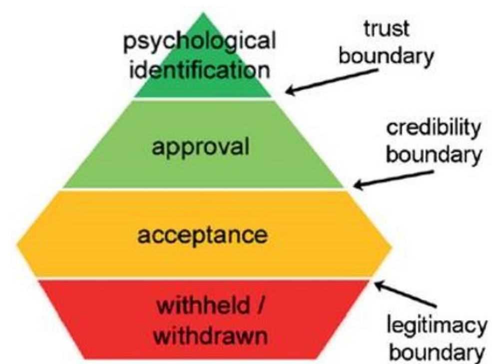
Hochschule für Angewandte Wissenschaften Hamburg
Hamburg University of Applied Sciences

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

How to Design Aircraft in Times of the Climate Crisis – Are We Losing Our Social License to Operate?

Aircraft Design and the SLO

Dieter Scholz



ENERGI I NORD

BLU GREEN ARCTIC AVIATION DEVELOPMENT

DEUTSCHE AIRCRAFT

Seminar on Commercial Development of E-Fuels in Aviation 2025

Bodø, Norway, 09-10 April 2025

https://doi.org/10.48441/4427.2455

Abstract

Purpose – What possibilities exist to design aircraft such that their operation is causing less global warming or even avoids it? Can this be communicated to society in a credible way to maintain or regain trust? Is the concept of the Social License to Operate (SLO) a helpful tool to manage this communication?

Methodology – A literature review combined with a summary of own research and teaching.

Findings – Current aviation growth is unsustainable. Flying less is necessary and a simple answer that works, but does not fulfil mobility expectations of society. A modern large turboprop (180 seats) flying slower and lower than a jet, fueled with e-fuel from renewable energy and CO2 (eventually) from Direct Air Capture (DAC), plus Carbon Capture and Storage (CCS) – with its problems – to compensate for remaining non-CO2 effects would be a first meaningful step.

Research limitations – There are no simple technical solutions for aviation.

Practical implications – Many arguments are given in one place.

Originality – A discussion of the Social License to Operate (SLO) applied to aviation, compared to Social Life Cycle Assessment (S-LCA) and aviation ethics was not found in the literature.

Definition of Title Terms

Aircraft: Any machine that can derive support in the atmosphere from the reaction of the air. (ICAO Annex 1)

Aircraft Category: Classification of aircraft according to specified basic characteristics, e.g. aeroplane, glider, rotorcraft, free balloon. (ICAO Annex 1)

Aircraft System: A combination of inter-related items arranged to perform a specific function on an aircraft, e.g. air conditioning (21), fuel (28), hydraulic power (29), navigation (34), ... (ATA 100)

Aircraft Design: Overall Aircraft Design (OAD):
Practical approach: Supply the "geometrical description of a new flight vehicle" for certification
1.) three-view drawing (today 3D model), 2.) fuselage cross-section, 3.) cabin layout, 4.) parameters
Theoretical approach: Determine the design parameters to ...
a) meet requirements and constraints, b) optimize design objectives: economic, ecologic, social

Climate Crisis: Climate change, global warming with consequences: temperatures are rising, environmental degradation, natural disasters, weather extremes, food and water insecurity, economic disruption, sea levels rising, the arctic melting, coral reefs dying, oceans acidifying, forests burning, human conflicts, and terrorism. (UN 2019)

SLO: Social License to Operate: An undertaking or a project having political and public acceptance. Stakeholders, the local and wider community approve the proposed way forward. (IAEA 2025)

Table of Content

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Social License to Operate (SLO)

Social License to Operate

From Definition to Typical Application

Definition

An informal, non-governmental approval that a business or project earns from the community and society at large. Unlike a formal legal license issued by authorities, this license is granted through ongoing trust, legitimacy, and acceptance by stakeholders.

Key Elements

Community Trust and Acceptance
Social and Environmental Responsibility
Continuous Dialogue

Why It Matters

Risk Mitigation (for a project)
Enhanced Legitimacy
Sustainable Long-Term Operations

Most Prominent Applications

Mining and Energy Projects
Infrastructure Development (building highways or urban development)

(from AI, checked)

Jim Cooney Coined the Term "Social License to Operate" (SLO)

Background and Circumstances

Year: 1997

Affiliation: Executive at Placer Dome, a Canadian mining company

Event: A World Bank meeting organized to address growing concerns about the environmental and social impacts of extractive industries.

Motivation: The mining sector faced increasing resistance from communities due to environmental degradation, displacement, and lack of consultation. Cooney proposed the concept of a "social license" to emphasize the importance of gaining and maintaining community approval, beyond just legal compliance.

https://mininghalloffame.ca/jim-cooney

Impact

Cooney's idea took root, especially in industries like mining, oil & gas, and infrastructure, where operations often intersect directly with local communities and ecosystems. Over time, the concept has become a fundamental part of **Corporate Social Responsibility** (**CSR**) and sustainability frameworks globally.

(from AI, checked)

Social License to Operate

Recommended Reading

Joel Gehman
Lianne M. Lefsrud
Stewart Fast

Social license to operate: Legitimacy by another name?

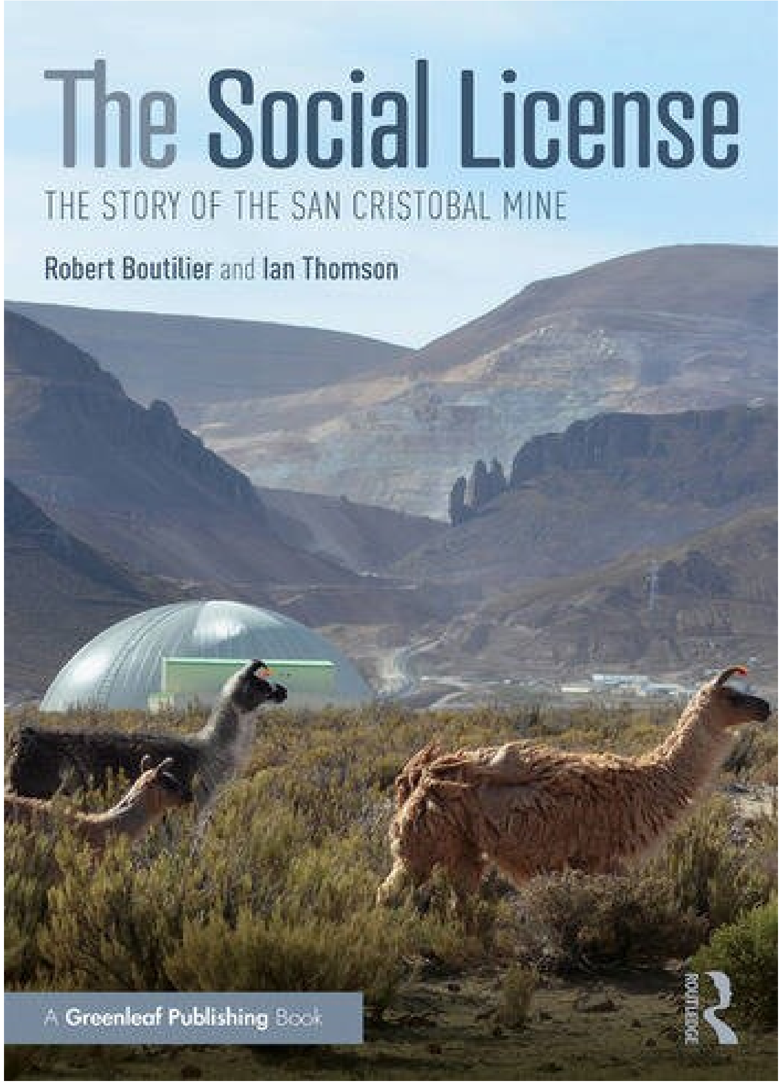
Canadian Public Administration, vol. 60, no. 2, Jun 2017,
pp. 293-317, https://doi.org/10.1111/capa.12218

MOFFAT, Kieren, LACEY, Justine, ZHANG, Airong, LEIPOLD, Sina:
The Social Licence to Operate: A Critical Review.
In: Forestry: An International Journal of Forest Research, vol. 89, no. 5, pp. 477-488, September 2016.
https://doi.org/10.1093/forestry/cpv044

Routledge, 2018, 204 pages
ISBN 9781138579699

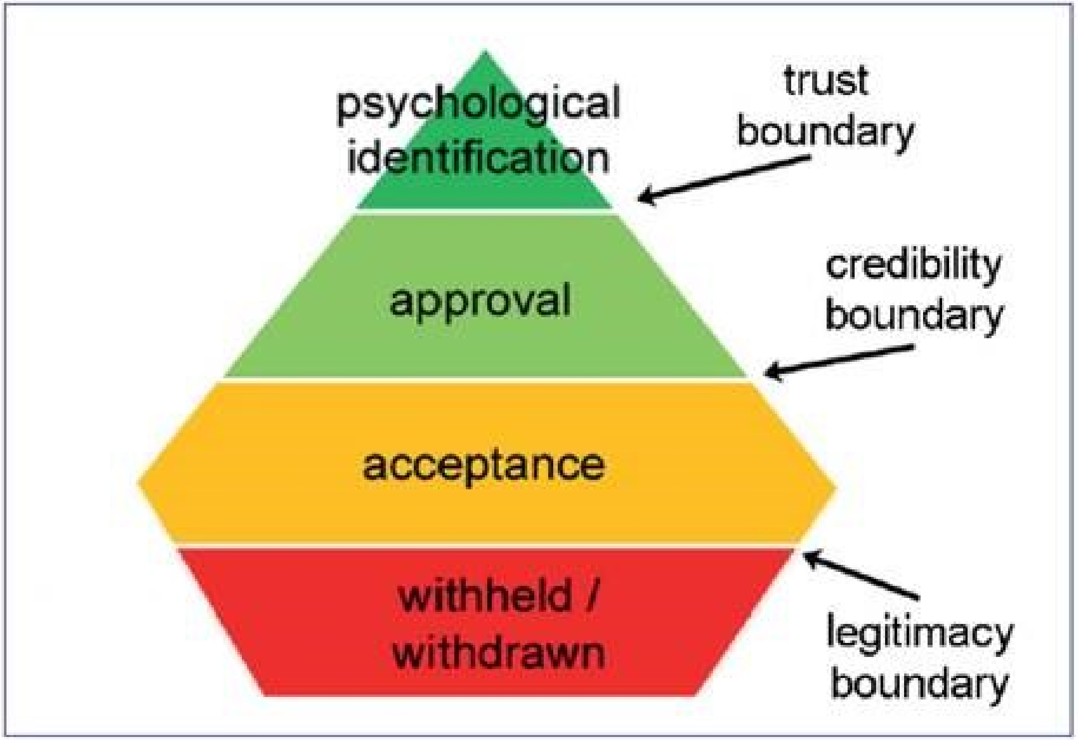
Archived webpage to the book:
https://bit.ly/4llHvnE (www.socialicense.com)

Robert Boutilier, consultancy:
https://stakeholder360.com



Social License to Operate

The Pyramid Model



Thomson, Ian; Boutilier Robert, 2011. The Social Licence to Operate. In: SME Mining Engineering Handbook. Colorado, USA: Society for Mining, Metallurgy, and Exploration, pp.1779-1796.
Quoted from: https://doi.org/10.1590/1679-395173811x

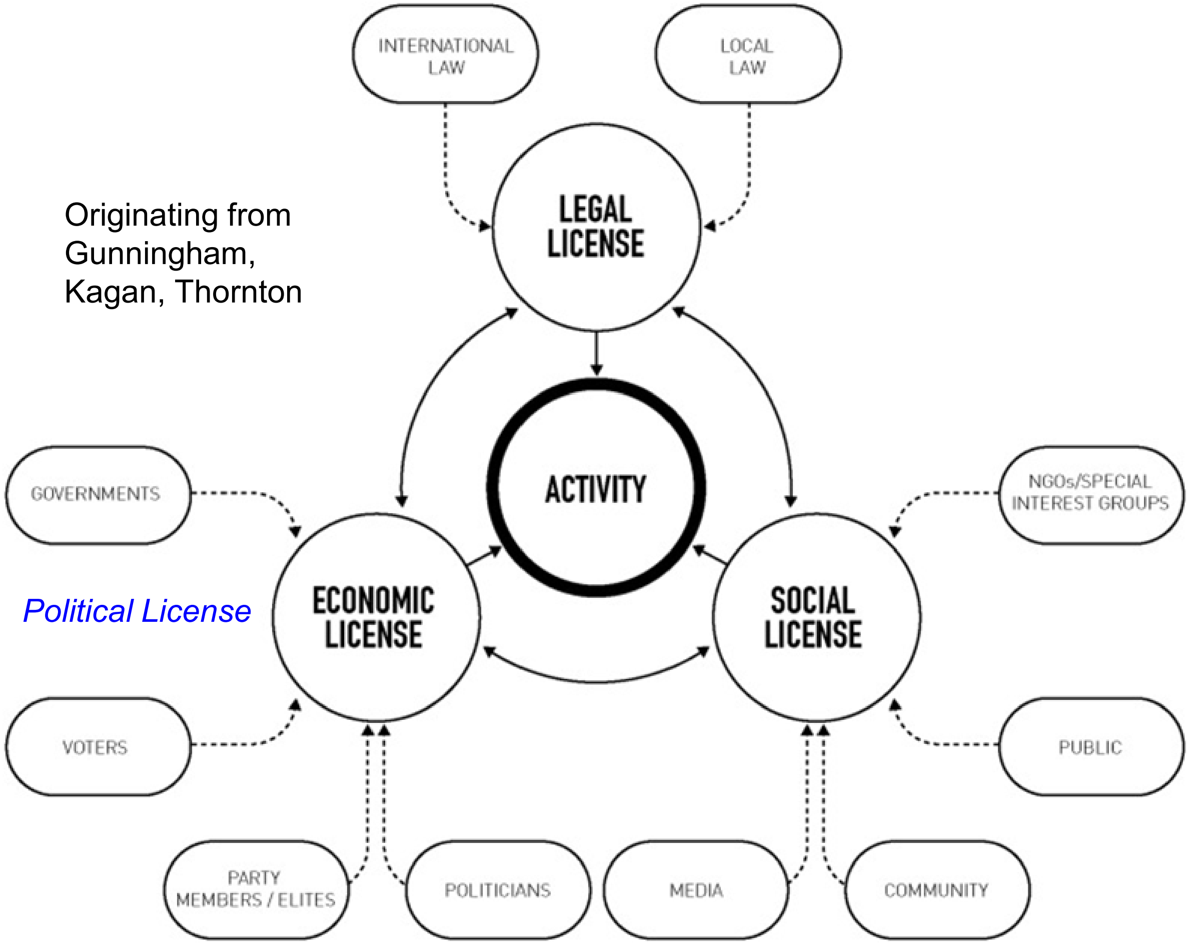
- **Legitimacy** distinguishes projects that have been rejected (projects for which the social license to operate has been withheld/withdrawn) from those that have been accepted by stakeholders through engagement with them according to the "rules of the game."
- **Credibility** distinguishes projects that have been accepted from those that have been approved by stakeholders through formal negotiation, definition, and agreement on the roles and responsibilities of the company and stakeholders.
- **Trust** distinguishes projects that have been approved from those for which stakeholders have adopted what they called a sense of co-ownership or psychological identification through collaborations, shared experiences, and vulnerabilities.

Quoted from:
https://doi.org/10.1111/capa.12218

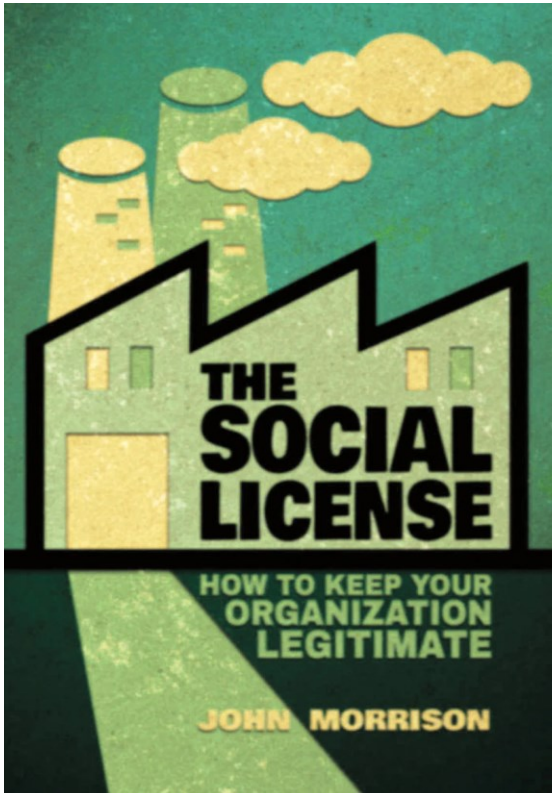
Social License to Operate

The Three Strand Model

Originating from Gunningham, Kagan, Thornton



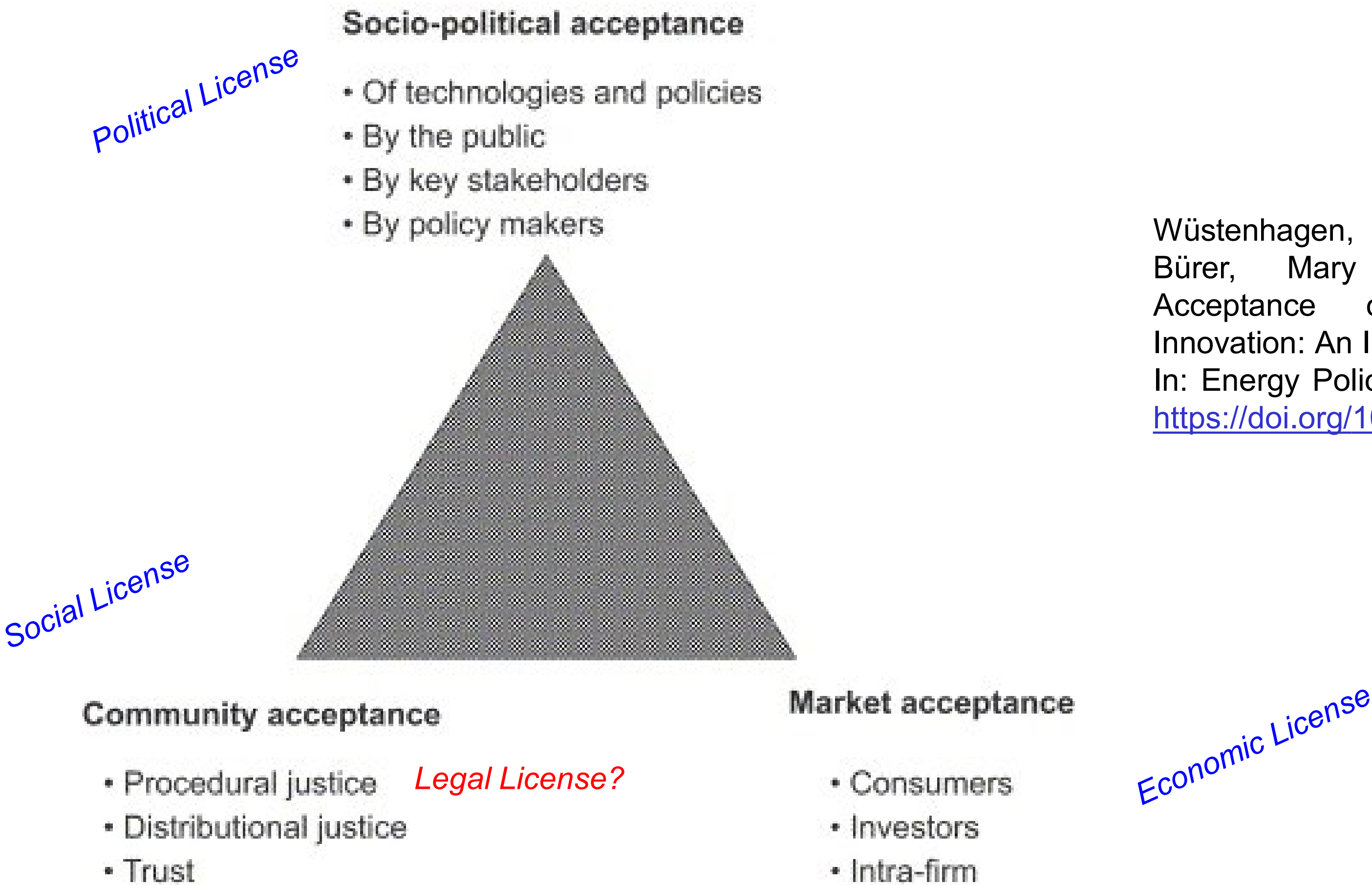
Political License



Morrison, John. 2014. The Social License: How to Keep Your Organization Legitimate. New York, USA: Palgrave Macmillan. https://doi.org/10.1057/9781137370723
Quoted from: https://doi.org/10.1111/capa.12218

Social License to Operate

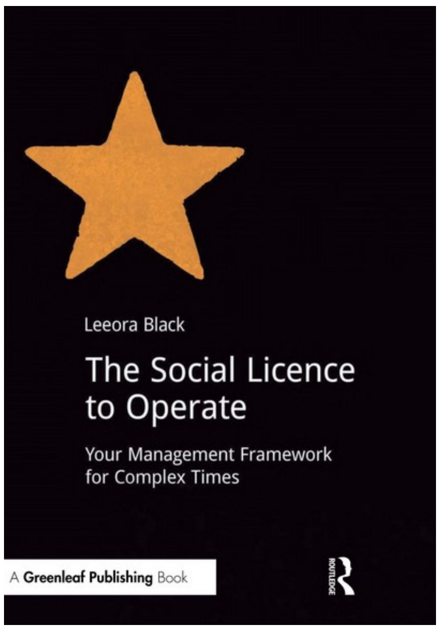
Triangle Model



Wüstenhagen, Rolf; Maarten Wolsink; Bürer, Mary Jean, 2007. Social Acceptance of Renewable Energy Innovation: An Introduction to the Concept. In: Energy Policy, vol. 35, pp. 2683-2691. https://doi.org/10.1016/j.enpol.2006.12.001

Social License to Operate

Measuring the Social License



Black, Leeora. 2013. The Social Licence to Operate: Your Management Framework for Complex Times. London, UK: Routledge. https://doi.org/10.4324/9781351275163

Black (2013) proposed measuring the pyramid model using 14 statements (see Table), which are rated on a **five-point Likert scale**, where 1 represents strong disagreement and 5 represents strong agreement. "To calculate a social license score, **calculate the mean of each stakeholder's responses** to the group of questions."

Item	*Statement*
1	We can gain from a relationship with [name of company].
2	We need to have the cooperation of [name of company] to reach our most important goals.
3	We are very satisfied with our relations with [name of company].
4	[Name of company] does what is says it will do in its relations with our organisation.
5	The presence of [name of company] is a benefit to us.
6	[Name of company] listens to us.
7	In the long term [name of company] makes a contribution to the well-being of the entire region.
8	[Name of company] treats everyone fairly.
9	[Name of company] respects our way of doing things.
10	Our organisation and [name of company] have a similar vision for the future of this region.
11	[Name of company] gives more support to those who it negatively affects.
12	[Name of company] shares decision-making with us.
13	[Name of company] takes account of our interests.
14	[Name of company] openly shares information that is relevant to us.

Possible Application of SLO in Aviation

1. Airport Expansion Projects (Specific Application of SLO)

- **Community Resistance:** Major airport projects like Heathrow (UK), Schiphol (Netherlands), and LAX (USA) have faced **community opposition** due to: Noise pollution, increased emissions, displacement or environmental degradation.
- **SLO Relevance:** These situations pushed airport authorities to consult with communities, offer compensations, limit flight times, and engage in **transparent dialogue** to maintain legitimacy and acceptance.

2. Sustainable Aviation Fuels (SAF)

- Public and regulatory approval for SAF development and biofuel production often hinges on **sustainability, transparency, and traceability** – key SLO principles.
- Airlines can engage stakeholders early in SAF initiatives to ensure **long-term community and environmental support**.

3. Climate Change & Net Zero Commitments (General Application of SLO)

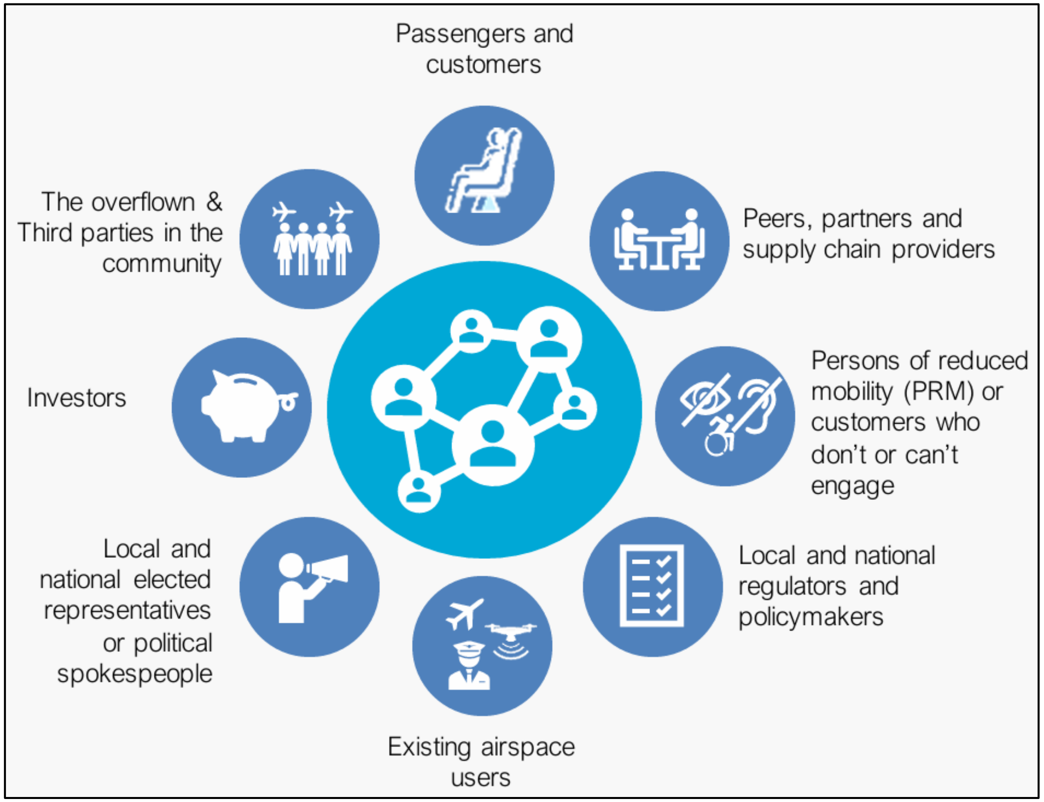
- Aviation is under increasing scrutiny for its **carbon footprint**.

4. Noise and Local Air Quality Concerns

- SLO is used when negotiating flight paths, nighttime flying curfews, and airport traffic caps – where **community health and quality of life** are at stake.

SLO Information from the UK CAA

UK CAA, 2020. Innovation Hub: Social Licence to Operate – Concept Guide for New Technologie. https://www.caa.co.uk/publication/download/17751, https://perma.cc/Y9YT-ZBMR



Principle	Explanation
Public safety	At all times, your responsibility is to maintain high levels of public and consumer safety, security and economic protection.
Transparency and openness	It should be clear to stakeholders how they could be affected by an operation in terms of safety, environmental, security and privacy issues.
Accessibility	Accessible proposals are good proposals. They should be as inclusive, legible and readable as possible.
Evidence-based	Data should drive decision-making, not hunches or guesswork. Gathering data should be an essential part of any proposal, easy to read and widely shared. Your decisions should be clearly recorded and explained.
Stakeholder needs	Proposal design starts with identifying potentially affected stakeholders and their concerns. If you don't know what your stakeholder needs are, you won't build the right thing. You should research, analyse data, and talk to stakeholders.
Integrity	To maintain trust you must act with integrity in all aspects of your operations.

