Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

AeroLectures
HAW Hamburg, 15.01.2026

New Blended Wing Body (BWB) Aircraft –

Is 50% Fuel Reduction a Credible Claim?

Prof. Dr.-Ing. Dieter Scholz, MSME, FRAeS

https://doi.org/10.5281/zenodo.18377808

Flight Test & Music, BWB, HAW Hamburg (2006)

https://purl.org/aerolectures/2026-01-15/Videos

Potential Advantages

According to publications, the BWB will have many advantages.

Can the BWB live up to its promise?

reduction in weight ?
better L/D ?
reduction in fuel consumption ?
reduction in emissions ?
reduction in noise ?
increase of airport capacity ?
reduction in Direct Operating Costs, DOC ?

Motivation

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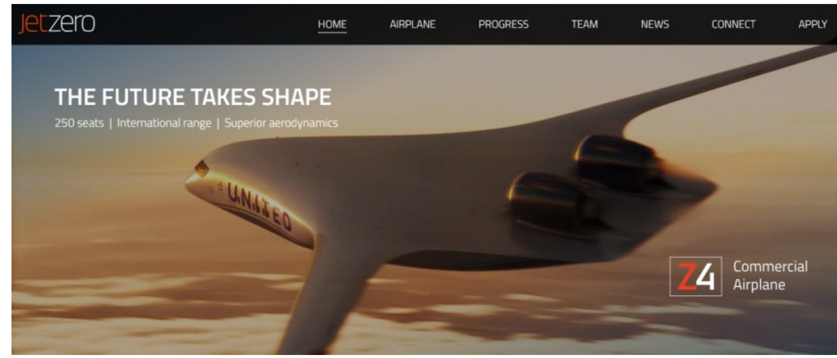
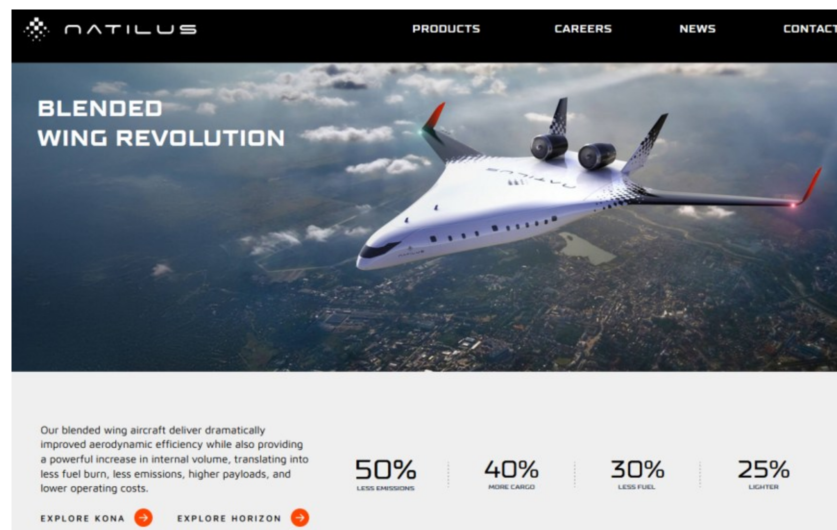
JetZero



Natilus



Outbound Aerospace: insolvency

Outbound Aerospace

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Outbound Aerospace had hoped to launch a radical new 200 to 250-seat blended-wing airliner in the 2030s. With a 52 m wingspan that might burn up to 50% less fuel. Insolvency end of 2025. Company had raised $1.3 million USD.

https://www.linkedin.com/company/outbound-aero
BBC: https://perma.cc/JDP8-WGYS

The team.

Demonstrator plane STeVE flew March 2025.

https://perma.cc/87S4-5WS9

https://perma.cc/QRK5-KGAZ

About JetZero

JetZero, co-founded in 2020 by start-up veteran Tom O'Leary and aerospace legend Mark Page, is developing the world's first commercial all-wing airplane. With up to 50% better fuel efficiency and lower carbon emissions compared to existing commercial airliners, JetZero's Z4 will offer the aviation industry a clear path to achieving its 2050 net-zero goals while also elevating the passenger experience. Working alongside the US Air Force, NASA, and the FAA, and backed by decades of investment and research into blended wing technology. JetZero looks to enter commercial service in the early 2030s.

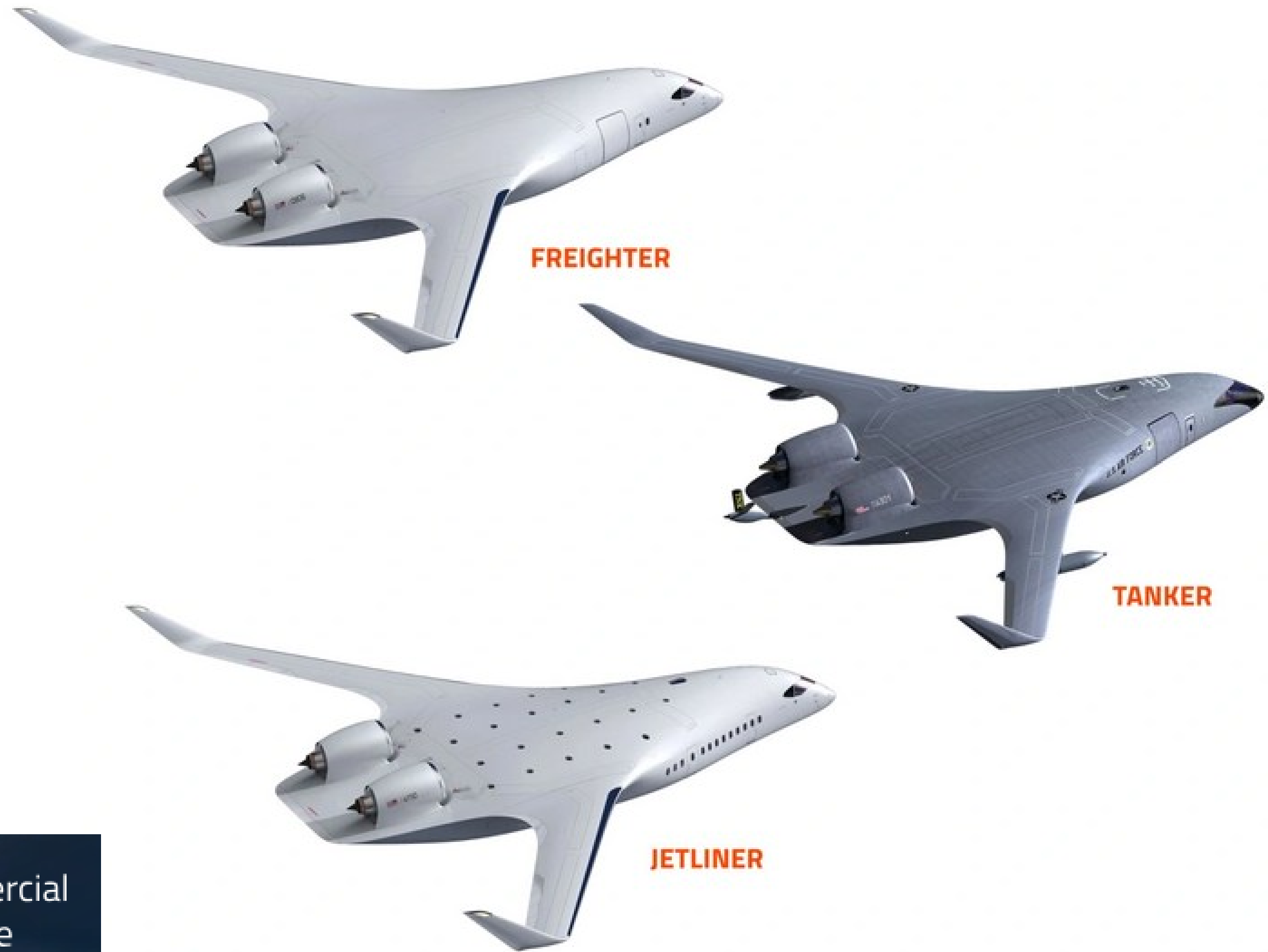
jetzero MENU

JetZero Raises $175 Million in Series B Financing to Transform Aircraft Innovation

The new capital will accelerate the development of JetZero's full-size Demonstrator, a prototype designed to achieve at least 30% improved aerodynamics compared to traditional tube and wing aircraft. The Demonstrator is on track for its first flight in 2027. Use of conventional jet engines: Pratt & Whitney PW2040.

https://perma.cc/WLZ6-N7P9, https://en.wikipedia.org/wiki/JetZero

JetZero



https://www.jetzero.aero

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A whole new experience within the existing airline and airport infrastructure

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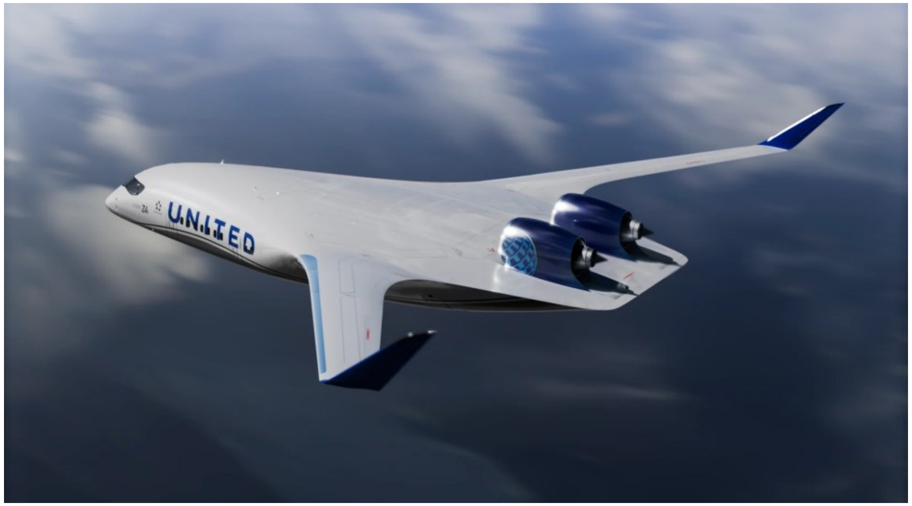

https://www.jetzero.aero

https://www.af.mil/News/Photos/igphoto/2003282050

https://www.jetzero.aero

(c) airliners.de, https://perma.cc/8QUG-4DDX

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https://www.af.mil/News/Photos/igphoto/2003282050

BWB and Stealth

Blended wing body configurations are inherently well-suited to low radar signature, but:

- Stealth comes from **shaping, alignment, materials, and integration**
- BWB is an *enabler*, not a guarantee
- When stealth is a top priority, **BWB is arguably the best possible starting point**

Why BWB *helps* radar stealth

1. Fewer radar-reflecting features

Radar cross-section (RCS) is dominated by **discontinuities**:

- Wing–fuselage junctions
- Vertical tails
- Sharp corners and cavities

A BWB:

- Eliminates the classic wing–fuselage intersection
- Often removes vertical tails entirely
- Uses continuous curvature

This directly reduces **specular radar reflections**.

2. Engine integration is critical

BWB designs often place engines:

- On top of the airframe (good for shielding)
- Or embedded near the trailing edge

However:

- Intake lips
- Fan face exposure
- Exhaust plume shape

...can dominate RCS if not treated correctly.

ChatGPT

JetZero

Mark Page

Founder, CTO

Mark has been designing airplanes for more than four decades. At Douglas Aircraft, Mark worked on the MD-92 Propfan, and Supersonic High-Speed-Civil-Transport, and the MD-90 Jetliner, and finally as Technical Program Manager for the NASA/Douglas Blended-Wing-Body Program where he co-invented the modern BWB with Blaine Rawdon, and Bob Liebeck.

In 2012 Mark co-founded DZYNE Technologies where he designed a BWB bizjet. In 2021, Mark spun-out the BWB project from DZYNE to form JetZero with co-founder and CEO Tom O'leary.

PRIOR EXPERIENCE

BOEING McDONNELL DOUGLAS Swift Engineering DZYNE TECHNOLOGIES

IT ALL STARTS WITH EFFICIENCY

The low-drag, lightweight, all-wing Z4 uses up to 50% less fuel than today's commercial jets.

JetZero

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31st Congress of the International Council of the Aeronautical Sciences

Belo Horizonte, Brazil; September 09-14, 2018

SINGLE-AISLE AIRLINER DISRUPTION WITH A SINGLE-DECK BLENDED-WING-BODY

M. A. Page, VP and Chief Scientist
E. J. Smetak, Program Manager
S. L. Yang, Program Manager
DZYNE Technologies Incorporated, Irvine, California 92618, USA
Key Words: Blended Wing Body, BWB, Efficient, Quiet, Safe, Comfort

The findings for an 800 passenger BWB flying 7,000 nmi were impressive:

Takeoff Gross Weight	15.2% less
Lift to Drag Ratio (L/D)	20.6% higher
Fuel-Burn	27.5% lower
Empty Weight	12.3% lower
Thrust Required	27% lower
Operating Cost	13% lower

https://www.icas.org/icas_archive/ICAS2018/data/papers/ICAS2018_0390_paper.pdf

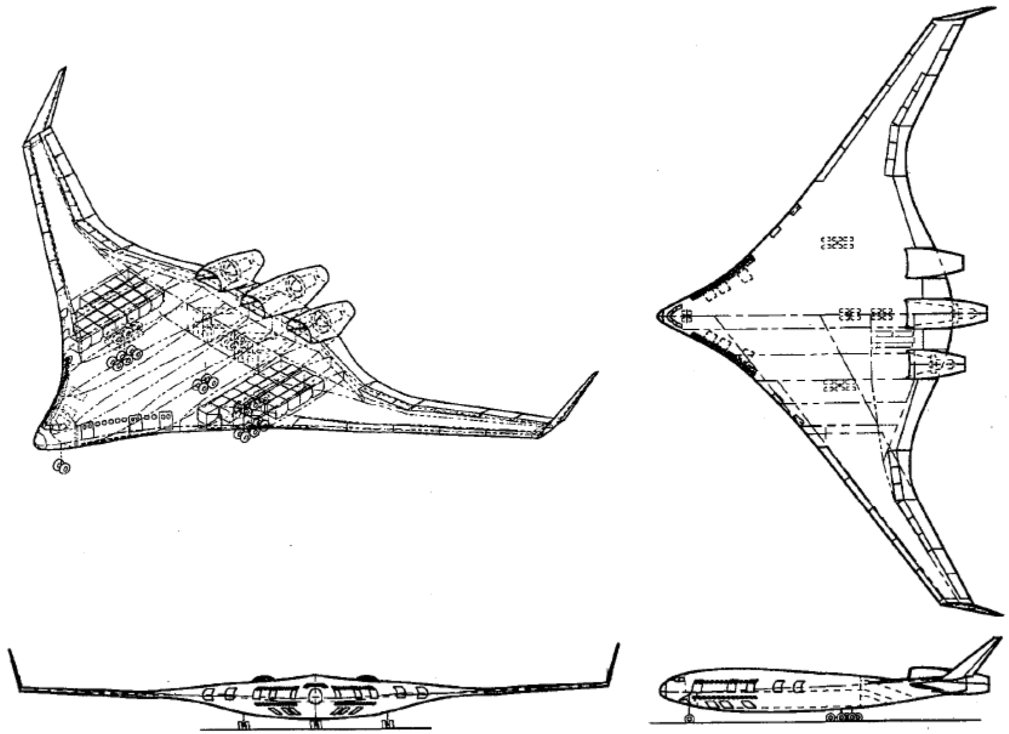

Figure 12. Current BWB configuration.

BLENDED-WING-BODY SUBSONIC COMMERCIAL TRANSPORT
AIAA 98-0438
R. H. **Liebeck**, M. A. **Page**, and B. K. **Rawdon**
The Boeing Company, Long Beach, CA, USA
36th Aerospace Sciences Meeting & Exhibit, January 12-15, 1998 / Reno, NV, USA
https://doi.org/10.2514/6.1998-438, https://www.researchgate.net/publication/245588156

Robert H. Liebeck

Add languages

Article Talk Read Edit View history Tools

From Wikipedia, the free encyclopedia

Robert H. Liebeck	
Occupation	Aircraft engineer
Known for	Aircraft designs Liebeck airfoils

Robert Hauschild Liebeck was an American aerodynamicist,[1] professor[2] and aerospace engineer. Until retiring from his position as senior fellow[3] at the Boeing Company[4] in 2020,[3] he oversaw their Blended Wing Body ("BWB") program.[5][6] He was a member of the National Academy of Engineering since 1992, where he was an AIAA Honorary Fellow, the organization's highest distinction.[4][7][8] He is best known for his contributions to aircraft design[7] and his pioneering airfoil designs known as the "Liebeck Airfoil".[9] After retirement he remained active in the aviation industry, most recently at the BWB startup JetZero where he served as a technical advisor[10], and continued to teach aerospace courses at University of California, Irvine. Liebeck passed away on January 13, 2026.

https://en.wikipedia.org/wiki/Robert_H._Liebeck, 2026-01-15

JetZero

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AIAA-98-0438

BLENDED-WING-BODY SUBSONIC COMMERCIAL TRANSPORT

R. H. Liebeck*, M. A. Page†, and B. K. Rawdon‡
The Boeing Company, Long Beach, California

Abstract

The Blended-Wing-Body (BWB) airplane concept represents a potential revolution in subsonic transport efficiency for large airplanes. NASA has sponsored an advanced concept study to demonstrate feasibility and begin development of this new class of airplane. In this study, 800 passenger BWB and conventional configuration airplanes have been compared for a 7000 nautical mile design range, where both airplanes are based on technology for a 2020 entry into service. The BWB, shown in Figure 1, has been found to be superior to the conventional configuration in all key measures.

The BWB advantage results from a double deck cabin that extends spanwise providing structural and aerodynamic overlap with the wing. This reduces the total wetted area of the airplane and allows a long wingspan to be achieved, since the deep and stiff centerbody provides efficient structural wingspan. Further synergy is realized through buried engines that ingest the wing's boundary layer, and thus reduce effective ram drag. Relaxed static stability allows optimal span loading and obviates the need for a tail. An outboard leading-edge slat is the only high-lift system required. Resulting improvements are:

Fuel Burn	27% lower
Takeoff Weight	15% lower
Operating Empty Weight	12% lower
Total Thrust	27% lower
Lift/Drag	20% higher

https://doi.org/10.2514/6.1998-438, https://www.researchgate.net/publication/245588156

Selected from Google Scholar

Blended-wing-body subsonic commercial transport

R **Liebeck**, M Page, B Rawdon - 36th AIAA aerospace sciences meeting …, 1998 - arc.aiaa.org

… Abstract The **Blended-Wing-Body** (**BWB**) airplane concept … In this study, 800 passenger **BWB** and conventional configuration … The **BWB**, shown in Figure 1, has been found to be superior …

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Design of the **blended wing body** subsonic transport

RH Liebeck - Journal of aircraft, 2004 - arc.aiaa.org

The Boeing **Blended-Wing–Body** (**BWB**) airplane concept … In this initial study, 800-passenger **BWB** and conventional … Results showed remarkable performance improvements of the **BWB** …

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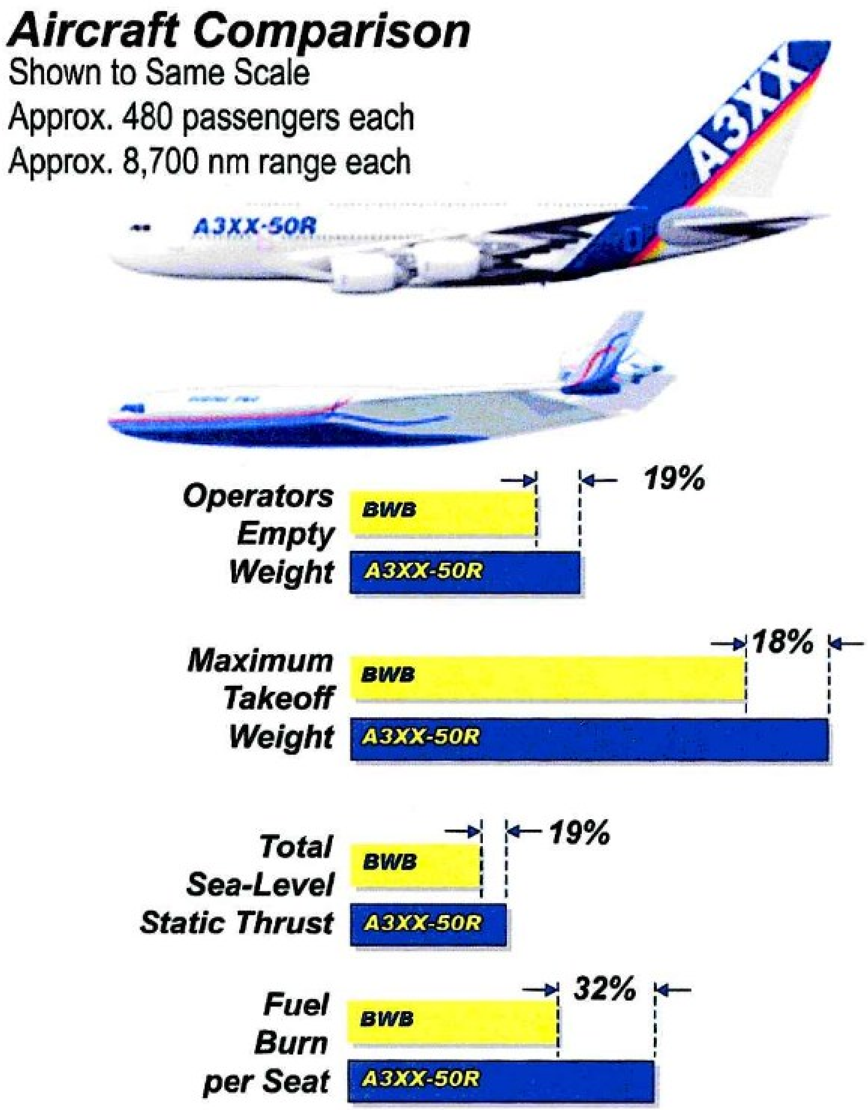
JetZero



LIEBECK, Robert H., 2004. **Design of the Blended Wing Body Subsonic Transport**. Journal of Aircraft, vol. 41, no. 1, pp. 10-25. https://doi.org/10.2514/1.9084, https://bit.ly/3LBZvgy

Liebeck meets HAW Hamburg

Hochschule für Angewandte Wissenschaften Hamburg
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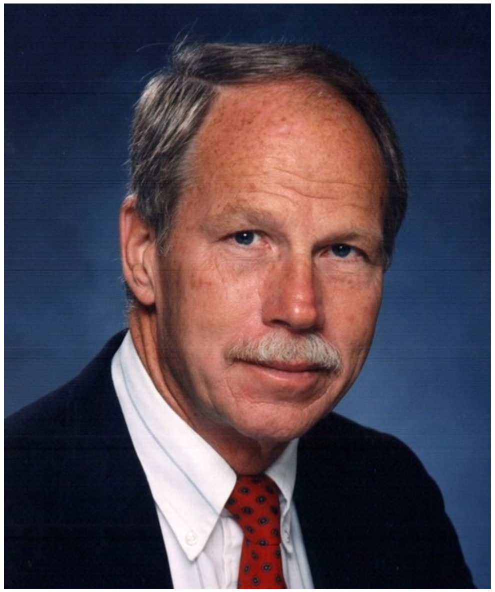


Bob Liebeck
https://news.mit.edu/2010/liebeck-Guggenheim
https://www.icas.org/icas_archive/ICAS2006/PAPERS/807.PDF

International Council of the Aeronautical Sciences

25TH INTERNATIONAL CONGRESS OF AERONAUTICAL SCIENCES

3 - 8 September 2006, Hamburg, Germany

25th Congress of International Council of the Aeronautical Sciences, 3 - 8 September 2006, Hamburg, Germany
Paper ICAS 2006-3.7.1

THE AC20.30 BLENDED WING BODY CONFIGURATION: DEVELOPMENT & CURRENT STATUS 2006

A. Schmidt, H. Brunswig
HAW Hamburg, Germany

https://www.icas.org/icas_archive/ICAS2006/PAPERS/178.PDF

Keywords: BWB, CFD, flight testing, wind tunnel

The AC20.30 Blended Wing Body configuration was conceptualized and built at the HAW Hamburg to study next generation civil transports. New cabin concepts are being developed. The aerodynamics are studied on a 3.24m span flying model by comparison of data gained from CFD, wind tunnel and flight testing.

Interview: Robert Liebeck, Co-designer of Blended Wing Body (BWB) Plane

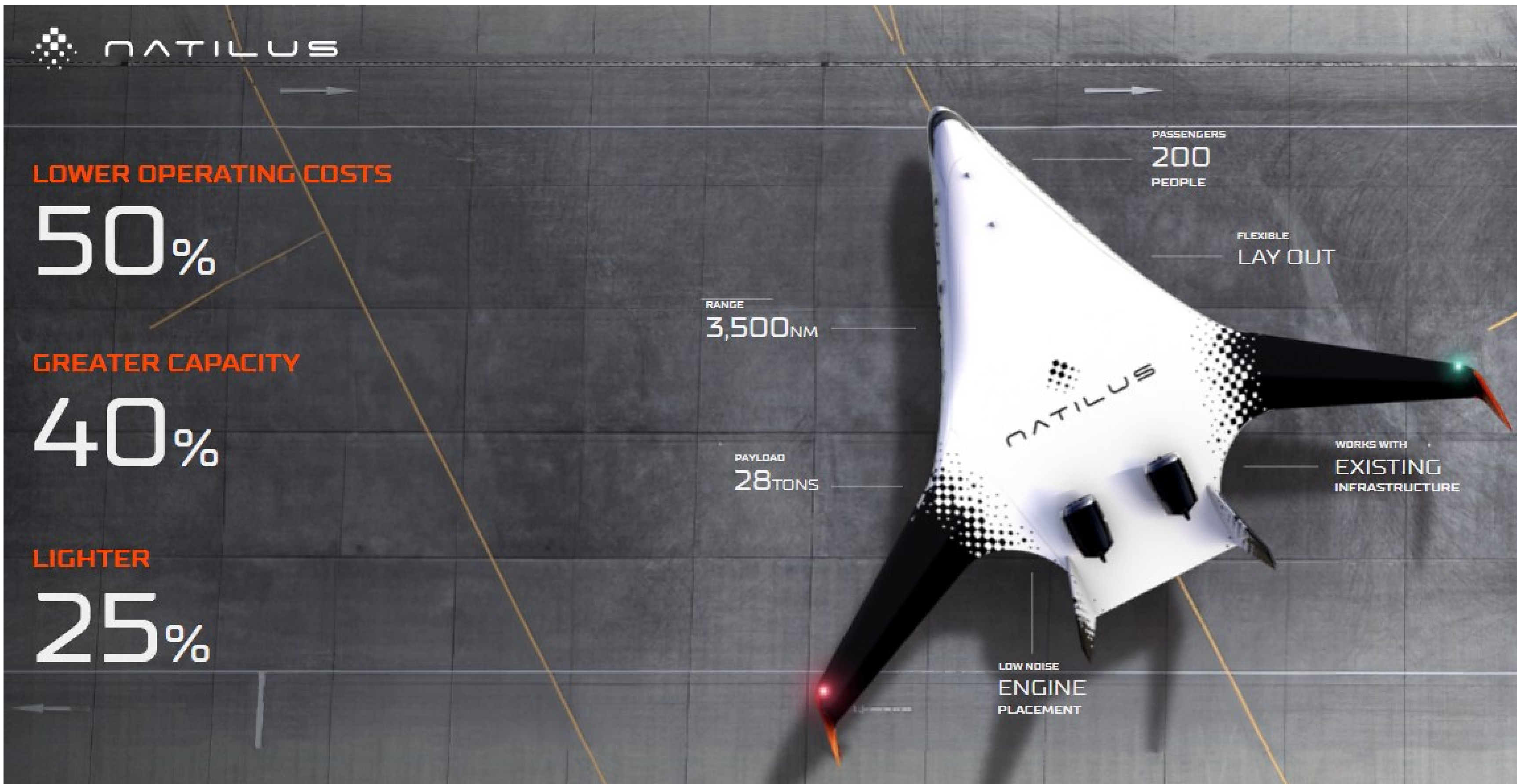
https://purl.org/aerolectures/2026-01-15/Videos

Natilus


NATILUS
REDEFINING EFFICIENCY
AND COMFORT IN AIR TRAVEL
HORIZON

Natilus


REDEFINING EFFICIENCY
AND COMFORT IN AIR TRAVEL
HORIZON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25%
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200
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3,500NM
PAYLOAD
28TONS
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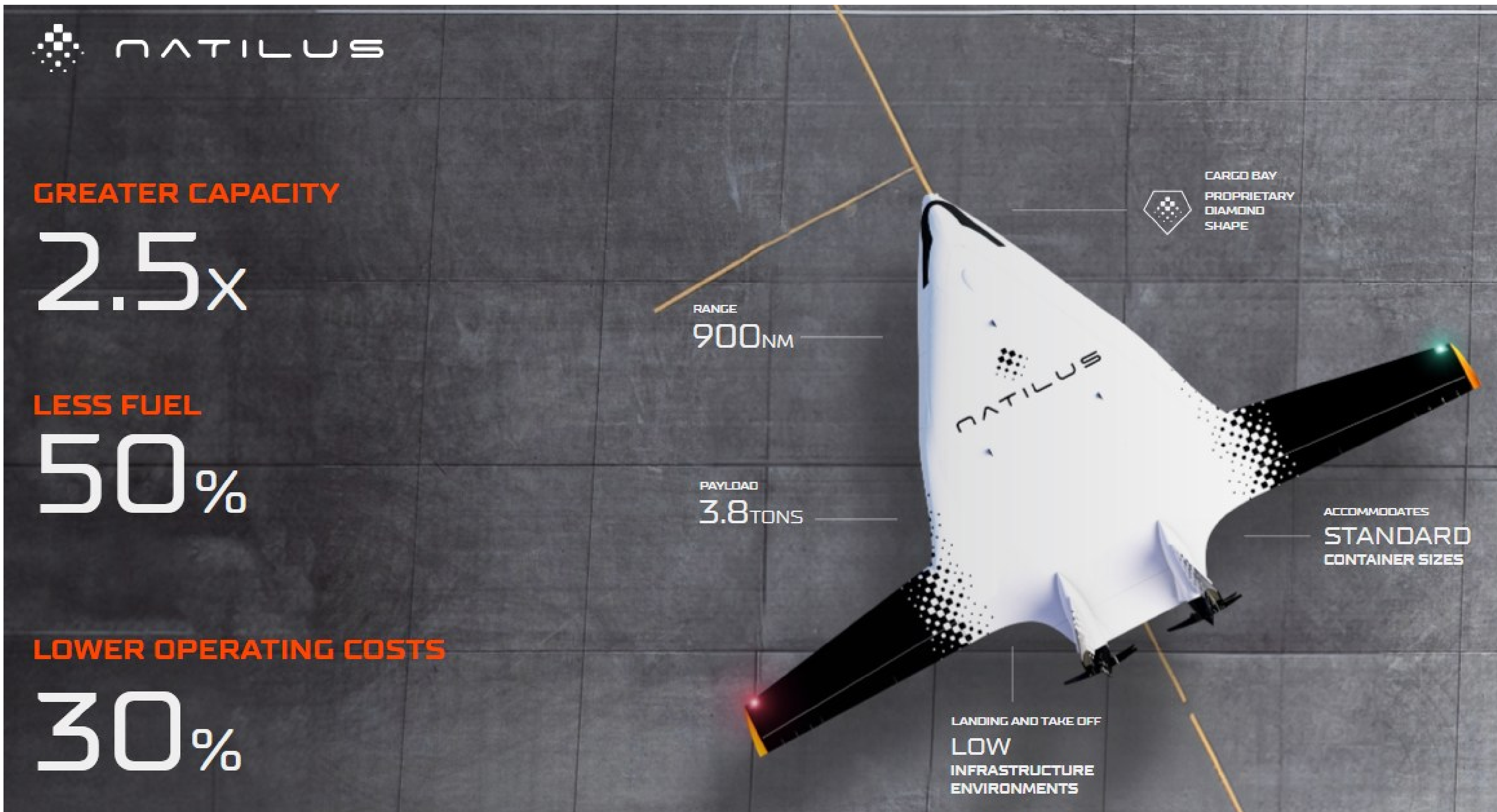
THE EVOLUTION OF
SUSTAINABLE AIR FREIGHT
KONA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LESS FUEL
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LOWER OPERATING COSTS
30%
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3.8TONS
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PROPRIETARY
DIAMOND
SHAPE
ACCOMMODATES
STANDARD
CONTAINER SIZES
LANDING AND TAKE OFF
LOW
INFRASTRUCTURE
ENVIRONMENTS
NATILUS

2006 to 2026

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Luftfahrtstandort Hamburg

Prof. Dr.-Ing. Dieter Scholz, MSME
Hochschule für Angewandte Wissenschaften Hamburg

Praxis-Seminar Luftfahrt

Die Blended Wing Body Flugzeugkonfiguration

Zeit: **Donnerstag, 28.09.2006, 17:30 Uhr**
✈ Eintritt frei
✈ Keine Voranmeldung erforderlich

Veranstaltungsort: **Hochschule für Angewandte Wissenschaften Hamburg**
Berliner Tor 5 (Neubau), Hörsaal 01.12

Wir sind fasziniert von der Größe eines Airbus A380 - ein Superlativ im Passagierflugzeugbau. Gleichzeitig stellen wir uns die Fragen: Könnten Flugzeuge sinnvollerweise auch noch größer gebaut werden? Wie sieht das Flugzeug der Zukunft aus? Weltweit geht man auch in Industrie, Großforschungseinrichtungen und Hochschulen diesen Fragen nach. Dabei wird zur Zeit gerade eine Konfiguration besonders intensiv betrachtet: Die Blended Wing Body (BWB) Flugzeugkonfiguration. Basierend auf Recherchen und den eigenen Arbeiten der HAW versucht Prof. Scholz Bilanz zu ziehen und aufzuzeigen, welche Möglichkeiten aber auch Herausforderungen in der BWB Konfiguration stecken.

Kontakt:

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DGLR	Thorsten Schiek	Tel.: (040) 743 78424	hamburg@dglr.de
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DGLR/VDI	Jürgen K. A. Schulz	Tel.: (04181) 72 45	Juergen.K.A.Schulz@t-online.de
RAeS	Richard Sanderson	Tel.: (04167) 92012	rmsand@t-online.de

Eine E-Mail-Verteilerliste mit den aktuellen Ankündigungen und Informationen ist verfügbar
Bei Eintrag in die Teilnehmerliste ist der Besuch der Veranstaltungen steuerlich absetzbar

→

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ROYAL AERONAUTICAL SOCIETY HAMBURG BRANCH e.V.

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New Blended Wing Body (BWB) Aircraft – Is 50% Fuel Reduction a Credible Claim?

Prof. Dr.-Ing. **Dieter Scholz**, MSME, FRAeS, HAW Hamburg

Date: **Thursday, 15 January 2025, 18:00**
Location: **HAW Hamburg, Berliner Tor 5, Hörsaal 01.11**


Rendering of the JetZero BWB, which could be the next generation US tanker.
By US Air Force, https://www.af.mil/News/Photos/igphoto/2003282050, Public Domain

Startup companies are convinced the Blended Wing Body (BWB) configuration will revolutionize flight and will use "up to 50% less fuel than today's commercial jets" (www.jetzero.aero). The US-based companies are **JetZero** and **Natilus**. In December 2025, **Outbound Aerospace** had to shut down, running out of funding. In contrast: "Substantial fuel reduction cannot be expected for passenger aircraft" is the research result from a former **HAW Hamburg** project featuring a **flying BWB demonstrator** called AC20230 with a span of 3 m. The presentation will guide the audience through the aeronautical disciplines and show with real numbers and a few equations what to expect beyond unfounded promises and artist's impressions. However, a viable application could be a BWB tanker. Large parts of such an aircraft could remain unpressurized, and like the Northrop B2 bomber, the BWB offers low-observable (stealth) characteristics. Even more important: The U.S. Air Force needs a tanker replacement and has funds available. In 2023, the U.S. Air Force awarded a $235-million contract to JetZero to build a full-scale demonstrator by 2027 in partnership with Scaled Composites (Northrop Grumman).

HAW/RAeS	Prof. Dr.-Ing. Dieter Scholz	Tel.: 040 42875 8825	info@ProfScholz.de
RAeS	Richard Sanderson	Tel.: 04167 92012	events@raes-hamburg.de

Hamburg Aerospace Lecture Series — DGLR, HAW Hamburg, RAeS, VDI, ZAL

DGLR Bezirksgruppe Hamburg	https://hamburg.dglr.de
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VDI, Arbeitskreis L&R Hamburg	https://www.vdi.de
ZAL TechCenter	https://www.zal.aero

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Contents

Acknowledgements

Data for this presentation
was obtained from:

Internet
Literature
Diplomarbeiten / Master Theses
Team Effort at HAW Hamburg
Airbus
Personal Communication

AC20.30 Exterior Model for ILA 2002

Introduction

Design, Build, Fly, BWB, HAW Hamburg [English Commentary] (2006)

https://purl.org/aerolectures/2026-01-15/Videos

A film by Axel Bohlmann

BWB Definition

Hochschule für Angewandte
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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

Square-Cube-Law

The BWB configuration is favoured for ultra-large aircraft.

Why does physics demand a BWB?

Geometric Scaling: $V \propto l^3$ $\quad m \propto l^3$ $\quad m_{MTO} \propto l^3$

$$S_W \propto l^2$$

Landing Field Length and Approach Speed is limited:

$$\Rightarrow \frac{m_{MTO}}{S_W} = const \ \wedge m_{MTO} \propto l^3 \ \Rightarrow \ S_W \propto l^3$$

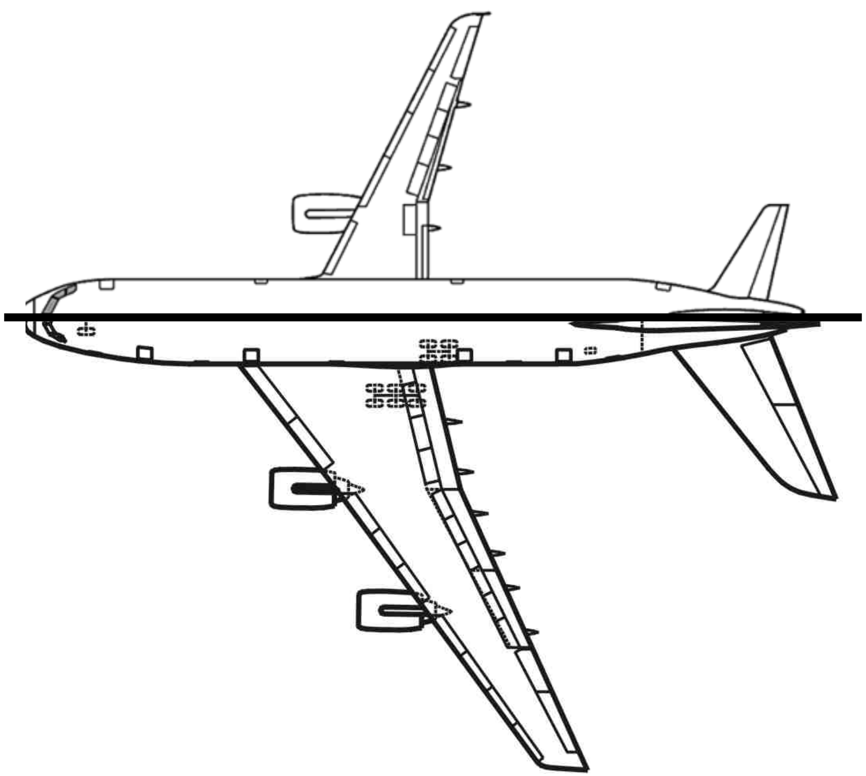
Square-Cube-Law

Square-Cube-Law

The BWB configuration is favoured for ultra large aircraft.

