Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

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**

http://hdl.handle.net/20.500.12738/12643

Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

Die Blended Wing Body (BWB) Flugzeugkonfiguration

Prof. Dr.-Ing. Dieter Scholz, MSME

in Zusammenarbeit mit allen Flugzeugbaukollegen des Departments Fahrzeugtechnik und Flugzeugbau

Contents

Acknowledgement

Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

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

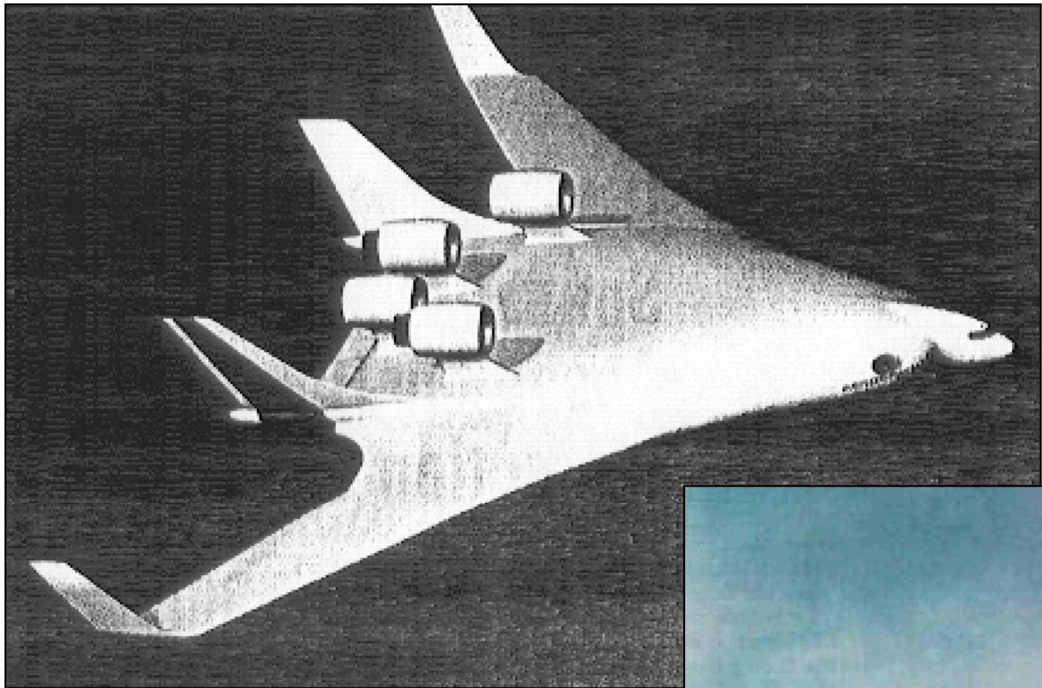
(from different internet sources)

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

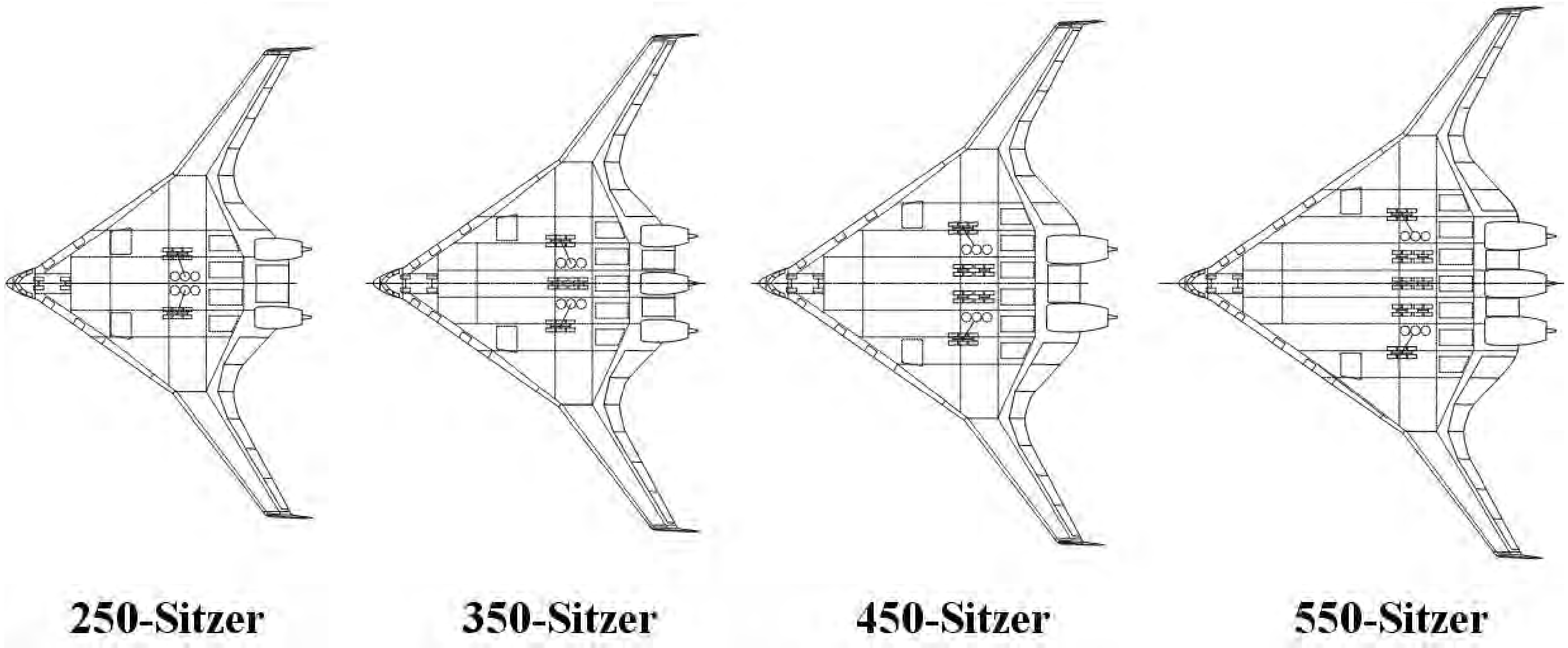
BWB Projects

Aerospatiale "Megajet"



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

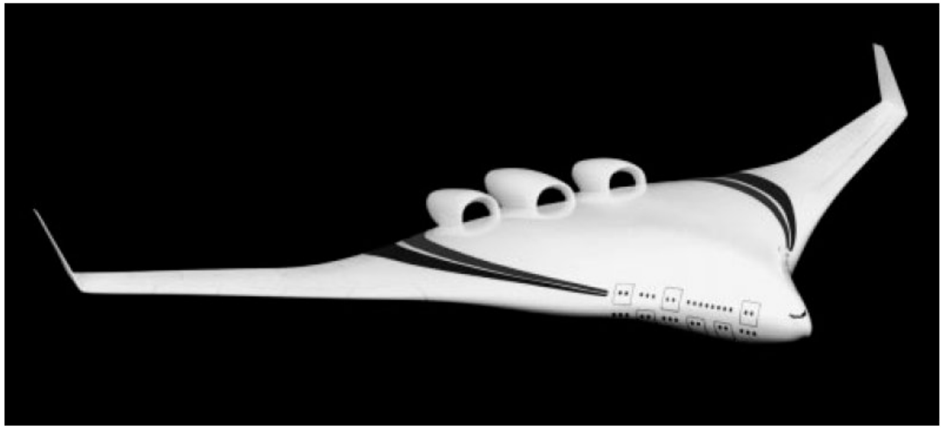
Boeing BWB-250 ... BWB-550



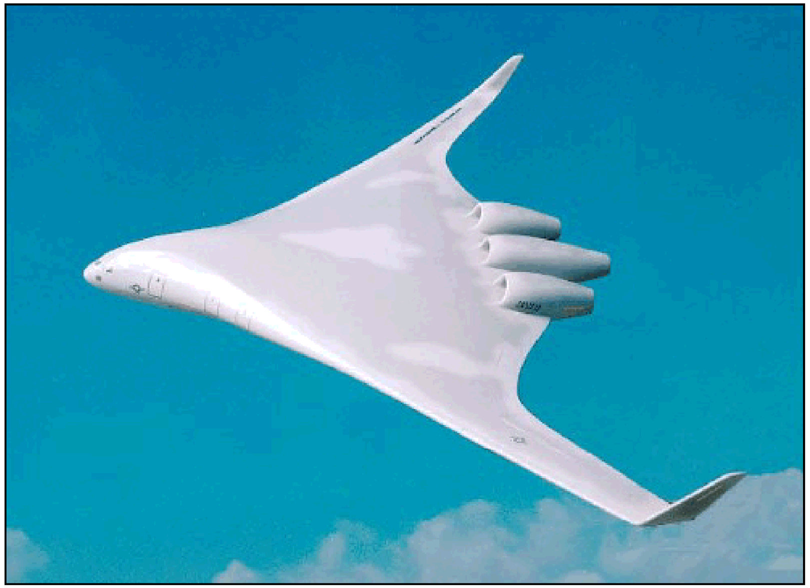
Boeing: study of BWB aircraft family

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

Boeing BWB-450

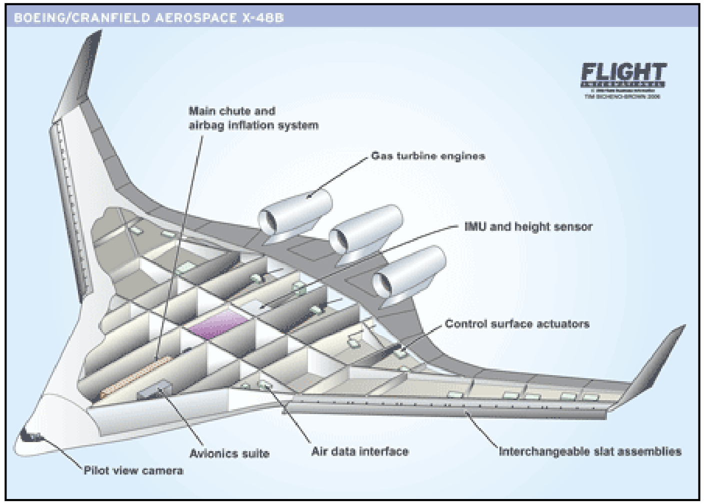


Blended Wing Body systems studies based on BWB-450 as part of the programme Ultra Efficient Engine Technology (UEET): Boundary Layer Ingestion (BLI) inlets with Active Flow Control (AFC).



NASA/CR-2003-212670

Boeing X-48B



<u>2006</u>: 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

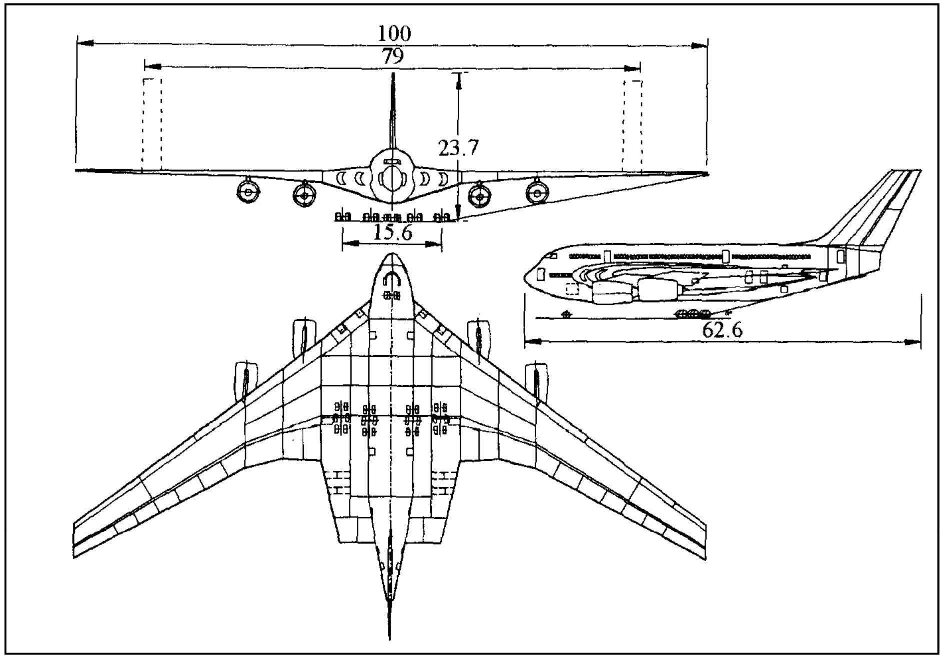
Air Force
Research Laboratory
(AFRL)

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.

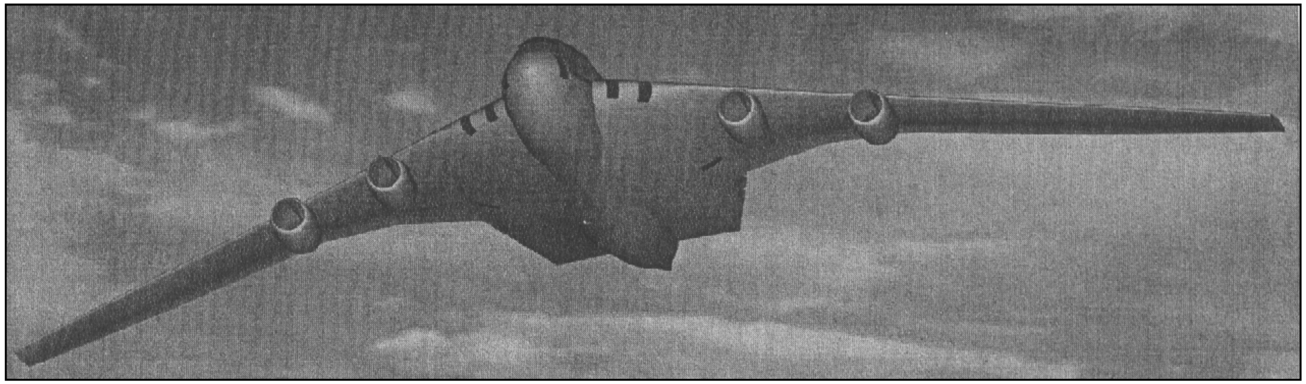
TsAGI (Russia) Integrated Wing Body (IWB)



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

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).

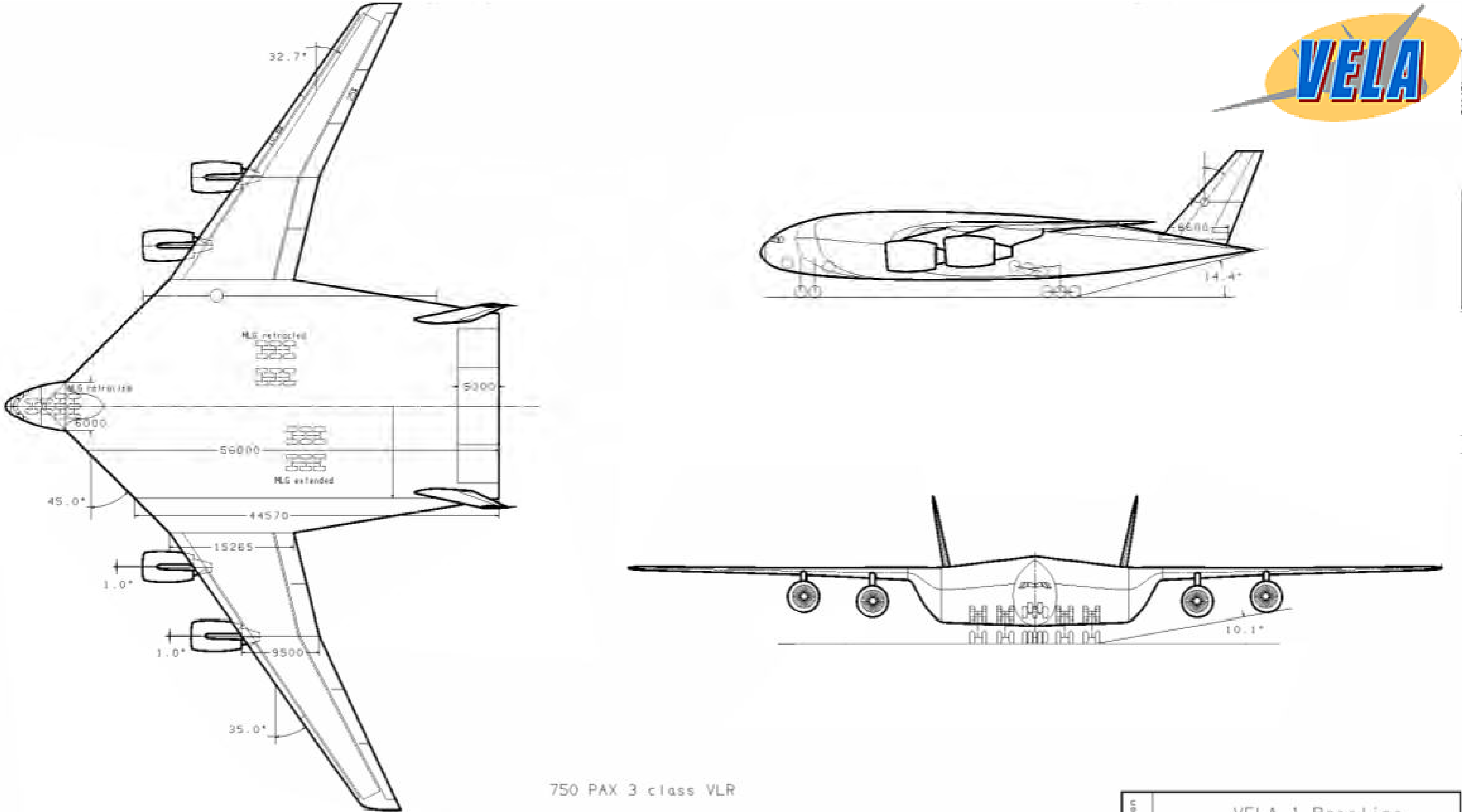
Passenger-carrying aircraft.

