Hochschule für Angewandte Wissenschaften Hamburg

Hamburg University of Applied Sciences

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Aircraft Design by Scholz – Adopted at Hamburg University of Applied Sciences and Beyond

Dieter Scholz

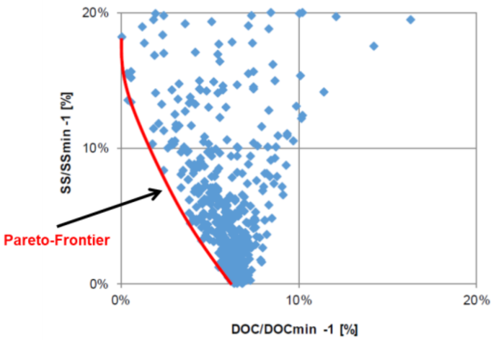
Aviation Industry Corporation of China (AVIC)

AVIC Aircraft Design and Research Institute

Aircraft Design Seminar

Hamburg University of Applied Sciences, 2025-11-18

$$m_{MTO} = \frac{m_{PL}}{1 - \frac{m_F}{m_{MTO}} - \frac{m_{OE}}{m_{MTO}}}$$



Abstract

Purpose – Presenting an overview of my (Prof. Dr. Scholz) aircraft design teaching and research.

Methodology – A review of lecture notes, short course notes, and guided research of students up to PhD-level.

Findings – Aircraft design teaching by Scholz follows 16 steps in a systematic way, starting with requirements (Step 1) and ending with a three-view drawing or a 3D model of the aircraft (Step 16). Central is Step 5 (preliminary sizing) based on Loftin (1980), making use of a 2D manual optimization. Conceptual design provides the details of cabin and fuselage design (Step 6), wing design (Step 7), design for high-lift (Step 8), empennage design (Step 9 and 11), mass estimation (Step 10), landing gear design (Step 12), drag estimation (Step13), aircraft performance checks (Step 14), design evaluation mainly based on Direct Operating Costs (DOC, Step 15) The method has been adopted at Hamburg University of Applied Sciences and at other universities in Germany.

Limitations – This presentation gives only an overview of methods and tools. For details, the aircraft design lecture notes, supporting documents, and tools may be consulted as referenced.

Practical implications – The overview may prevent getting lost in the details of the aircraft design method.

Originality – For the first time "the method" is clearly linked to the name of the author.

Table of Content

Introduction

Introduction

HAW Hamburg

Berliner Tor Campus with Main Building (blue)

Numbers

Type	Public university
Established	1970
Students	17000

Studies

40 bachelor degree programs
36 master degree programs

4 Main Topics, 4 Campus Locations

Engineering and Computer Science	Berliner Tor Campus
Business and Social Sciences	Berliner Tor Campus
Design, Media and Information	Armgartstrasse / Finkenau Campus
Life Sciences	Bergedorf Campus

Faculty of Aviation and Automotive Systems (LFS)

Bachelor degree programs:	Aeronautical Engineering and Automotive Engineering
Master degree programs:	Aeronautical Engineering and Automotive Engineering
Bachelor degree program:	Mechatronics

=> Aircraft Design and Systems Group (AERO), http://AERO.ProfScholz.de

Introduction

Aircraft Design Short Courses

Type On and Off Campus
Started 2007

hamburg open online university

SC Aircraft Design

南京航空航天大學 NANJING UNIVERSITY OF AERONAUTICS AND ASTRONAUTICS 1952 NUAA

2018 暑期国际课程 Summer Lecture Program

EMBRAER

AIRBUS

Aircraft Design = 飞行器设计

http://AircraftDesign.ProfScholz.de

Introduction

Teaching in China / Visiting China

Teaching in China at AVIC and NUAA

2016 AVIC Qingan Group (QAG), Xi'An, Shaanxi
2018 Nanjing University of Aeronautics and Astronautics (NUAA)
2019 Nanjing University of Aeronautics and Astronautics (NUAA)
2021 AVIC Shaanxi Aircraft Corporation (Online Teaching)

中航工业陕西飞机工业(集团)有限公司
AVIC SHAANXI AIRCRAFT INDUSTRY(GROUP) CORPORATION LTD.

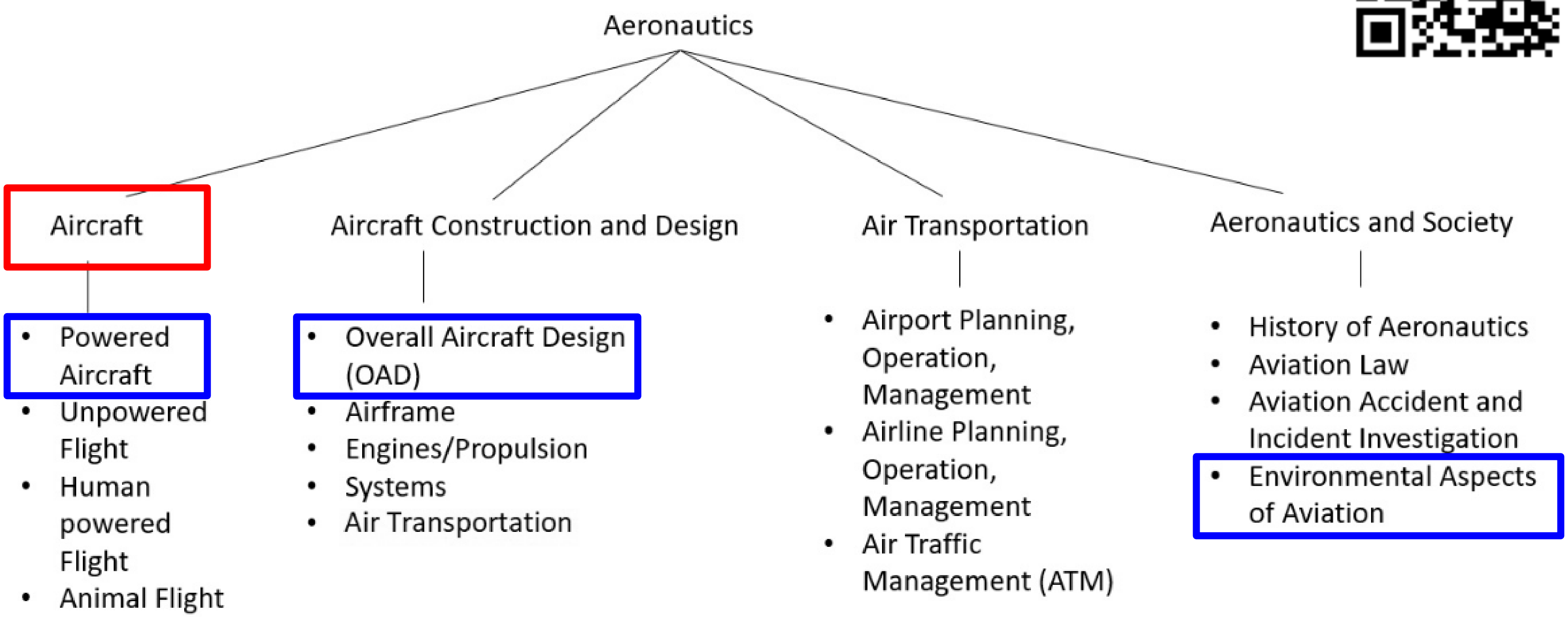
Visiting China by Train

Xi'An, Nangin, Wuhan, Beijing, Shanghai, Suzhou, Hangzhou, ...
Lhasa (Tibet),
Kaxgar, Turpan, ..., Ürümqi (Xinjiang)

Reisebericht, 2019: In China lehren – von China lernen
https://perma.cc/4EYH-7REG

https://purl.org/aero/classification/html

Classification for Aerospace: Aeronautics, Astronautics, and Aerospace Sciences



https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2022-10-06.015

Introduction

Classification for Aerospace: Aeronautics (=> Aircraft)

Compare with the (confusing)

Dewey Decimal Classification (DDC)

629.1	Aerospace engineering
629.13	Aeronautics
629.132	Mechanics of flight; flying and related topics
629.133	Aircraft types
629.134	Aircraft components and general techniques
629.135	Aircraft instrumentation (Avionics)
629.136	Airports
629.4	Astronautics
629.41	Space flight
629.43	Unmanned space flight
629.44	Auxiliary spacecraft
629.45	Manned space flight
629.46	Engineering of unmanned spacecraft
629.47	Astronautical engineering

Aeronautics	**100**
➢ Aircraft	110
■ Powered Aircraft	111
• Manned Aircraft	111.1
o Heavier than Air Vehicles	111.11
▪ Fixed Wing Aircraft	111.111
– Subsonic	111.111.1
– Supersonic	111.111.2
– Transonic	111.111.3
– Hypersonic	111.111.4
▪ Rotorcraft	111.112
– Helicopter	111.112.1
– Autogiro	111.112.2
– Gyrodyne	111.112.3
o Lighter than Air Vehicles	111.12
▪ Blimps	111.121
▪ Zeppelins	111.122
• Unmanned Aircraft	111.2
o Unmanned Aerial Systems (UAS)	111.21
o Missiles	111.22
■ Unpowered Flight	112
• Gliders	112.1
• Kites	112.2
• Balloons	112.3
o Moored	112.31
o Free	112.32
■ Human Powered Flight	113
■ Animal Flight	114

My Approach to Aircraft Design

SCHOLZ, Dieter, 2015. *Aircraft Design*. Lecture Notes. Hamburg University of Applied Sciences.

Available from:

http://LectureNotes.AircraftDesign.org

or

https://purl.org/AircraftDesign

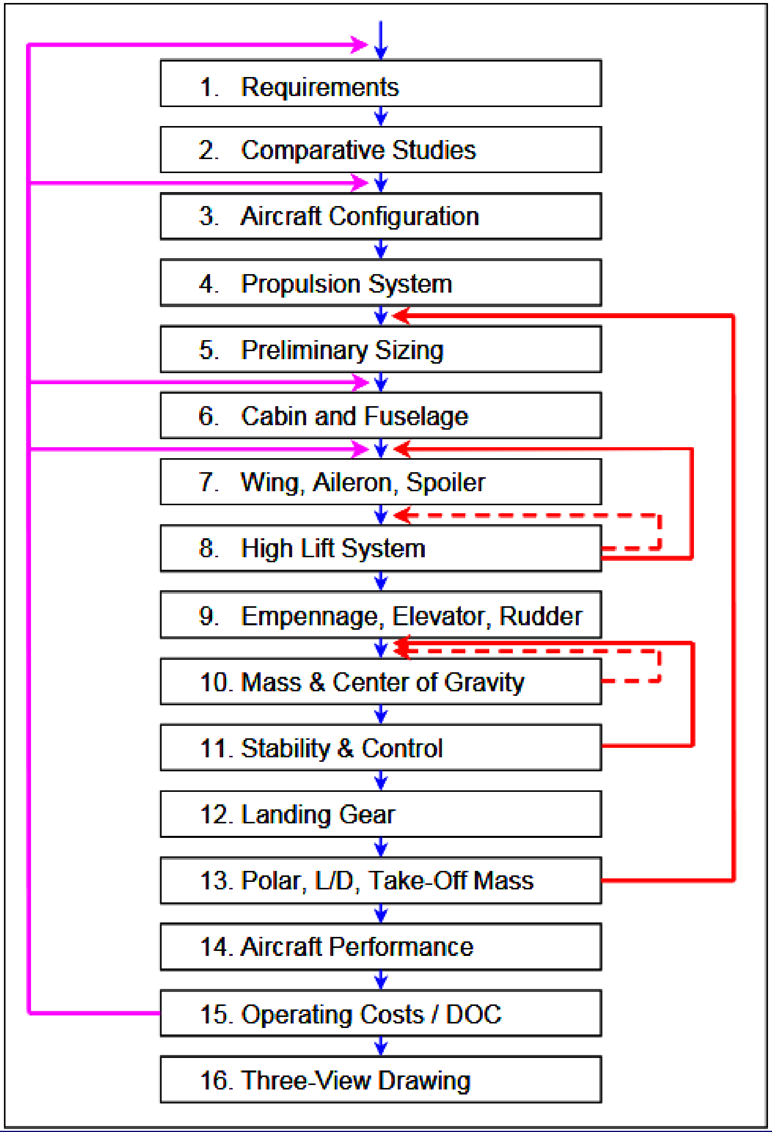
see also the Short Course Aircraft Design (2007)

https://doi.org/10.48441/4427.2747

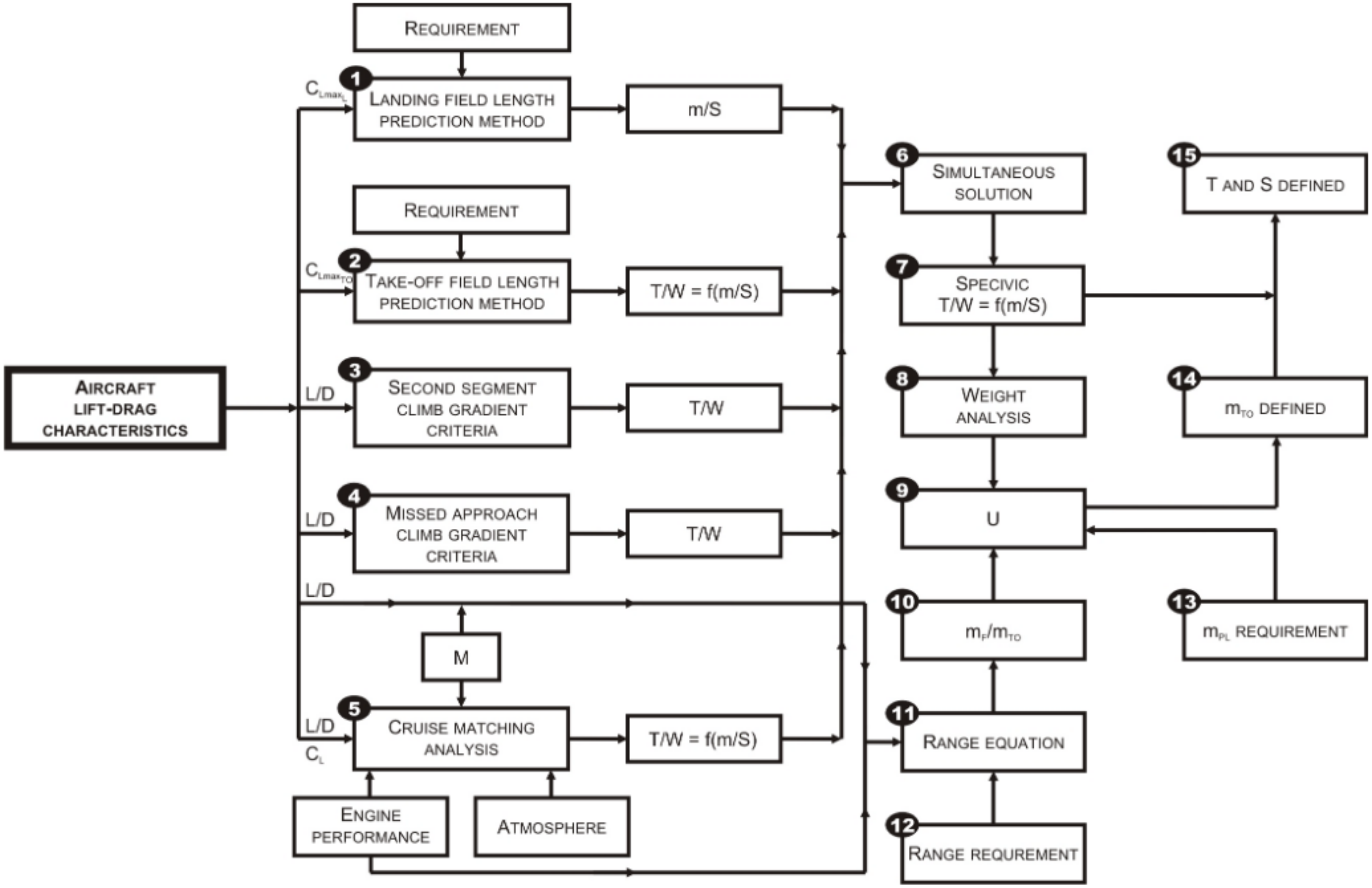
From Requirements to the Three-View Drawing (3D Aircraft) in 16 Steps

Iterations and Optimization

- (red dashed line) One step is iterative in itself
- (red solid line) Iteration over several steps
- (magenta line) Optimization possibilities