Why does physics demand a BWB?

$$S_W \propto l^3$$



A321 scaled to the same size as the A380.

A321: $$\frac{m_{MTO}}{S_W} = 727 \text{ kg/m}^2$$

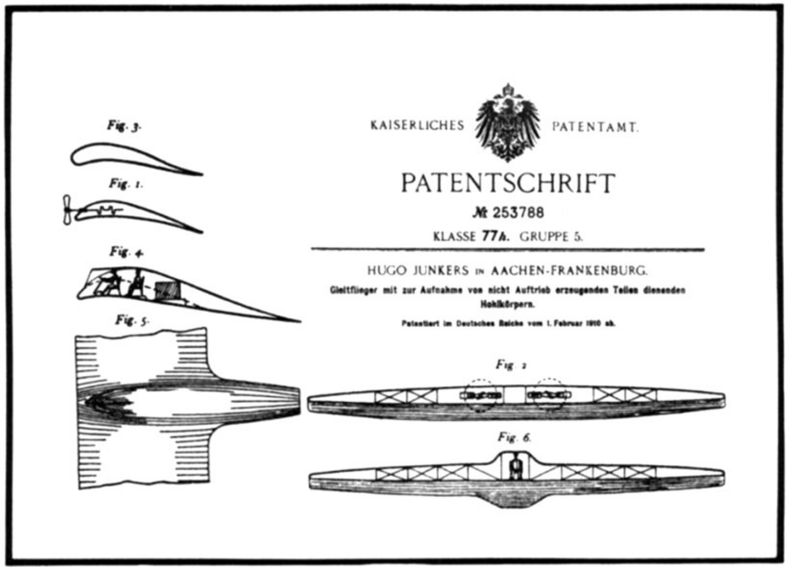
A380-800F: $$\frac{m_{MTO}}{S_W} = 698 \text{ kg/m}^2$$

Aircraft even bigger => BWB

BWB Projects

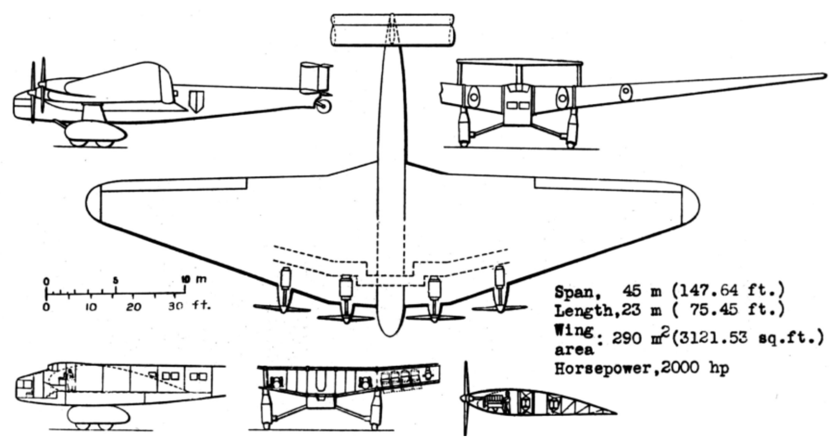
BWB Projects

From the Thick Airfoil (1910) to the Junkers G 38 (1929)



Kaiserliches Patentamt (Imperial Patent Office), Patent No. 253788 by Hugo Junkers: "Glider with Hollow Bodies Serving to hold Non-Lift-Generating Parts". 1. February 1910. Figures 1 to 6. The patent describes a wing housing engines, crew and payload (passengers). The patent does not make the explicit claim of a flying wing. Based on this idea Junkers developed the G 38. Except from the tail, the three-view resembles a BWB.

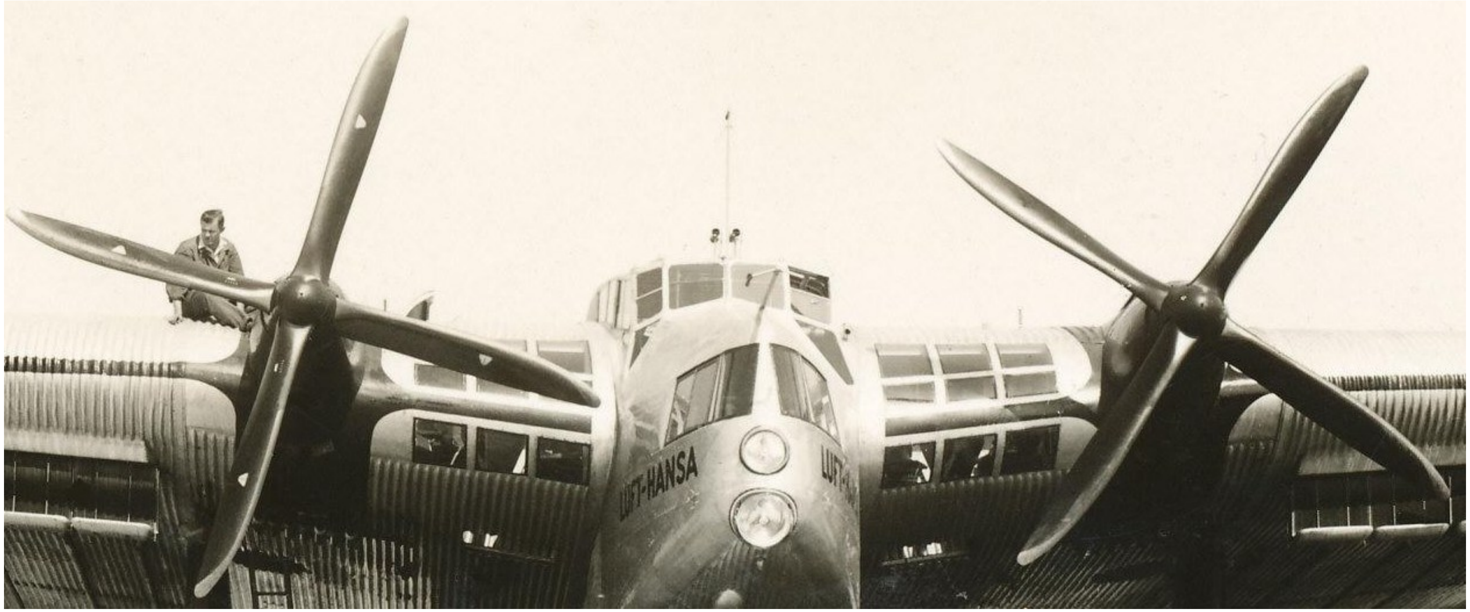
https://en.wikipedia.org/wiki/Junkers_G.38
https://de.wikipedia.org/wiki/Junkers_G_38
Pictures: Public Domain



Junkers G 38 (1929)

During its early life the G.38 was the largest landplane in the world. The plane was unique in that passengers were seated in the wings, which were 1.7 m thick at the root. There were also two seats in the extreme nose. The leading edge of each wing was fitted with sloping windscreens giving these passengers the forward-facing view. Structurally the G.38 conformed to standard Junkers' practice, with a multi-tubular spar cantilever wing covered (like the rest of the aircraft) in stressed, corrugated duraluminium. The wing had the usual Junkers "double wing" form, the name referring to the full span movable flaps which served also as ailerons in the outer part.

https://en.wikipedia.org/wiki/Junkers_G.38



Joost J. Bakker, CC BY 2.0, https://en.wikipedia.org/wiki/Junkers_G.38#/media/File:Junkers_G-38_D-2500.jpg

BWB Projects

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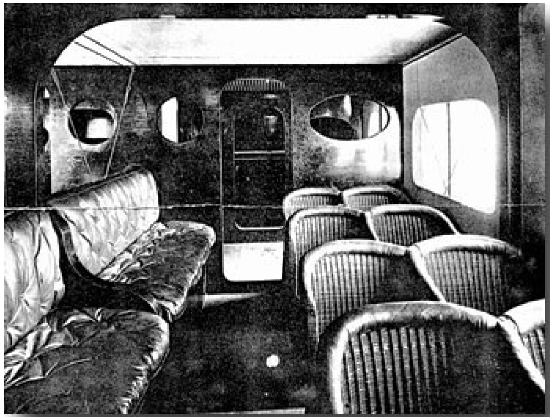
Hamburg University of Applied Sciences

Burnelli RB-1: Lifting Body and Wings

1921 - Long Island, NY
Burnelli RB-1 -- the first lifting-body reduced to practice.

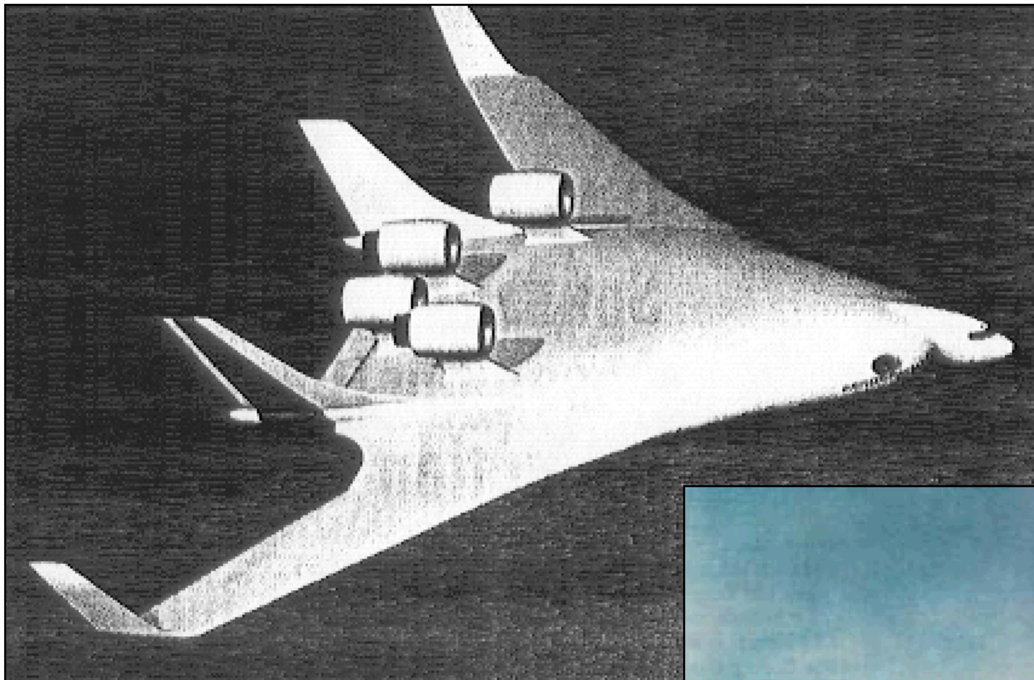
In 1921 pioneering aviator and aircraft designer Vincent Justus Burnelli patented the concept of an airfoil shaped airframe to increase the lift and load capacity of aircraft.



Burnelli RB-1 interior (half)

Aerospatiale "Megajet"

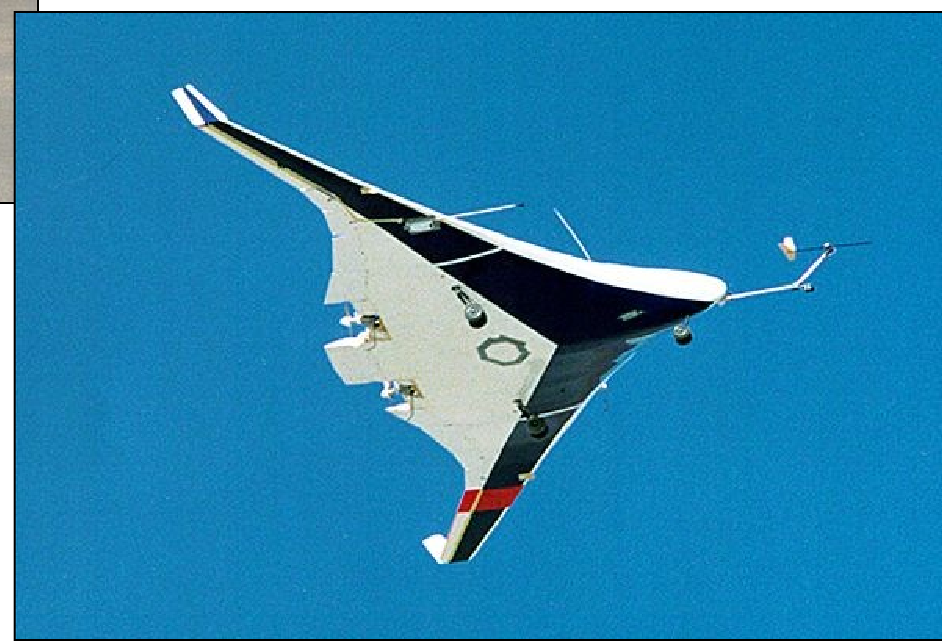
Design study,1995:
1000 seats,
range 6450 NM,
span 96 m,
cruise at Mach 0.85.



BWB Projects

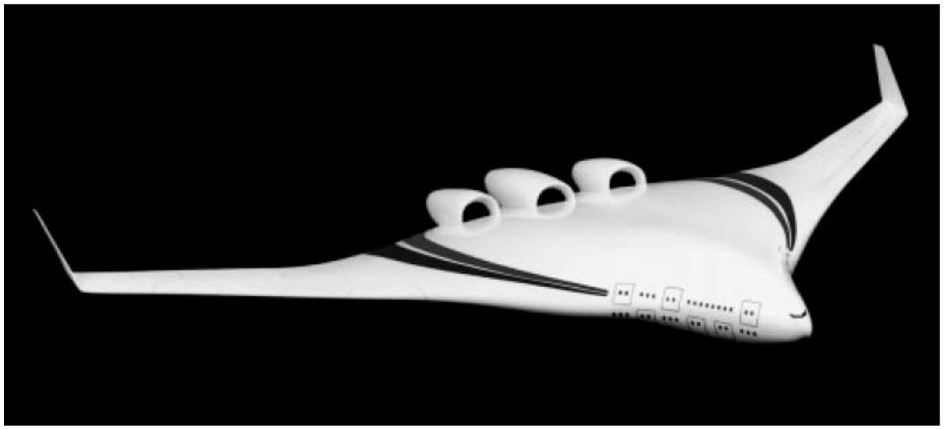
MDC, NASA, Stanford: BWB-17

1997:
McDonnell Douglas (R. Liebeck),
NASA,
Stanford (Ilan Kroo), et. al.



17 ft span
radio controlled model aircraft

Boeing BWB-450



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

Boeing X-48

Boeing; NASA; Old Dominion University, Norfolk, VA:

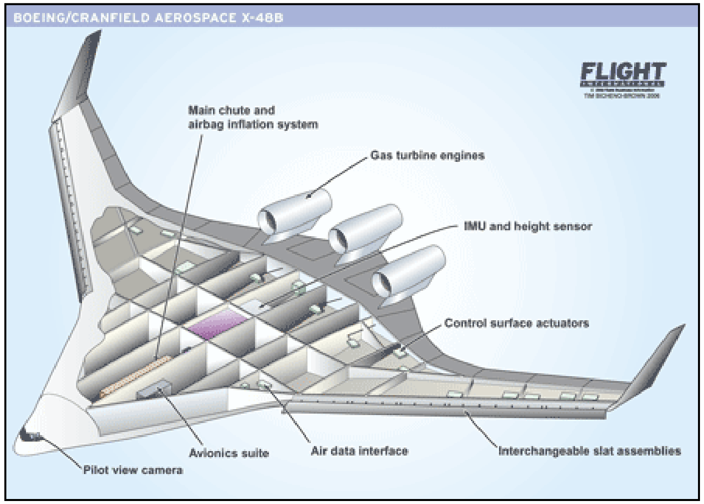
2001	construction started
2002	completion
2003	integration and ground tests
2004	wind tunnel tests
2004	flight test was planned with max. 165 mph at 10000 ft.

35 ft span wind tunnel and flight test model
(called BWB-LSV; low speed vehicle).

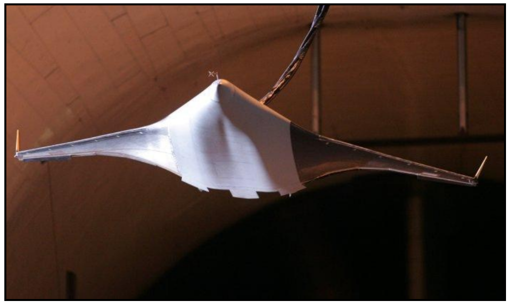
Original:
450 seats
span 250 ft = 76.2 m

BWB Projects

Boeing X-48B



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.



Boeing X-48B - tanker

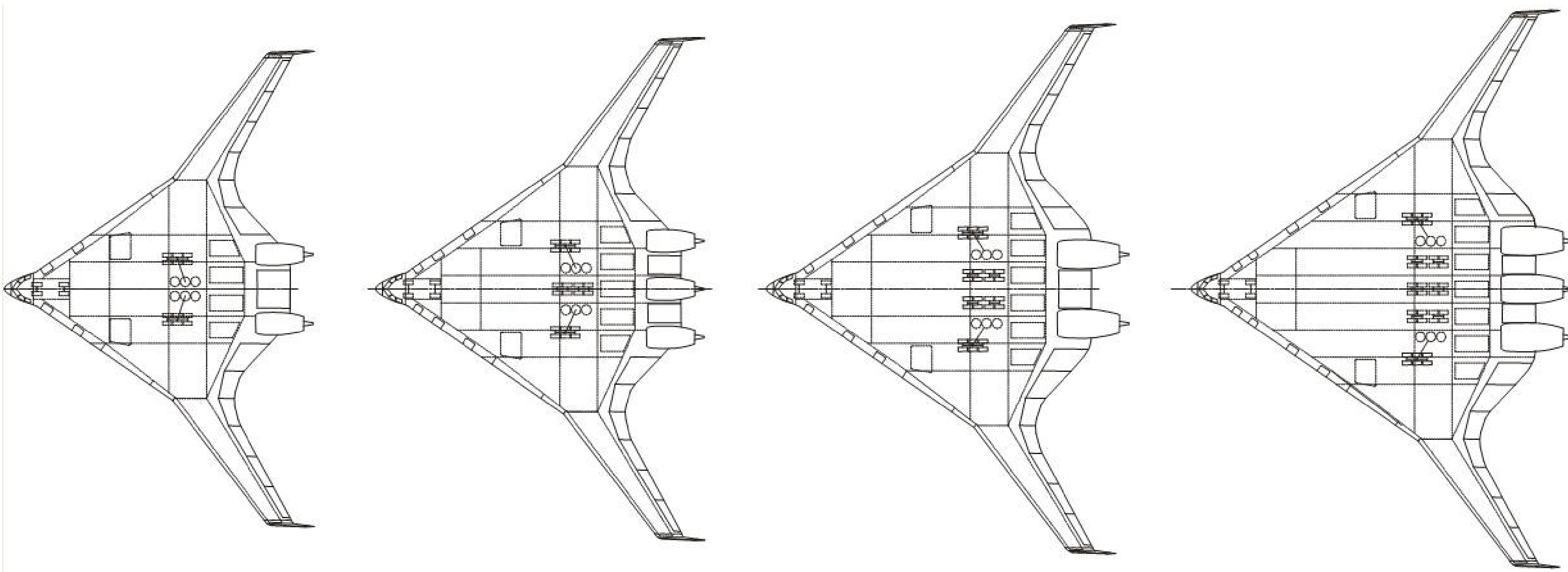
Air Force
Research Laboratory
(AFRL)

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.

Boeing BWB-250 ... BWB-550

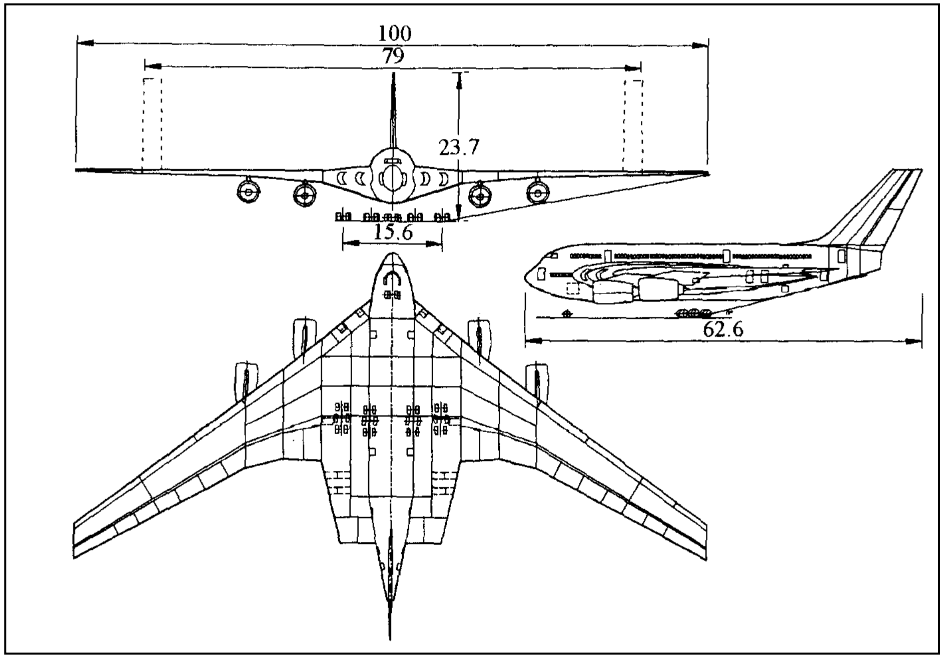


250-Sitzer | 350-Sitzer | 450-Sitzer | 550-Sitzer

Boeing: study of BWB aircraft family

Today BWBs are not a topic anymore at Boeing for civil transport!

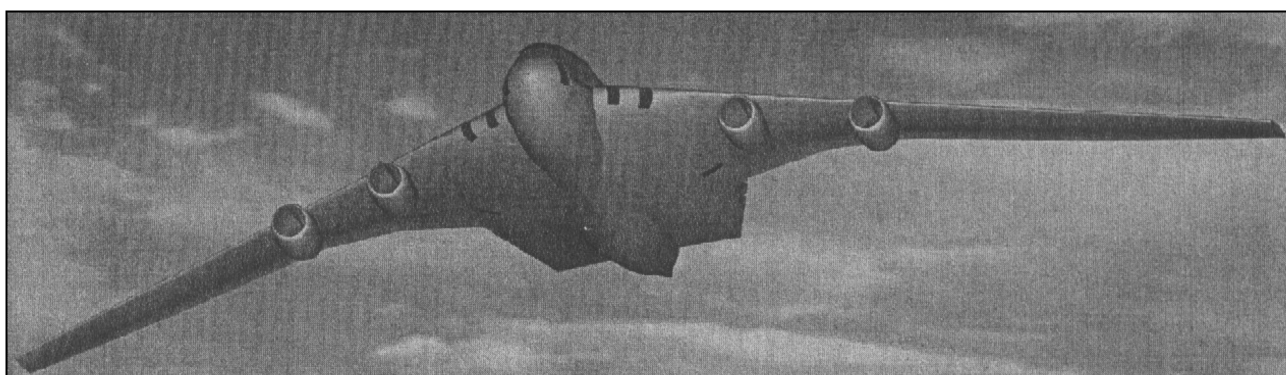
TsAGI (Russia) Integrated Wing Body (IWB)



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

Research sponsored by AIRBUS INDUSTRIE

AIRCRAFT DESIGN, Vol 4 (2001)



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

1999 - 2002

VELA

17 partners: D, F, UK, E, I, NL, CZ, P

Very Efficient Large Aircraft (VELA)

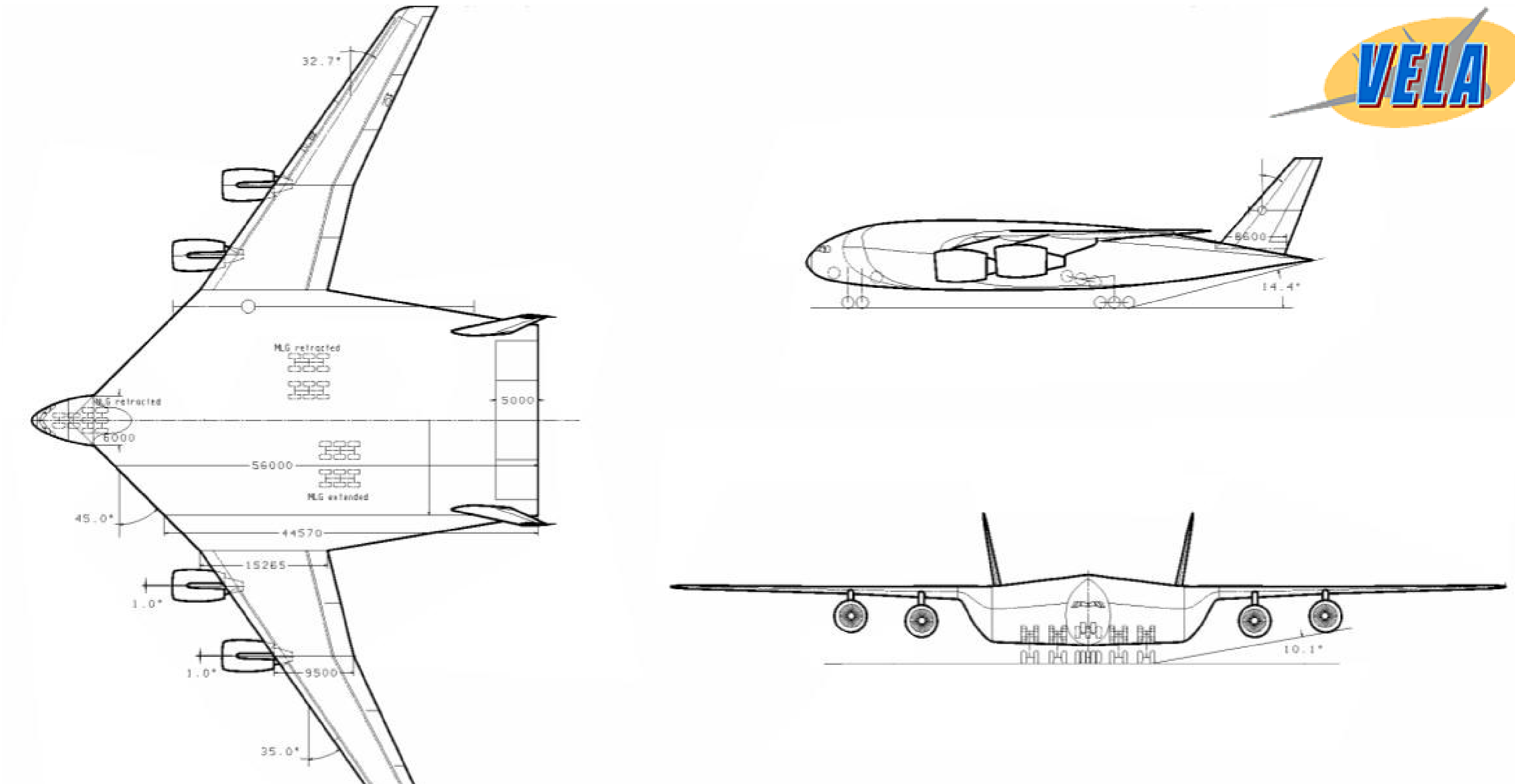
Two datum configurations for a flying wing (VELA 1 and VELA 2).
A first step in a long-term work plan will be followed by further research work.
Passenger-carrying aircraft.

Multidisciplinary Optimisation of a BWB (MOB)
Freighter version.

BWB Projects

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

VELA 1



750 PAX 3 class VLR

Engines: Trent900f1S (116"fan)

Door positions tbd

	Wing	Fin
Area sqm	2012.2	2 X 64.3
Aspect ratio	4,871	1,831
Taper ratio	0.0803	0.378

For information only

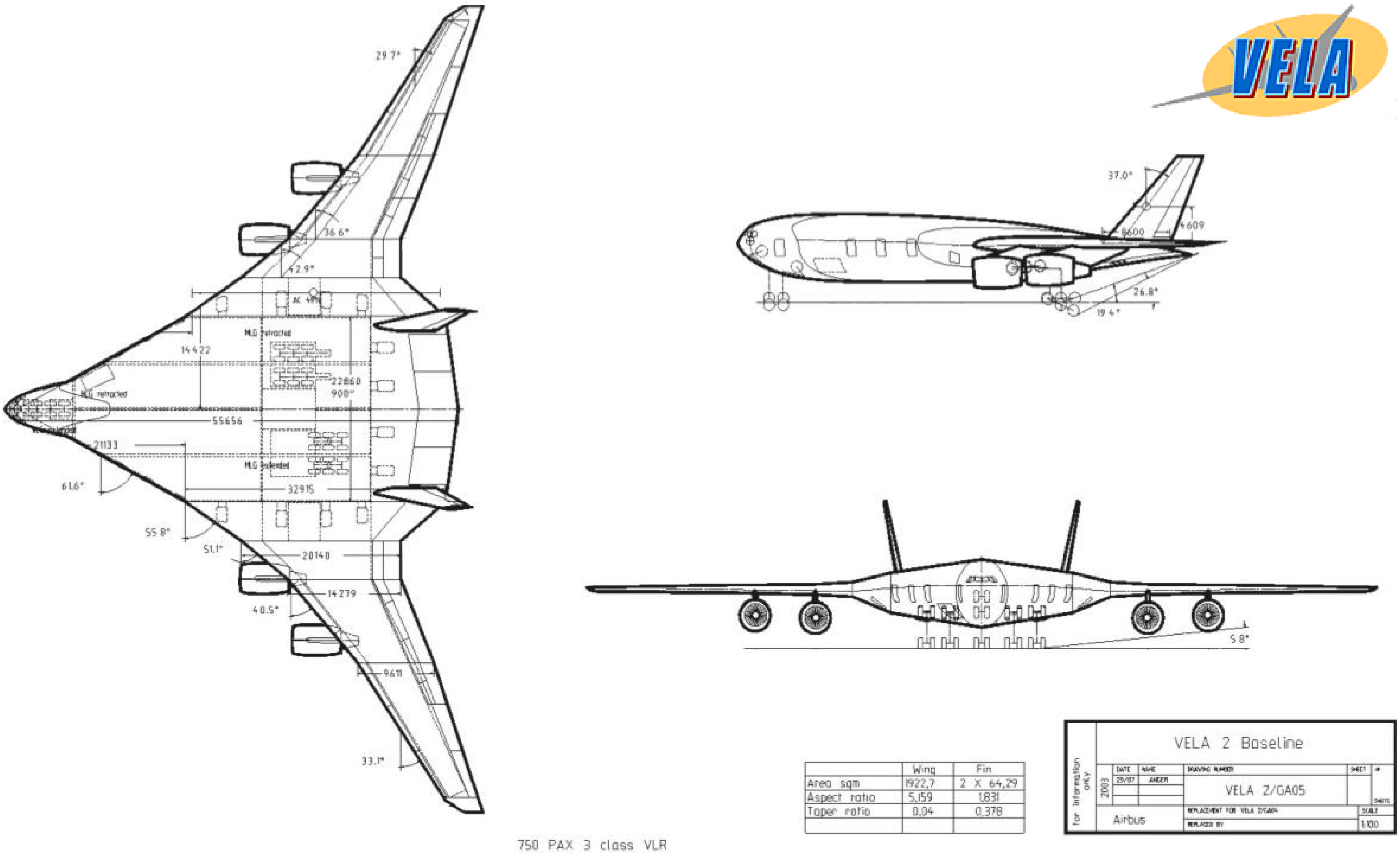
VELA 1 Baseline

2002	DATE: 18/06	NAME: ANGER	DRAWING NUMBER: VELA 1/GA03	SHEET OF
Airbus			REPLACEMENT FOR VELA 1/GA02	SCALE 1:100
			REPLACED BY	

BWB Projects

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

VELA 2



	Wing	Fin
Area sqm	1922,7	2 X 64,29
Aspect ratio	5,159	1,831
Taper ratio	0,04	0,378

BWB Projects

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

6th Framework Programme of the European Commision: NACRE with PDA (VELA follow on)

SIXTH FRAMEWORK PROGRAMME

2003 - 2006

WP3: Payload Driven Aircraft (VELA 3)

WP4: Flying scale model for novel aircraft configuration

Payload Driven Aircraft (PDA)

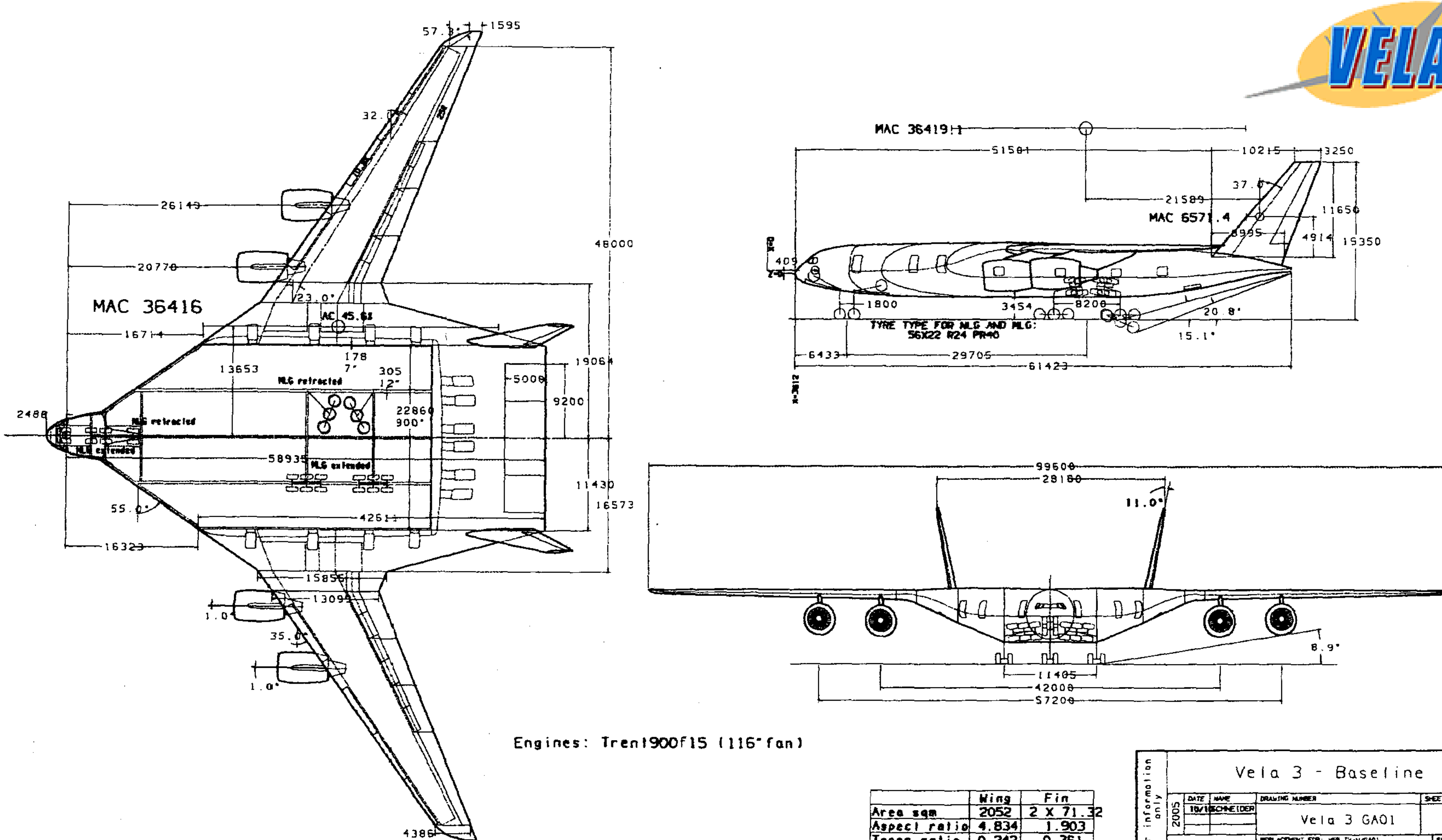
National: LuFo III, K2020

BWB (VELA 2) der Uni Stuttgart

BWB Projects

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

VELA 3



	Wing	Fin
Area sqm	2052	2 X 71.32
Aspect ratio	4.834	1.903
Taper ratio	0.242	0.361

750 PAX 3 class VLR

Vela 3 - Baseline

For information only

2005

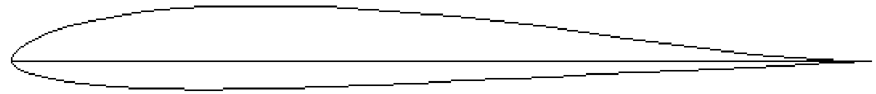
Drawing number: Vela 3 GA01

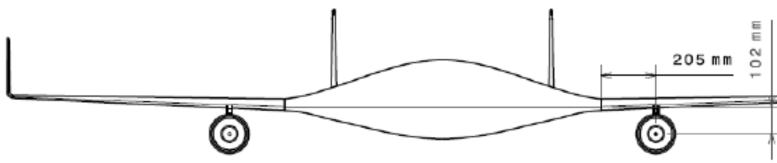
Airbus

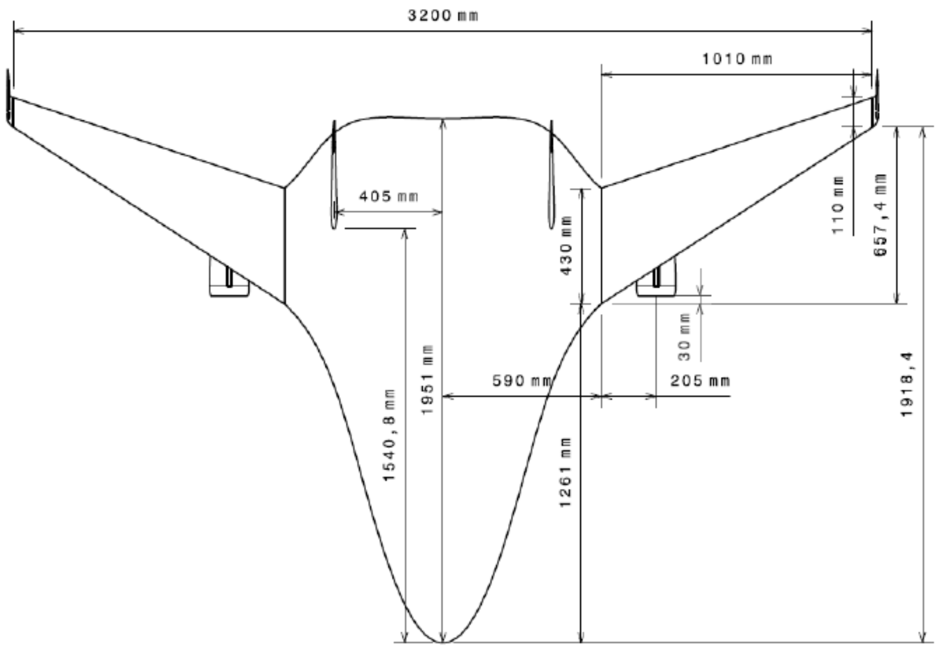
Scale: 1:100

BWB Projects

HAW Student Project: AC 20.30

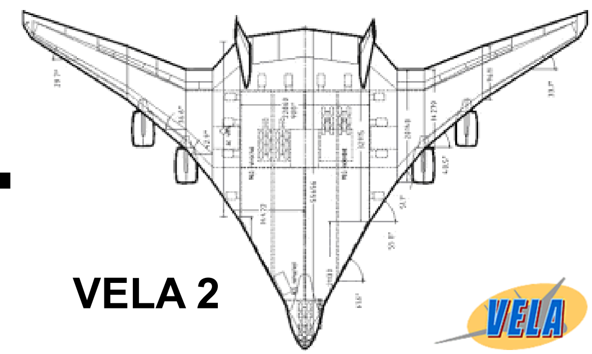






Wing profile: MH-45 (Martin Hepperle)
t/c = 9.85%,
c_{M0} = +0,0075
twist: ε_t = -3° (wash out)

Body profile: MH-91
t/c = 14.98%,
c_{M0} = +0,025



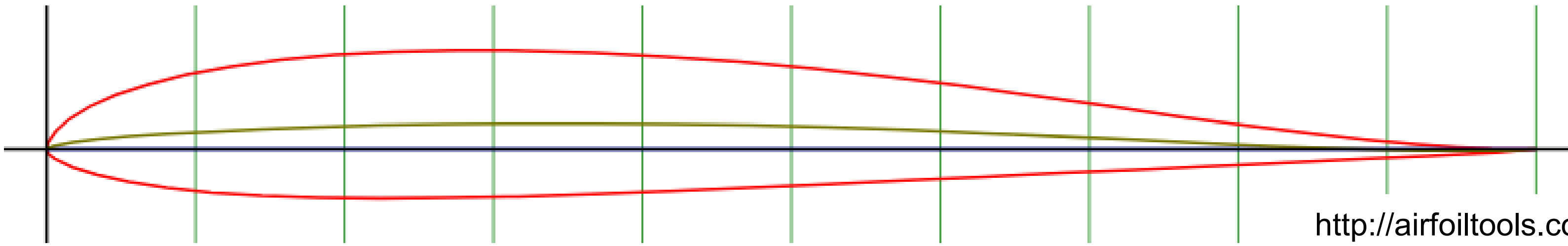
VELA 2

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

BWB Projects

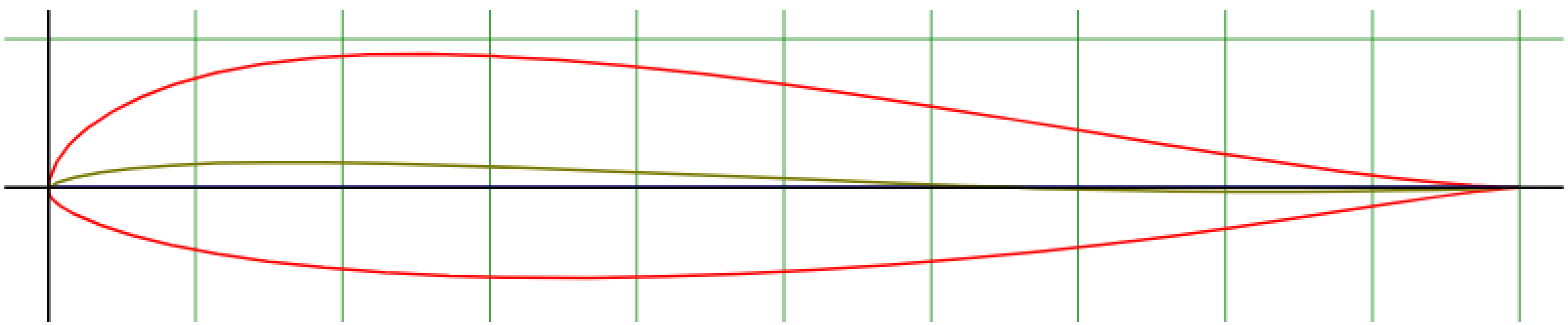
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Wing profile: MH-45 (Martin Hepperle), *t/c* = 9.85%, c_{M0} = +0.0075,
low drag, improved max. lift, proven even at Reynolds numbers below 200000.