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

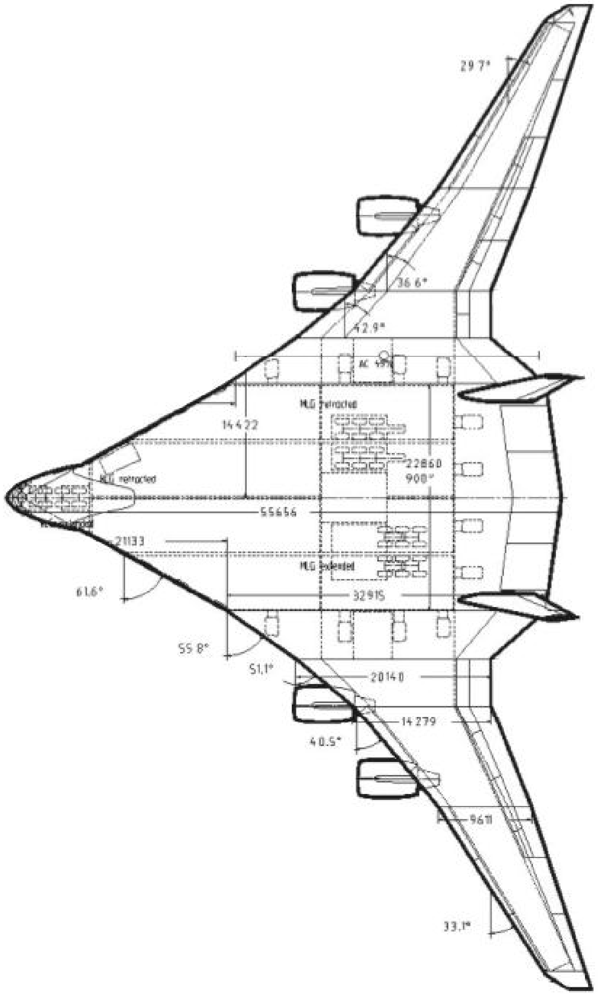
2002 | DATE 18/08 | NAME ANGER | DRAWING NUMBER VELA 1/GA03 | SHEET | OF

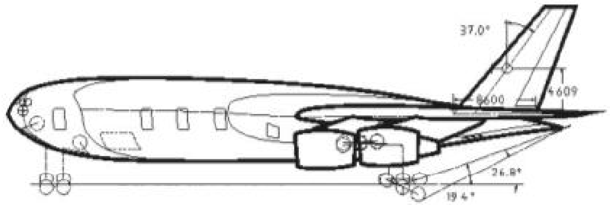
Airbus | REPLACEMENT FOR VELA 1/GA02 | REPLACED BY | SCALE 1:100

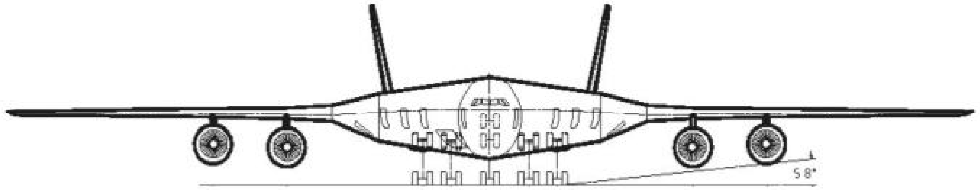
BWB Projects

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

750 PAX 3 class VLR

VELA 2 Baseline

for information only	2003	DATE 29/07	NAME ANGER	DRAWING NUMBER VELA 2/GA05
Airbus		REPLACEMENT FOR VELA 2/GA04		SCALE 1:100
		REPLACED BY		

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)

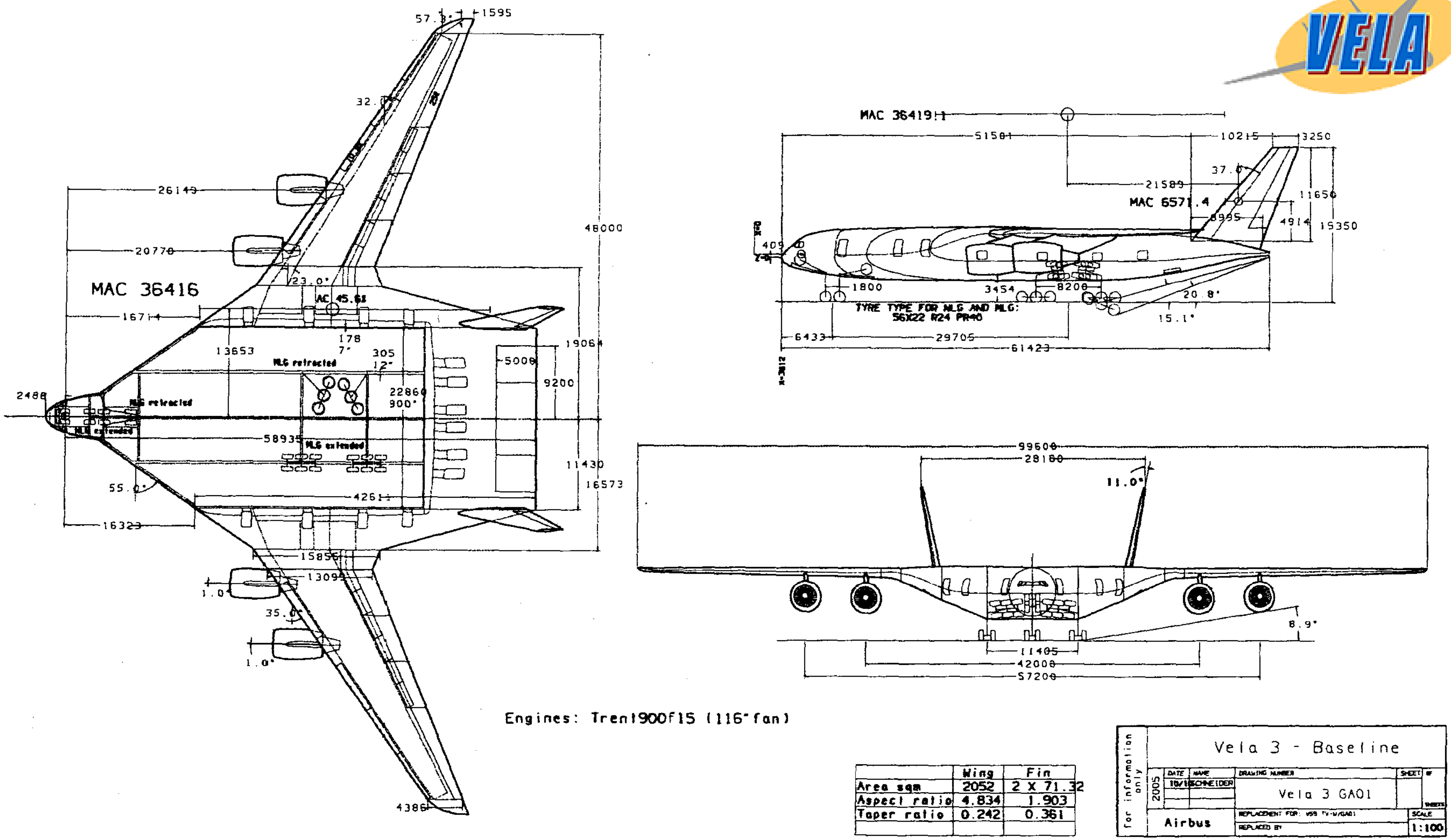
National: LuFo III, K2020

BWB (VELA 2) der Uni Stuttgart

BWB Projects

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

VELA 3

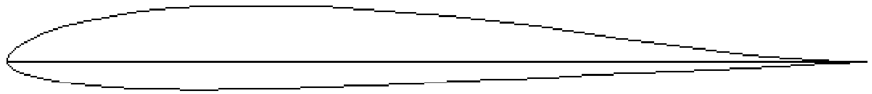


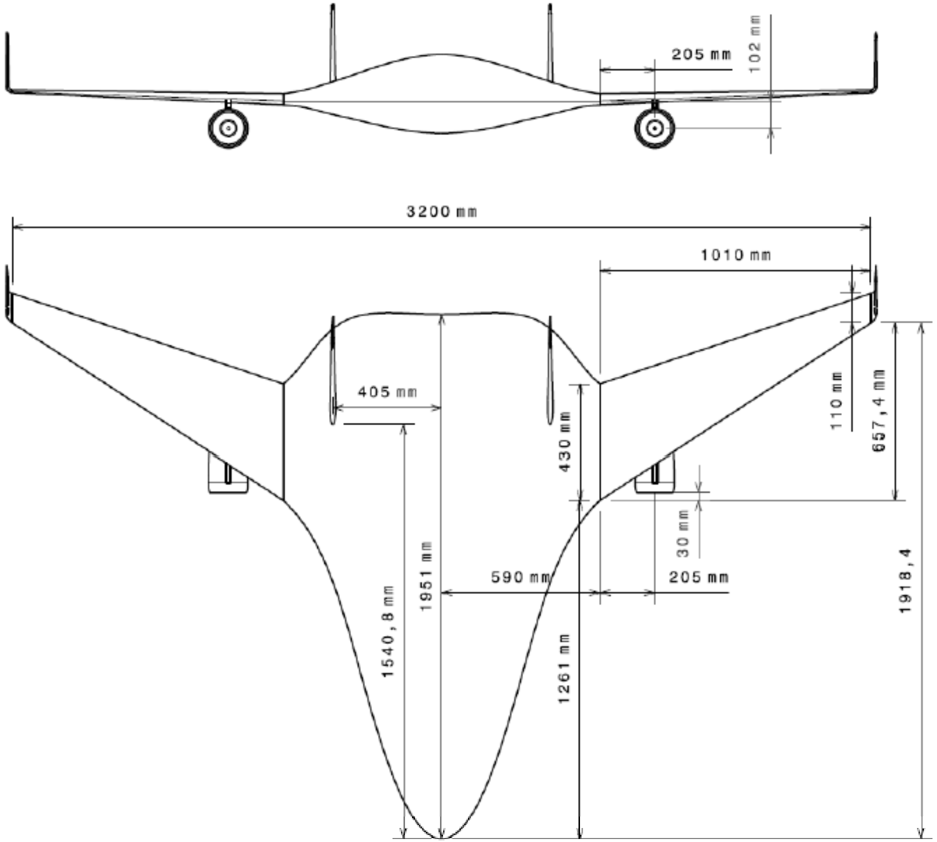
	Wing	Fin
Area sqm	2052	2 X 71.32
Aspect ratio	4.834	1.903
Taper ratio	0.242	0.361

BWB Projects

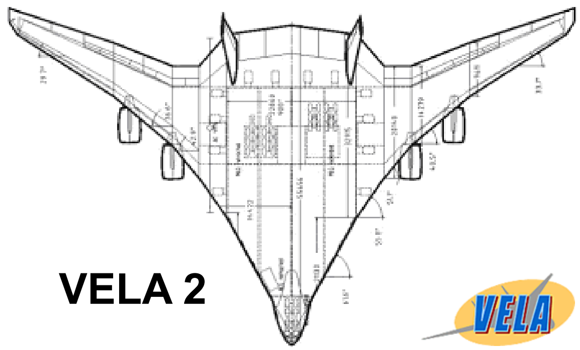
Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

HAW Student Project: AC 20.30





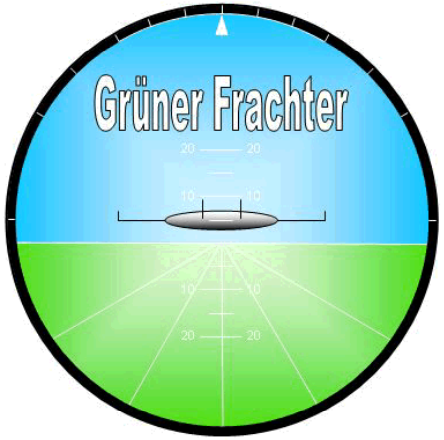
Wing profile: MH-45
(Martin Hepperle)
t/c = 9.85%,
low drag, improved max. lift,
low $c_{m,\ c/4}$,
proven even at Reynolds
numbers below 200000.
Body profile: MH-91.



VELA 2

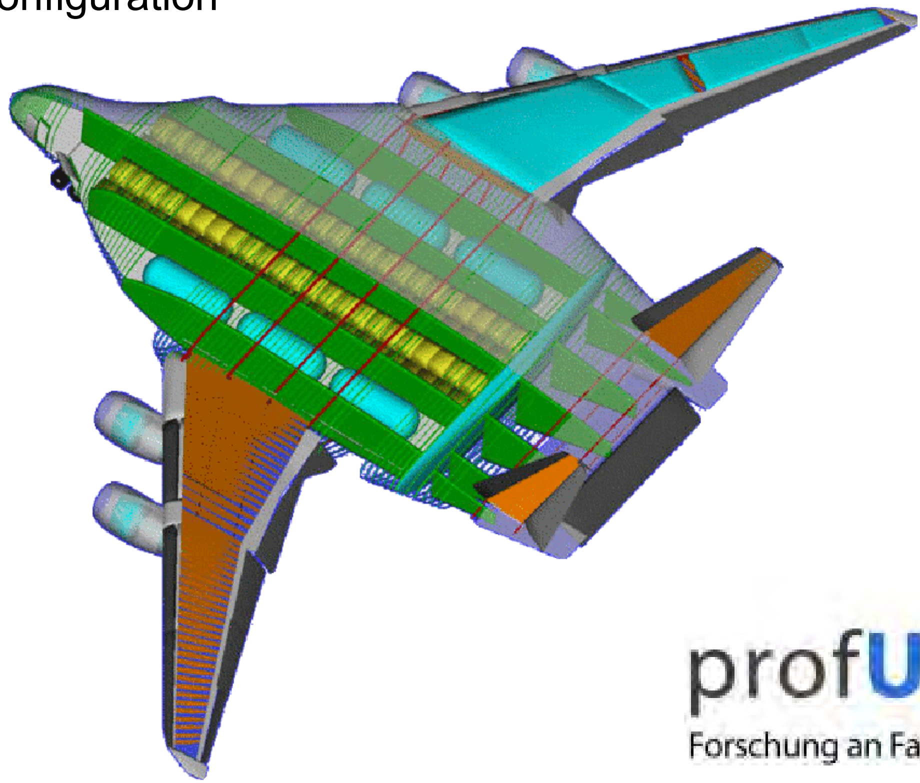
AC 20.30: geometry is based on VELA 2; student project; sponsor: "Förderkreis"

Research: Green Freighter



GF - Grüner Frachter

Entwurfsuntersuchungen zu umweltfreundlichen und kosteneffektiven Frachtflugzeugen mit unkonventioneller Konfiguration



Bundesministerium für Bildung und Forschung

profUnt
Forschung an Fachhochschulen mit Unternehmen

Aeronautical Disciplines

VELA 2 Technical Data

Requirements:

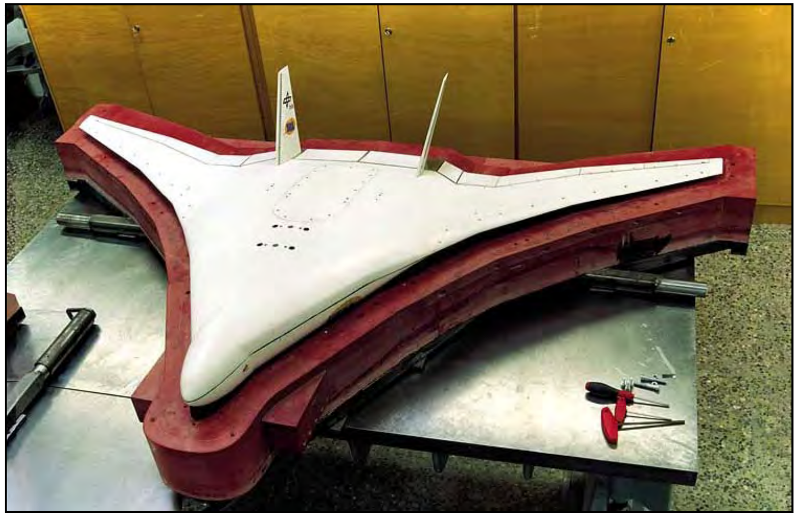
3-class seating: 750 pax (22 / 136 / 592)
cargo capacity > 10 t

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

span < 100 m



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: $e \approx 0.85$

from statistics: $k_E = 15{,}8$

S_{wet} / S_W :	conv. aircraft	6.0 ... 6.2
	BWB	$\approx$ 2.4
A :	conv. aircraft	7.0 ... 10.0
	VELA 2	5.2

$E_{max} = 23{,}2$

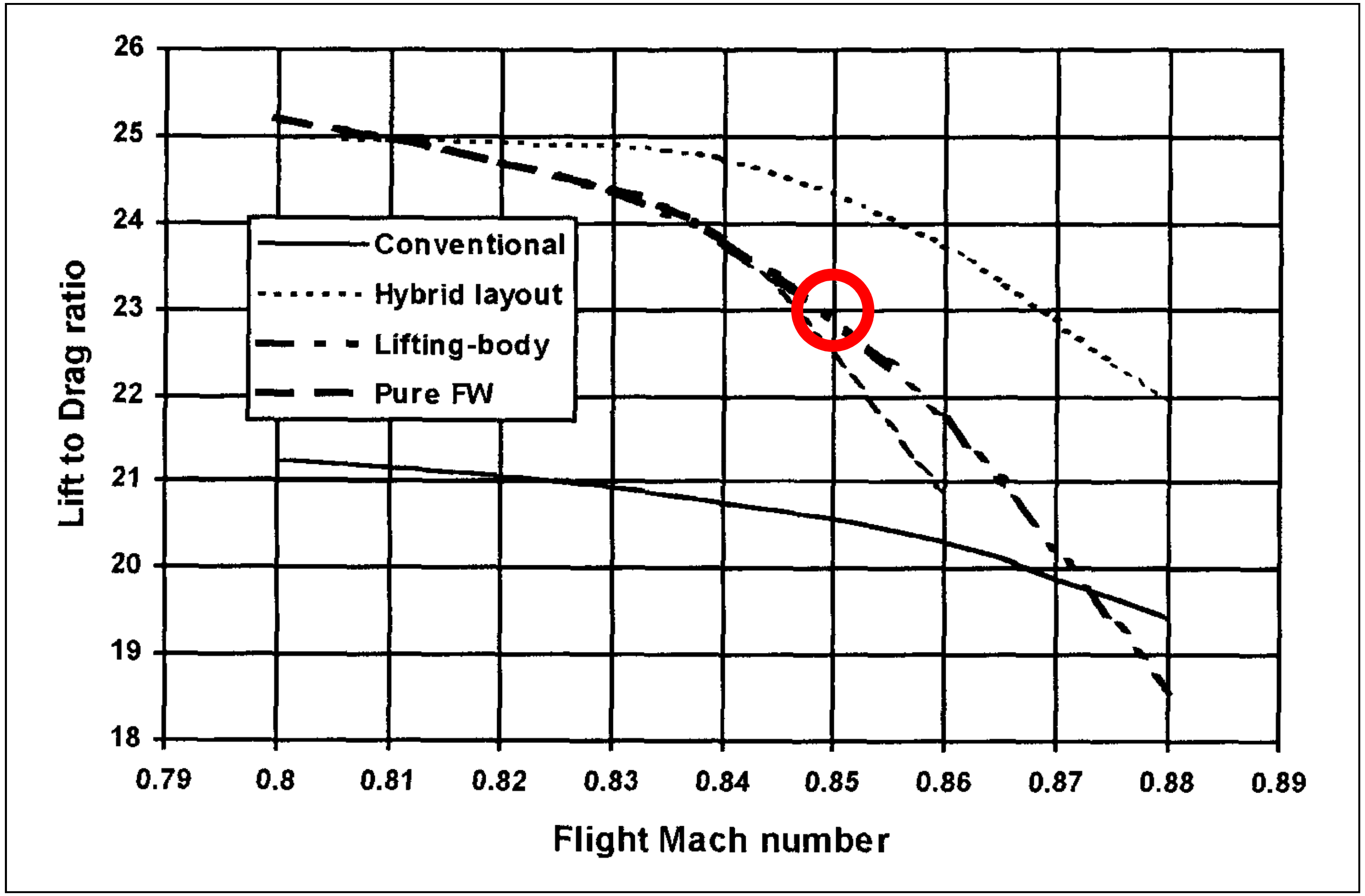
$$E_{max} = k_E \sqrt{\frac{A}{S_{wet} / S_W}}$$