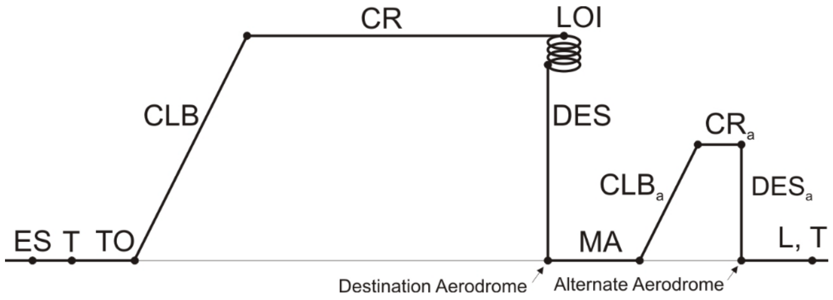
Step 5: Preliminary Sizing (Loftin 1980): The Method



Step 5: Preliminary Sizing: First Law of Aircraft Design

$$m_{MTO} = \frac{m_{PL}}{1 - \frac{m_F}{m_{MTO}} - \frac{m_{OE}}{m_{MTO}}}$$

First Law of Aircraft Design



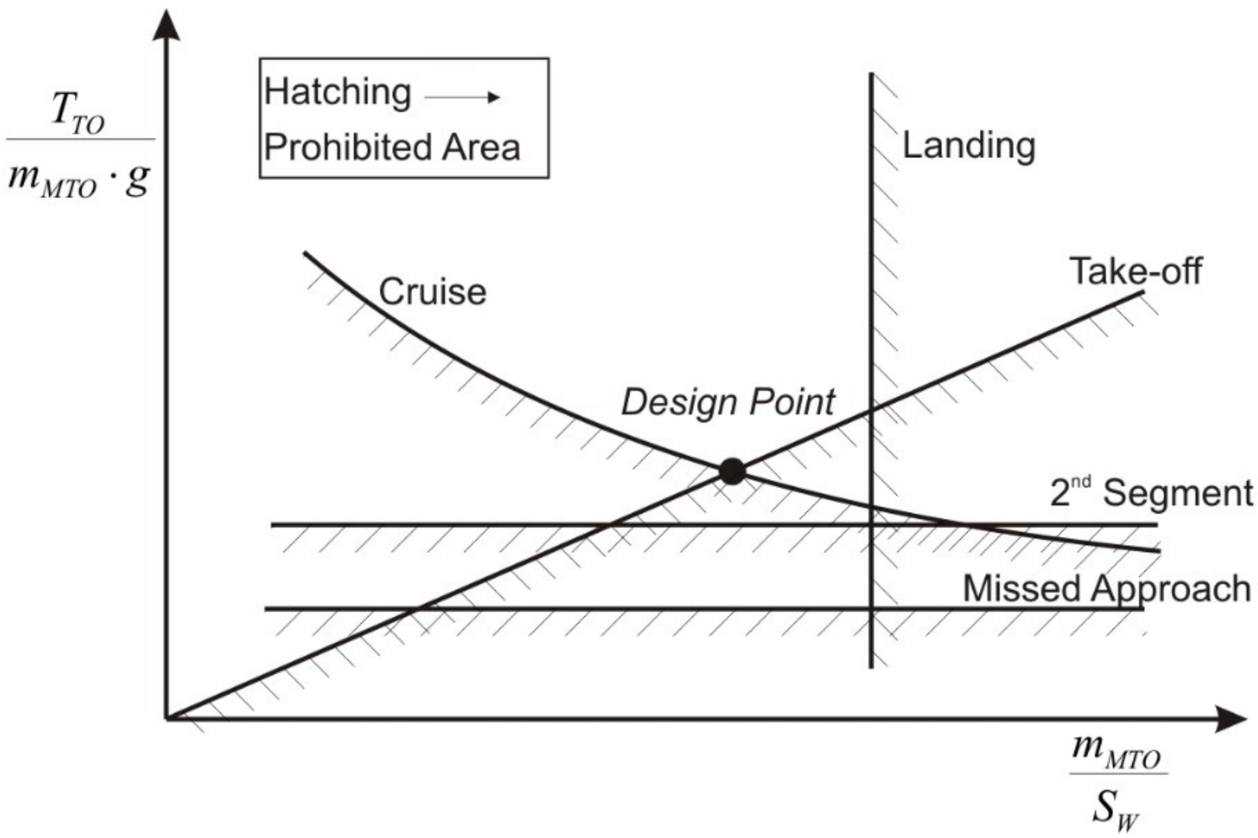
$$\frac{m_{OE}}{m_{MTO}} = 0.23 + 1.04 \cdot \frac{T_{TO}}{m_{MTO} \cdot g}$$

$$\frac{m_F}{m_{TO}} = 1 - M_{ff}$$

$$M_{ff} = \frac{m_{SO}}{m_T} \cdot \frac{m_T}{m_L} \cdot \frac{m_L}{m_{DES}} \cdot \frac{m_{DES}}{m_{CR,alt}} \cdot \frac{m_{CR,alt}}{m_{CLB}} \cdot \frac{m_{CLB}}{m_{MA}} \cdot \frac{m_{MA}}{m_{DES}} \cdot \frac{m_{DES}}{m_{LOI}} \cdot \frac{m_{LOI}}{m_{CR}} \cdot \frac{m_{CR}}{m_{CLB}} \cdot \frac{m_{CLB}}{m_{TO}} = \frac{m_{SO}}{m_{TO}}$$

List of Symbols in https://purl.org/AircraftDesign

Step 5: Preliminary Sizing: Matching Chart



Step 5: Preliminary Sizing: Results

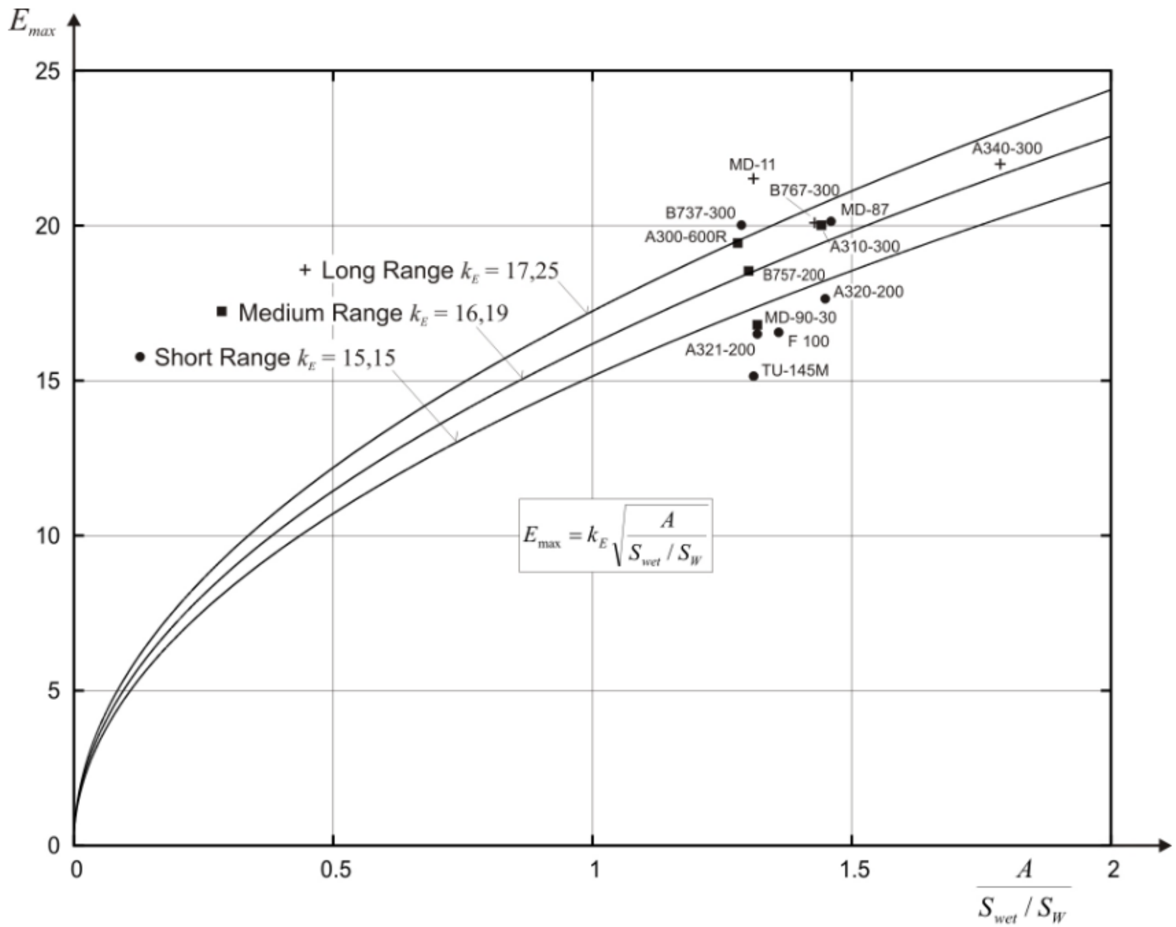
$$T_{TO} = m_{MTO} \cdot g \cdot \left(\frac{T_{TO}}{m_{MTO} \cdot g} \right)$$

$$S_W = m_{MTO} / \left(\frac{m_{MTO}}{S_W} \right)$$

Cruise altitude follows from the Matching Chart

My Approach to Aircraft Design

Step 5: Preliminary Sizing: Details (Example)

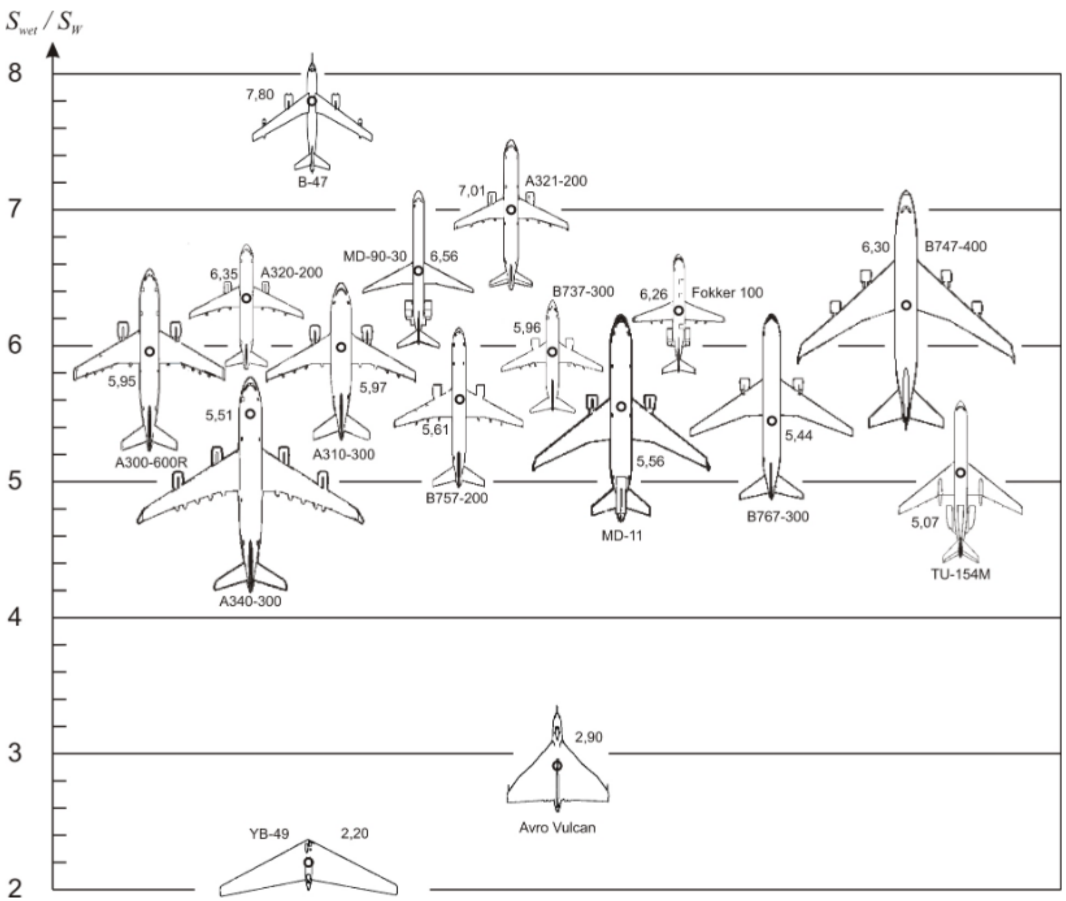


$$E_{max} = k_E \sqrt{\frac{A}{S_{wet}/S_W}}$$

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

My Approach to Aircraft Design

Step 5: Preliminary Sizing: Details (Example)

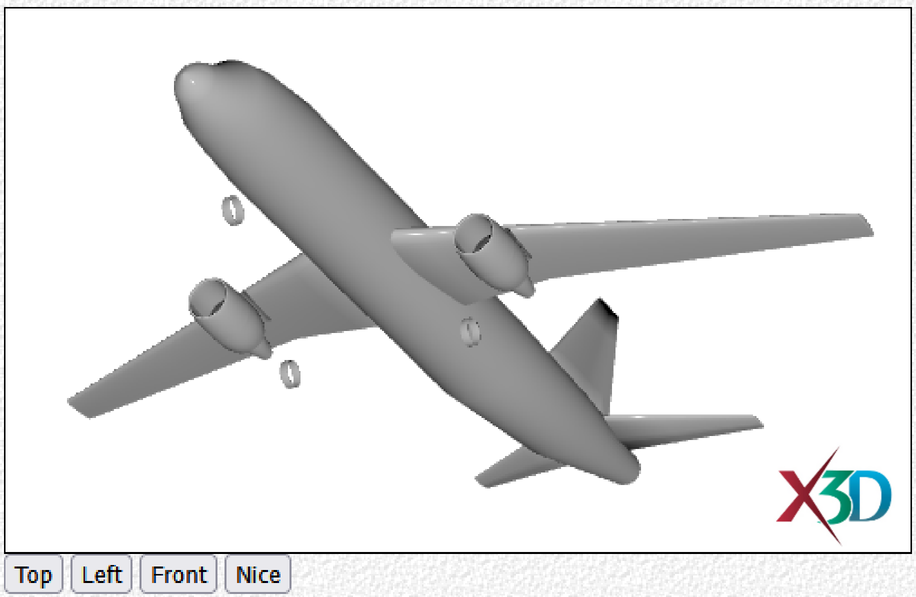


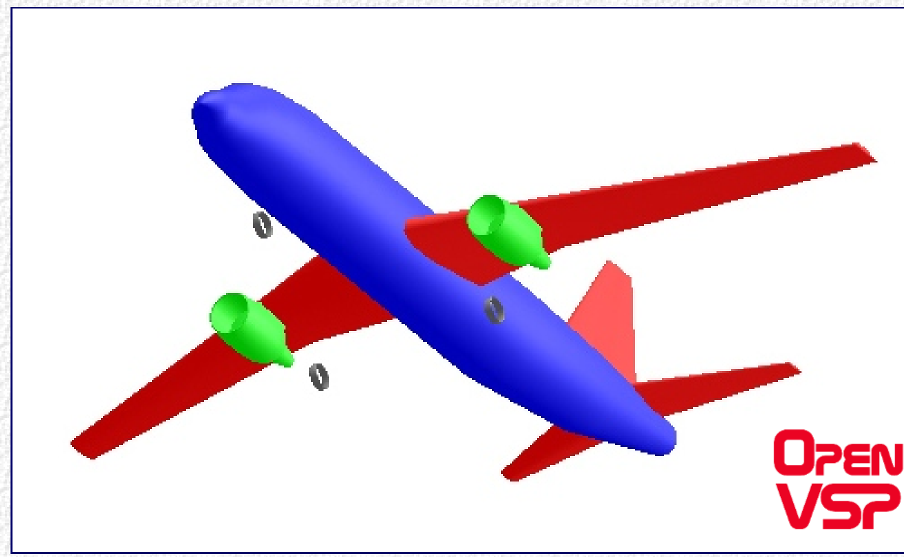
$$S_{wet} / S_W = 6.0 \ldots 6.2$$

Step 16: Three-View Drawing or 3D Geometric Model

OpenVSP-Connect

Connect YOUR Aircraft Design Tool with Vehicle Sketch Pad from NASA





http://OpenVSP.ProfScholz.de

Our
Aircraft Design
Tools

Overview

PreSTo – Aircraft Preliminary Sizing Tool
PreSTo-Classic (Step 5: Preliminary Sizing)
PreSTo-Cabin (Step 6: Cabin and Fuselage)
PreSTo Combined Modules (Steps 5 to 15)

http://PreSTo.ProfScholz.de

OPerA – Optimization in Preliminary Aircraft Design (PhD-Level)
Optimization of passenger jet aircraft, CS-25

http://OPerA.ProfScholz.de

PrOPerA – Propeller Aircraft Optimization in Preliminary Aircraft Design (PhD-Level)
Optimization of passenger propeller aircraft, CS-25 (http://Airport2030.ProfScholz.de)