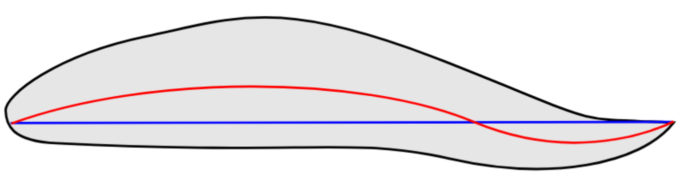


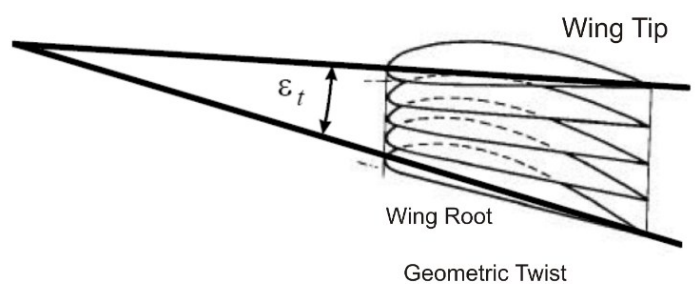
http://airfoiltools.com/plotter

Body profile: MH-91, *t/c* = 14.98%, c_{M0} = +0.025, reflexed airfoil



Exaggerated reflexed airfoil





Aeronautical Disciplines

VELA 2 Technical Data

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 desity seating: 1040 pax

cruise Mach number: 0.85

M_{MO} : 0.89

take-off field length < 3350 m (MTOW, SL, ISA +15°C)

approach speed < 145 kt   (here: approach speed = 165 kt)

ICA (300 ft/min, max. climb) > 35000 ft

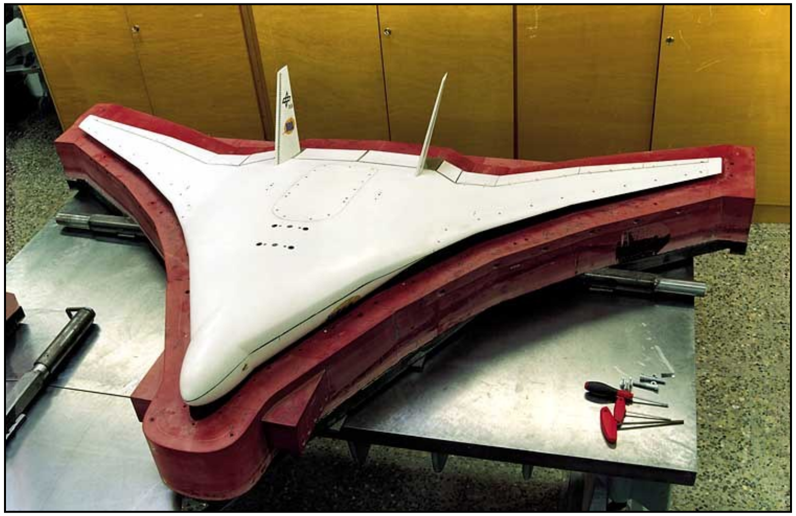
time to ICA (ISA) < 30 min.

max. operating altitude > 45000 ft (=> cabin Δp)

runway loading (ACN, Flex. B) < 70

span < 100 m

wheel spacing < 16 m



VELA 2 Model at DLR

Preliminary Sizing

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Input Parameters for Preliminary Sizing

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

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

from statistics: k_E = 15,8

S_{wet} / S_W :	conv. aircraft	6.0 ... 6.2
	VELA 2	≈ 2.4
A :	conv. aircraft	7.0 ... 10.0
	VELA 2	5.2
E_{max} :	conv. aircraft	20.4
	VELA 2	23.2 (+ 13%)

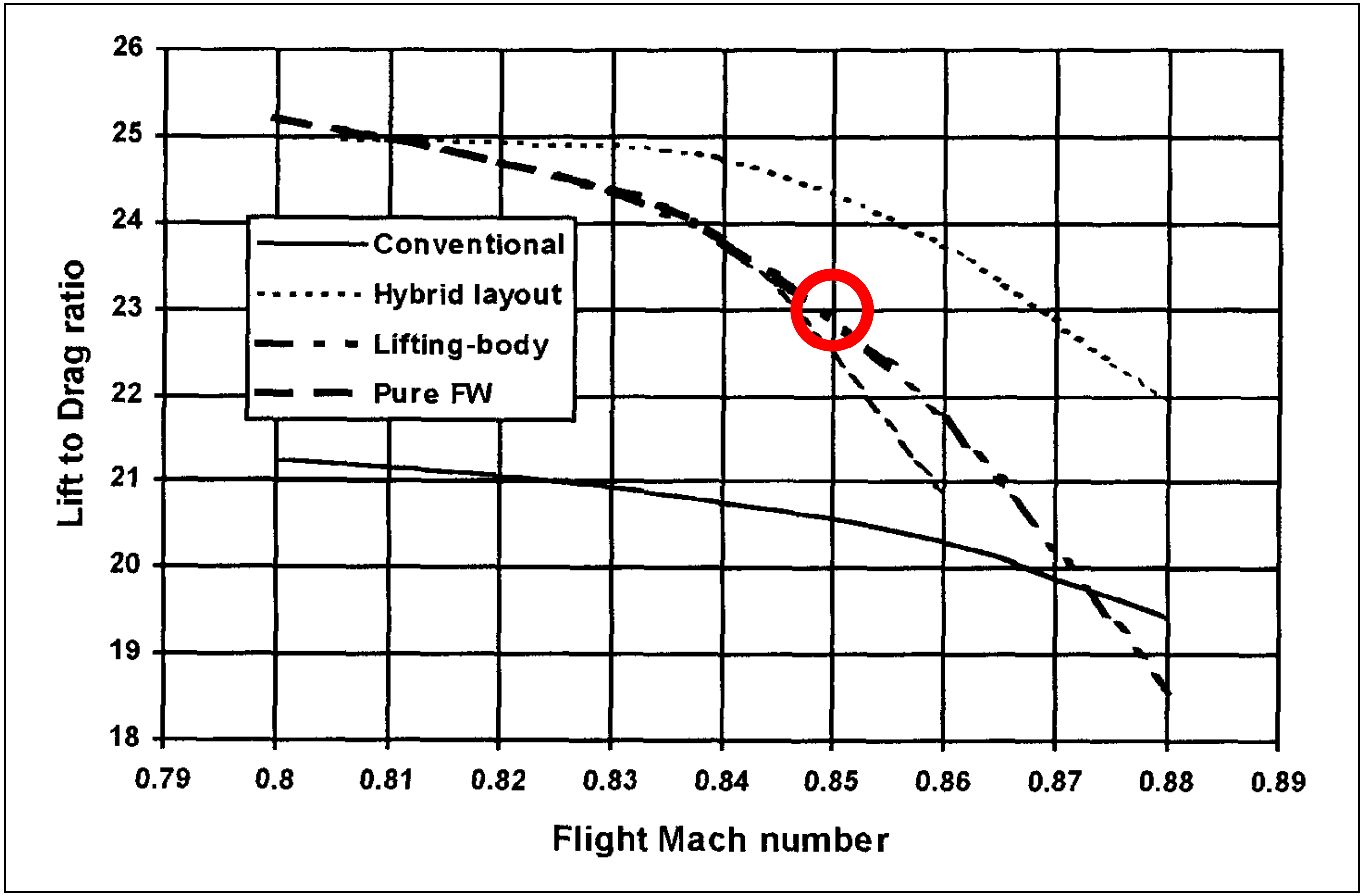
$$E_{max} = k_E \sqrt{\frac{A}{S_{wet} / S_W}}$$

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

$$\overline{c_f} = 0.003$$

Input Parameters for Preliminary Sizing

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



TsAGI for AIRBUS

Preliminary Sizing

AIAA-98-0438

BLENDED-WING-BODY SUBSONIC COMMERCIAL TRANSPORT

R. H. Liebeck*, M. A. Page†, and B. K. Rawdon‡
The Boeing Company, Long Beach, California

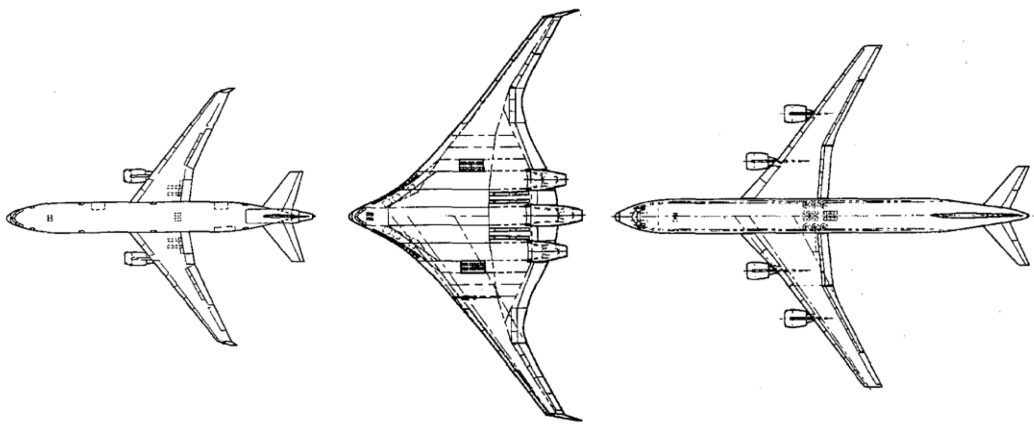


Figure 32. MD-11, Blended-Wing-Body and Conventional planview size comparison.

		BWB	Conventional
Passengers	n.d.	800	800
Range	nmi	7000	7000
TOGW	lbs	823,000	970,000
OEW	lbs	412,000	470,000
Fuel Burned	lbs	213,000	294,000
L/D @ Cruise	n.d.	23	19
Wing Span	ft	280	235
Wing Area (trap)	sq ft	7840	6100
Total Thrust	lbs	3 x 61,900	4 x 63,600
T/W	n.d.	0.226	0.262
TSFC	(lb/hr)/lb	0.466	0.466

Table 1. Performance comparison between BWB and conventional baseline.

$$A = \frac{b^2}{S}$$

L/D got 23/19 = 1.21 or 21% better

$$E_{max} = \frac{1}{2}\sqrt{\frac{\pi A e}{C_{D0}}}$$

But with any aircraft improvement due to wing span alone a factor of 280/235 = 1.19 (**19% better**) can be expected.

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**

$\frac{\partial C_L}{\partial \alpha}$ = **2,5**

α = **12 °**

$\frac{\partial C_L}{\partial \eta_W}$ = **0.22**

η_W = **18 °**

$\frac{\partial C_L}{\partial \eta_B}$ = **0.43**

η_B = **18 °**

VELA 2

Problem: $C_{L,max}$ = 0.73 means that all trailing edge flaps are deflected downwards. This results in a nose down pitching moment, which presses the nose landing gear on the ground. As such, the BWB cannot rotate and cannot achieve an angle of attack for lift-off. In contrast, AC20.30 had an unlimited take-off distance and hence in comparison a very high lift-off speed. This enabled to lift off with trailing edge flaps up.

Solution: Solution for large BWB would be a nose landing gear that extends on take-off to achieve the necessary angle of attack despite trailing edge flaps being deflected downwards.

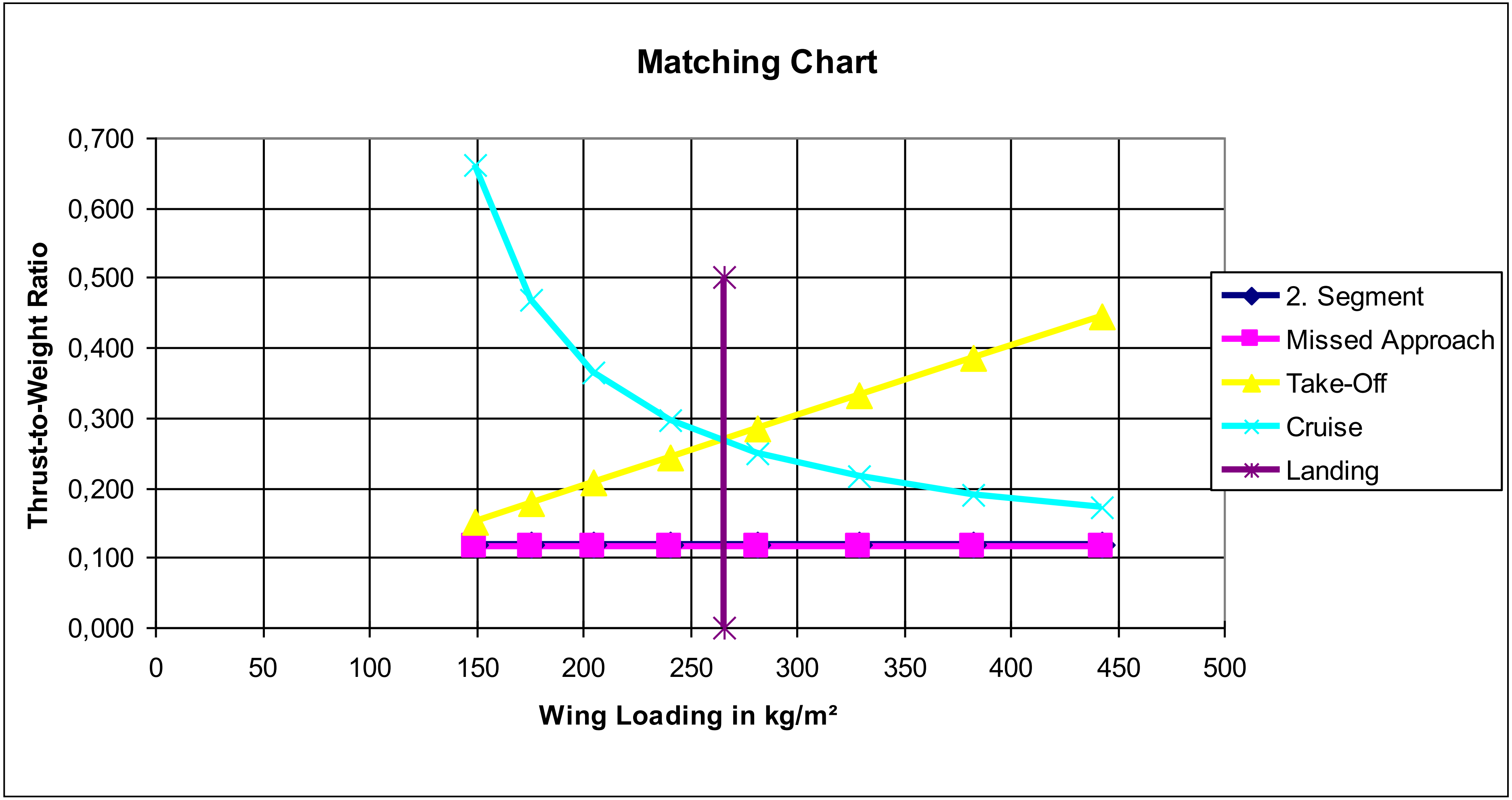
Assumptions:

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


Matching Chart
Thrust-to-Weight Ratio
0,700
0,600
0,500
0,400
0,300
0,200
0,100
0,000
0
50
100
150
200
250
300
350
400
450
500
Wing Loading in kg/m²
2. Segment
Missed Approach
Take-Off
Cruise
Landing

VELA 2

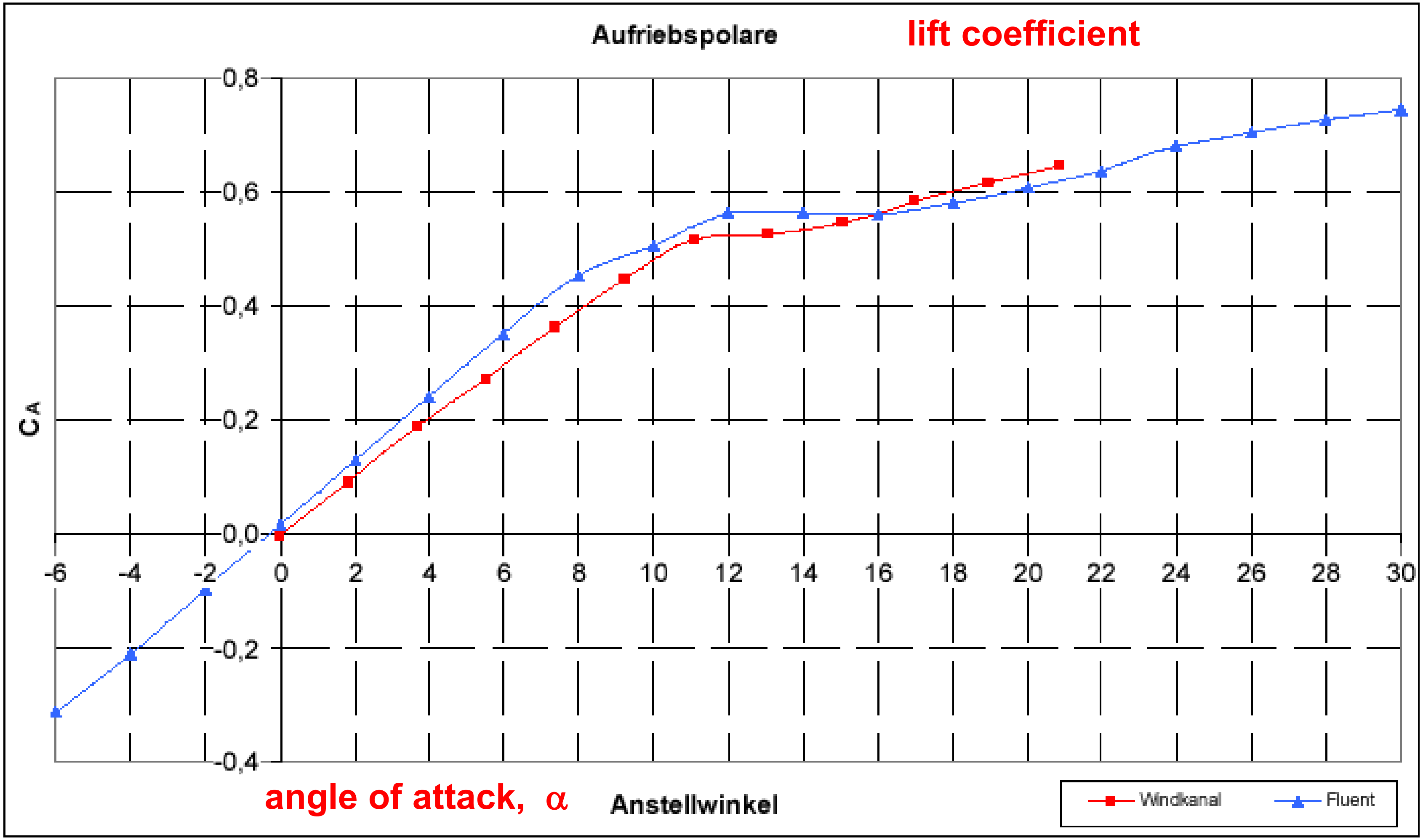
Sizing Results:

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 ... 1.316) => 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)
wing loading: 260 kg/m² (very low for passenger transport, due to low lift coefficient)
Initial Cruise Altitude (ICA): 38400 ft (= 11.7 km)

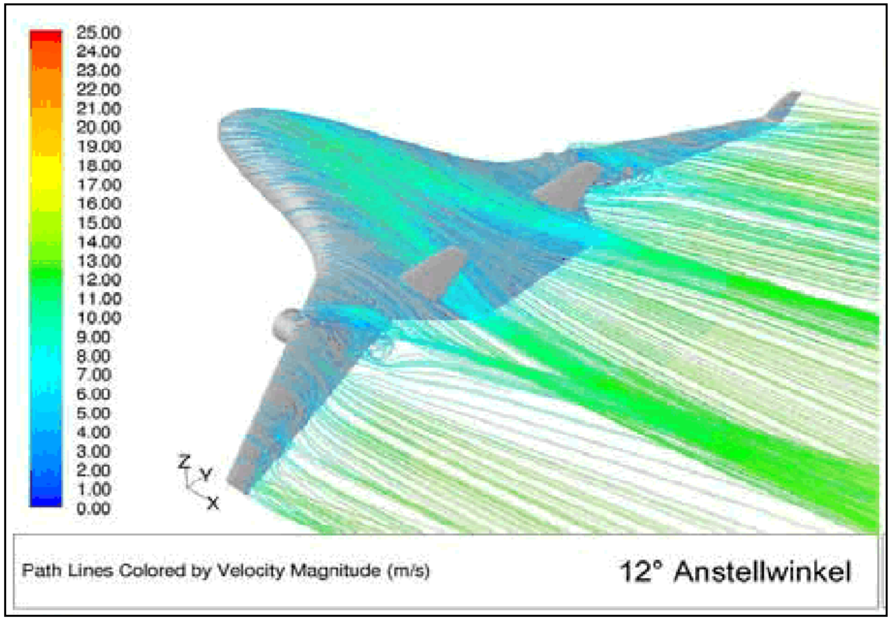
payload:	83000 kg	
MTOW:	501000 kg	(VELA 2: 691200 kg)
Wing Area:	1923 m²	(VELA 2: 1923 m² - forced to fit)
MLW:	366000 kg	
OEW:	251000 kg	(VELA 2: 380600 kg)
Fuel:	167000 kg	(VELA 2: 278200 kg ?)
Thrust:	344 kN	(for each of the four engines)

AC20.30: CFD with FLUENT

Diplomarbeit: H. Brunswig



AC20.30: CFD with FLUENT



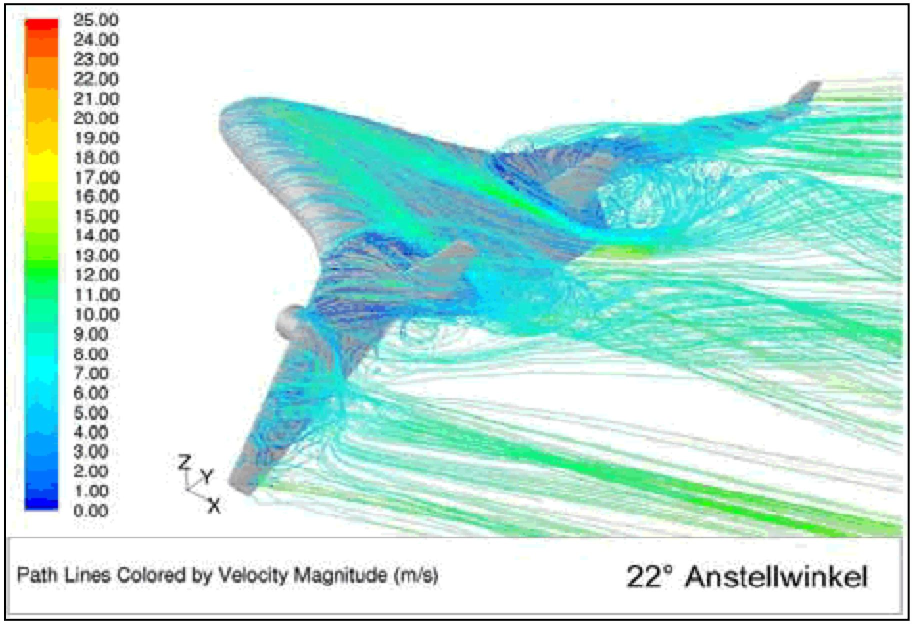
Stalls can easily be handled

Usable lift up to AOA of 12°

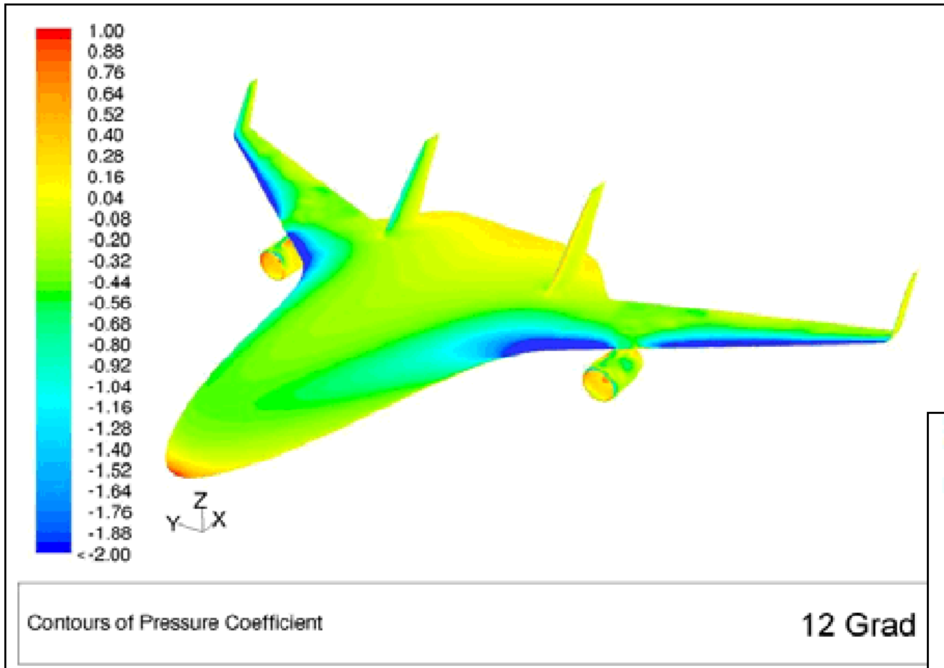
At 22° AOA:

- wings are stalled
- body continues to produce lift but control surfaces do not deliver control power

path lines

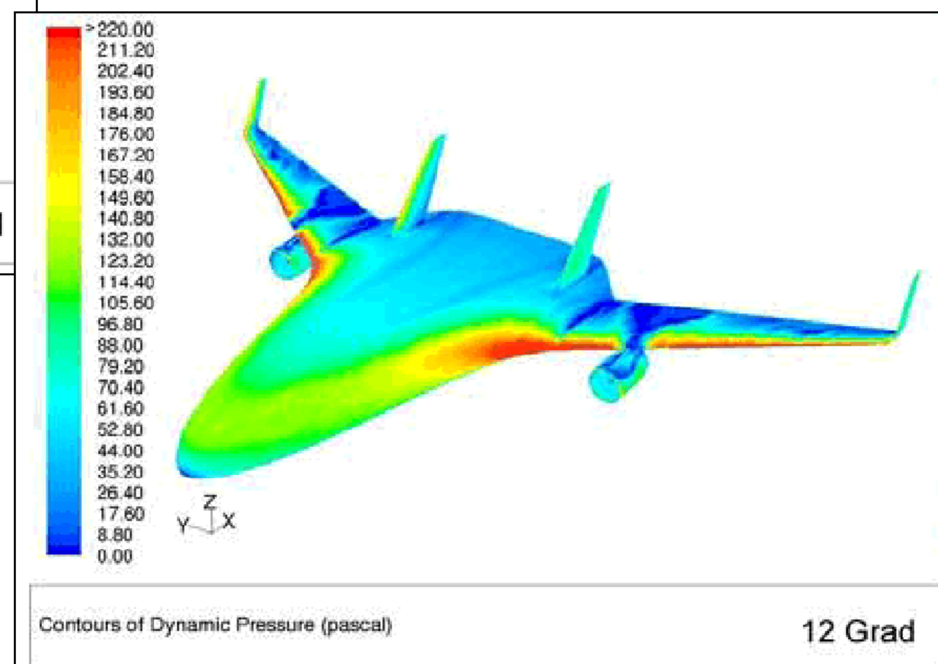


AC20.30: CFD with FLUENT



$$q = \frac{1}{2}\rho V^2$$

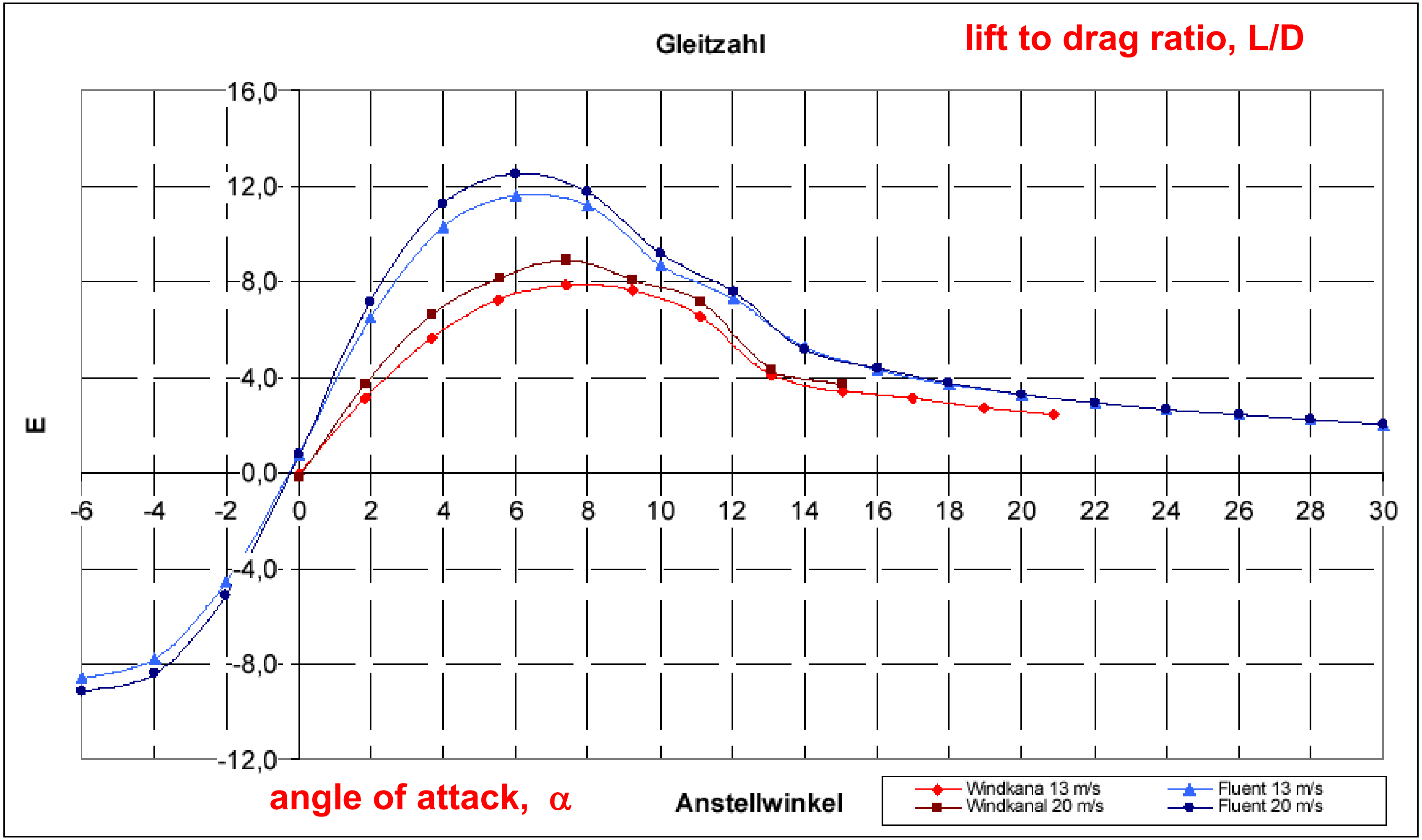
dynamic pressure



pressure coefficient

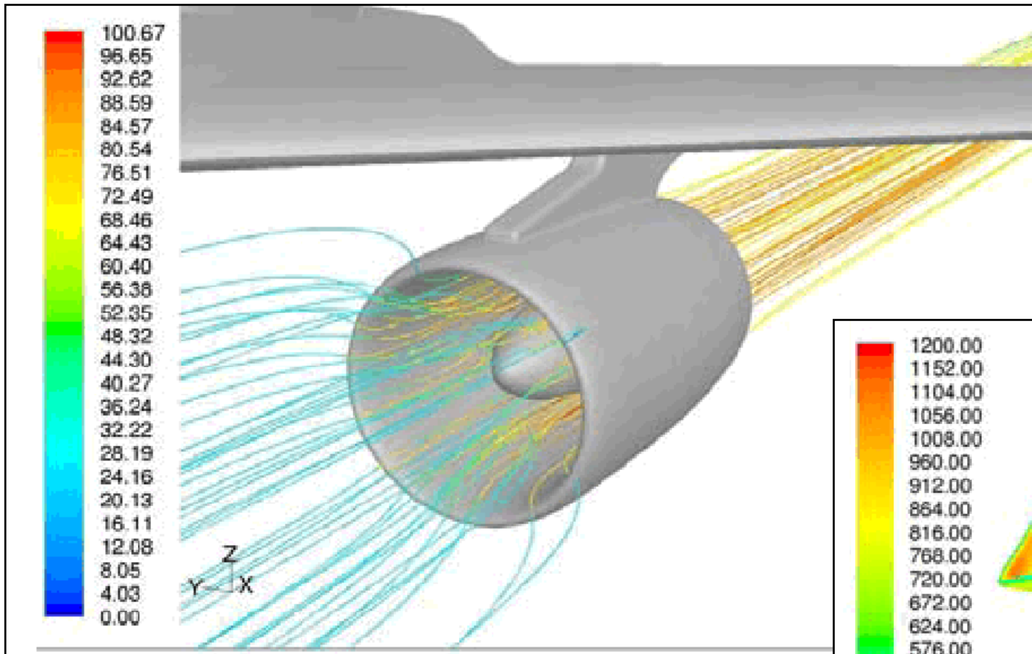
$$c_p = \frac{p - p_\infty}{q} = 1 - \left(\frac{V}{V_\infty}\right)^2$$

AC20.30: CFD with FLUENT

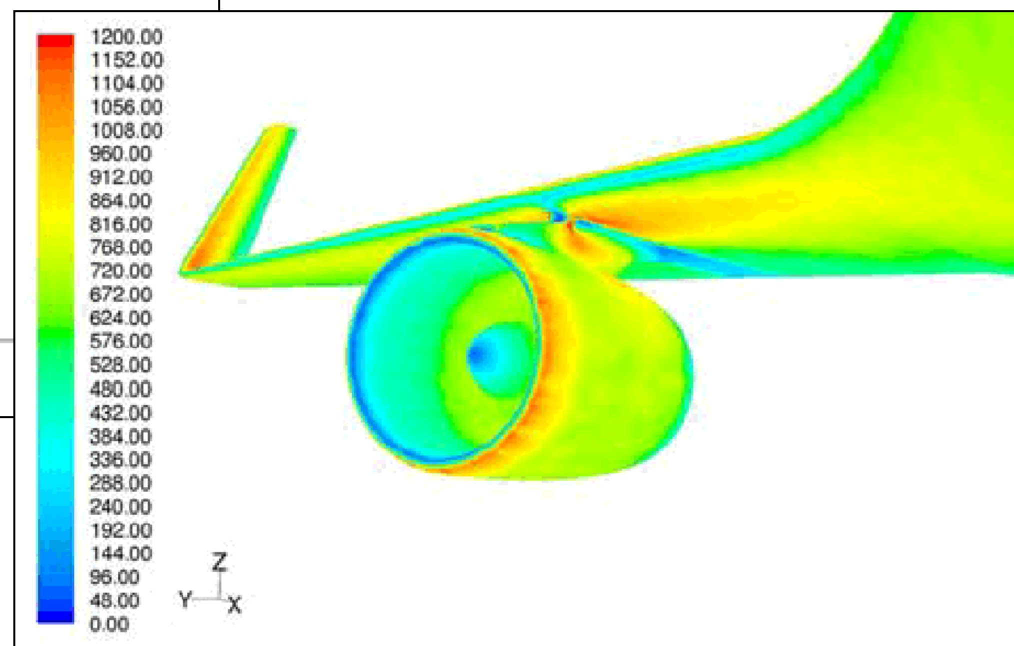


AC20.30: CFD with FLUENT

Engine Integration

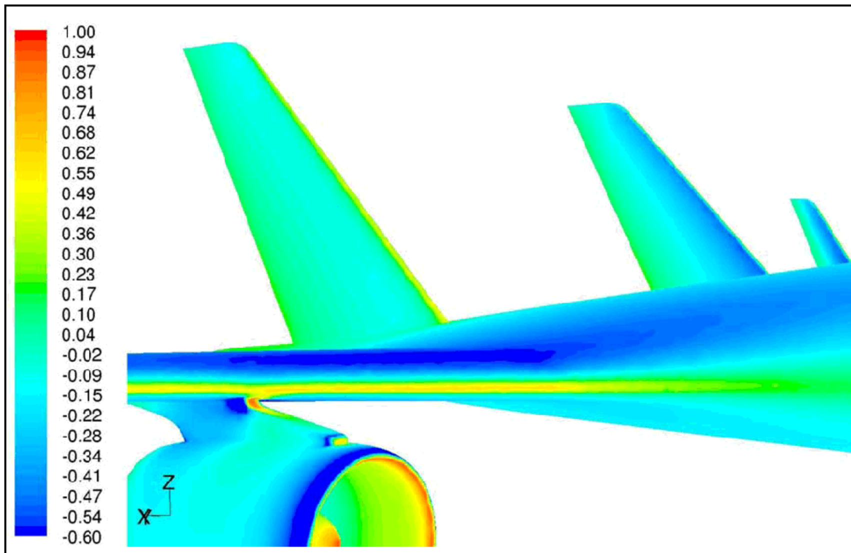


Path Lines Colored by Velocity Magnitude (m/s)



