Hochschule für Angewandte Wissenschaften Hamburg

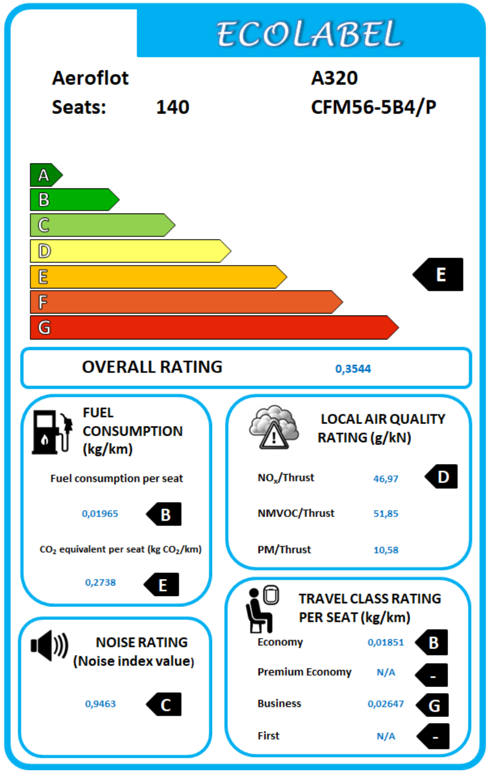
Hamburg University of Applied Sciences

AIRCRAFT DESIGN AND SYSTEMS GROUP (AERO)

Ecolabel for Aircraft –
Definition and Application

with backup slides

Dieter Scholz Hamburg University of Applied Sciences



Hamburg Aerospace Lecture Series (Aero Lectures)
DGLR, RAeS, VDI, ZAL, HAW Hamburg
Online, 04 June 2020
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including work of:

- **Tim Haß** (Bachelor Thesis)
- **Lynn Van Endert** (Master Thesis)
- **Sophie Sokour** and **Tobias Bähr** (Project)
- **Benjanin Kühner**
- **Alejandro Ridao Velasco** (Bachelor Thesis)

Abstract

Background: In 2019 EASA started work on a labeling system for the aviation industry. This let to a workshop on 2019-10-24, but activities stopped already shortly after that date. An "Ecolabel for Aircraft" was proposed and published by HAW Hamburg already in 2017.
Motivation: With IPCC Reports, "Fridays for Future", and "Flygskam", the aviation industry is getting into defense. Recent industry climate initiatives failed to convince, because an agreed metric is missing, based on which the proposals could be discussed.
Method: The proposed label follows requirements from ISO 14020 Series: Environmental labels and declarations. The label considers resource depletion (fuel consumption), global warming (equivalent CO2), local air quality (NOx) based on ozone formation potential and particulate matter formation, and finally noise. Seat arrangements in different travel classes are considered based on the cabin floor area occupied by each passenger. Even a comparison of airline fleets is possible with the proposed metric.
Results: Modern aircraft are better than older aircraft designs. Different modern engines yield similar environmental results. Low cost carrier are better than legacy carrier, because they transport more passengers in the same cabin. Modern propeller driven aircraft have the lowest environmental impact. They are environmentally much better than comparable jets. If travel plans require use of an aircraft, passengers should select a flight on the shortest route and select the best aircraft-airline-combination based on the ecolabel. Airlines that operate a modern fleet, have tight seating in a single (economy) class, and are known for their high load factor may not be fun to fly with, but are better for the environment. Obviously, a ticket in the economy class should be booked, if the cabin features more than one class.

Table of Content

New Motivation: #Flygskam, #StayGrounded

Strategy

Flight shame is changing the face of travel

By Kerry Reals | 6 September 2019

FlightGlobal

Swedish might not be one of the world's most widely spoken languages – but most people are now familiar with the term "flygskam". This "flight shame" campaign to make people think twice about travelling by air because of concerns about the aviation industry's impact on climate change is gathering pace – and it is already having an impact on passenger numbers in its country of origin.

As more people sign up to movements on social media carrying hashtags such as #StayGrounded and #FlyingLess, airlines face more public pressure than ever to show that they are serious about cutting carbon dioxide (CO_2) emissions.

https://perma.cc/Y5N4-7MZZ

New Motivation: #Flygskam, #StayGrounded

Kai Bauer, principal adviser for environment and sustainability to EASA's strategy and safety management director, says one of the "triggers" for examining an aircraft emissions labelling system was the "changing world" of public opinion on climate change. "In other industries, labelling systems have been used to communicate environmental performance to the general public. In this changing world, a labelling system for the aviation industry can play a role," says Bauer. "A starting point for our exploration was to address concerns expressed by European citizens."

https://perma.cc/Y5N4-7MZZ

New Motivation: #Flygskam, #StayGrounded

FlightGlobal

RESEARCH EFFORT

EASA surveyed 6,000 respondents from 15 EU member states and found that 80% were "open to receiving environmental information in the form of a label", and the majority wanted the information to be available "during the booking process or on the boarding pass".

The agency is in the "proof of concept" stage for the system and aims to set out a more detailed plan by the end of the year, with the intention of launching it in 2020. One option under consideration when it comes to presentation is a colour-coding system so "people can easily understand where there is good performance", says Bauer. "The aim is to increase awareness and transparency, and ultimately help passengers make more informed choices."

While the details are still being hammered out, EASA aims to use data generated by the certification process for the ICAO noise and emissions standards, including the new CO2 standard from 2020, as the basis for its proposed grading system. The labelling system is "intended as a voluntary scheme", but Bauer says that despite some concerns over the type of data that ends up being used, some airlines expressed broad interest in the idea: "We've had initial discussions with some airlines and we've found broad agreement that there's a need to communicate on environmental performance.

"Airlines also had legitimate concerns to make sure the data is robust and doesn't compare things that aren't comparable."

https://perma.cc/Y5N4-7MZZ

!
ICAO Noise Standard
ICAO Emission Standard
ICAO CO2 Standard

Environmental Label Programme – Stakeholders Workshop

HAW HAMBURG

EASA European Aviation Safety Agency

24 Oct 2019

@ Contact

Aviation is increasingly challenged from an environmental performance and sustainability perspective (IPCC Report, "Fridays for future", "Flygsham").
Citizens receive very little information on the actual aviation environmental performance. Furthermore, the information provided is frequently inconsistent and contradictory, as many measures and calculation methods exist.

Passengers, general public and people around airports should be provided with **visual, relevant, consistent and up-to-date information** on aviation environmental performance.
It will help to increase transparency and help passengers to make more informed choices.

As shown in other industries, an **environmental label is an effective tool for communicating environmental performance.**
To develop the concept EASA engaged with Member States, Industry and NGOs.

The label will initially focus on the performance of aircraft technology and may later be expanded to look at other aspects, like the overall CO2 performance, airlines, airports or the use of sustainable aviation fuels. **!**

This technical workshop will provide information and allow for discussions about the rationale, metrics, graphical concepts and communication elements around environmental labelling for aviation. Interventions will be from Member States, Industry and NGOs.

SAB: EASA Stakeholder Advisory Body
MAB: EASA Member States Advisory Body
NGO: Non-Governmental Organization

Registration

The meeting is open only to MAB and SAB members/alternates/observers and NGOs.