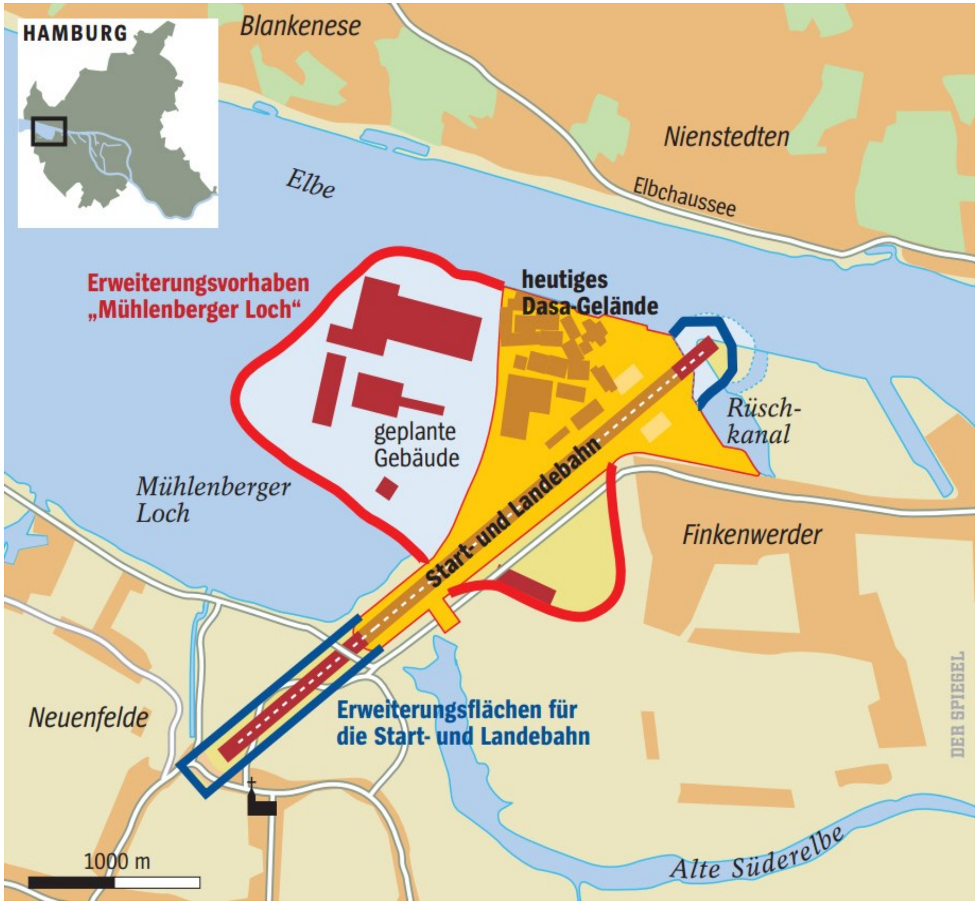
Runway Extension, Airbus, Hamburg-Finkenwerder, SLO?

Evaluated with a Social Life Cycle Assessment (S-LCA) A380: Stakeholder: Local Population (can also be seen under "SLO")

Press Release: https://purl.org/ProfScholz/A380
Presentation: https://doi.org/10.5281/zenodo.5844726
Project: https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2021-12-16.012

Airbus demands:

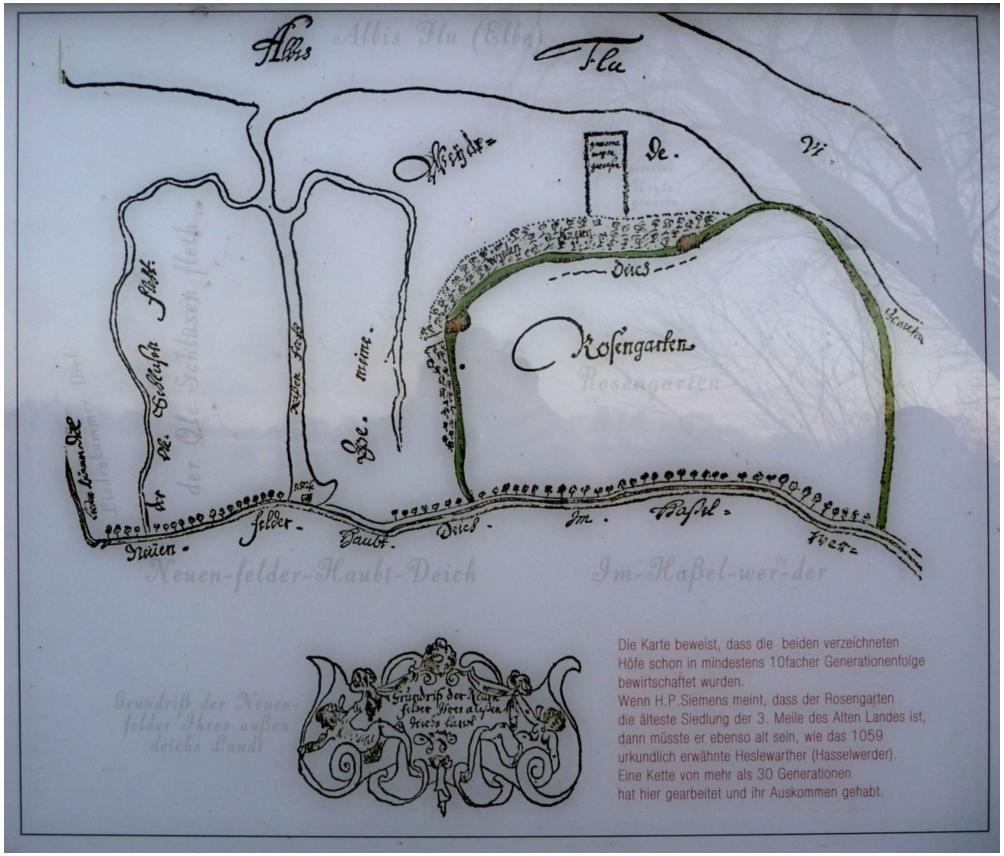
- Runway extension into the village.
- Relocation of the church.
- Farmers must give up their land.
- Nature reserve (river bay) is transformed into an industrial site.



At Stake: Cultural Heritage (Rosengarten)

- The **Rosengarten** is possibly as old as Hasselwerder, which was first **mentioned in 1059**.
- A chain of more than **30 generations** has worked here and made their living.

We were first.
Airbus came much later!

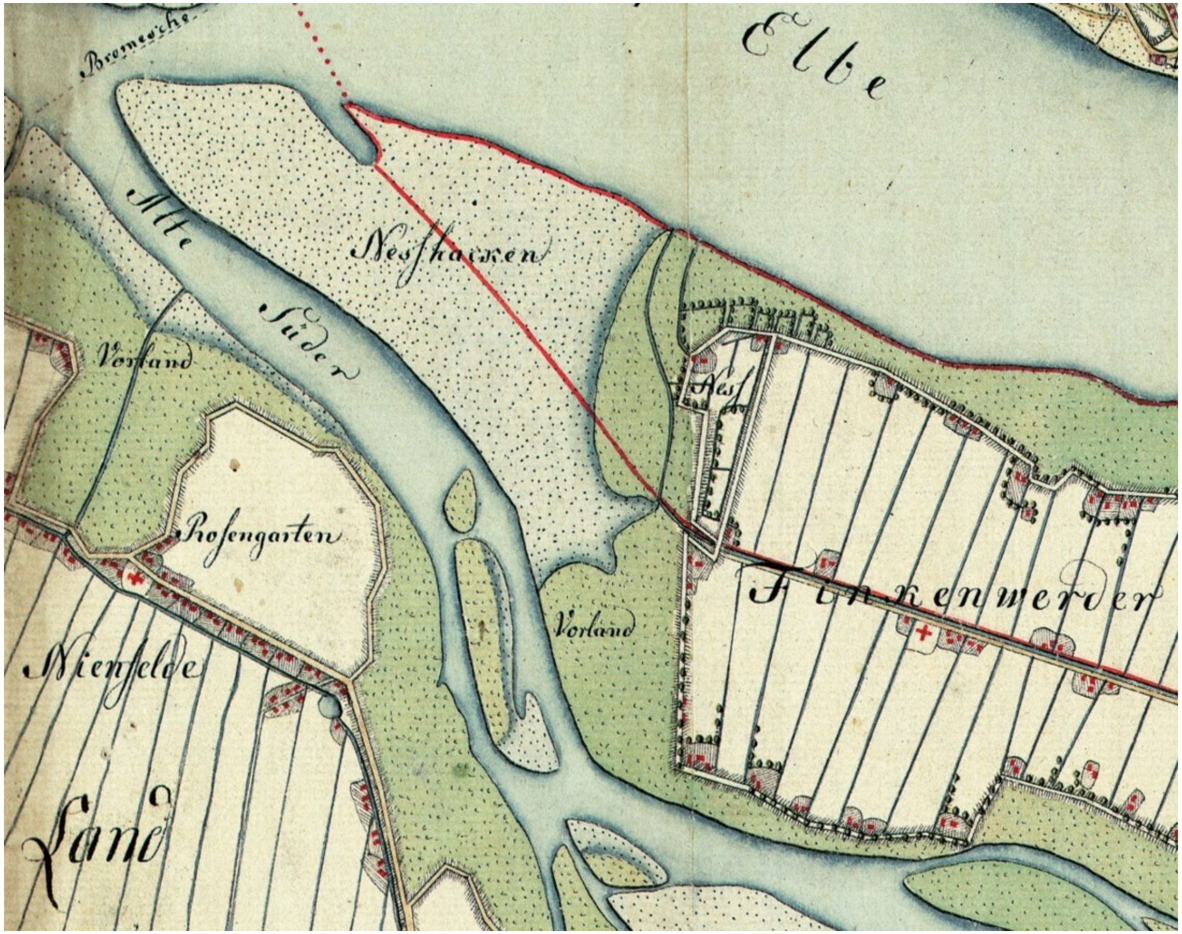


At Stake: Cultural Heritage (Rosengarten)

Map of 1762:

- Finkenwerder
- Rosengarten
- Neuenfelde

We were first.
Airbus came much later!



Map with Finkenwerder, Rosengarten, and Neuenfelde from 1762 (https://perma.cc/L65V-YLN8)

Infringement Proceedings by the EU Environment Commissioner Against Germany

Massive environmental protest (1999) by societies representing 30000 members.

Runway Extension, Airbus, Hamburg-Finkenwerder, SLO?

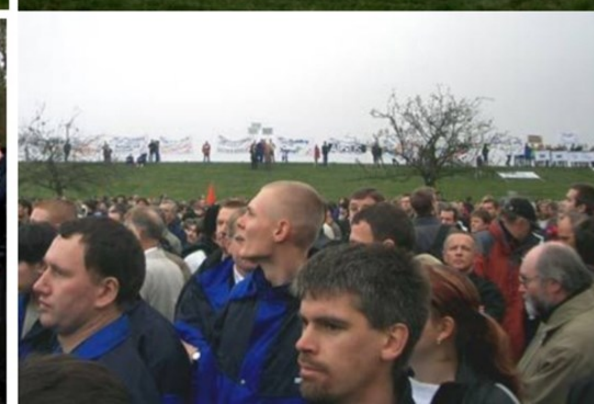
Stakeholder: Local Population

Social commitment against
- runway extension into the village,
- river bay filling,
- tear down of houses (Hasselwerder Straße)

At a meeting at the Eck family farm in Neuenfelde, locals discuss resistance to the filling of the river bay and the extension of the runway. (https://perma.cc/SP35-EH8W)

When the Court Intervened: Hamburg/Airbus: Talks and Threats

Only when the court ruled against expropriation of farmers for the benefit of a private company, official talks start with the local community. The mayor of Hamburg (Ole von Beust) in a village restaurant.



Airbus held an "open-air works meeting" – a counter-demonstration. Airbus employees, their families, the works council, and management – approximately 10,000 people – marched from the factory gate to the village (27 October 2004). Symbolic coffin: "RIP WORKPLACES destroyed by 3 FARMERS and the church".

Runway Extension, Airbus, Hamburg-Finkenwerder, SLO?

Whistleblower Warns Village People – Court Stops Airbus
Airbus Planned Illegal Digging Through the Public Dike

"Himmelfahrtskommando" (Suicide Mission) on Ascension Day to Create Precedents.
This would have Rendered the South of Hamburg Unprotected Again a Storm Tide and Flooding

But eventually:
Clearing the Land

Several farms and 20 hectares of fruit trees had to be removed for the preparations of the extension of the runway in 2006. In the foreground, the village of Neuenfelde.

https://perma.cc/2AYS-KALD
https://perma.cc/NC8W-BAMC

Runway Extension, Airbus, Hamburg-Finkenwerder, SLO?

Runway Extension, Airbus, Hamburg-Finkenwerder, SLO?

Note: The Old Runway Was Long Enough for the A380!

Now the unnecessary runway extension is done.
It was based on Airbus' "410 t landing lie".

Details in a report:
https://purl.org/bv-nfc/bericht (pdf) pp. 190-204
Restored community webpage (from 2004):
https://purl.org/bv-nfc

The runway extension was funded by the taxpayers of Hamburg. About 100 Million EUR were spent.

Production of A380 in Hamburg: 2006 to 2021 – Only 15 Years
½ of a Generation A380 versus 30 Generations of Farming
SLO? Legitimacy Withheld by Local Population!

An A380 approaching Finkenwerder.
Neuenfelde church in the background.

Photo: Dennis Scheffler

Aviation Ethics

Business Ethics: G^4

Business ethics regulates details of behavior that goes beyond governmental control (areas that are difficult to be controlled by laws and regulations).

Unethical business practice *may include*:

- contract violation,
- anticompetitive agreement to raise the price,
- conspiracy against the public,
- deceitful practices,
- ...

Industry is in danger to run into this negative sequence: G^4 = ↑ $ ☹ †

Continuous growth to increase gain to satisfy shareholders expectations can lead to greed and to an ever more ruthless industry behavior accumulating guilt in the end.

Many infamous examples in: "Aviation Ethics – Growth, Gain, Greed, and Guilt"
https://doi.org/10.5281/zenodo.4068008

Only One Example: Boeing – B737 MAX

- In March 2019, the Boeing 737 MAX passenger airliner was grounded worldwide after 346 people died in two crashes on October 29, 2018 and on March 10, 2019.
- In November 2018 Boeing revealed the MAX had a new automated flight control, the Maneuvering Characteristics Augmentation System (MCAS). Boeing had omitted any mention of the system from the aircraft manuals!
- MCAS is activated by input from only one of the airplane's two angle of attack sensors, making the system susceptible to a single point of failure.
- Transport Airplane Risk Assessment Methodology (TARAM): "if left uncorrected, the MCAS design flaw in the 737 Max could result in as many as 15 future fatal crashes over the life of the fleet"
- Boeing was also already well aware, before the first crash, that if a pilot did not react to unintended MCAS activation within 10 seconds, the result could be catastrophic.
- The grounding cost Boeing $18.6 billion in compensation to airlines and victims' families (as of 2020).

Sources:	**Wikipedia**		https://en.wikipedia.org (several pages)
	Seattle Times	Archived at:	https://perma.cc/5KSP-BRZ9 (summary with further links)

Only One Example: Boeing – B737 MAX





Boeing agreed to plead guilty to a felony charge of conspiring to defraud the federal government over two fatal crashes of the 737 Max. Boeing CEO David Calhoun in Senate Hearing (2024-06-18).

The Corporate Social Responsibility (CSR) Pyramid

Carroll's pyramid of
Corporate Social Responsibility (CSR)
https://doi.org/10.1186/s40991-016-0004-6

Cascade of Obedience to the Law (Scholz)

Possible **hidden company policies** related to **legal responsibilities** as part of **business ethics**:

0) **do not abide by the law** – if caught, take severe punishment & ruin your company
1) abide by the **law**, only if it is **enforced** with strong punishment
2) abide by the **law** that is **enforced** (even if punishment is mild)
3) abide by all **law** (enforced or not)
4) abide by all **law and** the **code of respectable businessmen** (German: Verhalten als "ehrbarer Kaufmann").

Level **and better behavior**

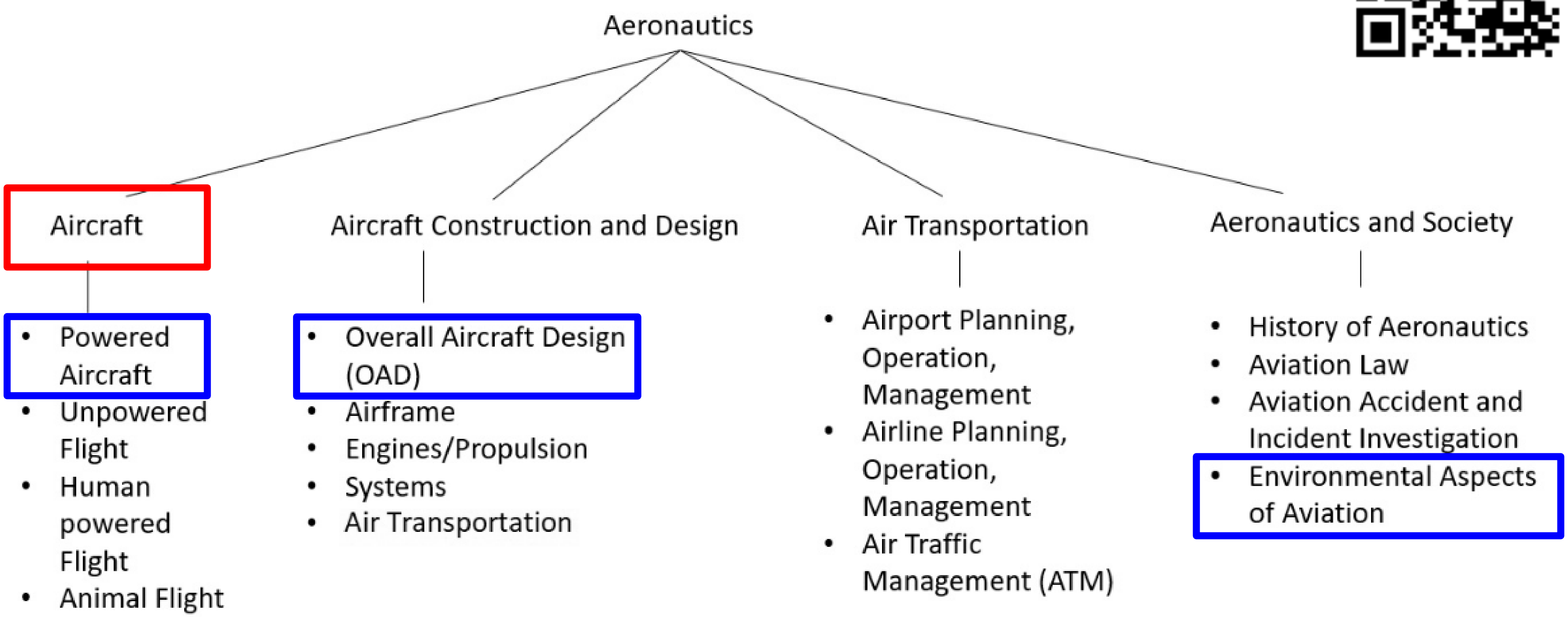
SLO, Social Life Cycle Assessment (S-LCA), Aviation Ethics

- The Social License to Operate (SLO) has its origin in managing stakeholders in specific projects (mining, oil & gas, and infrastructure) and less as an overarching concept like "aviation".
- Likewise, the SLO can be used in aviation for specific projects (large aircraft project, runway extension). Nevertheless, the general concept of the SLO may also be used for "aviation" as a whole. Meesters 2021 demands an SLO "connected to wider sustainability issues including pollution and emissions, patterns of production and consumption".
- Stakeholder management for an SLO should be done with an honest interest in the fate of the people and not just to accomplish project goals in time as set by management and investors.
- A discussion forum towards an SLO decays to a fig leaf and symbolic activity if the outcome (the project / operation) is predetermined (compare with https://perma.cc/9LFT-KEJP). If the local community just does not want the project, any effort towards an SLO is in vain.
- Two different things: An SLO measures stakeholder satisfaction (Black 2013). Business ethics measure company behavior.
- Aviation ethics measures company behavior with the "Cascade of Obedience to the Law" or the "Corporate Social Responsibility Pyramid". A S-LCA (page 85) measures objective stakeholder parameters. The SLO measures subjective stakeholder satisfaction.

Classification

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

HAW HAMBURG

Classification

Aeronautics

Aeronautics (=> Aircraft)

Aeronautics	**100**
➢ Aircraft	110
■ Powered Aircraft	111
• Manned Aircraft	111.1
○ 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
○ Lighter than Air Vehicles	111.12
▪ Blimps	111.121
▪ Zeppelins	111.122
• Unmanned Aircraft	111.2
○ Unmanned Aerial Systems (UAS)	111.21
○ Missiles	111.22
■ Unpowered Flight	112
• Gliders	112.1
• Kites	112.2
• Balloons	112.3
○ Moored	112.31
○ Free	112.32
■ Human Powered Flight	113
■ Animal Flight	114

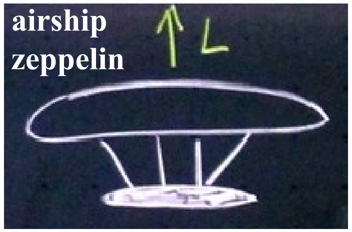
Compare with the (confusing)

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

Forward Force to Keep a Vehicle Aloft during Operation – Compensating Drag Due to Lift, D_i

vehicle with less drag



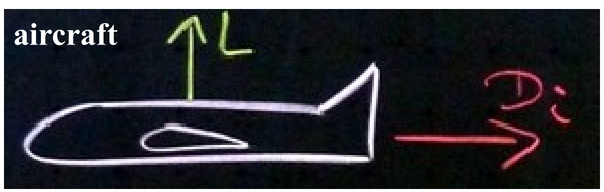
$D_i = L / \infty = 0$

$D = D_0 + D_i$ => big: go slow

zero-lift drag force to push vehicle through the air

L

$D_i = L / 700$



$D_i = L / 40$

$D_i = L / 70$: car on tarmac

$D_i = L / 20$: car on sand

$L = T$

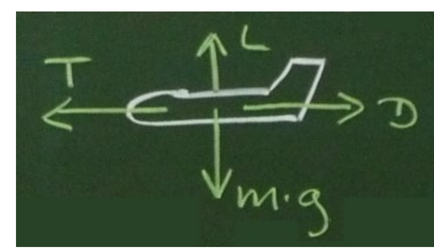
helicopter

$D_i = T = L / 1$

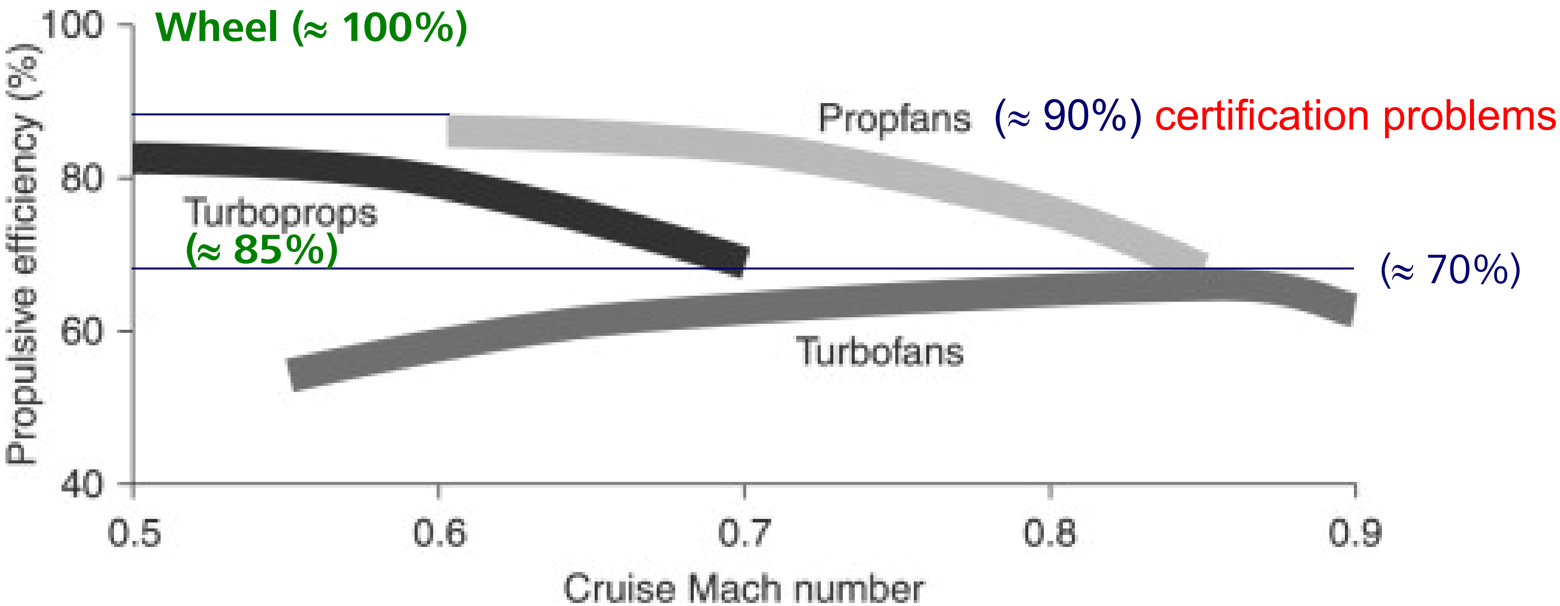
D_i = induced Drag

L = Lift = weight

T = Thrust



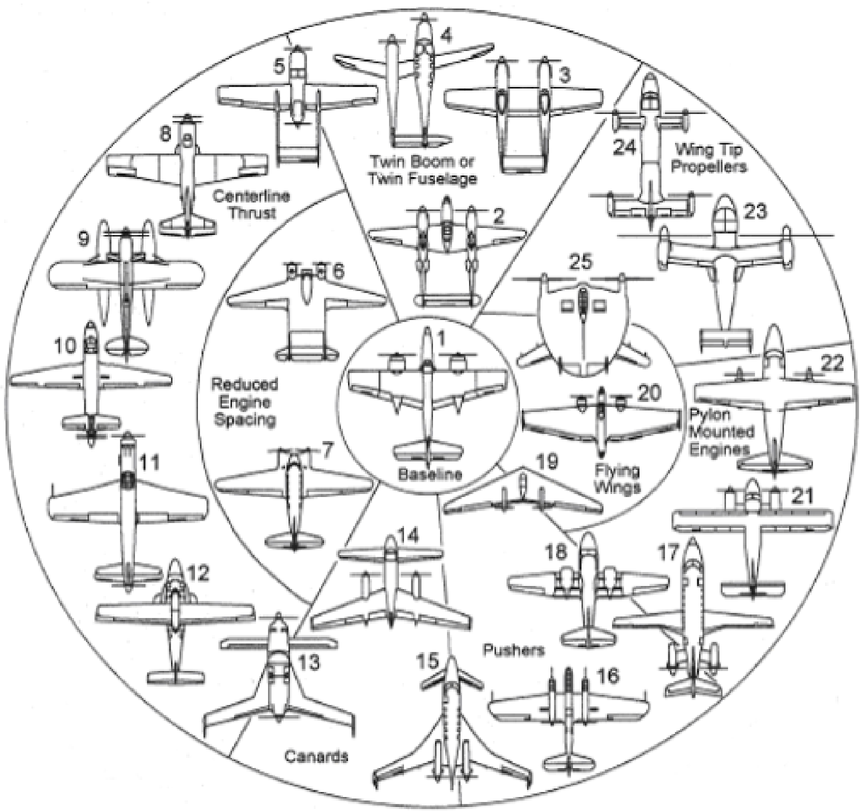
Propulsive Efficiency

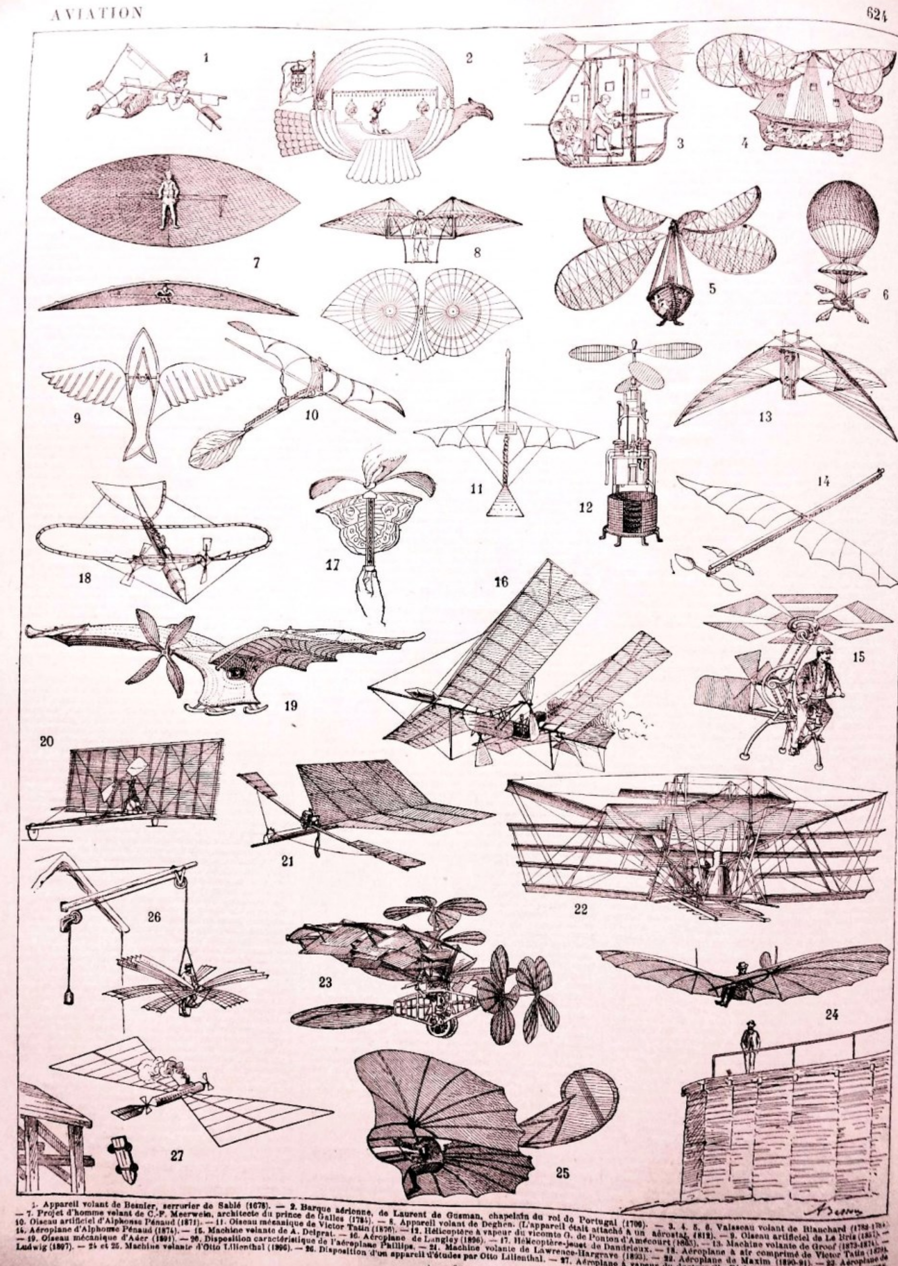


https://www.sciencedirect.com/topics/engineering/propulsive-efficiency

Classification

Aircraft Design Systematics 19th and 20th Century





Leonard 2001 from Müller 2006 Wikimedia 2018

Classification

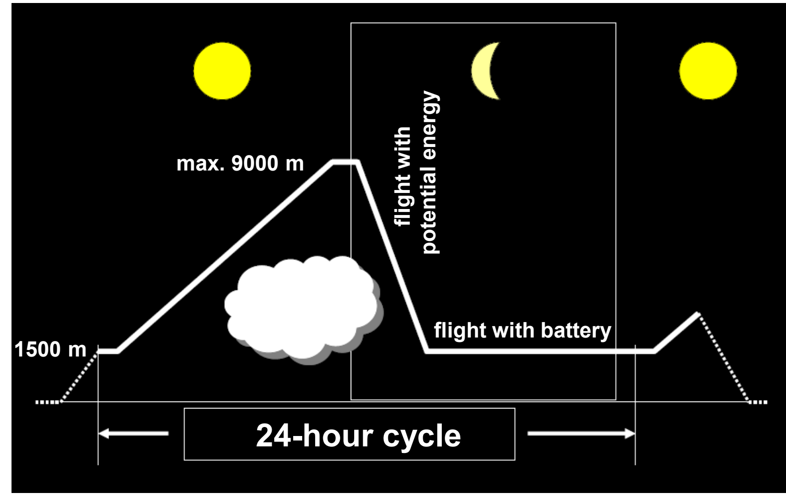
Aircraft Design Systematic – A Morphological Approach Combining Aircraft Configuration and Fuel