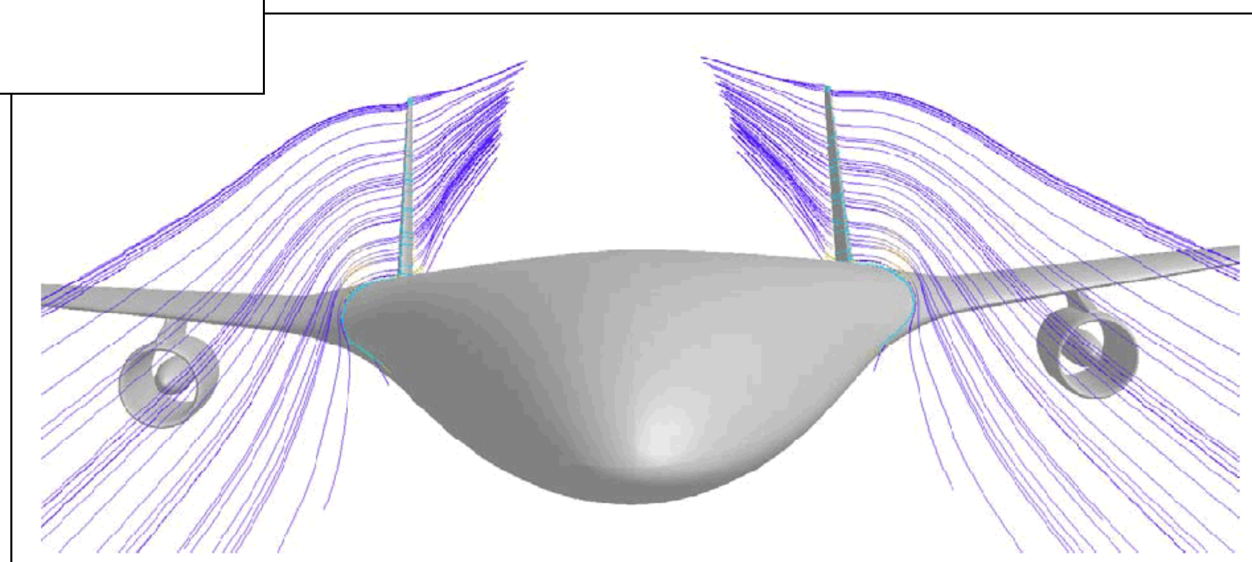
Contours of Dynamic Pressure (pascal)

AC20.30: CFD with FLUENT



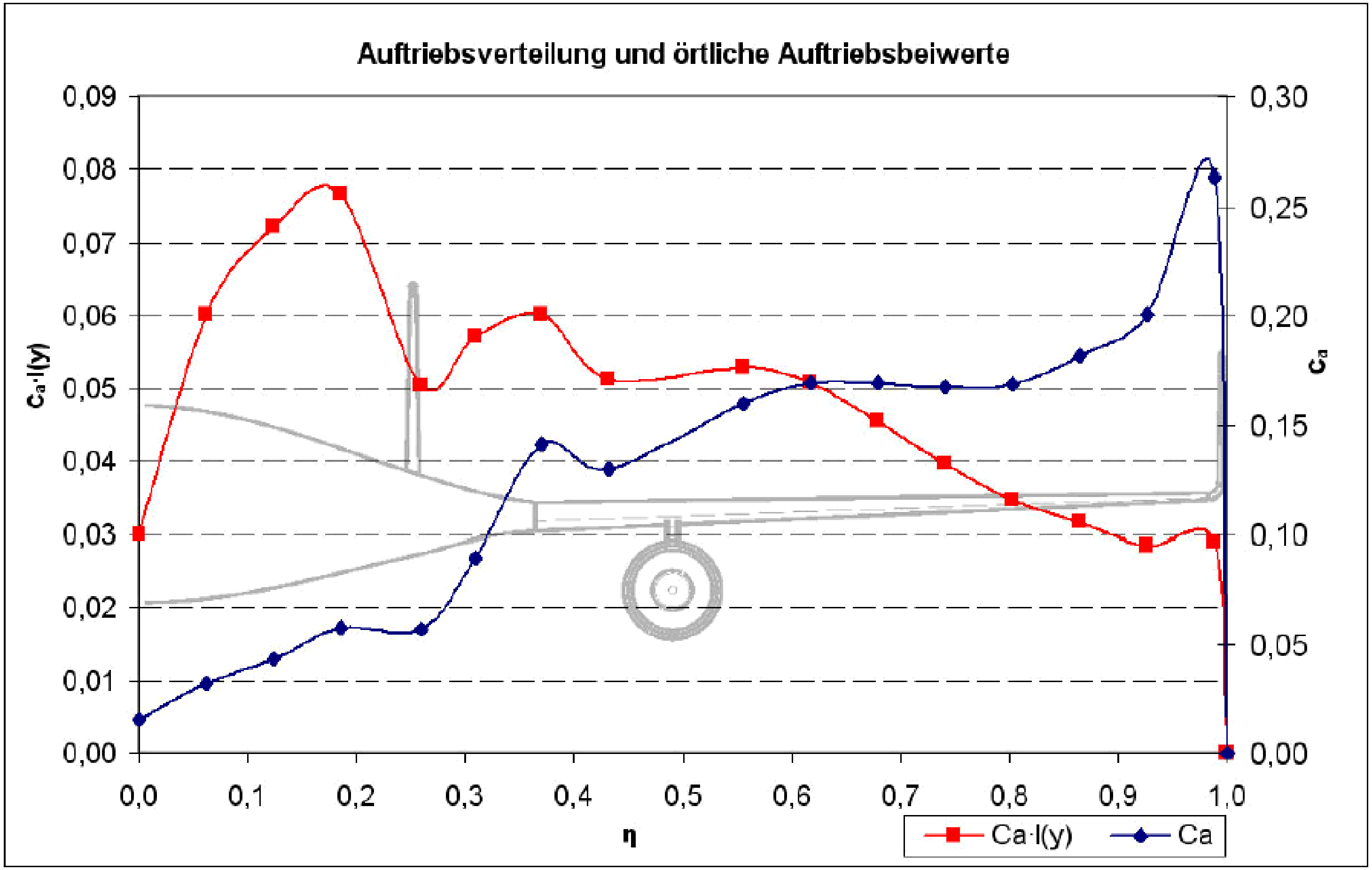
Fin Integration:

The fins experience a cross flow at an angle of 3° ... 5°.
An optimized fin setting could reduce drag.



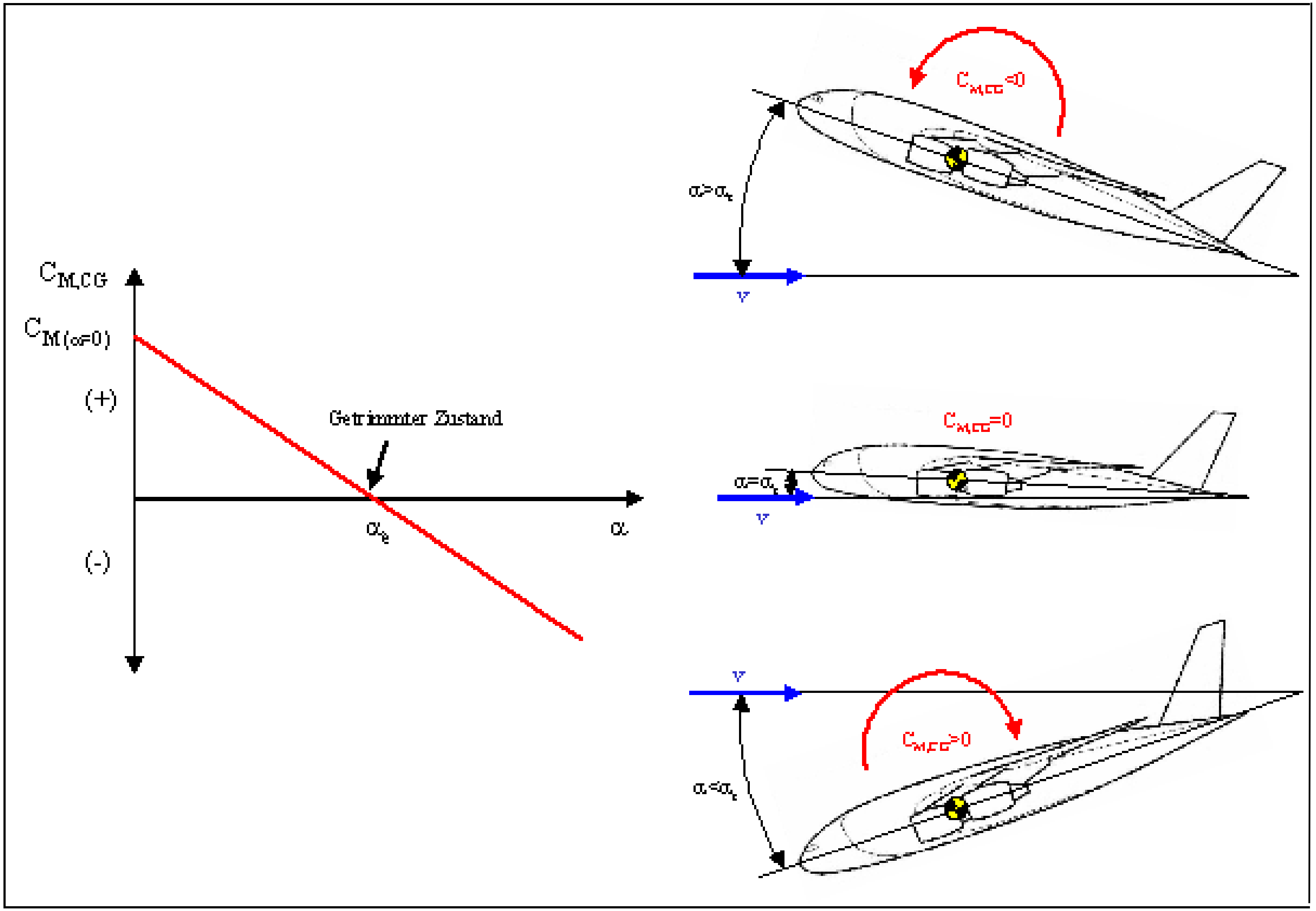
AC20.30: CFD with FLUENT

cruise, α = 1.2 °



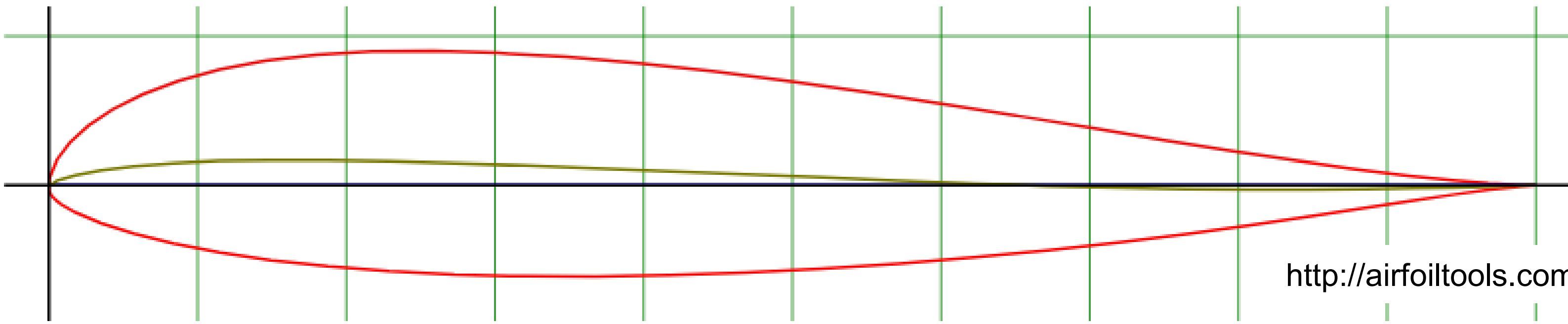
lift distribution / distribution of local lift coefficient

Static Longitudinal Stability Fundamentals

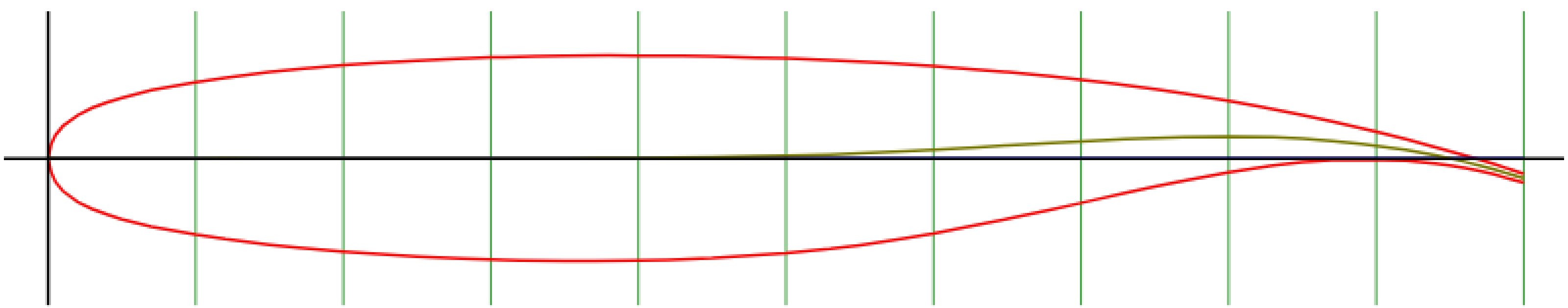


Static Longitudinal Stability Fundamentals

AC20.30: Body profile: MH-91, *t/c* = 14.98%, c_{M0} = +0.025, reflexed airfoil



A supercritical airfoil body profile would be necessary for cruise at M = 0.76: Example: NASA SC(2)-0714, *t/c* = 14%, c_{M0} = -0.16 at M = 0.76



CONFLICT: A supercritical airfoil is required for high cruise Mach number.
A reflexed airfoil is required for static longitudinal stability and certification to CS-25 / FAR Part 25.

Certification Requirements

CERTIFICATION SPECIFICATIONS, CS-25.173 Static Longitudinal Stability:

(a) A pull must be required to obtain and maintain speeds below the specified trim speed, and a push must be required to obtain and maintain speeds above the specified trim speed.

Hence the conflict for BWB design:

A) Design to Requirements:

1.) Center of Gravity (CG) forward of Aerodynamic Center (AC).

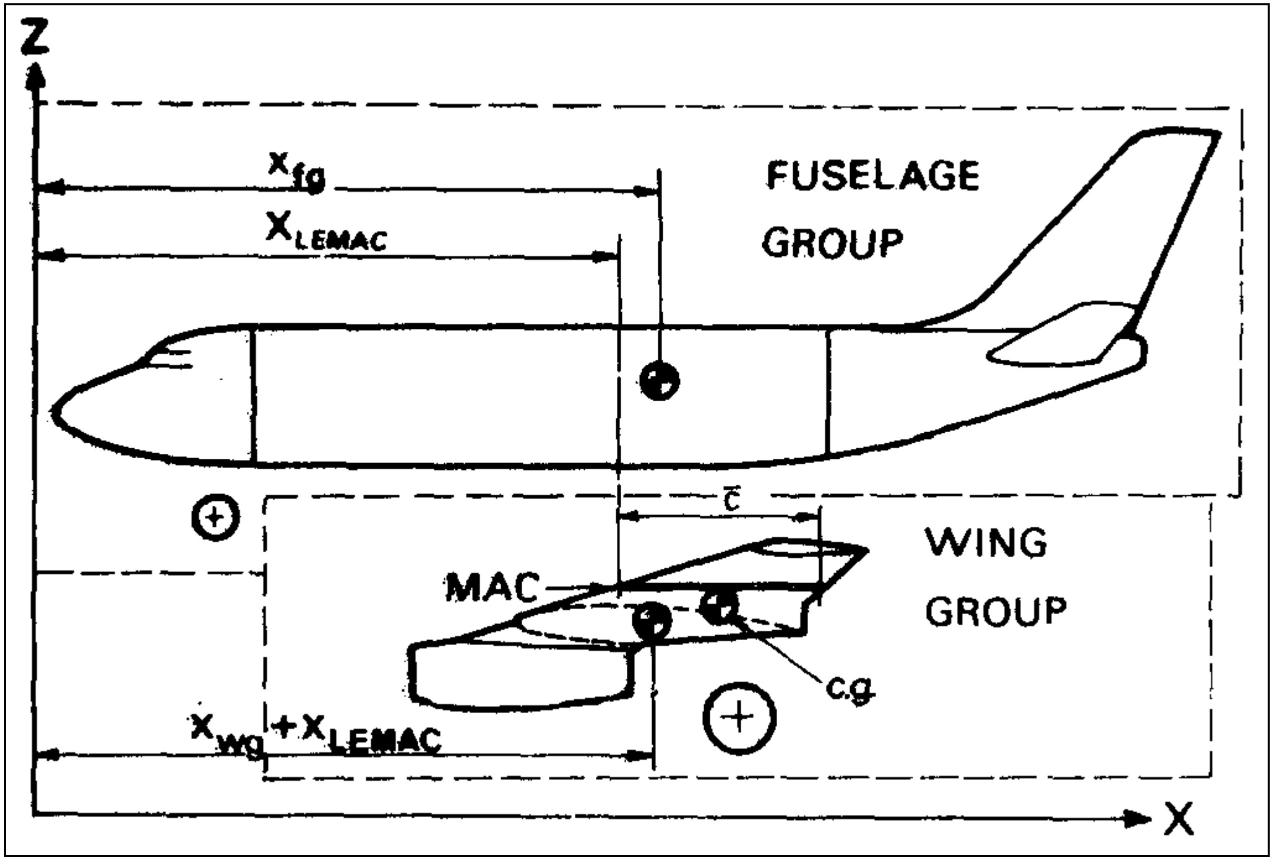
2.) Pitching Moment at $C_L = 0$, called c_{M0} has to be positive.

or

B) Change Requirements (Will this be possible?):

Design an unstable aircraft with c_{M0} negativ.

Stabilized by flight control system.

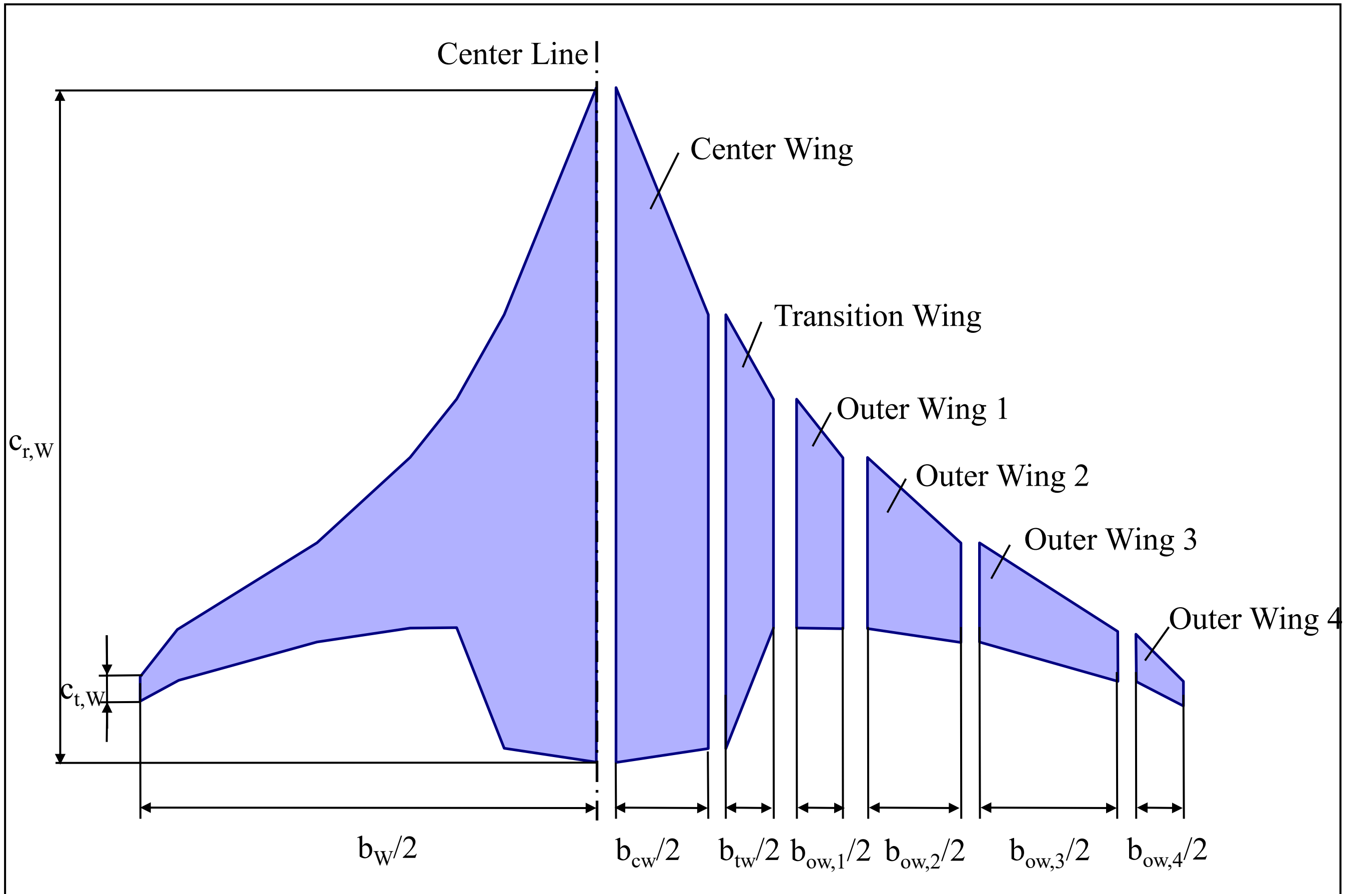


Positioning of the CG on the Mean Aerodynamic Chord (MAC) for required *static margin* is achieved in conventional design by shifting the wing with respect to the fuselage. This approach is not possible in BWB design!

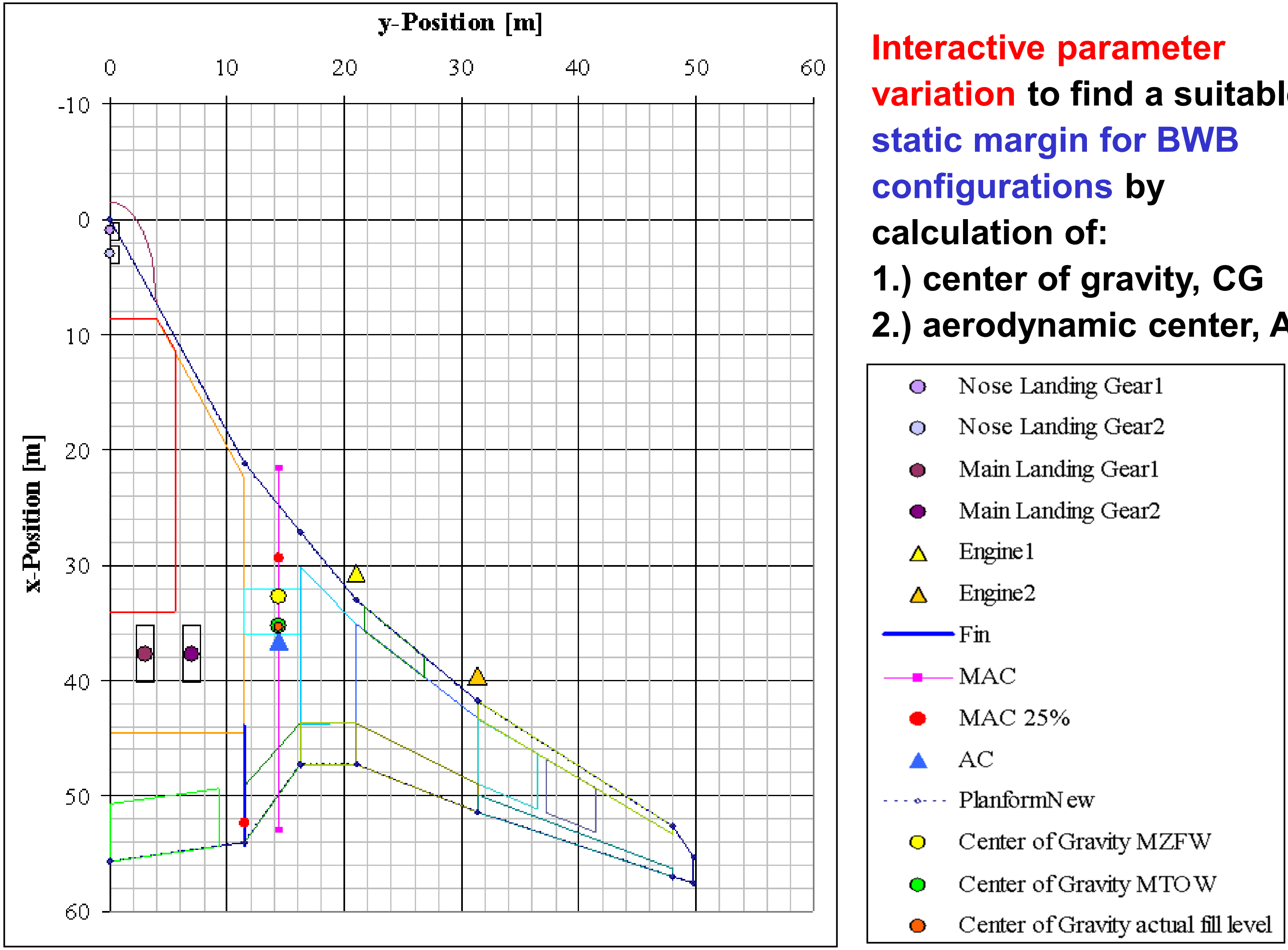
$$x_{LEMAC} = x_{fg} - x_{cg} + \frac{m_{wg}}{m_{fg}}\left(x_{wg} - x_{cg}\right)$$

Static Longitudinal Stability for BWB Configurations

Diplomarbeit: F. Bansa



A BWB can be designed for static longitudinal stability with an interactive EXCEL-based program. The program assumes the BWB to consist of a maximum of 6 different wing trapezoids.

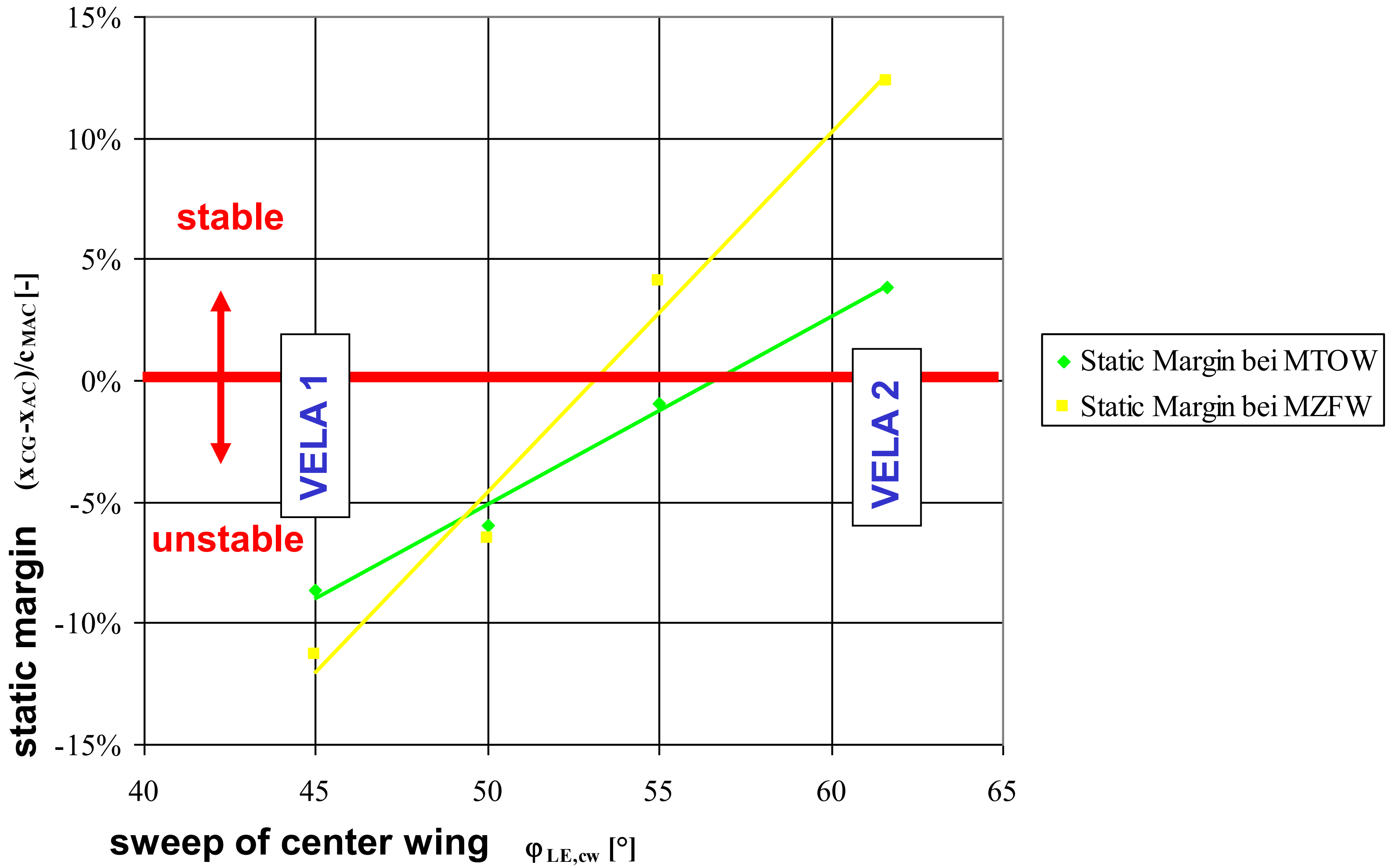


Interactive parameter variation to find a suitable **static margin for BWB configurations** by calculation of:

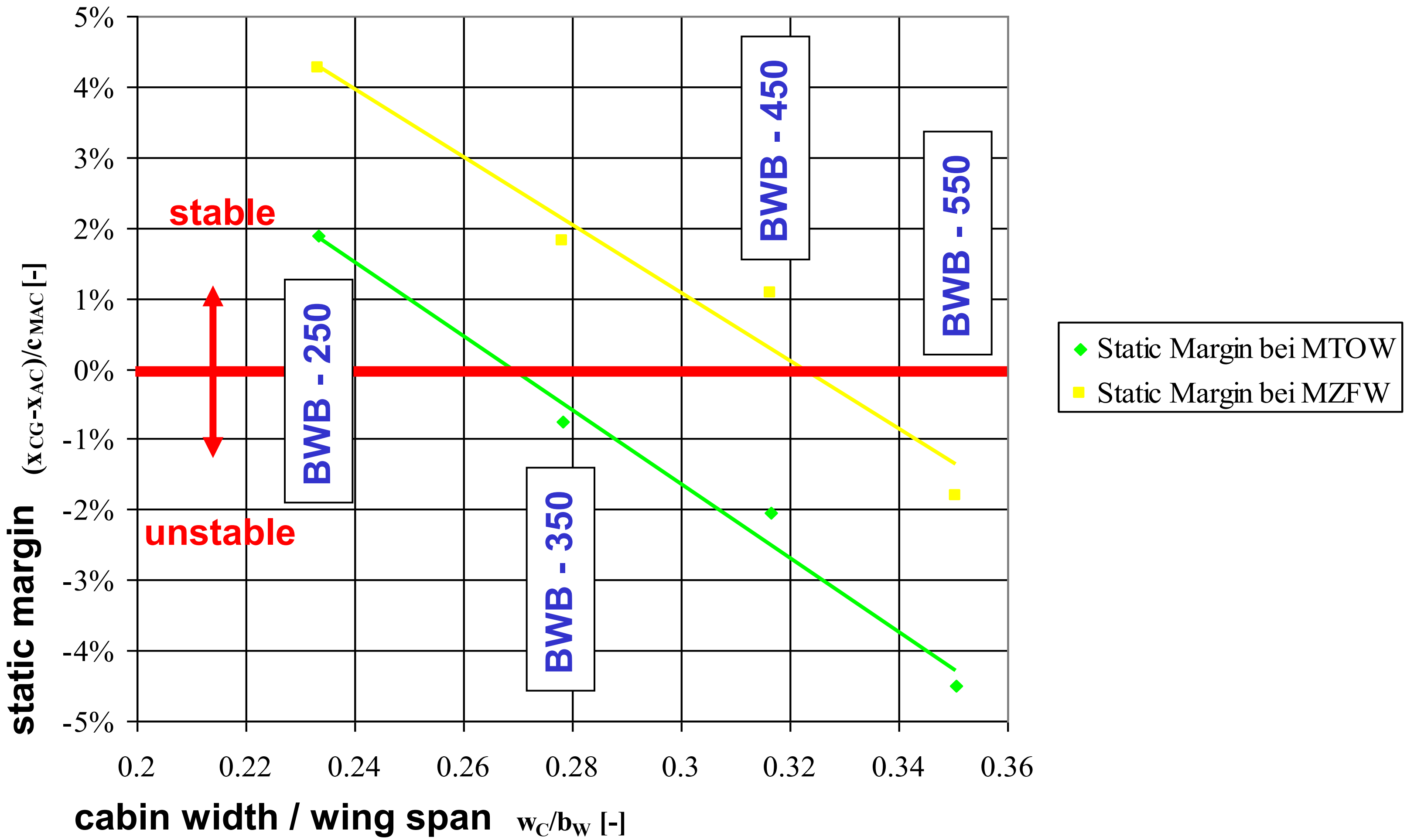
1.) center of gravity, CG

2.) aerodynamic center, AC.

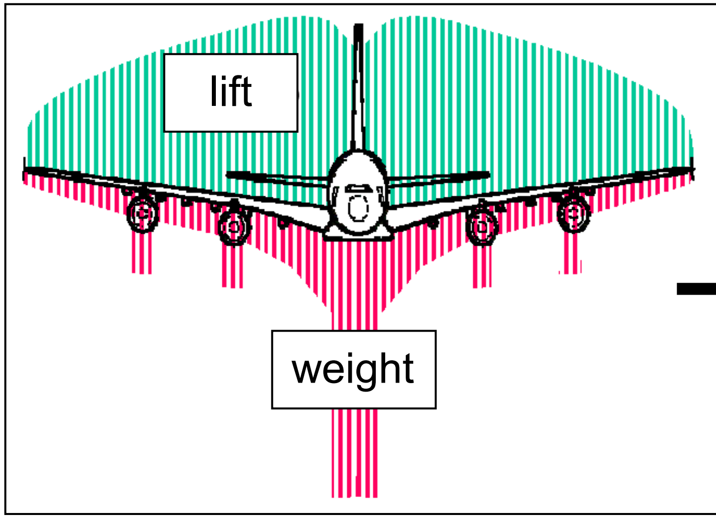
Static Longitudinal Stability for VELA Configurations

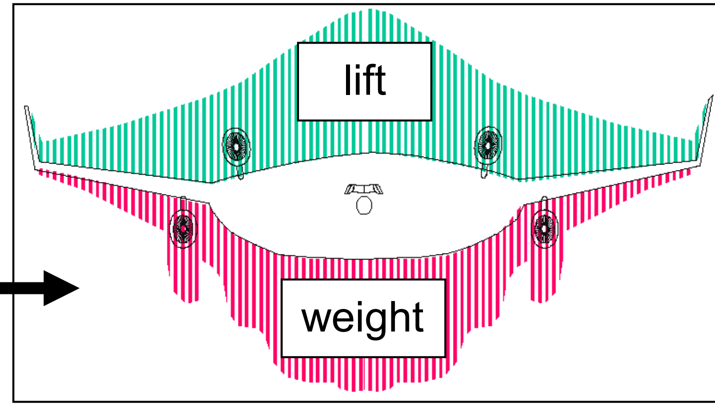


Static Longitudinal Stability for Boeing BWB Configurations

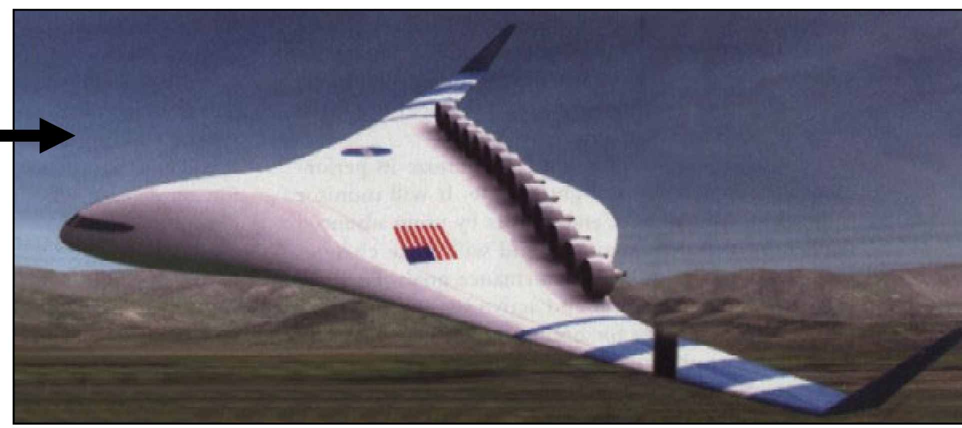


Weight Saving Potential of BWB Configurations





Less bending moments in a flying wing or BWB

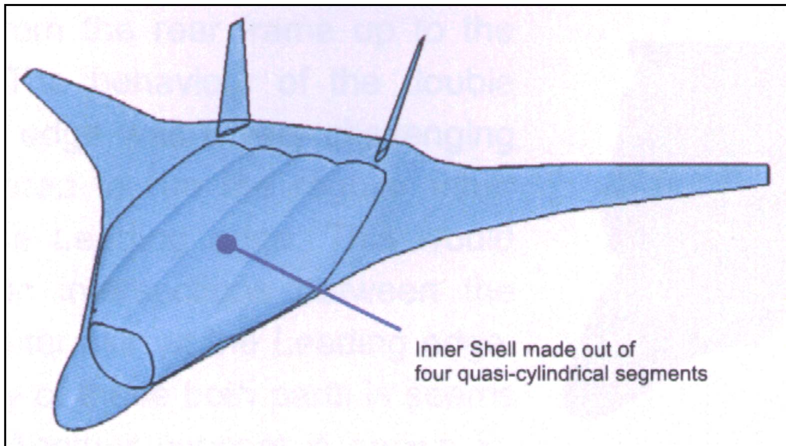


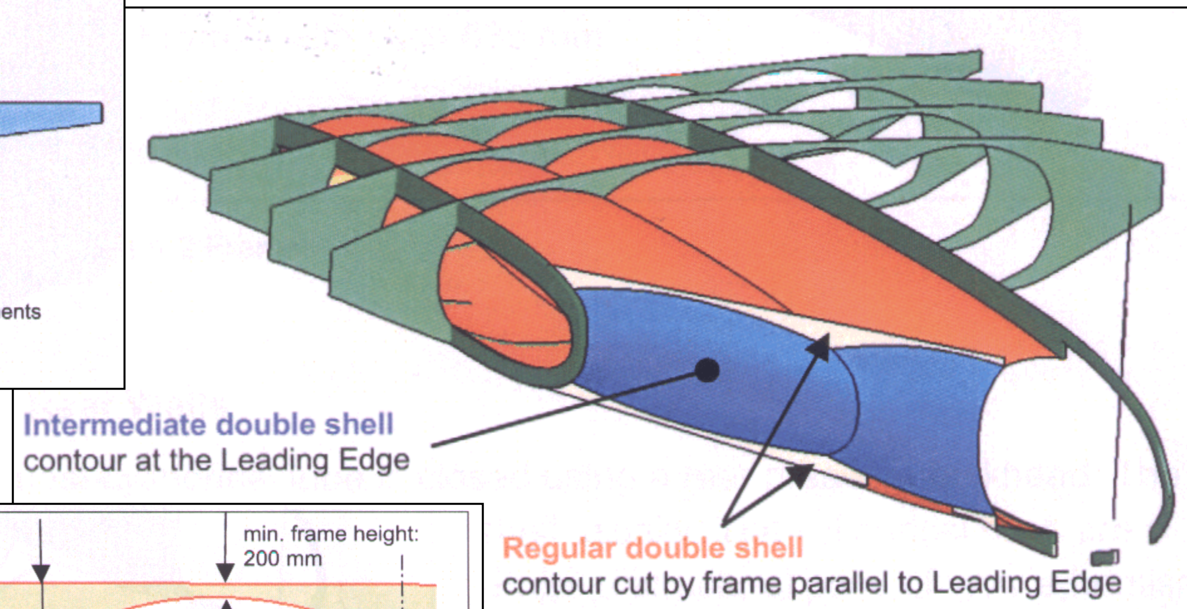
BWB study with distributed propulsion (Virginia Polytechnic)

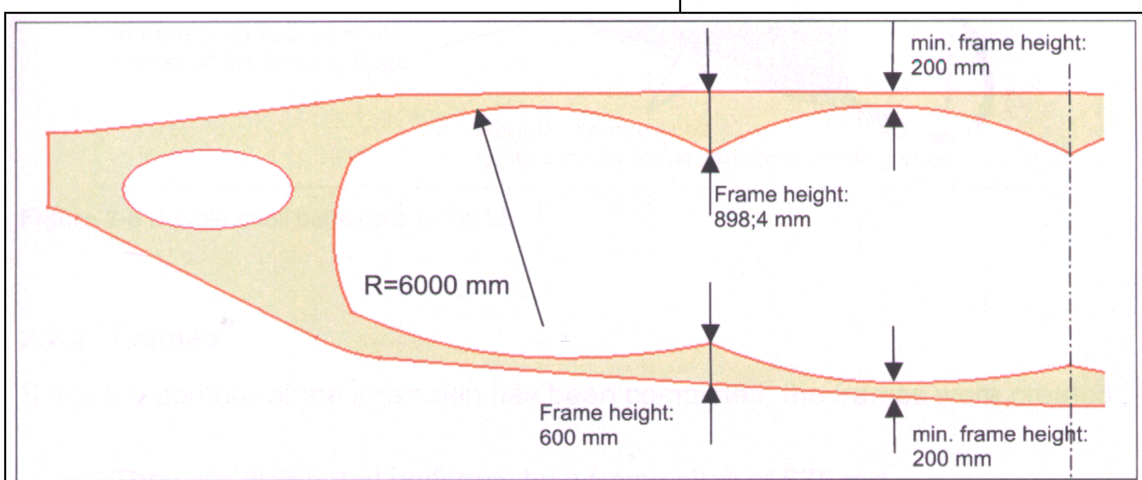
Helios - example of an extreme span loader with distributed propulsion (NASA / AeroVironment, Inc.)