New Motivation: EASA Workshop

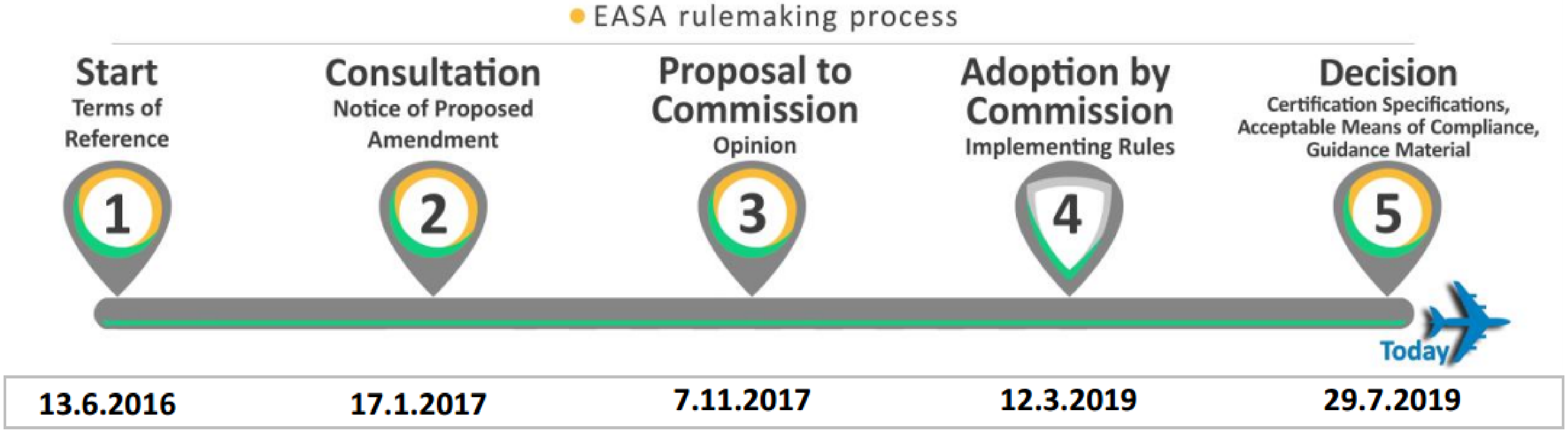
https://perma.cc/ZA25-GE4Q

HAW HAMBURG

EASA's Vision for the Label: ICAO Noise, Emission, CO2 Standards

EASA European Aviation Safety Agency

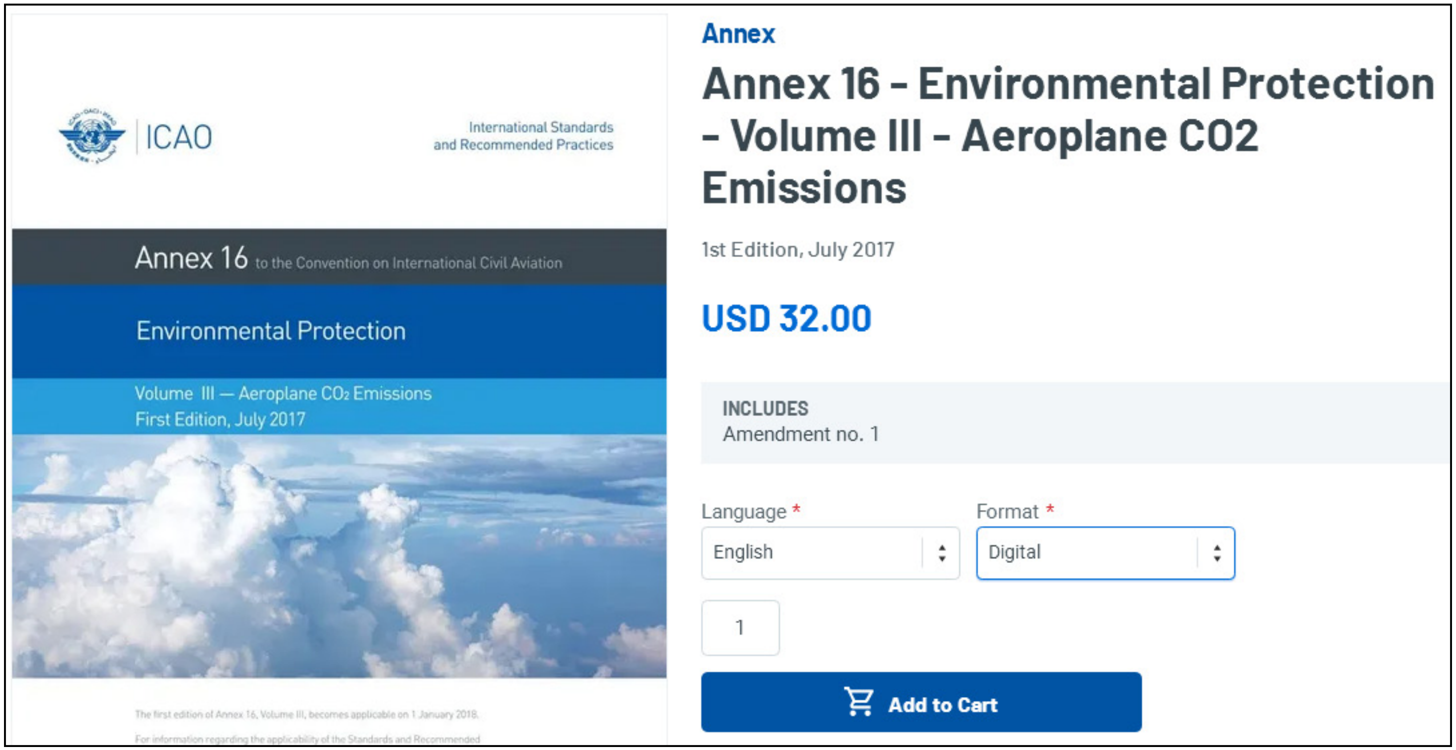
Action area:	Aircraft noise (RMT.0513); climate change (RMT.0514)		
Affected rules:	Annex I (Part 21) and related AMC and GM; CS-CO_2 (new)		
Affected stakeholders:	Design and production organisations; design approval holders (DAHs); national aviation authorities (NAAs); Member States		
Driver:	Environment	**Rulemaking group:**	No
Impact assessment:	Full (by ICAO CAEP)	**Rulemaking Procedure:**	Standard



https://perma.cc/9TSE-RF87

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

- ICAO CO2 adopted CO2 standard in 2016 after 6 years of negotiations.
- EASA requirement CS-CO2 introducted after further 3 years in 2019.

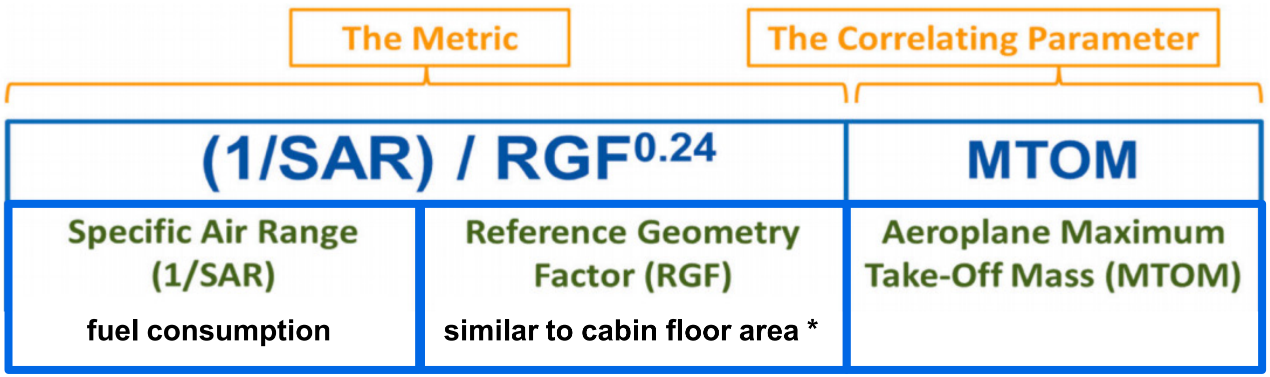


https://store.icao.int/en/annex-16-environmental-protection-volume-iii-aeroplane-co2-emissions

http://purl.org/aero/ICAO-2017_CO2-Emissions

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

- ICAO CO2 adopted CO2 standard in 2016 after 6 years of negotiations.
- EASA requirement CS-CO2 introducted after further 3 years in 2019.
- **Metric Value (MV)** is limited as a function of MTOM (see page 13).



https://perma.cc/U6R3-RJHE

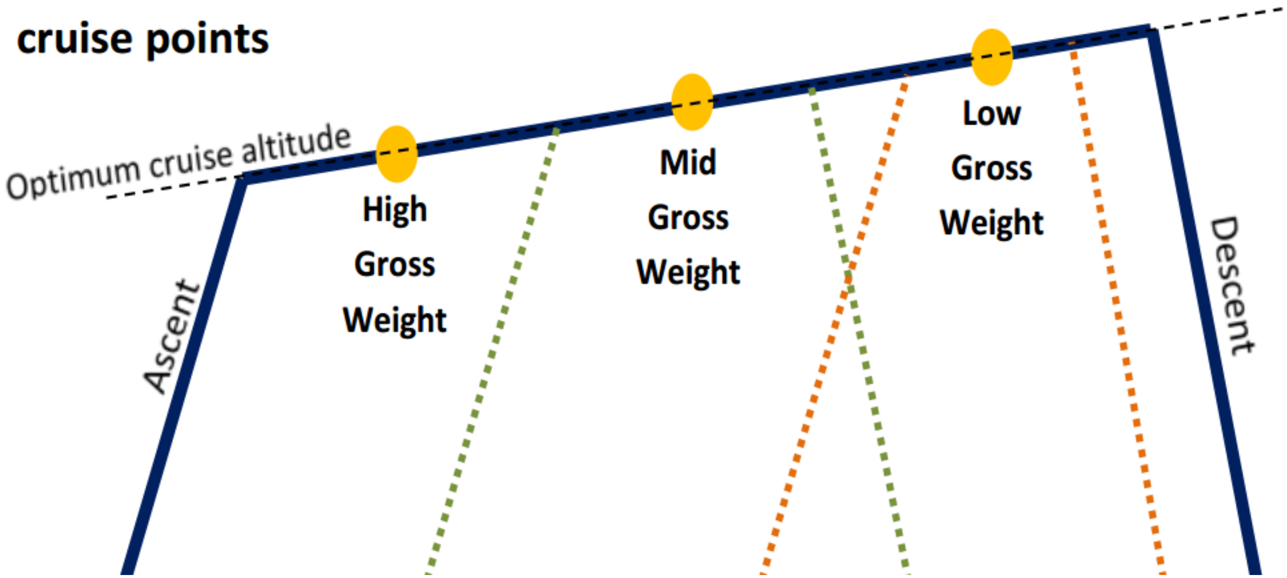
* divided by 1 m²

- **1/SAR** (in kg/km) determined for the aircraft either ...
  - from validated performance model or
  - from flight test: $SAR = TAS/W_f$
    where: TAS is the true air speed, W_f is total aeroplane fuel flow.
- An RGF-exponent of 1 would normalize the fuel consumption by a payload substitute.
- The "magic" exponent 0.24 obscures the metric. So, MV is not helpful for an ecolabel!

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

- **1/SAR** determined as the average of 3 conditions (given by aircraft mass in flight):
  high gross mass: 92% MTOM
  low gross mass: 0.45 MTOM + 0.63 $MTOM^{0.924}$
  mid gross mass: average of high and low gross mass.

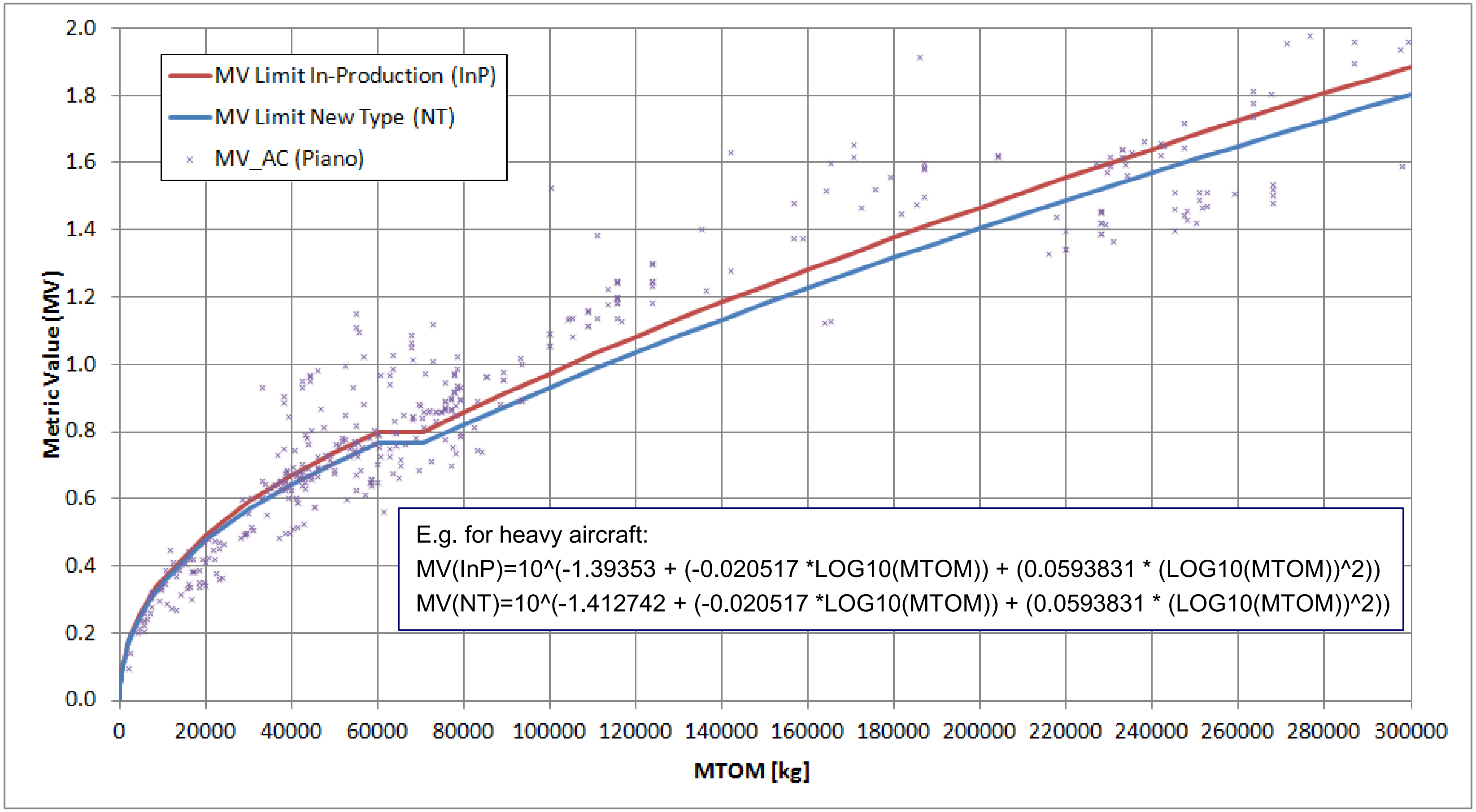
An illustrative example of the three representative cruise points