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

$$\overline{c_f} = 0.003$$

Input Parameters for Preliminary Sizing

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



TsAGI for AIRBUS

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

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

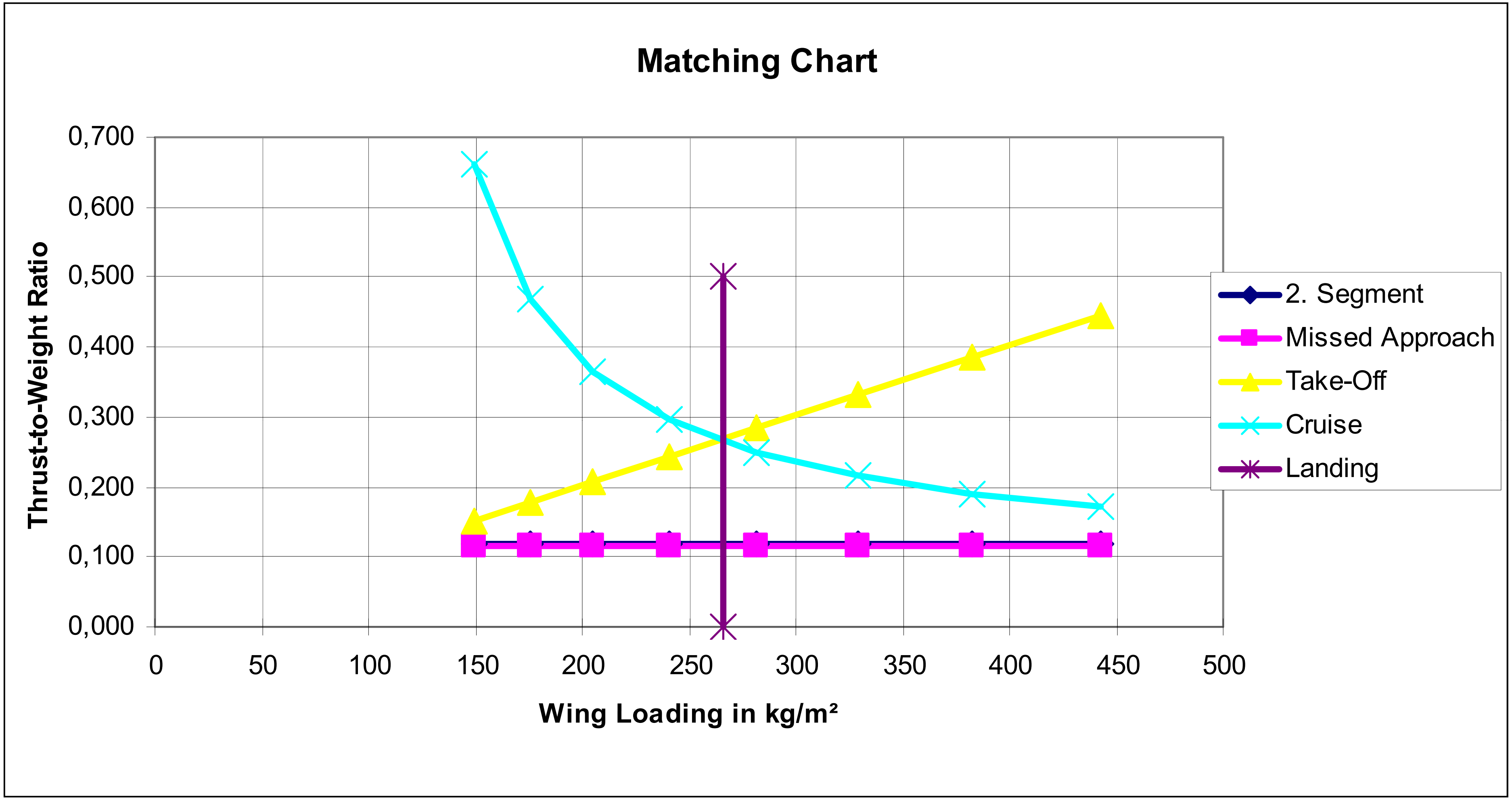
Given:

Wing Area:	1923 m²

Preliminary Sizing

Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

VELA 2



VELA 2

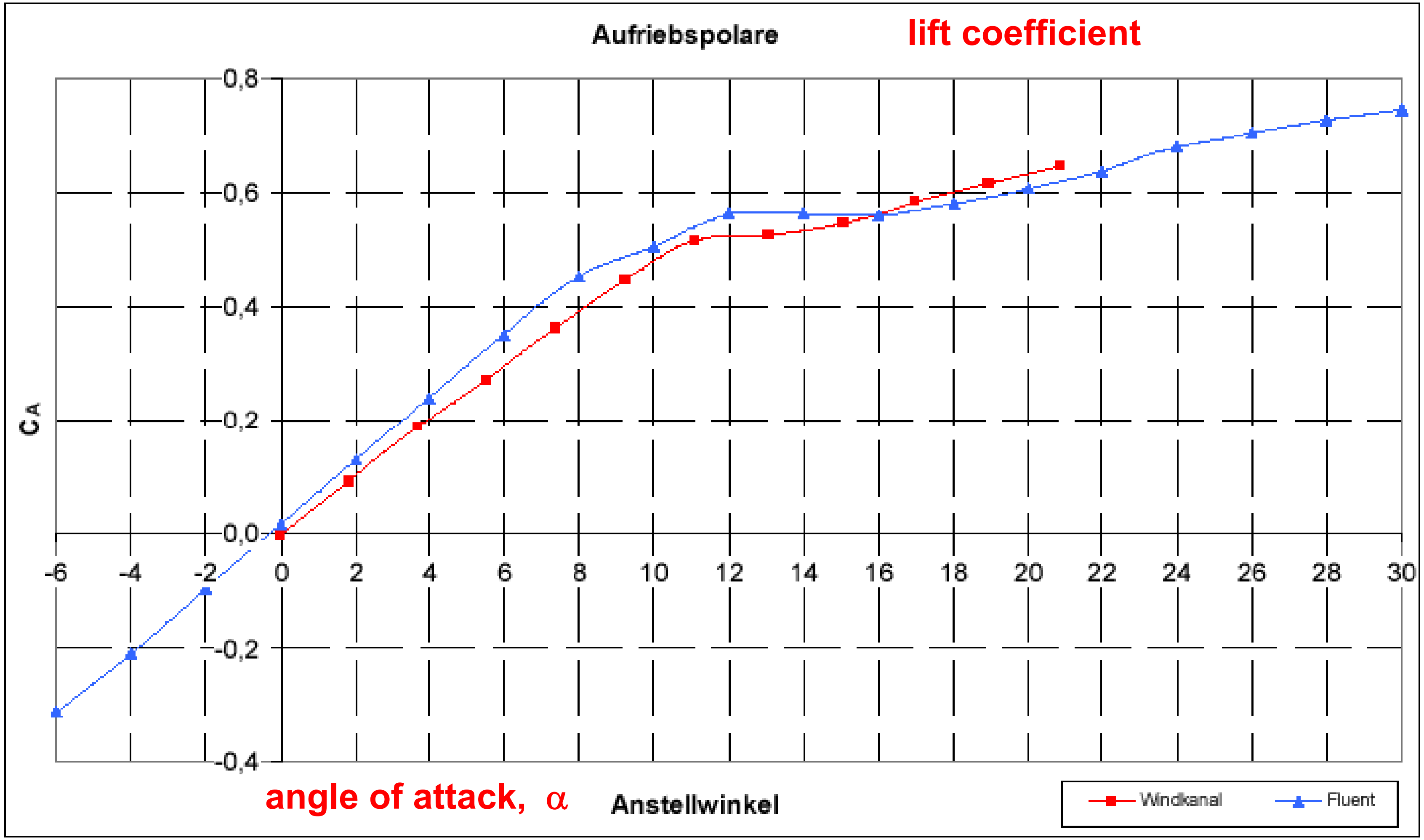
Sizing Results:

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)

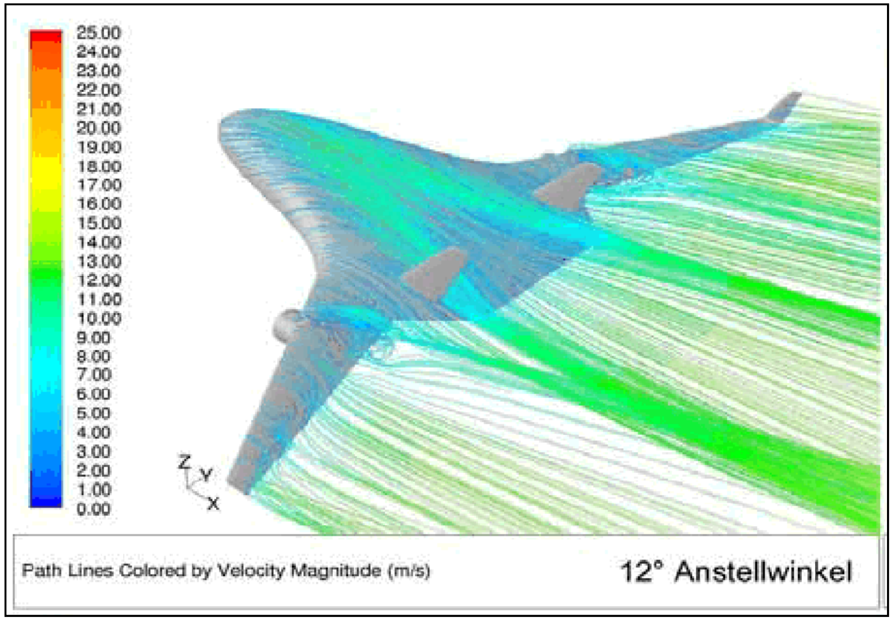
payload:	83000 kg	
MTOW:	501000 kg	(VELA 2: 691200 kg)
Wing Area:	1923 m²	(VELA 2: 1923 m² - forced to fit)
MLW:	366000 kg	
OEW:	251000 kg	(VELA 2: 380600 kg)
Fuel:	167000 kg	(VELA 2: 278200 kg ?)
Thrust:	344 kN	(for each of the four engines)

AC20.30: CFD with FLUENT

Diplomarbeit: H. Brunswig



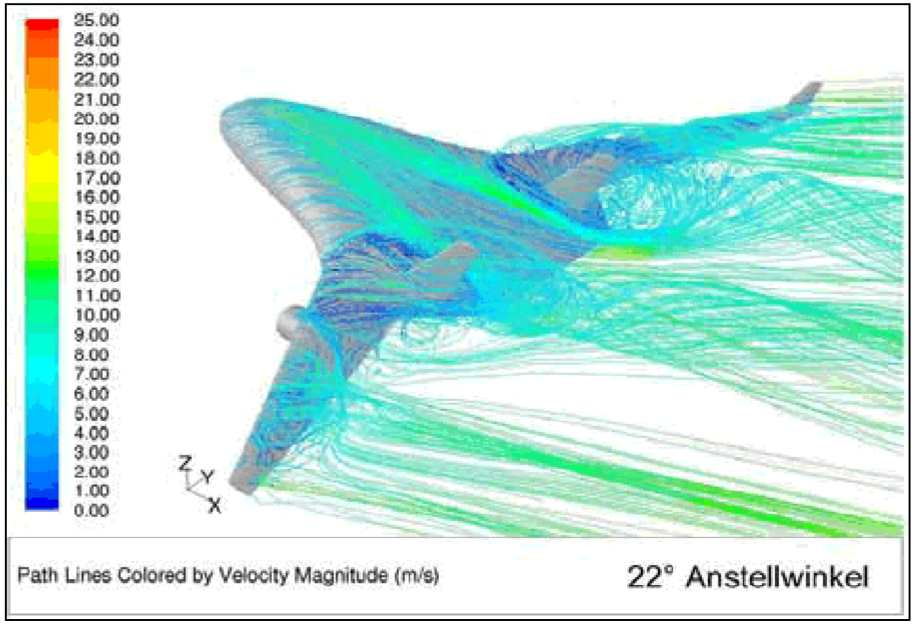
AC20.30: CFD with FLUENT



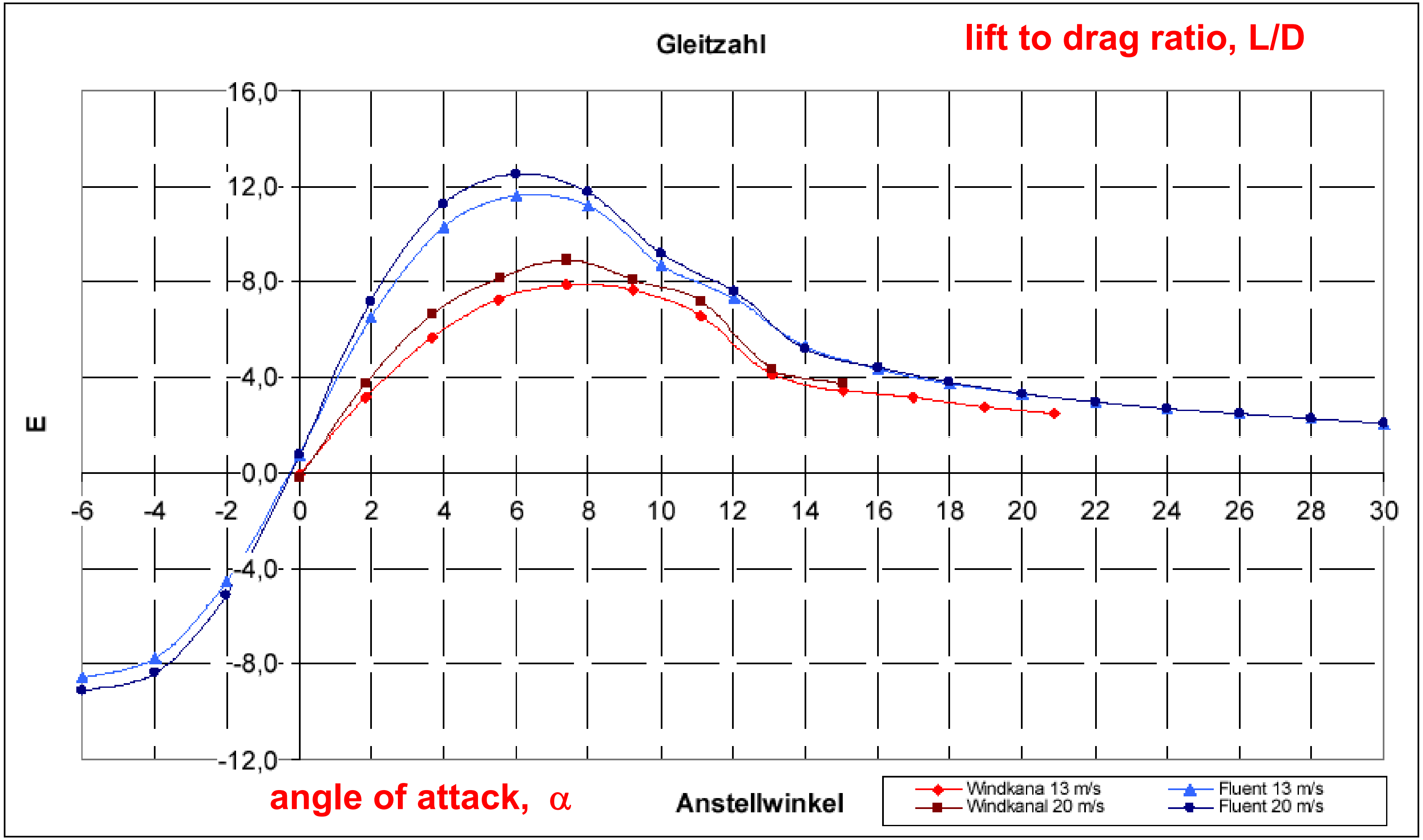
Stalls can easily be handled
Usable lift up to AOA of 12°
At 22° AOA:

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

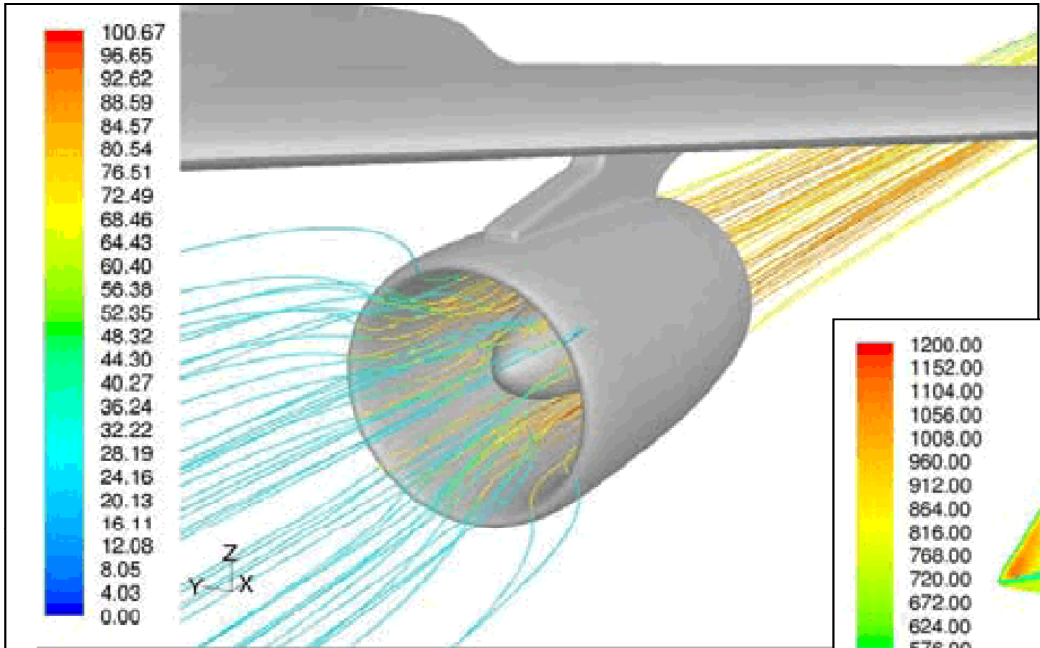
path lines



AC20.30: CFD with FLUENT

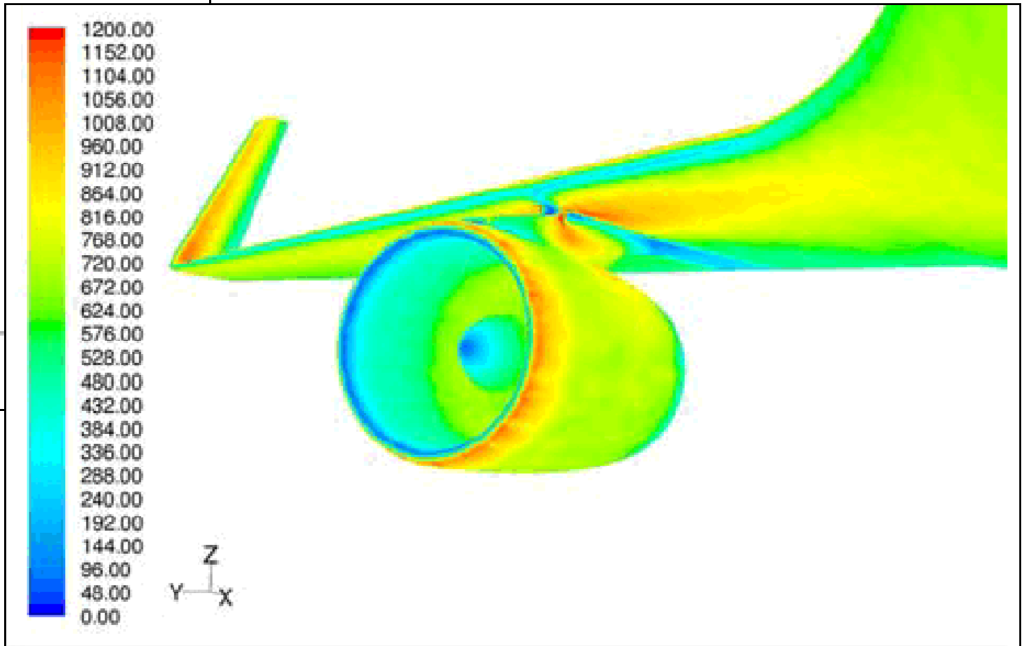


AC20.30: CFD with FLUENT

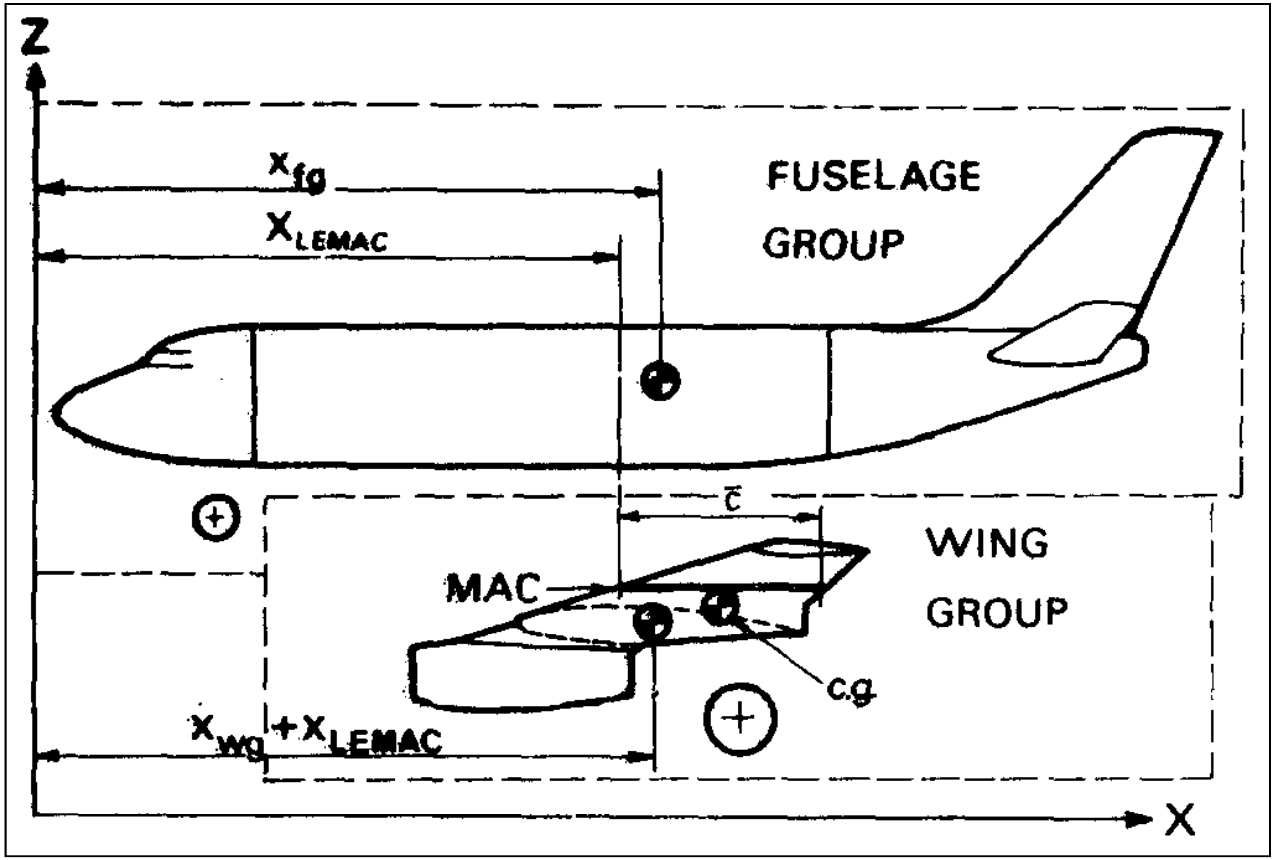


Path Lines Colored by Velocity Magnitude (m/s)

Engine Integration



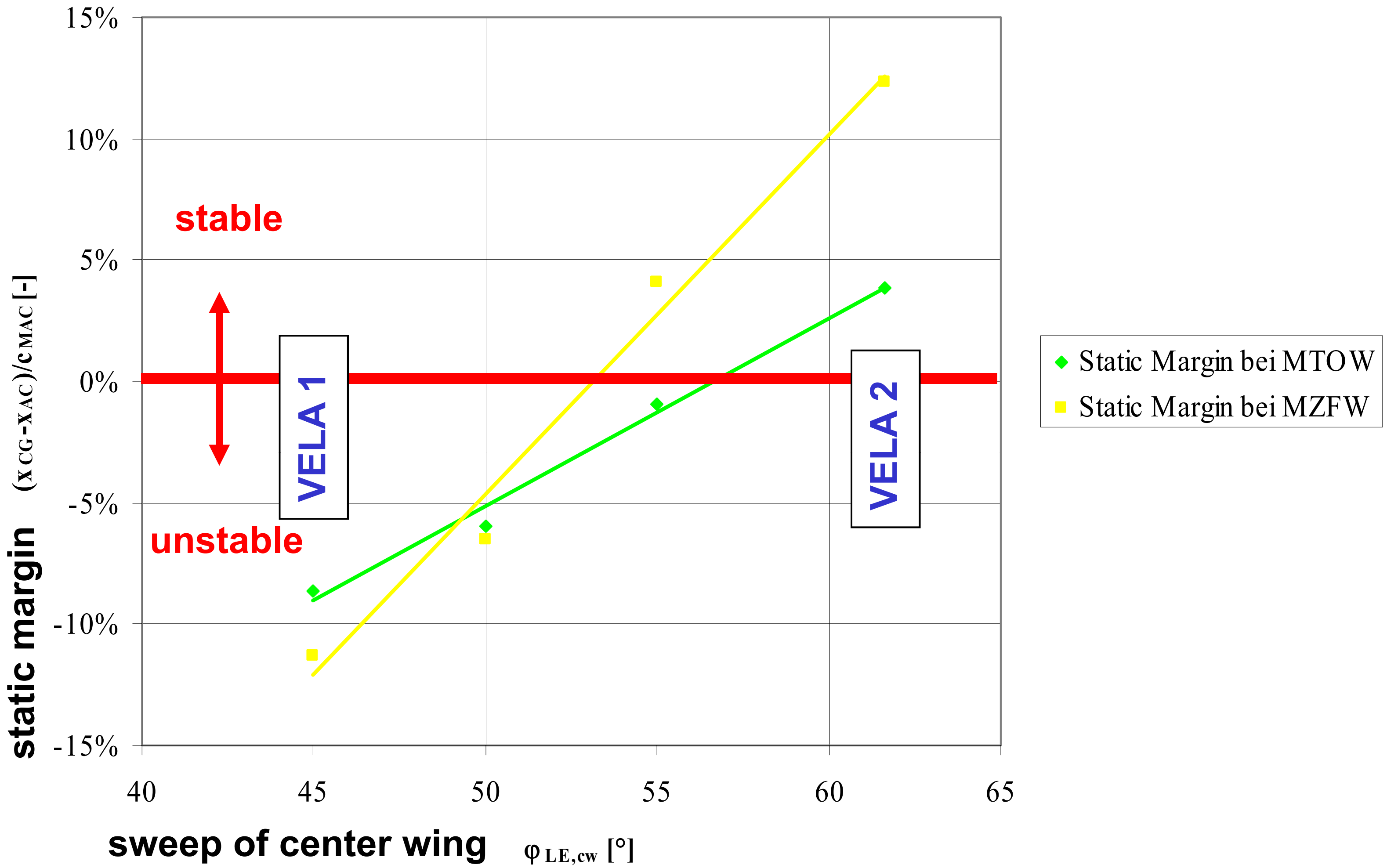
Contours of Dynamic Pressure (pascal)



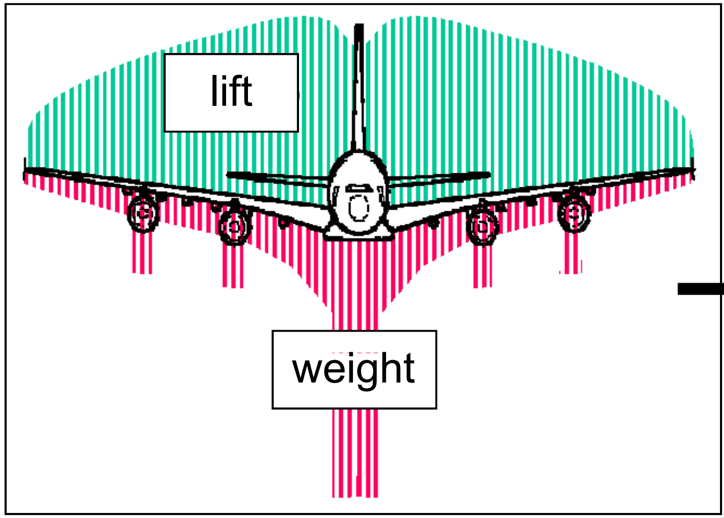
Positioning of the CG on the Mean Aerodynamic Chord (MAC) for required *static margin* is achieved in conventional design by shifting the wing with respect to the fuselage. This approach is not possible in BWB design!

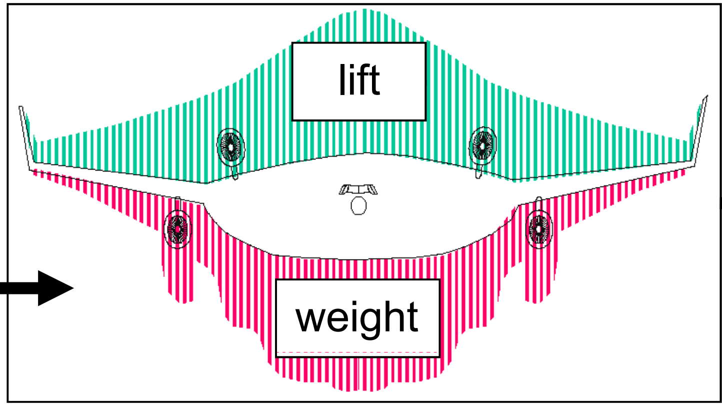
$$x_{LEMAC} = x_{fg} - x_{cg} + \frac{m_{wg}}{m_{fg}}\left(x_{wg} - x_{cg}\right)$$

Static Longitudinal Stability for VELA Configurations



Weight Saving Potential of BWB Configurations





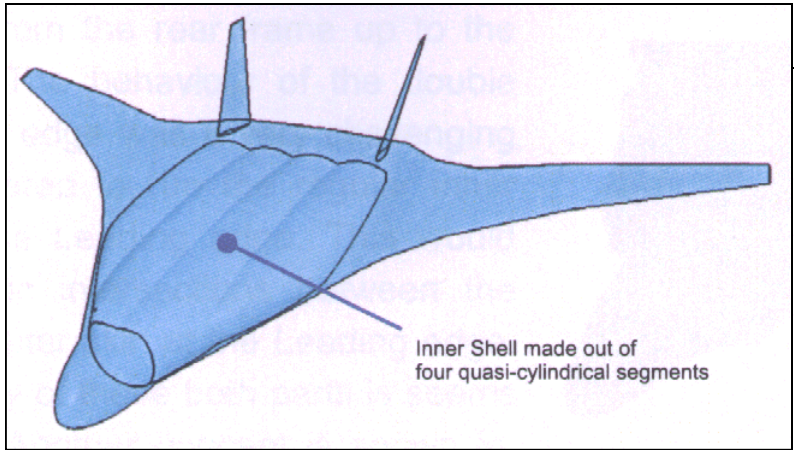
Less bending moments in a flying wing or BWB

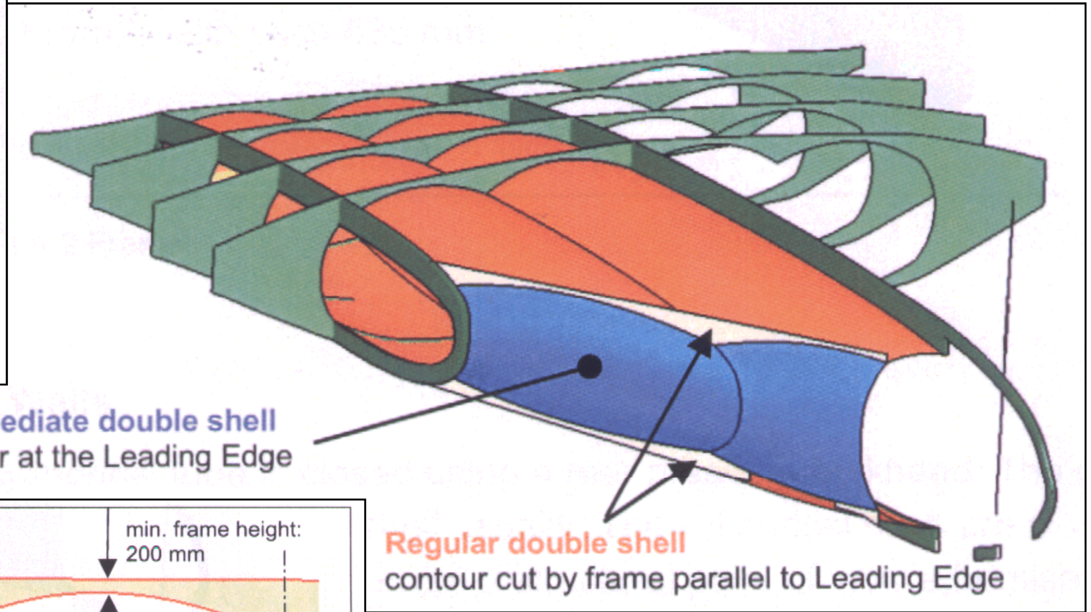
BWB study with distributed propulsion (Virginia Polytechnic)

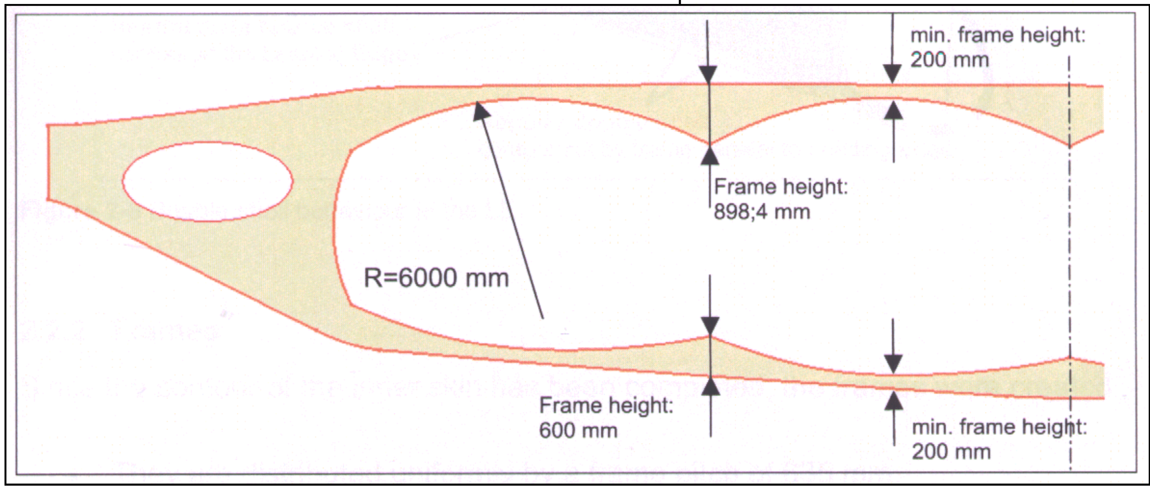
Helios - example of an extreme span loader with distributed propulsion (NASA / AeroVironment, Inc.)