SAS – Simple Aircraft Sizing and Optimization
Simplified versions of OPerA and PrOPerA (Step 5 and more)

http://SAS.ProfScholz.de

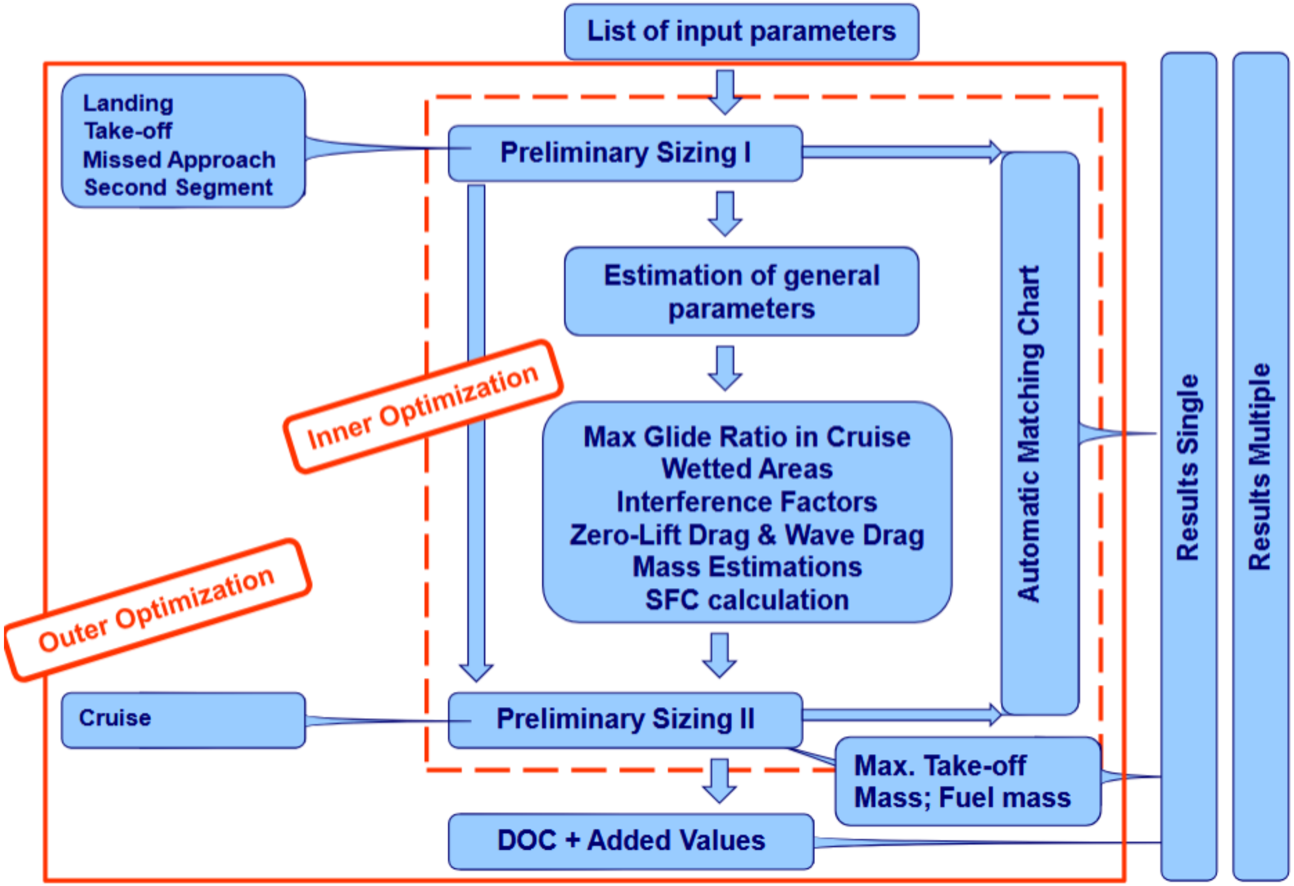
Calculating the Wing Lift Distribution with the Diederich Method in Microsoft Excel
Lift distribution and maximum lift coefficient (http://Diederich.ProfScholz.de)

OpenVSP-Connect (VSP = Vehicle Sketch Pad)
=> Automatically Design Your Aircraft
=> Visualize YOUR Aircraft Sizing Results with NASA's OpenVSP

http://OperVSP.ProfScholz.de

Our Aircraft Design Tools

OPerA – Optimization in Preliminary Aircraft Design



About 230 input variables

About 150 geometry parameters

At least 15 iteration loops

20 optimization variables

15 calculation sheets

Mihaela Niţă, 2012, https://doi.org/10.48441/4427.2587

Special Problems Solved

Examples

Calculating the Drag Polar
Zero-Lift drag, induced drag, wave drag. Fitting aircraft data. Drag estimation for new aircraft.
https://doi.org/10.48441/4427.2893

Specific Fuel Consumption (SFC) Calculation
From theory / from engine data / comparison jet and prop engines
https://doi.org/10.48441/4427.2132, https://doi.org/10.48441/4427.2130

8 Methods to Calculate Aircraft Fuel Consumption for Real Aircraft
No other report discusses so many ways to determine fuel consumption of passenger aircraft.
https://doi.org/10.48441/4427.1045

Calculating Aircraft Fuel Consumption as Function of Flight Distance
The "Bath Tube Curve" calculated from the payload-range diagram.
https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2017-12-13.019

Mass Estimation for Folding Wings
Important to stay within ICAO span limits at airports
https://doi.org/10.48441/4427.1586

...

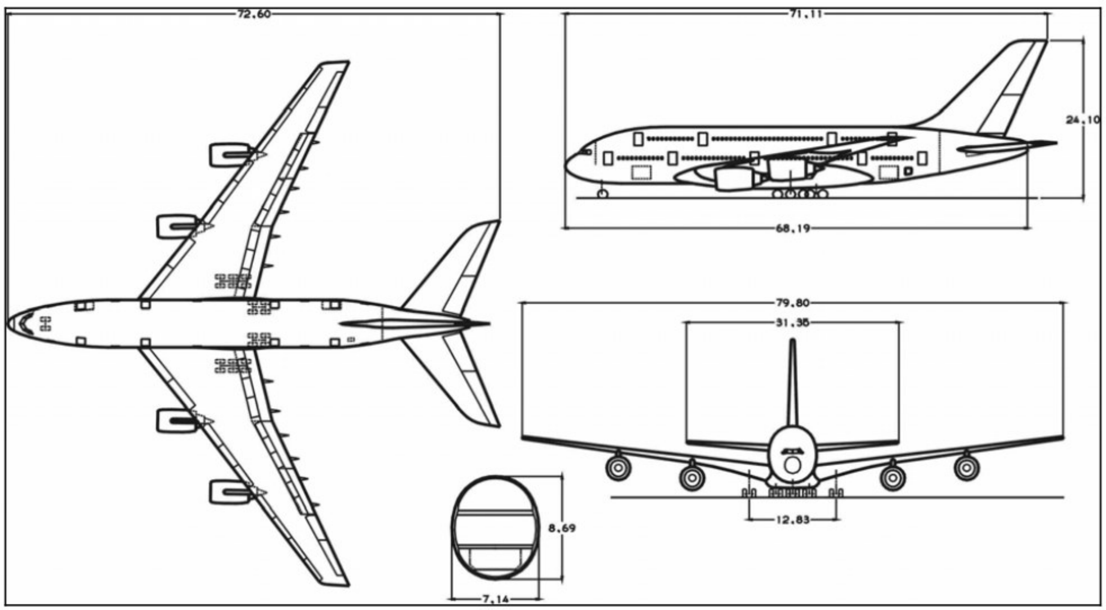
Search for an Efficient Configuration

Conventional Aircraft

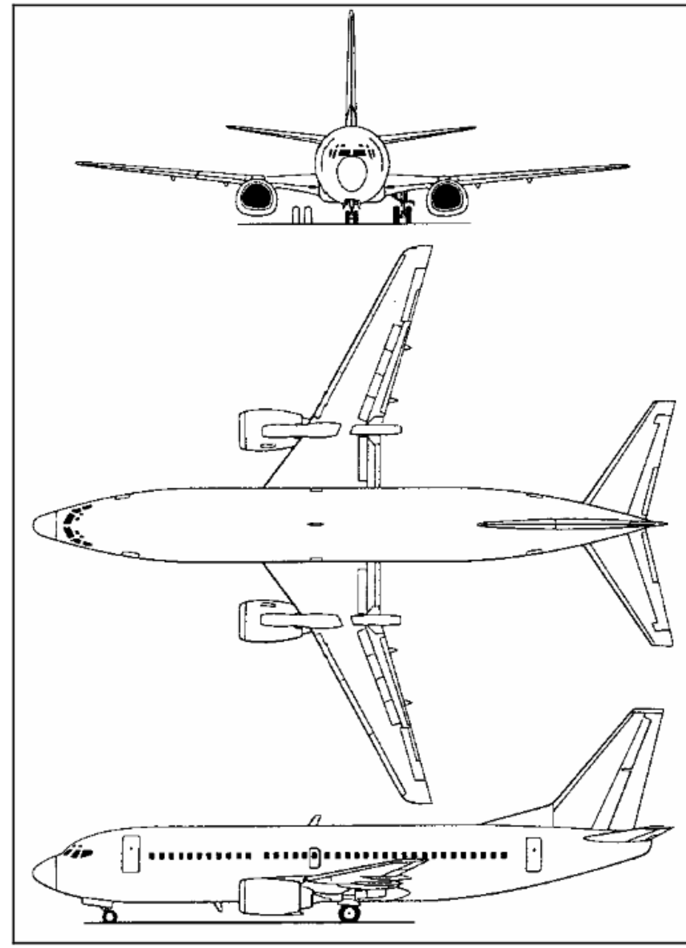
Conventional aircraft configurations are **symmetric** and have **one fuselage**, **one pair of wings** and an **empennage at their rear** end.

This configuration is also called **tail aft aircraft**.

http://LectureNotes.AircraftDesign.org



Airbus A380



Boeing 737

Search for an Efficient Configuration

Conventional Aircraft

High Performance German Glider *eta*

Glider aerodynamics: role model for passenger aircraft ?

aspect ratio, $A = b / c$ (for c = const) or $A = b^2 / S = b^2 / (c^*b) = b / c$

A = 51.3, b = 30.9 m, aerodynamic efficiency, glide ratio: L/D = 70

https://wingsandwheels.com/eta-844.html

https://de.wikipedia.org/wiki/Eta_(Flugzeug)

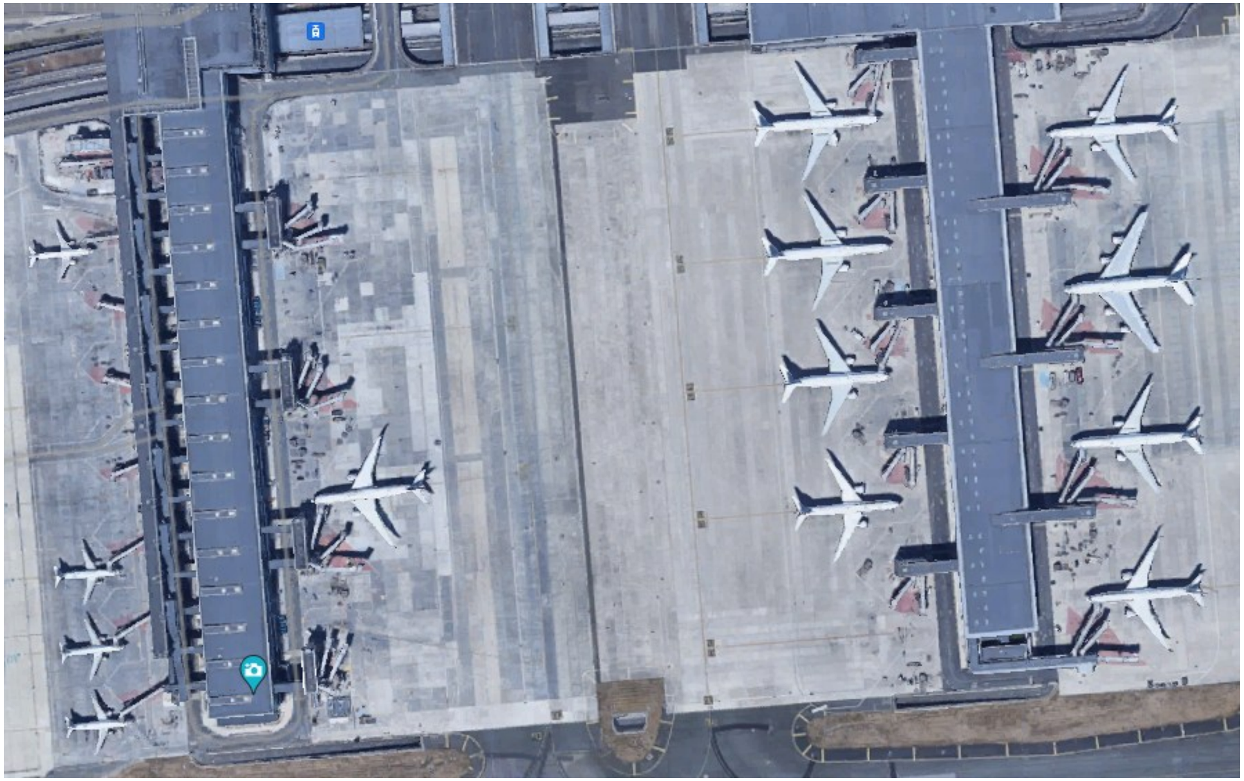
Search for an Efficient Configuration

Wingspan Limitations at Airports: ICAO Aerodrome Reference Code

Code letter	Wingspan	Typical aeroplane
A	< 15 m	PIPER PA-31/CESSNA 404 Titan
B	15 m but < 24 m	BOMBARDIER Regional Jet CRJ-200/DE HAVILLAND CANADA DHC-6
C	24 m but < 36 m	BOEING 737-700/AIRBUS A-320/EMBRAER ERJ 190-100
D	36 m but < 52 m	B767 Series/AIRBUS A-310
E	52 m but < 65 m	B777 Series/B787 Series/A330 Family
F	65 m but < 80 m	BOEING 747-8/AIRBUS A-380-800