https://perma.cc/J4JY-JGXX

ICAO Annex 16, Volume III: Aeroplane CO_2 Emissions

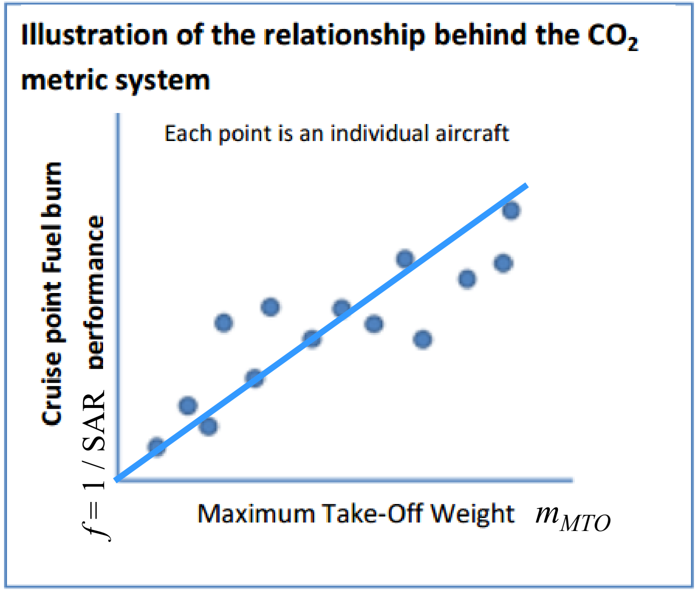
- The Metric Value (MV) as defined by ICAO



Compare with https://perma.cc/P8SG-8K5N   Piano data: https://perma.cc/J6UF-RHMJ   Equations are given in the ICAO standard

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

- The Metric Value (MV) – Attempt of a Derivation



based on https://perma.cc/J4JY-JGXX

$$f = a_f \; m_{MTO}$$ f: fuel burn $f = 1 / SAR$

$$RGF \propto m_{MTO}$$

$$MV = \frac{f}{RGF^{0.24}} = a_{MV} \frac{f}{m_{MTO}^{0.24}}$$

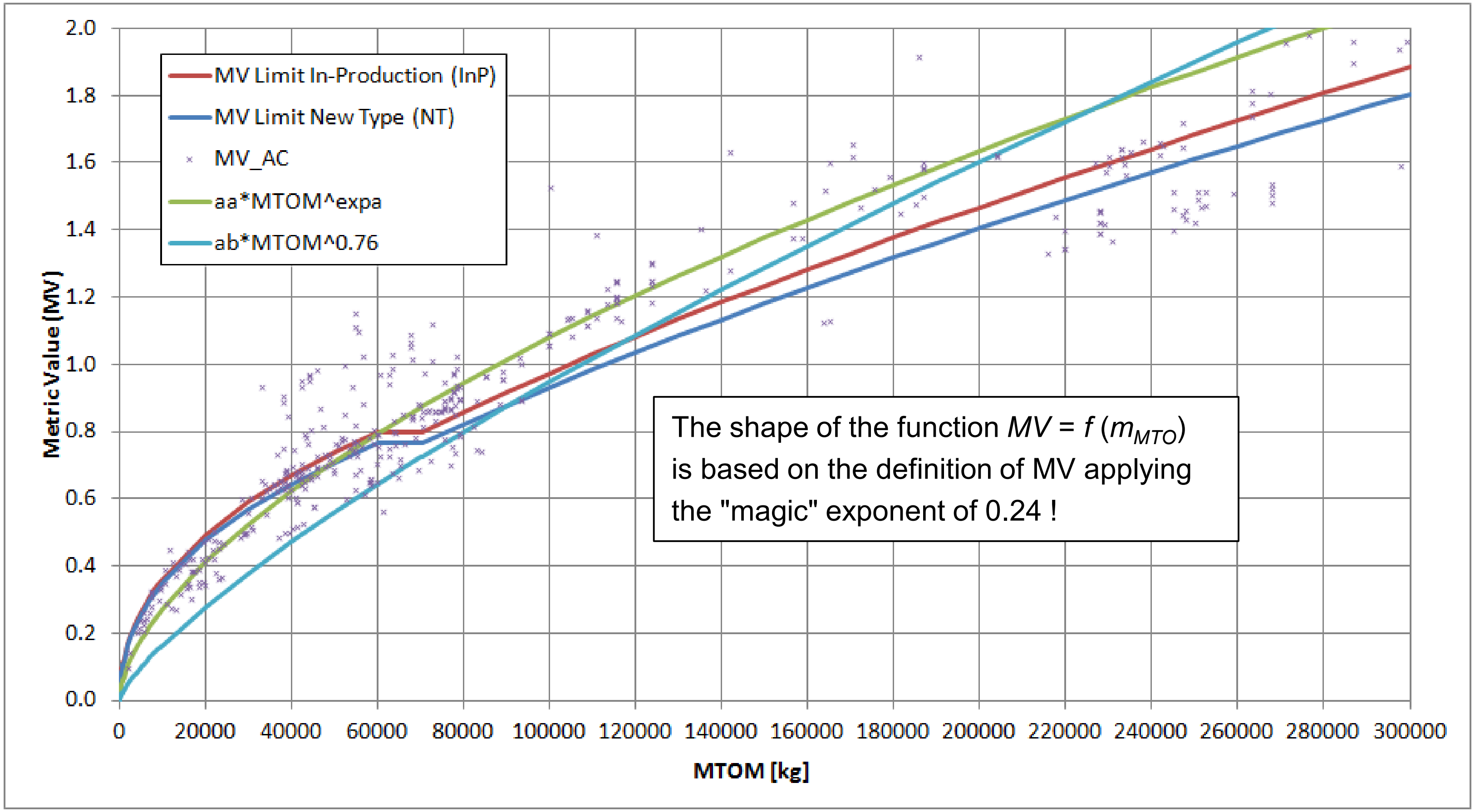
$$MV = a_{MV} \cdot a_f \frac{m_{MTO}}{m_{MTO}^{0.24}}$$

$$MV = a \cdot m_{MTO}^{0.76}$$ or

$$MV = a \cdot m_{MTO}^{x}$$

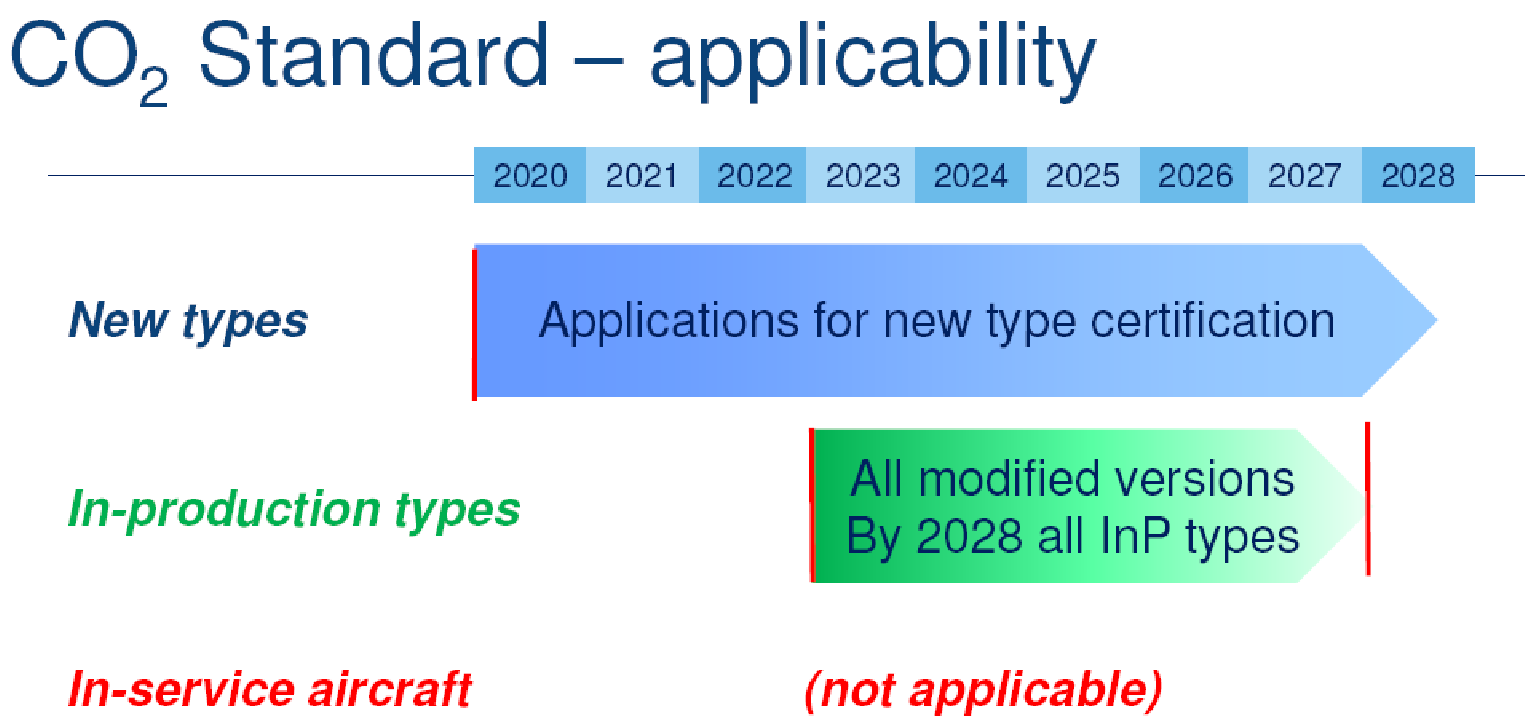
ICAO Annex 16, Volume III: Aeroplane CO_2 Emissions