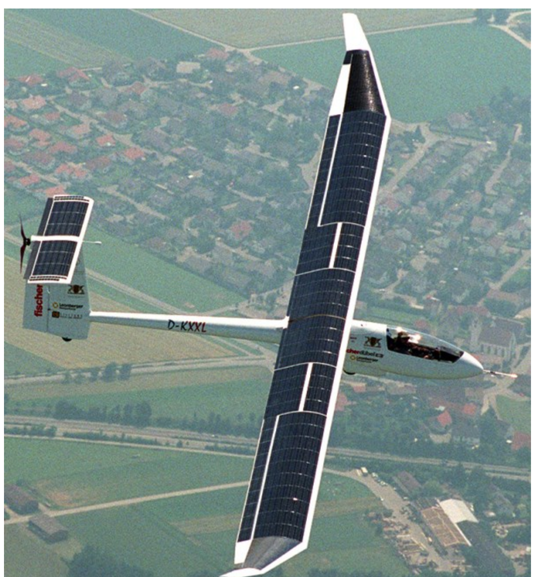
Lift	1	Lift	aerodynamic	thrust	aerostatic	
Thrust	2	Thrust	coupled to Lift Gen-eration	independent from Lift Generation		
Energy Stor-age	3	Internal Energy storage	non	chemical, reversible (e.g. LiPo battery)	chemical, irreversible (e.g. fuel tank)	mechanic (e.g. fly-wheel)
Energy supply	4	External Energy Supply	non	continuous (e.g. solar, microwave)	interrupted, discon-tinuous (e.g. tank)	
Power genera-tion	5	Engines	electric	internal combustion (e.g. diesel engine)	gas turbine	reaction engine (e.g. rocket mo-tor)
	6	Engines	single engine	twin engines	more than 2 engines	
Flight control	7	Flight height control	aerodynamic (e.g. elevators)	Changing of thrust	aerostatic	
	8	Flight directional control	aerodynamic (e.g. rudder)	Thrust imbalance (e.g. two engine		
Fuselage	9	Fuselage	no	one fuselage	twin-boom	

Bardenhagen 2019: https://www.dglr.de/publikationen/2019/490063.pdf

Classification

Solar Powered Aircraft



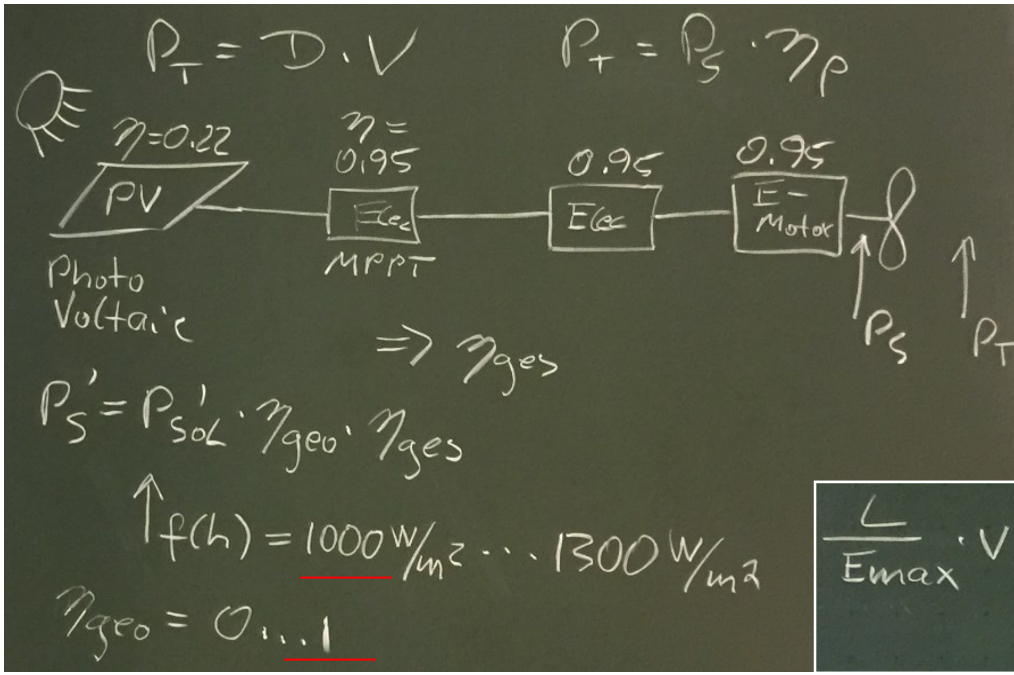


Solar Impulse. https://doi.org/10.5281/zenodo.1133172

https://www.icare-solar.de

Classification

Solar Powered Aircraft



$$D \cdot V = P_S \cdot \eta_P$$

$$D = \frac{L}{E_{max}}$$

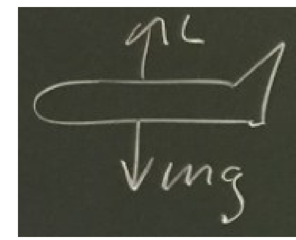
$\eta_P = 0.85$

E_{max} = 25

$$E = L/D$$

$$P_{sol}' = \frac{P_{sol}}{S_W}$$

P_{sol}' = 1000 W/m²



$$\frac{L}{E_{max}} \cdot V = P_{sol}' \cdot \underbrace{\eta_{geo} \cdot \eta_{ges} \cdot \eta_P}_{\eta} \cdot S_W$$

η = 0.16

$$S_W = \frac{mg}{\frac{1}{2} \rho V^2 \cdot C_L}$$

$$V^3 = \frac{E_{max} \cdot P_{sol}' \cdot \eta}{\frac{1}{2} \rho \cdot C_{L,md}}$$

$C_{L,md}$ = 0.5

ρ = 1.225 kg/m³

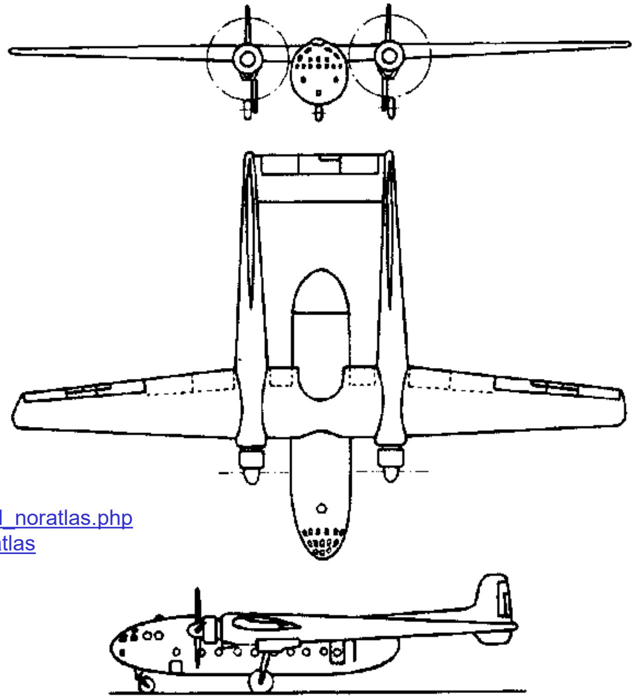
V = 24 m/s = 85 km/h

quite slow !

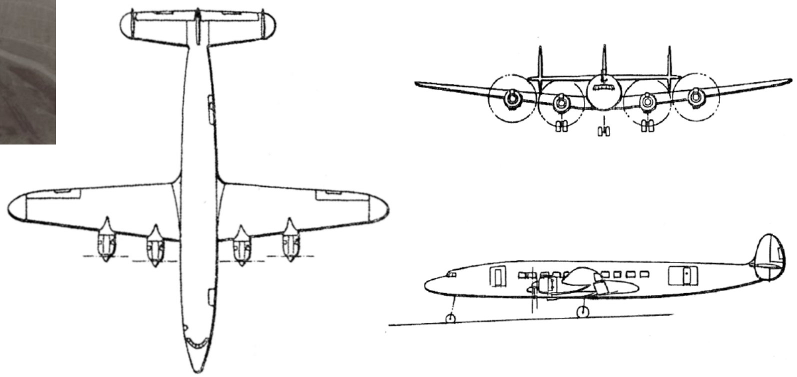
Aircraft Configurations

Conventional Aircraft Configurations

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



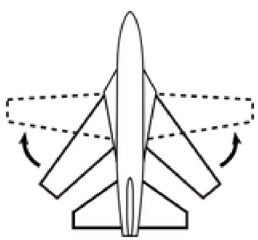
Triple tail, Lockheed Constellation
https://en.wikipedia.org/wiki/Lockheed_Constellation



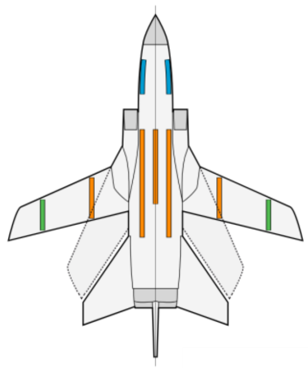
Twin-boom aircraft,
Nord 2500 Noratlas
https://www.aviastar.org/air/france/nord_noratlas.php
https://en.wikipedia.org/wiki/Nord_Noratlas

Conventional Aircraft Configurations

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

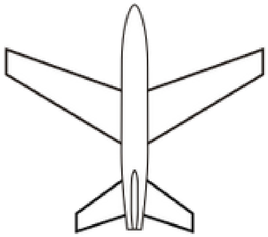


Variable sweep
(swing-wing)

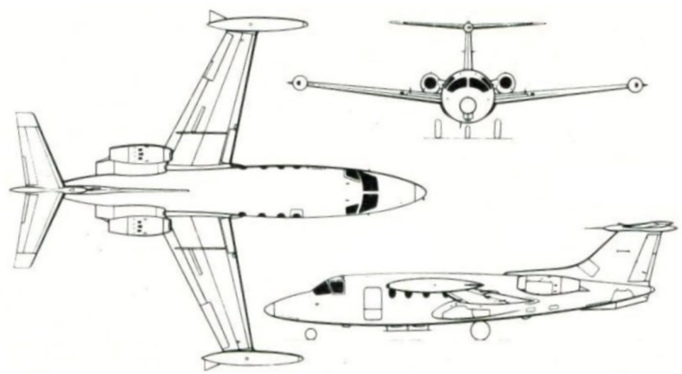


Variable sweep aircraft,
Panavia Tornado
https://en.wikipedia.org/wiki/Panavia_Tornado

Forward swept wing aircraft
Hamburger Flugzeugbau, HFB 320 Hansa Jet
https://www.armedconflicts.com/HFB-320-t231562



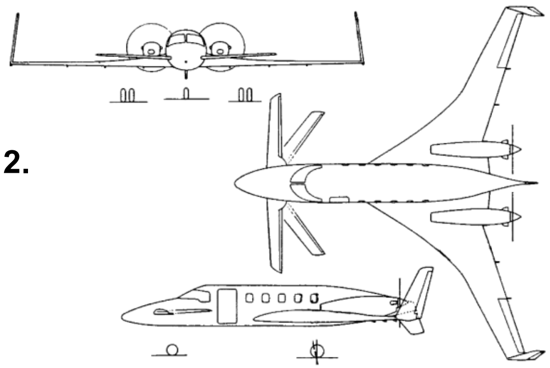
Forward swept



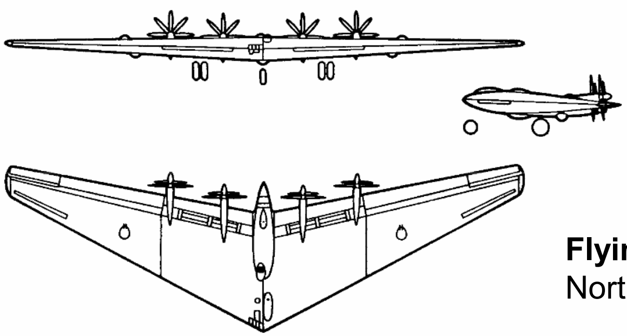
Unconventional Aircraft Configurations

An unconventional aircraft configurations: unsymmetric. Fuselage: no or 2. Wing: no or 2, 3. Empennage: at the front, no or 2.

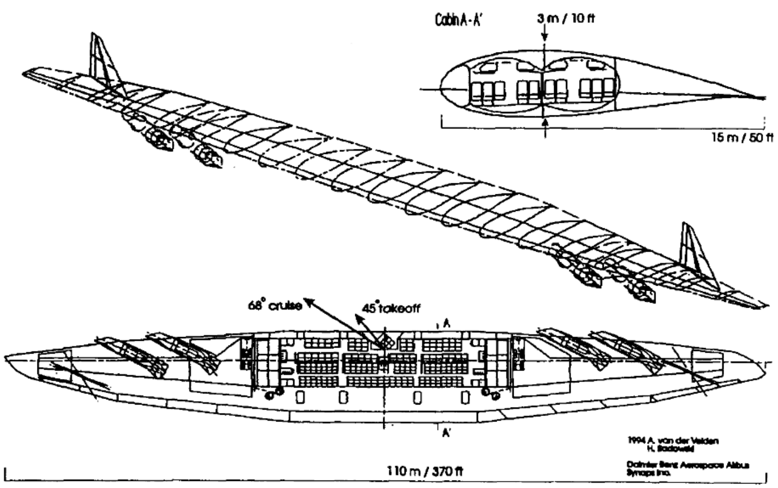
http://LectureNotes.AircraftDesign.org

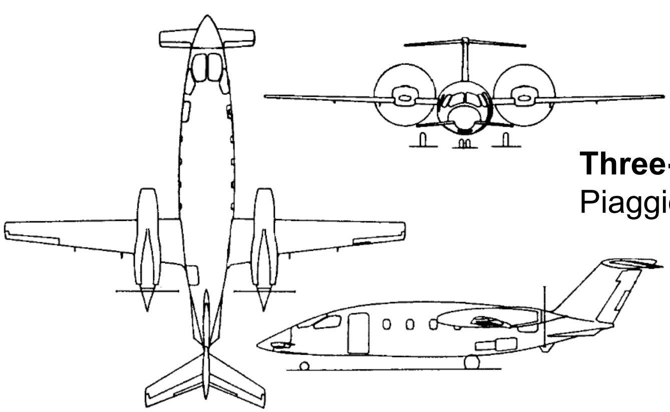


Canard, Beech Starship



Flying wing, Northrop XB-35



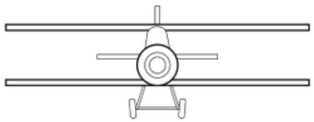


Three-surface aircraft, Piaggio GP-180

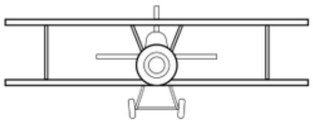
Oblique flying wing aircraft, study

Aircraft Configurations

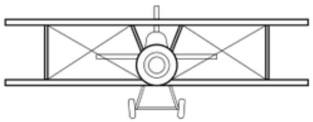
Unconventional Aircraft Configurations



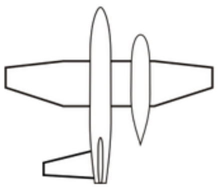
Biplanes: Cantilever



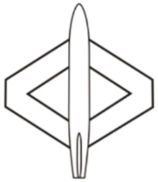
Strut braced



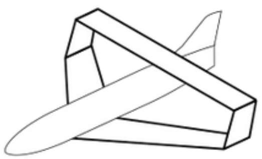
Wire braced



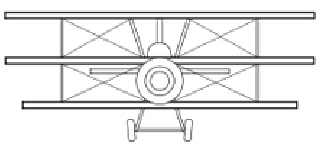
Asymmetrical



Rhomboidal wing

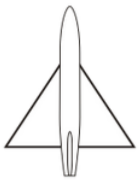


Box Wing Aircraft

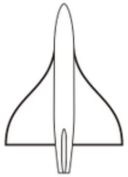


Triplane

https://en.wikipedia.org/wiki/Wing_configuration

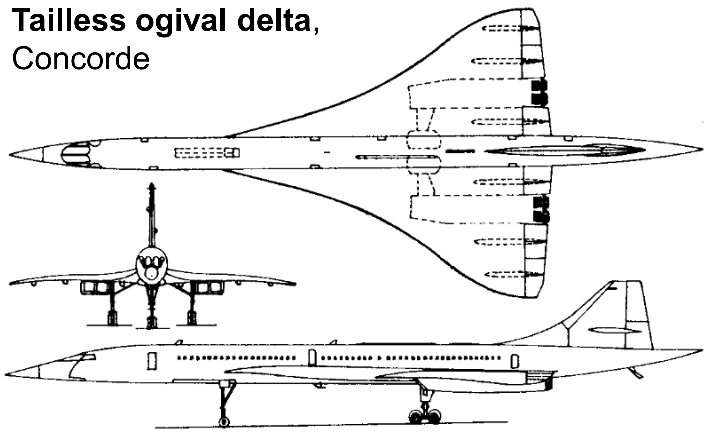


Tailless delta



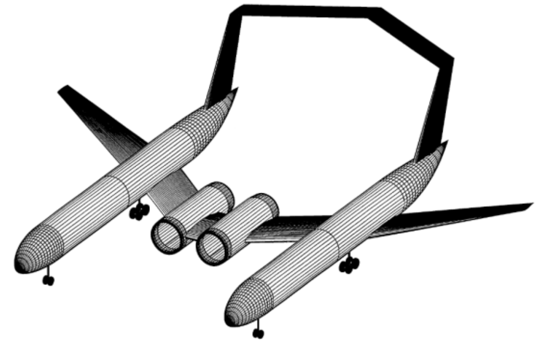
Ogival delta

Tailless ogival delta, Concorde



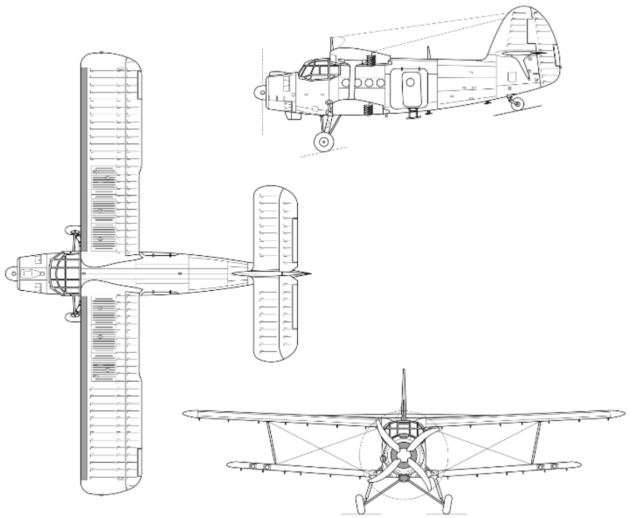
http://LectureNotes.AircraftDesign.org

Double fuselage aircraft, study

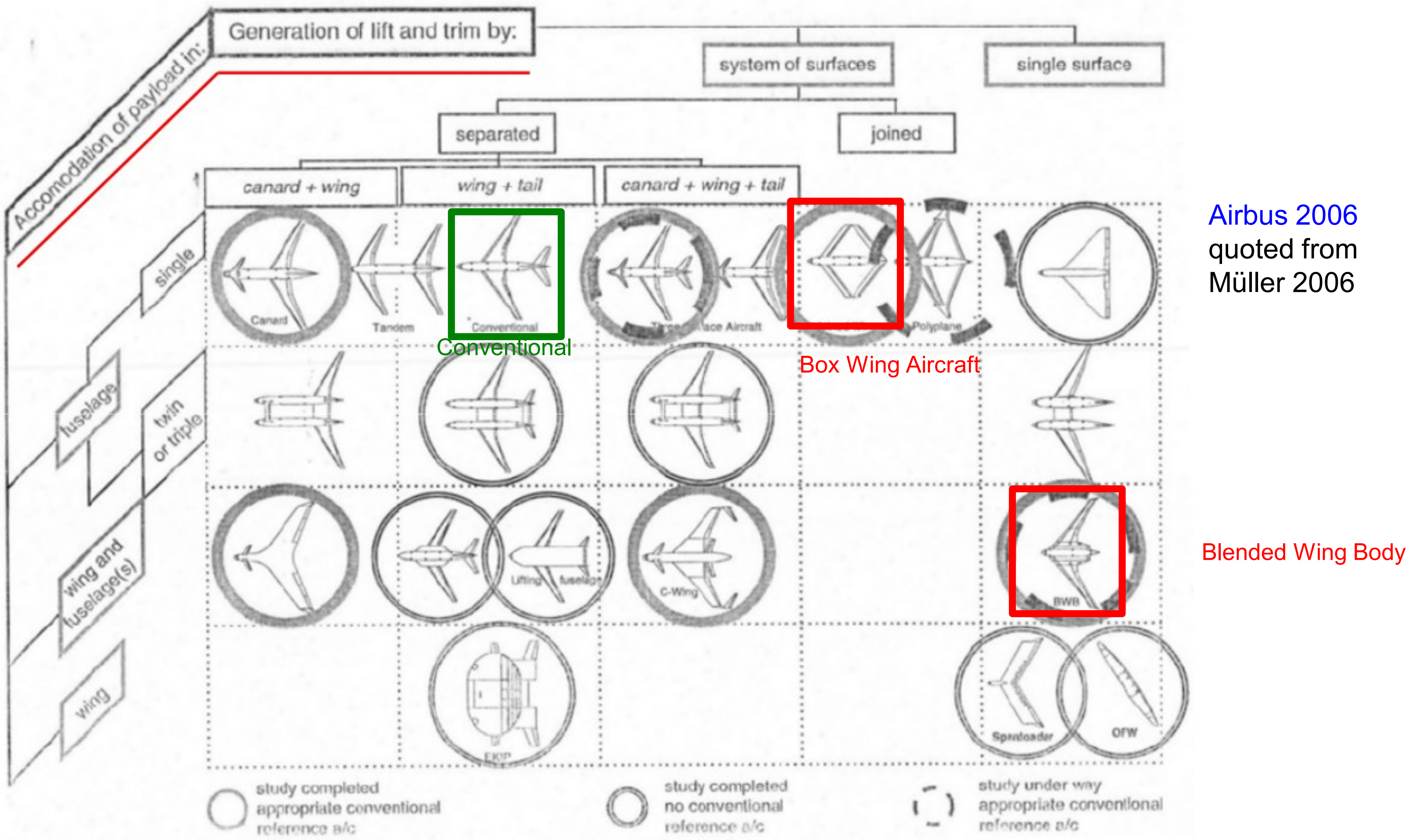


http://LectureNotes.AircraftDesign.org

Biplane, Antonov An2
https://en.wikipedia.org/wiki/Antonov_An-2



Aircraft Design Systematic 21st Century



Airbus 2006 quoted from Müller 2006

Aircraft Design – Search for an Efficient Configuration

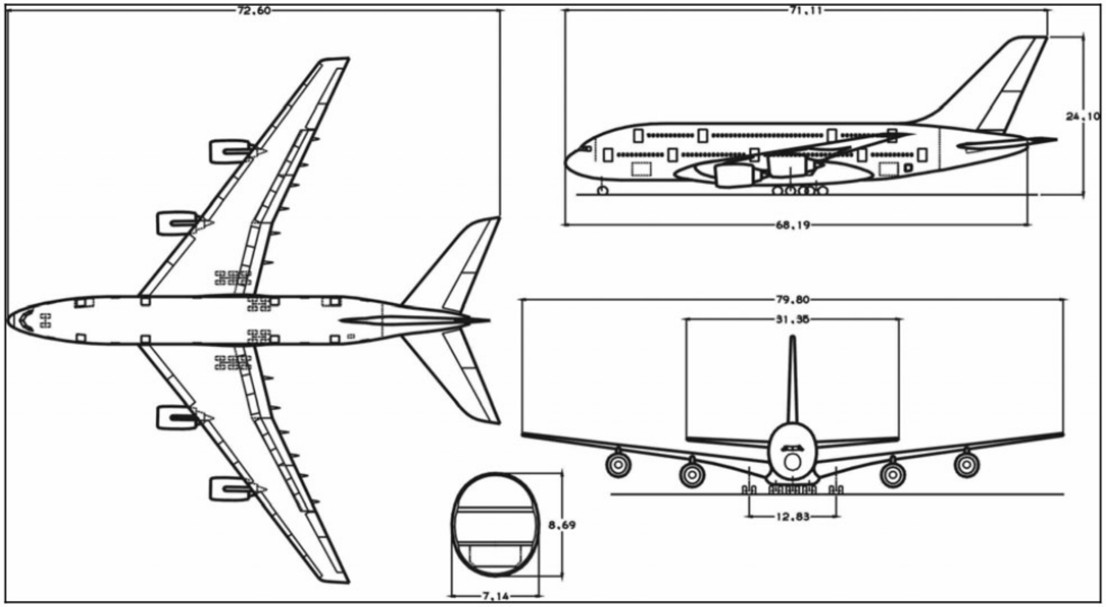
Aircraft Design – Search for an Efficient Configuration

Conventional Aircraft

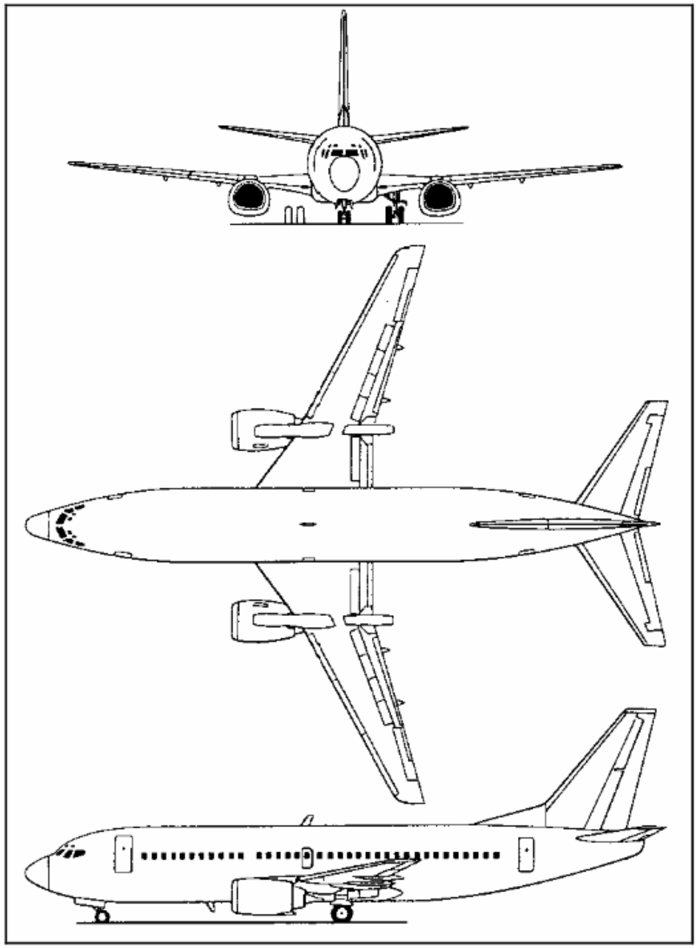
Conventional aircraft configurations are **symmetric** and have **one fuselage**, **one pair of wings** and an **empennage at their rear** end.