https://skybrary.aero/articles/icao-aerodrome-reference-code

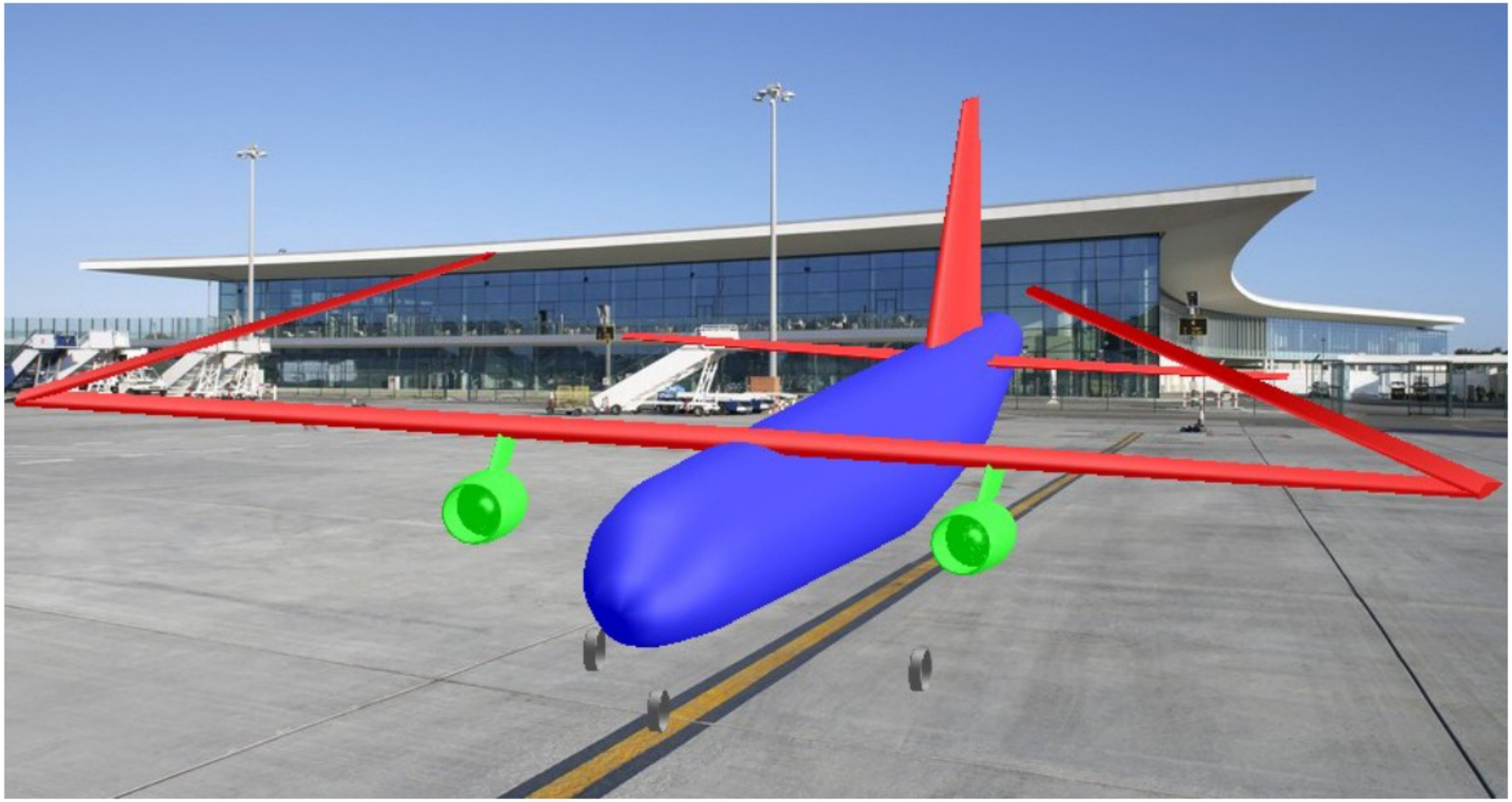
Different Gates at Airports for Different Code Letters (Wingspan)



Airports offer gates for aircraft with different size (wingspan and code letter) **according to demand**.
Airport Charles de Gaulle, Terminal 2, Paris
(Google Maps, https://maps.app.goo.gl/m7iAjuBuob71wi6j9)

Search for an Efficient Configuration

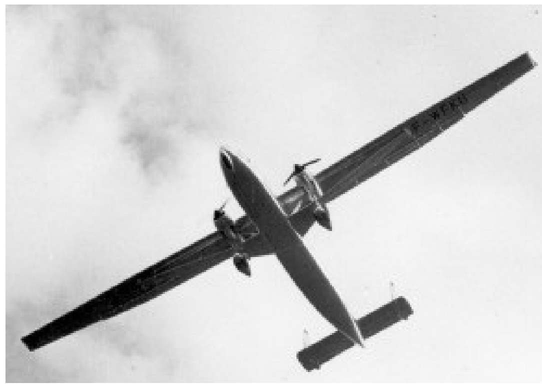
Folding Wings at Airports



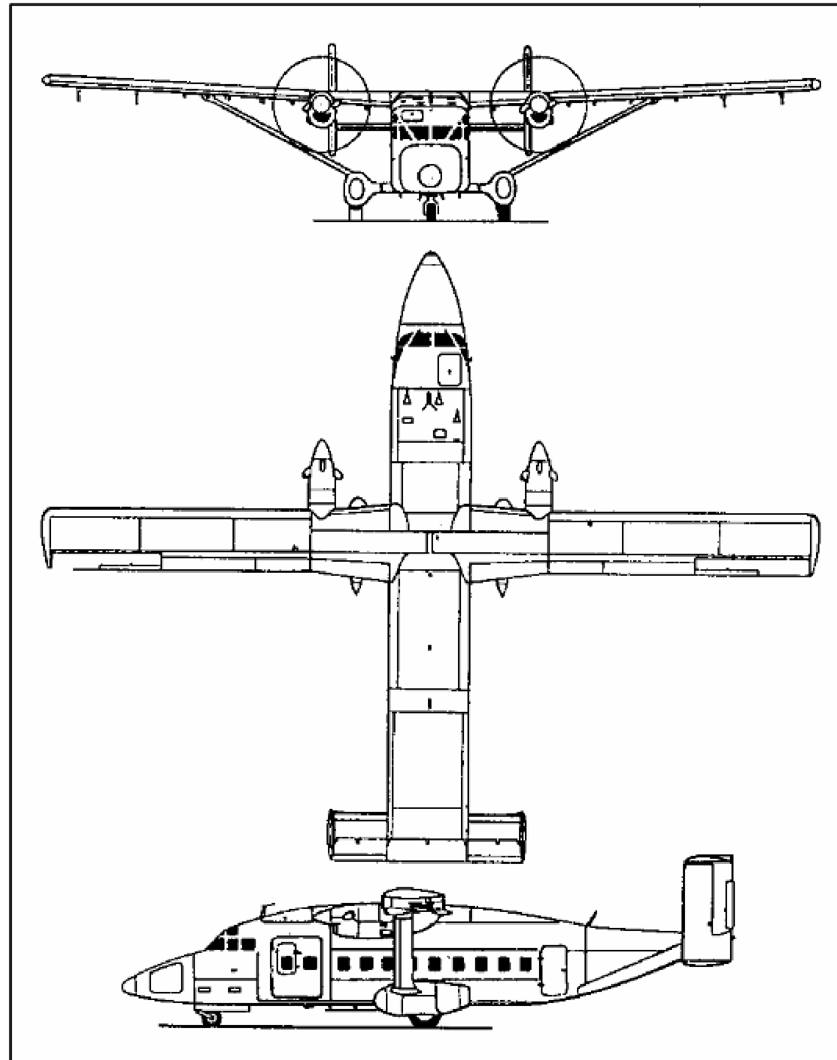
Impression of an aircraft with folding wings (Scholz)

Conventional Aircraft
High Aspect Ratio, Braced Wing

The high aspect ratio wing reduces induced drag (drag due to lift). The wing brace keeps wing mass low.



Hurel Dubois HD 31, first flight 1953



Shorts 330, first flight 1974

Search for an Efficient Configuration

Conventional Aircraft
High Aspect Ratio, Braced Wing: Boeing Proposal

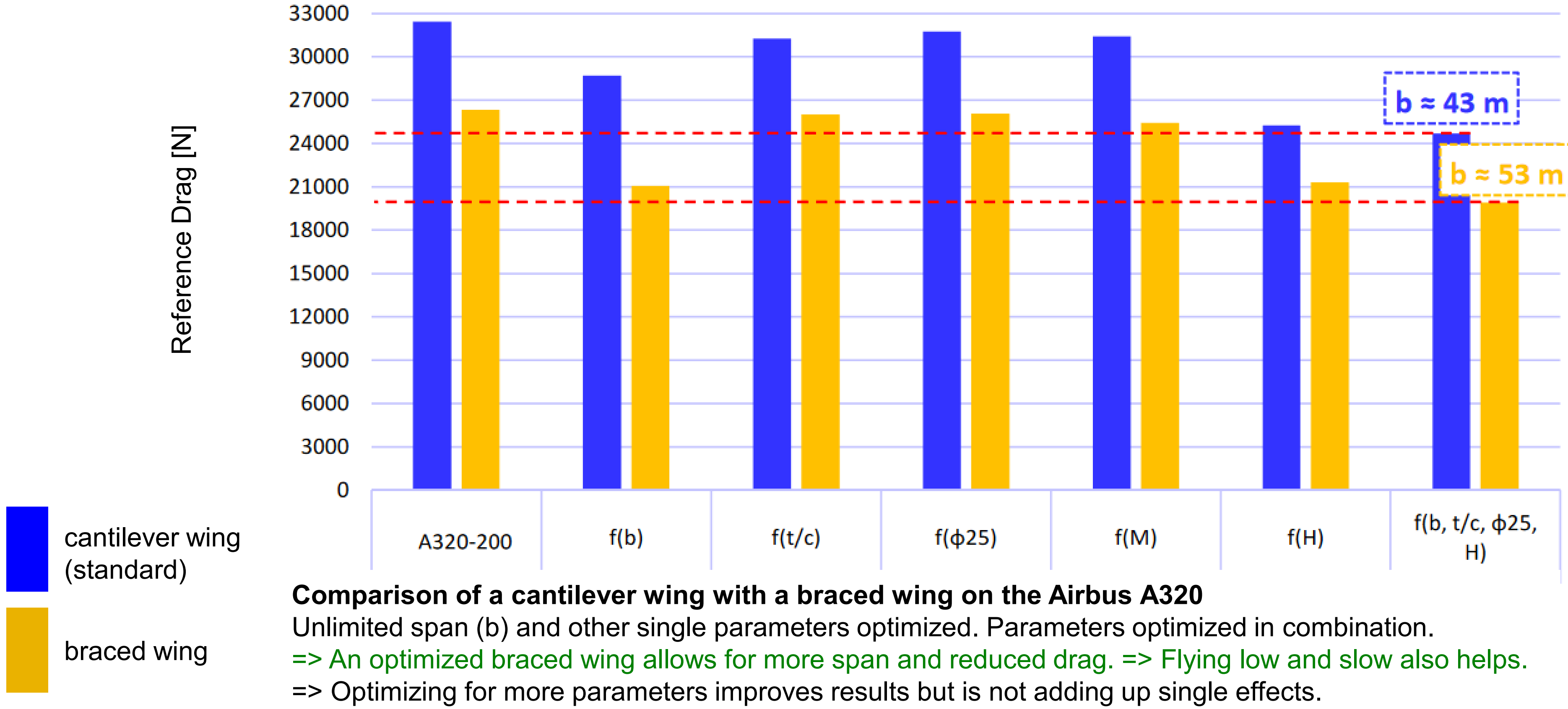
The high aspect ratio wing reduces induced drag (drag due to lift).

The wing brace keeps wing mass low.

Boeing Transonic Truss-Braced Wing (TTBW) from 2019 based on the Subsonic Ultra Green Aircraft Research (SUGAR) program (2009). Now "Sustainable Flight Demonstrator", Boeing X-66A with NASA. Boeing canceled its part of the research project.

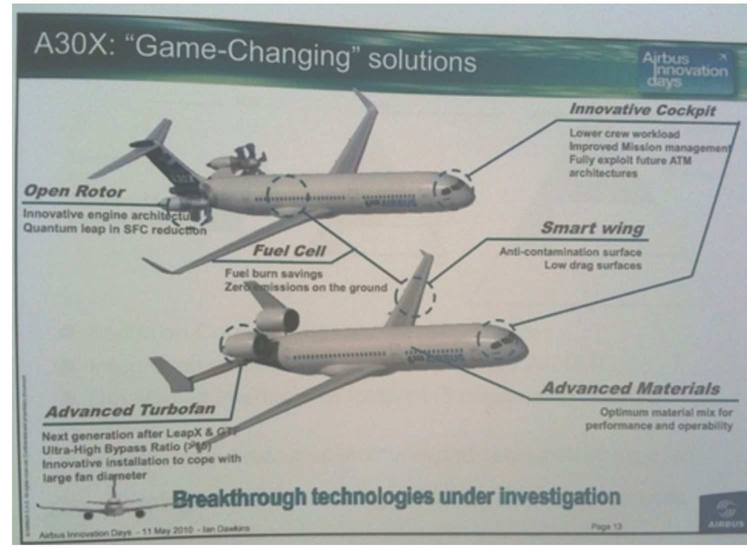
Conventional Aircraft
High Aspect Ratio, Braced Wing: Airbus A320 Possibilities

A320 wingspan: 34.1 m (without winglets), **35.8 m** (with winglets), **ICAO-limited to 36.0 m**



Comparison of a cantilever wing with a braced wing on the Airbus A320
Unlimited span (b) and other single parameters optimized. Parameters optimized in combination.
=> An optimized braced wing allows for more span and reduced drag. => Flying low and slow also helps.
=> Optimizing for more parameters improves results but is not adding up single effects.

Propulsion Concepts at MBB / Airbus: 40 Years of Open Rotor



A propfan, also called open rotor, is an aircraft engine combining features of turbofans and turboprops.

Flight International:

14 June 1986: MBB to build Chinese propfan

21 May 1988: Allison joins MBB/China propfan project

Airbus press conference, 11 May 2010:

"Game-Changing" Solutions:

Open Rotor (propfan)

20 July 2022: On the way to a zero-emission aircraft, Airbus is reviving the open-rotor idea, which is at least 40 years old (Welt)

31 March 2025: Airbus Planning Open Rotor Engine for A320 Replacement

(https://perma.cc/85N5-8LVS, https://perma.cc/4MKB-GUKA)

* The abbreviation "MPC" came from "MBB" and "Peoples Republic of China" – a joint venture of Germany and China.

Turboprop Aircraft for 180 Passengers with Engines of the A400M ?

Airbus A400M

ATR 72

Q400

	m_MTO	M_CR	P_eq	Pax
A320	78 t	0,76	xxx	180
A400M	141 t	0,70	4 x 8250 kW	xxx
ATR 72	23 t	0,46	2 x 1950 kW	72
Q400	29 t	0,60	2 x 3780 kW	78
Smart TP	56 t	0,51	2 x 5000 kW	180

The design of the "Smart Turboprop (TP)" on the next pages!

HAW HAMBURG

A Larger Propeller Aircraft Is Discussed for More than 10 Years!

FLIGHT INTERNATIONAL

05/2011:

PROPULSION JOHN CROFT WASHINGTON DC

90-seat turboprop beckons to P&WC

Engine manufacturer to begin assembling next-generation powerplant to prepare for possible creation of bigger airframes

01/2013:

AIRFRAMES MAVIS TOH SINGAPORE

ATR keen to satisfy 90-seat audience

Turboprop manufacturer yet to convince shareholders despite Asian regional carriers' interest in potential larger aircraft

01/2013:

ANALYSIS MURDO MORRISON LONDON

ATR ascends as Bombardier suffers

Growing demand from lessors helps Franco-Italian airframer beat Canadian rival in turboprop orders and deliveries race

01/2013:

WHO WILL LAUNCH AN ALL-NEW 90-SEAT TURBOPROP?

The chances are, nobody will – but pressure from airline customers might conjure up a 2013 launch of a product that regional aircraft makers agree will eventually be a necessity.