- The Metric Value (MV) – ICAO and Derivation Compared



Excel Solver, minimum of error square: aa = 0.0011, expa = 0.59874, ab = 0.00015, **Excel: https://doi.org/10.7910/DVN/FFQPEP**

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions



https://doi.org/10.5281/zenodo.4461948

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

ICAO CO2 Standard / EASA CS-CO2 are criticized:

- **Green and Jupp**: ICAO goal of reducing fuel used per revenue ton-kilometer performed and makes no reference to payload. This defect could be eliminated simply by omission of the exponent 0.24 of the Reference Geometric Factor (RGF). Retaining the RGF to the power unity and multiplying it by an appropriate value of the effective floor loading would convert it to what the 37th Assembly of ICAO called for – a statement of fuel used per revenue ton-kilometer performed. Finally, correlating the metric against design range. (https://perma.cc/4LUW-KKPH)
- **International Coalition for Sustainable Aviation (ICSA)**: "It is critical that ... the metric values be made public along with the measured and certified SAR points used to establish them." "Such transparency will also provide researchers, industry, the public and regulators access to accurate information on aircraft fuel efficiency performance for the first time. The present situation where only estimates are in the public domain is unacceptable." "Six years of intense effort have failed to produce a CO2 standard for new types or in production aircraft that will reduce emissions beyond what they might otherwise have been without the standard. Given the expected growth in aviation CO2 and the urgency of adopting all feasible mitigation measures as the Paris agreement so starkly underlines, this result is deeply disappointing. (https://perma.cc/69B3-RE5D)

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

ICAO CO2 Standard / EASA CS-CO2 are criticized:

- **Transport & Environment**: "extraordinary is the static concept of the standard" "CAEP decided that the stringency options for the standard would all be based on TRL8 (technology readiness level 8 – i.e. technology already flying) in year 2016." "Aircraft efficiency scores (MVs) are planned to be declared on a voluntary basis only and with only partial data revealed making it very difficult to compare aircraft efficiency. Civil society believes all efficiency data including the three measured and certified specific air ranges, should be published." "Over 90% of global [aviation] emissions stem from large Airbus and Boeing aircraft. They are the emissions which the standard must first address effectively." (https://perma.cc/F9NP-LRDX)
- **Simos** (Piano): One fatal flaw ... is that the metric ignores payload and distance. Yet aircraft produce CO2 only because they carry payloads over distances. Bypassing elementary physics, ICAO chooses to sanctify an irrelevant concoction of ersatz cabin size and a certification weight restriction. It cannot work. ICAO's metric is ... insensitive to the [empty] weight of the aircraft. ICAO is sheltering behind the crude fact that 'large' aircraft produce more CO2. ICAO recognizes that the metric is meaningless in its direct form. ICAO resorts to the MTOW and calls it 'The Correlation Parameter'. (https://perma.cc/Y229-5D9U).
- The metric is unique for aviation and precludes a comparison with other modes of transport.

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

ICAO CO2 Standard / EASA CS-CO2 are criticized :

- **Simos**: It is not clear how ICAO's Pass / Fail metric proposes to influence either aircraft design or market behavior towards a reduction of CO2. Aircraft sizing decisions and fleet purchases are both based on strategic and commercial considerations that often result in far from CO2-optimal compositions. (https://perma.cc/2Z89-YK7Z)
- **Transport & Environment**: New aircraft types today may take 10 years to bring to production and cost $15 billion to develop. Which regulator will fail such an aircraft and see its manufacturer potentially go bust? (https://perma.cc/F9NP-LRDX)

ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

TRANSPORT & ENVIRONMENT

PRESS RELEASES November 23, 2017 - 17:01

Emails show Airbus writes aircraft CO2 rules; Commission, France, Germany and Spain complicit

Emails between Airbus and the European Commission show that, when drafting climate rules for new aircraft, Airbus was given special privileges in determining essential aspects of the EU's position at the United Nations' aviation body (ICAO). The result is a global aircraft standard which will do nothing to cut the sector's soaring emissions and a regulatory process steeped in secrecy and corporate interests, entirely removed from the normal European democratic process. NGO Transport & Environment obtained the emails via an access to documents request, after Airbus and ICAO opposed the public disclosure of the emails. The correspondence was finally released after an 18-month appeal process.

https://perma.cc/65H6-5UNP

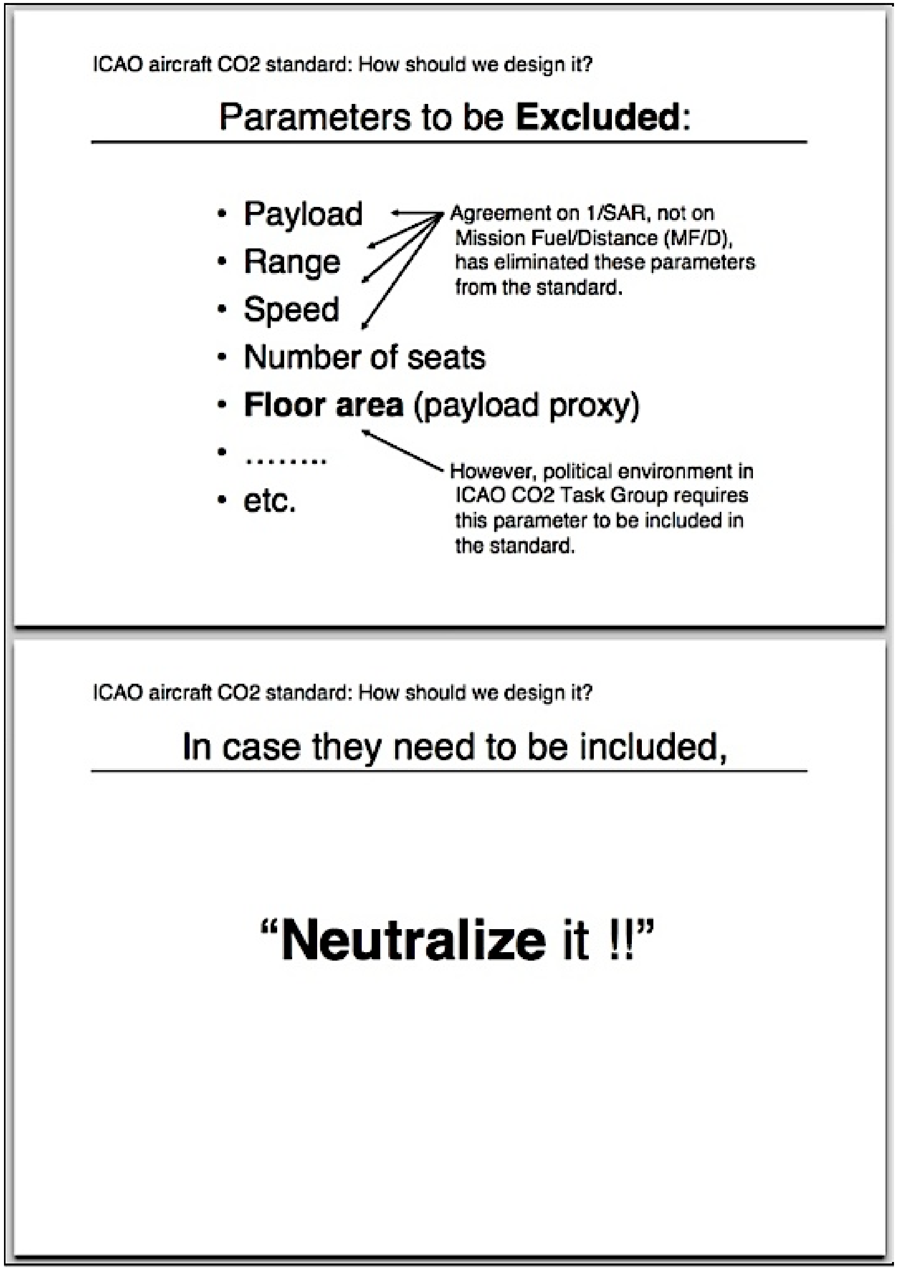
ICAO Annex 16, Volume III: Aeroplane CO2 Emissions

Development process of the ICAO CO2 Standard criticized:

- **Simos**: Observing the ICAO process from its periphery over an extended period exposes the committee dynamics that cause eminent groups of thinking, educated and capable professionals to act together to produce the worst possible result. ICAO is a loose organization of participants with conflicting interests. Everyone is wary of everyone else, and environmental groups, manufacturers and airline groups all seem to be entrenched in narrow positions. A March 2012 slide presentation by one particular airframe manufacturer brandished these extraordinary bullet points:
  - *"Our ultimate Goal is to **design** the CO2 standard so that it does not interfere with the market"*
  - *"**Exclude all** commercially important parameters from the metric system of the standard*
  - *to eliminate its **potential** to interfere with the market"*
  - *"Parameters to be **Excluded**: Payload, Range ... etc."*
  - *"In case they need to be included, **Neutralize** it!!"*

  (all bold emphases and exclamations are per the original.)

