing more than 12,500 lb. (5,625 kg) and less than 300,000 lb. (135,000 kg)
Heavy: aircraft weighting in excess of 300,000 lb. (135,000 kg)

A380 interim value: 10 NM
VELA 1 - Cabin Layout

Diplomarbeit: S. Lee

Vertical acceleration for pax on outer seats.
Interior Design

Double Deck BWB
Interior Design

Underfloor Usage - Artificial Windows
Interior Design

BWB Center Wing Shapes from Inside
# Test Flights

## AC20.30 Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Scale</td>
<td>1:30</td>
</tr>
<tr>
<td>Span</td>
<td>3.24 m</td>
</tr>
<tr>
<td>Length</td>
<td>2.12 m</td>
</tr>
<tr>
<td>MTOW</td>
<td>12.5 kg</td>
</tr>
<tr>
<td>Engines</td>
<td>2 electric driven fans</td>
</tr>
<tr>
<td>Thrust</td>
<td>2 x 30 N</td>
</tr>
<tr>
<td>Power input</td>
<td>2 x 1400 W</td>
</tr>
</tbody>
</table>
Test Flights

Recorded Parameters
barometric height, two temperatures
voltage, current
air speed, engine RPM
GPS-Coordinates (=> position and ground speed)
angle of attack, side slip angle
3 accelerations, 3 rotational speeds
position of 4 control surfaces
turn coordinator, ping, airborne camera picture

Gyrocube
Wind Tunnel Tests
AC20.30

CFD surface stream lines (left)
Fluorescent paint in wind tunnel (right).

Lift coefficient dependent on flap angle (wing) and angle of attack.
Summary
### Summary

BWB advantages compared to todays advanced aircraft
*(checked now again, at the end of presentation):*

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Description</th>
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<tr>
<td>Reduction in weight</td>
<td>single shell required. In this case: 8% better</td>
</tr>
<tr>
<td>Better L/D</td>
<td>10 to 15% better (not apparent from AC20.30)</td>
</tr>
<tr>
<td>Reduction in fuel consumption</td>
<td>yes, due to L/D</td>
</tr>
<tr>
<td>Reduction in emissions</td>
<td>yes</td>
</tr>
<tr>
<td>Reduction in noise</td>
<td>only with engines on top</td>
</tr>
<tr>
<td>Increase of airport capacity</td>
<td>yes, more than 750 pax per A/C</td>
</tr>
<tr>
<td></td>
<td>(probably no problems with wake turbulence)</td>
</tr>
<tr>
<td>Reduction in DOC</td>
<td>down ??% (mostly due to scale effect)</td>
</tr>
</tbody>
</table>

**But:**

<table>
<thead>
<tr>
<th>Problem</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open certification problems</td>
<td>unstable configuration (?), ditching</td>
</tr>
<tr>
<td>Open design problems</td>
<td>rotation on take-off, landing gear integration, ...</td>
</tr>
</tbody>
</table>
Future?

Box Wing Aircraft

Airport 2030