01/2011:

DEVELOPMENT DAVID KAMINSKI-MORROW TOULOUSE

Demand for big turboprops will grow, says ATR

Airframer seeks 'convergent' solution with engine manufacturers to develop future 90-seat models

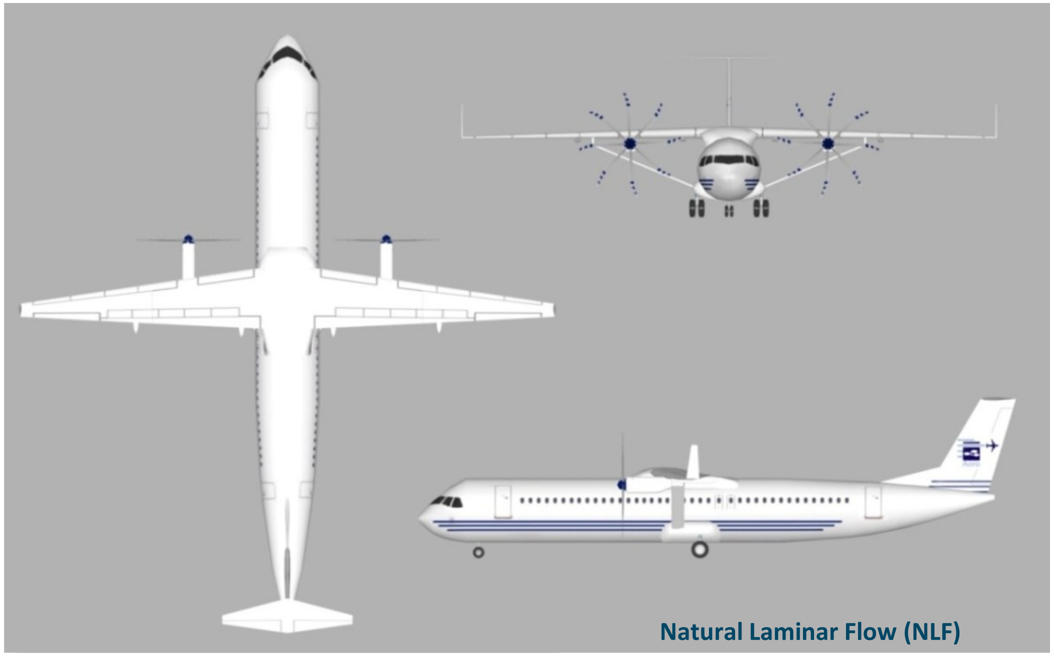
"I'm insisting on one point. The priority is cost-effectiveness, not spending money on speed"

FILIPPO BAGNATO
Chief executive, ATR

"Smart Turboprop": Large Propellers, Braced Wing, Flying Slower and Lower, Partial Natural Laminar Flow on Wing

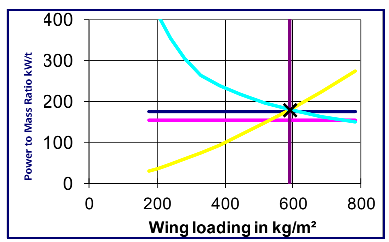
http://Airport2030.ProfScholz.de

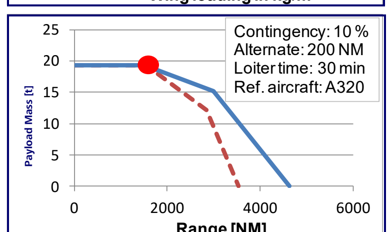
“Smart Turboprop”: Flying Slow and Low: Low Emission Flight!



Parameter	Value	Deviation from A320*
Main aircraft parameters		
m_{MTO}	56000 kg	- 24 %
m_{OE}	28400 kg	- 31 %
m_F	8400 kg	- 36 %
S_W	95 m²	- 23 %
$b_{W,geo}$	36.0 m	+ 6 %
$A_{W,eff}$	14.9	+ 57 %
E_{max}	18.8	≈ + 7 %
$P_{eq,ssl}$	5000 kW	------
d_{prop}	7.0 m	------
η_{prop}	89 %	------
PSFC	5.86E-8 kg/W/s	------
h_{ICA}	23000 ft	- 40 %
s_{TOFL}	1770 m	0 %
s_{LFL}	1300 m	- 10 %
t_{TA}	32 min	0 %

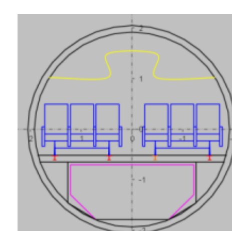
Parameter	Value	Deviation from A320*
Requirements		
m_{MPL}	19256 kg	0 %
R_{MPL}	1510 NM	0 %
M_{CR}	0.51	- 33 %
max(s_{TOFL} , s_{LFL})	1770 m	0 %
n_{PAX} (1-cl HD)	180	0 %
m_{PAX}	93 kg	0 %
SP	29 in	0 %





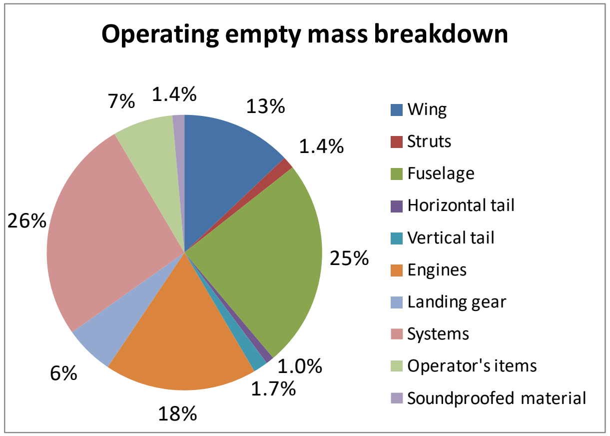
36 % less fuel consumption (and CO2).

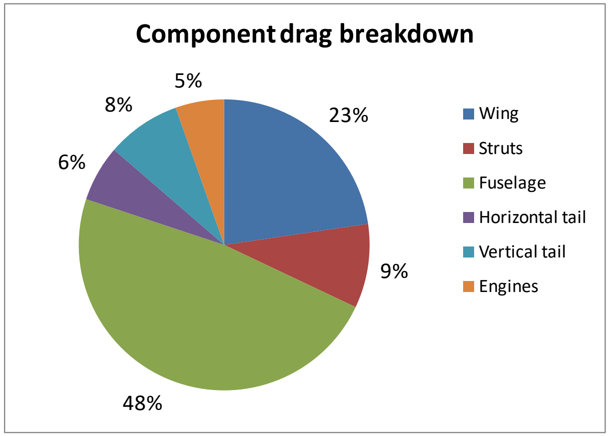
Cruise altitude 23000 ft: low Aviation Induced Cloudiness (AIC). Low warming potential.

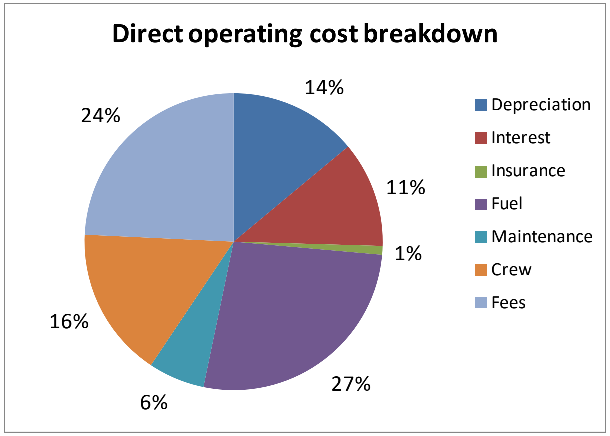


"Smart Turboprop": 17% Less Direct Operating Costs, DOC !

Parameter	Value	Deviation from A320*
DOC mission requirements		
R_{DOC}	755 NM	0 %
$m_{PL,DOC}$	19256 kg	0 %
EIS	2030	-----
c_{fuel}	1.44 USD/kg	0 %
Results		
$m_{F,trip}$	3700 kg	- 36 %
$U_{a,f}$	3600 h	+ 5 %
DOC (AEA)	83 %	- 17 %







Search for an Efficient Configuration

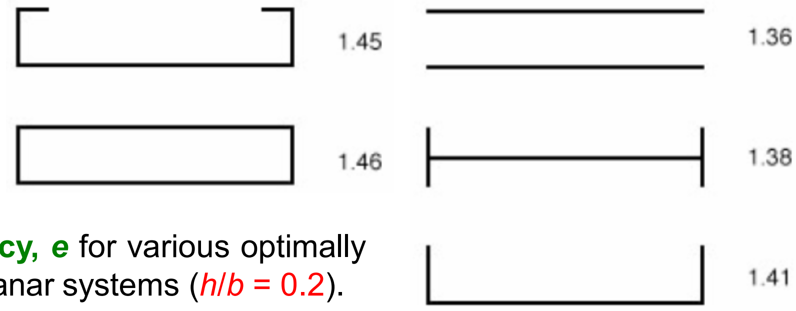
Box Wing Aircraft (BWA)

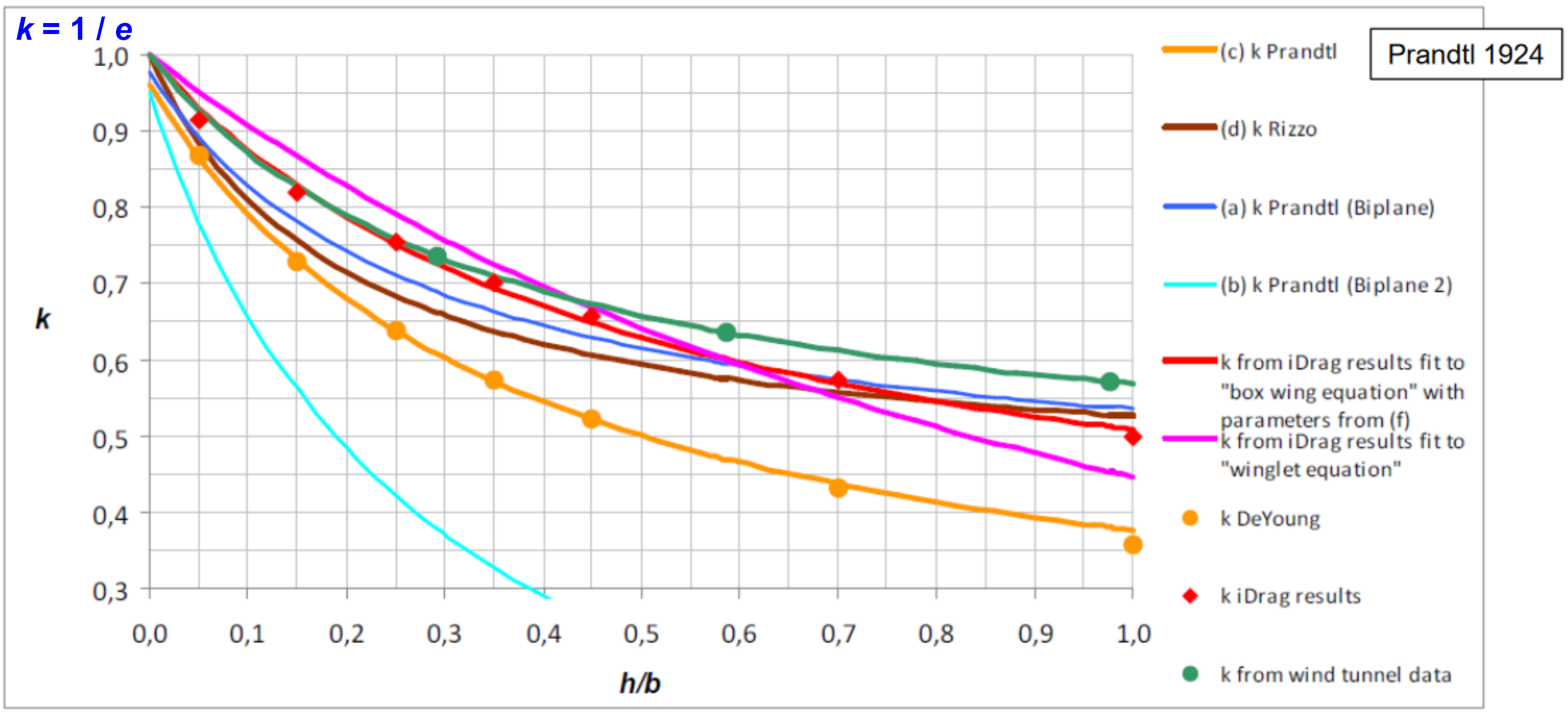
Search for an Efficient Configuration

From Winglets via Biplane to Box Wing Aircraft (BWA)

BWA reduce induced drag (due to lift)

Span efficiency, *e* for various optimally loaded non-planar systems (*h*/*b* = 0.2).

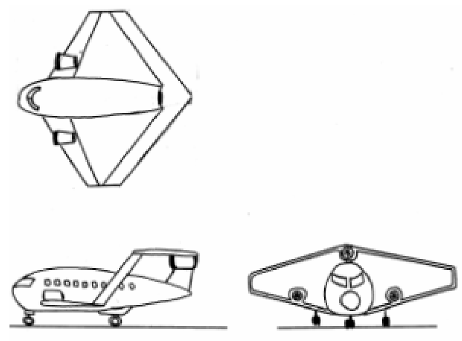


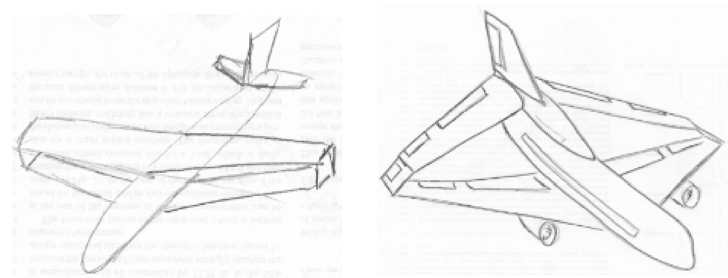


https://purl.org/AircraftDesign/OswaldFactor

Box Wing Aircraft (BWA): Genesis

- Hand Sketches





- Creative Methods
  - Brainstorming
  - Gallery Method

VERHEIRE, E.: Systematic Evaluation of Alternative Box Wing Aircraft Configurations. Bachelor Thesis, HAW Hamburg, 2013

- Modified Morphological Analysis

Morphological Analysis Matrix created after down selection

Stagger	Sweep	Box Wing Vertical Position	Horizontal Stabilizer Position	Vertical Stabilizer Position	Engine Position
=	<<	L – H	Can	Aft	Fuse – aft
–_	>>	L – SH	No		Fuse – mid
_–	< >		Aft		Wing

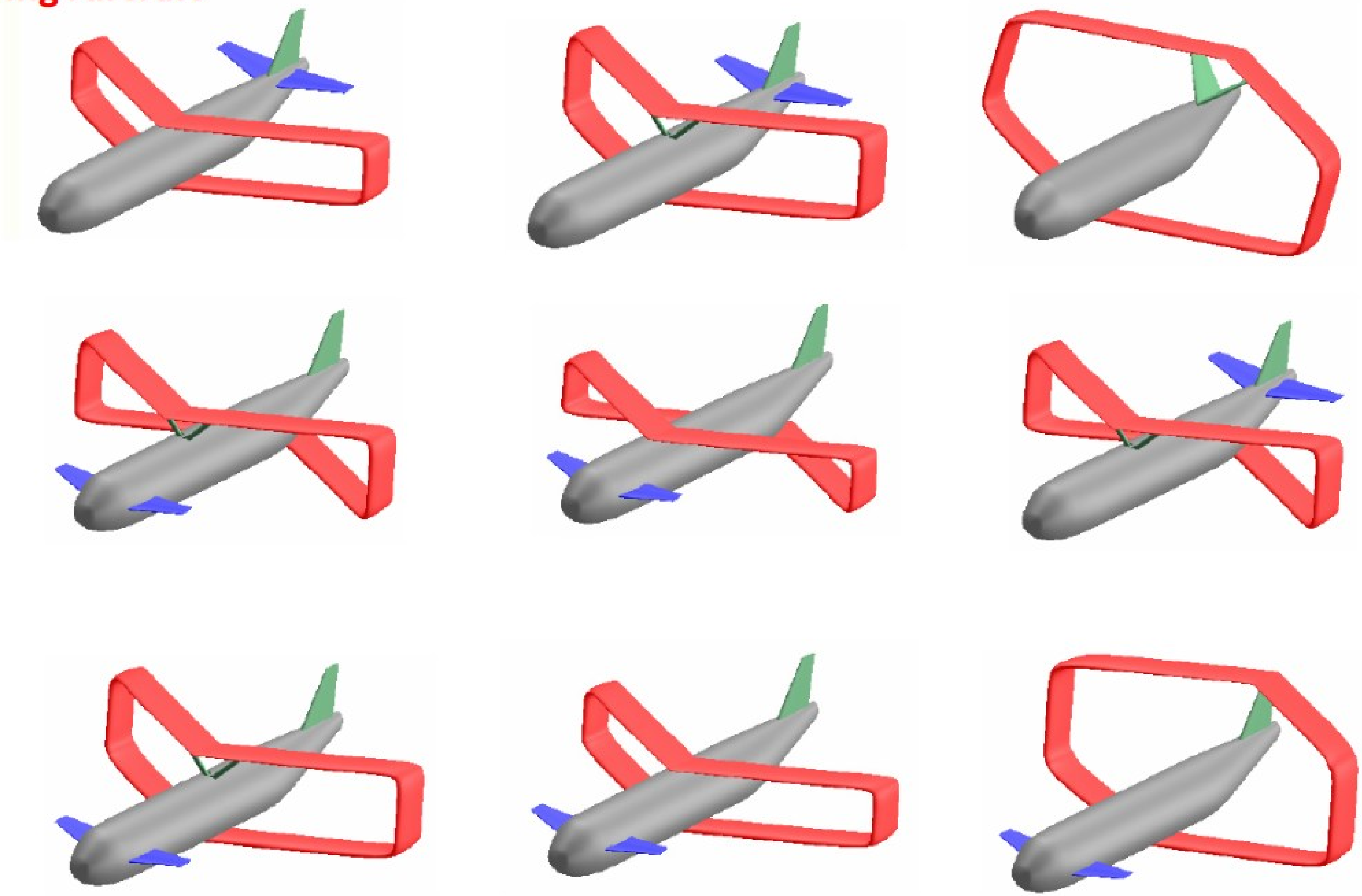
Number of Combinations: $3 \cdot 3 \cdot 2 \cdot 3 \cdot 1 \cdot 3 = 162$