  (https://perma.cc/2Z89-YK7Z)



Perspectives of one manufacturer participating in the ICAO process

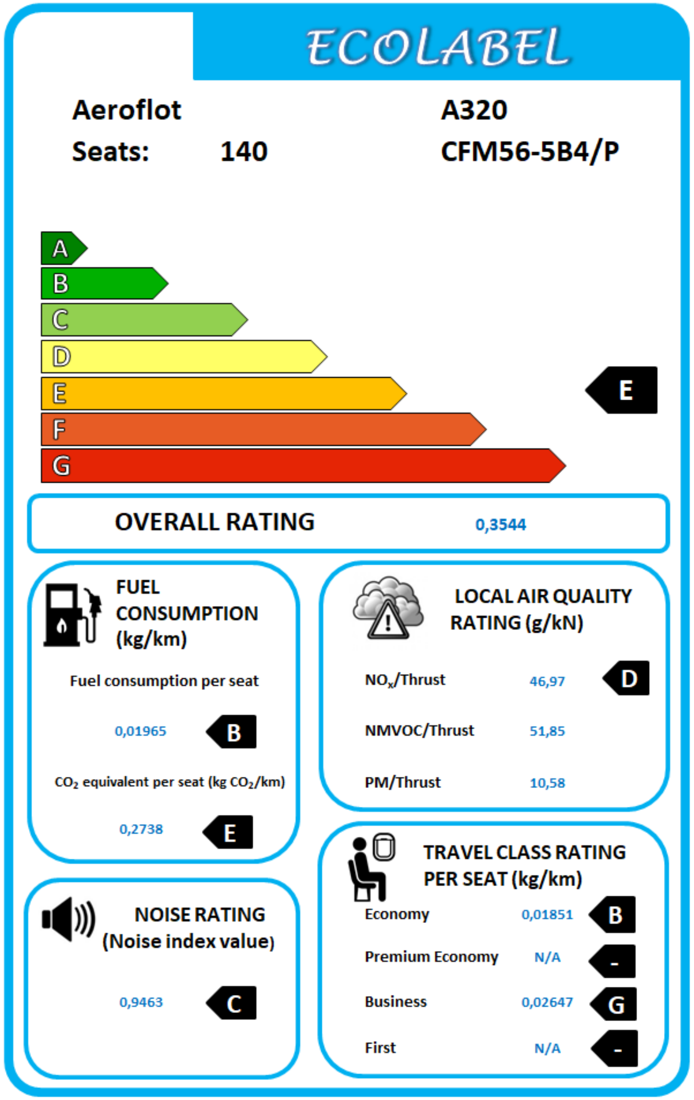
(https://perma.cc/2Z89-YK7Z)

Idea / Goal & the "Ecolabel for Aircraft"

- **The travelling public should make an informed choice when selecting a flight**
  - **Price**
    - ticket price (basic fare, baggage, seat selection, ..., payment fees)
  - **Time**
    - useful time & wasted time
  - **Comfort**
    - travel class (=> seat pitch, seat width, ...)
    - number of transfers
  - **Environmental footprint** => **Ecolabel for Aircraft**
    (**simplified** Life Cycle Assessment, **LCA**)
    - **Resource depletion** (fuel burn)
    - **Global warming** (fuel burn)
    - **Local air quality** (NOx)
      - + **Ozone** formation potential (NMVOC: NOx, SO2, CO, HC)
      - + **Particulate matter** formation (PM: NOx, PM)
    - **Noise**

The Ecolabel for Aircraft

- Information: airline, aircraft, number of seats, engine
- Overall Rating (average rating on airline level)
  - Metric scaled between 0 and 1 (90% of aircraft)
  - category: A to G
- Fuel consumption (from manufacturer's payload & range diagram)
  - resource depletion: fuel per seat-km (kg/km) & A to G
  - global warming (depending on altitude): CO2-equivalent per seat-km (kg/km) & A to G
- Local air quality (ICAO LTO cycle)
  - NOx (g/kN) & A to G
  - NMVOC (g/kN) – for information only
  - PM-equivalent (g/kN) – for information only
- Noise (from NoisedB database; ICAO & DGAC)
- Rating according to passenger travel class



The Beginning in 2012

- **My presentation at the German Aerospace Conference 2012*:**
  - o Eco-efficiency: Create more with less waste and pollution.
  - o Aviation growth does not (and will never) be met by aviation's efficiency gain!
  - o Jevson's Paradox: "Fuel Can Not Be Saved from Efficiency Increase!"
  - o **ACARE goals** (fuel burn reduction, NOx, ...)
    - – are unrealistic and will not be met
    - – this without any consequences (today: see "Vision 2020")
  - o **IATA** / ATAG goal: "**carbon-neutral growth from 2020**"
    - – would need massive & effective compensation scheme. CORSIA?
    - – Why 2020 and not today?
  - o CO_2 is not the (major) problem. **The major problem is water!**
  - o It is already too late to safe the world. **We need resilience!**
    - – Do not bother about aviation, rather increase height of the dikes (Hamburg)

* http://www.fzt.haw-hamburg.de/pers/Scholz/Airport2030/Airport2030_PRE_DLRK_2012_EcoEfficiencyOffCourse_2012-09-10.pdf

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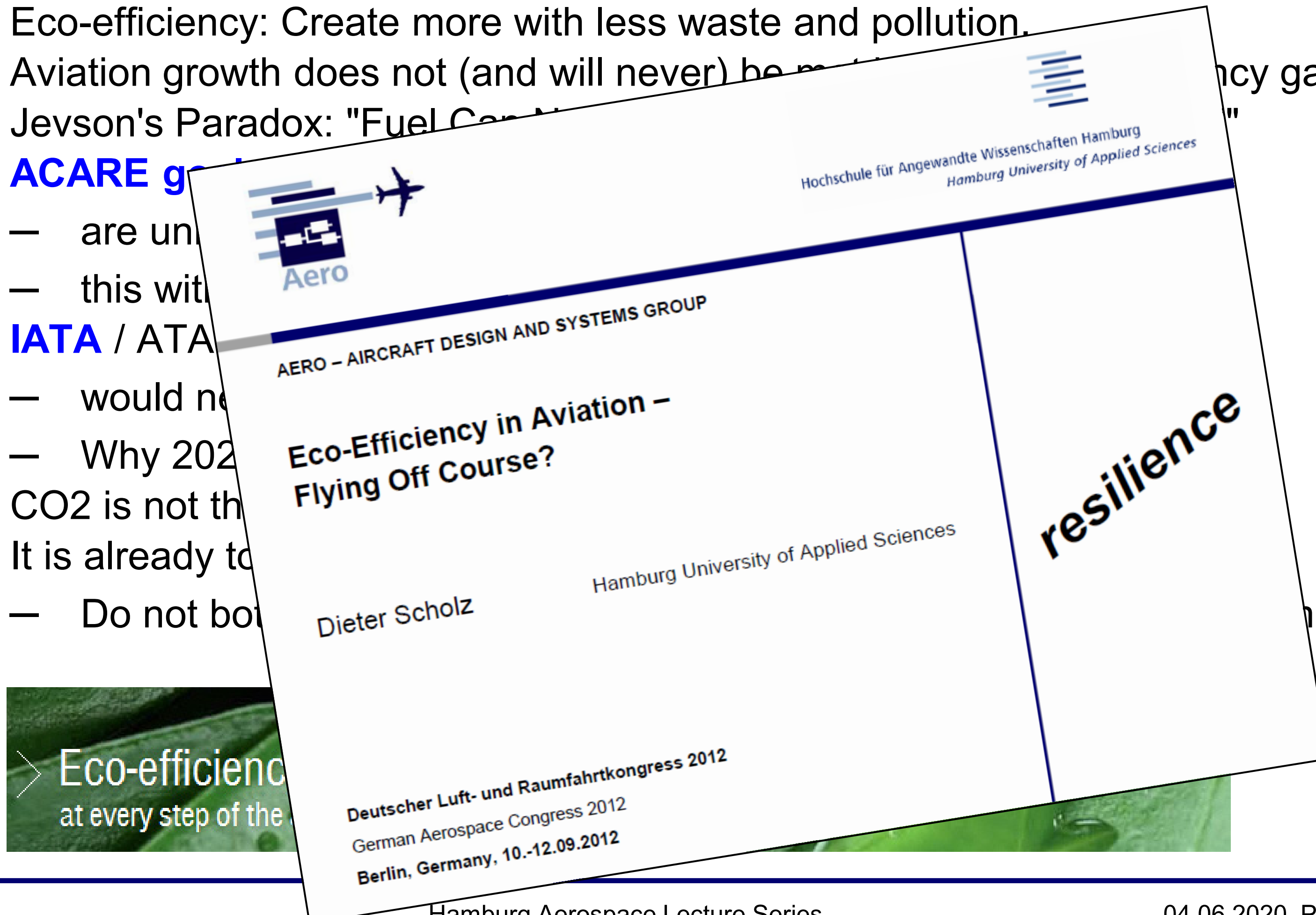