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

http://LectureNotes.AircraftDesign.org



Airbus A380



Boeing 737

Aircraft Design – 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

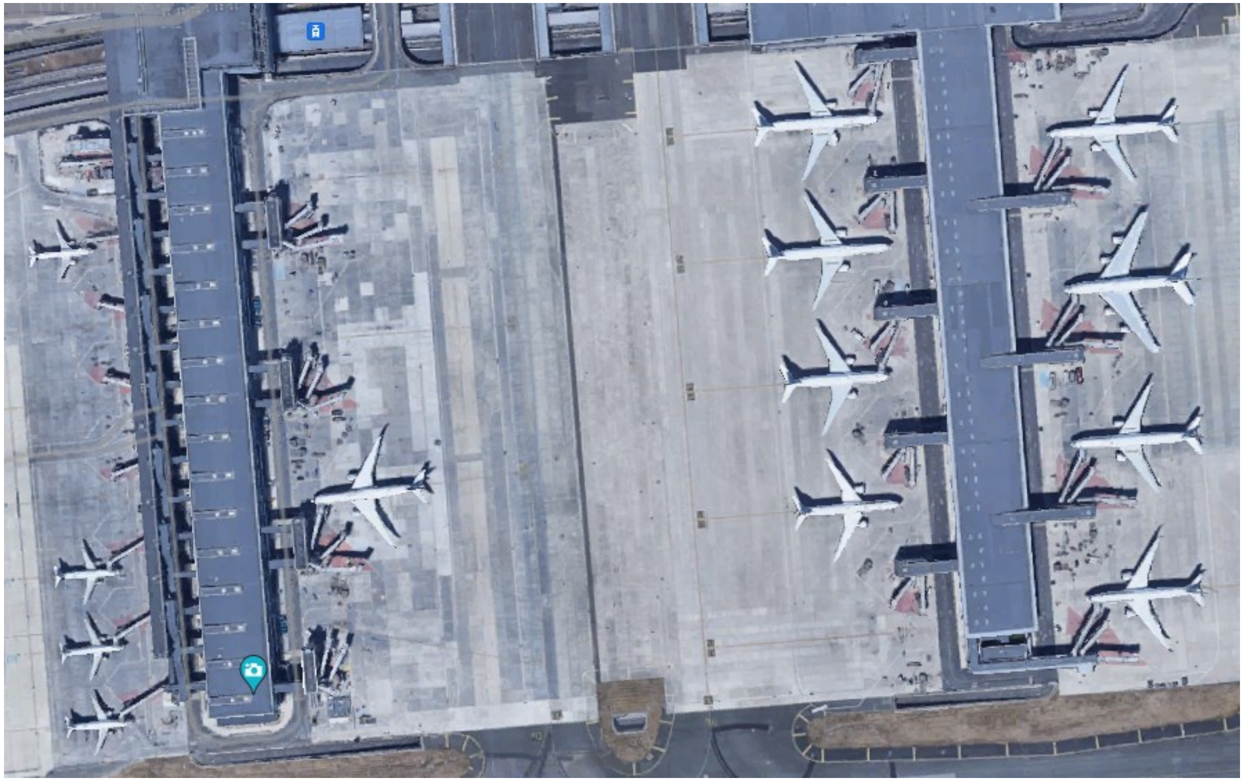
https://de.wikipedia.org/wiki/Eta_(Flugzeug)

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

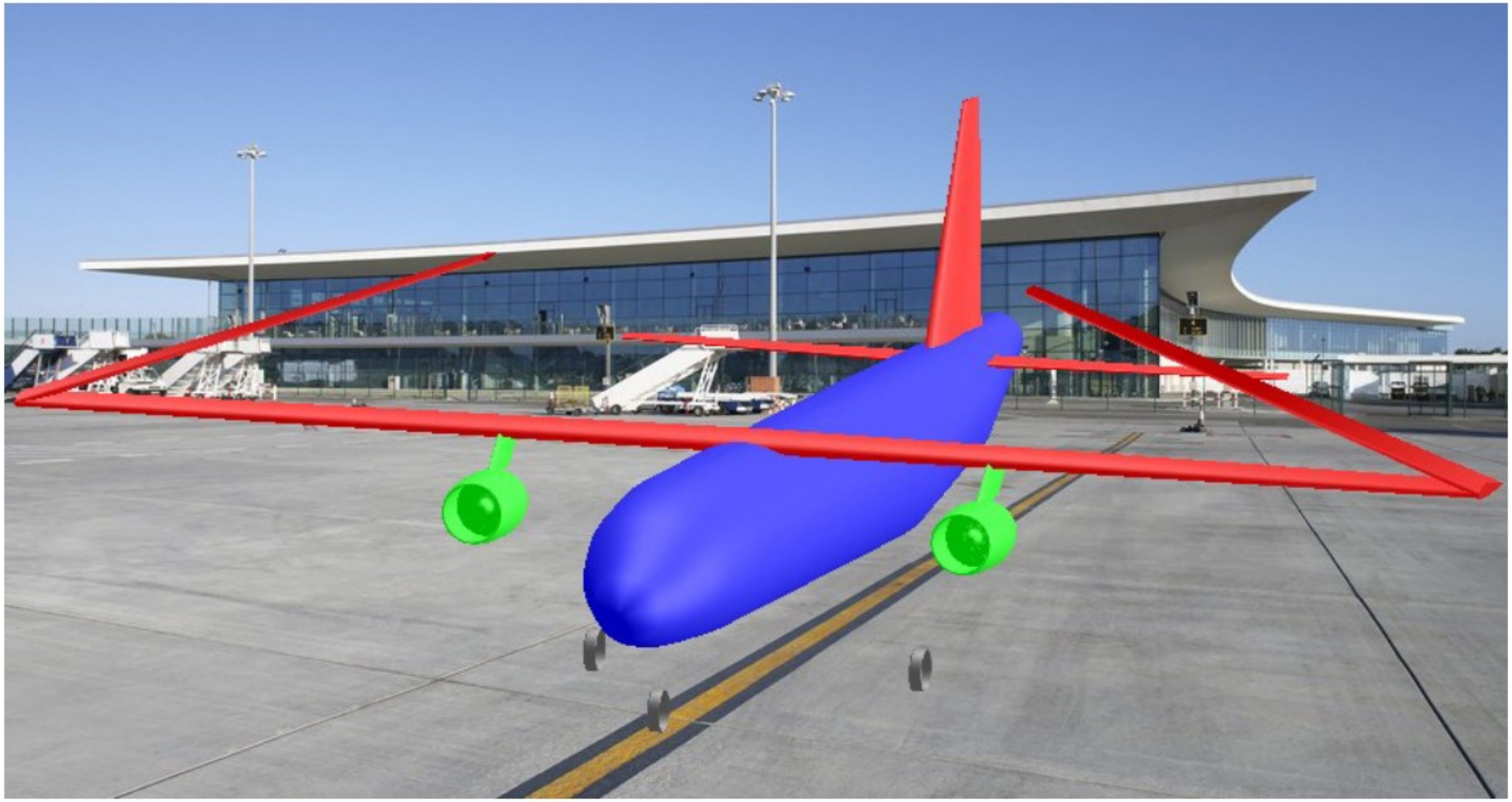
https://skybrary.aero/articles/icao-aerodrome-reference-code

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)

Folding Wings at Airports

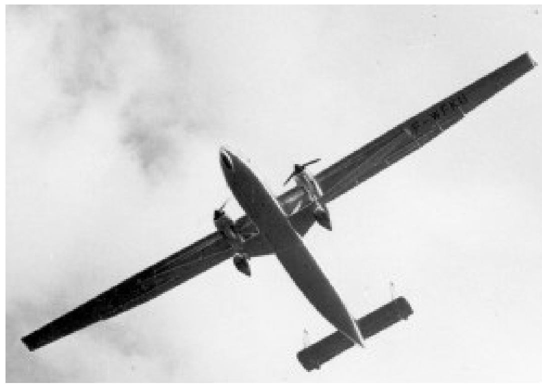


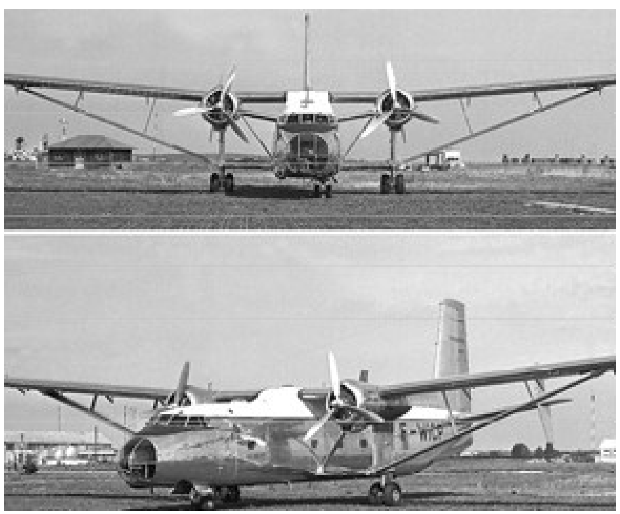
Impression of an aircraft with folding wings (Scholz)

Aircraft Design – Search for an Efficient Configuration

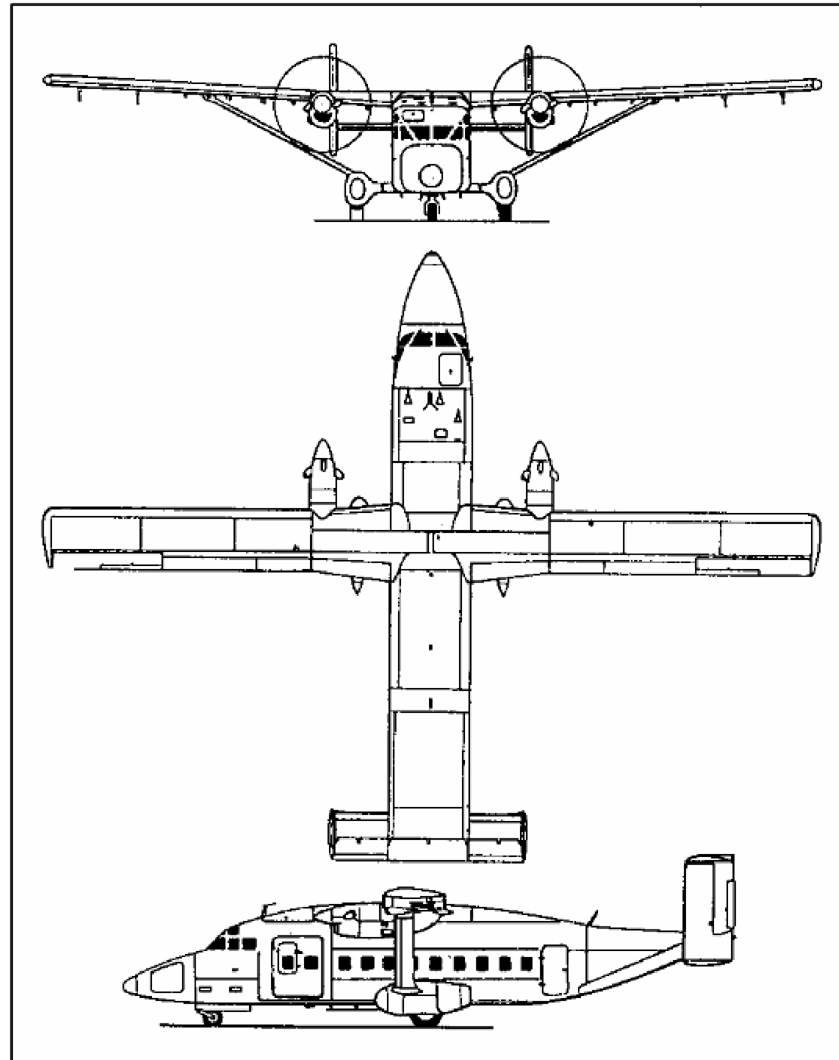
Conventional Aircraft
High Aspect Ratio, Braced Wing

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

Conventional Aircraft High Aspect Ratio, Braced Wing: Boeing Proposal

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

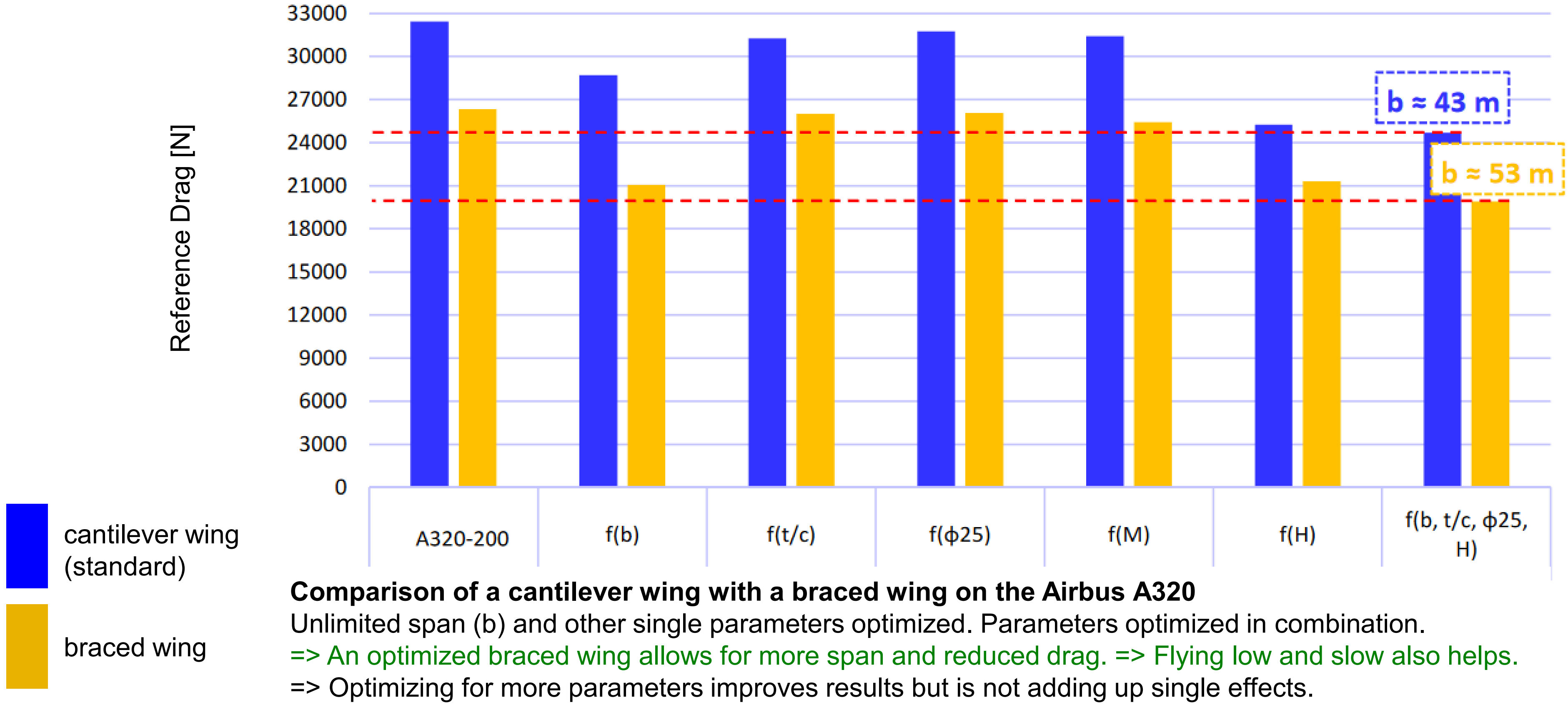
The wing brace keeps wing mass low.

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.

Mahfouz 2024

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.

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

Turboprop Aircraft for 180 Passengers with Engines of the A400M ?

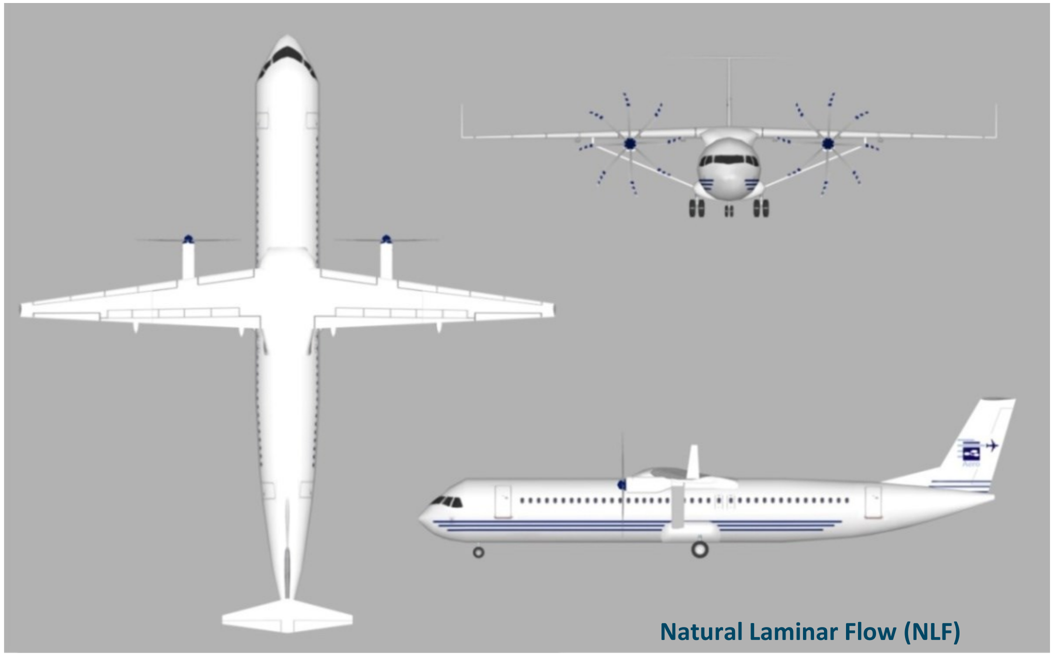
	m_MTO	M_CR	P_eq	Pax
A320	78 t	0,76	xxx	180
A400M	141 t	0,70	4 x 8250 kW	xxx
ATR 72	23 t	0,46	2 x 1950 kW	72
Q400	29 t	0,60	2 x 3780 kW	78
Smart TP	56 t	0,51	2 x 5000 kW	180

"Smart Turboprop": The design on the next pages!

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

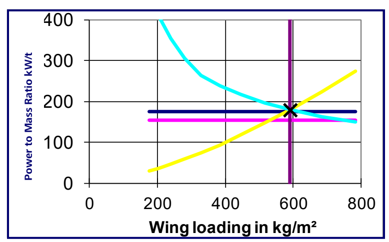
http://Airport2030.ProfScholz.de

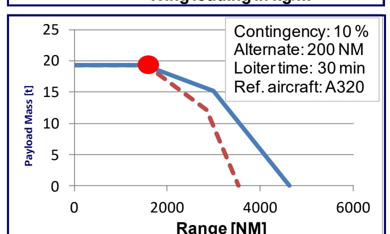
"Smart Turboprop": Flying Slow and Low: Low Emission Flight!



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 %

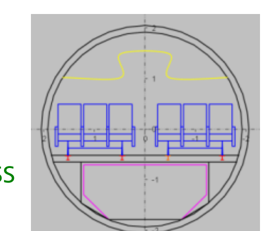
Parameter	Value	Deviation from A320*
Requirements		
m_{MPL}	19256 kg	0 %
R_{MPL}	1510 NM	0 %
M_{CR}	0.51	- 33 %
max(s_{TOFL} , s_{LFL})	1770 m	0 %
n_{PAX} (1-cl HD)	180	0 %
m_{PAX}	93 kg	0 %
SP	29 in	0 %





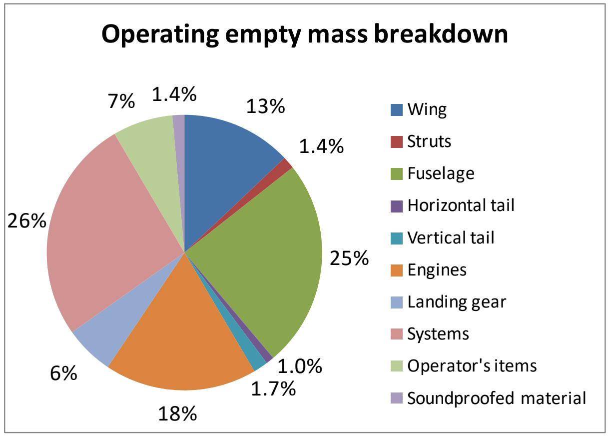
36 % less fuel consumption (and CO2).

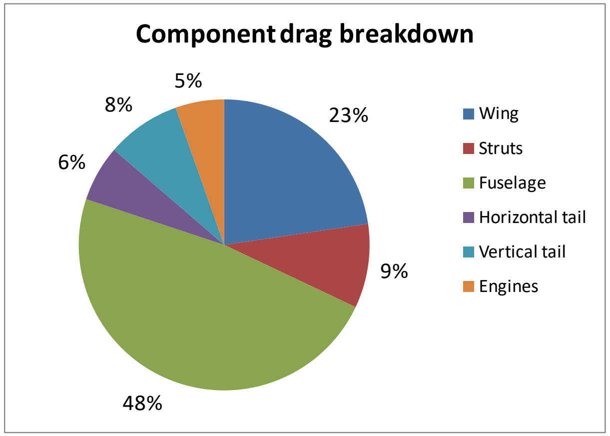
Cruise altitude 23000 ft: low Aviation Induced Cloudiness (AIC). Low warming potential.

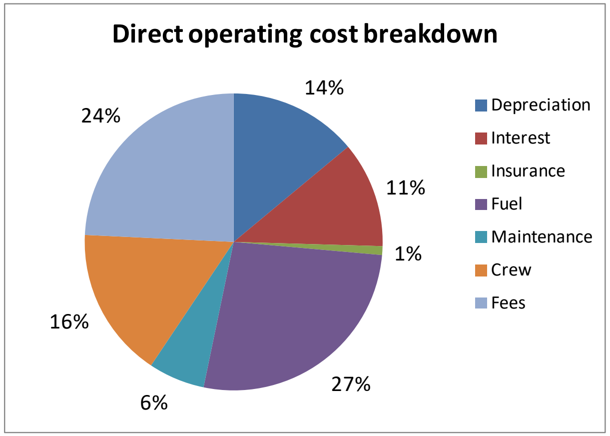


"Smart Turboprop": 17% Less Direct Operating Costs, DOC !

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 %



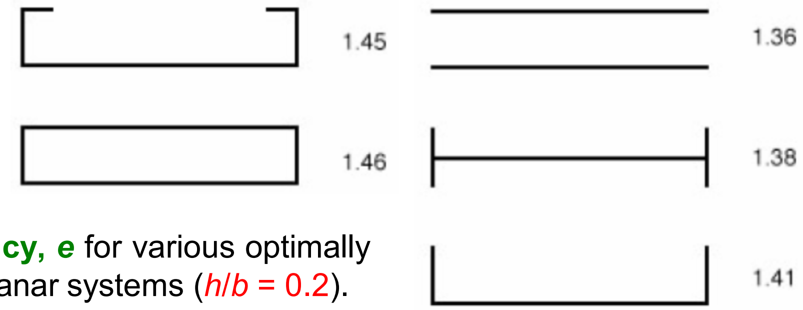




Box Wing Aircraft (BWA)

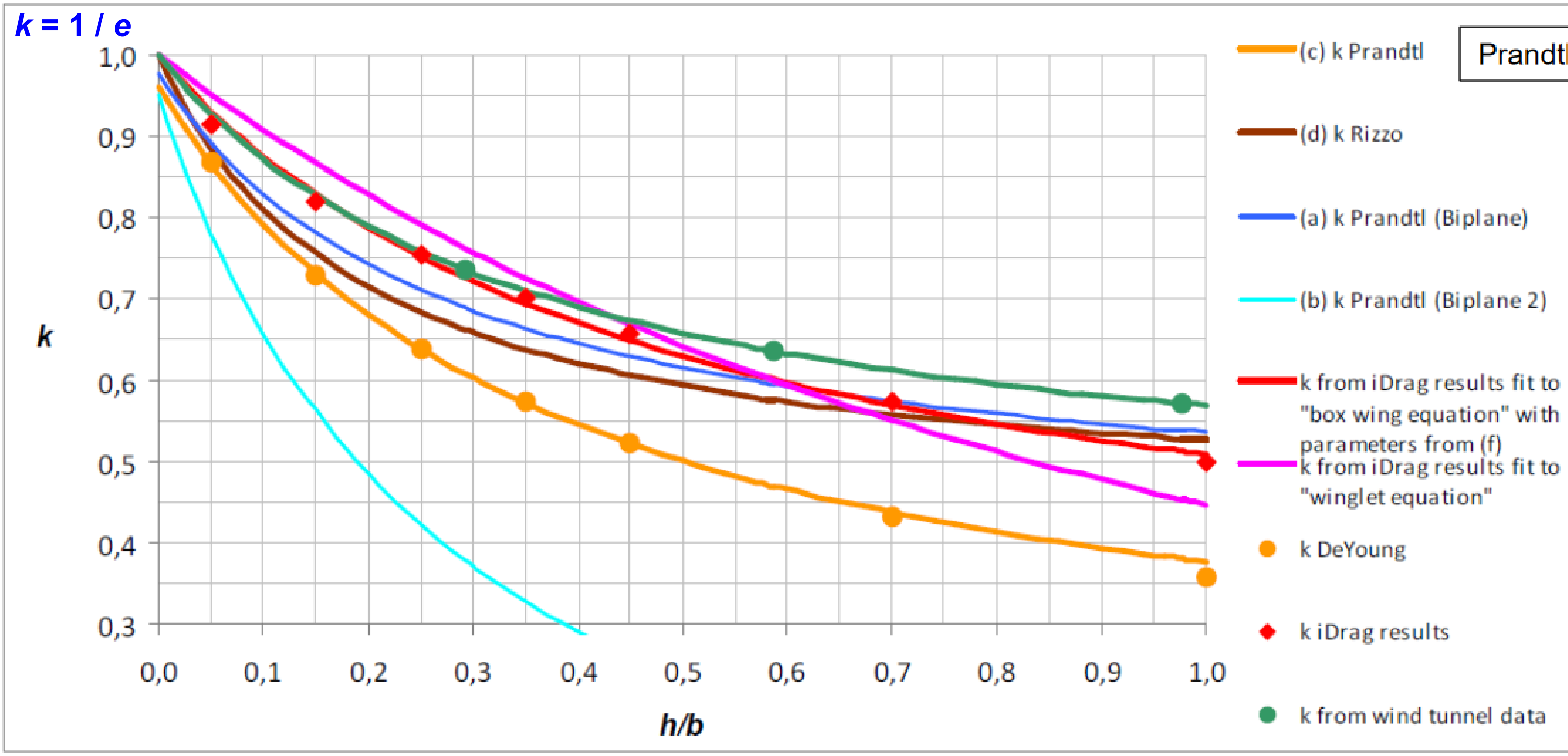
Aircraft Design – Search for an Efficient Configuration

From Winglets via Biplane to Box Wing Aircraft (BWA)



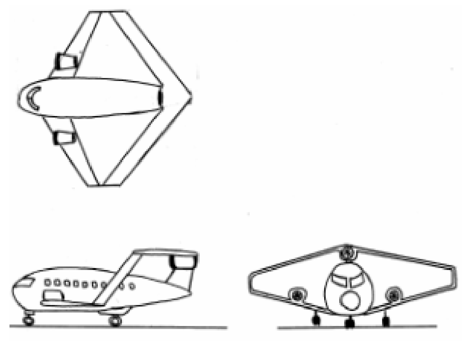
BWA reduce induced drag (due to lift)

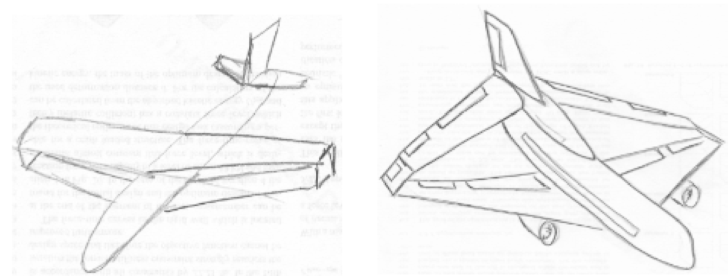
Span efficiency, *e* for various optimally loaded non-planar systems (h/b = 0.2).