BARUA, P; SCHOLZ, D.: Systematic Approach to Analyze, Evaluate and Select Box Wing Aircraft Configurations from Modified Morphological Matrices. TN, HAW Hamburg, 2013
https://doi.org/10.48441/4427.2477

Modified Morphological Analysis:
Successive combination (in „best" order) followed by immediate down selection => 18

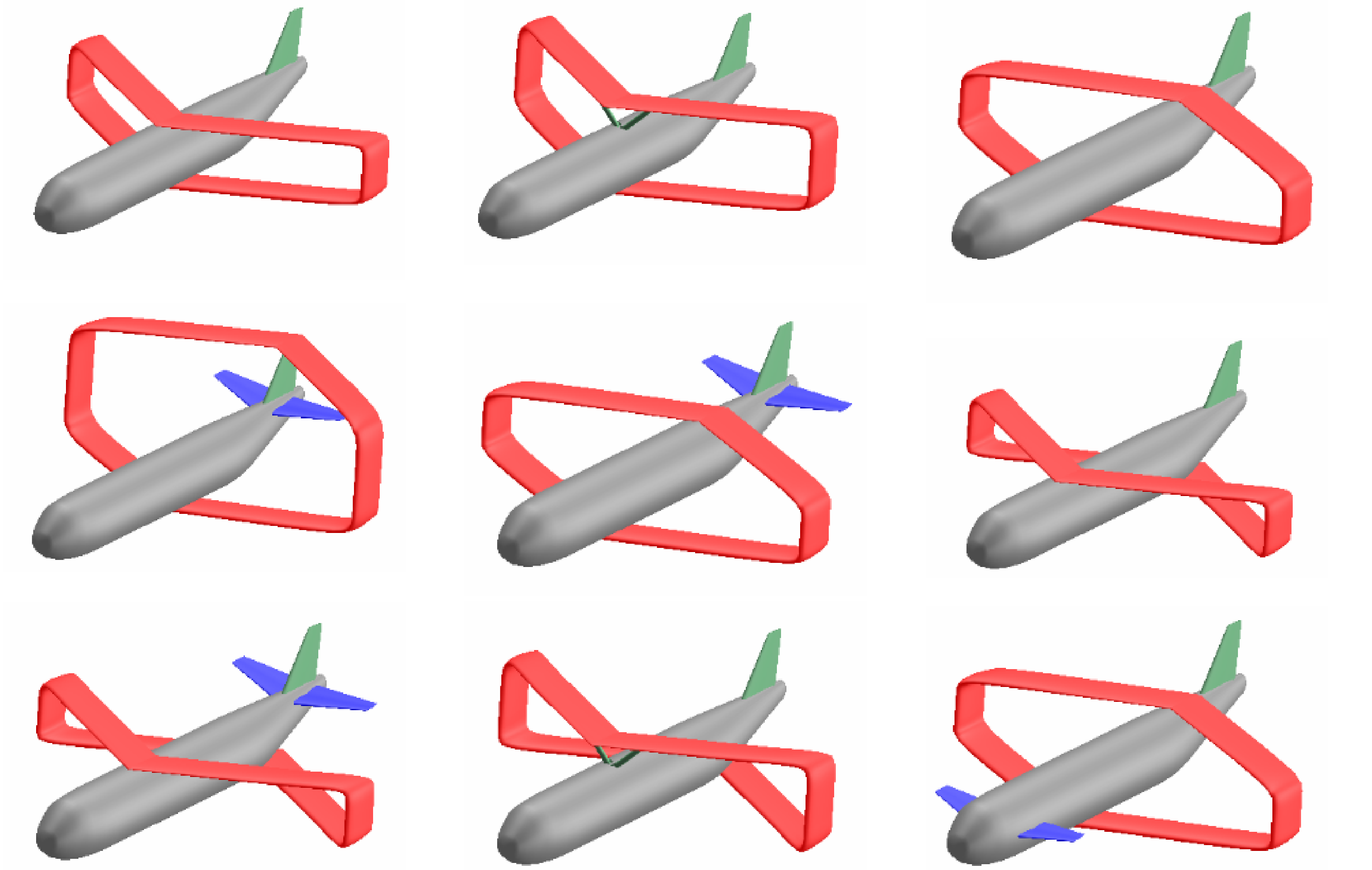
Box Wing Aircraft

Downselection: 9 + 9 = 18 configurations were chosen from the 162 configurations.



Box Wing Aircraft

Downselection: 9 + 9 = 18 configurations were chosen from the 162 configurations.

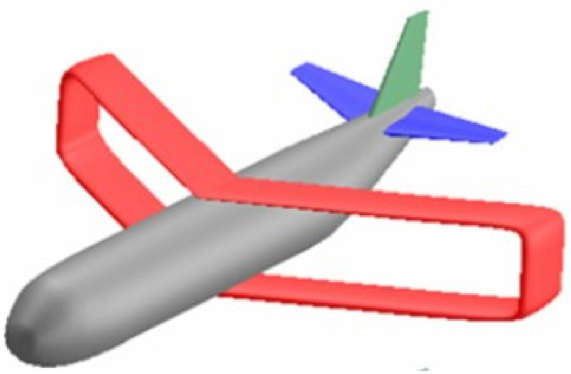


Box Wing Aircraft: General Morphological Analysis: Results

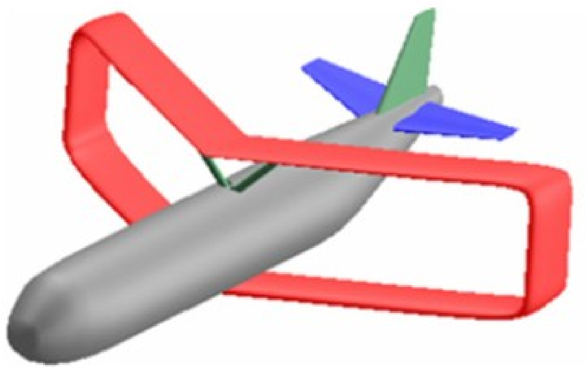
Multi-Criteria Decision Analysis (MCDA): The best known and simplest method is ...

the Weighted Sum Model (WSM) also known as the Weighted Linear Combination (WLC). Used to select 3 from 18:

1.

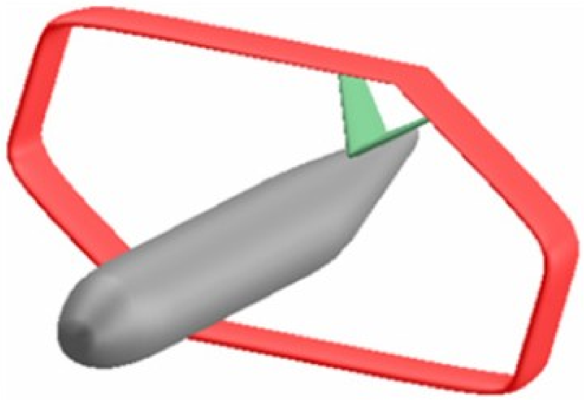


2.



Configuration 1 and 3 were calculated in detail and built as a model.

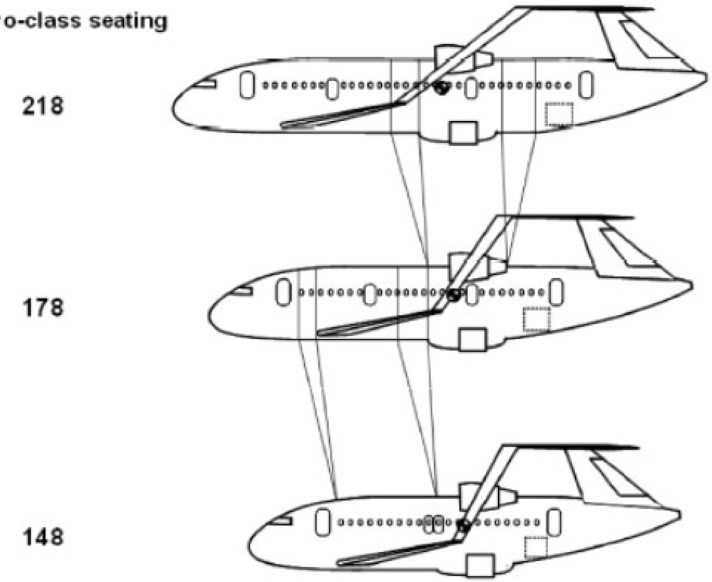
3.

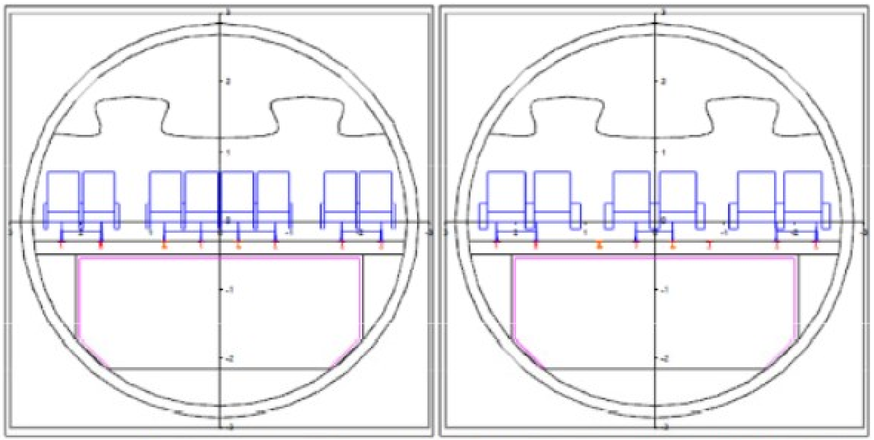


Configuration 3 was the best configuration without tail.

Box Wing Aircraft (BWA): Family Concept

Two-class seating





Fuselage cross section for economy class and business class (modelled with PreSTo Cabin)

http://Airport2030.ProfScholz.de

Search for an Efficient Configuration

"Smart Turboprob" (STP) and Box Wing Aircraft (BWA) in the News

FLIGHT INTERNATIONAL

Flightglobal
AVIATION CONNECTED

RESEARCH DAVID KAMINSKI-MORROW LONDON

Study backs 'smart turboprop' design

Researchers looking to increase medium-haul aircraft efficiency favour an advanced turboprop over box-wing concepts.

In co-operation with Airbus, Hamburg University of Applied Sciences embarked on a study to explore a possible successor to the A320, as part of a project known as Airport 2030.

As well as an optimised conventional jet configuration, the study examines various box-wing designs, as well as the option of a turboprop. The team aims to consider high-efficiency aircraft designs which would avoid changing ground infrastructure.

The project involves studying families of single- and twin-aisle box-winged aircraft of 126-218 seats. However, while box-wing concepts offer a reduction in drag, this economic advantage is countered by the increased weight of the wing.

The direct operating costs of box-wing models are calculated to be some 20% higher than those of the A320.

However, the "smart turboprop" design's economics prove more promising, the study says, with a 17% lower operating cost and a 36% cut in fuel burn.

This is based on a twin-engined aircraft with a high wing braced by struts, and a T-tail configuration featuring technologies including laminar flow. ■

Hamburg University of Applied Sciences

The project aims to explore a possible successor to the A320

14 | **Flight International** | 2-8 September 2014 flightglobal.com

Search for an Efficient Configuration

Box Wing Aircraft (BWA) and "Smart Turboprop" (STP)

BWA (tail aft)	STP	BWA (diamond wing)
better, but: not recommended	good	not recommended

Blended Wing Body (BWB)

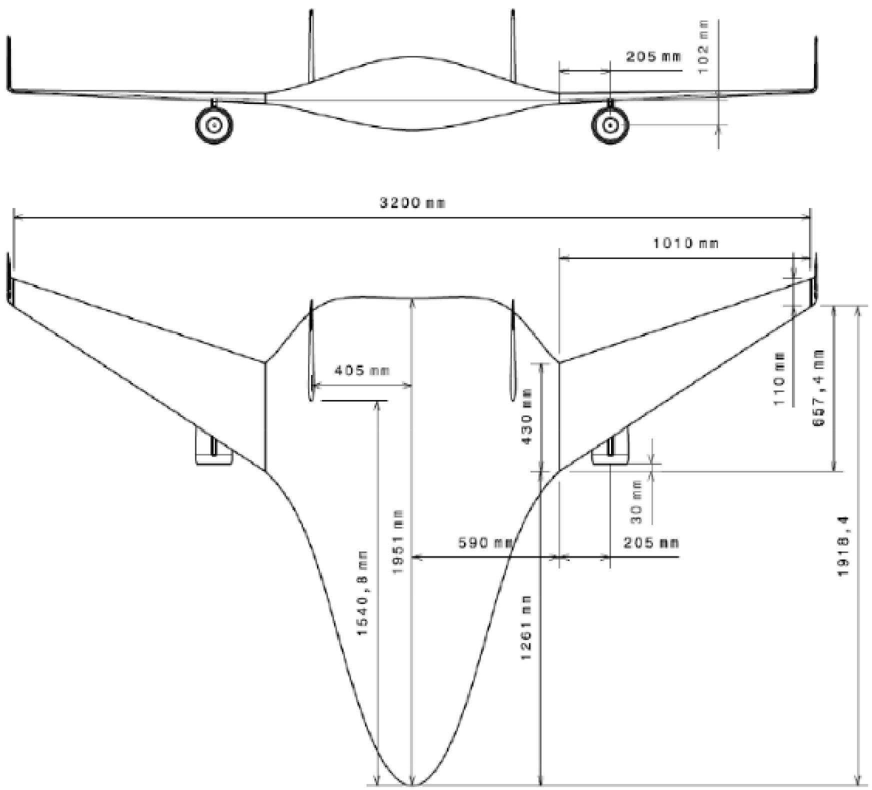
1) Conventional Configuration: "Tube and Wing" or "Tail Aft" (Drachenflugzeug)
2) Blended Wing Body (BWB)
3) Hybrid Flying Wing
4) Flying Wing

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.