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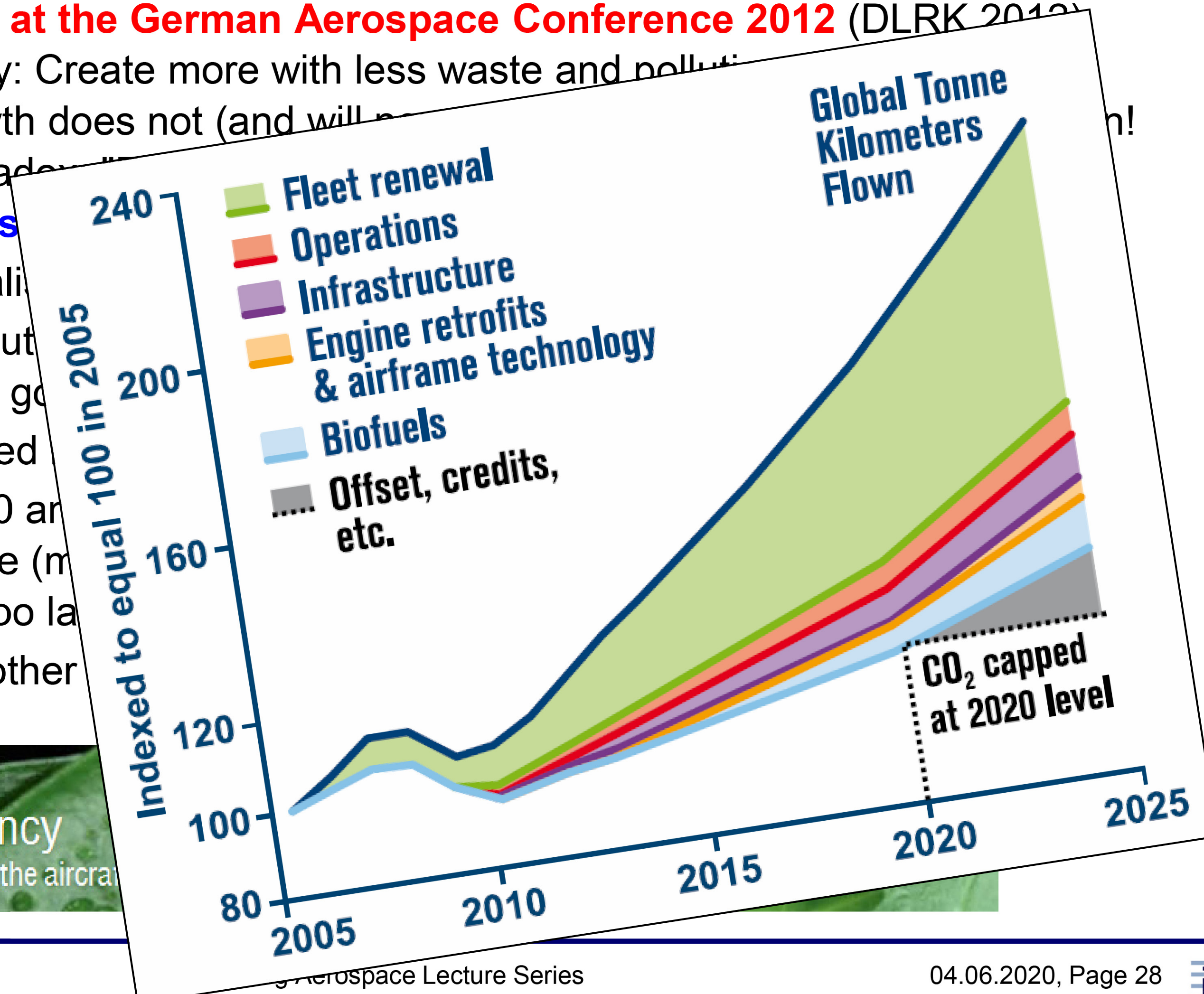

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Priorities

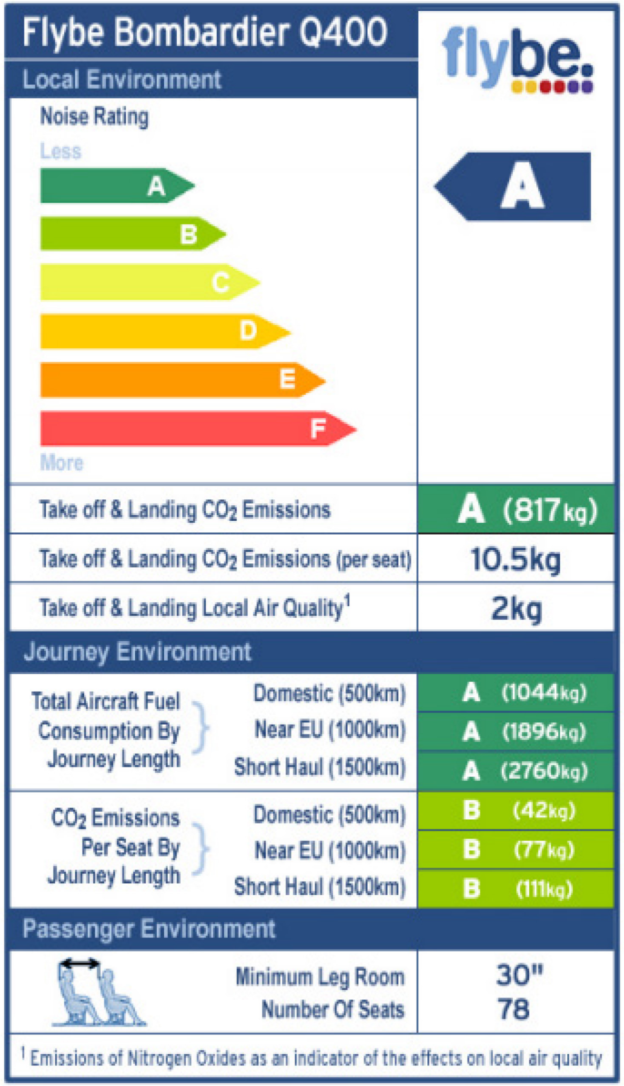
Let's get priorities right to protect the **environment**:

1. **Avoid to travel** (do something else instead)
2. For each trip select the **best mode of transportation** (aircraft, train, bus?)
3. Select the **shortest route**
4. Select the **best aircraft-airline-combination** (**based on the Ecolable for Aircraft**)
5. Select an **economy seat** and hope the **aircraft is full**.
6. **Compensate** (... or maybe just do not compensate, if you do not like the idea)

Review

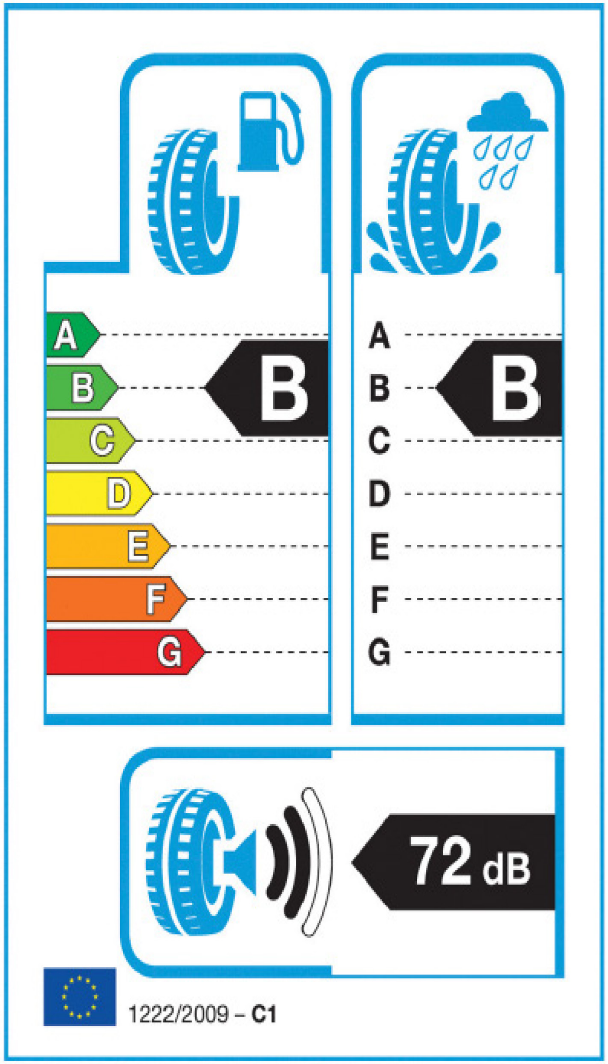
- **Flybe's Ecolable** (2007):
  - o Label not used anymore by Flybe
  - o Never used by other airlines (as intended)

  - o Detail design shows **many deficiencies**.



Review

- **Labeling of Tires** (2009):
  - o "Regulation (EC) No 1222/2009 on the labeling of tires" *
  - o An example to learn from



* http://eur-lex.europa.eu/legal-content/EN/ALL/?uri=CELEX:32009R1222

Review

- **Other schemes**

1. **ICAO Emission Calculator**

http://www.icao.int/env

2. **Atmosfair Emission Calculator**
3. **Atmosfair Airline Index**

http://www.atmosfair.de

Standards

- **ISO 14020 Series: Environmental labels and declarations**

ISO 14020:2000 Environmental labels and declarations –
General principles
ISO 14021:2016 Environmental labels and declarations –
Self-declared environmental claims (Type II environmental labeling)
ISO 14024:1999 Environmental labels and declarations –
Type I environmental labeling -- Principles and procedures
ISO 14025:2006 Environmental labels and declarations –
Type III environmental declarations -- Principles and procedures
ISO/TS 14027:2017 Environmental labels and declarations –
Development of product category rules

Type II	Used for the **traveling public**	=> **Ecolabel for Aircraft**
Type III	Used for the **experts**	=> **Full Report for Experts**

http://www.iso.org

Standards

- **ISO 14025 (Type III) for Experts => Full Report**

    - **The label has to be** voluntary
    - The label has to be **life cycle based**
    - The label has to be verifiable
    - The label has to be open for interested parties
    - The label has to be **transparent**
    - The label has to be flexible
    - The label **allows comparing** different offers
    - The label can be calculated by anyone

- **ISO 14021 (Type II) for the Travelling Public => Ecolabel derived from Report**

Standards

- **ICAO-Regulations**

ICAO Annex 16 - Volume 1: Environmental Protection – Aircraft Noise

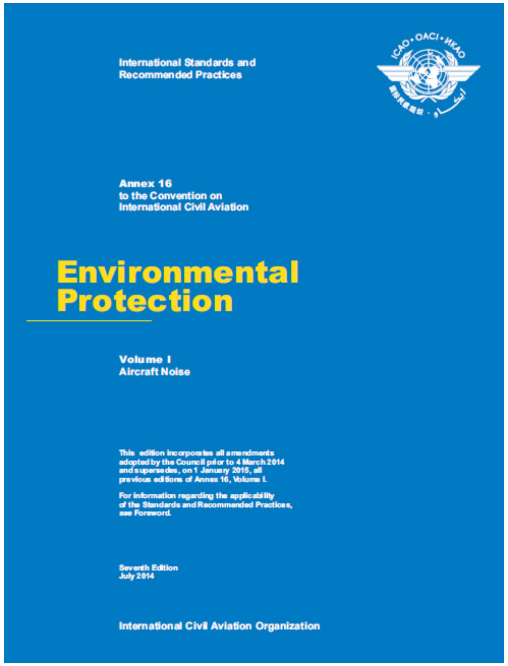
http://cockpitdata.com/Software/ICAO Annex 16 Volume 1