VELA 2 - Basic Structural Layout

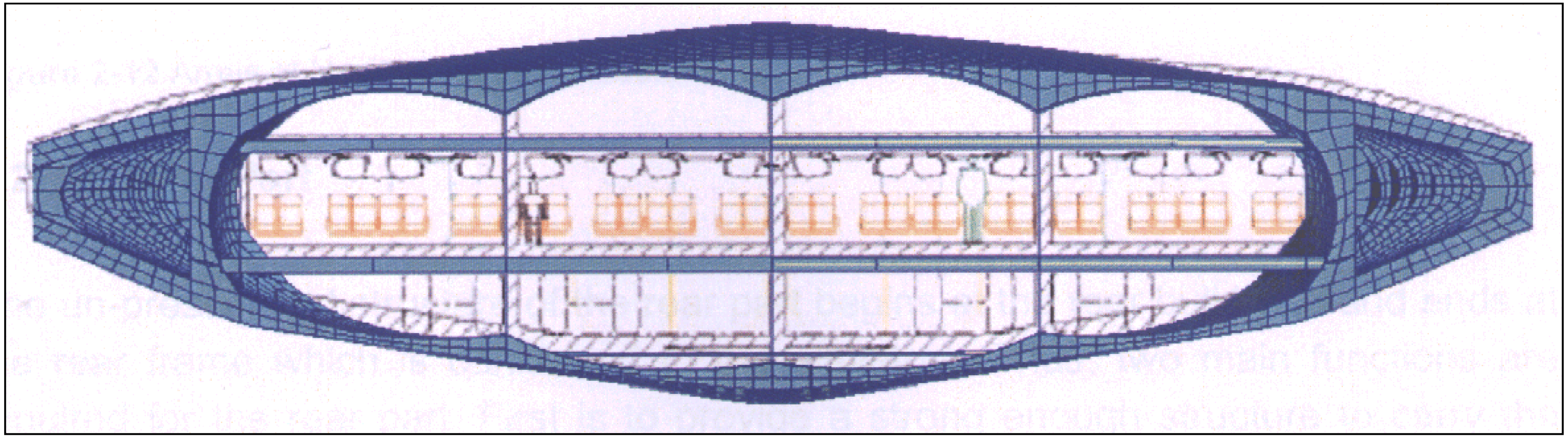
Thesis: T. Kumar Turai

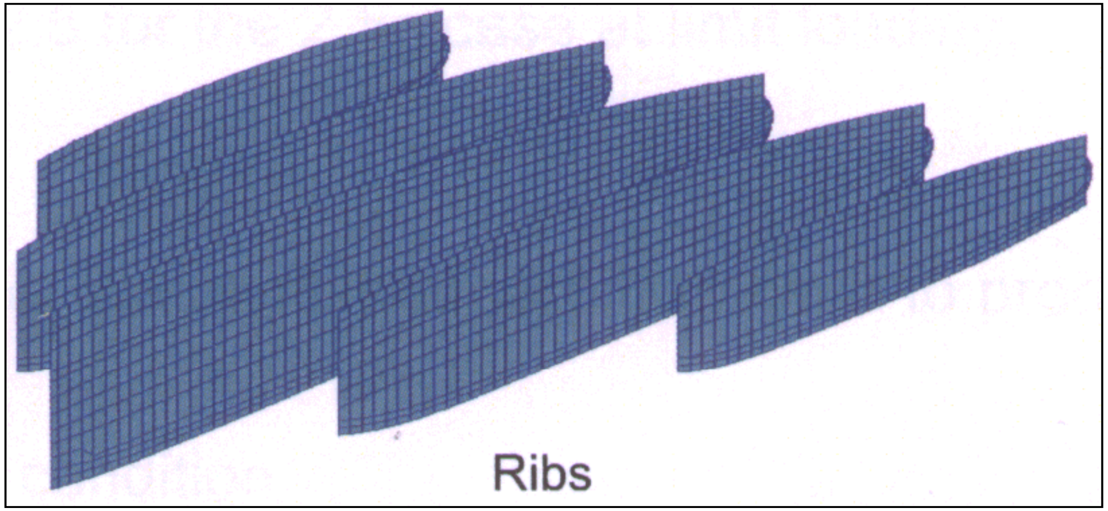




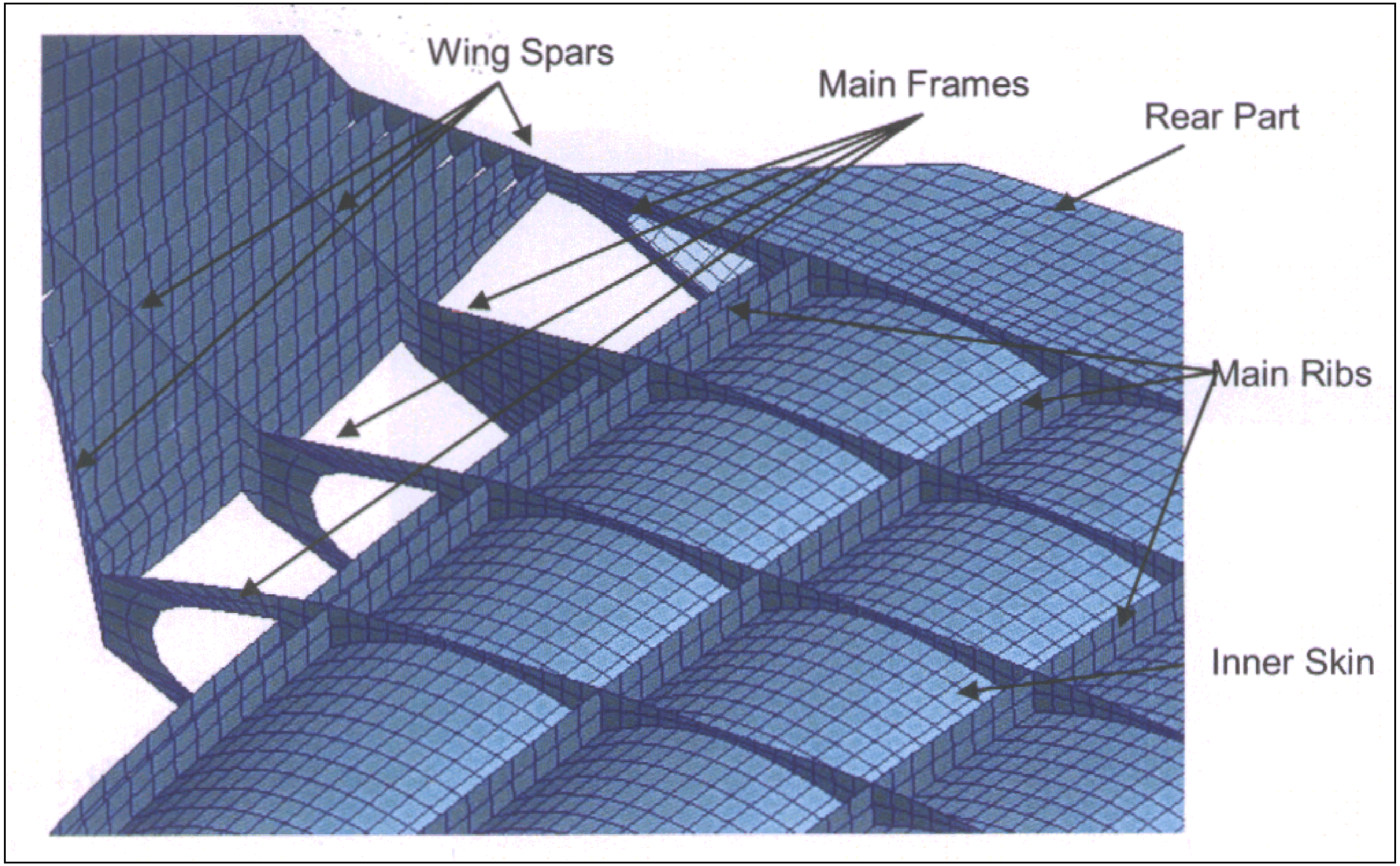


VELA 2 - Cabin

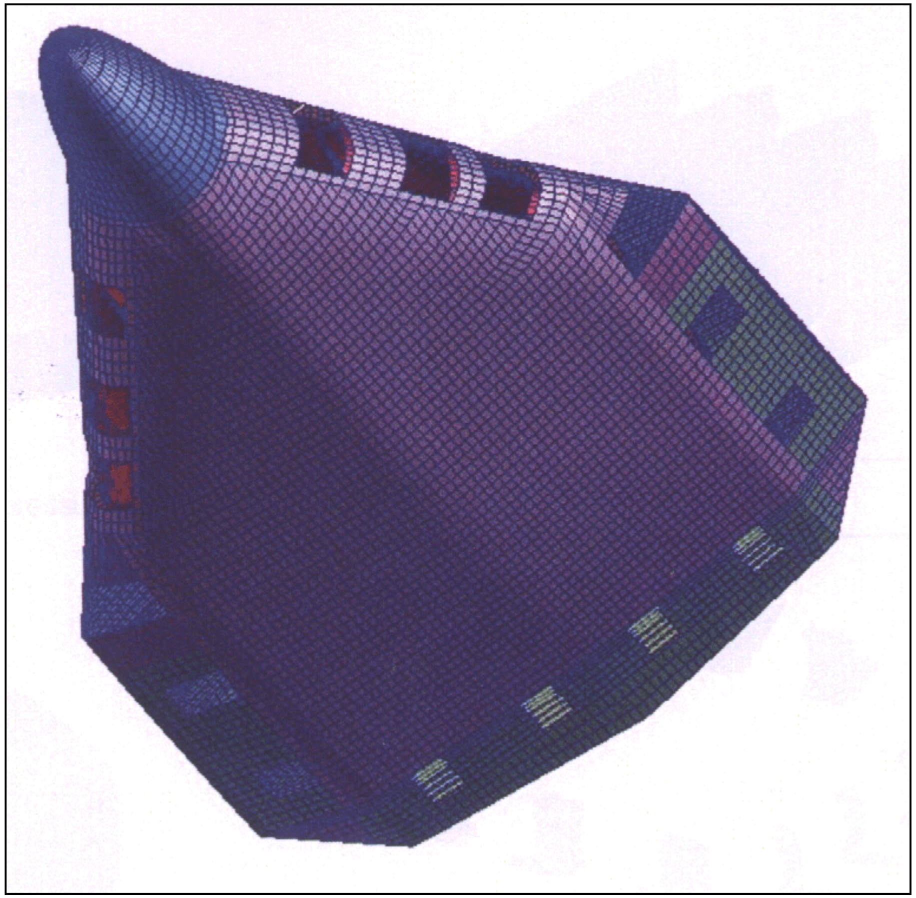




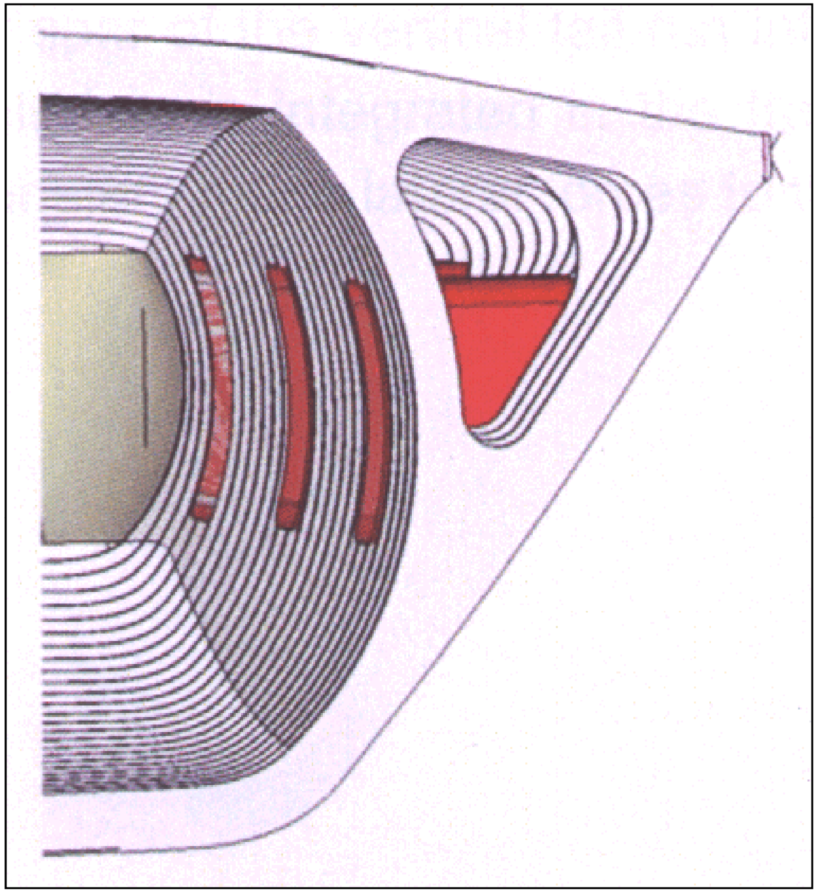
VELA 2 - Wing Integration



VELA 2 - Doors



Door cut-outs



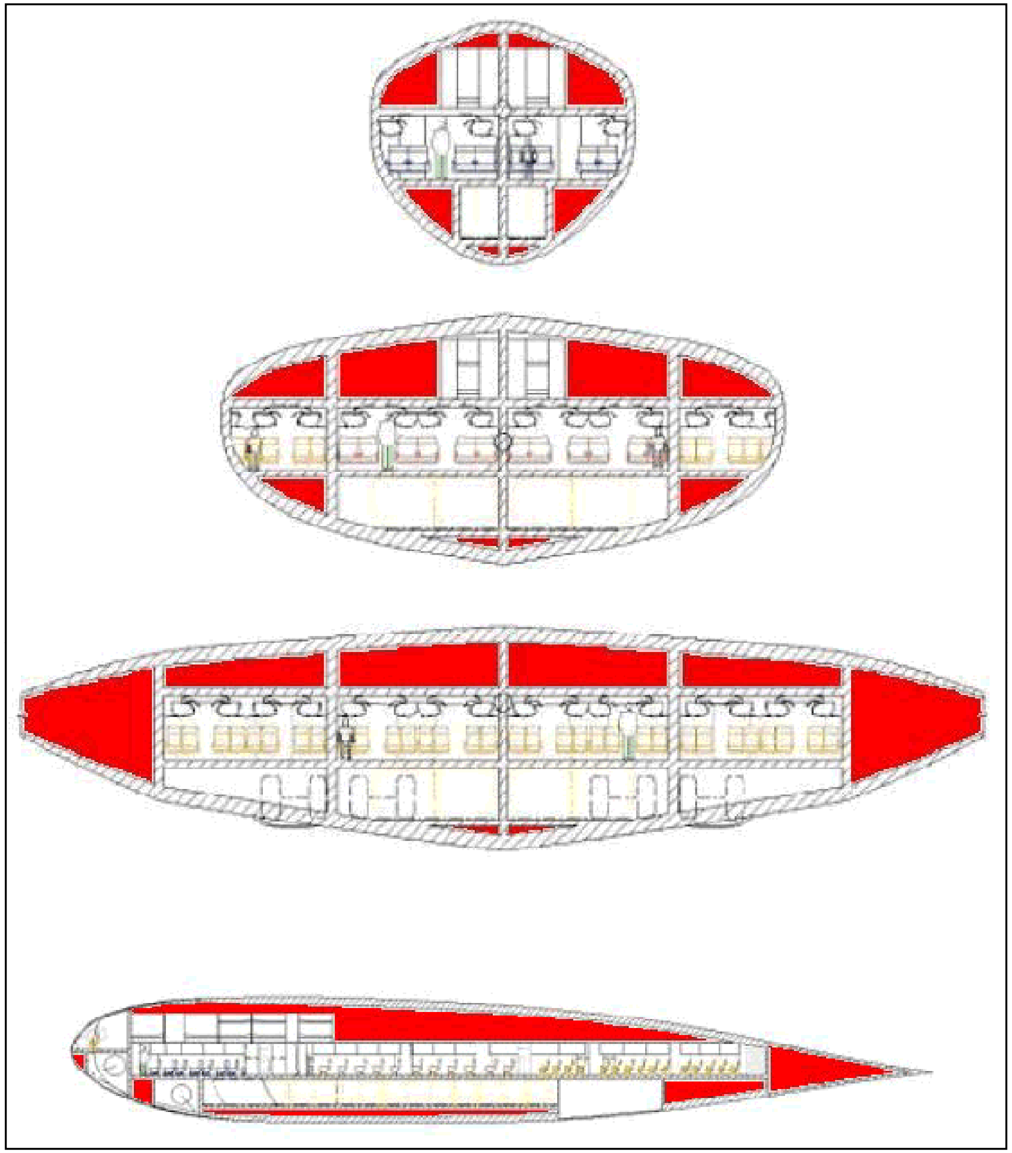
Side door integration

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** !