VELA 2 - Basic Structural Layout

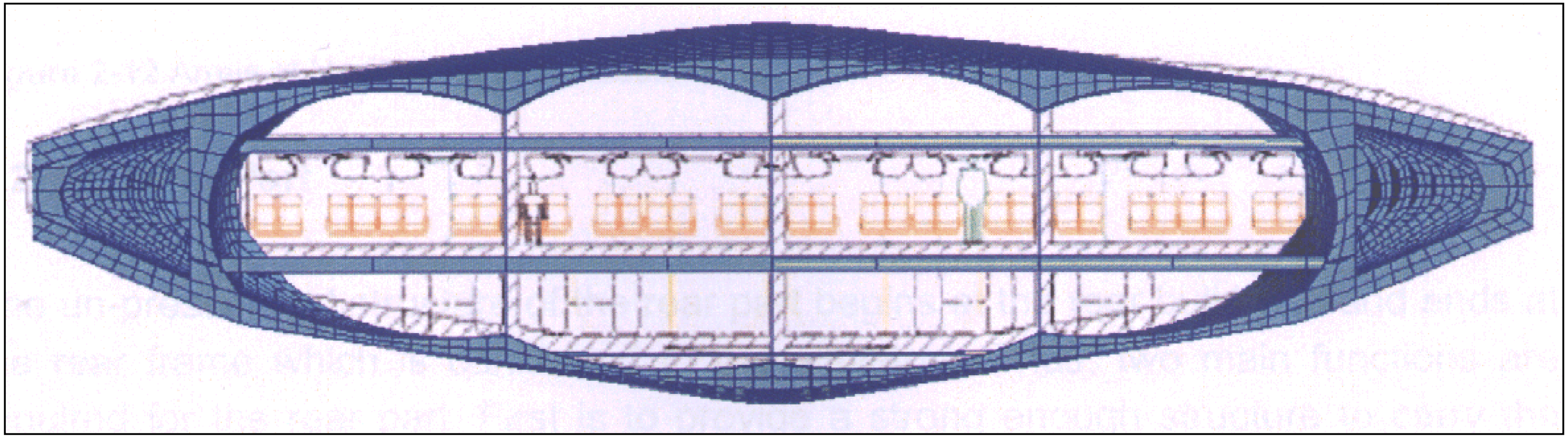
Thesis: T. Kumar Turai

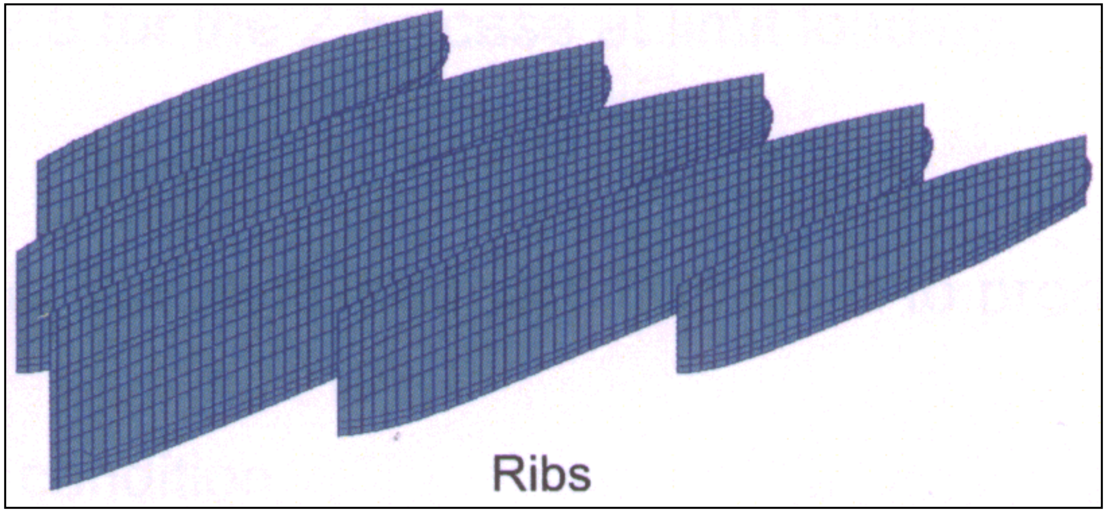




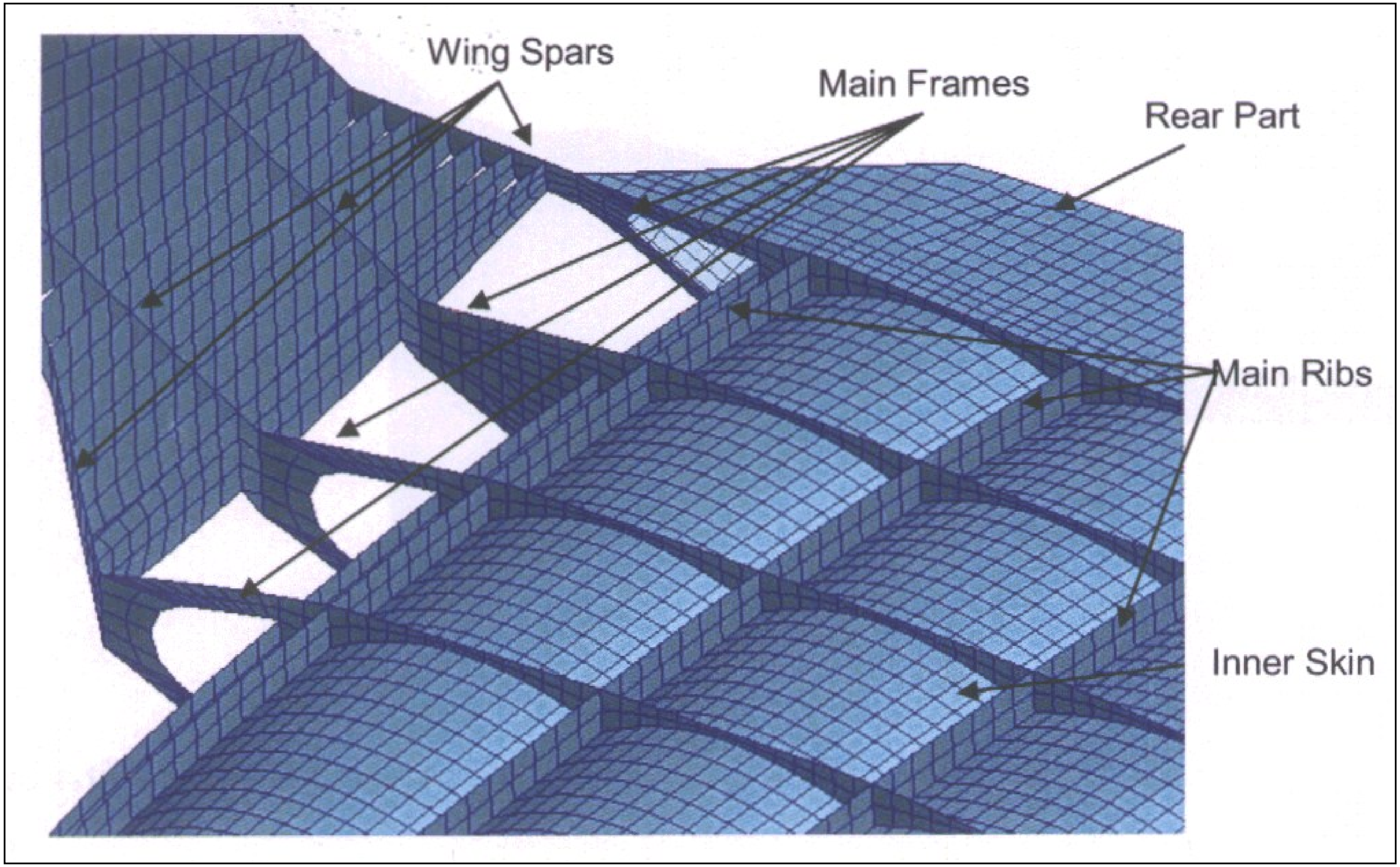


VELA 2 - Cabin

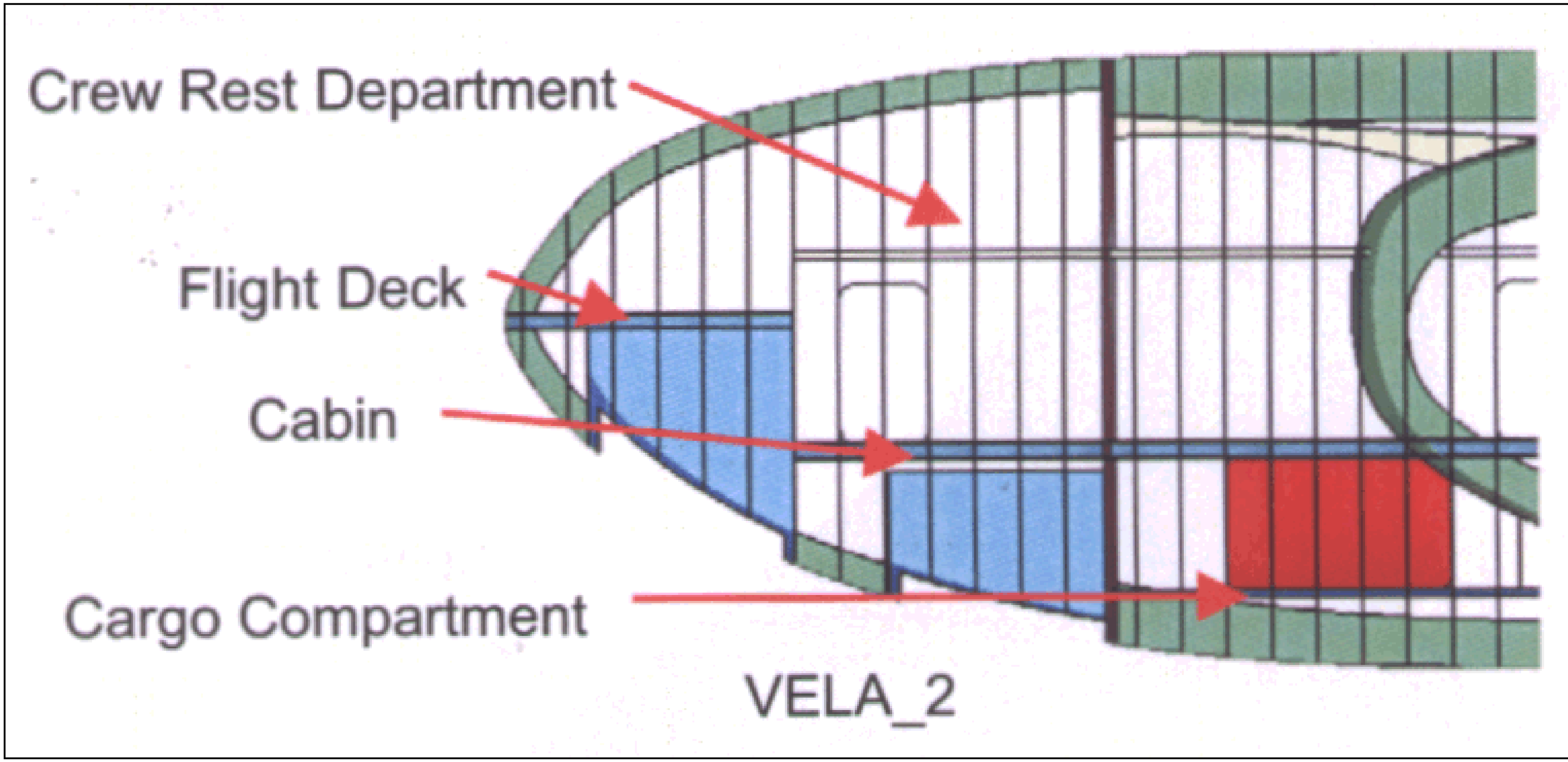




VELA 2 - Wing Integration

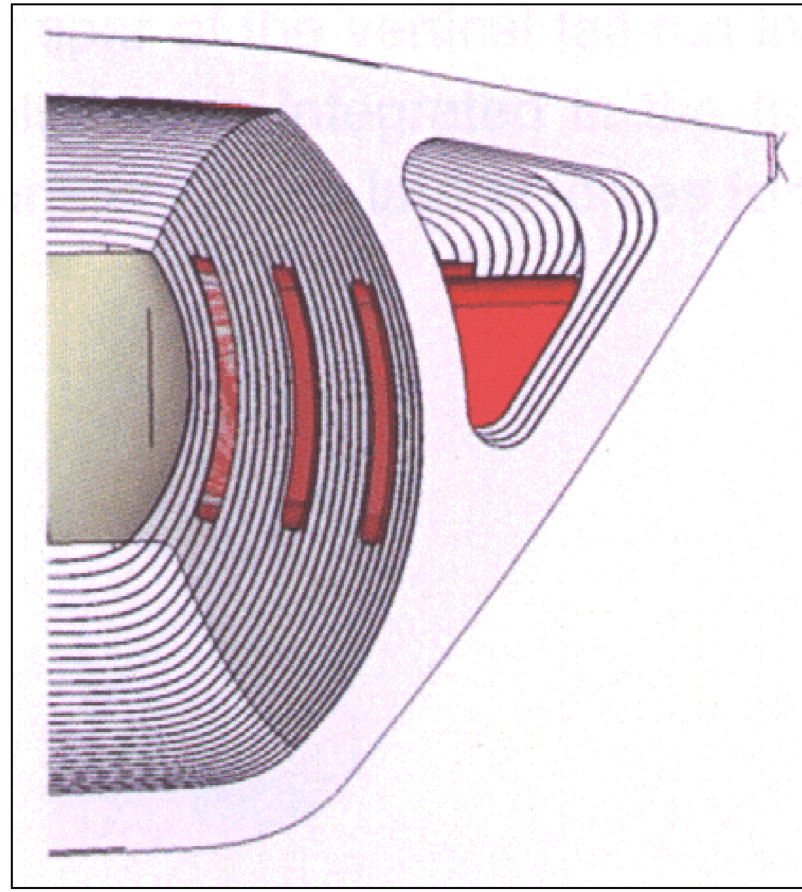


VELA 2 - Floor Integration



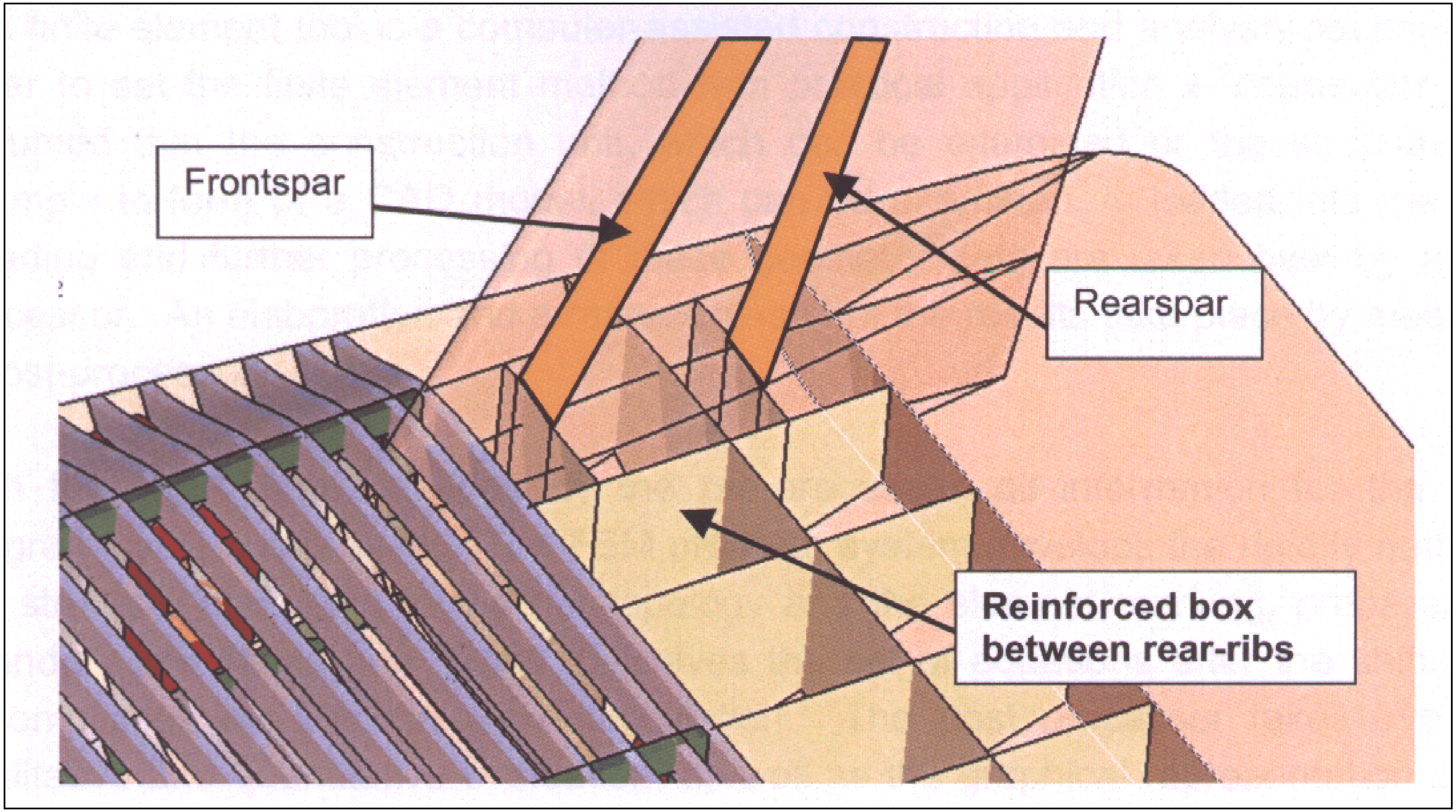
VELA 2 - Doors

Door cut-outs

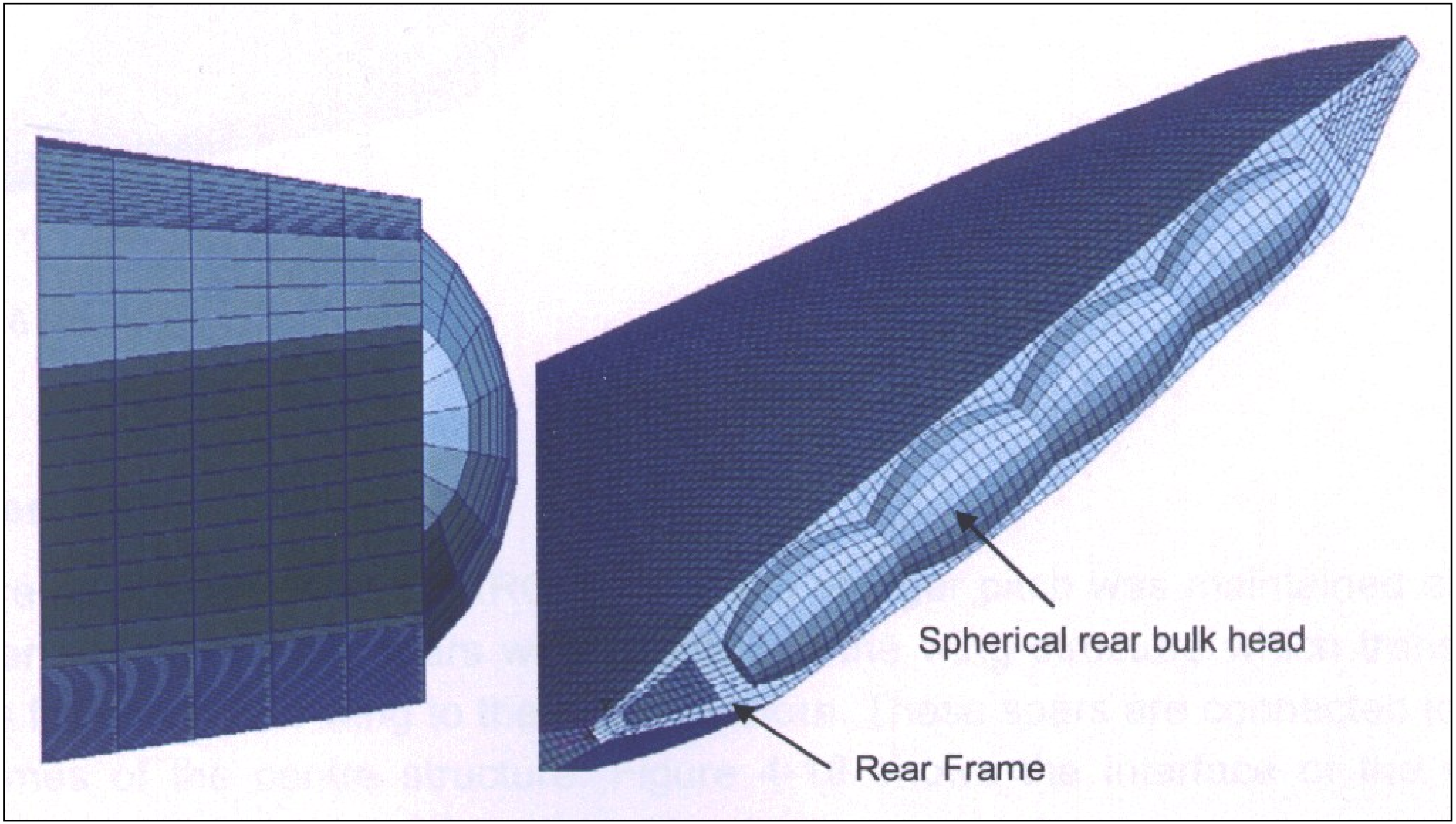


Side door integration

VELA 2 - Fin Integration



VELA 2 - Rear Pressure Bulkhead



VELA 2

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

System Integration

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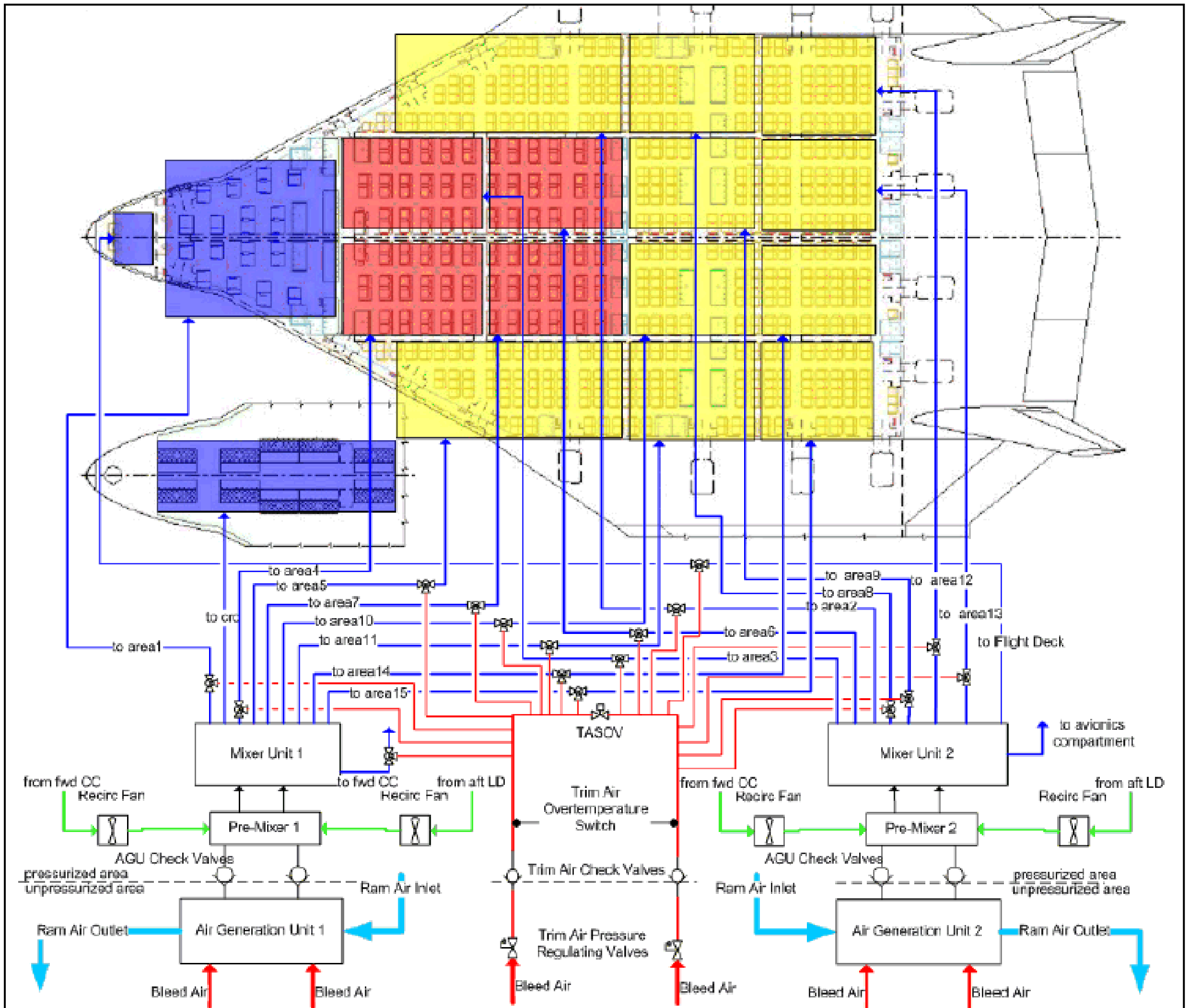
VELA 2 - ATA 21 - Temperature Control & Ventilation



Diplomarbeit: M. Mahnken

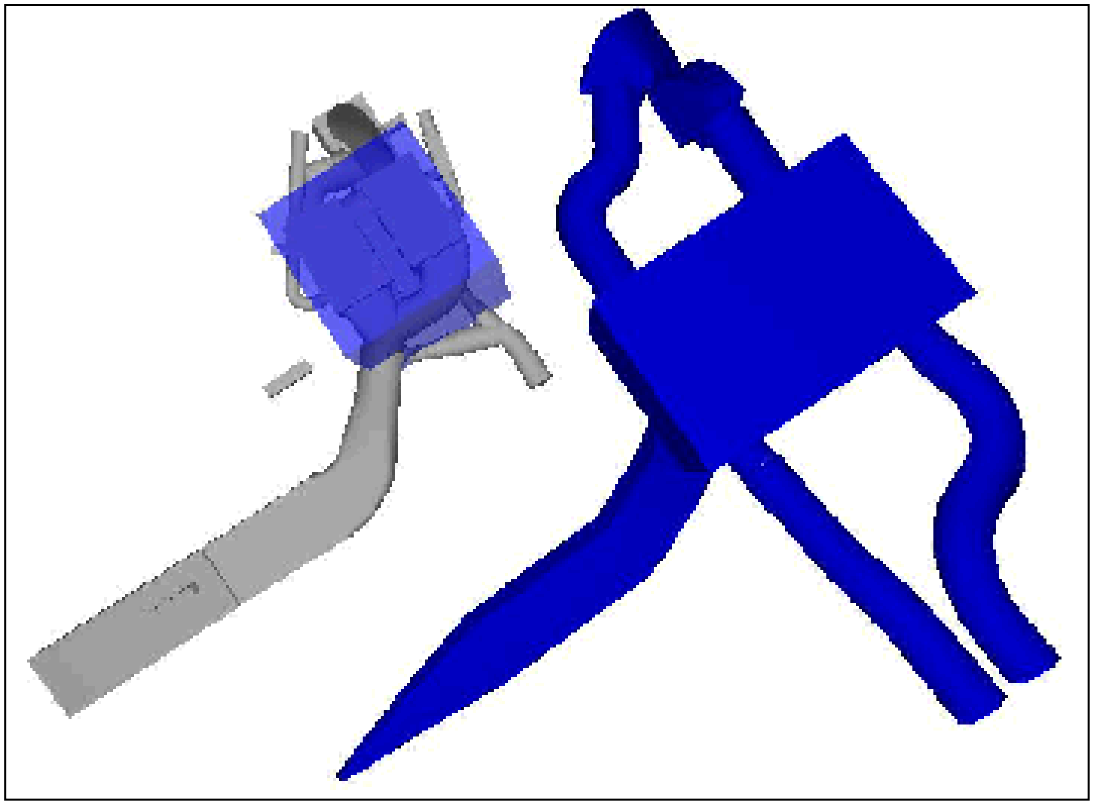
Steps in system integration:

1.) System diagram

2.) Sizing

3.) Routing & ducting

VELA 2 - ATA 21 - Pack Sizing



Air Generation Unit (pack): A380 and VELA 2

Steps in system integration:

1.) System diagram

2.) Sizing

3.) Routing & ducting

System Integration

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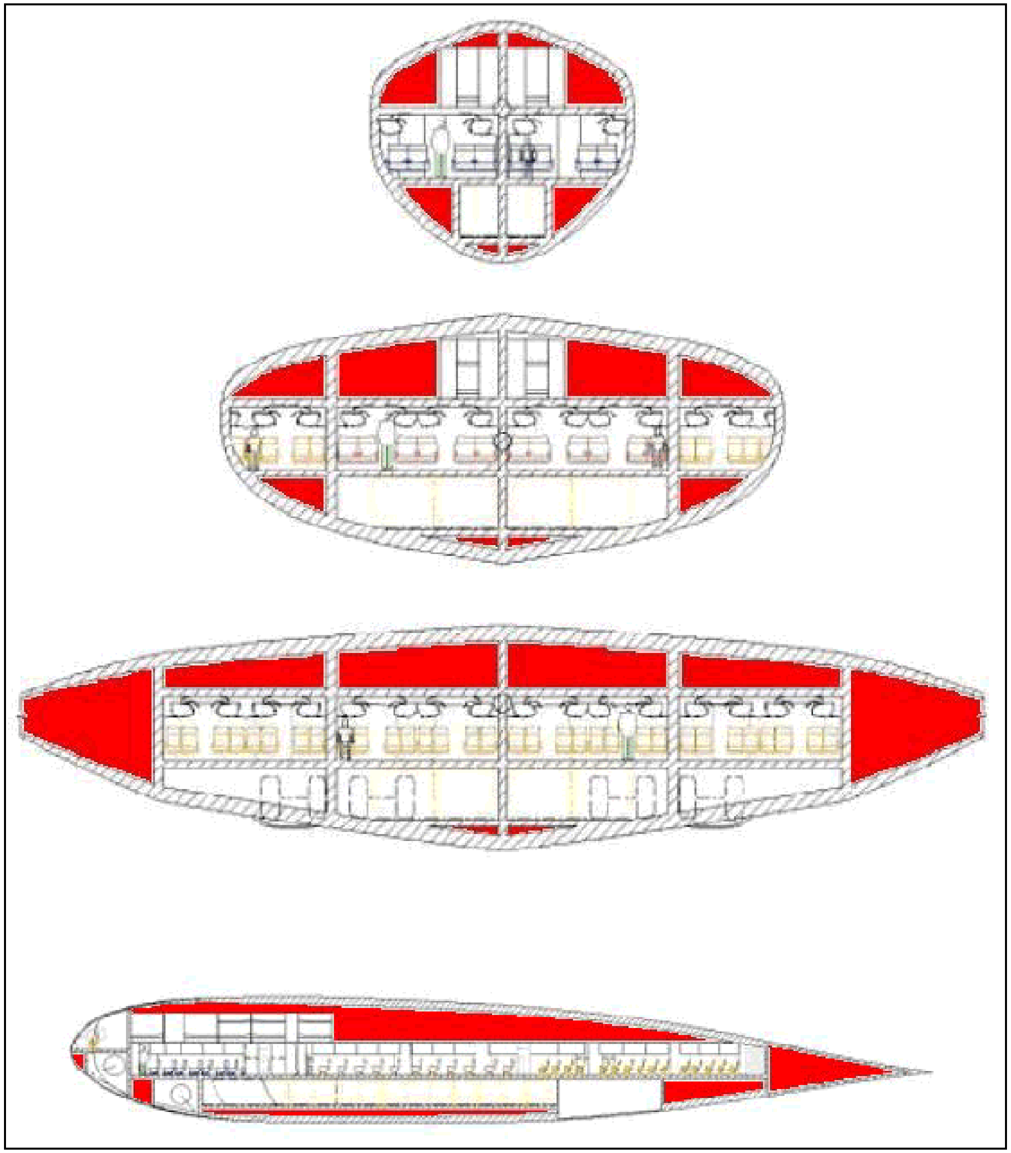


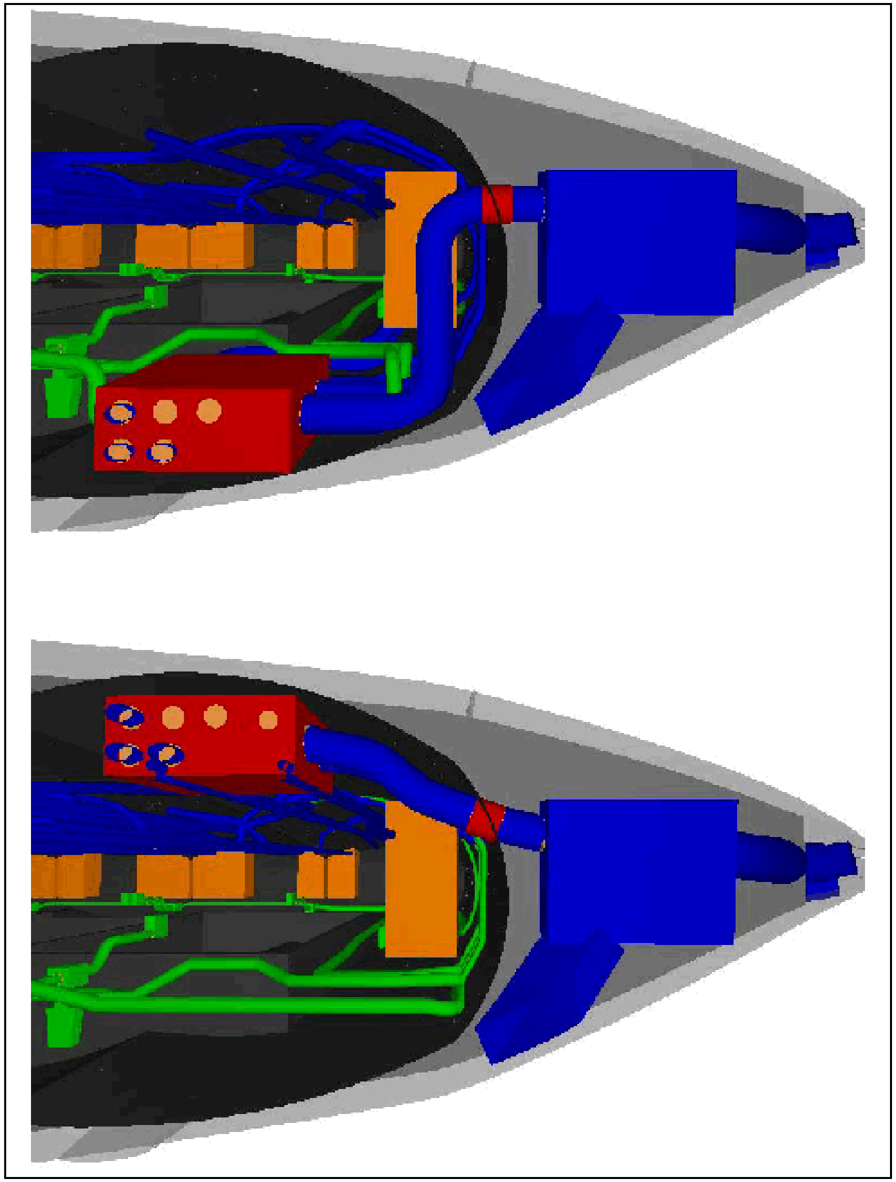
VELA 2 - System Installation Areas

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

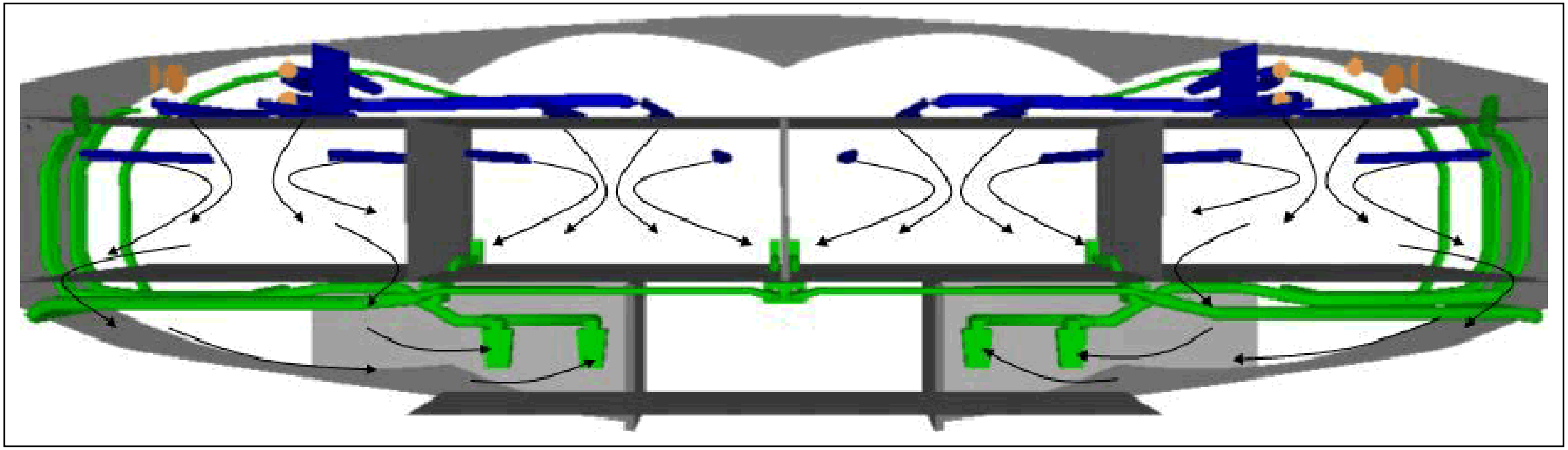
3.) Routing & ducting

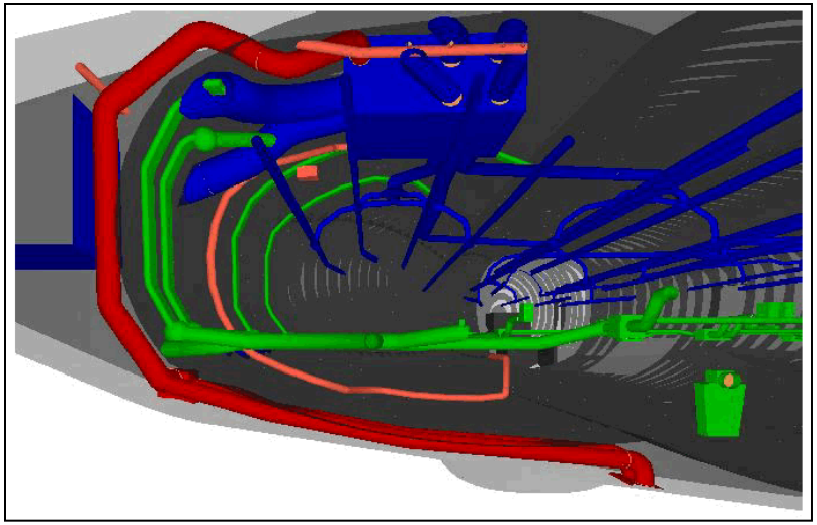
Air Generation Unit is positioned in the transition wing.