ICAO Annex 16 - Volume 2: Aircraft Engine Emissions – Aircraft Engine Emissions

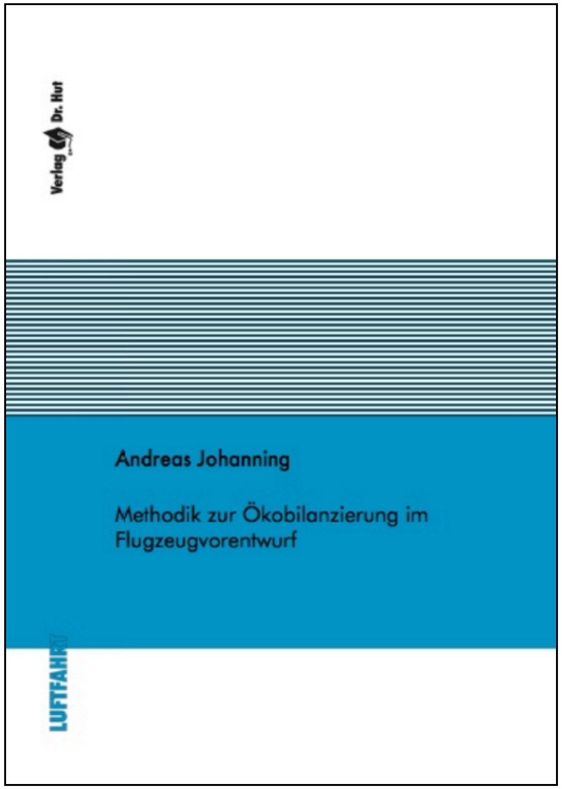
http://cockpitdata.com/Software/ICAO Annex 16 Volume 2

ICAO Annex 16 - Volume 3: Aircraft Engine Emissions – CO2 Certification Requirement

http://www.fzt.haw-hamburg.de/pers/Scholz/materialFM1/ICAO-2017_Annex16_Volume3_CO2CertificationRequirement.pdf



Life Cycle Assessment (LCA)



Johanning (2017):
Life Cycle Assessment in Aircraft Design

ISO 14040:2006
Environmental Management -- Life Cycle Assessment

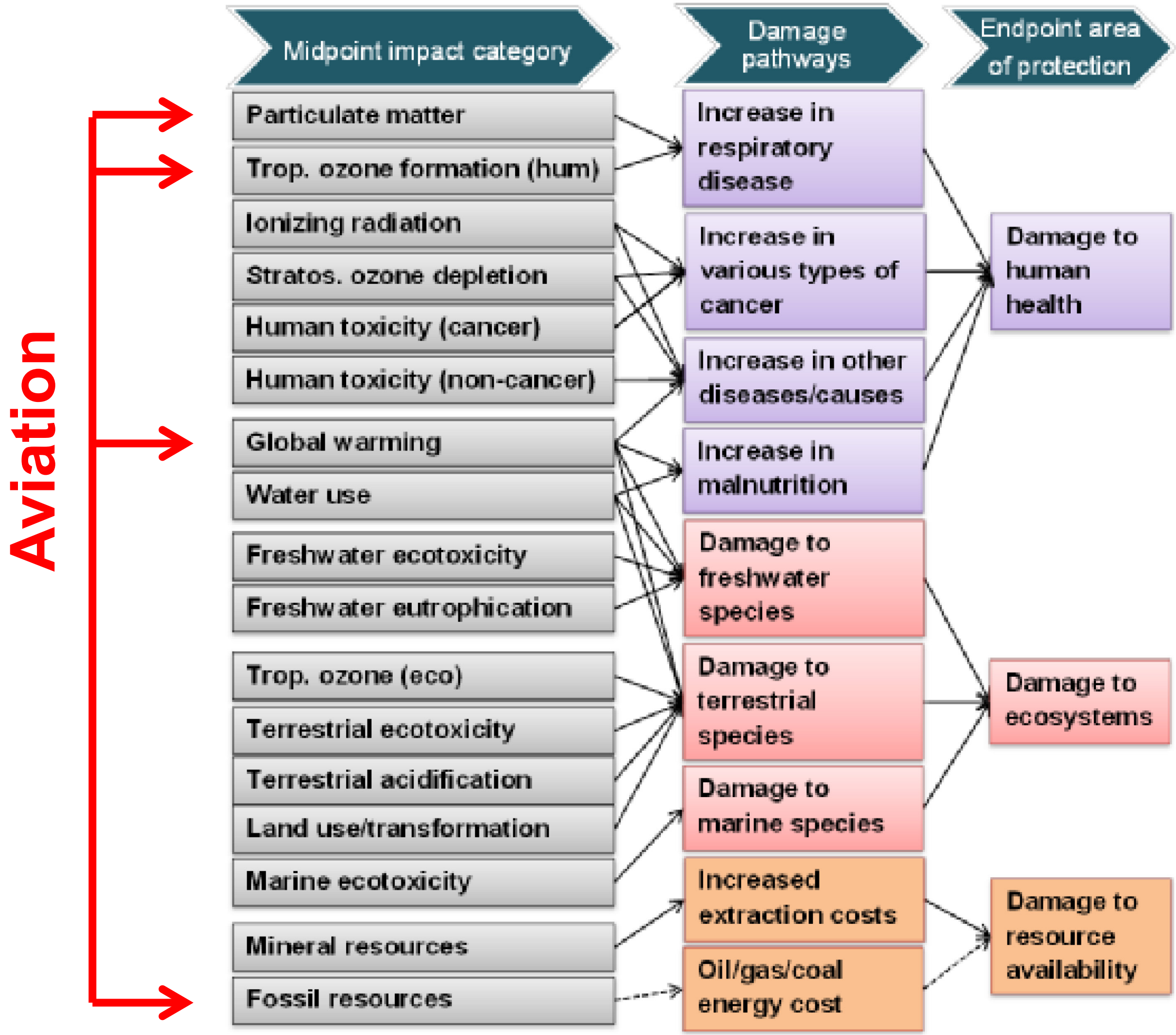
National Institute for Public Health and the Environment
Ministry of Health, Welfare and Sport
NL
http://www.lcia-recipe.net

ReCiPe

ReCiPe is a method for the impact assessment in a **Life Cycle Assessment** LCA. LCA translates emissions and resource extractions into a limited number of environmental impact scores by means of so-called characterization factors. There are two ways to derive **characterization factors**, i.e. at midpoint level and at endpoint level. ReCiPe calculates:

- **18 Midpoint Indicators**
- **3 Endpoint Indicators**
- **1 Single Score**

http://www.fzt.haw-hamburg.de/pers/Scholz/Airport2030/JOHANNING_DISS_Methodik_zur_Oekobilanzierung_im_Flugzeugvorentwurf_2017.pdf



ReCiPe

It was added to the basic Method:

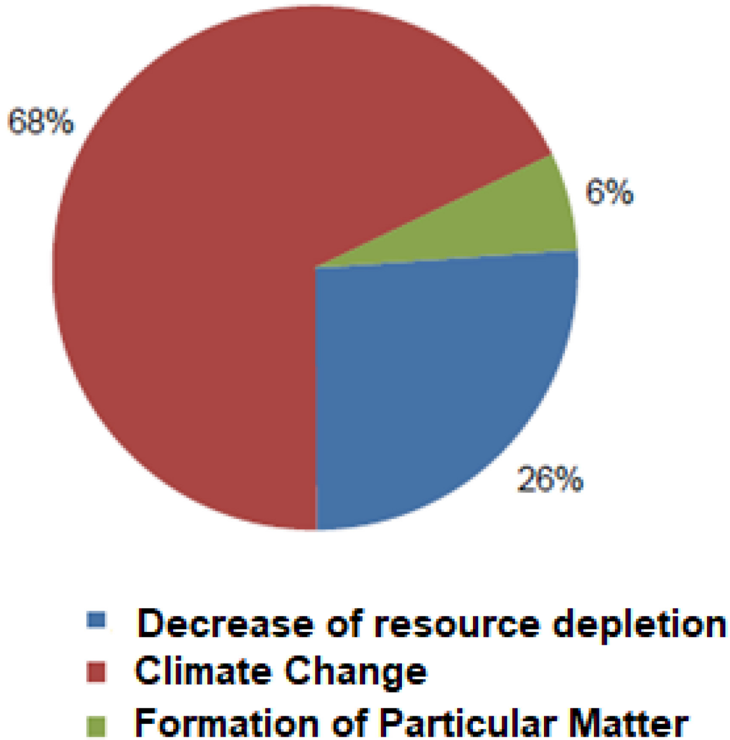
1.) by Johanning:
Altitude Dependency

2.) here:
Noice

Life Cycle Assessment (LCA)

ReCiPe – Result (A320):

Johanning (2017)



Ecolabel for Aircraft

Overall Rating:

$$
\begin{aligned}
R_{overall} = \; & 0.4 R_{warming} \\
& + 0.2 R_{depletion} \\
& + 0.2 R_{localAir} \\
& + 0.2 R_{noice}
\end{aligned}
$$

Fuel Consumption

Table 1: Summary of candidate metrics

	Full Mission Metrics				
Single parameter metric	Block Fuel ---------------- Range				
Two-parameter metric	Block Fuel ---------------- **Payload** * Range	Block Fuel ---------------- **Useful Load** * R	Block Fuel ---------------- **MTOW** * Range	Block Fuel ---------------- **Floor Area** * R	Block Fuel ---------------- **Av. Seats** * R
Three-parameter metric	Block Fuel ---------------- **Payload** * R.*Speed	Block Fuel ---------------- **Useful Load** * R.*Speed	Block Fuel ---------------- **MTOW** * R. *Speed	Block Fuel ---------------- **Floor Area***R.*Speed	Block Fuel ---------------- **Av. Seats** * R. *Speed
	Block Fuel ---------------- **Payload** * R./Time	Block Fuel ---------------- **Useful Load***R./Time	Block Fuel ---------------- **MTOW** * R./Time	Block Fuel ---------------- **Floor Area***R./Time	Block Fuel ---------------- **Av. Seats** * R./Time
	Instantaneous Performance Metrics				
Single parameter metric	1 ---------------- **Specific Air Range** = 1 ----- **SAR**				
Two-parameter metric	1 ---------------- SAR * **Payload**	1 ---------------- SAR * **Useful Load**	1 ---------------- SAR * **MTOW**	1 ---------------- SAR * **Floor Area**	1 ---------------- SAR * **Av. Seats**
Three-parameter metric	1 ---------------- SAR * **Payload** * Speed	1 ---------------- SAR * **Useful Load** * Speed	1 ---------------- SAR * **MTOW** *Speed	1 ---------------- SAR * **Floor Area*** Speed	1 ---------------- SAR * **Av. Seats** * Speed