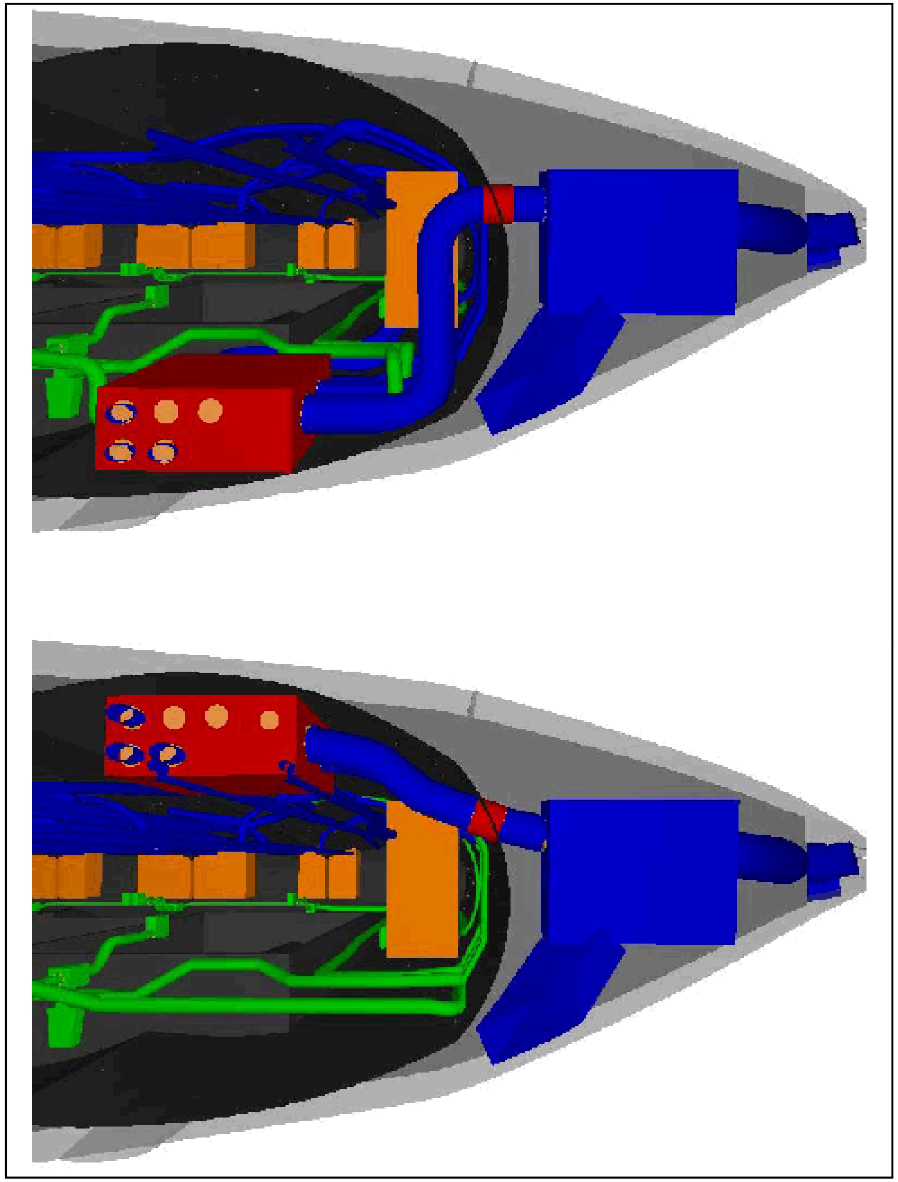
VELA 2 - System Installation Areas

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:

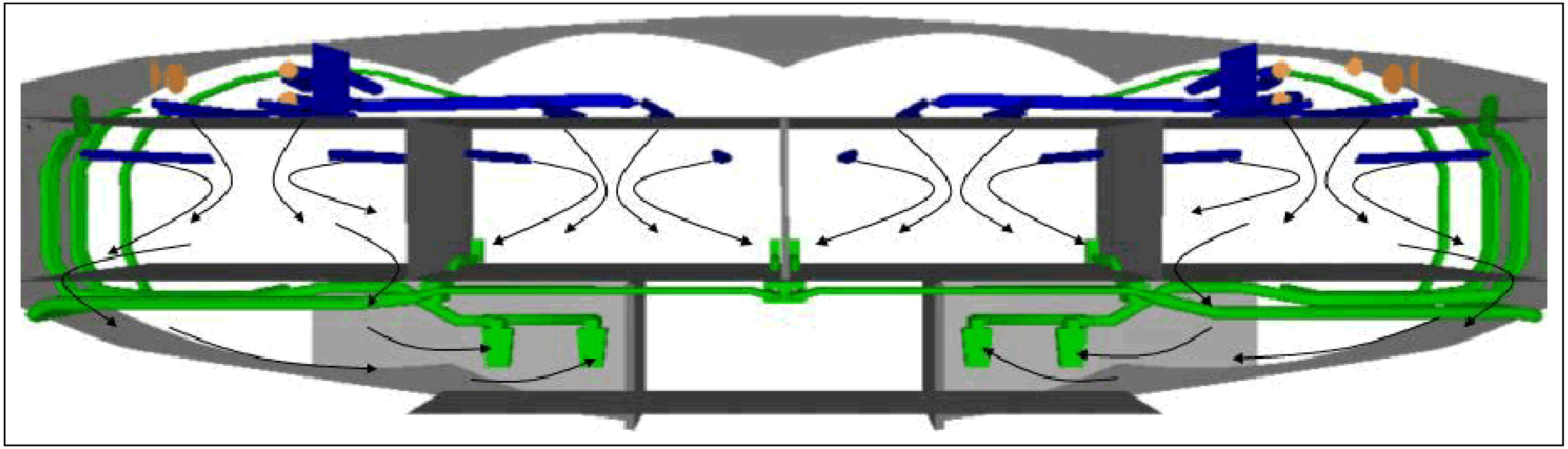
1.) System diagram
2.) Sizing
3.) Routing & ducting

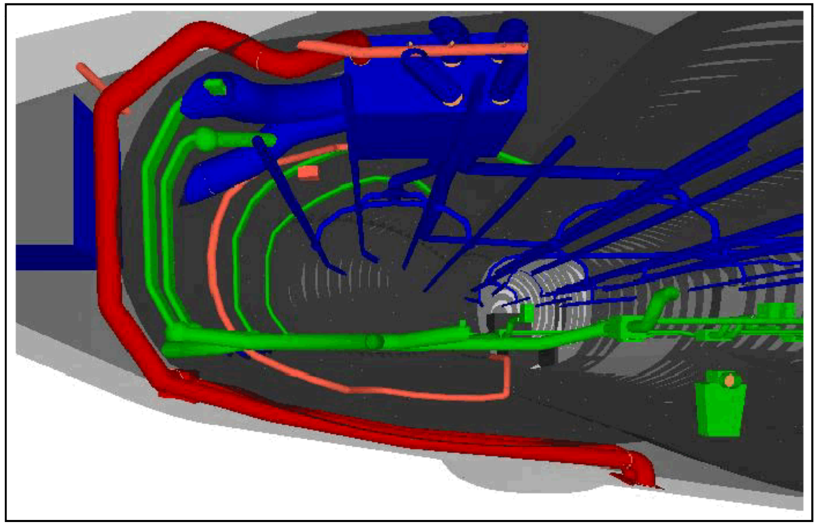
Air Generation Unit is positioned in the transition wing.

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

Ducts for recirculation air.

VELA 2 - ATA 21 - Ducting



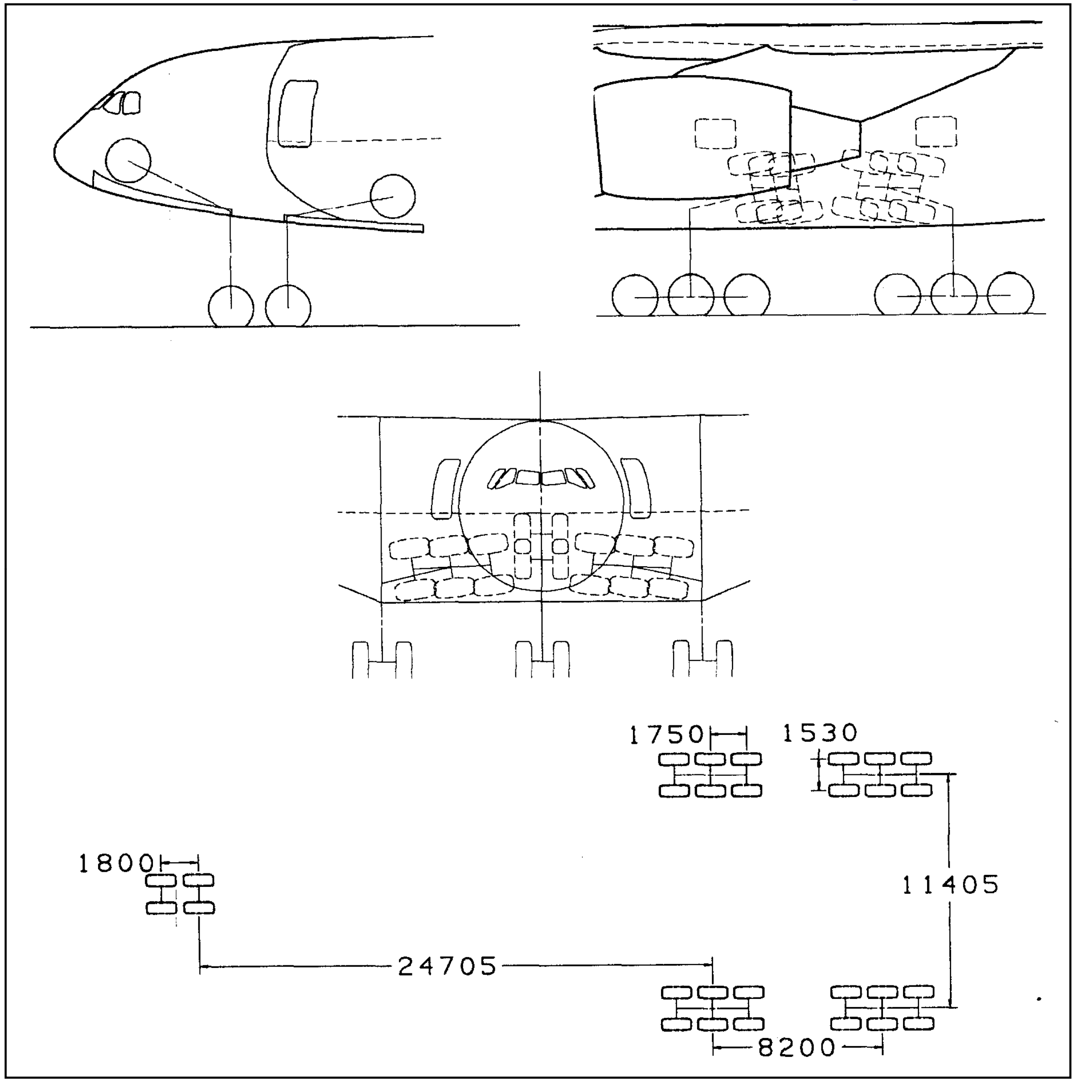


Air circulation. Recirculation requires ducts.

Low pressure air connector and duct to mixing unit.

Duct for emergency air.

VELA 3 - Landing Gear Integration



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

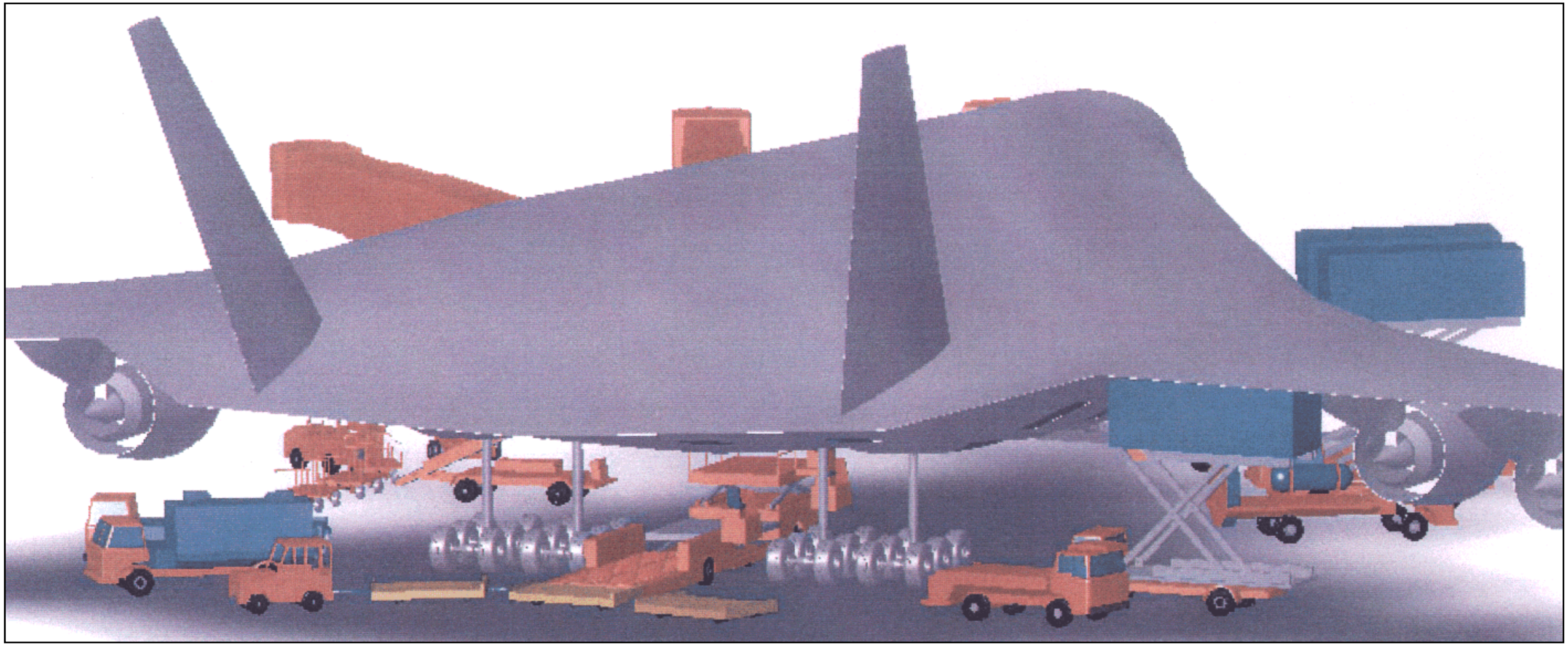
Two twin tri-tandem (6-wheel) main landing gears on each side.
Special retraction mechanism.

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

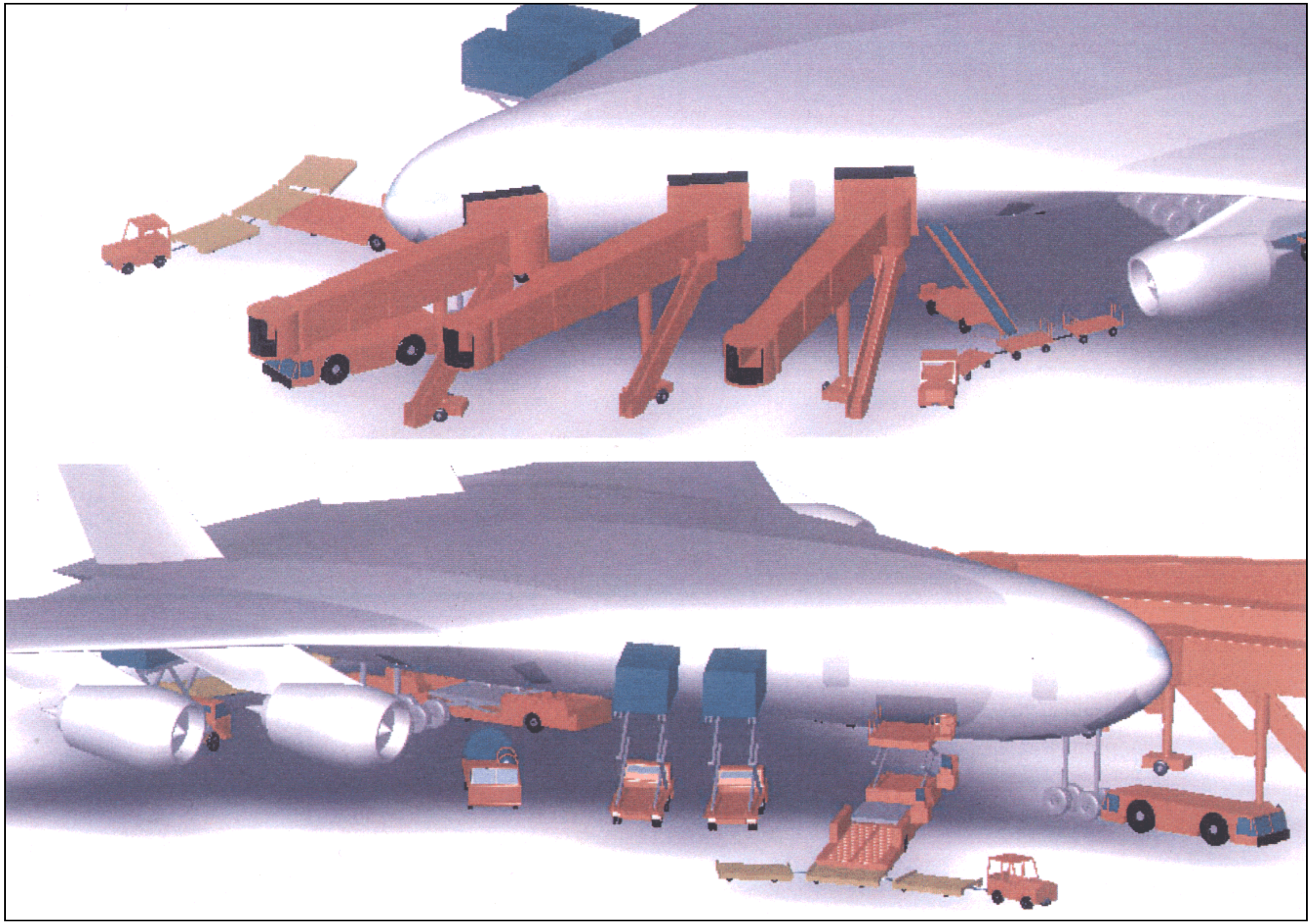
VELA 3



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.

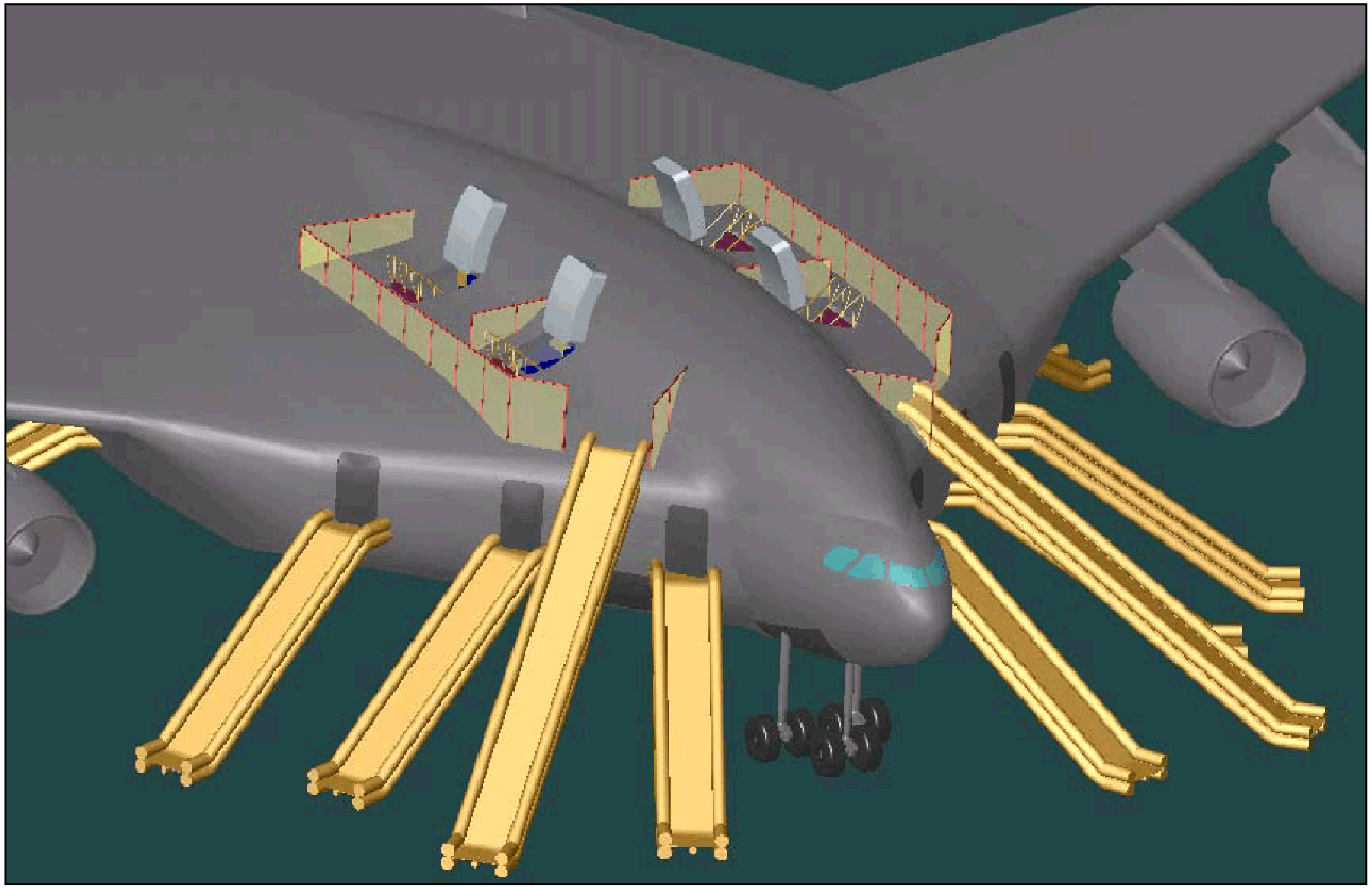
Catering from the right.