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

Ducts for recirculation air.

VELA 2 - ATA 21 - Ducting



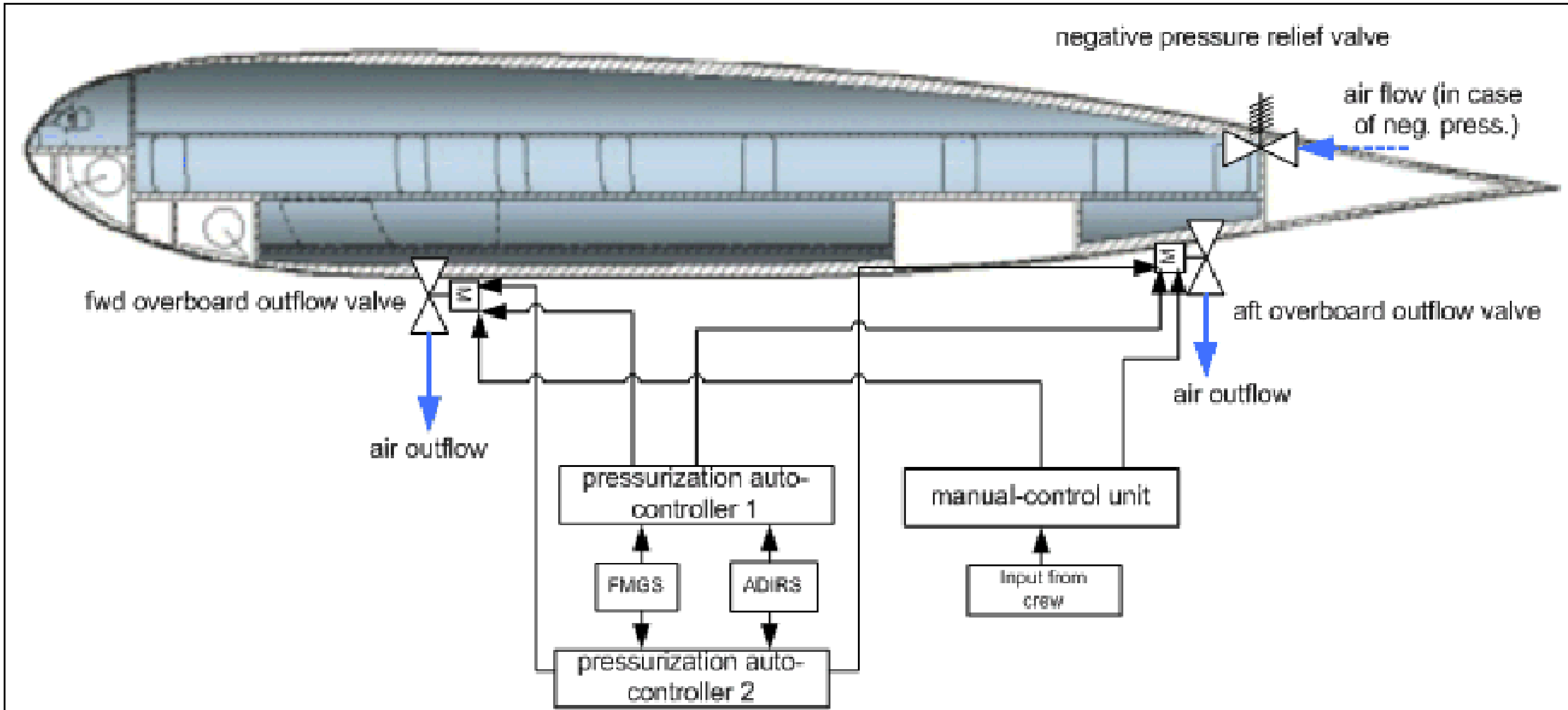


Air circulation. Recirculation requires ducts.

Low pressure air connector and duct to mixing unit.

Duct for emergency air.

VELA 2 - ATA 21 - Pressure Control



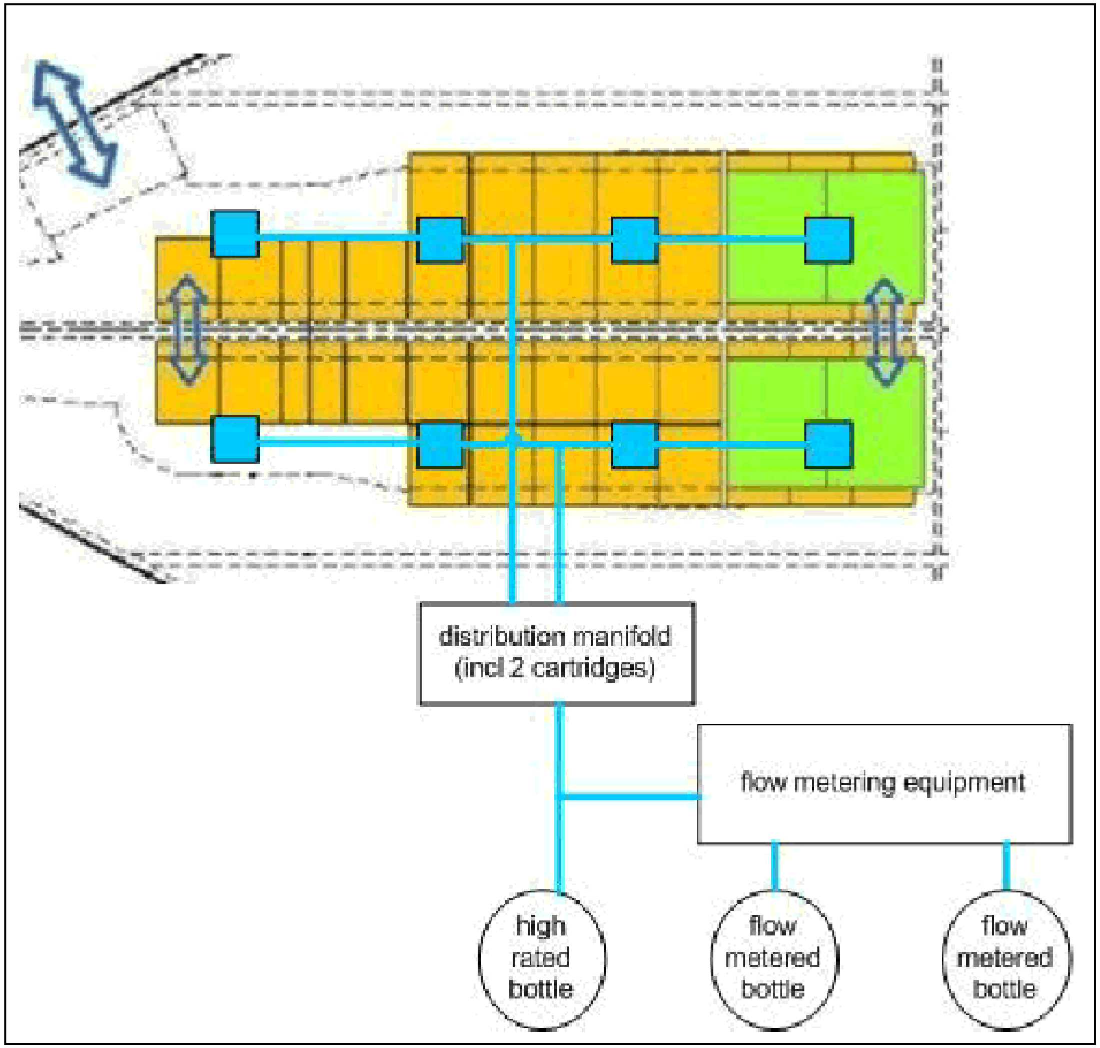
Steps in system integration:

1.) System diagram

2.) Sizing

3.) Routing & ducting

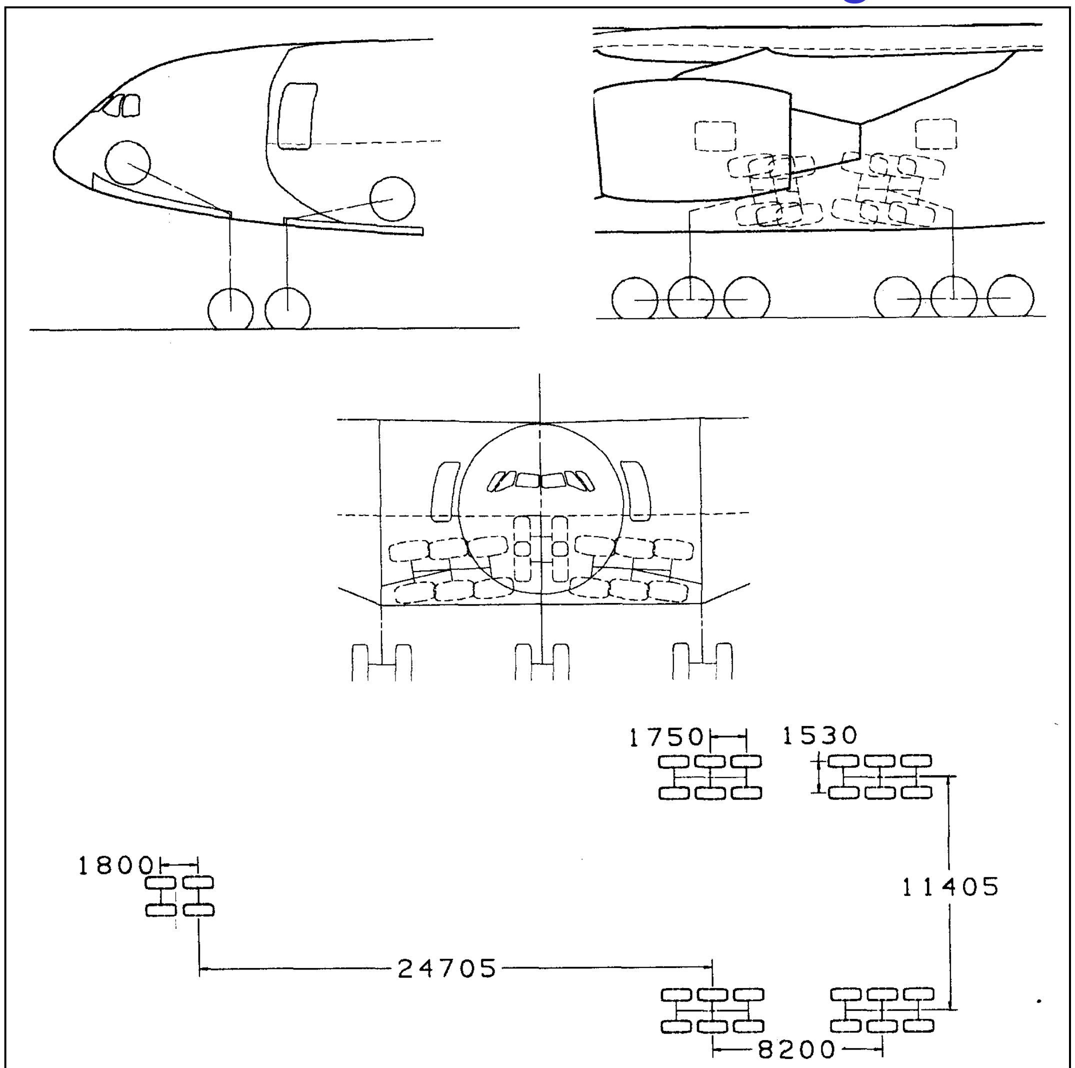
VELA 2 - ATA 26 - Cargo Fire Suppression System



Steps in system integration:

1.) System diagram
2.) Sizing
3.) Routing & ducting

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

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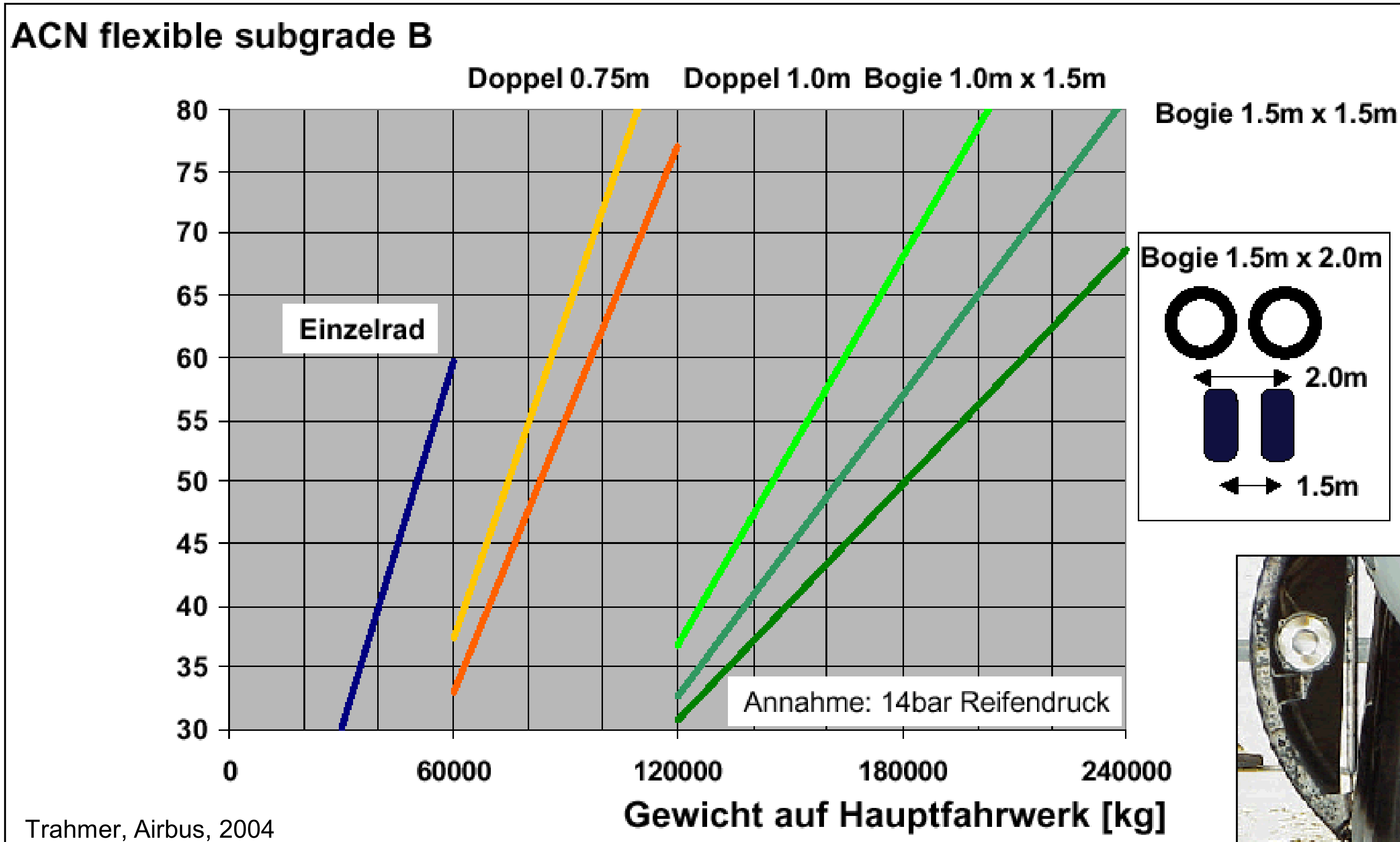
Aircraft Classification Number (ACN)

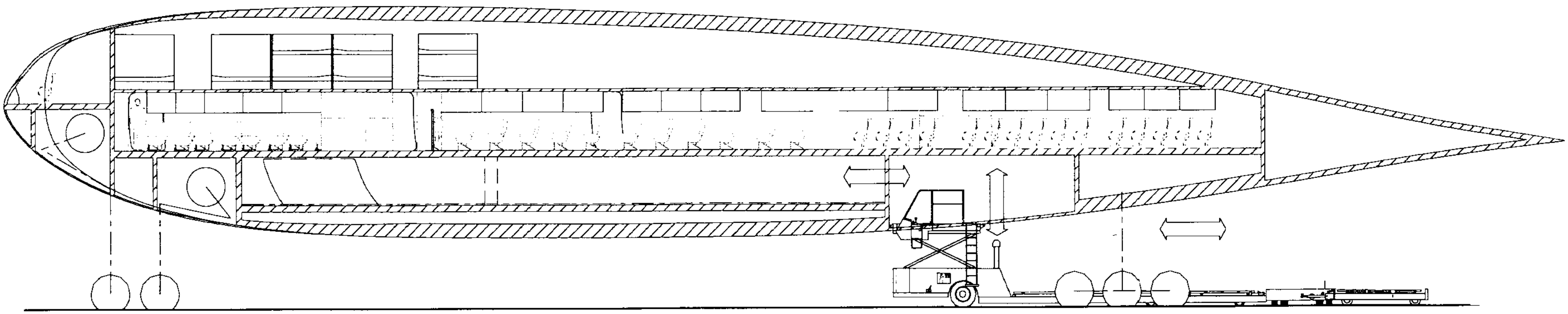


ACN calculation requires a computer program from ICAO or FAA.

α-factor for 6-wheel: 0.72

Air Transport System

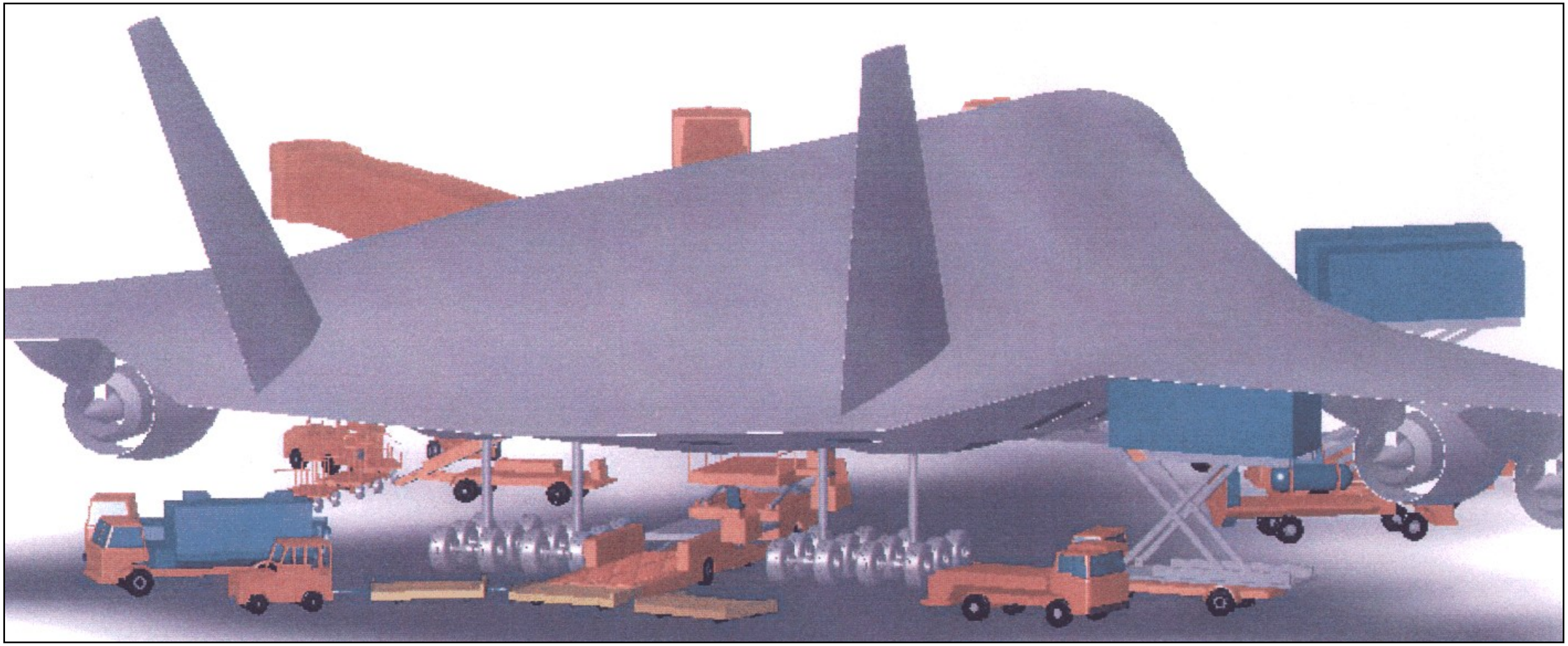
VELA 3 - Cargo Loading



A cargo loading vehicle drives in between the MLGs.
Cargo loading from below with lifting system.

Note also:
1.) NLG / MLG and wheel well positions.
2.) Far aft position of MLG => problem to rotate the aircraft on take-off.

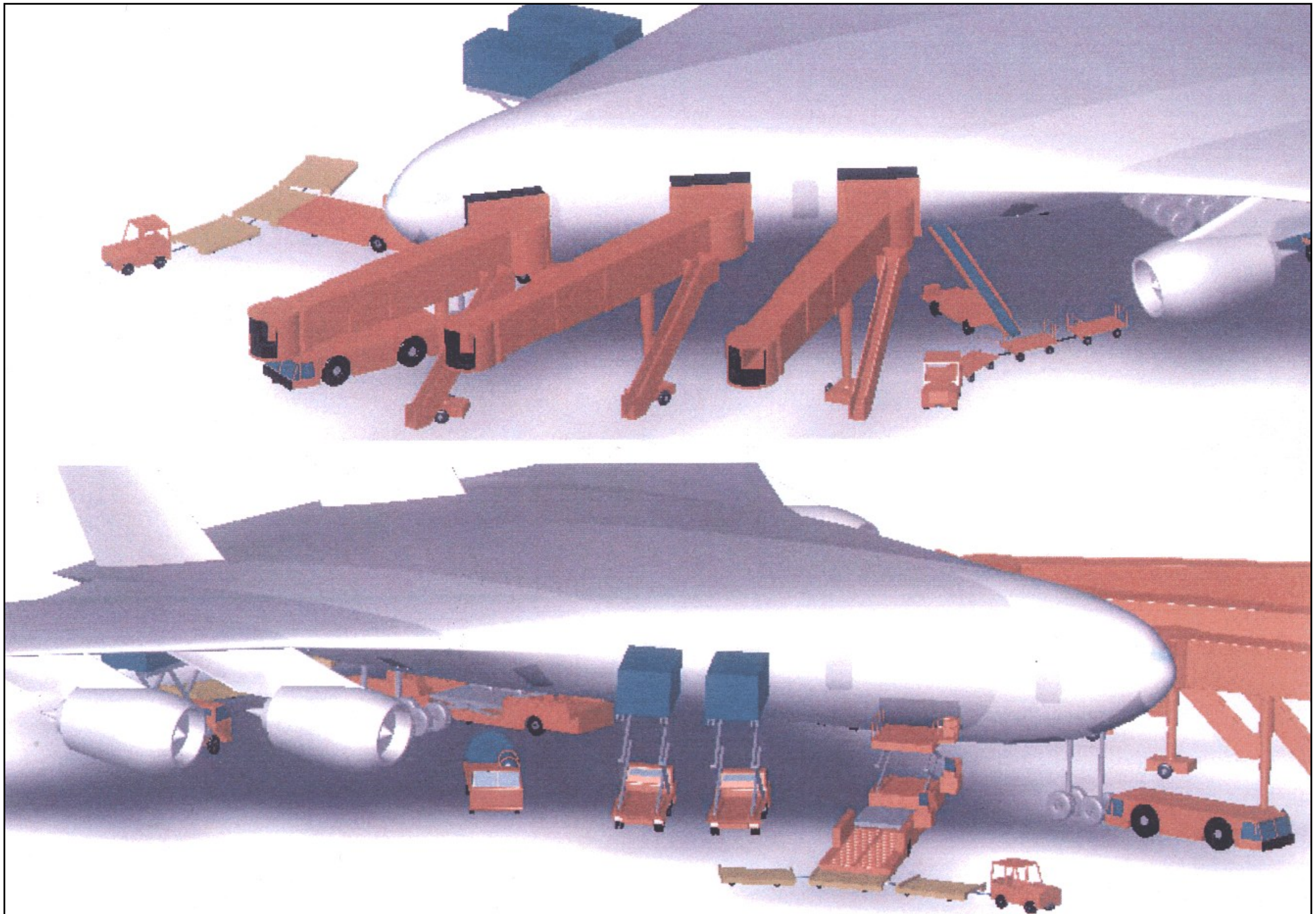
VELA 3



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.

VELA 2



Cargo loading from the right.

Catering from the right.

Boarding through three bridges.

Fuel truck under right wing.

Towing truck.

Not shown: Electrical ground power unit, air starting unit, air conditioning vehicle, water service truck, lavatory service truck.

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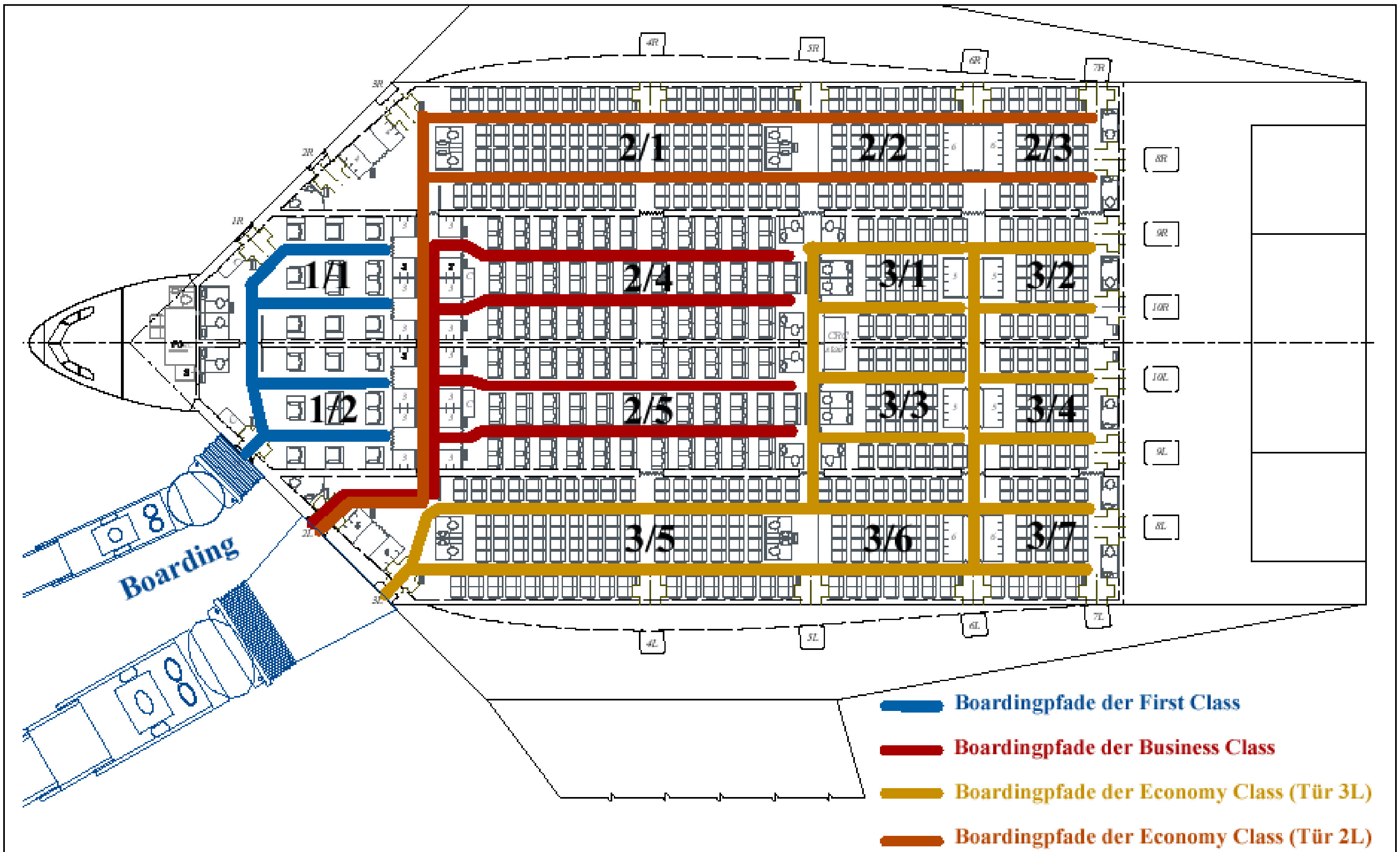
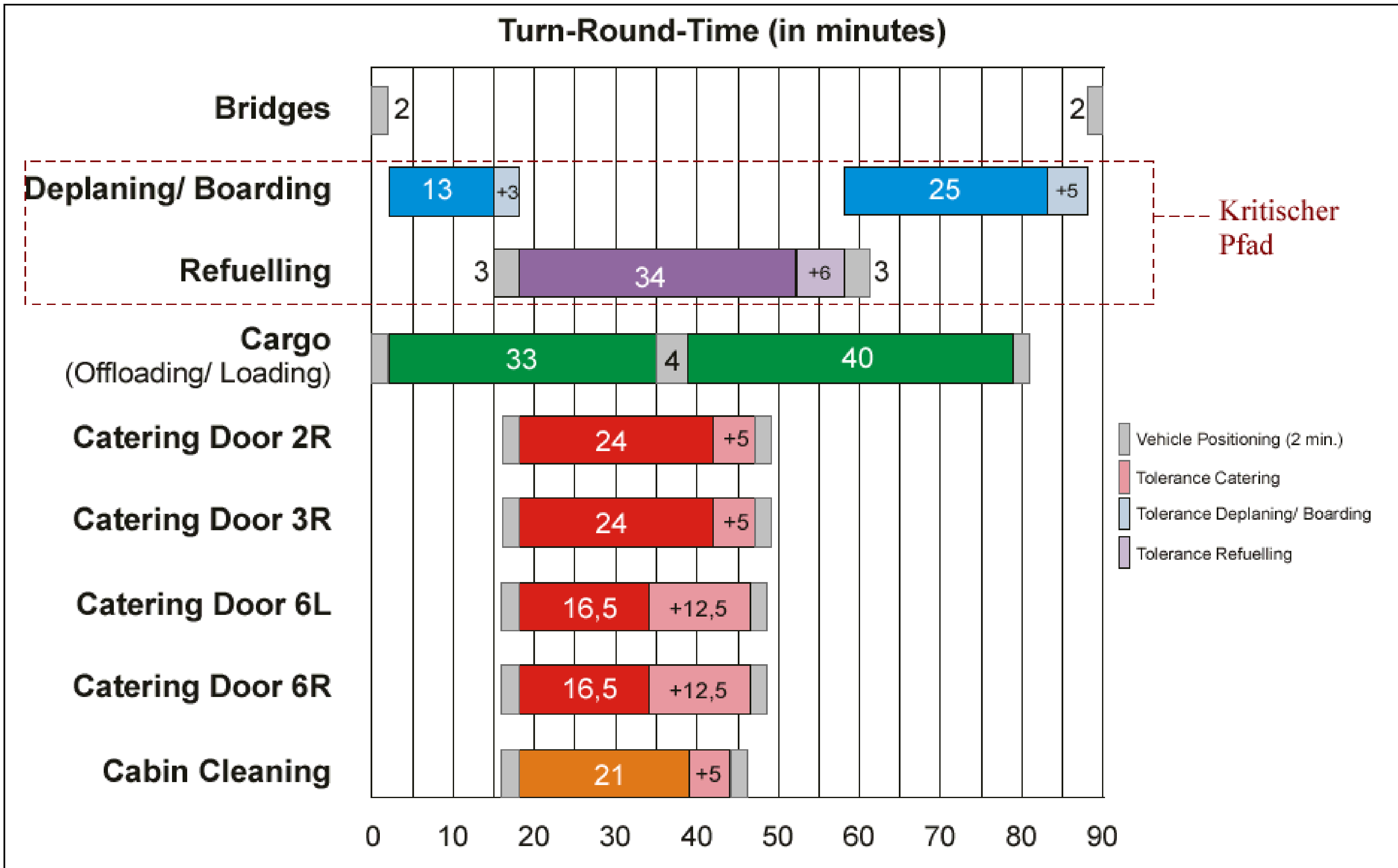
VELA 1 - Boarding

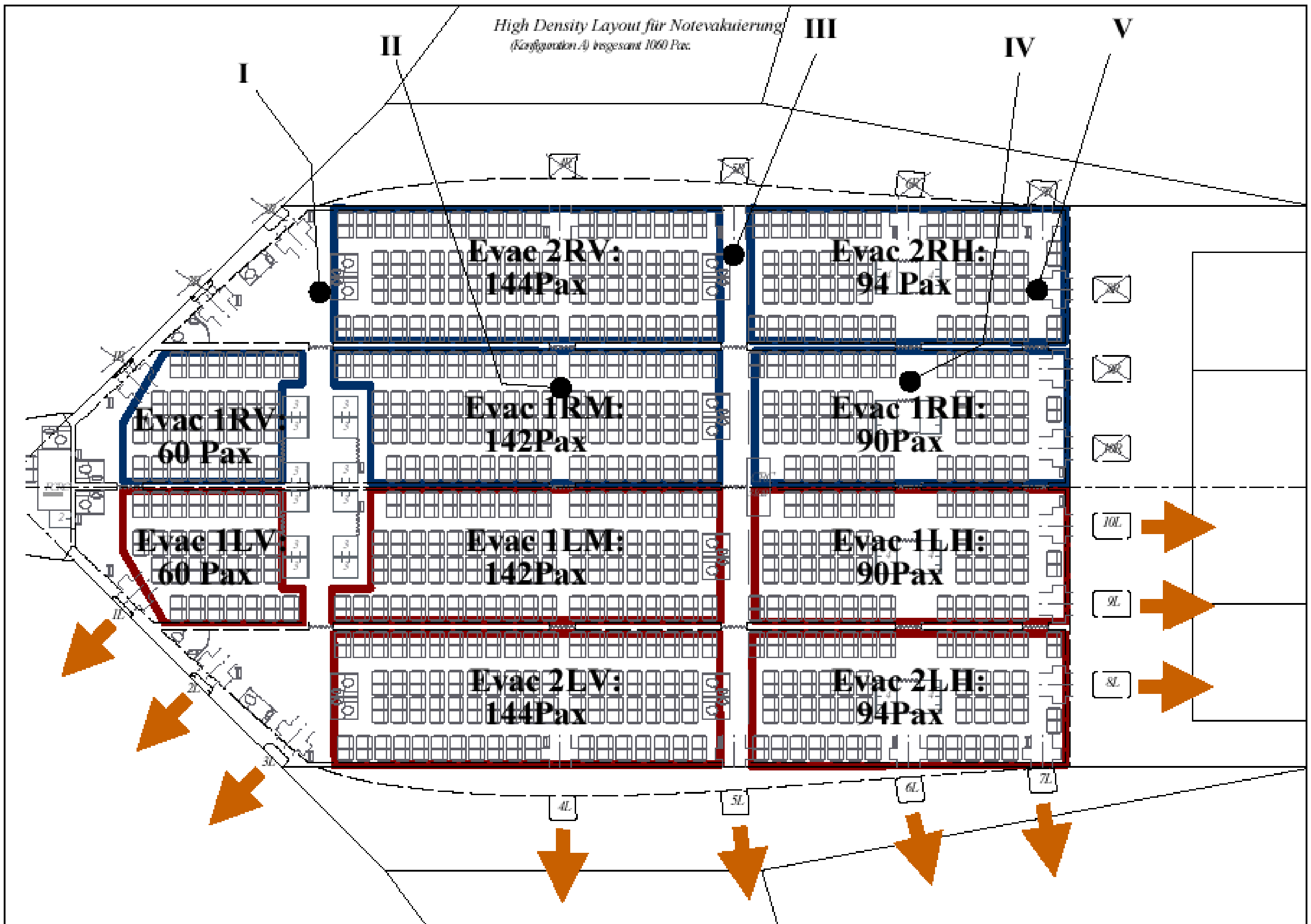
Diplomarbeit: S. Lee



VELA 1 - Turn Around Time



VELA 1 - Emergency Evacuation



Emergency

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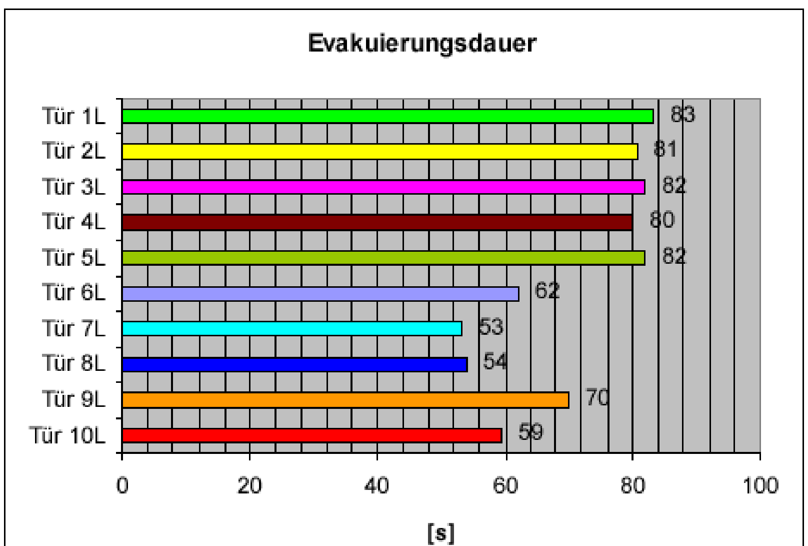
Evakuierungsdauer und –aufteilung an den Türen 1L bis 10L

Türen	Evakuierungs- Zone (Evac)										Pax an Tür	Zeit [s]
	1 LV	1LM	1LH	2LV	2LH	1RV	1RM	1RH	2RV	2RH		
Tür 1L	60					60	5				125	**83**
Tür 2L		34		35			32		20		121	**81**
Tür 3L		30		35			28		30		123	**82**
Tür 4L		26		37			32		25		120	**80**
Tür 5L		26		37			25		35		123	**82**
Tür 6L					32			27	34		93	**62**
Tür 7L					31			27		22	80	**53**
Tür 8L					31			18		32	81	**54**
Tür 9L		13	44				10	18		20	105	**70**
Tür 10L		13	46				10			20	89	**59**
Summe [Pax]	**60**	**142**	**90**	**144**	**94**	**60**	**142**	**90**	**144**	**94**	**1060**	

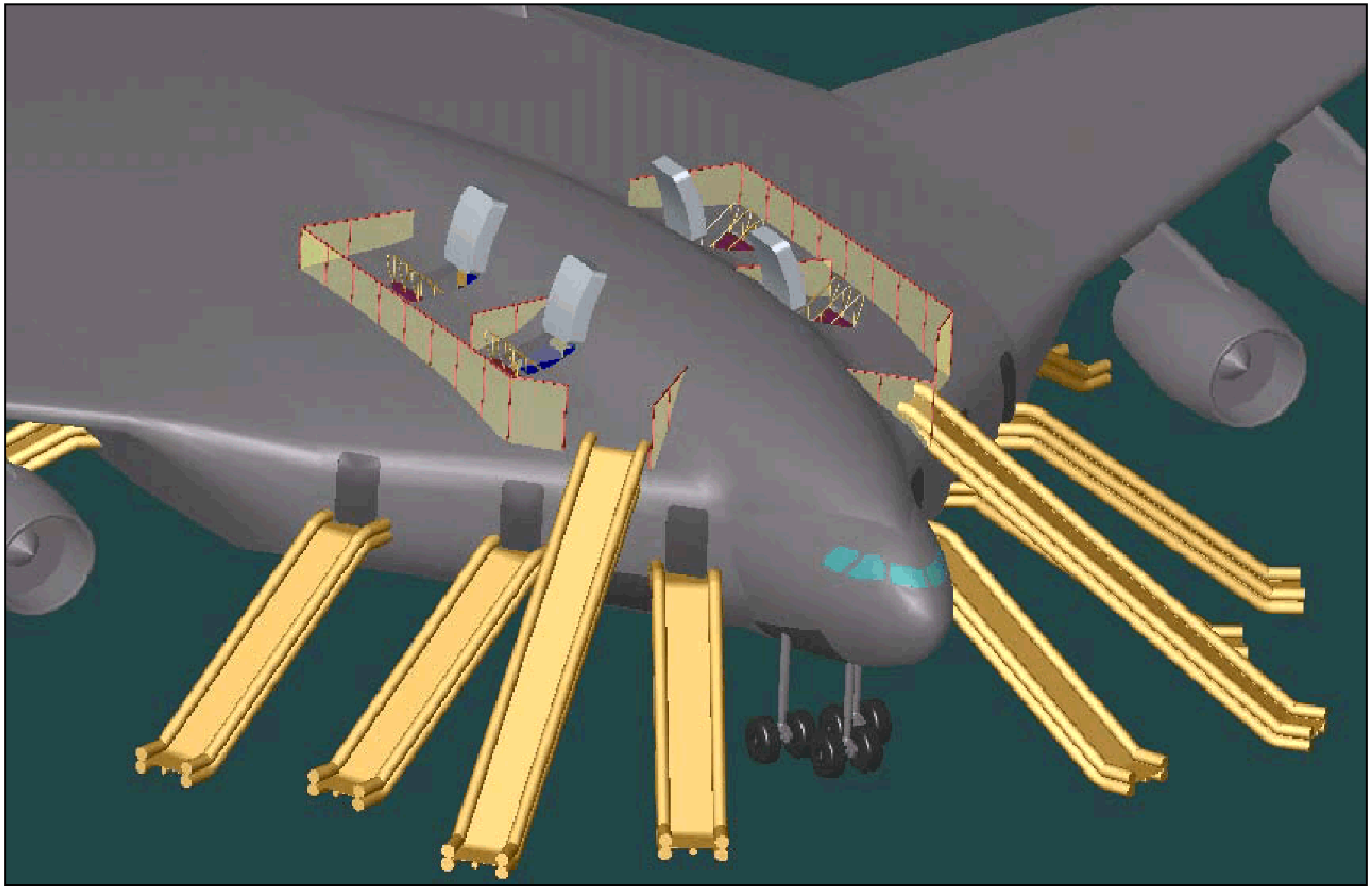


VELA 1 - Emergency Evacuation

Evacuation of possible in less than 90s if passengers are routed through their assigned door.