Box Wing Aircraft (BWA): Genesis

- Hand Sketches





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

- Creative Methods
  - Brainstorming
  - Gallery Method

- 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

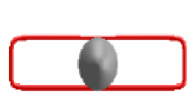
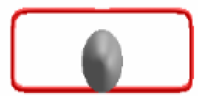
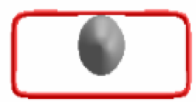
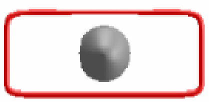
Number of Combinations: 3 · 3 · 2 · 3 · 1 · 3 = 162

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

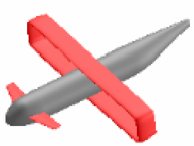
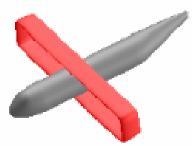
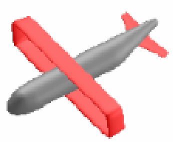
Modified Morphological Analysis:
Successive combination (in „best“ order) followed by immediate down selection => 18

Box Wing Aircraft

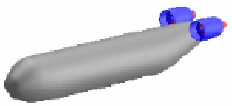
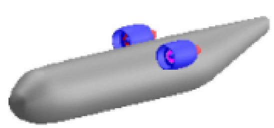
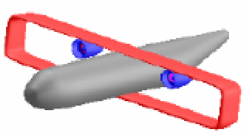
Box wing with different wing vertical position

	Low – High Position	Low – Super High Position	Super Low – High Position	Super Low – Super High Position
OpenVSP front view figure				

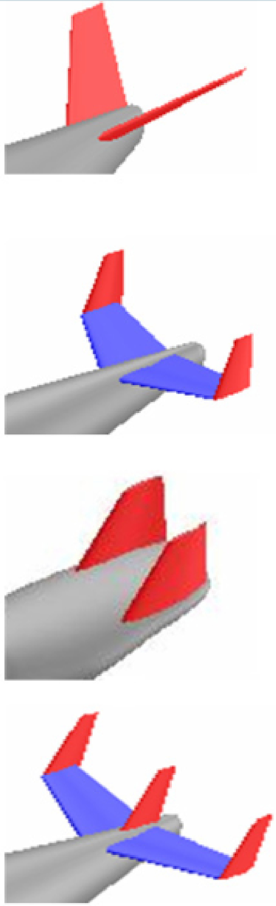
Horizontal tail surface position along the fuselage length

	Canard	No Horizontal tail	Horizontal surface
OpenVSP 3-D figure			

Engine positions for box wing aircraft

	Fuselage Aft	Fuselage Middle	On the wing
OpenVSP 3-D figure			

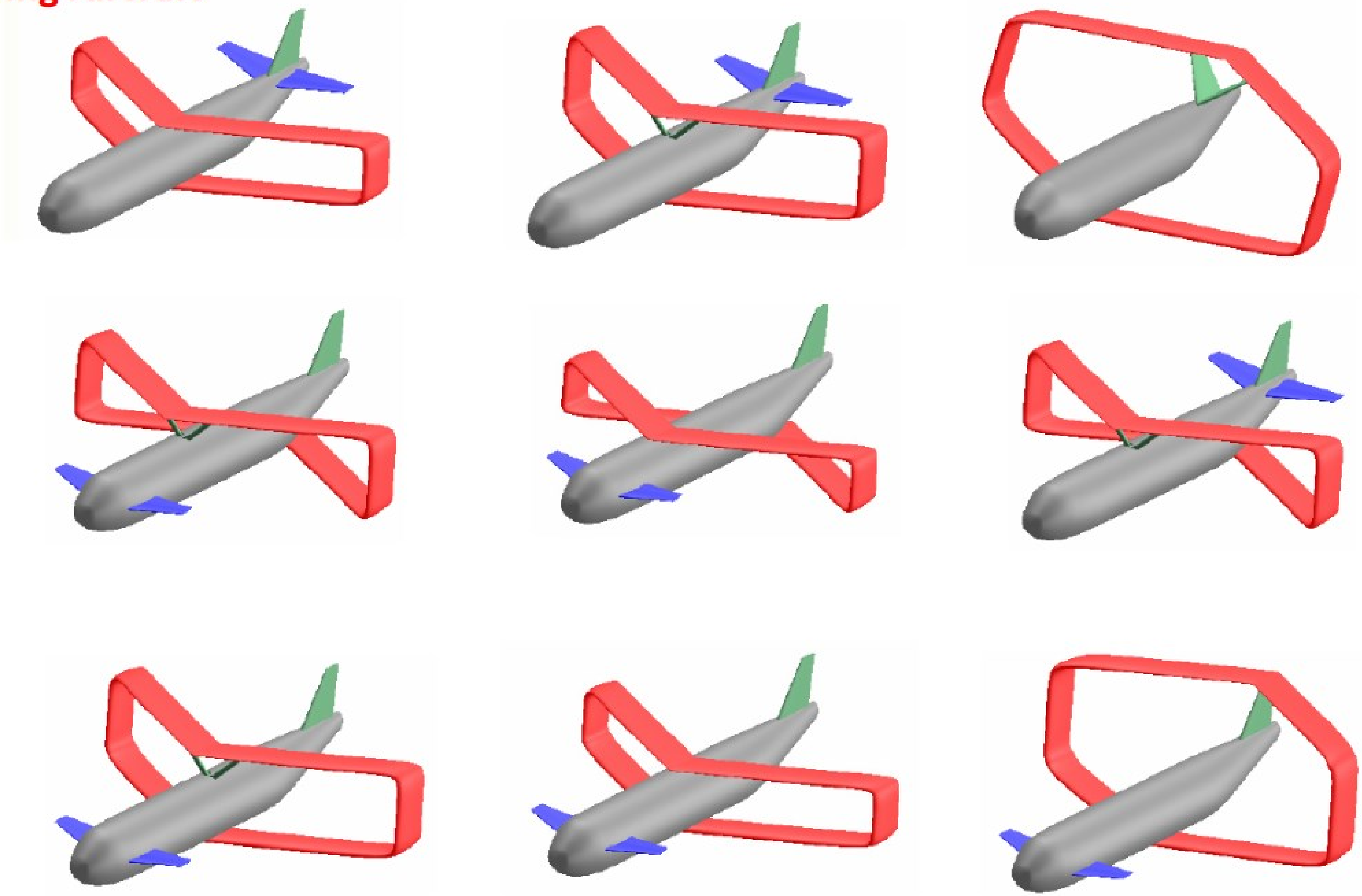
Example of possible vertical tails



All possible variations together would lead to 31 104 000 combinations (from Bachelor thesis)

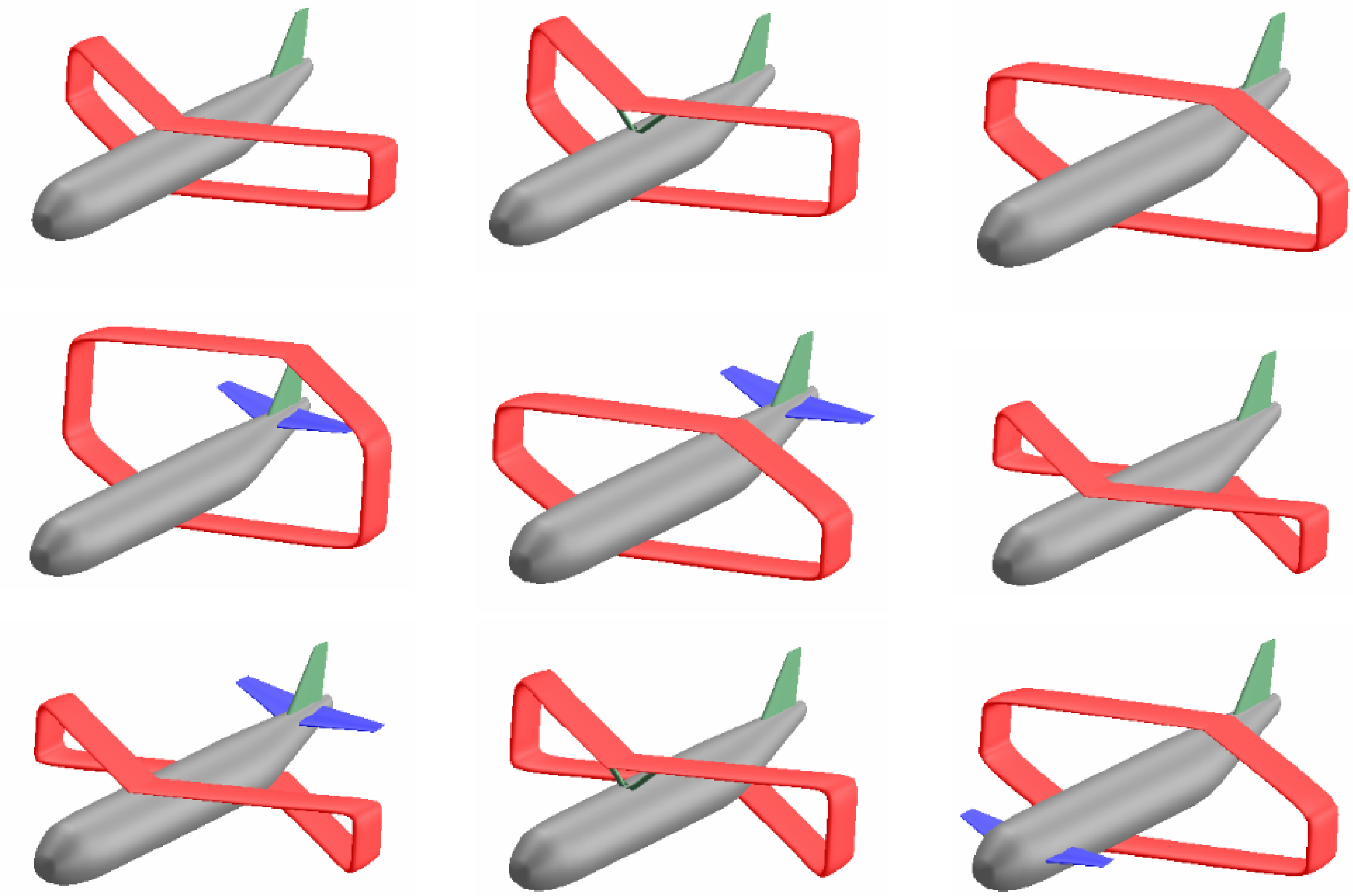
Box Wing Aircraft

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.

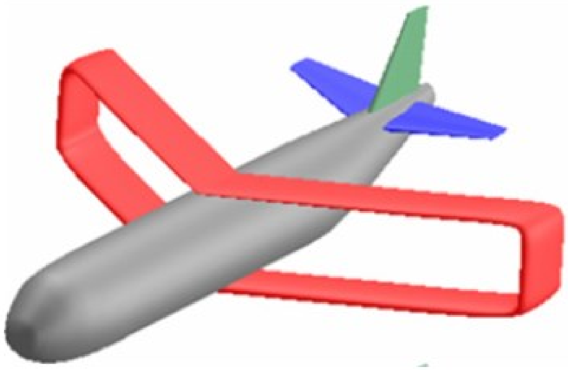


Box Wing Aircraft: General Morphological Analysis: Results

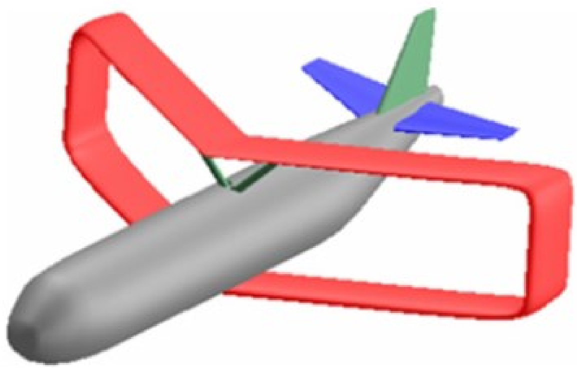
Multi-Criteria Decision Analysis (MCDA): The best known and simplest method is ...

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

1.

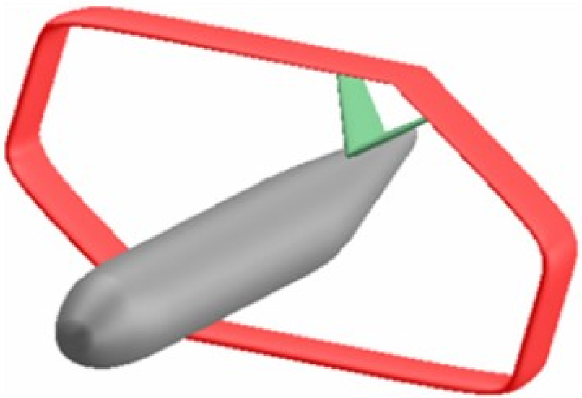


2.



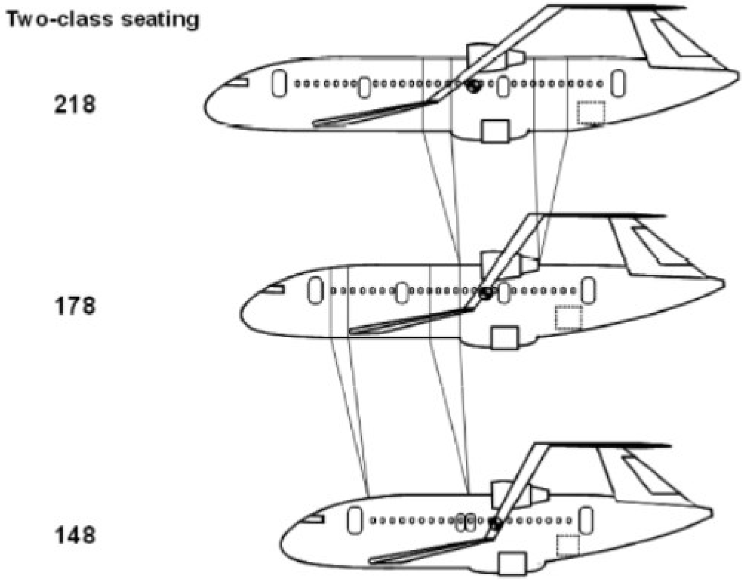
Configuration 1 and 3 were calculated in detail and built as a model.

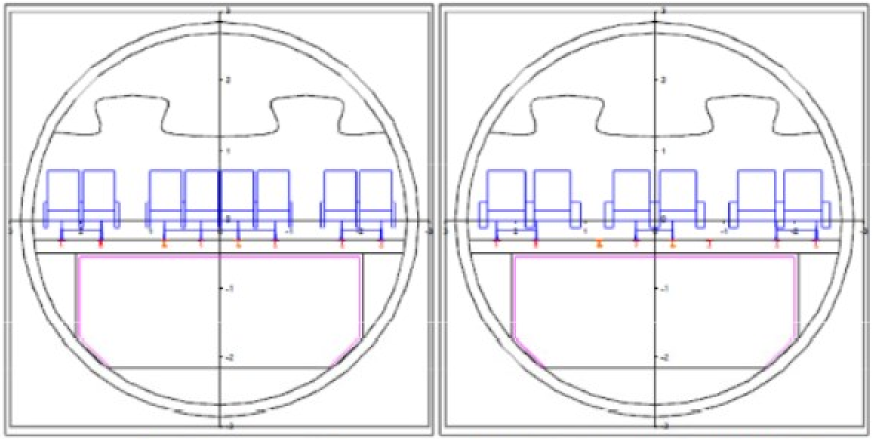
3.



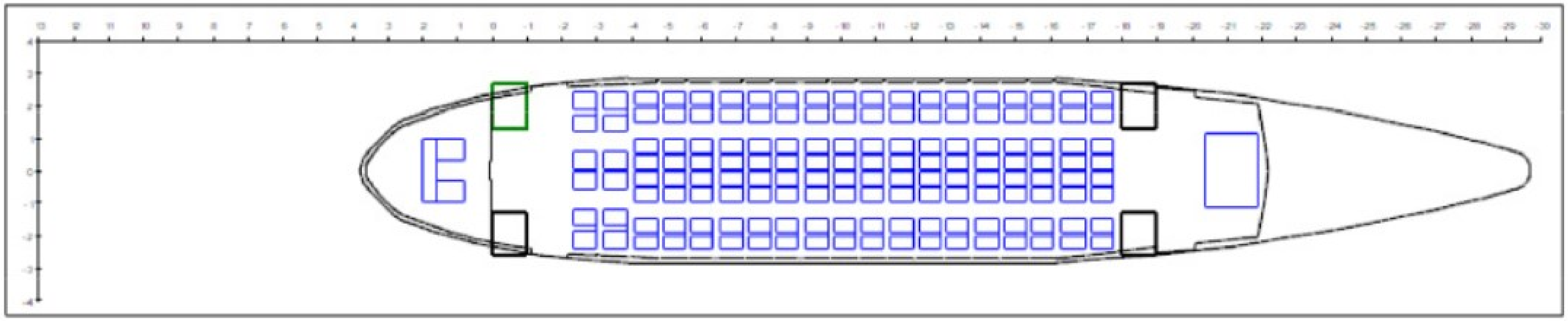
Configuration 3 was the best configuration without tail.

Box Wing Aircraft (BWA): Family Concept





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



Aircraft Design – Search for an Efficient Configuration

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

BWA (tail aft)
better, but: not recommended

STP
good

BWA (diamond wing)
not recommended

Aircraft Design – 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.

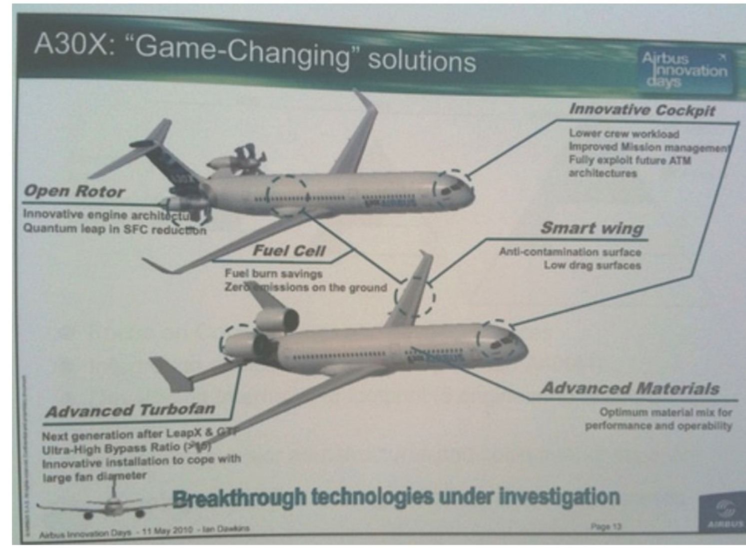
This is based on a twin-engined aircraft with a high wing braced by struts, and a T-tail configuration featuring technologies including laminar flow.

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

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)

Aircraft Design – Search for an Efficient Configuration

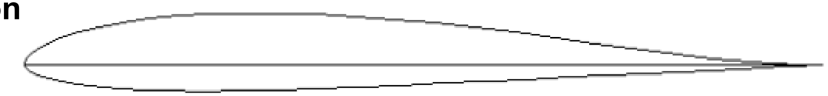
Blended Wing Body (BWB)

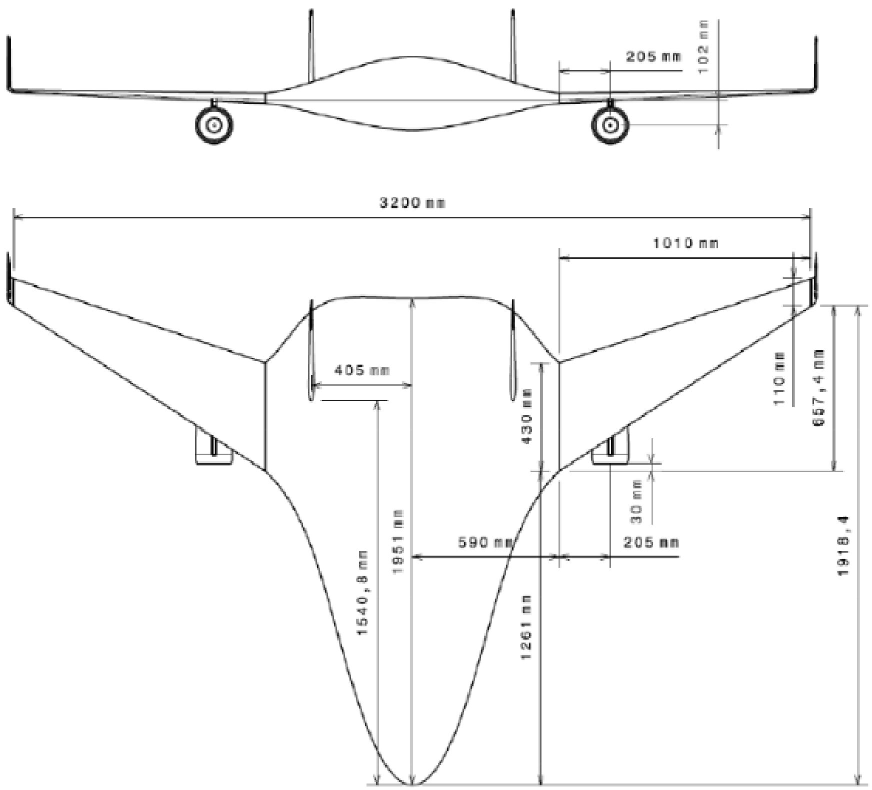
1) Conventional Configuration: "Tube and Wing" or "Tail Aft" (Drachenflugzeug)
2) Blended Wing Body (BWB)
3) Hybrid Flying Wing
4) Flying Wing

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.

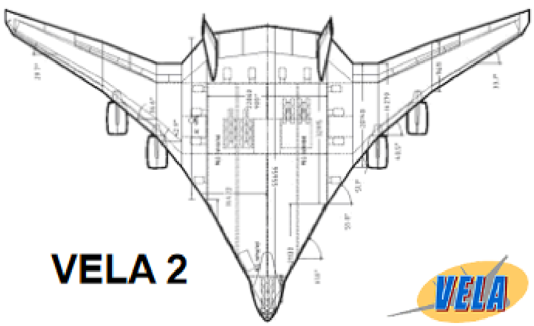
https://doi.org/10.48441/4427.442

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

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

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

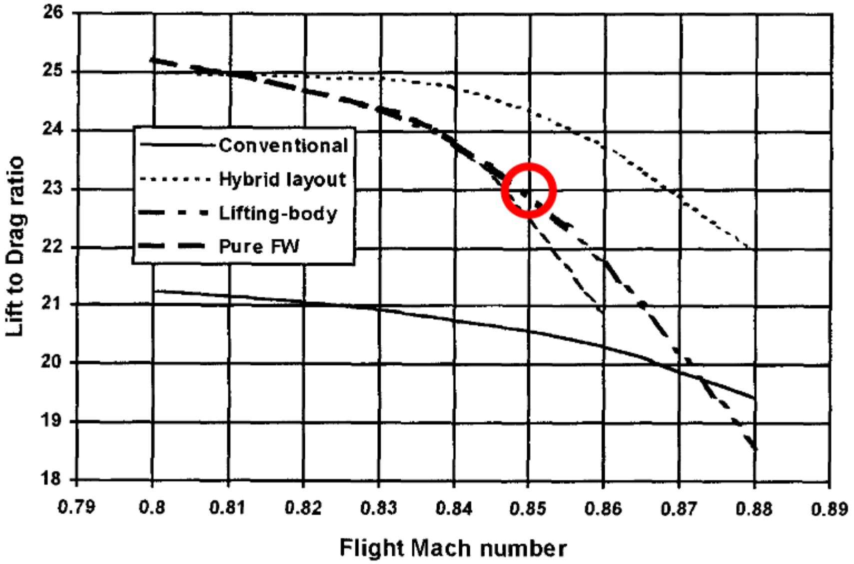
$$k_E = \frac{1}{2}\sqrt{\frac{\pi \, e}{\overline{c_f}}} = 14.9 \qquad \overline{c_f} = 0.003$$

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

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

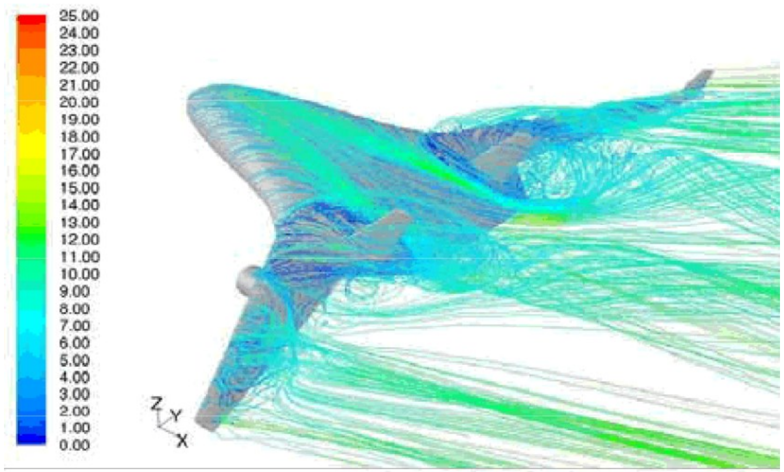


TsAGI for Airbus

Aircraft Design – Search for an Efficient Configuration

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

CFD: Stall (high angle of attack)



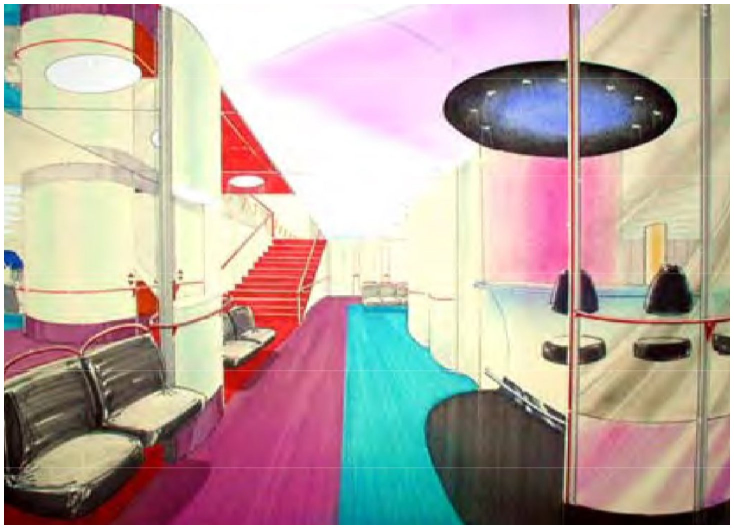
Path Lines Colored by Velocity Magnitude (m/s) 22° Anstellwinkel

Wind tunnel,Dresden

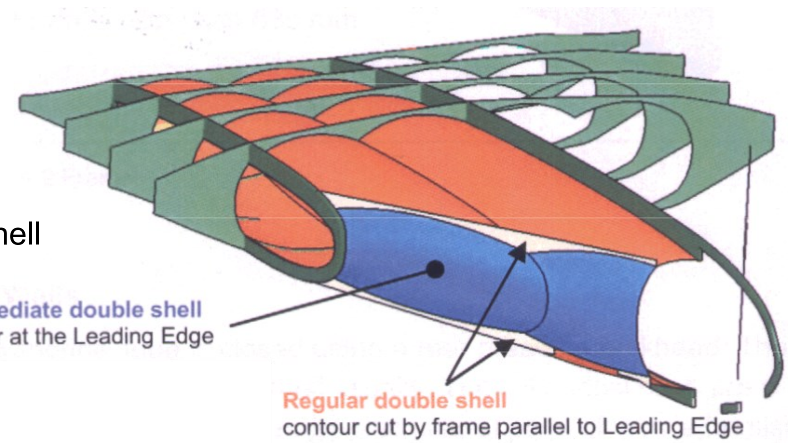
Flight testing

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

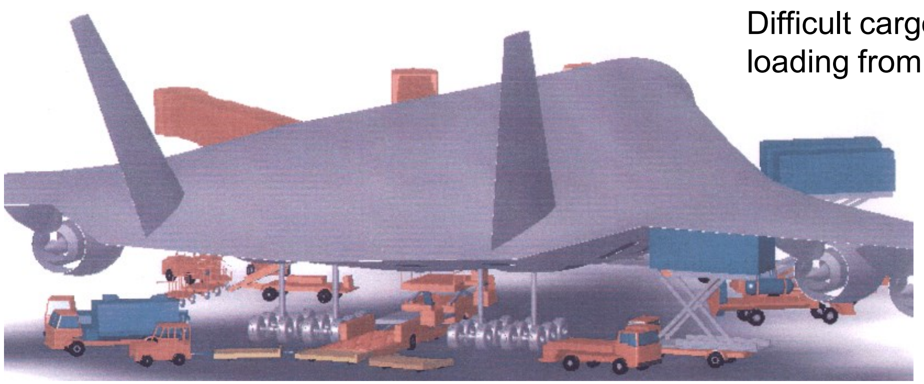
Much space for (heavy) luxury. Who can pay for it?