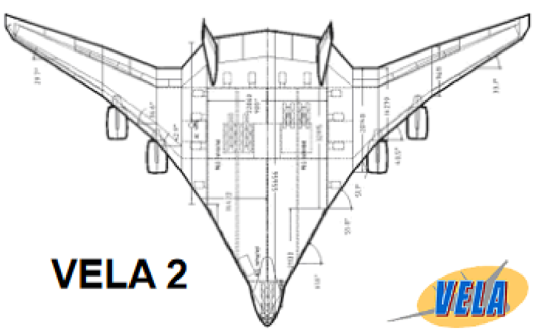
https://doi.org/10.48441/4427.442

Search for an Efficient Configuration

Blended Wing Body (BWB)



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"

Blended Wing Body (BWB): Aerodynamic Efficiency

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

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

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

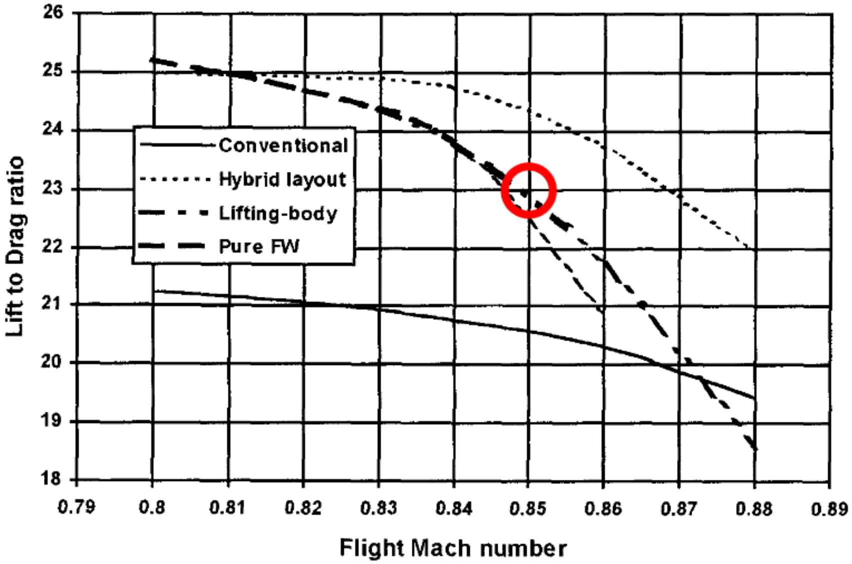
from statistics: $k_E = 15{,}8$

$$k_E = \frac{1}{2}\sqrt{\frac{\pi e}{\overline{c_f}}} = 14.9 \qquad \overline{c_f} = 0.003$$

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

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

BWB reduce zero-lift drag

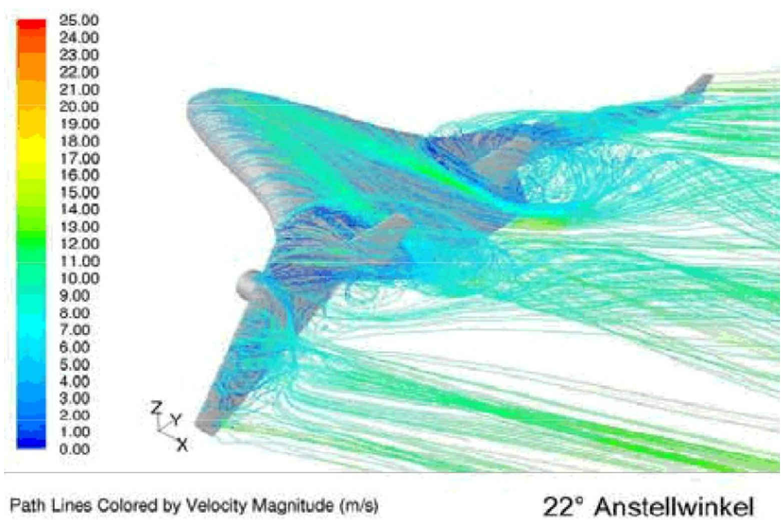


TsAGI for Airbus

Search for an Efficient Configuration

Blended Wing Body (BWB): CFD, Wind Tunnel, Flight Testing

CFD: Stall (high angle of attack)



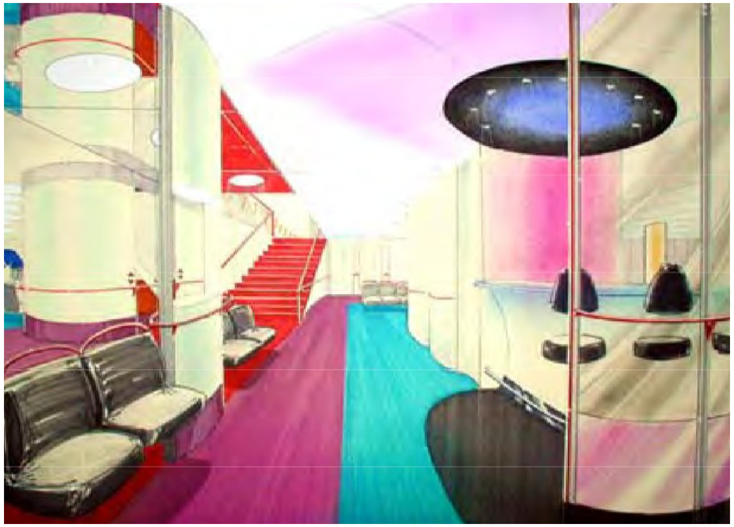
Wind tunnel, Dresden, Germany

Flight testing

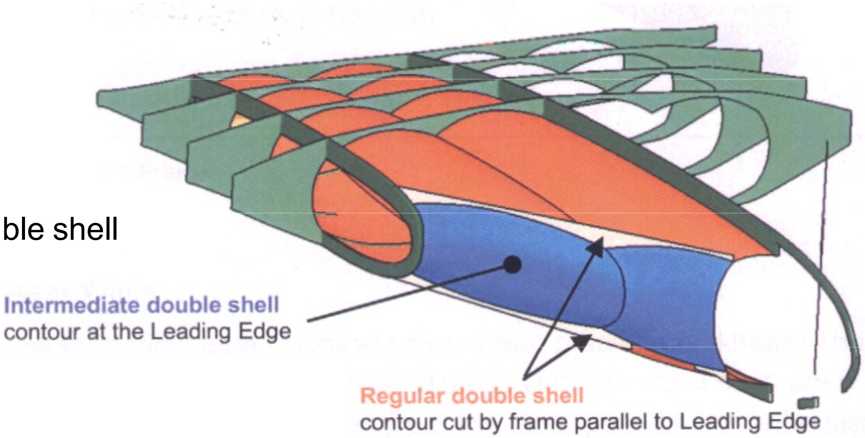


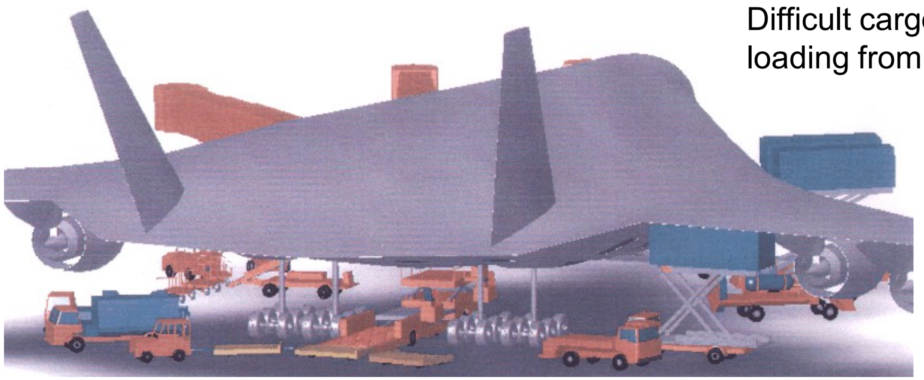

Blended Wing Body (BWB): Cabin Comfort and "Show Stoppers"

Much space for (heavy) luxury. Who can pay for it?



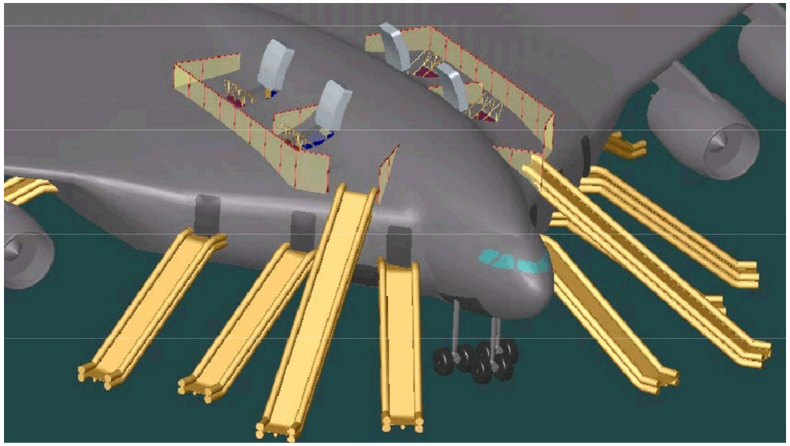
Heavy double shell





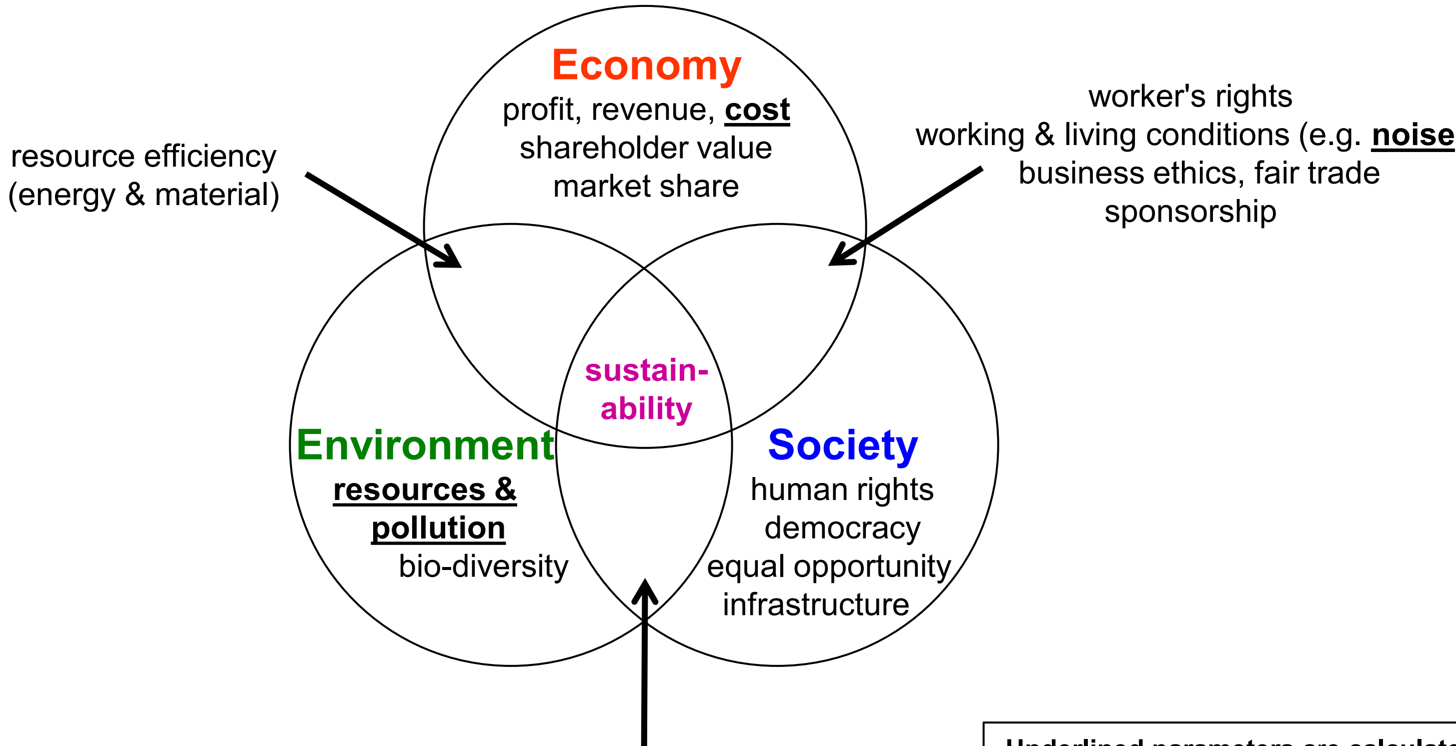
Difficult cargo loading from below

"Show Stopper": Evacuation after ditching (in water)



Evaluation in Aircraft Design

The 3 Dimensions of Sustainability



→: disaster control
←: access limitation

Underlined parameters are **calculated**
for the proposed evaluation
in aircraft design

https://doi.org/10.15488/3986

Sustainability Venn Diagram

Evaluation: Purpose

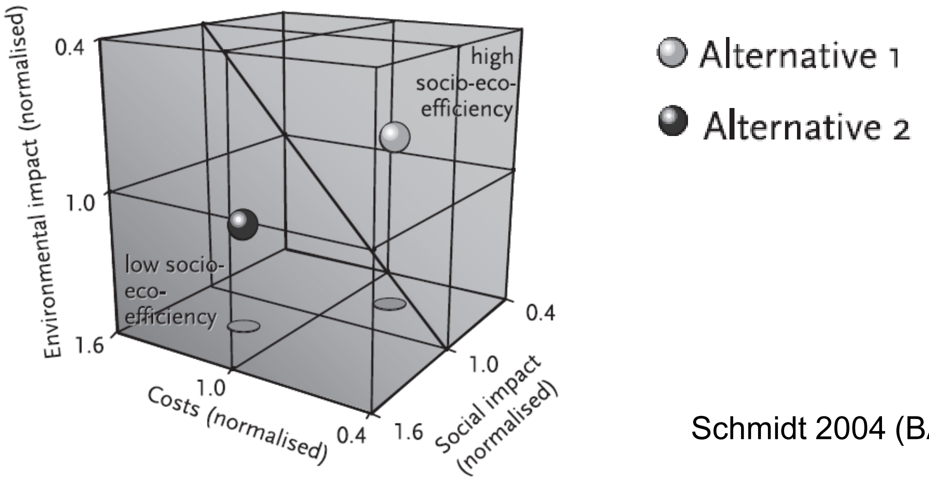
- evaluation of the aircraft for **optimum design** (definition of an objective function)
- **technology evaluation** (on an assumed aircraft platform)
- evaluation for **aircraft selection** (for aircraft purchase by an airline)

Evaluation in the 3 Dimensions of Sustainability: Measuring Socio-Eco-Efficiency

- Economic Evaluation
- Environmental Evaluation
- Social Evaluation

Economic + Environmental } Eco-Efficiency

Eco-Efficiency + Social } Socio-Eco-Efficiency (SEE)



Type of Evaluation	Method
Economic	DOC
Environmental	LCA
Social	S-LCA

Schmidt 2004 (BASF SEE)

DOC Cost Elements

$$C_{DOC} = C_{DEP} + C_{INT} + C_{INS} + C_F + C_M + C_C + C_{FEE}$$

- depreciation C_{DEP}
- interest C_{INT}
- insurance C_{INS}
- fuel C_F
- maintenance C_M, consisting of the sum of
  - airframe maintenance $C_{M,AF}$
  - power plant maintenance $C_{M,PP}$
- crew C_C, consisting of the sum of
  - cockpit crew $C_{C,CO}$
  - cabin crew $C_{C,CA}$
- fees and charges C_{FEE}, consisting of the sum of
  - landing fees $C_{FEE,LD}$
  - ATC or navigation charges $C_{FEE,NAV}$
  - ground handling charges $C_{FEE,GND}$

Annual Costs:

$$C_{DOC} = C_{a/c,a}$$

Trip-Costs:

$$C_{a/c,t} = \frac{C_{a/c,a}}{n_{t,a}}$$

Mile-Costs:

$$C_{a/c,m} = \frac{C_{a/c,t}}{R} = \frac{C_{a/c,a}}{n_{t,a}\, R}$$

Seat-Mile-Costs:

$$C_{s,m} = \frac{C_{a/c,t}}{n_{pax}\, R} \text{ or } \frac{C_{a/c,a}}{n_s\, n_{t,a}\, R}$$

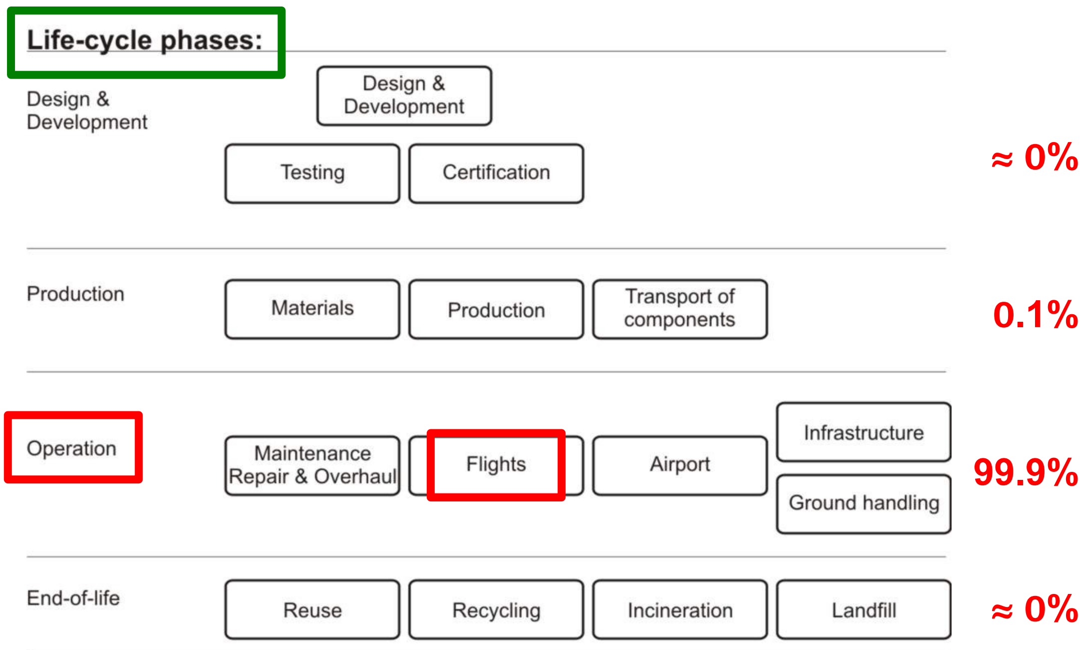
Utilization, annual, flight time: $U_{a,f} = t_f \frac{k_{U1}}{t_f + k_{U2}}$