Emergency

VELA 1 - Emergency Evacuation - Slides - Ditching



Slides on forward doors.

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.

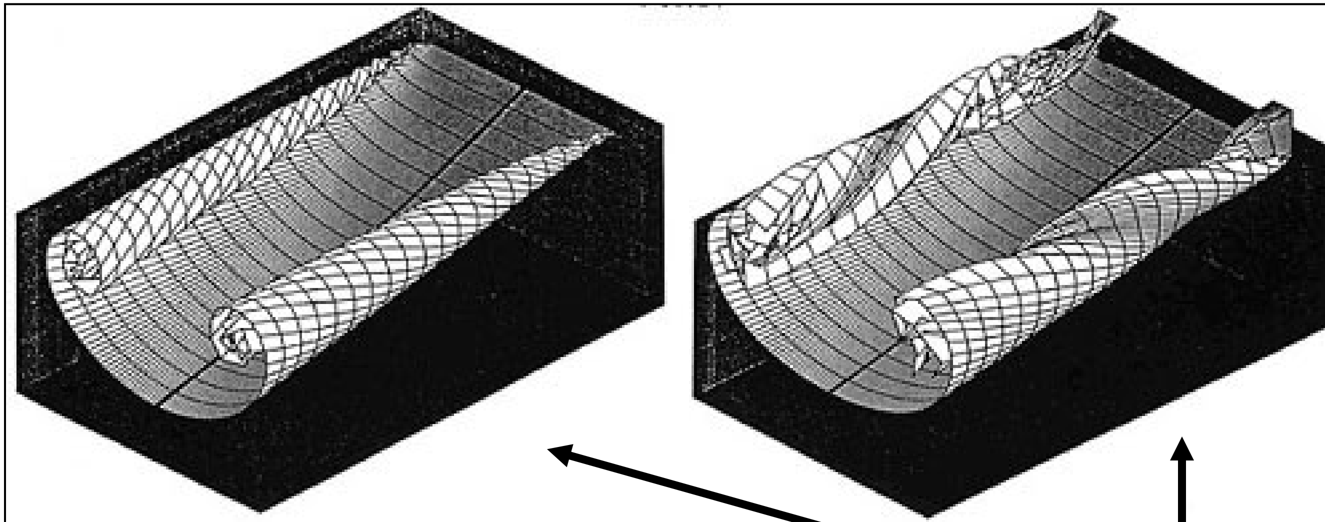
Wake Turbulence - Fundamentals

Wing tip vortices cause induced drag, D_i .

Wake turbulence cause a danger to following aircraft.

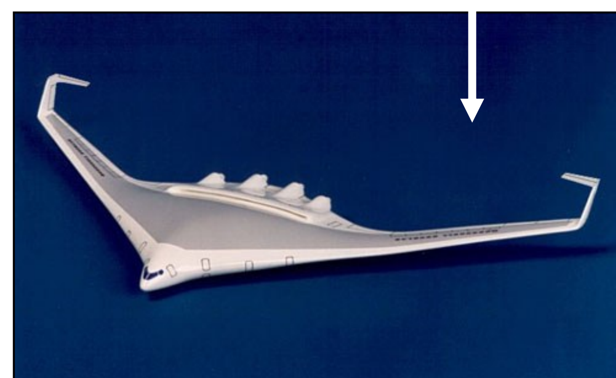
The initial strength of the wake turbulence is based on basic aircraft parameters:

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



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

C-Wing-BWB:



Wake Turbulence

Cessna Citation VI,
170 kt, 8400 kg

http://www.diam.unige.it/~irro/gallery.html, http://www.diam.unige.it/~irro/gallery/Cessna_downwash.jpg

Wake Turbulence - Comparison

$$\frac{P_{wake,BWB}}{P_{wake,A380}} \approx \frac{A_{A380}}{A_{BWB}} \cdot \frac{m_{MTO,BWB}}{m_{MTO,A380}} \cdot \frac{(m/S)_{BWB}}{(m/S)_{A380}} = \frac{7.53}{4.83} \cdot \frac{700}{560} \cdot \frac{341}{663} = 1.00$$

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

Wake Turbulence - Separation

IFR Minimum Separation Rules on Approach (nm)

	Trailing aircraft type[a]		
Leading aircraft type[a]	Small	Large	Heavy
Small	3.0	3.0	3.0
Large	4.0	3.0	3.0
Heavy	6.0	5.0	4.0

Source: FAA [1978]

[a] Small: aircraft weighting no more than 12,500 lb. (5,625 kg)
Large: aircraft weighting 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

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ICAO and FAA Requirements on Aircraft Parameters for Airport Compatability

Airport Category	Airplane Overall Length (m)
1	0-9
2	9-12
3	12-18
4	18-24
5	24-28
6	28-39
7	39-49
8	49-61
9	61-76

VELA 3: 65 m

Requirements from Aerodrome

ICAO aerodrome reference codes [ICAO, 1999]

Aerodrome code number	Reference field length (m)	Aerodrome code letter	Wingspan (m)	Outer main gearwheel span (m)
1	<800	A	<15	<4.5
2	800–<1200	B	15–<24	4.5–<6
3	1200–<1800	C	24–<36	6–<9
4	≥1800	D	36–<52	9–<14
		E	52–<65	9–<14
		F	65–<80	14-<16

VELA 3: 11,4 m

FAA airport reference codes [FAA, 1989]

Aircraft approach category	Aircraft approach speed (kn)	Aeroplane design group	Aircraft wingspan (m)
A	<91	I	<15
B	91–<121	II	15–<24
C	121–<141	III	24–<36
D	141–<166	IV	36–<52
E	≥166	V	52–<65
		VI	65–<80

VELA 3: 99,6 m

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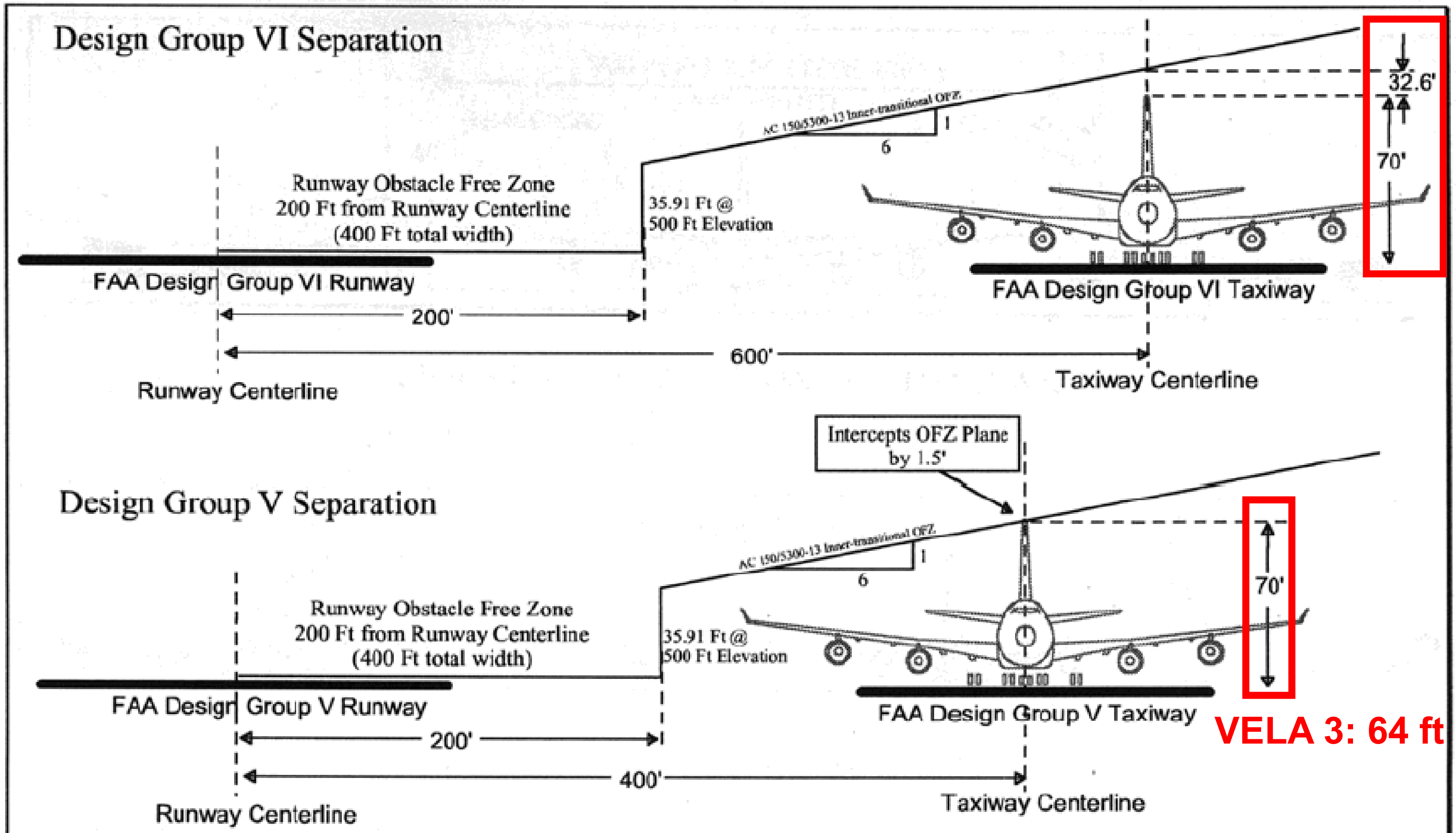
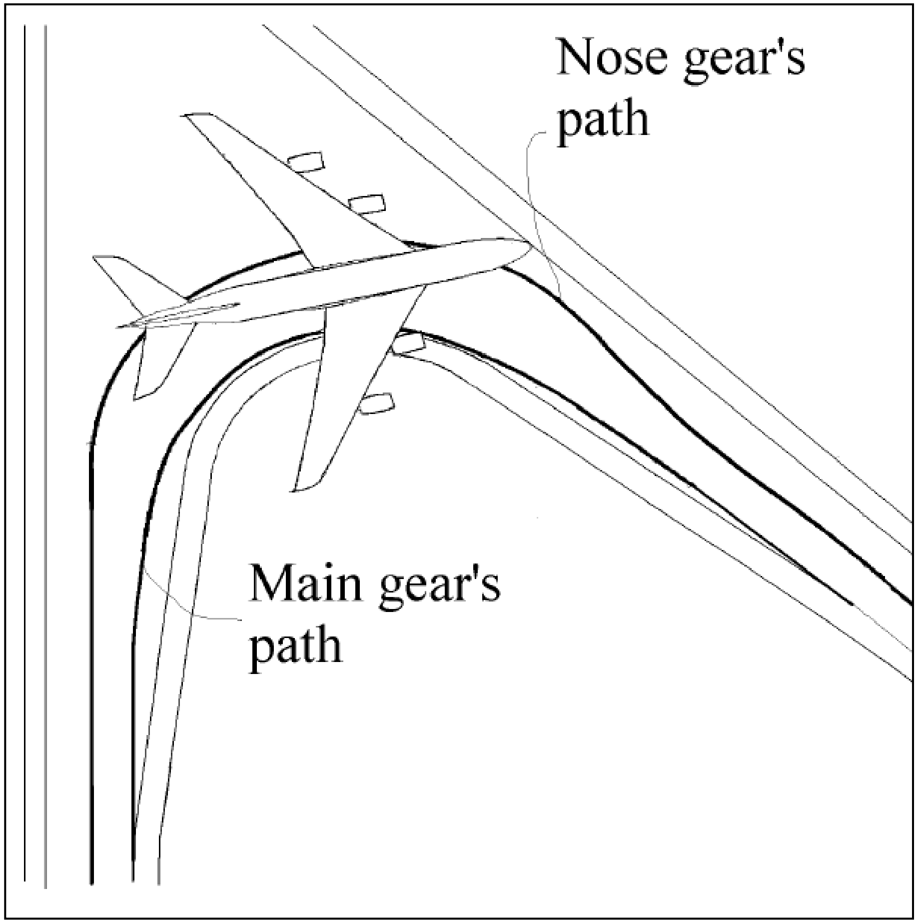
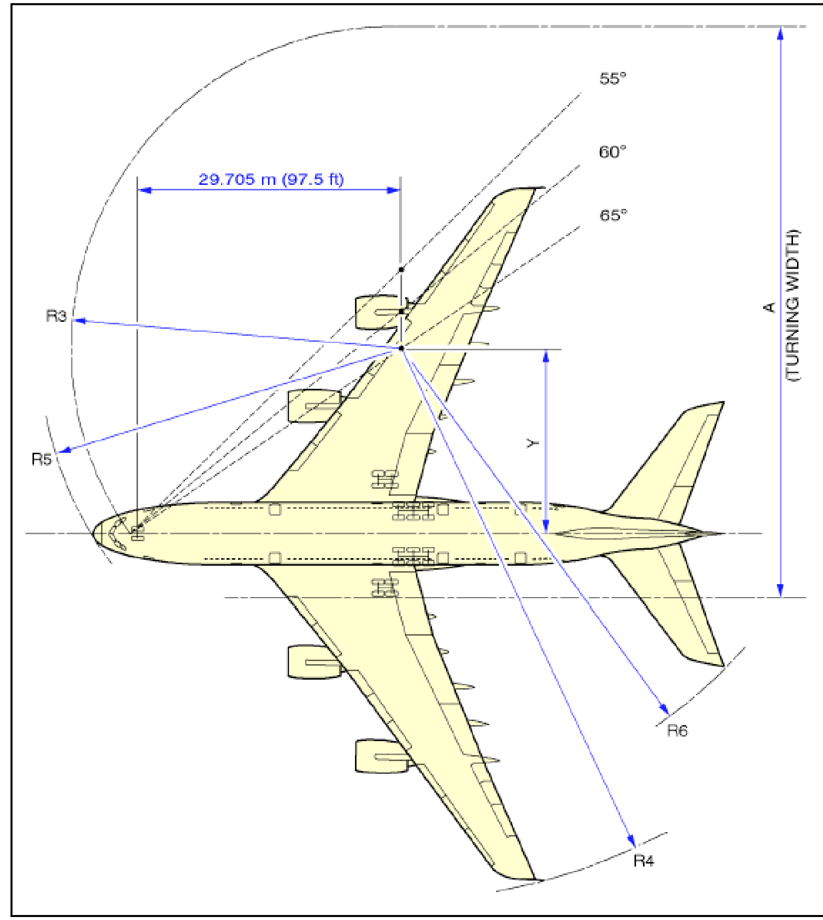


Clearance between runway and parallel taxiway (FAA 1998) =>
Maximum aircraft height (80 ft).

Requirements from Aerodrome



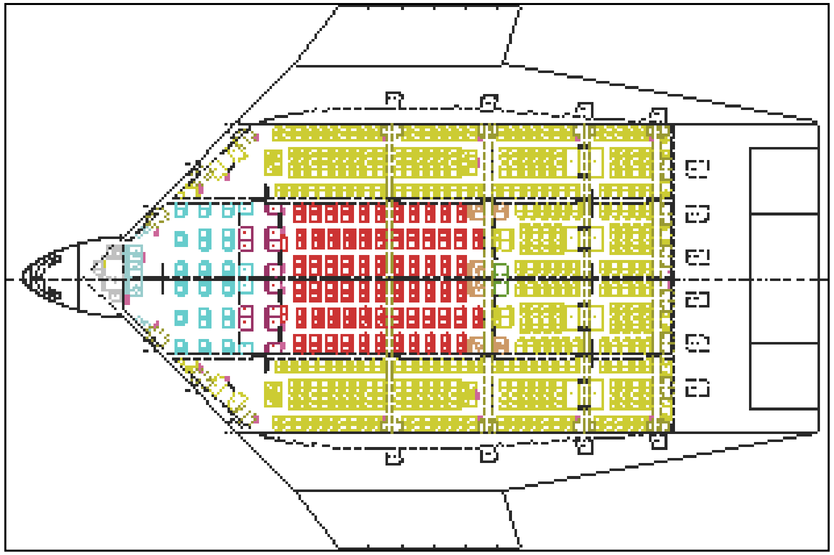


Turning radius and taxiway fillets for aircraft turning.

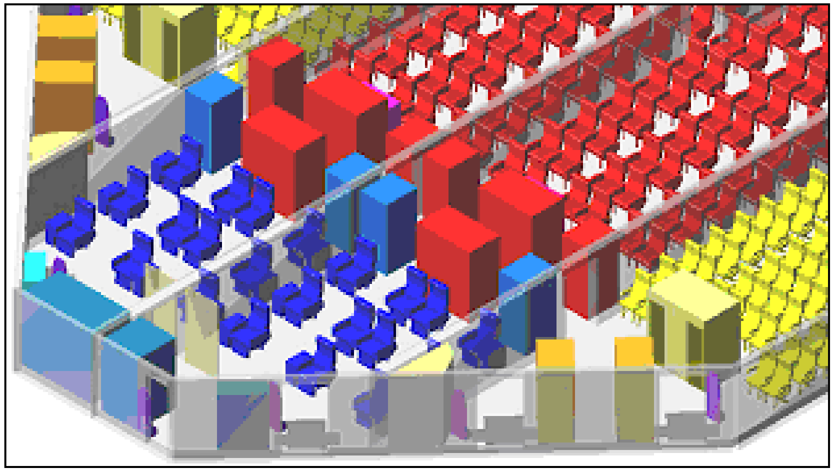
Wheel span:	**A380:**	**12.5 m**	
	VELA:	**11.4 m**	**=> similar turn characteristic.**

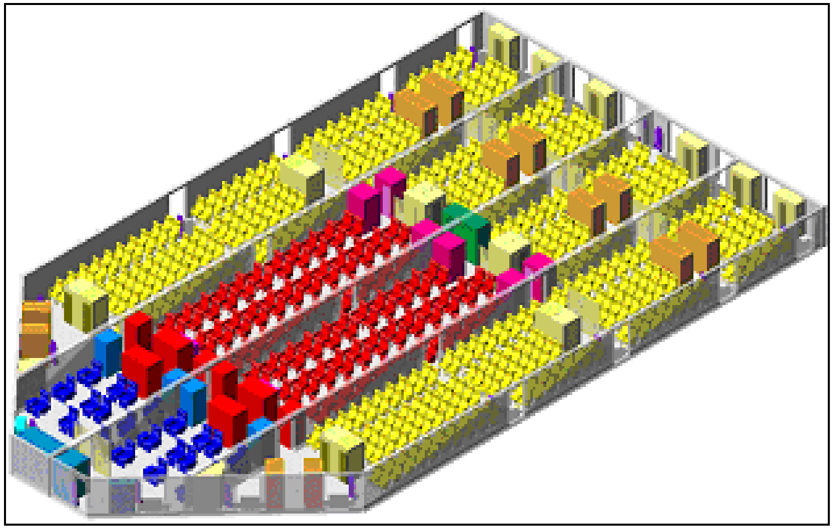
VELA 1 - Cabin Layout

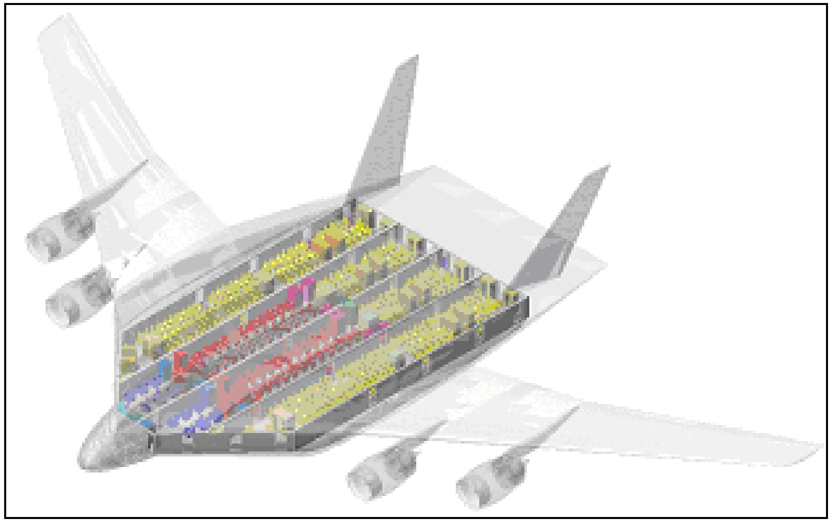
Diplomarbeit: S. Lee



Vertical acceleration for pax on outer seats.







Double Deck BWB

W. Granzeier

Interior Design

Underfloor Usage - Artificial Windows

W. Granzeier

BWB Center Wing Shapes from Inside

W. Granzeier

AC20.30

AC20.30

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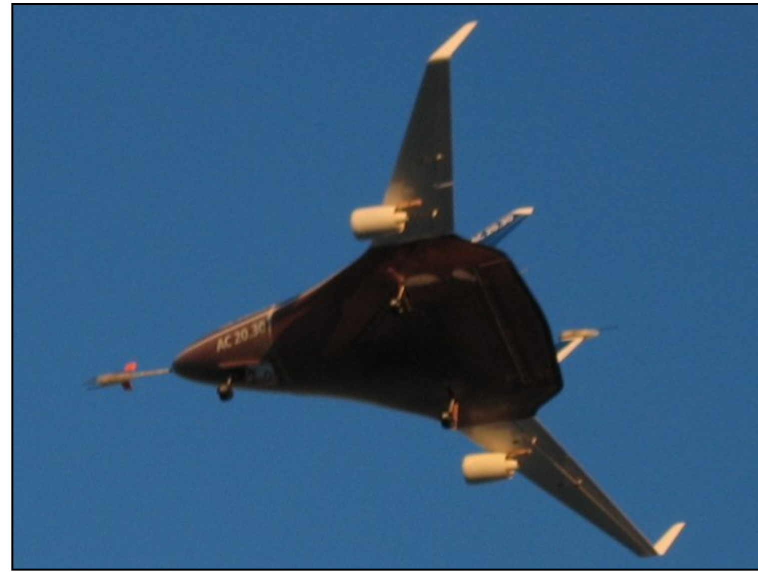
Test Flights



AC20.30 Parameters

Scale	1:30
Span	3.24 m
Length	2.12 m
MTOW	12.5 kg
Engines	2 electric driven fans
Thrust	2 x 30 N
Power input	2 x 1400 W

Oliver Drescher prepares the AC20.30 for flight.

AC20.30

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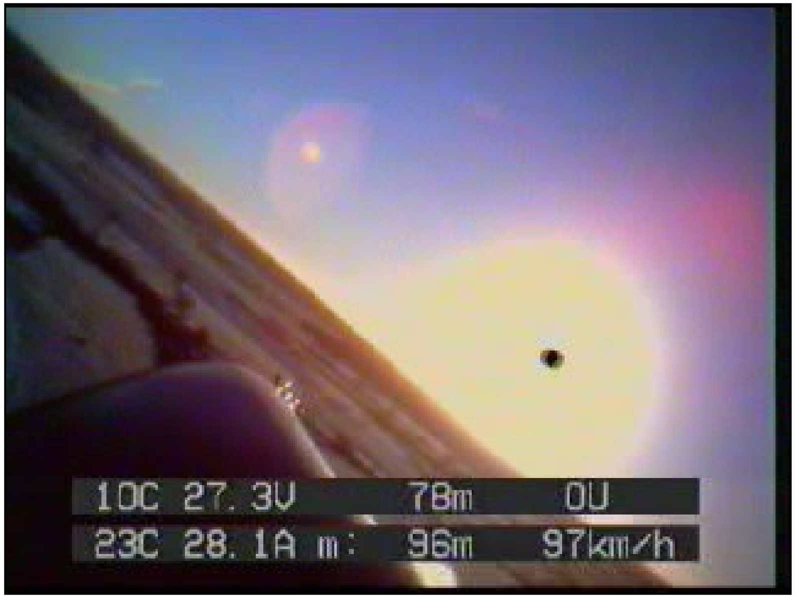
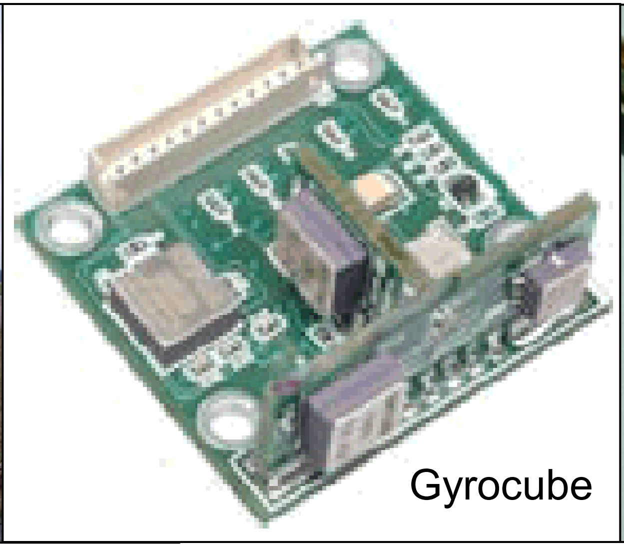
Test Flights

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, aerborne camera picture



The telemetry ground station.



Gyrocube

BWB Video

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Flight Test / Flugerprobung, BWB, HAW Hamburg (2005)

https://purl.org/aerolectures/2026-01-15/Videos

AC20.30

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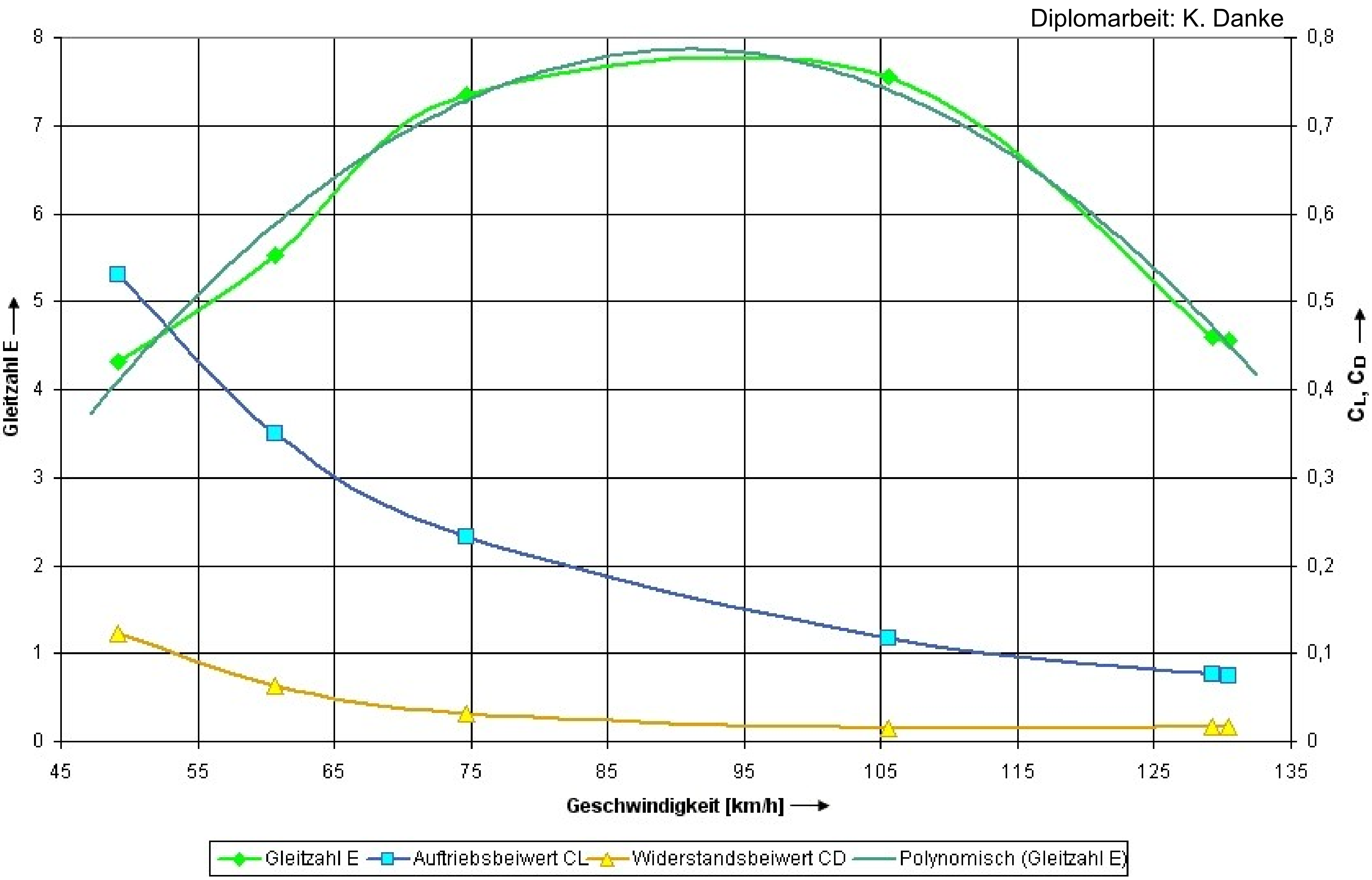
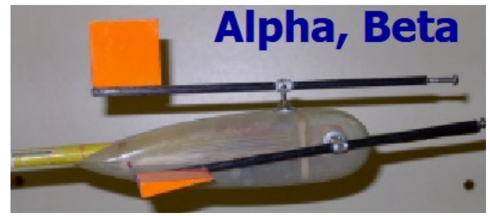


Euler Angles: Pitch Angle, Θ and Roll Angle, Φ from Test Flights with the "Gyrocube"

$$U = V_T \cos\beta \cos\alpha$$
$$V = V_T \sin\beta$$
$$W = V_T \cos\beta \sin\alpha$$



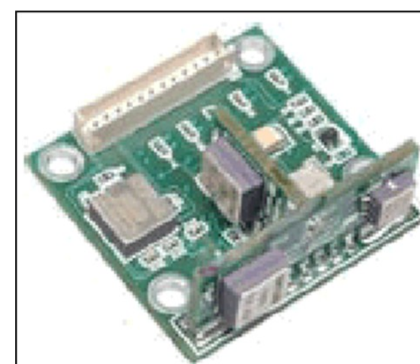
$$a_x = \dot{U} + QW - RV + g\sin\Theta$$ ← solved for pitch angle, Θ

$$a_y = \dot{V} + RU - PW - g\cos\Theta\sin\Phi$$ ← solved for roll angle, Φ

$$a_z = \dot{W} + PV - QU - g\cos\Theta\cos\Phi$$ ← check results

Experience with Measurement Technique:
Simple and inexpensive method.
Drift problems are unknown.
Good results only for manoeuvres with moderate dynamic.

D. Scholz



The Gyrocube provides the three accelerations in x, y, z and the three angular velocities, P, Q, R.

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Wind Tunnel Tests

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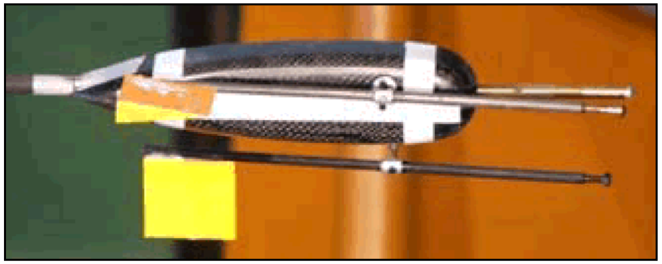

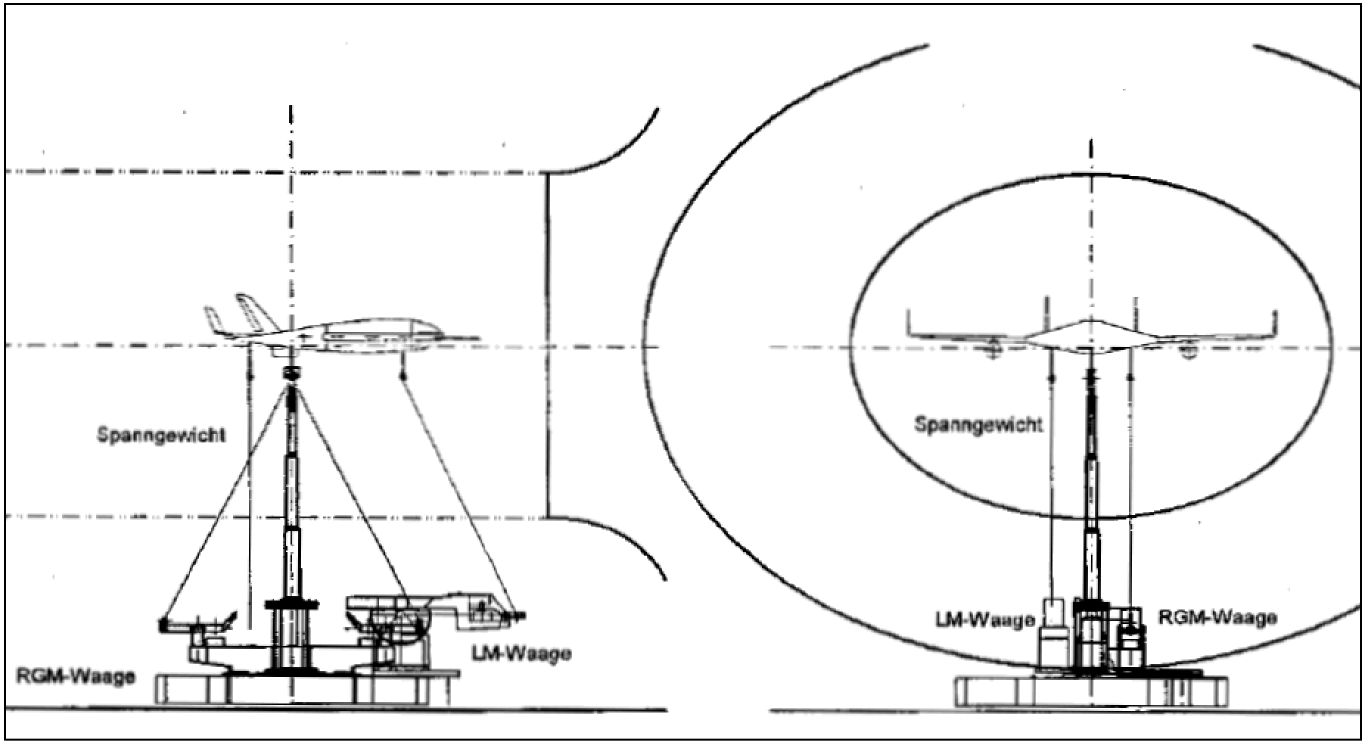

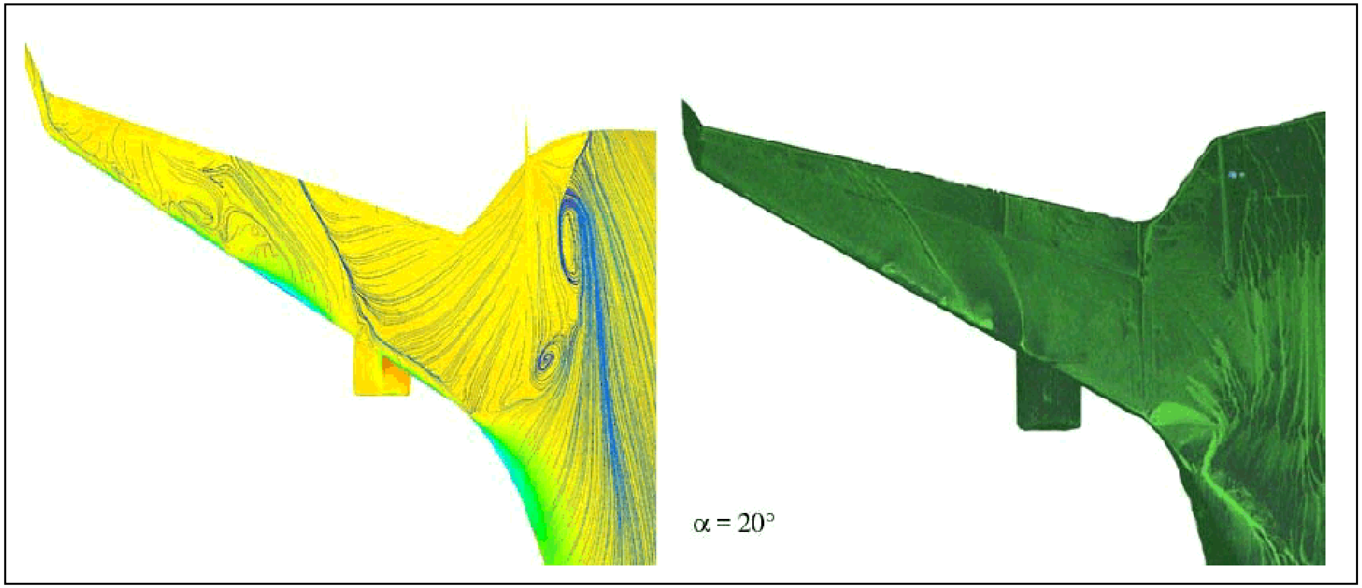

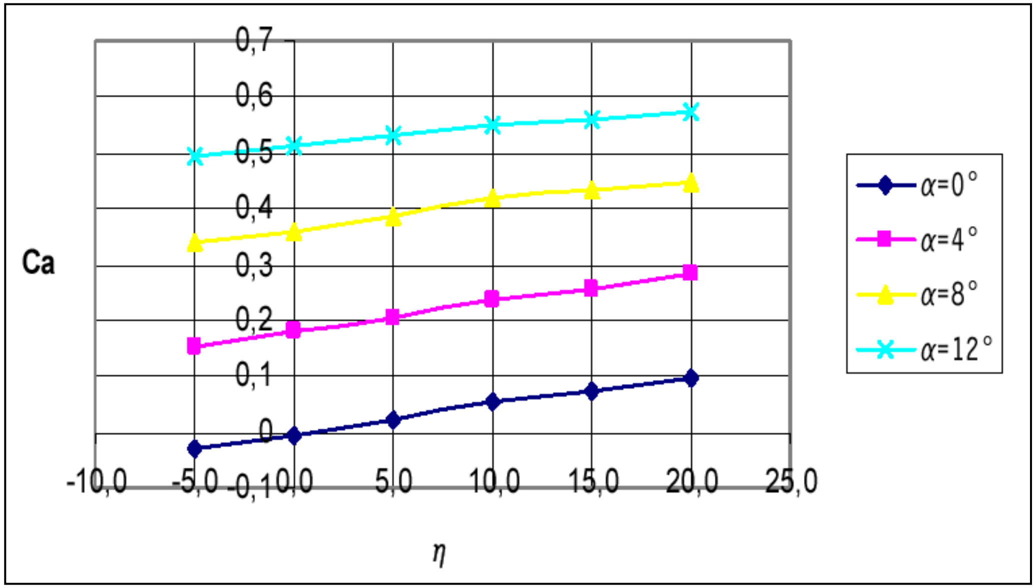

CFD surface stream lines (left)
Fluorescend paint in wind tunnel (right).