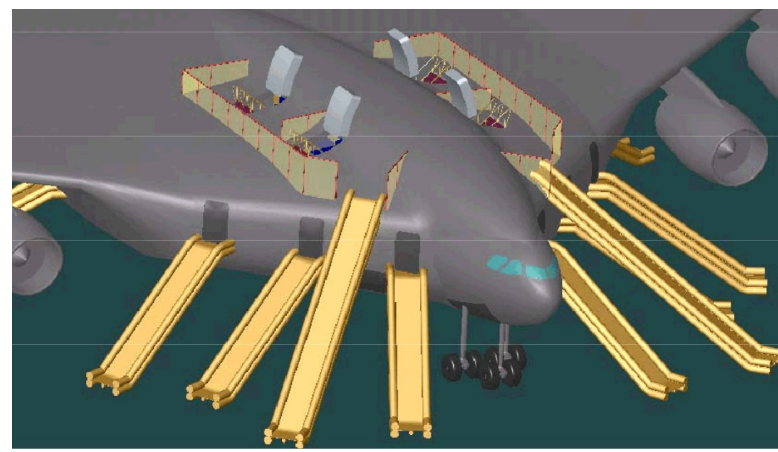
Heavy double shell



Difficult cargo loading from below



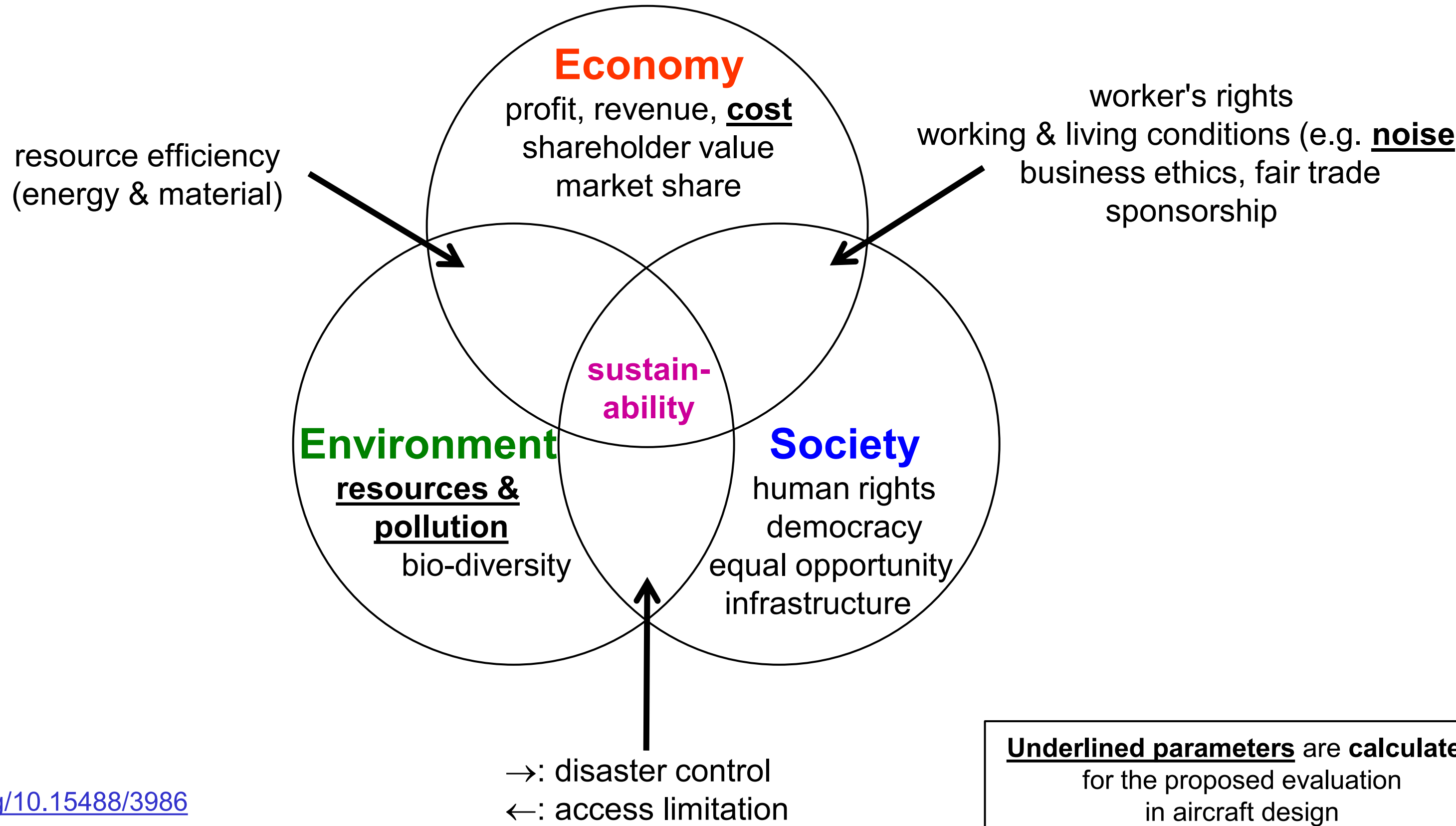
"Show Stopper": Evacuation after ditching (in water)



Evaluation in Aircraft Design

Evaluation in Aircraft Design

The 3 Dimensions of Sustainability



https://doi.org/10.15488/3986

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

Sustainability Venn Diagram

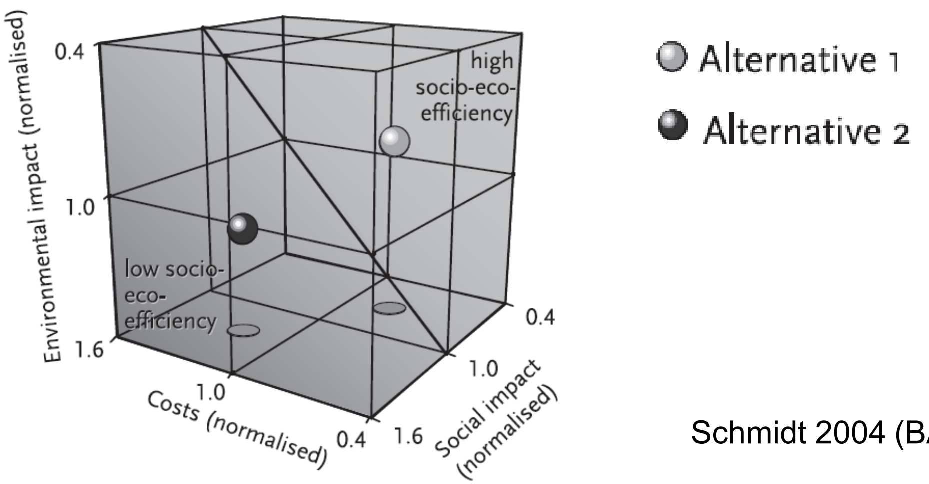
Evaluation: Purpose

- 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)

Evaluation in Aircraft Design

Scholz 2015

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:

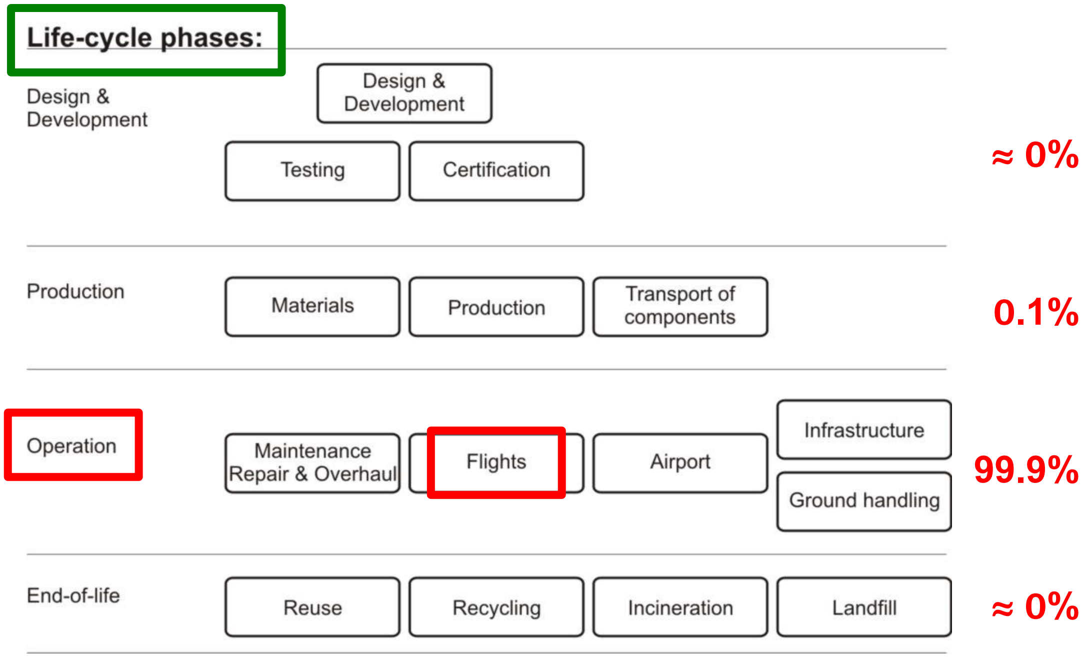
$$C_{s,m} = \frac{C_{a/c,t}}{n_{pax}\, R} \text{ or } \frac{C_{a/c,a}}{n_s\, n_{t,a}\, R}$$

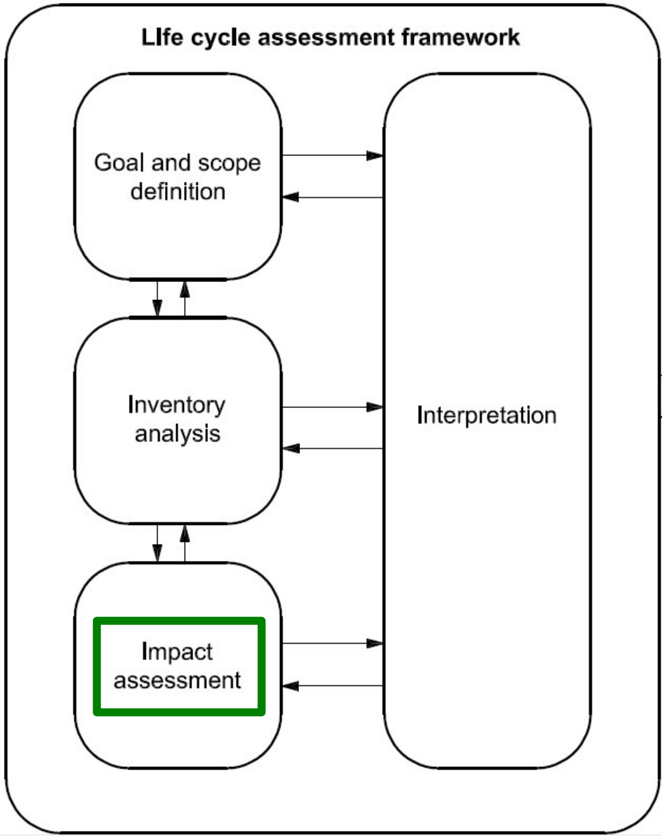
Utilization, annual, flight time: $U_{a,f} = t_f \dfrac{k_{U1}}{t_f + k_{U2}}$

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

Life Cycle Assessment (LCA) Applied to Aviation

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

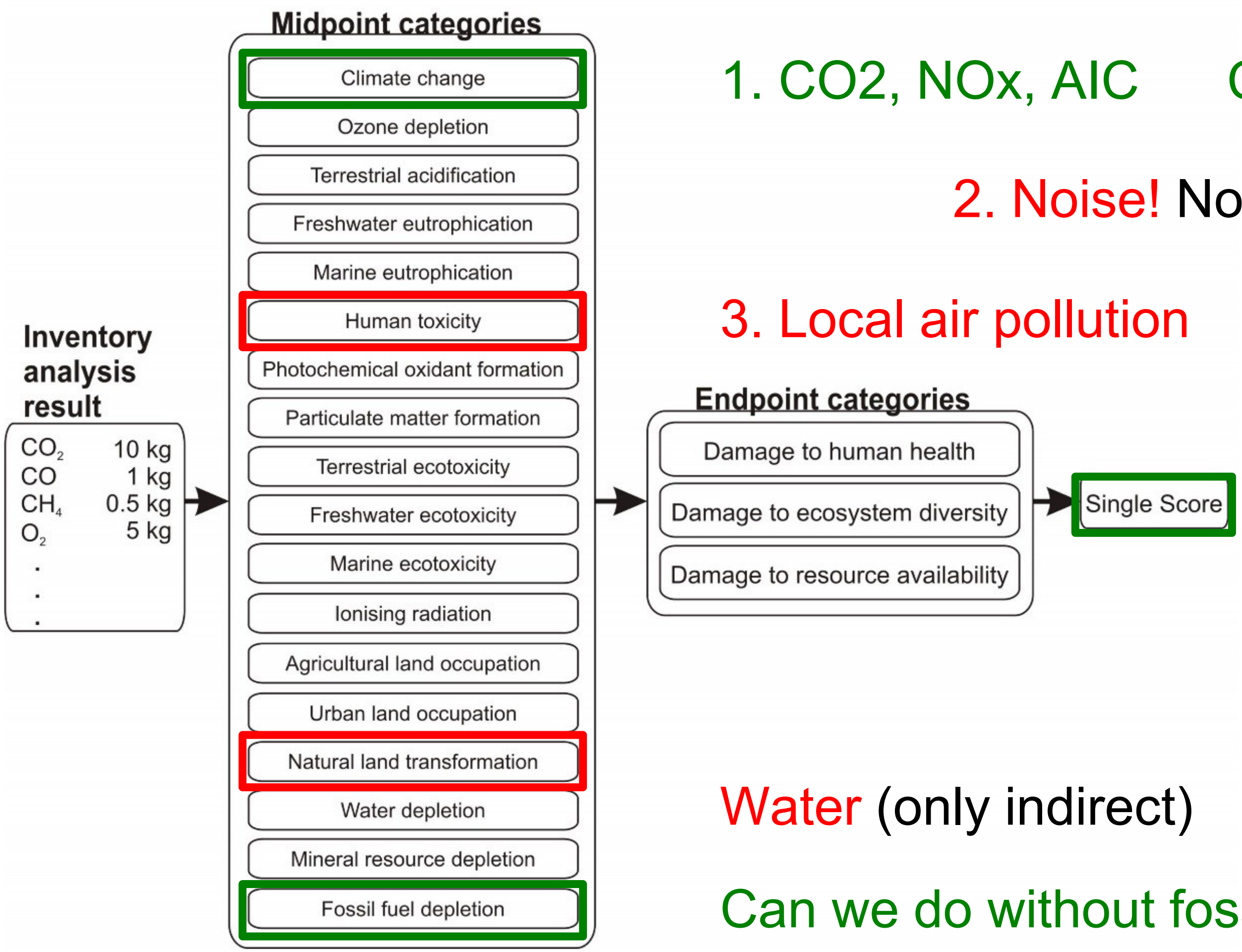




Standardized according to ISO 14040, ISO 14044

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



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

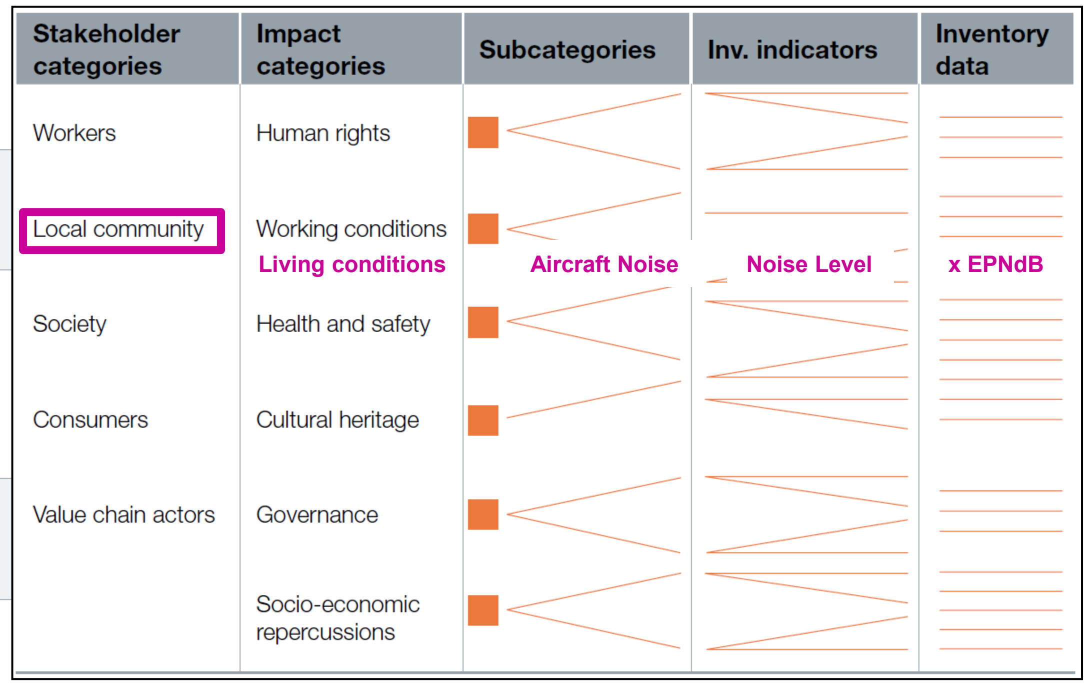
Evaluation in Aircraft Design

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)

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 <u>one of many</u> possible indicators in an S-LCA



Multiple-Criteria Decision Analysis (MCDA)

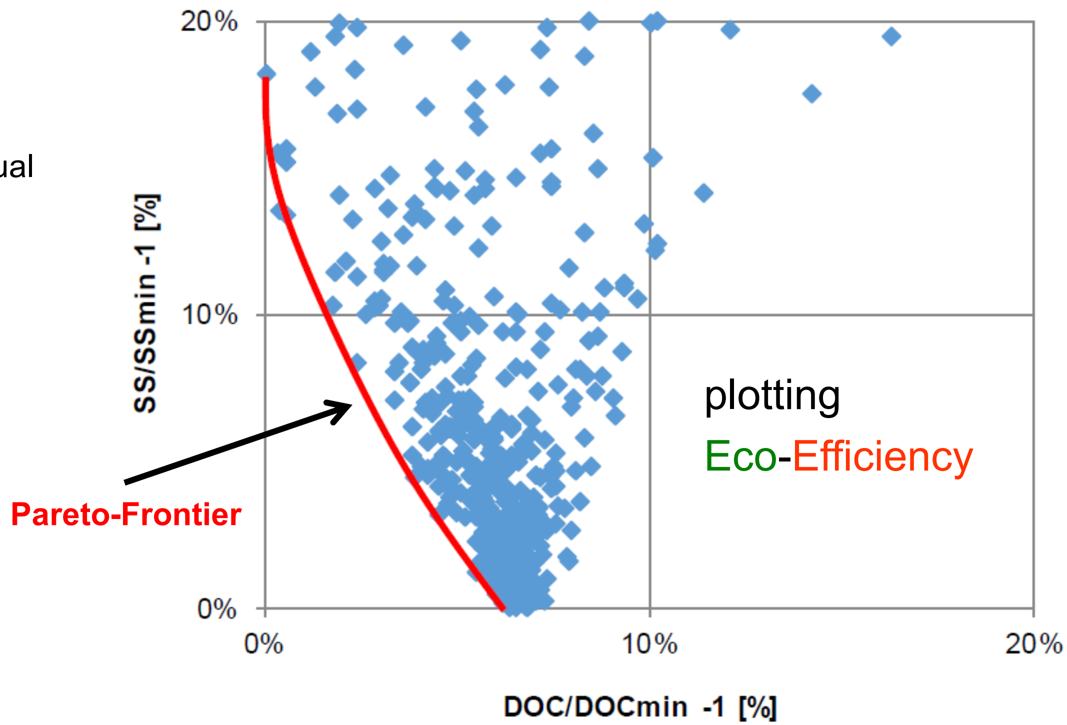
- **Many techniques** exist => Literature
- **Weighted Sums Analysis**: $SS_{total} = k_{DOC}\ DOC + k_{SS,LCA}\ SS_{LCA} + k_{SS,S-LCA}\ SS_{S-LCA}$
- **Pareto-Optimum**:

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 are show from **two variables only**.

Here **three plots** could be used to overcome the limitations:

- $DOC - SS_{LCA}$
- $DOC - SS_{S-LCA}$
- $SS_{LCA} - SS_{S-LCA}$



Johanning 2017

How to Fly with Electric Energy?

Direct Use of Electric Energy

From Electric Energy to Approximate Emission Comparison

Type of Comparison	Kerosene	Electricity / Battery
Energy (wrong)	$E = m_F \; H_L$	$E = E_{bat} / \eta_{charge}$
Max. Exergy (not good)	$B_{max} = \eta_C \; H_L \; m_F$	$B_{max} = E$
Exergy (ok)	$B = \eta_{GT} \; H_L \; m_F$	$B = \eta_{EM} \; E$
Primary Energy (better)	$E_{prim} = 1.1 \, H_L \; m_F$	$E_{prim} = k_{PEF} \; E$
CO2 (without altitude effect)	$m_{CO2} = 3.15 \cdot 1.1 \, m_F$	$m_{CO2} = 3.15 \, x_{ff} \; E_{prim} / H_L$
Equivalent CO2 (good, simple)	$m_{CO2,eq} = m_{CO2} (k_{RFI} + 0.1)$	$m_{CO2,eq} = m_{CO2}$

$H_L = 43$ MJ/kg $\quad \eta_{charge} = 0.9$

Carnot Efficiency:

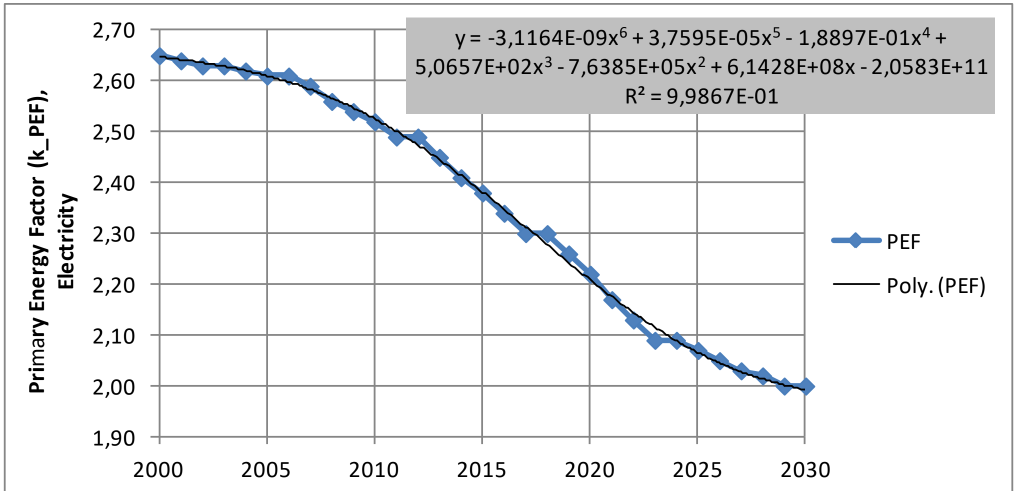
$\eta_C = 1 - T/(h) / T_{TET} =$

$= 1 - 216.65 / 1440 = 0.85$

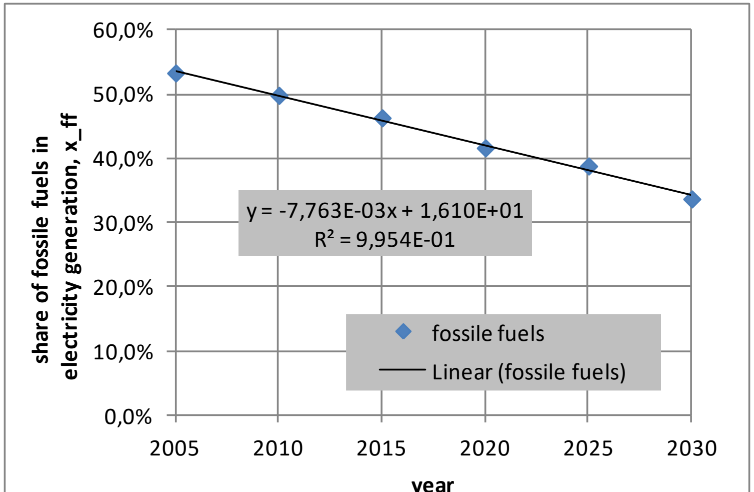
$\eta_{GT} = 0.35 \quad \eta_{EM} = 0.9$

Radiative Forcing Index:

$k_{RFI} = 2.7 \quad (1.9 \ldots 4.7)$



ESSER 2016, Table 73



ESSER 2016, Table 15

ESSER, Anke, SENSFUSS, Frank, 2016. *Evaluation of Primary Energy Factor Calculation Options for Electricity*. Karlsruhe: Fraunhofer-Institut für System- und Innovationsforschung (ISI). Available from: https://ec.europa.eu/energy/sites/ener/files/documents/final_report_pef_eed.pdf
Archived at: https://perma.cc/WMY7-QER4

How to Fly with Electric Energy?

Grid-Connected

- **Aircraft**: Induced drag is drag due to lift = weight.
- **Train**: Rolling friction is caused by weight.
- Aircraft: For minimum drag: Induced drag is 50% of total resistance.
- For the same weight: Rolling friction from the train is 5% of the induced drag of the aircraft!
- This means: For the same weight: **Drag of the aircraft is reduced by 47.5%, on rails!**

How to Fly with Electric Energy?