Boarding through three bridges.

Fuel truck under right wing.

Towing truck.

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.

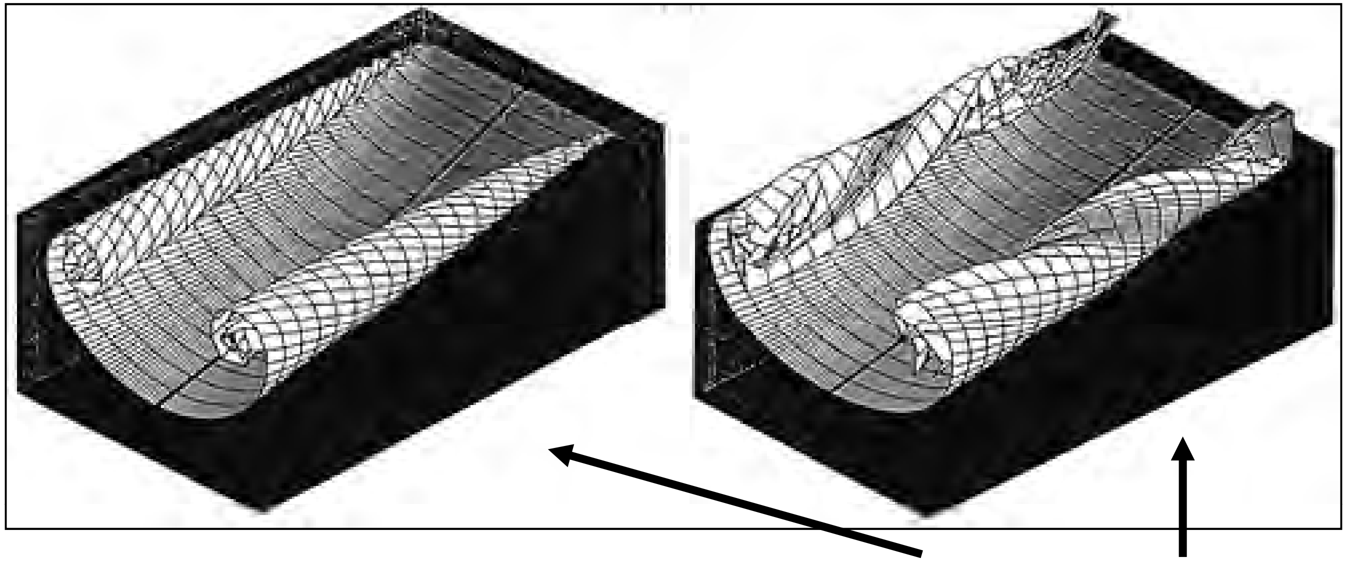
Wake Turbulence - Fundamentals

Wing tip vortices cause induced drag, D_i .

Wake turbulence cause a danger to following aircraft.

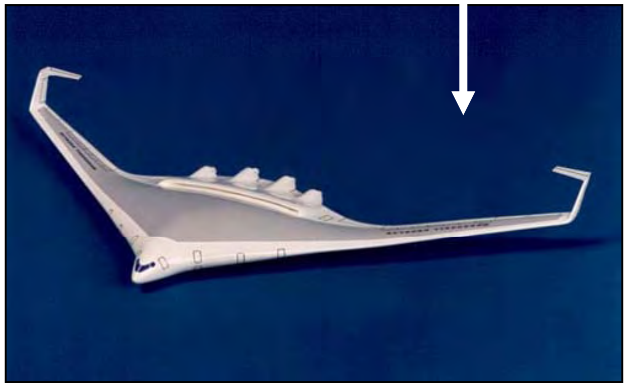
The initial strength of the wake turbulence
is based on basic aircraft parameters:

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



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

C-Wing-BWB:



Wake Turbulence - 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

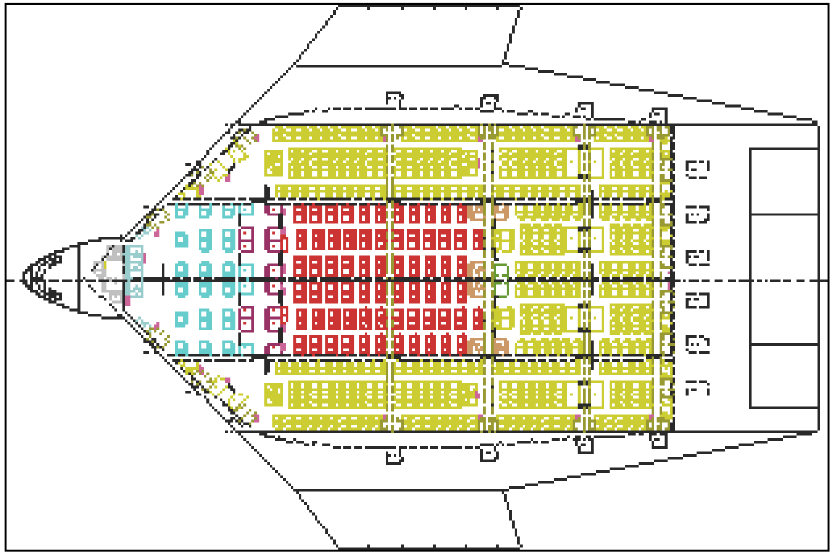
Source: FAA [1978]

[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)

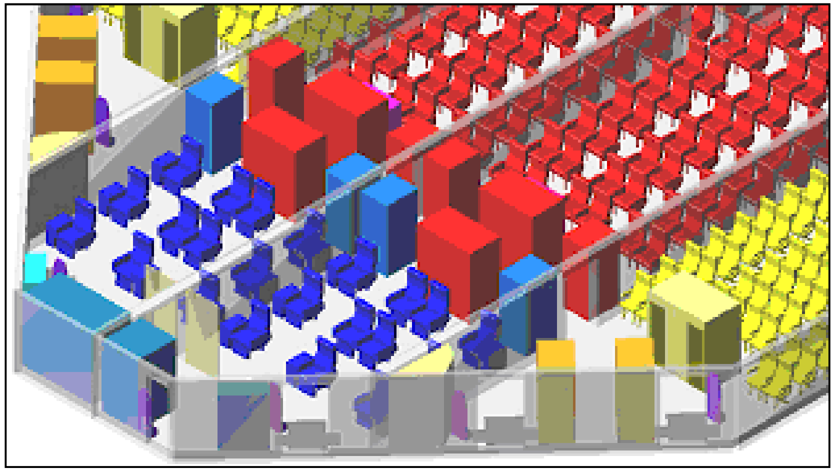
A380 interim value:
10 NM

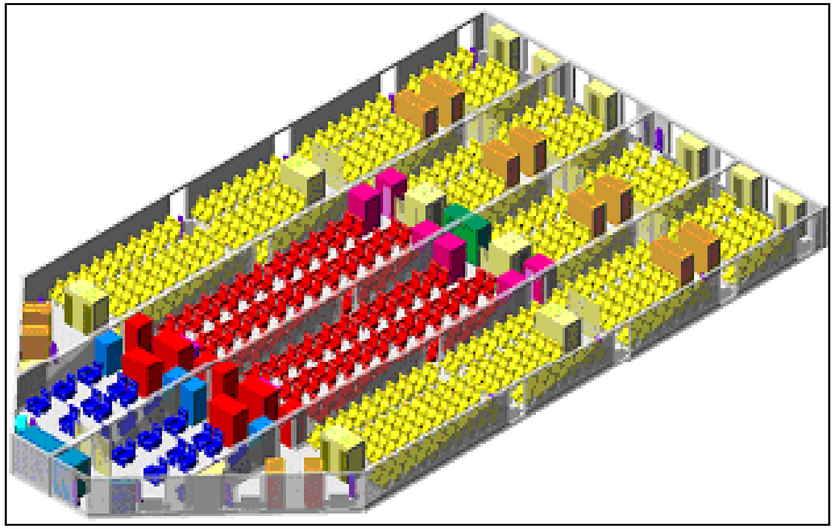
VELA 1 - Cabin Layout

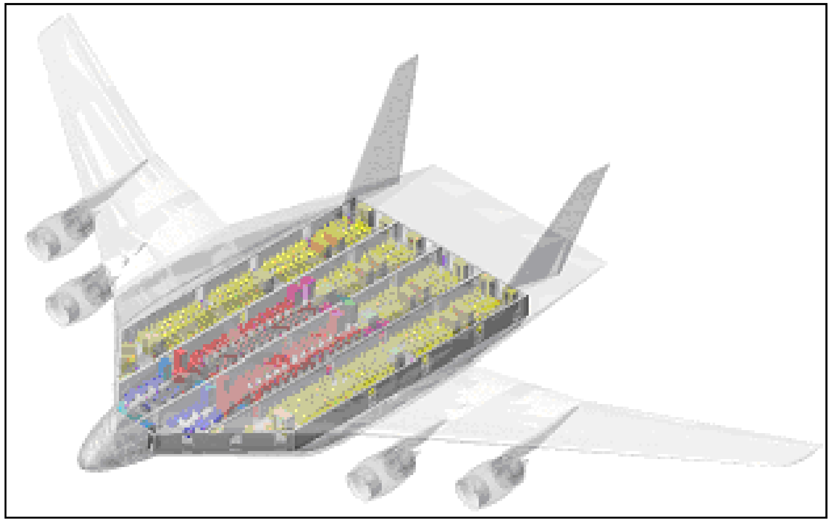
Diplomarbeit: S. Lee



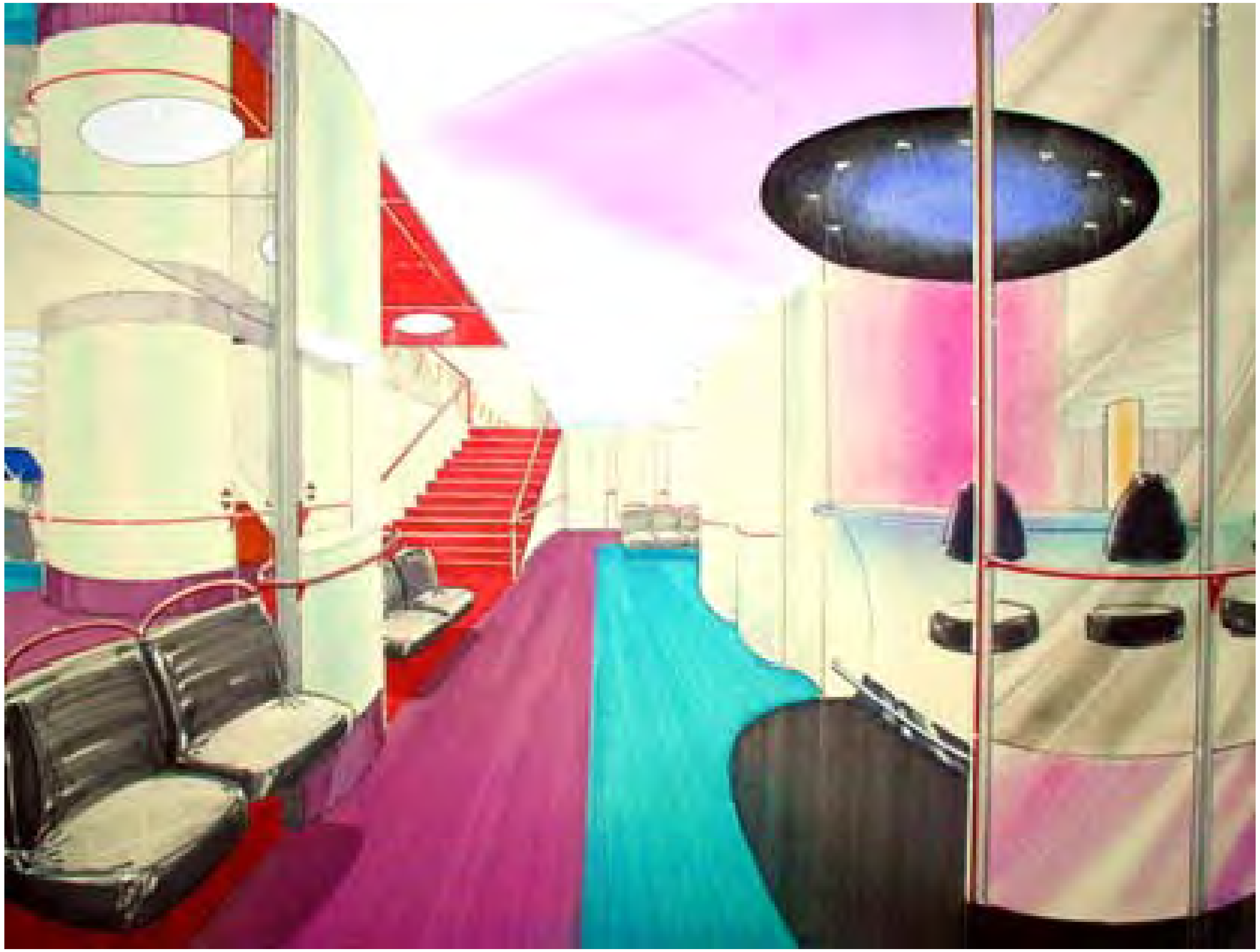
Vertical acceleration for pax on outer seats.







Double Deck BWB



Interior Design

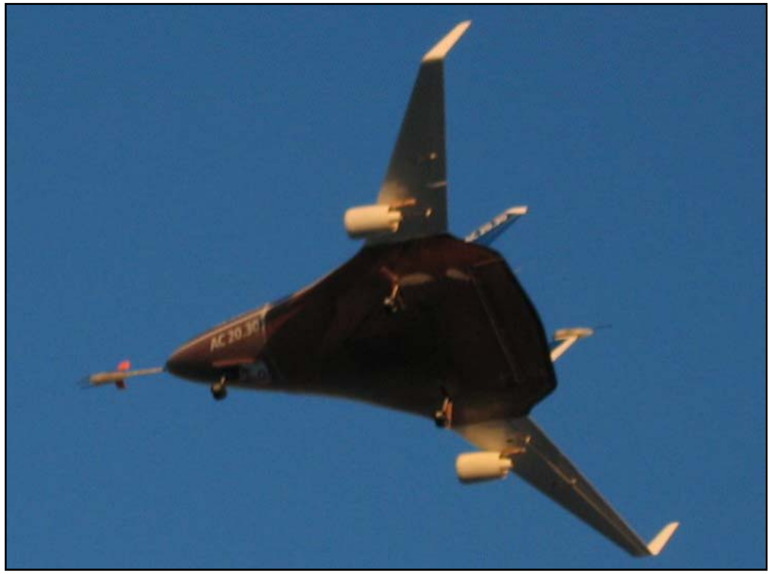
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