Lift coefficient dependend on flap angle (wing) and angle of attack.

AC20.30 Model 2

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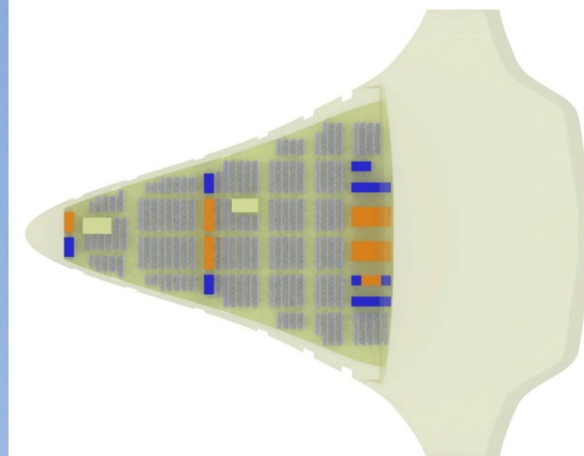

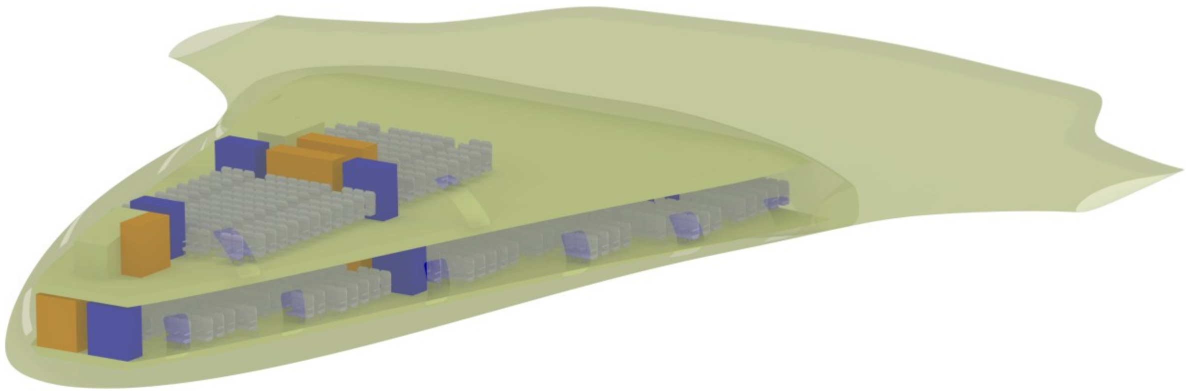

Student Group AC20.30 (2008-2013)

AC20.30
Model 2

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Student Group AC20.30 (2008 – 2013)

AC20.30 Milestones

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2000: **Prof. Granzeier** starts to work with students on cabin layouts for BWBs.
2002: **Building a model for expositions**. Idea to build a flying model. **Prof. Dr. Zingel** active.
2003: **First flight of Model 1** with propellers, later with impellers.
2004: Crash of Model 1, but it gets repaired in 6 month, adding sensors and telemetry.
2005: **Many test flights** (supervision by Prof. Dr. Scholz)
2005: **Wind tunnel testing** (supervision by Prof. Dr. Zingel)
2006: BWB AC20.30 presentation at ICAS (Hamburg) and other conferences
2007: ---
2008: Start of building Model 2 over 3 years including a professional sensor system.
2010: Celebrating 10 years of BWB AC20.30 student group.
2011: **First flight of Model 2**.
2012: **Prof. Dr. Netzel** takes over.
2013: Crash of Model 2.
2014: **Building a "Mini BWB"**. **Prof. Dr. Schulze** takes over.
2015: The BWB student group moves on to start something new:

https://**NewFlyingCompetition**.com
https://NeuesFliegen.de

2024: Prof. Granzeier dies.

Double Anniversary

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2010

Double **anniversary** at HAW Hamburg:

75 years of aircraft engineering studies

10 years of the BWB AC20.30 student group

75 Jahre

1935 - 2010
Flugzeugbaustudium
in Hamburg

Summary

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Summary

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

reduction in weight :	single shell required, then maybe 8% lighter, double shell: heavier
better L/D :	10 to 15% better (not apparent from AC20.30)
reduction in fuel consumption :	yes, due to L/D
reduction in emissions :	yes
reduction in noise :	only with engines on top
increase of airport capacity :	yes, with more than 750 pax per A/C (probably no problems with wake turbulence)
reduction in DOC :	down ??% (mostly due to scale effect)

But:

open certification problems :	unstable configuration (?), ditching
open design problems :	rotation on take-off, landing gear integration, ...

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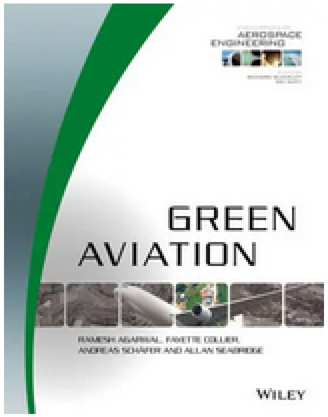

Green Aviation

Richard Blockley (Series Editor), Ramesh Agarwal (Editor), Fayette Collier (Editor), Andreas Schaefer (Editor), Allan Seabridge (Editor)

ISBN: 978-1-118-86643-6 | September 2016 | 536 pages

Chapter 7

Blended Wing Body Aircraft: A Historical Perspective

Egbert Torenbeek
Department of Aerospace Engineering, Delft University of Technology, Delft, The Netherlands

Some critical development aspects are mentioned hereafter (Torenbeek, 2013).

- Number, location, and structure of emergency exits.
- Comfort in the passenger cabin in terms of cabin volume, floor area, and ceiling height.
- Appreciation by passengers of a windowless cabin.
- Cabin floor inclination in high-speed and low-speed flight.
- Embarking and disembarking of passengers.
- Arrangement and accessibility of cargo holds.
- Landing gear wheel base and track.
- Turning the plane on taxiways.
- Community noise and wake vortices.
- Possibility of the family concept: stretching and shrinking.
- Acceptance of the airplane layout by airlines.

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Box Wing Aircraft (BWA)

SCHOLZ, Dieter, 2015. **Innovative Aircraft Design – Options for a New Medium Range Aircraft**. Hamburg Aerospace Lecture Series (Hamburg, 25 June 2015). Available from: https://doi.org/10.5281/zenodo.22468.

© NASA/Lockheed Martin

Aircraft Design and Systems Group,
HAW Hamburg, A. Johanning, D. Scholz
http://Airport2030.ProfScholz.de

Comparison

Comparison of Aircraft Configurations

Characteristics	tail aft (tube & wing)	BWB	BWA
L/D	-	+	+
emissions	-	+	+
stall characteristic	o	+	o
CLmax	+	-	o
OEW / MTOW	+	-	(-)
noise shielding	o	+	o
stat. long. stab.	+	-	o
take-off rotation	+	(SS)	+
L/G integration	+	(SS)	o
tank volume	o	+	-
wake vortex	o	o	+
streching	+	-	(-)
turn around	+	-	o
ditching	o	SS	o

Comparison

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Final Result of the Comparison of Aircraft Configurations

Characteristic	tail aft (tube & wing)	BWB	BWA
total	+5	-3	+1

+	The design has positive characteristics (in comparison)
-	The design has negative characteristics
o	The design has does not change the characteristics
SS	Show Stopper: This is an unsolved issue. If it remains unsolved, this could be a reason for not achieving certification! Counted here as "-".
total	Overall result: "o" is neutral, one "+" cancels one "-".

Winner is the conventional tail aft configuration.
Overall, the BWA seems to be better than the BWB.

The "evolution in aircraft design" has resulted in the tail aft (tube & wing) configuration for good reasons. This should be respected.

Hence: "Never change a running system!"

AC20.30 Publications

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

DRESCHER, Oliver, 2004. **Entwurf eines Blended-Wing-Body-Modell-Flugzeugs mit Hilfe eines Panel-Verfahrens**. Deutscher Luft- und Raumfahrtkongress 2004 (Dresden, 21.–23.09.2004). CD-Publication.

ANDRÉ Schmidt, 2005. **Projekt AC20.30 – Entwicklung und Stand**. Deutscher Luft- und Raumfahrtkongress 2005 (Friedrichshafen, 26.-29.09.2005). CD-Publication.

BANSA, Florian, 2005. **Interaktive Parametervariation zur Einstellung eines geeigneten Stabilitätsmaßes für BWB-Flugzeugkonfigurationen**. Deutscher Luft- und Raumfahrtkongress 2005 (Friedrichshafen, 26.-29.09.2005). Available from: https://www.fzt.haw-hamburg.de/pers/Scholz/arbeiten/PaperBansaDipl.pdf.

SCHOLZ, Dieter, 2006. **The Blended Wing Body (BWB) Aircraft Configuration**. Presentation. Hamburg Aerospace Lecture Series 2006 (HAW Hamburg, 28.09.2006). Available from: https://doi.org/10.48441/4427.442.

SCHMIDT, André, BRUNSWIG, Hans. 2006. **The AC20.30 Blended Wing Body Configuration: Development & Current Status 2006**. ICAS 2006 (Hamburg, 03.-08.09.2006). Available from: https://www.icas.org/icas_archive/ICAS2006/PAPERS/178.PDF.

BRUNSWIG, Hans, SCHULZE, Detlef, ZINGEL, Hartmut, 2006. **Bestimmung der aerodynamischen Eigenschaften des BWB-Modells AC20.30 mit Methoden der CFD und Vergleich mit dem Experiment**. Deutscher Luft- und Raumfahrtkongress 2006 (Braunschweig, 06.-09.11.2006). Available from: https://www.fzt.haw-hamburg.de/pers/Scholz/ewade/2007/CEAS2007/papers2006/dglr-2006-202.pdf.

SCHOLZ, Dieter, 2007. **A Student Project of a Blended Wing Body Aircraft – From Conceptual Design to Flight Testing**. EWADE 2007 – 8th European Workshop on Aircraft Design Education (Samara State Aviation University, Samara, Russia, 30. May - 2. June 2007). Available from: https://www.fzt.haw-hamburg.de/pers/Scholz/ewade/2007/EWADE2007_Scholz.pdf.

AC20.30 Publications

Hochschule für Angewandte Wissenschaften Hamburg
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SCHOLZ, Dieter, 2010.**Die Blended Wing Body (BWB) Flugzeugkonfiguration**. Presentation. Kolloquium : 75 Jahre Flugzeugbaustudium in Hamburg (Hamburg, 04.06.2010). Available from: https://doi.org/10.48441/4427.438.

NETZEL, Thomas, 2013. **The Project AC20.30**. Presentation. CARPE Conference 2013 (Manchester, UK, 04.-06.11.2013). See: https://reposit.haw-hamburg.de/cris/events/events06031. Available from: https://web.archive.org/web/20220121103453/https://www.mmu.ac.uk/media/mmuacuk/content/documents/carpe/2013-conference/papers/creative-engineering/Thomas-Netzel-et-al.pdf.

This list may not be complete!

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Projects and Theses: Department of Automotive and Aeronautical Engineering, HAW Hamburg

REZAC, Marcel, MAHNKEN, Max, ROTHFUCHS, Miller, LEISING, Tobias, 2002.
Hochschulprojekt A20.30 – Bau des Exterior-Modells der Blended Wing Body-Konfiguration.
Supervisor: Granzeier, W.

REHSÖFT, Markus, 2003.
Geometrische Aerodynamik einer Nurflügelkonfiguraiton (Blended-Wing-Body). Studienarbeit.
Supervisor: Zingel, H.

DRESCHER, Oliver, 2003.
Entwurf eines Blended-Wing-Body-Modell-Flugzeugs mit Hilfe eines Panel-Verfahrens. Diplomarbeit.
Supervisor: Zingel, H.

LEE, Stefan, 2003.
Konzeptionelle Untersuchung einer Flying Wing Zweideckkonfiguration.
Supervisor: Scholz, D.

HARS, Christian, GÄHLER, Christian, URBAN, Daniel, 2003.
Dokumentation über den Blended-Wing-Body AC 20.30 (Erstes CAD-Modell des AC 20.30). Wahlplichtentwurf.

FROBEEN, Markus, 2004.
Entwurf, Bau und Erprobung eines Telemetriesystems für Flugmodelle zur Bestimmung von Flugleistungsparametern.
Theoretische Arbeit.
Supervisor: Scholz, D.

Projects and Theses

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Projects and Theses: Department of Automotive and Aeronautical Engineering, HAW Hamburg

BANSA, Florian, 2004.
Interaktive Parametervariation zur Einstellung eines geeigneten Stabilitätsmaßes fuer BWB-Flugzeugkonfigurationen. Diplomarbeit. (DGLR-Preis).
Supervisor: Scholz, D.

SCHMIDT, Andre, 2005.
Berechnung der Strömung einer Blended-Wing-Body-Konfiguration mit dem Paneelverfahren Pan Air. Diplomarbeit.
Supervisor: Zingel, H.

DANKE, Kevin, 2005.
Flugerprobung mit einem BWB Flugmodell. Diplomarbeit.
Supervisor: Scholz, D.

ZINGEL, Till, 2005.
Auswertung: Windkanalversuche am BWB-Modell AC20.30. Pflichtentwurf.
Supervisor: Zingel, H.

MAHNKEN, Max, 2006.
Integration von Kabinensystemen in BWB-Flugzeugkonfigurationen. Diplomarbeit.
Supervisor: Scholz, D.

BRUNSWIG, Hans, 2006.
Bestimmung der aerodynamischen Eigenschaften eines BWB-Modells AC20.30 mit Methoden der CFD. Diplomarbeit. (DGLR-Preis)
Supervisor: Schulze, D.

Projects and Theses

Projects and Theses: Department of Automotive and Aeronautical Engineering, HAW Hamburg

NEUBACHER, Christoph, 2008.
Flight Dynamic Investigations of a Blended Wing Body Aircraft. Project.
Supervisor: Scholz, D.

VELIKOV, Stefan, 2008.
Flight Test Planning and Data Extraction. Diplomarbeit.
Supervisor: Scholz, D.

\- - -

SCHWART, S., 2013.
Entwurf, Konzept- und Projektplanerstellung für ein einsitziges Nurflügelflugzeug mit einem elektrischen Antrieb zum Bau eines entsprechenden Prototypens. Masterarbeit.

BACKES, Tim, 2013.
Integration des AC20.30 in einem Modellflugsimulator. Projekt.

MEIER, S., WINCKLER, D., 2013.
Konstruktion eines parametrisierten BWB-CATIA Modells. Schwerpunktarbeit.

WINCKLER, Dennis, 2014.
Strömungsanalyse des Seitenleitwerkes eines BWB-Modells mit Hilfe des CFD-Programmes "XFlow". Bachelorarbeit.
Supervisor: Netzel, T. (Hinweis: Manntragender "BWB-X")

This list may not be complete!

Bachelor Theses

Projects and Theses: Department of Computer Science, HAW Hamburg

RICHTER, Arne Maximilian, 2013.
Konzept und Einführung von Safety-Analysen bei Mikrocontroller-basierten Anwendungen in UAVs. Bachelorarbeit.
Supervisor: Lehmann, T., https://hdl.handle.net/20.500.12738/6228

ROHRER, Alexander, 2014.
Softwarearchitektur für Airborne Embedded Systems. Bachelorarbeit.
Supervisor: Lehmann, T.

HASBERG, Hagen, 2014.
Ein Testkonzept für Flugregler. Bachelorarbeit.
Supervisor: Lehmann, T., https://hdl.handle.net/20.500.12738/6646

BÜSCHER, René, 2014.
Ein Safety-Konzept für Airborne Embedded Systems. Bachelorarbeit.
Supervisor: Lehmann, T., https://hdl.handle.net/20.500.12738/6659

TRAPP, Benjamin-Yves Johannes, 2014.
Ein Konzept für die Testfallentwicklung für sicherheitskritische Anforderungen unter Verwendung von Fault- Injection und Mutationstests. Bachelorarbeit.
Supervisor: Buth, B., https://hdl.handle.net/20.500.12738/6609

JÄHNICHEN, Tobias, 2015.
Entwicklung eines Telemetriesystems für flugfähige eingebettete Systeme. Bachelorarbeit.
Supervisor: Lehmann, T., https://hdl.handle.net/20.500.12738/6982

This list may not be complete!

The End

Reserve Slides
(Appendix)

Preliminary Sizing

VELA 3

Assumptions:

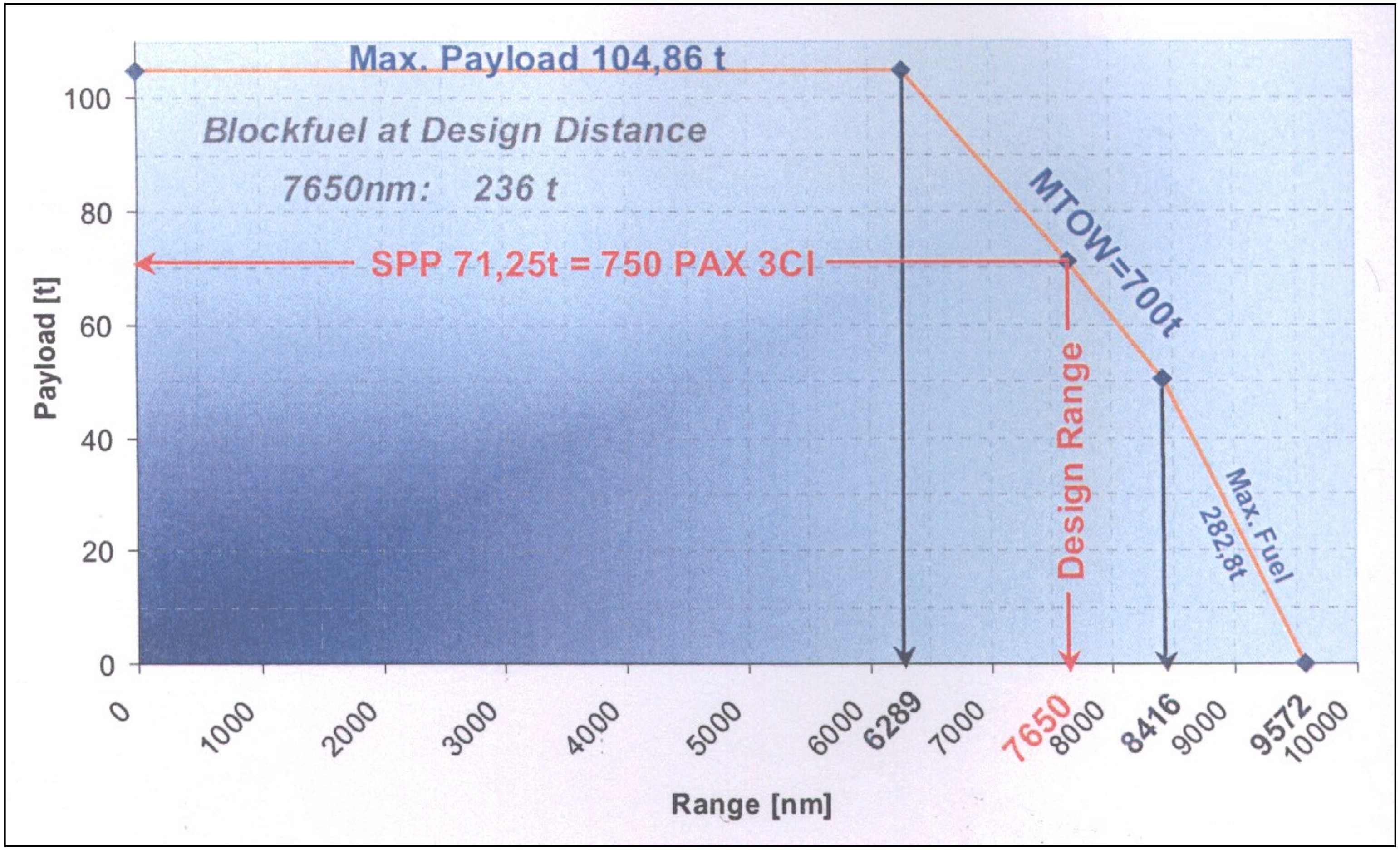
OEW / MTOW = 0,5	LOFTIN: 0,52 (T/W!) A380: 0,49 BWB structural benefits?
SFC = 1.6 mg/(Ns)	normal technology level assumed
approach speed = 165 kt	
Reserves:	200 NM to alternate, 30 min. holding, 5% trip fuel allowance

Given:

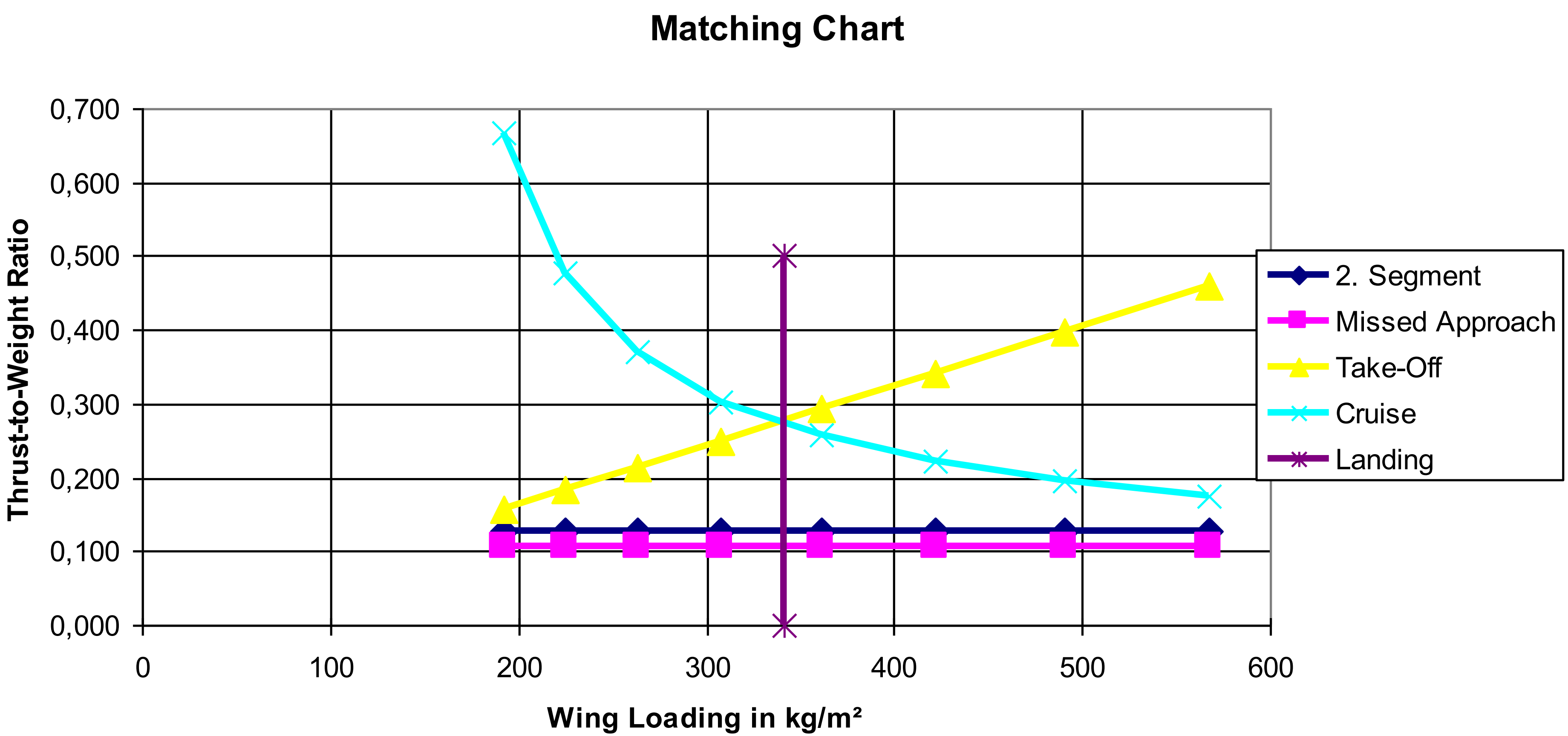
range:	7650 NM
MTOW:	700000 kg
Wing Area:	2052 m²
Wing Loading:	341 kg/m² (very low for pass. transp. due to low lift coeff.)
mass of pax and luggage:	95.0 kg per pax
payload:	71250 kg

VELA 3

Given:


Max. Payload 104,86 t
Blockfuel at Design Distance
7650nm: 236 t
SPP 71,25t = 750 PAX 3Cl
MTOW=700t
Design Range
Max. Fuel
282,8t
Payload [t]
100
80
60
40
20
0
0
1000
2000
3000
4000
5000
6000
6289
7000
7650
8000
8416
9000
9572
10000
Range [nm]

VELA 3



Matching Chart
Thrust-to-Weight Ratio
0,700
0,600
0,500
0,400
0,300
0,200
0,100
0,000
0
100
200
300
400
500
600
Wing Loading in kg/m²
2. Segment
Missed Approach
Take-Off
Cruise
Landing

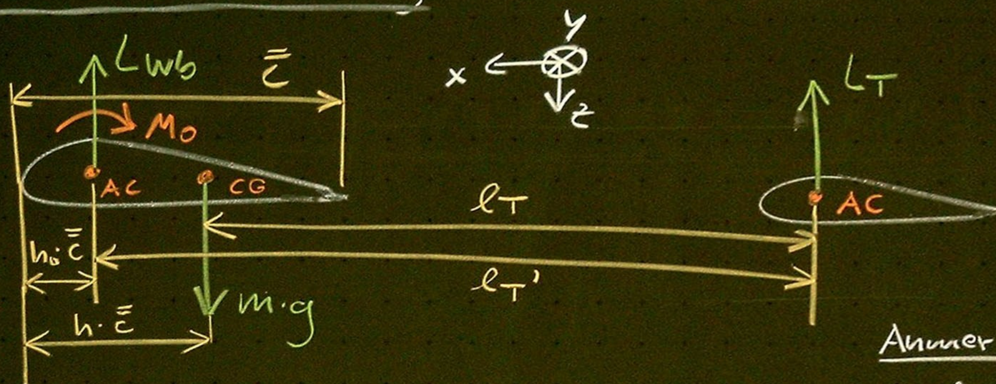
VELA 3

Sizing Results:

lift coefficient landing: 0.86 (higher than HAW wind tunnel results)
L/D during 2. segment: 15.2 (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!)
L/D_{max} : 20.9 (lower than BWB estimate)
V / V_{md} = 1.0 => $L/D = L/D_{\text{max}}$ (normal: V / V_{md} = 1.0 ... 1.316)
lift coefficient cruise: 0.31
trust to weight ratio: 0.28 (value is slightly high for 4-engined A/C, reason: TOFL and C_L)
Initial Cruise Altitude (ICA): 37800 ft (= 11.7 km)
MLW: 469000 kg
OEW: 350000 kg
Fuel: 279000 kg (VELA 3: 282800 kg)
Thrust: 481 kN (for each of the four engines)

Flight Mechanics (from the lecture)

11.3.1 Herleitung



L_{wb}: Auftrieb durch Flügel und Rumpf
↳ wing, body

L_T: Auftrieb durch Leitwerk
↳ tail

Anmerkung: Das Leitwerk produziert Abtrieb, L_T ist demnach in der Praxis negativ.

$$\sum F_z = -L_{wb} - L_T + m \cdot g = 0$$

$$L_{wb} = m \cdot g - L_T$$

$$\boxed{L_{wb} = L - L_T}$$

$$\sum \overset{\curvearrowright}{M}_{CG} = M_0 + L_{wb}(h-h_0) \cdot \bar{\bar{c}} - L_T \cdot l_T = 0$$

$$M_0 + (L - L_T)(h-h_0) \cdot \bar{\bar{c}} - L_T \cdot l_T = 0$$

$$M_0 + L(h-h_0)\bar{\bar{c}} - L_T \underbrace{\left[(h-h_0)\bar{\bar{c}} + l_T\right]}_{l_T'} = 0 \qquad \Big| : \tfrac{1}{2}\rho V^2 S \cdot \bar{\bar{c}}$$

$$C_{M_{CG}} = C_{M_0} + (h-h_0) \cdot C_L - \frac{l_T' \cdot S_T}{\bar{\bar{c}} \cdot S} \cdot C_{L_T}$$

Definition: Leitwerksvolumenbeiwert
tail volume coefficient

$$\bar{V} = \frac{l_T \cdot S_T}{\bar{\bar{c}} \cdot S}$$

Definition: modifizierter Leitwerksvolumenbeiwert
modified tail volume coefficient

$$\bar{V}' = \frac{l_T' \cdot S_T}{\bar{\bar{c}} \cdot S}$$

Damit:

$$\boxed{C_{M_{CG}} = C_{M_0} + (h - h_0) \cdot C_L - \bar{V}' \cdot C_{L_T}}$$

Stabilitätsbedingungen

Nach den Vorüberlegungen aus Abschnitt 11.2 müssen zwei Bedingungen erfüllt sein für statische Längsstabilität:

Flight Mechanics

1.) $$\frac{dC_{M_{CG}}}{dC_L} < 0$$

Die Gerade muß neg. Steigung haben

$$\frac{dC_{M_{CG}}}{dC_L} = h - h_0 - \bar{V}' \cdot \frac{dC_{L_T}}{dC_L} < 0$$ oder

$$h < h_0 + \bar{V}' \cdot \frac{dC_{L_T}}{dC_L}$$

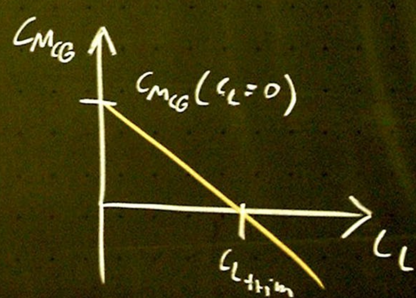
2.) $$C_{M_{CG}}(C_L = 0) > 0$$

Die Gerade muß die $C_{M_{CG}}$-Achse im pos. Bereich schneiden, denn sonst gibt es auch keinen Schnittpunkt mit der C_L-Achse und damit kein $C_{L_{trim}}$ also keinen getrimmten Zustand

mit $C_L = 0$:

$$C_{M_{CG}} = C_{M_0} - \bar{V}' \cdot C_{L_T} > 0$$

$$C_{M_0} - \bar{V}' \cdot C_{L_T} > 0$$



Flight Mechanics

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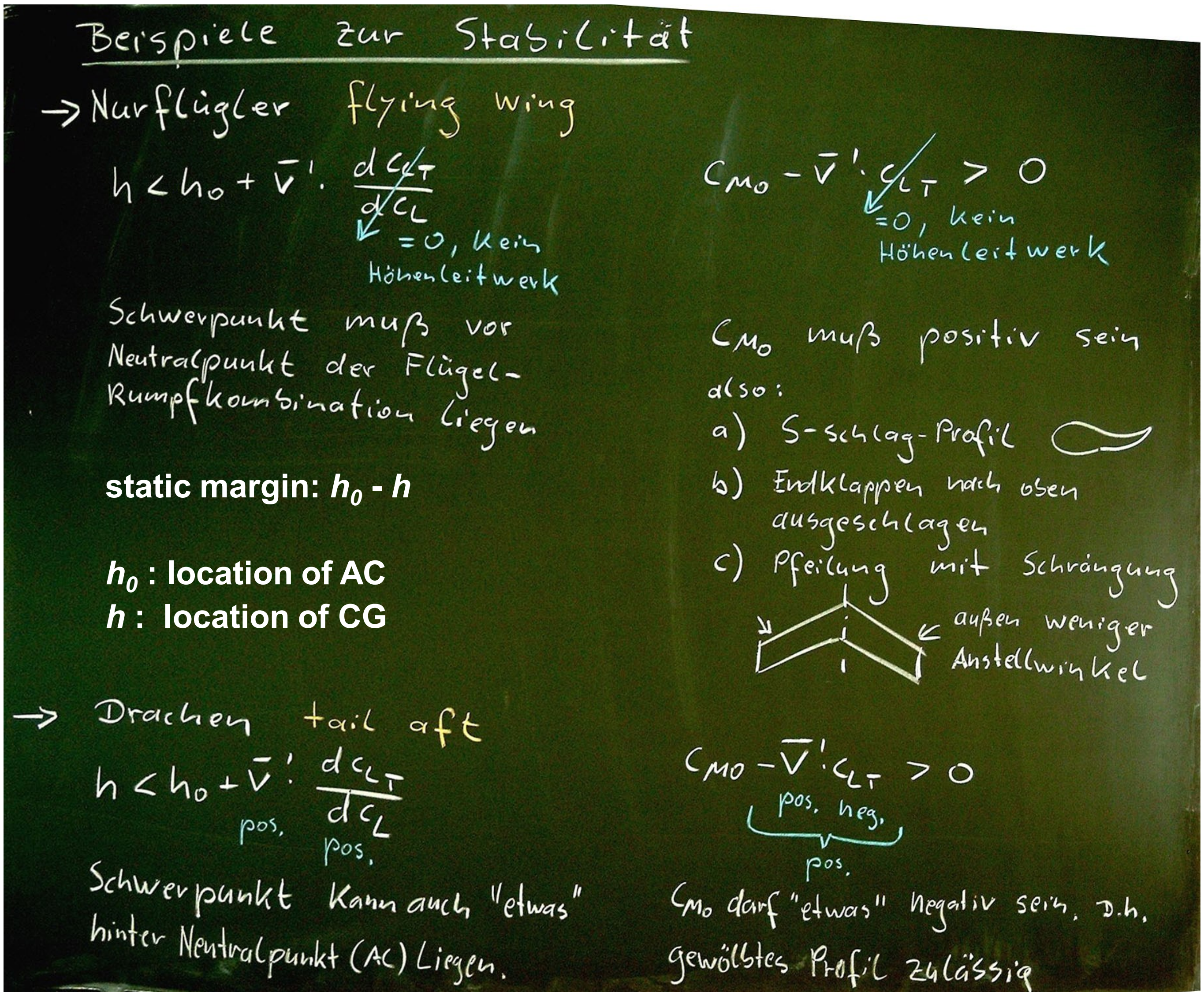

static margin: $h_0 - h$

h_0 : location of AC
h : location of CG

Wake Turbulence

Derivation & Example

Wake Turbulence

Strength of wake turbulence $\sim D_i$

Energy " " " $\sim D_i \cdot s$

Power " " " $\sim D_i \cdot V = P_{wake}$

$$D_i = \frac{1}{2}\rho V^2 \cdot c_{D_i} \cdot S = \frac{1}{2}\rho V^2 \cdot \frac{C_L^2}{\pi A e} \cdot S$$

$$m \cdot g = \frac{1}{2}\rho V^2 \cdot c_L \cdot S \qquad c_L = \frac{2 m g}{\rho V^2 \cdot S}$$

$$D_i = m \cdot g \cdot \frac{C_L}{\pi A e} = \frac{2 m^2 \cdot g^2}{\rho V^2 S \cdot \pi A e}$$

$$D_i \overset{!}{=} \frac{2 g^2}{\pi A e} \cdot \frac{m \cdot m/S}{\rho \cdot V^2}$$

$$\boxed{P_{wake} = \frac{2 g^2}{\pi A e} \cdot \frac{m \cdot m/S}{\rho \cdot V}}$$

$$\frac{P_{wake,BWB}}{P_{wake,A380}} = \frac{A_{A380}}{A_{BWB}} \cdot \frac{m_{BWB}}{m_{A380}} \cdot \frac{(m/S)_{BWB}}{(m/S)_{A380}} \overset{!}{=} 1{,}00$$

Flugzeugvergleichsdaten

	A380	VELA3
S	845 m²	2052 m²
b	79,75 m	99,6 m
m_{MTO}	560 t	700 t
m/S	663 kg/m²	341 kg/m²
$A = \frac{b^2}{S}$	7,53	4,83

$$\frac{P_{wake,BWB}}{P_{wake,A380}} = \frac{7{,}53}{4{,}83} \cdot \frac{700\,t}{560\,t} \cdot \frac{341\ kg/m^2}{663\ kg/m^2} \overset{!}{=} \underline{\underline{1{,}00}}$$