Battery-Electric: Low Specific Energy

🔋 Battery Specific Energy (Typical Ranges):

Battery Type	Specific Energy (Wh/kg)	Specific Energy (MJ/kg)
Lead-acid	30–50 Wh/kg	0.11–0.18 MJ/kg
Nickel-Metal Hydride (NiMH)	60–120 Wh/kg	0.22–0.43 MJ/kg
Lithium-ion (Li-ion)	150–250 Wh/kg	0.54–0.90 MJ/kg
Solid-state (next-gen)	300–500 Wh/kg (goal)	1.08–1.80 MJ/kg

⚖️ Comparison:

- **Kerosene**: ~43 MJ/kg
- **Li-ion battery**: ~0.9 MJ/kg (at best)

So **kerosene has ~50× the specific energy** of lithium-ion batteries. That's a huge reason why electric **cars** are viable (you can carry heavy batteries), but **electric airplanes** are much more challenging — weight is critical in aviation.

How to Fly with Electric Energy?

Battery-Electric: Limited Range

$$e_{bat} = \frac{E_{bat}}{m_{bat}} \qquad L = W = m_{MTO}\, g \qquad E = \frac{L}{D} \qquad D = \frac{m_{MTO}\, g}{E}$$

$$P_D = D V = \frac{m_{MTO}\, g}{E} V = P_T = P_{bat}\, \eta_{prop}\, \eta_{elec} \qquad V = \frac{R}{t}$$

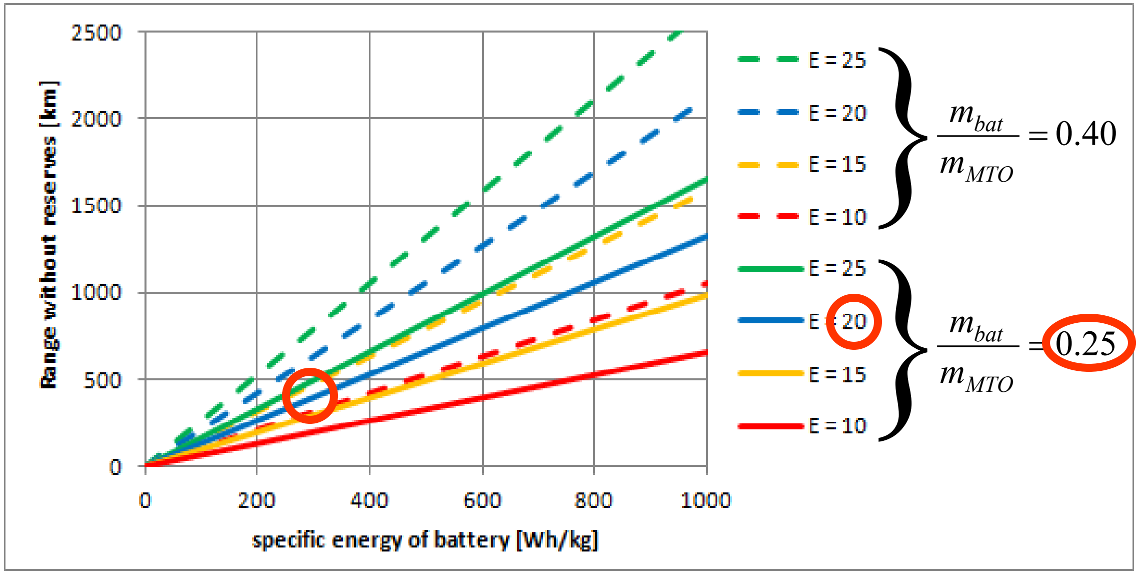
$$P_{bat} = \frac{E_{bat}}{t} = m_{bat}\, e_{bat} \frac{V}{R}$$

$$m_{bat}\, e_{bat} \frac{V}{R} \eta_{elec}\, \eta_{prop} = \frac{m_{MTO}\, g}{E} V$$

$$\boxed{R = \frac{m_{bat}}{m_{MTO}} \frac{1}{g} e_{bat}\, \eta_{elec}\, \eta_{prop}\, E}$$

$$\eta_{elec} = 0.9; \qquad \eta_{prop} = 0.8$$

e_{bat} : specific energy
E_{bat} : energy in battery
E : glide ratio (aerodynamic efficiency)
L : lift
D : drag
W : weight
V : flight speed
R : range
t : time
g : earth acceleration
P : power
η : efficiency (prop : propeller)



: realistic parameters

How to Fly with Electric Energy?

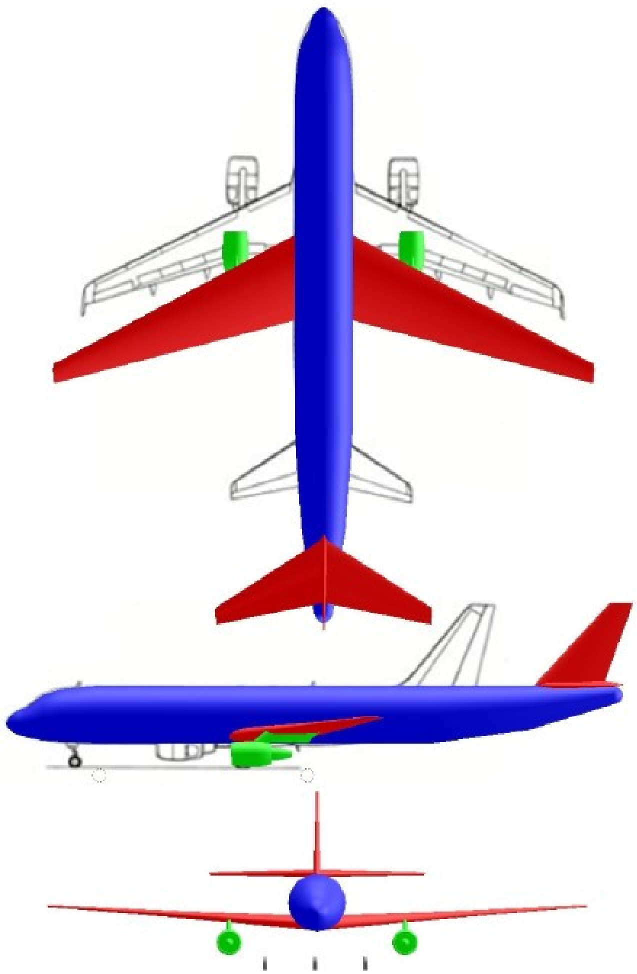
Battery-Electric Design

- Only design solution with Range reduced by 50%
  => not a fair trade-off <=

- Specific Energy: 1870 Wh/kg
- Energy density: 938 kWh/m³
- Batteries in LD3-45 container
- 2 container in cargo compartment
- 13 container forward and aft of cabin
- Fuselage streched by 9 m to house batteries

- MTOW plus 38%
- Battery mass plus 79% (compared with fuel mass)
- On study mission (294 NM) environmental burden (SS) down by 45% (EU electrical power mix)

Parameter	Value	Deviation from A320
Requirements		
m_{MPL}	19256 kg	0%
R_{MPL}	755 NM	-50%
M_{CR}	0.76	0%
max(s_{TOFL} , s_{LFL})	1770 m	0%
n_{PAX} (1-cl HD)	180	0%
m_{PAX}	93 kg	0%
SP	29 in	0%
Main aircraft parameters		
m_{MTO}	95600 kg	30%
m_{OE}	54300 kg	32%
m_F	22100 kg	70%
S_W	159 m²	30%
$b_{W,geo}$	36.0 m	6%
$A_{W,eff}$	9.50	0%
E_{max}	18.20	≈ + 3%
T_TO	200 kN	38%
BPR	6.0	0%
h_{ICA}	41000 ft	4%
s_{TOFL}	1770 m	0%
s_{LFL}	1450 m	0%
Mission requirements		
R_{Mi}	294 NM	-50%
$m_{PL,Mi}$	13057 kg	0%
Results		
$m_{F,trip}$	7800 kg	72%
SS	0.0095	-45%



Eviation Aircraft: Alice All-Electric Business and Commuter Aircraft

won't meet spec

- One main pusher propeller at the tail and two pusher propellers at the wingtips to improve efficiency
- 9 passengers (plus 2 pilots) up to 650 sm (1000 km) at a cruise speed of 240 kt
- Li-Ion battery: 900 kWh
- MTOW: 6350 kg

(https://www.eviation.co/alice as of 2019)

- Battery mass is 65% of total aircraft mass (without payload)
- Specific energy of battery is 400 Wh/kg [much too high]

(https://www.eviation.co/alice as of 2017)

Sarsfield 2019

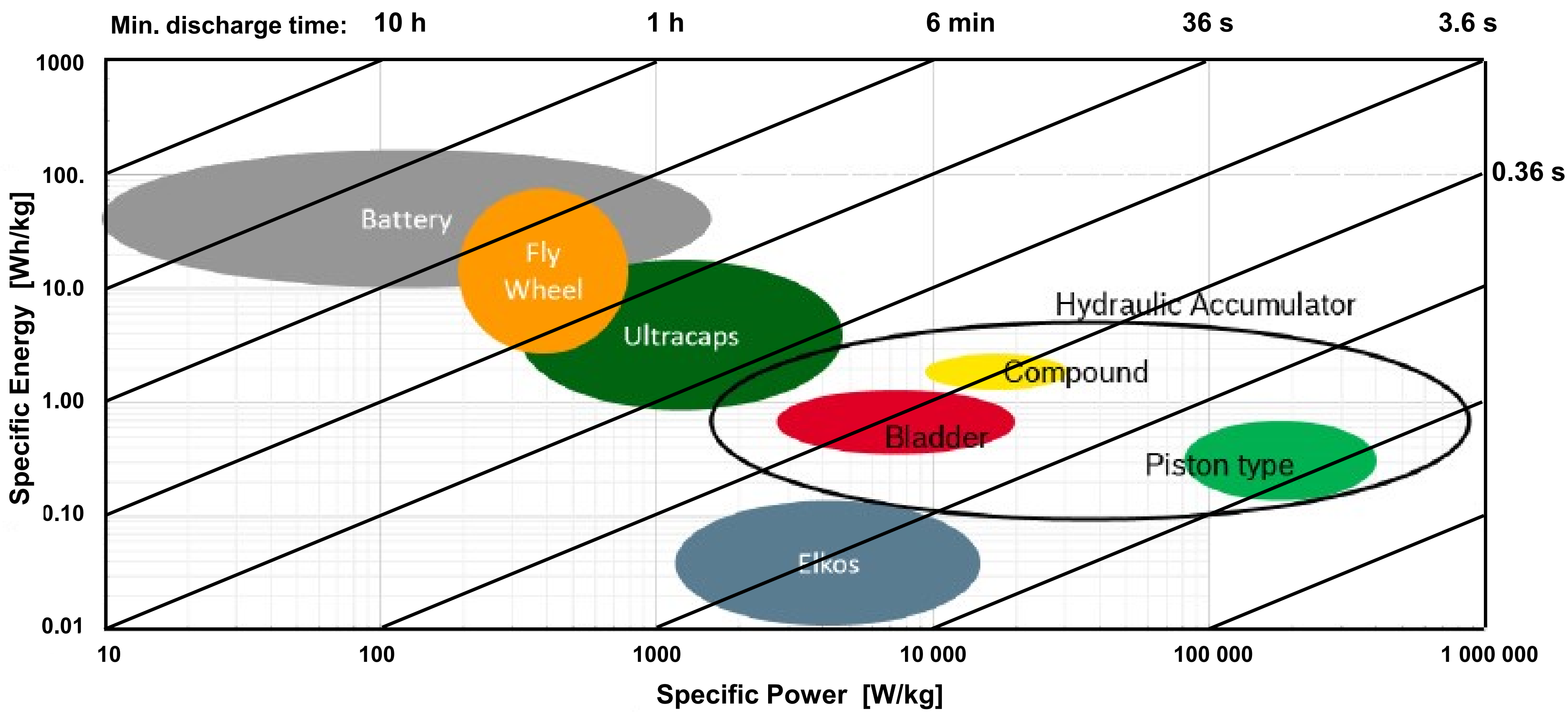
- Service entry is expected in 2022
- Maximum payload: 1250 kg (including pilots). This is only 13.7% of MTOW (low due to batteries).
- 183 kg cargo (with assumed 97 kg per person)
- Direct Operating Costs (DOC): 200 USD per flight hour with 11 person at 240 kt

(Hemmerdinger 2019)

Own calculations based on given data:

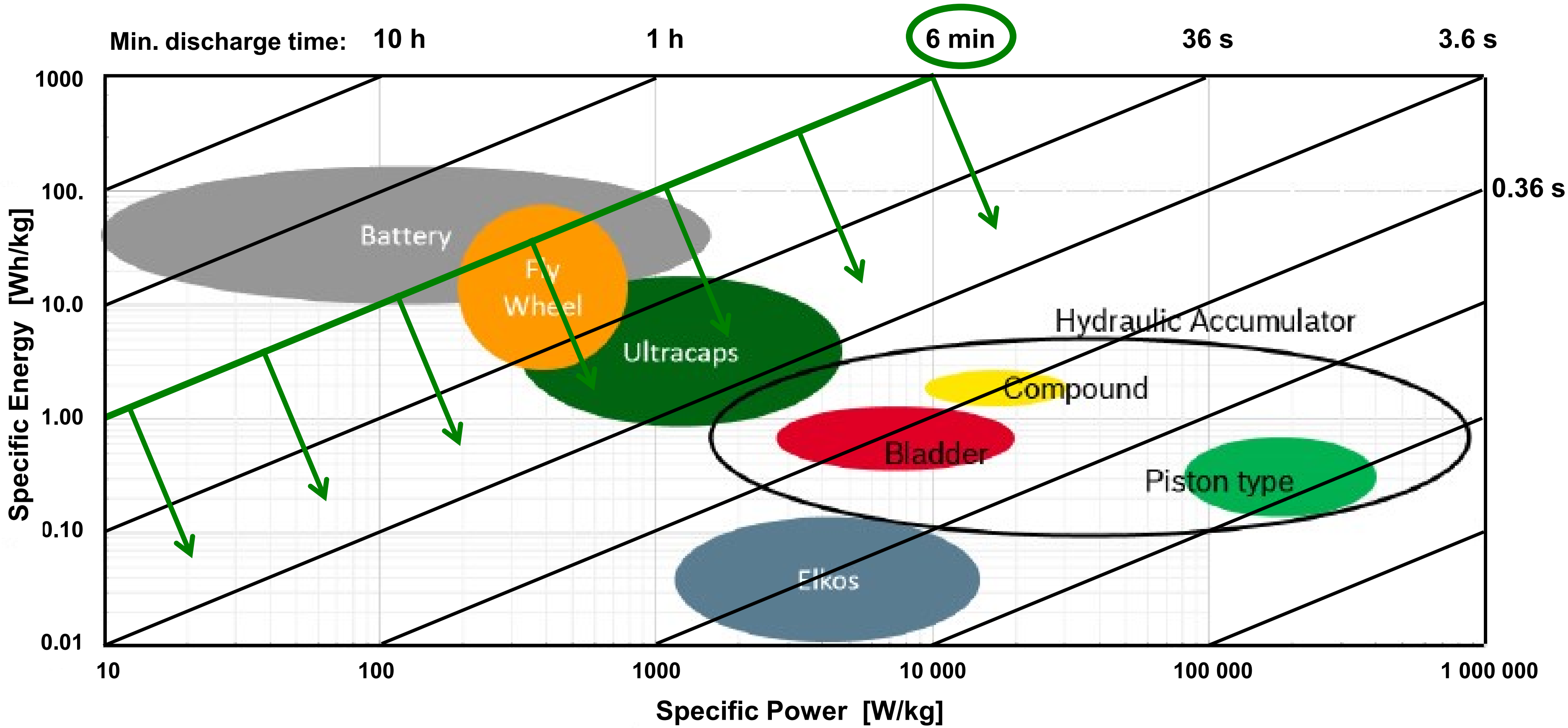
- OEW: 2043 kg
- battery mass: 3434 kg
- OEW/MTOW = 0.32 (too low)
- Specific energy of battery calc.: 285 Wh/kg (high)
- L/D in cruise: 17.5 (based on 400 Wh/kg)
- L/D in cruise: 24.5 (based on 285 Wh/kg) (too high)

Ragone Diagram for Energy Storage Devices (Energy versus Power)



based on Geerling 2017

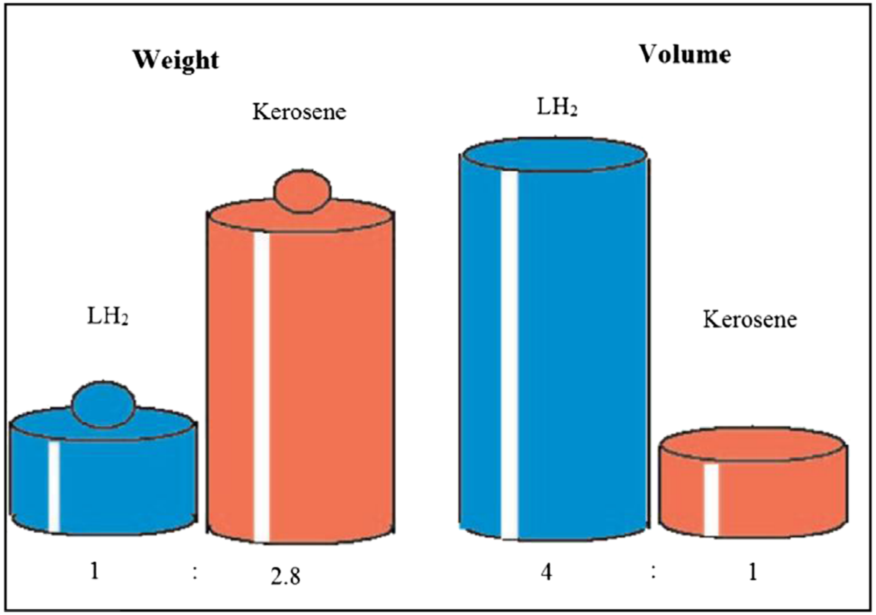
Save Jet Engine Mass with Parallel Electric Engine: Not with Battery!



Use of Electric Energy via Liquid Hydrogen (LH2)

Characteristics of Hydrogen – Important for Aircraft Design

- **LH2 comparison at equal energy (20 K = -253 °C):**



KHANDELWAL, 2013, http://doi.org/10.1016/j.paerosci.2012.12.002

- **Boil-off**
- **Hydrogen embrittlement** (Wasserstoffversprödung) **of materials**

EU-Study, May 2020

https://doi.org/10.2843/471510
Archived at: https://perma.cc/BJJ6-5L74

AIRBUS and many others

Emissions

Average values	CO_2	NO_x	Water vapor	Contrails	Total
Kerosene	100%	100%	10%	100%	**310%**
Synfuel	0%	100%	10%	75%	**185%**
H_2 turbine	0%	35%	25%	60%	**120%**
H_2 fuel cell	0%	0%	25%	30%	**55%**

≠ 0%

Energy / Primary Energy

Production well-to-tank %

Total efficiency %

LH_2 from electrolysis and lique-faction on site: 100 (Renewable energy) x 70 (Electrolysis) x 83 (Distribution & liquefaction) = 58

no PtL heat used for CO2 separation

Synfuel from direct air carbon capture: 100 (Renewable energy) x 70 (Electrolysis) x 32 (FT-Production) x 99 (Transport & distribution) = 22

energy factor compared to electricity and to electricity with k_{PEF} = 2

1.7
3.4

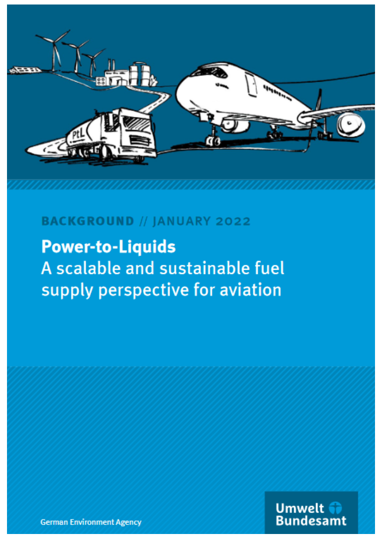
4.5
9.2

PtL: **2.6** times more than LH2!

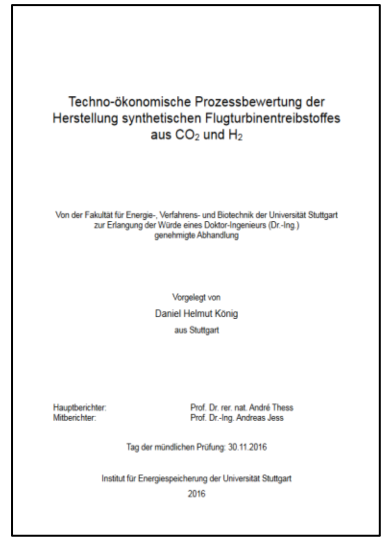
How to Fly with Electric Energy?

Primary Energy Needs: PtL (from DAC) versus LH2

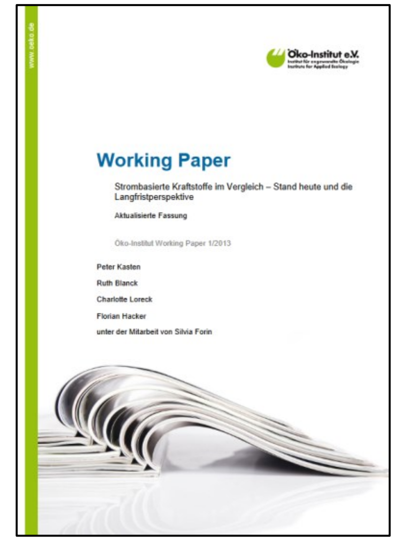
Schmidt 2023 (LBST)
https://perma.cc/CPN8-CH9H



Batteiger 2022 (UBA)
https://perma.cc/8VEN-Q9VG



König 2016 (Diss)
https://doi.org/10.18419/opus-9043



Kasten 2013 (Öko-Institut)
https://doi.org/10.18419/opus-9043

	Schmidt 2023	Batteiger 2022	König 2016	Kasten 2013
PtL efficiency:	39%	**37%**	**40%**	**28%**
Energy PtL/LH2:	**1.47**	**1.57**	**1.45**	**2.10**
			PtL heat used for CO2 separation	

Comparison is based on LH2 efficiency of 58% (from EU study).

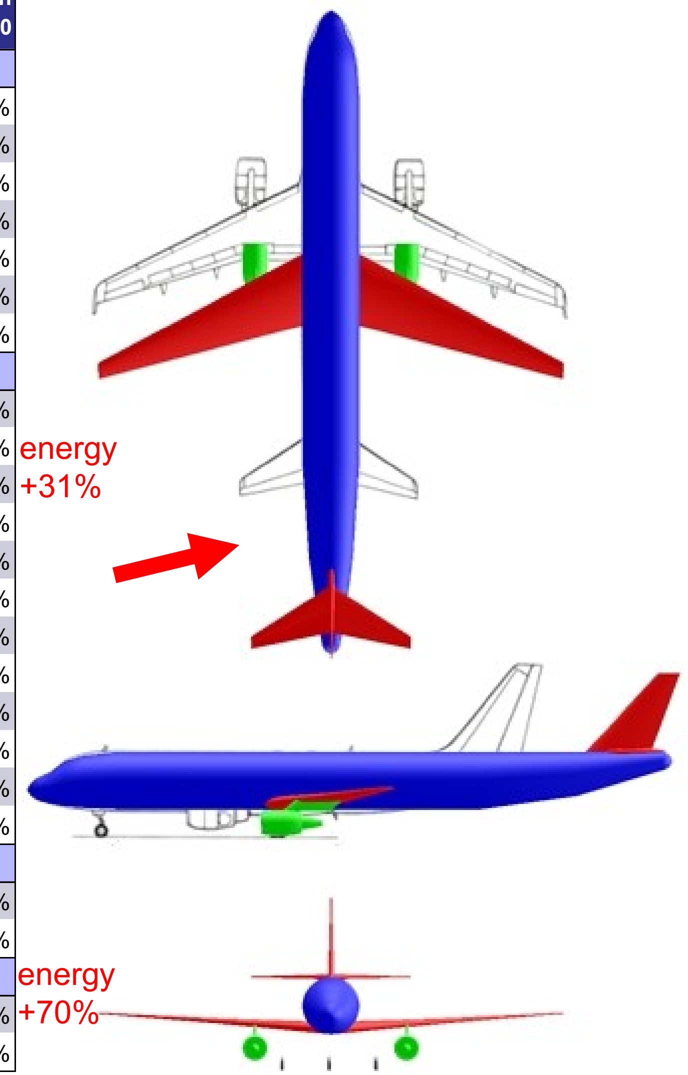
LH2 aircraft need more energy (from tank) due to higher mass and drag: **Factor: 1.3** or more (depending on flight distance).

This means **PtL aircraft need only a little more primary energy** (Factor: 1.13, 1.21, 1.12, 1.62 depending on study from above).

Hydrogen Powered A320

- Reduced hydrogen mass due to high mass energy density
- Stretched fuselage for additional tanks du to low volumetric energy density: 11 m
- In total: No improvement of the Maximum Take-Off Mass (MTOM)
- Steam reforming and electricity mix: SS = +300%
- Electrolysis and electricity from renewable sources: SS = -27%

Parameter	Value	Deviation from A320
Requirements		
m_{MPL}	19256 kg	0%
R_{MPL}	1510 NM	0%
M_{CR}	0.76	0%
max(s_{TOFL} , s_{LFL})	1770 m	0%
n_{PAX} (1-cl HD)	180	0%
m_{PAX}	93 kg	0%
SP	29 in	0%
Main aircraft parameters		
m_{MTO}	74200 kg	1%
m_{OE}	48800 kg	18%
m_F	6200 kg	-53%
S_W	124 m²	1%
$b_{W,geo}$	34.3 m	0%
$A_{W,eff}$	9.50	0%
E_{max}	17.00	≈ - 3%
T_TO	100 kN	12%
BPR	6.0	0%
h_{ICA}	40000 ft	2%
s_{TOFL}	1770 m	0%
s_{LFL}	1450 m	0%
Mission requirements		
R_{Mi}	589 NM	0%
$m_{PL,Mi}$	13057 kg	0%
Results		
$m_{F,trip}$	2800 kg	-39%
SS	0.0692	300%



How to Fly with Electric Energy?

Large Very Long Range Passenger LH2 Aircraft

DESIGN GROSS WT - 266.429 KG

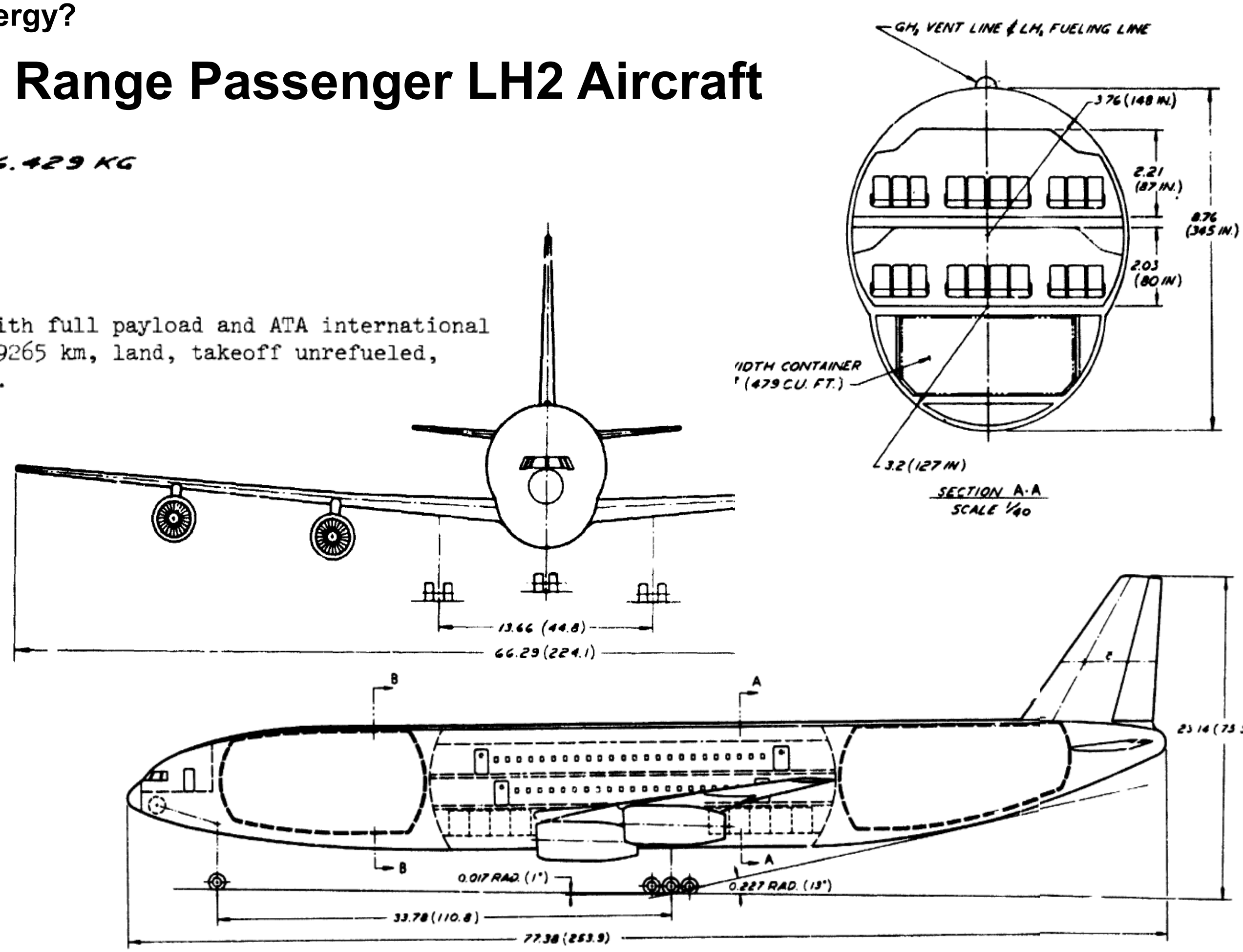
PASSENGERS - 400

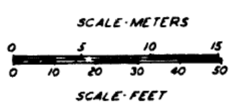
FUEL (LH_2) - 68,424 KG.