Underfloor Usage - Artificial Windows

BWB Center Wing Shapes from Inside

AC20.30

Test Flights

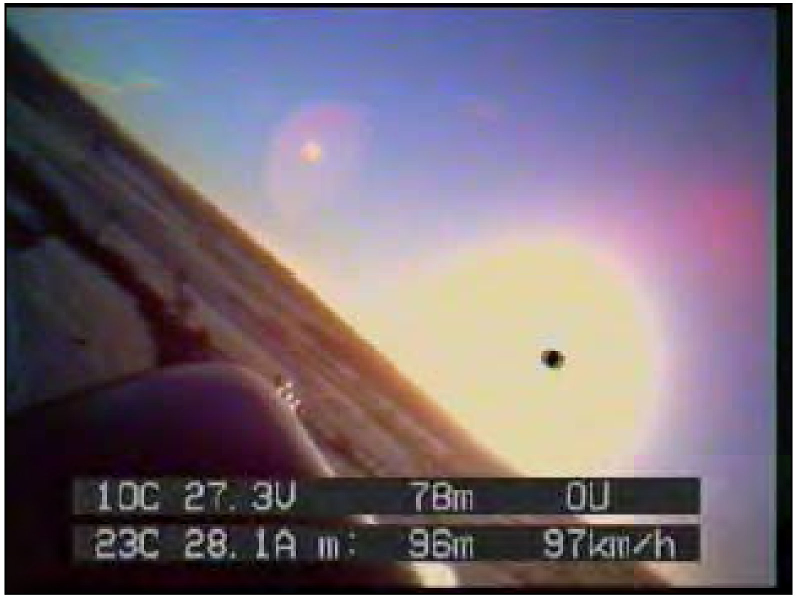


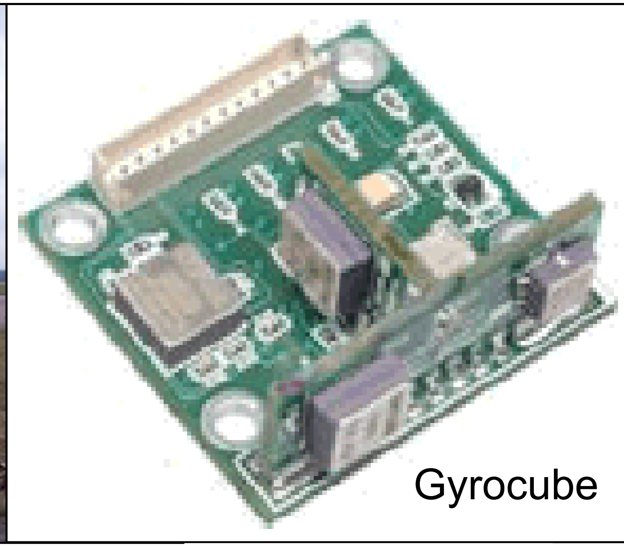
AC20.30 Parameters

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

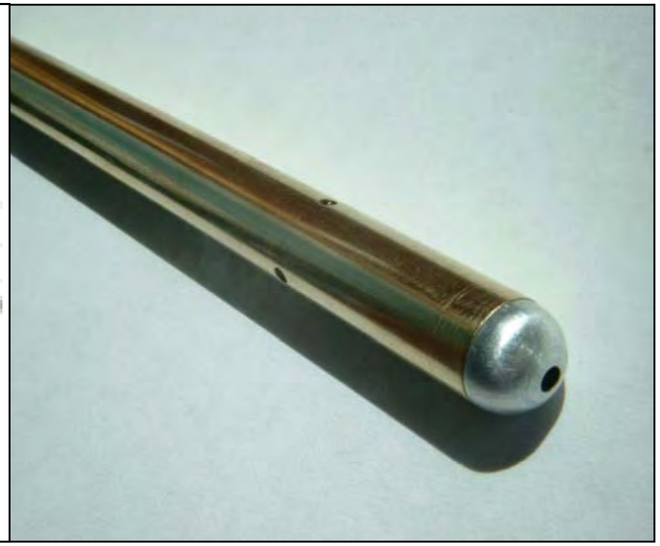
Test Flights

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



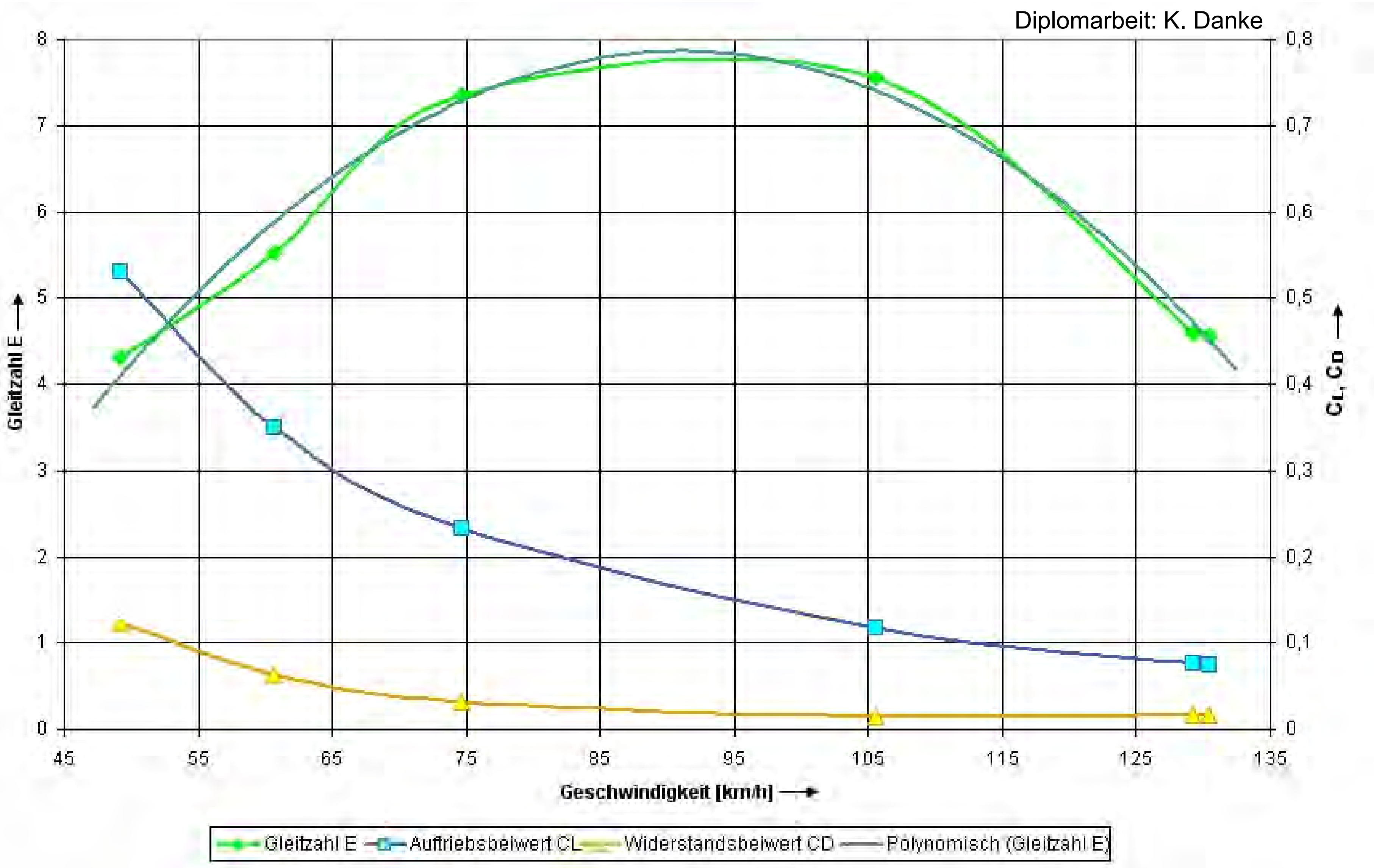


Gyrocube



AC20.30

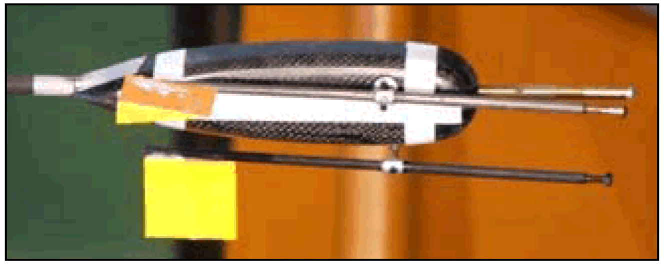
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

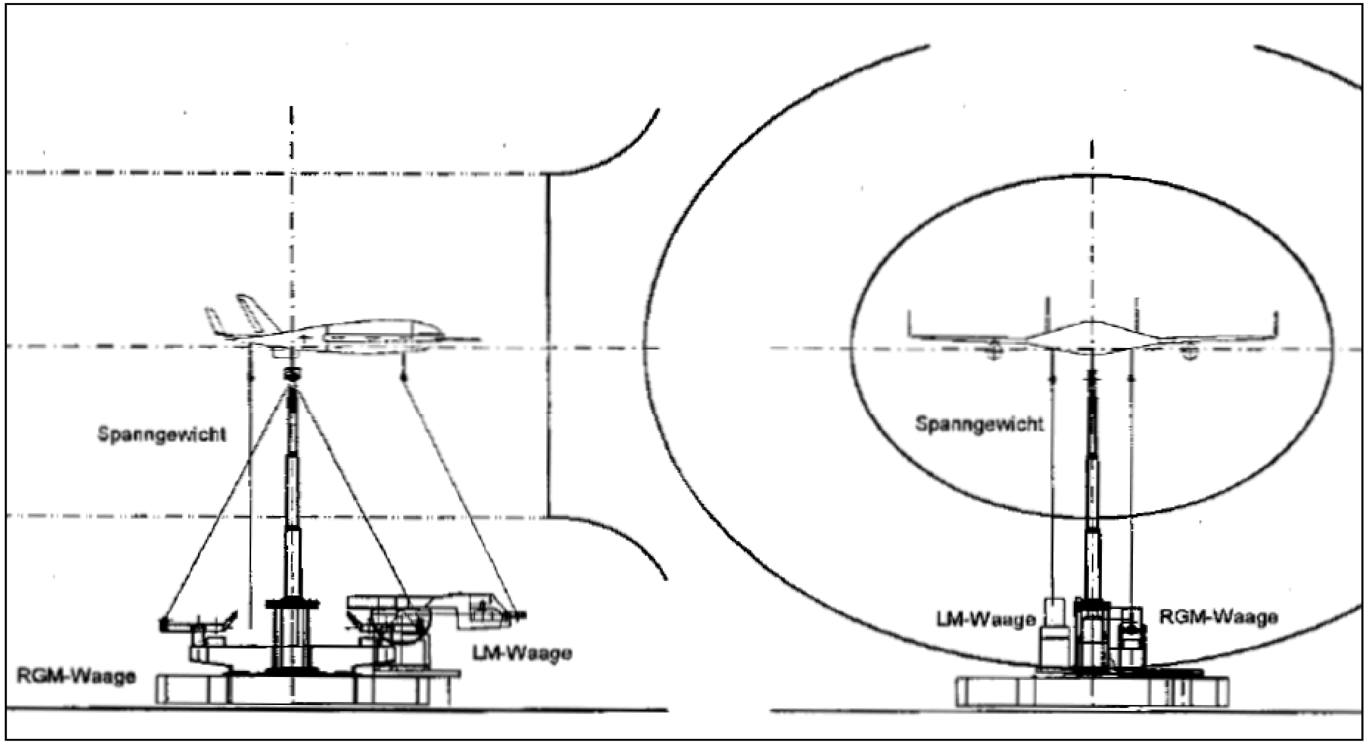


Wind Tunnel Tests

AC20.30

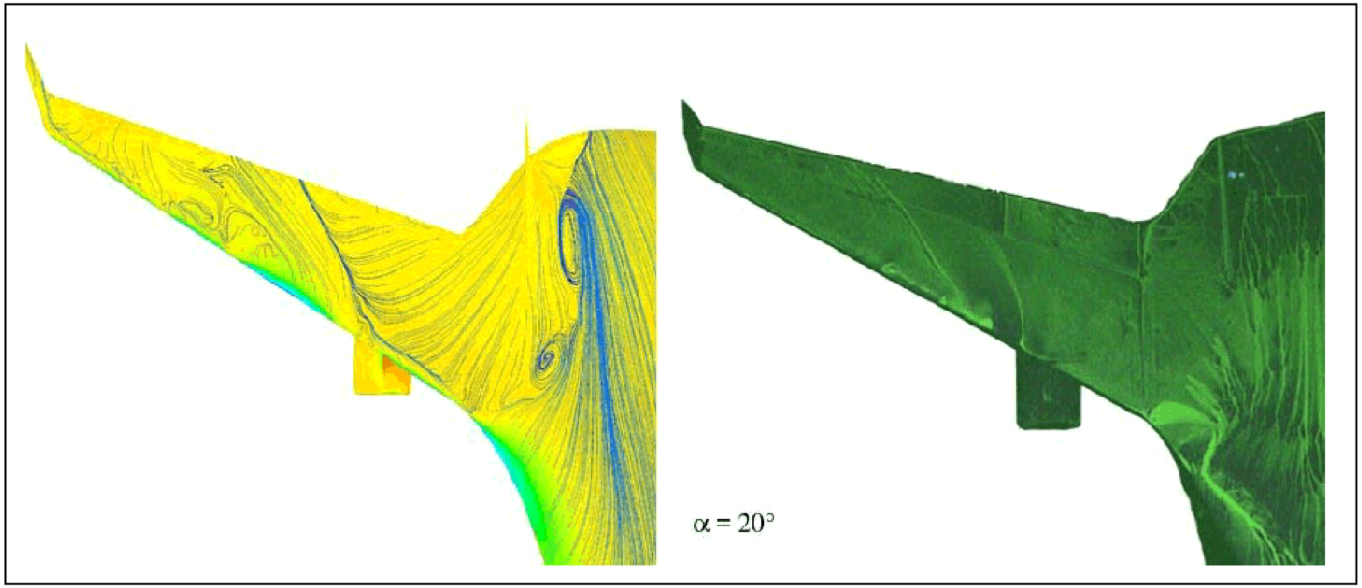
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

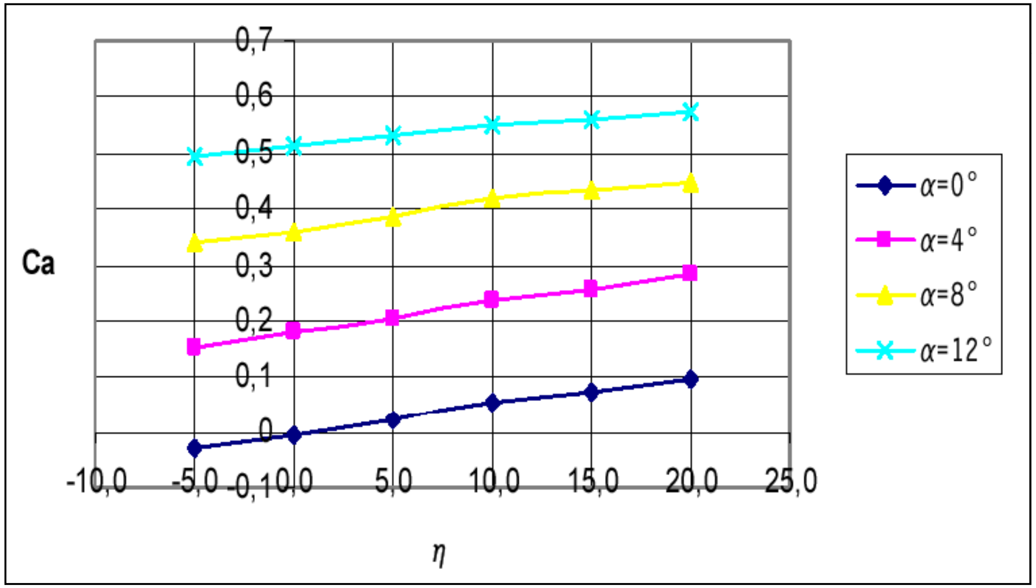




AC20.30

Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences





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

Lift coefficient dependend 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):

reduction in weight :	single shell required. In this case: 8% better
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, more than 750 pax per A/C (probably no problems with wake turbulence)
reduction in DOC :	down ??% (mostly due to scale effect)

But:

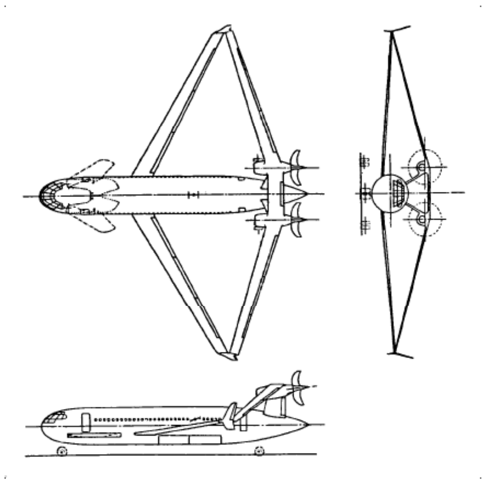
open certification problems :	unstable configuration (?), ditching
open design problems :	rotation on take-off, landing gear integration, ...

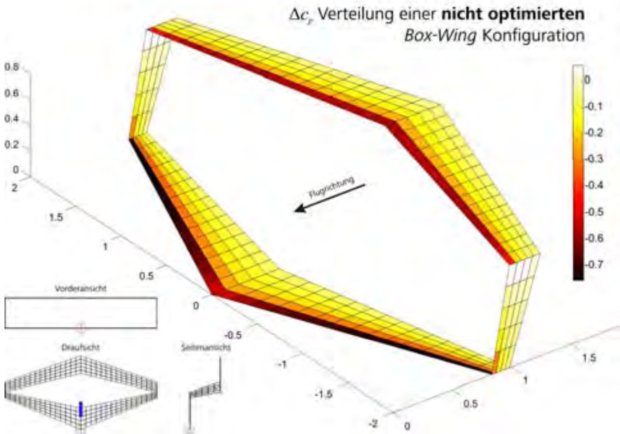
Future?

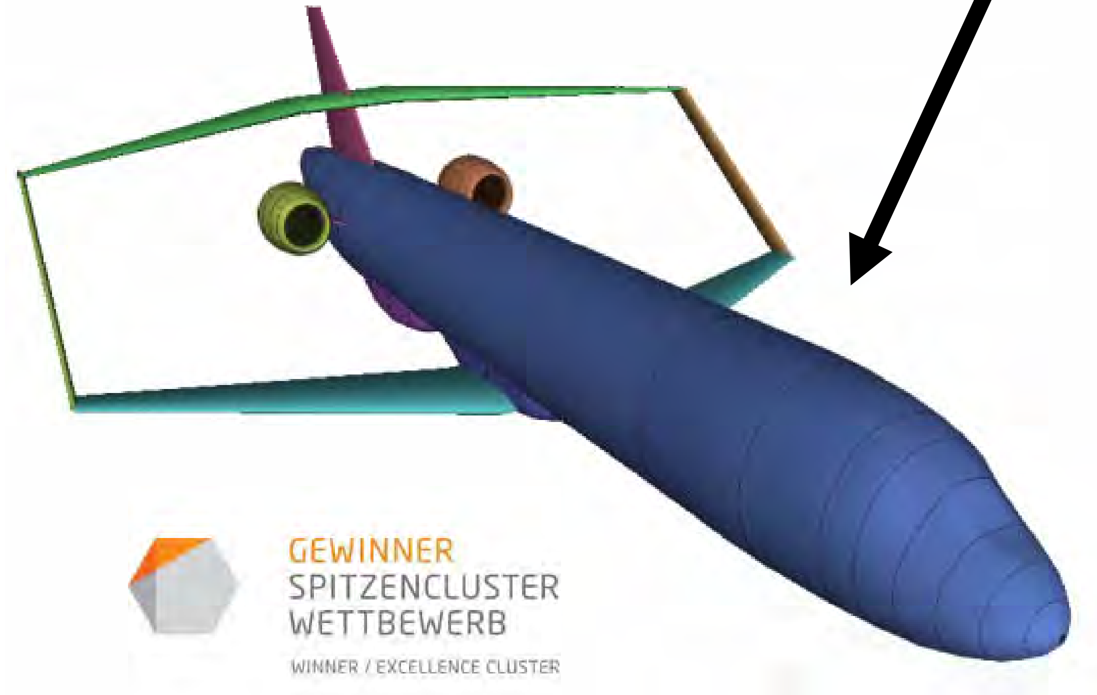
Hochschule für Angewandte
Wissenschaften Hamburg
Hamburg University of Applied Sciences

Box Wing Aircraft

Airport2030







GEWINNER
SPITZENCLUSTER
WETTBEWERB
WINNER / EXCELLENCE CLUSTER