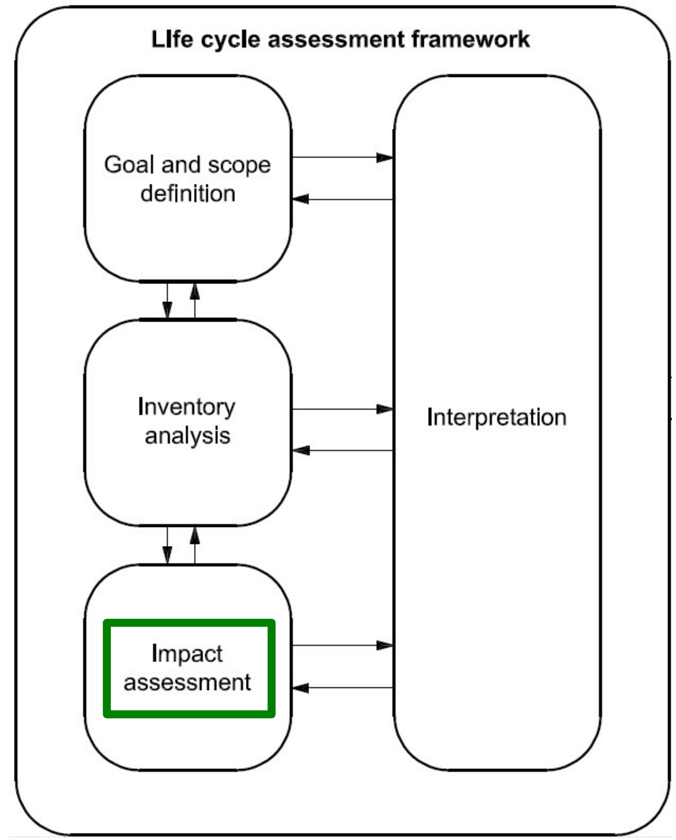
number of trips, annual: $n_{t,a} = \frac{U_{a,f}}{t_f}$

Life Cycle Assessment (LCA) Applied to Aviation

Johanning 2017

"Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system during its life cycle"



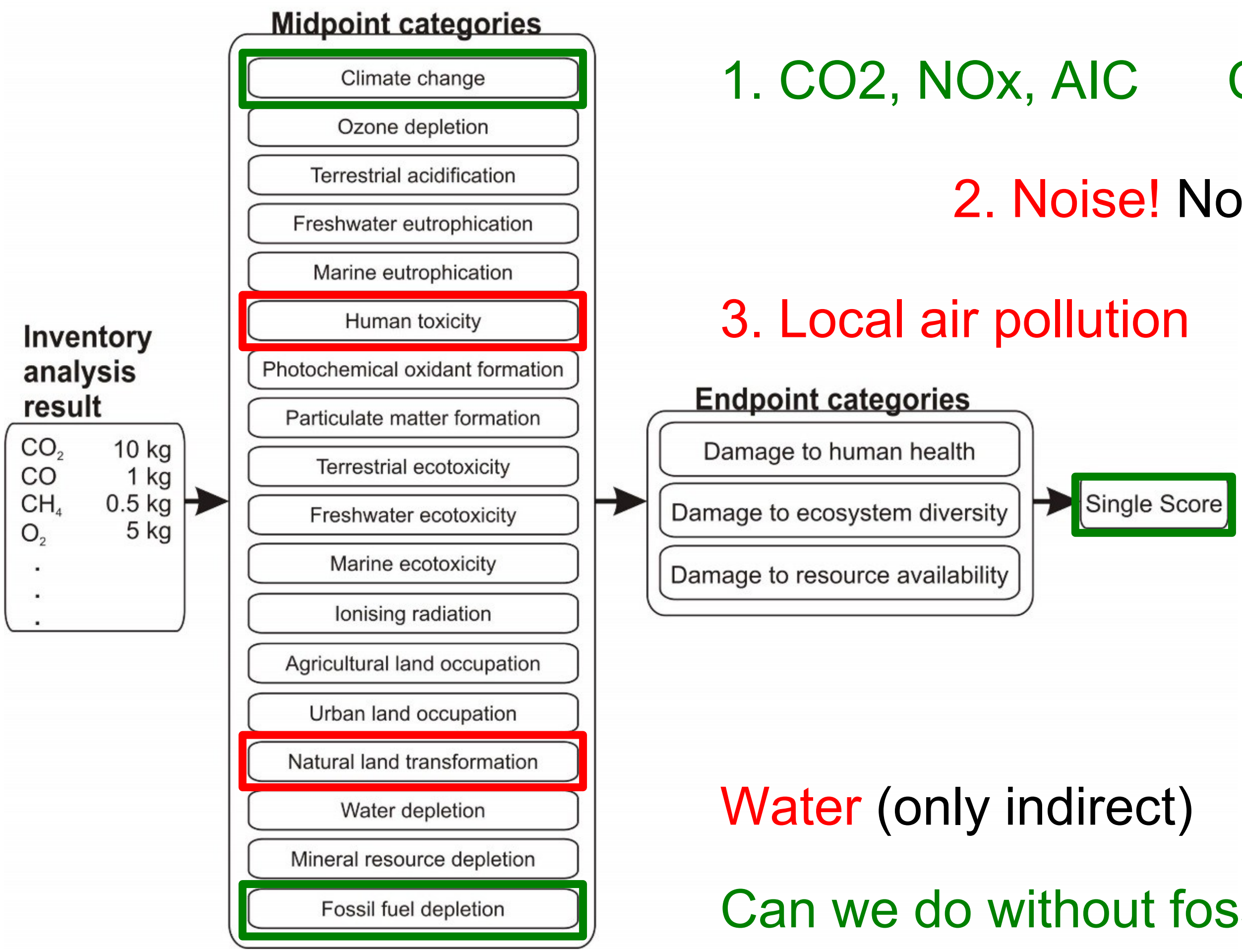


Standardized according to ISO 14040, ISO 14044

INTERNATIONAL STANDARD ORGANIZATION, 2006. ISO 14040: *Environmental management — Life cycle assessment — Principles and framework*. July 2006. Available from: https://www.iso.org/standard/37456.html

Impact Assessment in LCA Applied to Aviation

Johanning 2017



1. $CO2$, NOx, AIC Can we do without?

2. Noise! Not included in LCA!?

3. Local air pollution

Water (only indirect)

Can we do without fossil fuels? E-Fuel?

ReCiPe Method – Available from: https://www.leidenuniv.nl/cml/ssp/publications/recipe_characterisation.pdf

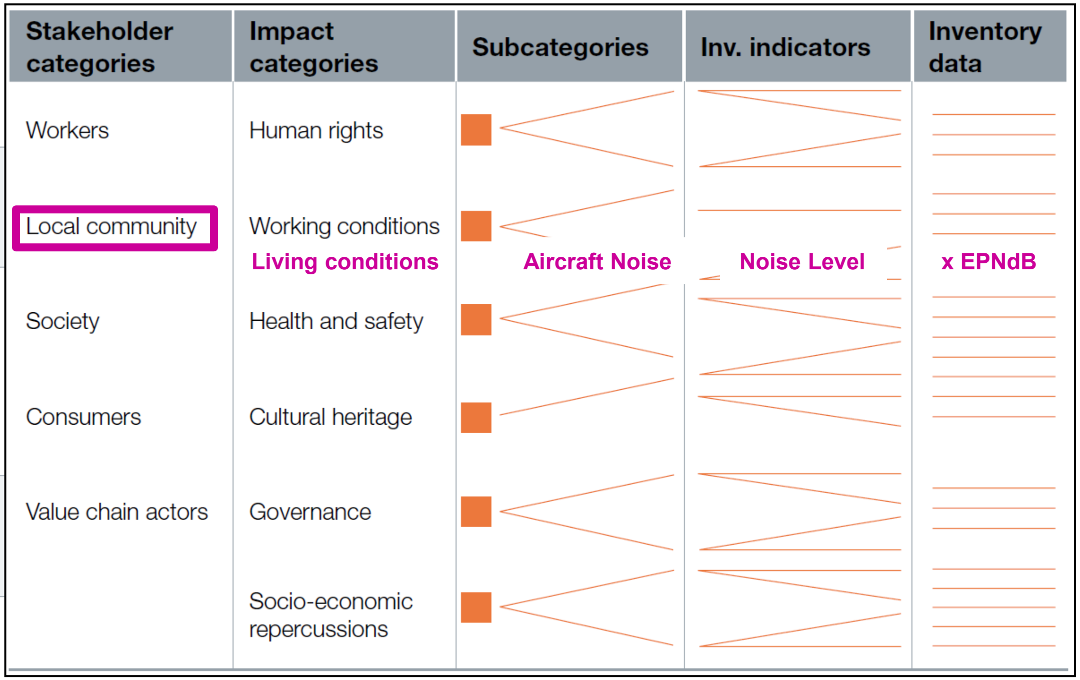
Evaluation in Aircraft Design

Social Life Cycle Assessment (S-LCA)

S-LCAs follow the ISO 14044 framework. They assess **social** and socio-economic **impacts** found along the life cycle (supply chain, use phase and disposal) of products and services. Aspects assessed are those **that** may directly or indirectly **affect stakeholders** positively or negatively. These aspects may be linked to the behaviors of socio-economic processes around enterprises, government, ... (UNEP 2009) (https://doi.org/10.48441/4427.2887)

Stakeholder categories	Subcategories
Stakeholder "worker"	Freedom of Association and Collective Bargaining Child Labour Fair Salary Working Hours Forced Labour Equal opportunities/Discrimination Health and Safety Social Benefits/Social Security
Stakeholder "consumer"	Health & Safety Feedback Mechanism Consumer Privacy Transparency End of life responsibility
Stakeholder "local community"	Access to material resources Access to immaterial resources Delocalization and Migration Cultural Heritage Safe & healthy living conditions Respect of indigenous rights Community engagement Local employment Secure living conditions
Stakeholder "society"	Public commitments to sustainability issues Contribution to economic development Prevention & mitigation of armed conflicts Technology development Corruption
Value chain actors* not including consumers	Fair competition Promoting social responsibility Supplier relationships Respect of intellectual property rights

Noise: Only one of many possible indicators in an S-LCA



Evaluation in Aircraft Design

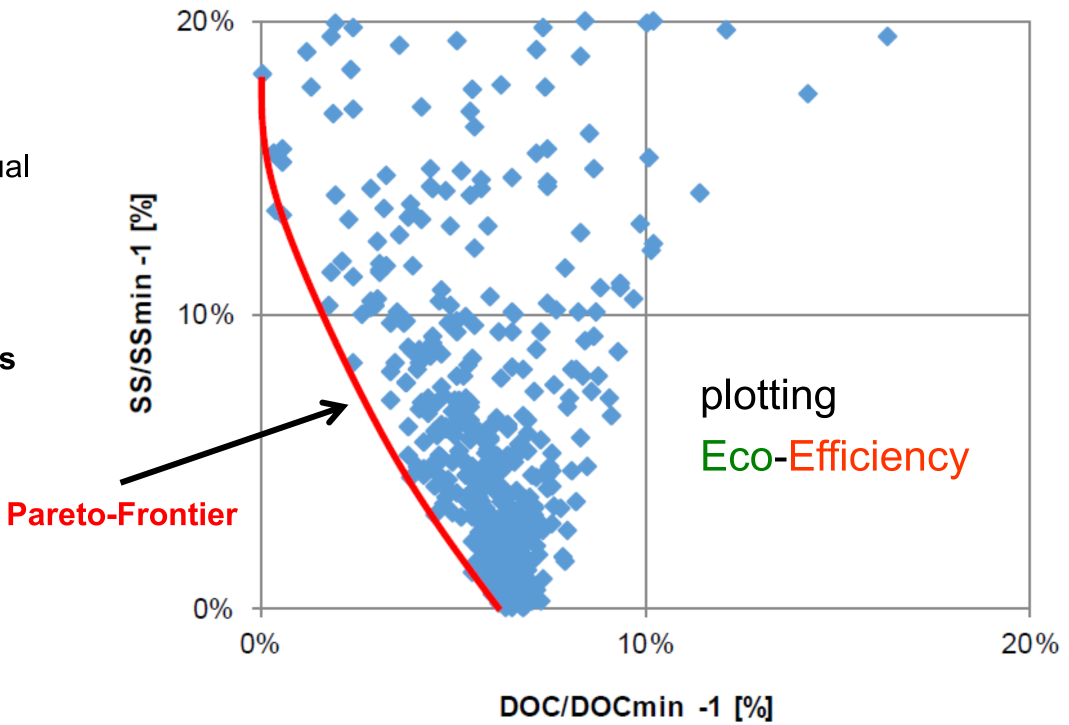
Multiple-Criteria Decision Analysis (MCDA)

- **Many techniques** exist => Literature
- **Weighted Sums Analysis**: $SS_{total} = k_{DOC}\ DOC + k_{SS,LCA}\ SS_{LCA} + k_{SS,S-LCA}\ SS_{S-LCA}$
- **Pareto-Optimum**:

Pareto optimality is a state of allocation of resources from which it is impossible to reallocate so as to make any one individual or preference criterion better off without making at least one individual or preference criterion worse off.

Usualy Pareto-Frontiers show **two variables only**.

Here **three plots** could be used to overcome the limitations:
- $DOC – SS_{LCA}$
- $DOC – SS_{S\text{-}LCA}$
- $SS_{LCA} – SS_{S\text{-}LCA}$



Johanning 2017

Summary

Summary

- Method "Aircraft Design by Scholz" used extensively in Germany.
- Many practical tools are available to design and optimize passenger aircraft (jet and propeller driven). Problem solving details are given.
- A good passenger aircraft design:
  - propeller driven, high aspect ratio with braced wing, folding wing
  - The Box Wing Aircraft (BWA) and the Blending Wing Body (BWB) have overall no advantage.
- Aircraft evaluation is important:
  - Direct Operating Costs (DOC), Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA)
  - Multi Criteria Decision Making, Pareto Front

"Smart Turboprop" (STP): How It Flys in the Simulator (Video)

Start Video online: https://youtu.be/Q4O1uJmwEzo

Contact

info@ProfScholz.de

http://ProfScholz.de

Quote this document:

SCHOLZ, Dieter, 2025. Aircraft Design by Scholz – Adopted at Hamburg University of Applied Sciences and Beyond. Aircraft Design Seminar for Aviation Industry Corporation of China (AVIC), AVIC Aircraft Design and Research Institute (Hamburg, Germany, 18 November 2025).
Available from: https://doi.org/10.48441/4427.2977.

References

Note: **Most references are given directly in the text** as URL, DOI, or link to an archive. Remaining references:

JOHANNING, Andreas, 2017. *Methodik zur Ökobilanzierung im Flugzeugvorentwurf*. Dissertation. Hamburg University of Applied Sciences, Aircraft Design and Systems Group (AERO).
Available from: https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2017-05-21.01

LOFTIN, L.K., 1980. Subsonic Aircraft: Evolution and the Matching of size to Performance. NASA Reference Publication 1060.
Available from: https://ntrs.nasa.gov/citations/19800020744

MAHFOUZ, Houssein, SCHOLZ, Dieter, 2024. Einfacher Flügelentwurf optimiert hinsichtlich Masse und Widerstand. Poster. Deutscher Luft- und Raumfahrtkongress (Hamburg, 30.09. - 02.10.2024).
Available from: https://doi.org/10.48441/4427.2124

SCHMIDT, I., MEURER, M., SALING, P., KICHERER, A., REUTER, W., GENSCH, C., 2014. SEEbalance – Managing Sustainability of Products and Processes with the Socio-Eco-Efficiency Analysis by BASF. In: Greener Management International, vol. 45, no. 1, pp. 79-94.
Available from: https://www.researchgate.net/publication/228693310