RANGE - 9,265 KM RADIUS

9265 km (5000 n.mi.) radius. With full payload and ATA international reserves for each segment, fly 9265 km, land, takeoff unrefueled, and fly another 9265 km segment.

Range: 18530 km = 10000 NM

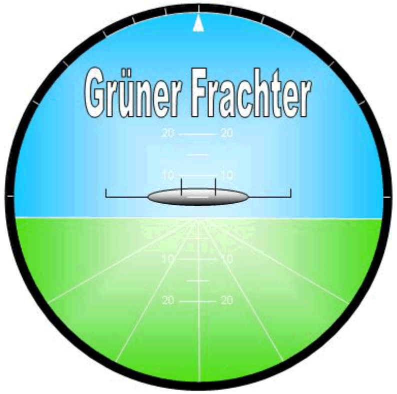


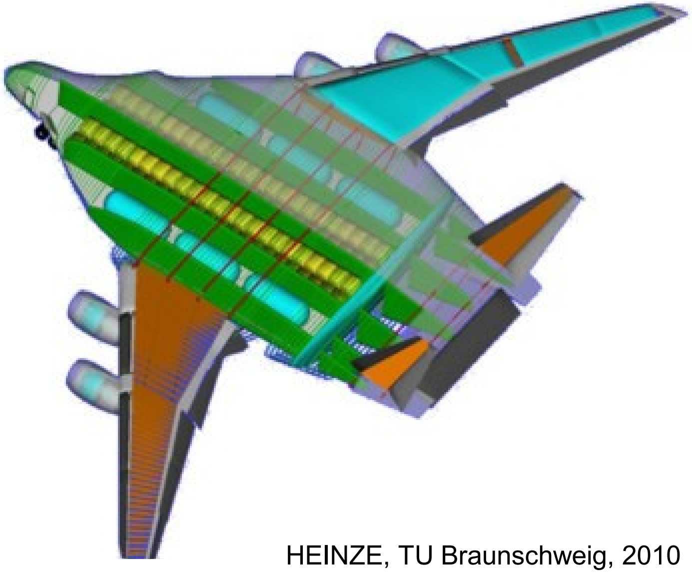


BREWER, G.D., MORRIS, R.E., 1976. *Study of LH2 Fueled Subsonic Passenger Transport Aircraft*. Lockheed, NASA CR-144935. Available from: https://ntrs.nasa.gov/citations/19760012056

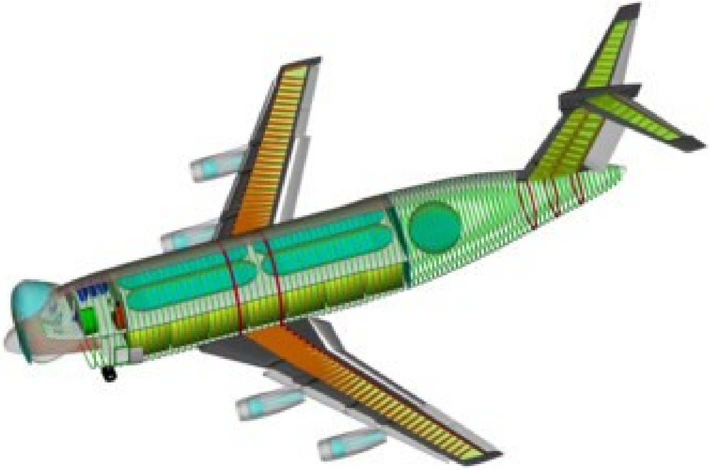
How to Fly with Electric Energy?

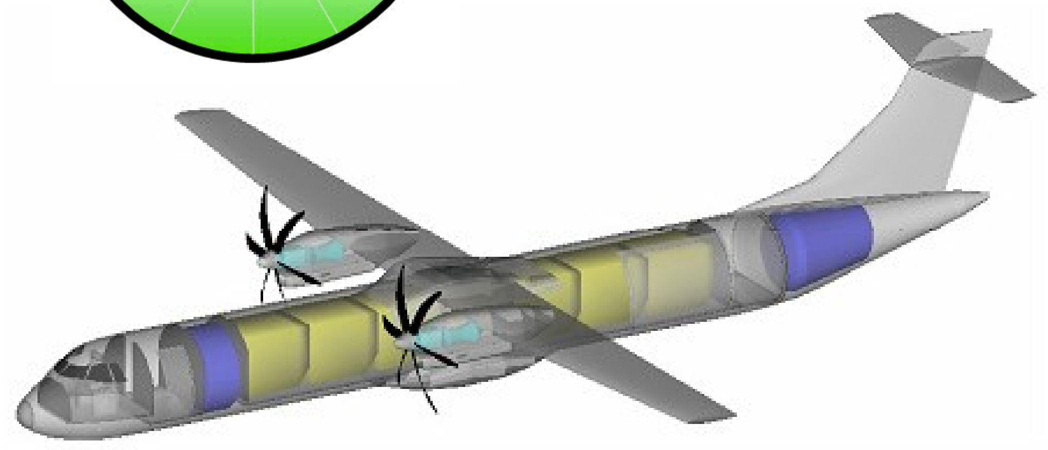
Configurations From the "Green Freighter" Project





HEINZE, TU Braunschweig, 2010





SEECKT, HAW Hamburg, 2010

http://GF.ProfScholz.de

How to Fly with Electric Energy?

Airbus – Past Technology Timeline for Hydrogen

FlightGlobal 1995-08-30

DASA plans to fly Dornier 328 with hydrogen power in 1998

https://perma.cc/RF4R-LS8R

... but nothing happend!

Airbus – Present Technology Timeline for Hydrogen: Canceled

Introducing #ZEROe, 2020-09-21, https://youtu.be/525YtyRi_Vc. Left to right: Jean-Brice Dumont (Executive Vice President Engineering, Airbus), Glenn Llewelyn (Vice President Head of Zero Emission Aircraft, Airbus), Grazia Vittadini (Chief Technology Officer, Airbus).

Use of Electric Energy
via
E-Fuel

Aircraft Design for E-Fuel (Drop-in Fuel): Same Aircraft Design, but ...

50% E-Fuel?

- **Still a long way for aviation to get to (real) 50%**.
- **E-Fuel is provided to the airport's main tank**
  => no (real) supply possible for individual aircraft, airline, or flight.

100% E-Fuel?

- **100% (or even more) can be done today with every flight via "Book & Claim":**
  => See: Sustainable Aviation Fuel (SAF) "Book & Claim" – Decoupling the Environmental Benefits from the Physical Product (https://doi.org/10.5281/zenodo.10371885).

E-Fuel and Reduced Aromatics?

- **If things work out unfavorably, refineries may mix kerosene with SAF such that the aromatics concentration stays the same as before.** This is likely to happen for economic reasons.
  See Faber (2022) from CE Delft.

Energy Considerations

Fundamental Advantage of Hydro Power Compared to Wind Power

Density of Water vs. Air

Substance	Density	Units
Water (liquid, at ~20 °C)	**~1000 kg/m^3**	kilograms per cubic meter
Air (at ~20 °C, sea level)	**~1.2 kg/m^3**	kilograms per cubic meter

💡 Key Insight:

Water is **about 800–850 times denser** than air.

This is why:

- Water-based turbines (like in hydropower) can generate a lot of force in small volumes.
- Air (wind) turbines need much larger blades and areas to capture enough energy.

(from AI, checked)

Disadvantages of Hydropower (Sustainability & Availability)

Sustainability Issues

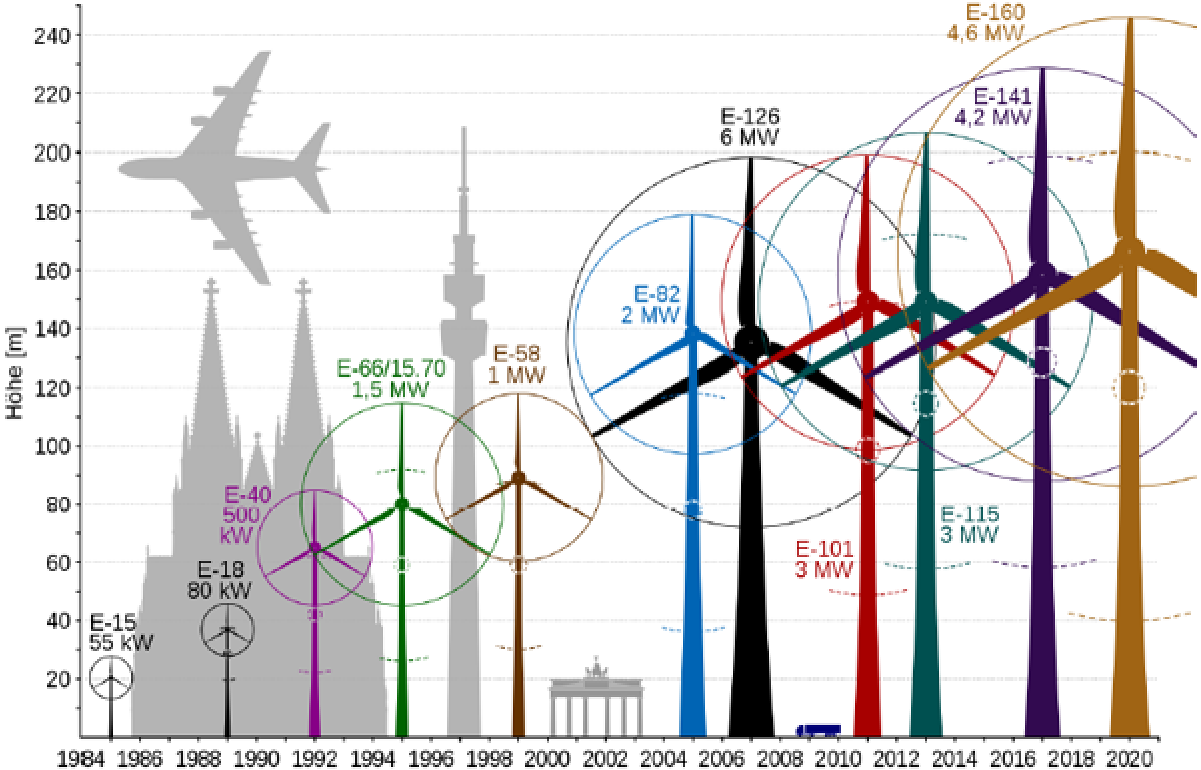
- **Ecosystem disruption:** Dams alter river flow, harm fish migration, and flood natural habitats.
- **Methane emissions:** Reservoirs, in tropical areas, can emit methane from decaying vegetation.
- **Biodiversity & social impact:** Projects may displace communities and destroy cultural sites.
- **Sedimentation:** Reduces reservoir capacity and dam lifespan over time.

Availability Limitations

- **Climate dependence:** Droughts and changing rainfall patterns affect reliability.
- **Seasonal variation:** Water flow fluctuates throughout the year, leading to inconsistent output.
- **Geographic limits:** Only certain locations are suitable – and many of the best sites are already developed.
- **Remaining sites often protected:** Potential new sites may be in **nature reserves** or ecologically sensitive areas. **Global growth of hydropower is limited** (in contrast to other renewable energies).
- **High costs & long timelines:** Expensive and slow to build, inflexible for fast-changing needs.

(from AI, checked)

Refueling One A350 Once per Day with SAF (E-Fuel): 53 of the Larges Wind Power Plants (4.6 MW each) Are Needed!



Airbus A350-900

Tank Volume: 138 m³

Fuel Mass:110.4 t (800 kg/m³)

Energy: 4747.2 GJ (43 MJ/kg)

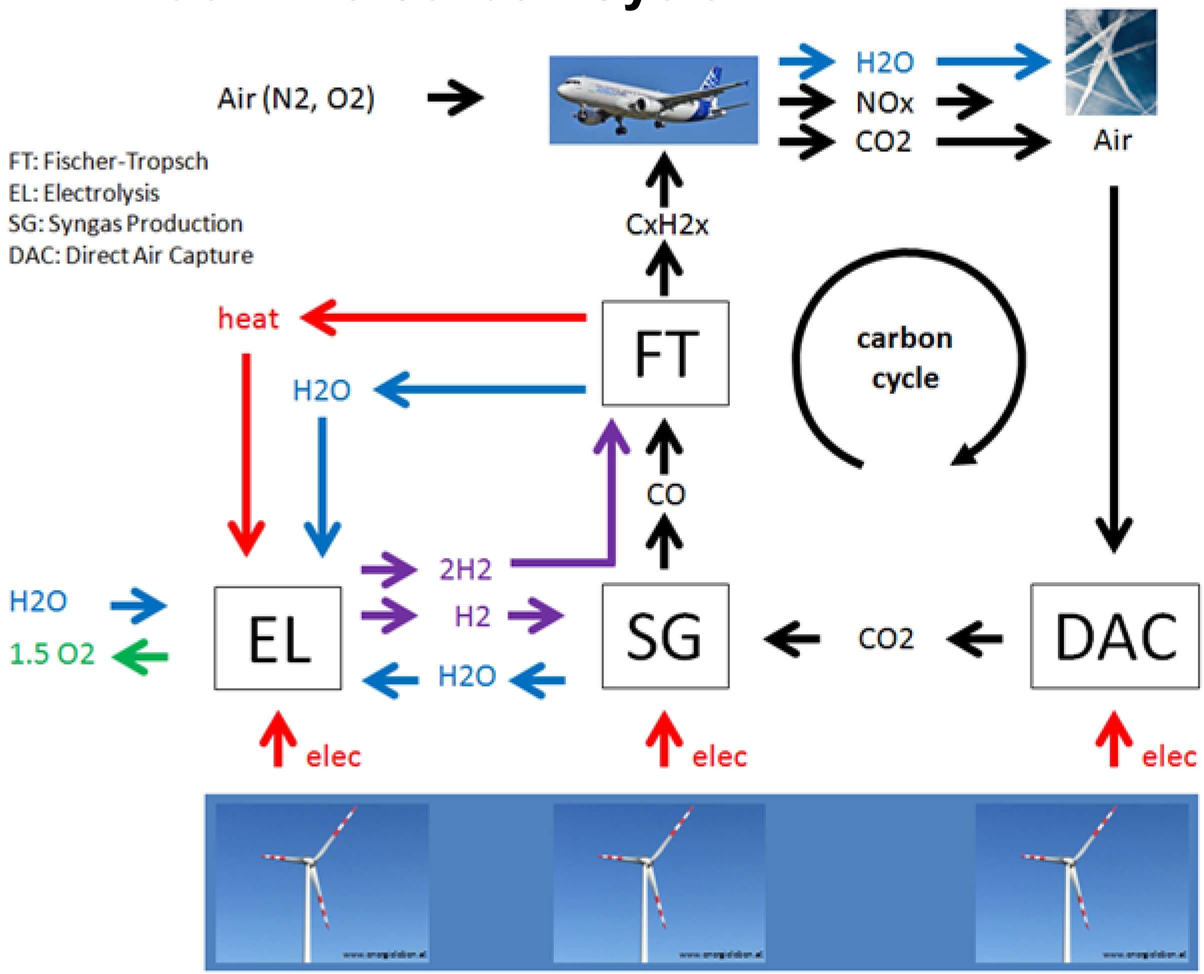
One E-160 per day: 89.4 GJ SAF

(Capacity Factor: 0.5, η_{PTL} = 0.45)

53 E-160 power plants required !

=> Globally, not enough wind power available for aviation.

E-Fuel: The Carbon Cycle



- **eSAF needs DAC (Direct Air Capure) to compensate for CO2 ("cabon cycle")**
- **In addition: eSAF and BioFuel need more CCS (Carbon Capture and Storage)** (with all its problems) **to compensate for the global warming effect due to**
  - **NOX and H2O (AIC)**

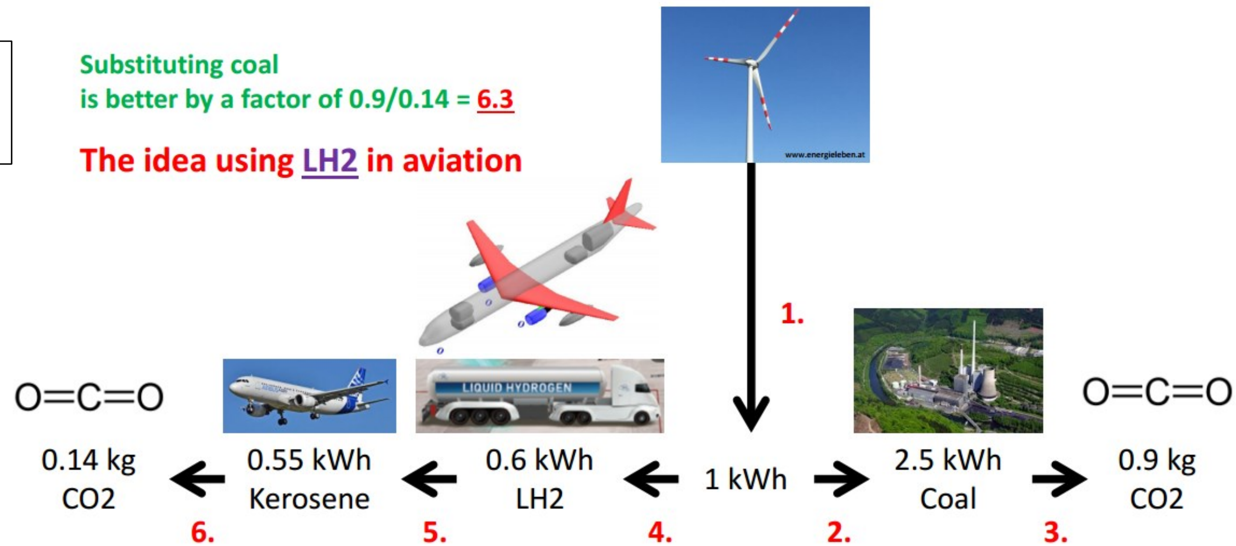
Production of synthetic kerosene (e-fuel) with power-to-liquid (PtL). Taking CO2 from the air (Direct Air Capture, DAC) enables a carbon cycle.

When taking CO2 from a point source (coal power plant, cement plant):
50% of CO2 savings allocated to plant
50% of CO2 saving allocated to aviation
based on common sense and wisdom.

Better Use Renewable Energy to Replace Coal Power Plants (LH2)

Factor: 6.3

http://ptl.ProfScholz.de



1.) 1 kWh of renewable energy ...

2.) ... can substitute 2,5 kWh of coal (lignite, brown coal) in a coal power plant (efficiency of a coal power plant: 40%) this is

3.) ... equivalent to 0.9 kg CO2 (0.36 kg CO2 for 1 kWh of energy burning lignite*)

4.) ... but if used in an aircraft it generates LH2 with energy of 0.6 kWh (efficiencies: 70% electrolysis, 83% liquefaction & transport)

5.) LH2 aircraft consume (say) 10% more energy (higher operating empty mass, more wetted area); so a kerosene aircraft needs ...

6.) only 0.55 kWh, which can be substituted. This is equivalent to 0.14 kg CO2 (0.26 kg CO2 for 1 kWh of energy burning kerosene*).

7.) Note: Not considered is that hydrogen aircraft may come with higher non-CO2 effects than kerosene aircraft.

* UBA, 2016. CO2 Emission Factors for Fossil Fuels. Available from: https://bit.ly/3r8avD1

Energy Considerations

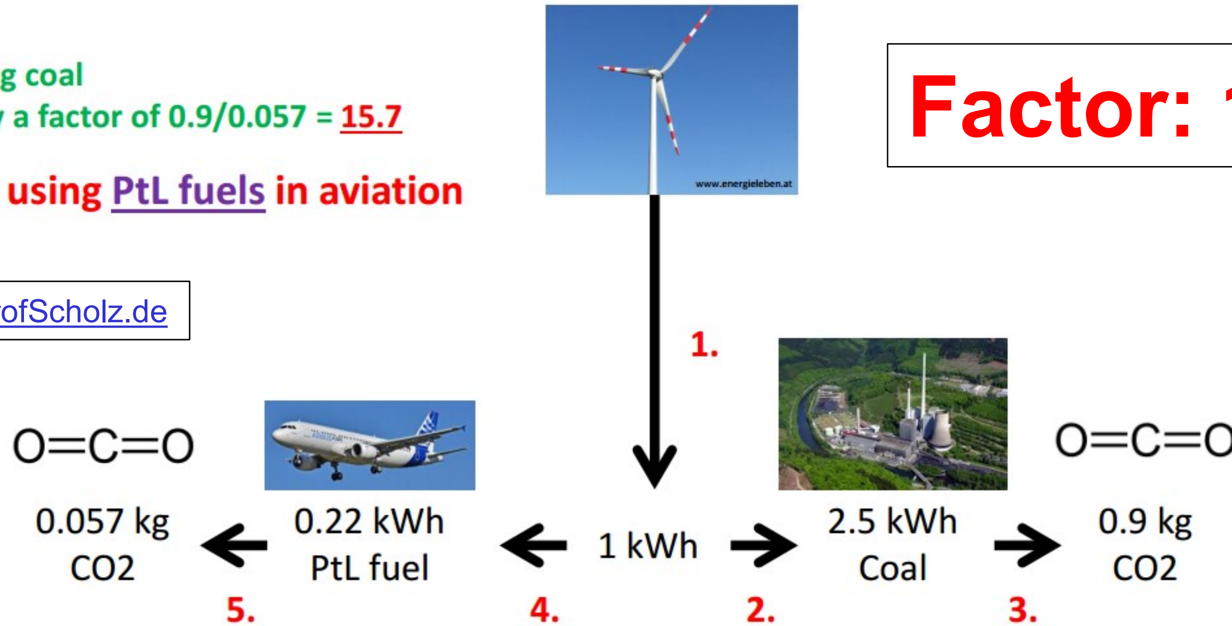
Better Use Renewable Energy to Replace Coal Power Plants (E-Fuel)

Substituting coal
is better by a factor of 0.9/0.057 = 15.7

The idea using PtL fuels in aviation

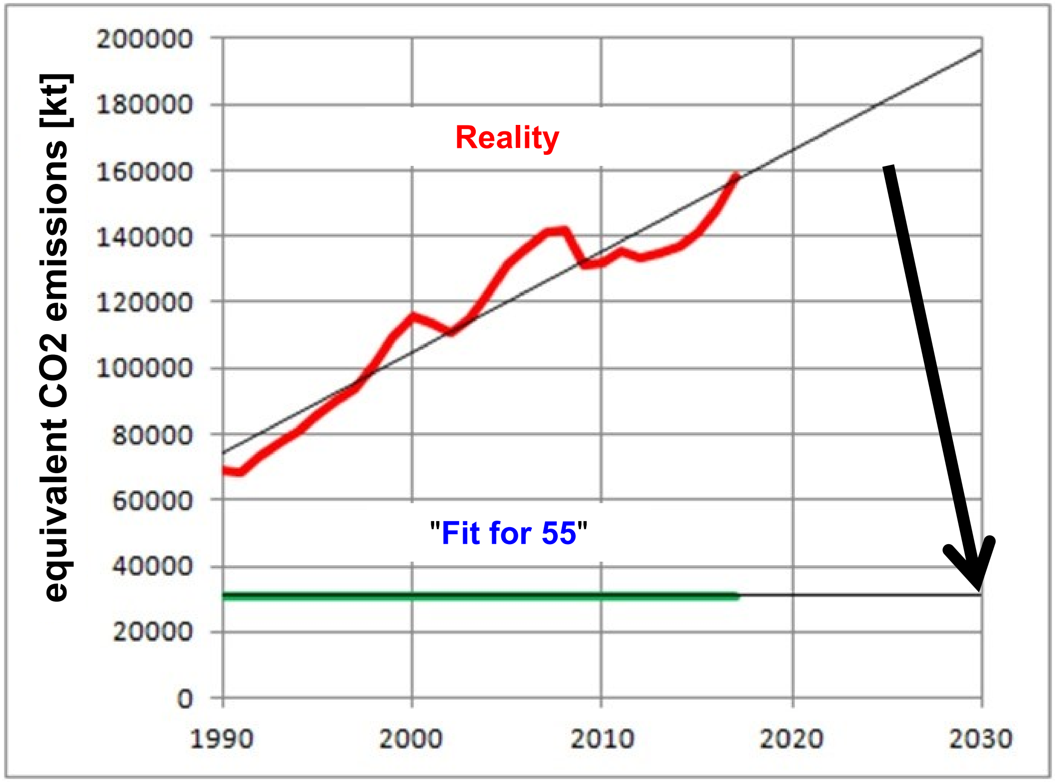
Factor: 15.7

http://ptl.ProfScholz.de



1.) 1 kWh of renewable energy ...
2.) ... can replace 2.5 kWh lignite in coal-fired power plants (efficiency 40%);
3.) This corresponds to 0.9 kg of CO2 (0.36 kg of CO2 for 1 kWh of energy from lignite *).
4.) ... converted into Sustainable Aviation Fuel (SAF) only 0.22 kWh remain (efficiency: 70% electrolysis, 32% Fischer-Tropsch), 99% transport; https://perma.cc/BJJ6-5L74 (EU-Study, May 2020)
5.) which save only 0.057 kg of CO2 (0.26 kg of CO2 for 1 kWh of kerosene *).
* UBA, 2016: CO2 Emission Factors for Fossil Fuels. https://bit.ly/3r8avD1

Climate Goals of the EU? => Drastic Reduction of Flights Necessary!



1.) 2019: The EU's "**Green Deal**": "**In 2050, net greenhouse gas emissions should no longer be released**".
2.) 2020: The European climate targets for 2030 were defined under the motto "**Fit for 55**". This is the interim goal of the Green Deal: "**Greenhouse gas emissions are to be reduced by 55% compared to 1990** – i.e. only 45% of the 1990 value. This value is to be achieved by 2030."

https://doi.org/10.48441/4427.225

The 55% reduction compared to 1990 means a reduction of more than 80% for aviation by 2030, i.e. by about 16% per year. Fuel consumption has so far been reduced by 1.5% annually through operational measures and technology. **Air traffic would therefore have to shrink permanently by 14.5% per year from now on for the next 5 years** based on 2025 traffic numbers.

Summary

Summary

- Current **aviation growth is unsustainable.**
- **Flying less** is necessary and a simple answer that **works**, but **does not fulfil mobility expectations** of society.
- There are **no simple technical solutions for aviation.**
- **A modern large turboprop (180 seats) flying slower and lower than a jet, operated with e-fuel from renewable energy and CO_2 (eventually) from DAC, plus CCS (with its problems) to compensate for remaining non-CO_2 effects would be a first meaningful step.**

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

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

Contact

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http://ProfScholz.de

Quote this document:

SCHOLZ, Dieter, 2025. How to Design Aircraft in Times of the Climate Crisis – Are We Losing Our Social License to Operate? *Seminar Sustainable Aviation Fuels 2025* (Bodø, Norway, 09-10 April 2025).
Available from: https://doi.org/10.48441/4427.2455.

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

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