Note: R = Range

http://partner.mit.edu/projects/metrics-aviation-co2-standard

PARTNER
Partnership for Air Transportation Noise and Emissions Reduction

Selecting a Fuel Metric:

$$1/(SAR \cdot n_{seat})$$

Fuel Consumption

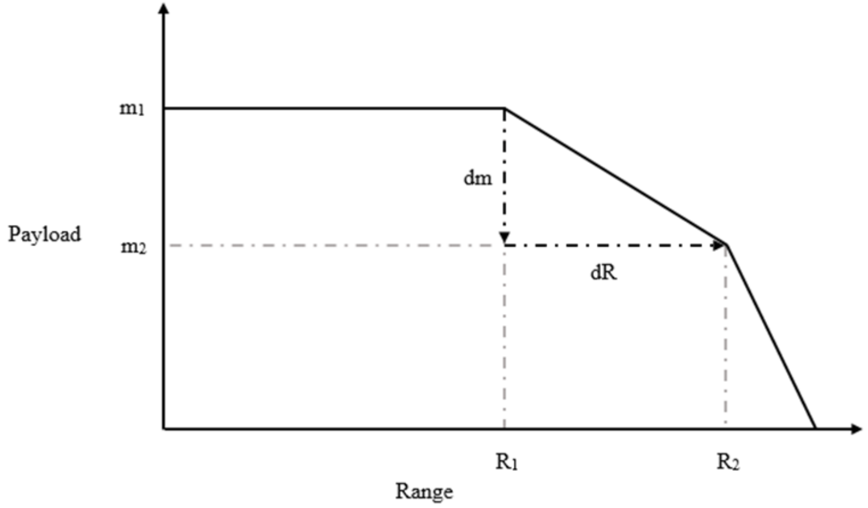
measured $$SAR = -\frac{dR}{dm} = \frac{V_{TAS}}{C_{gross}}$$

calculated $$SAR = -\frac{dR}{dm} = \frac{V \cdot E}{c \cdot g}$$

Here taken from:

Payload-Range-Diagram available from: "Documents for Airport Planning"

See: http://links.ProfScholz.de



$$SAR = -\frac{dR}{dm}$$

$$SAR = \frac{R_2 - R_1}{m_1 - m_2}$$

Fuel Consumption

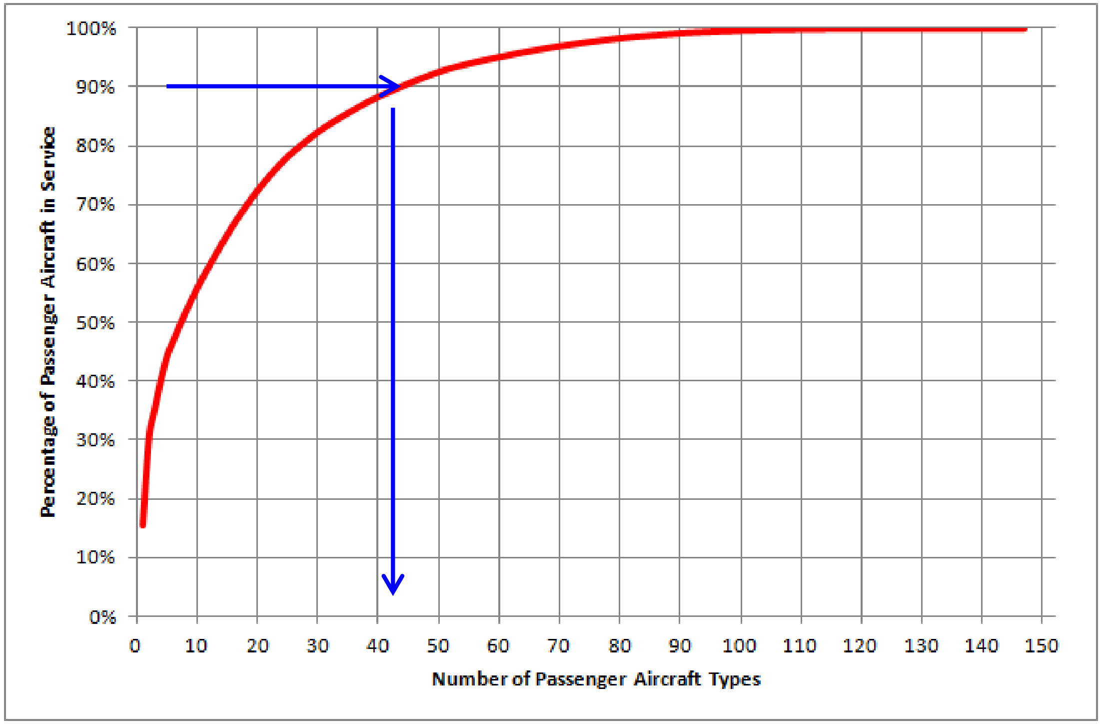
Global airliner fleet by type and operator

Airbus A300	**Total 210**
Africa	**Total 3**
Egyptair (600)	2
Egyptair (B)	1
Asia Pacific & Middle East	**Total 47**
Air Hong Kong (600)	10
Global Charter Services (B)	4
Iran Air (600)	3
Iran Air (B)	4
Mahan Air (600)	14
Mahan Air (B)	1
Meraj Air (600)	2
Qeshm Airlines (600)	4
Silk Road Cargo Business (600)	1
Unique Air (600)	2
Uni-top Airlines (600)	2
Turkish Airlines	3
North/South America	**Total 17**
Air Transat	9
FedEx	8
Airbus A318	**Total 43**
Europe	**Total 24**
Air France	18
British Airways	2
TAROM	4
North/South America	**Total 19**
Avianca	10
Avianca Brazil	9
Airbus A319	**Total 1,327 (6)**
Africa	**Total 34**
Afriqiyah Airways	2
Air Côte d'Ivoire	4
Druk Air	3
Etihad Airways	2
Lucky Air	3
Mihin Lanka	1
Myanmar Airways International	3
R Airlines	1
Rotana Jet	1
Royal Jordanian	4
Safi Airways	2
Saudia	4
Shenzhen Airlines	5
Sichuan Airlines	23
SilkAir	4
Tibet Airlines	14
Tigerair	2
West Air (China)	4
Dart Airlines	1
EasyJet	133
EasyJet Switzerland	11
Ellinair	2
Finnair	9
Germania	8
Germania Flug	2
Germanwings	43
Hamburg International	(2)
Helvetic Airways	1
Iberia	16
Lufthansa	30
Niki	5
Rossiya	26
S7 Airlines	20
SAS	4

147 different aircraft types and
26000 aircraft in database

Flight International, 2016-08-04: World Airliner Census 2016. Archived at: https://perma.cc/38XC-C74T

Fuel Consumption



$$\left(\frac{n}{n_{max}}\right)_{in\_service} = 1 - a \cdot e^{b\left(\frac{n}{n_{max}}\right)_{type}}$$

$$a = 0.748$$

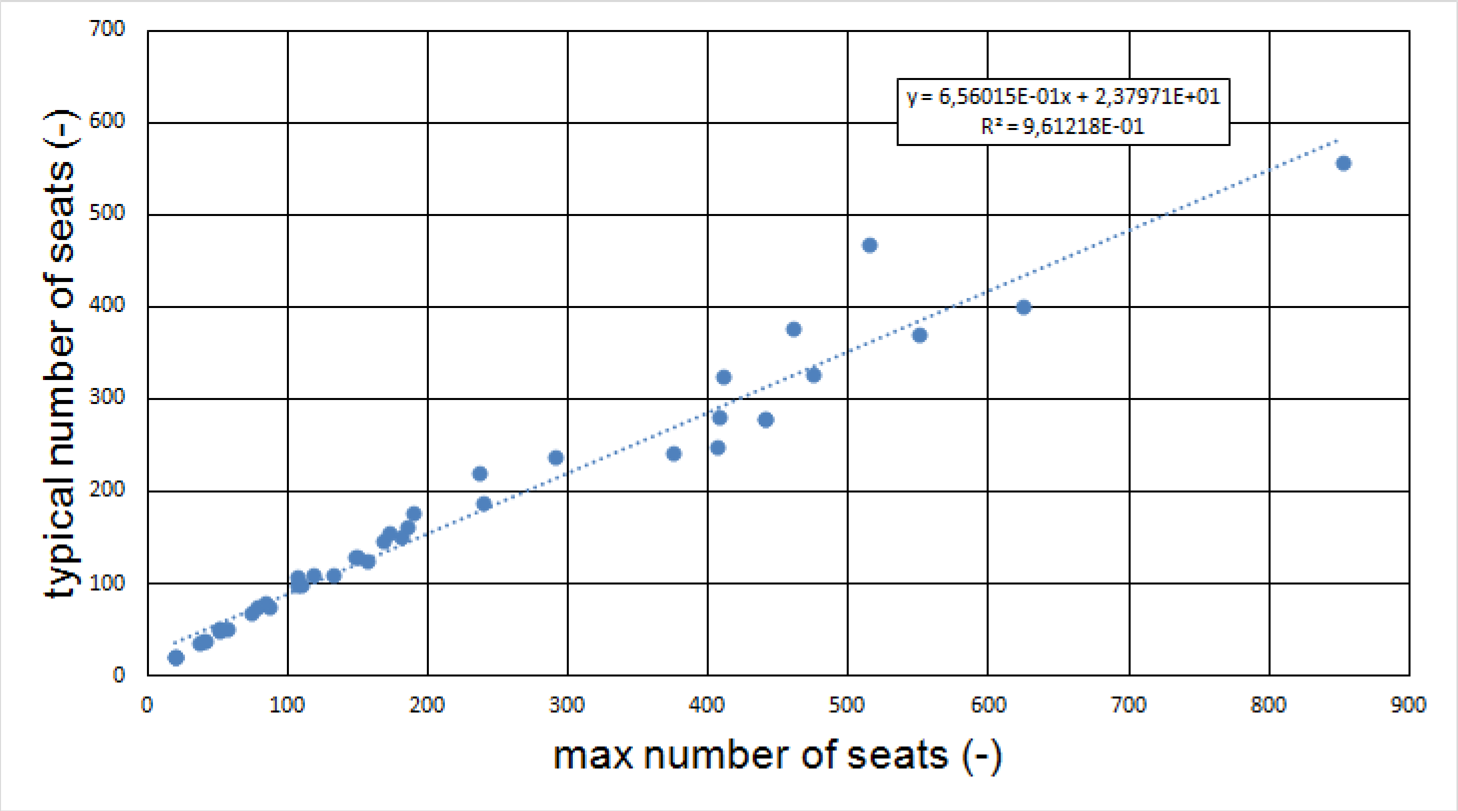
$$b = -0.0480$$

Some of the most operated 49 types where selected to describe 90% of all passenger aircraft (n_{seat} > 14).

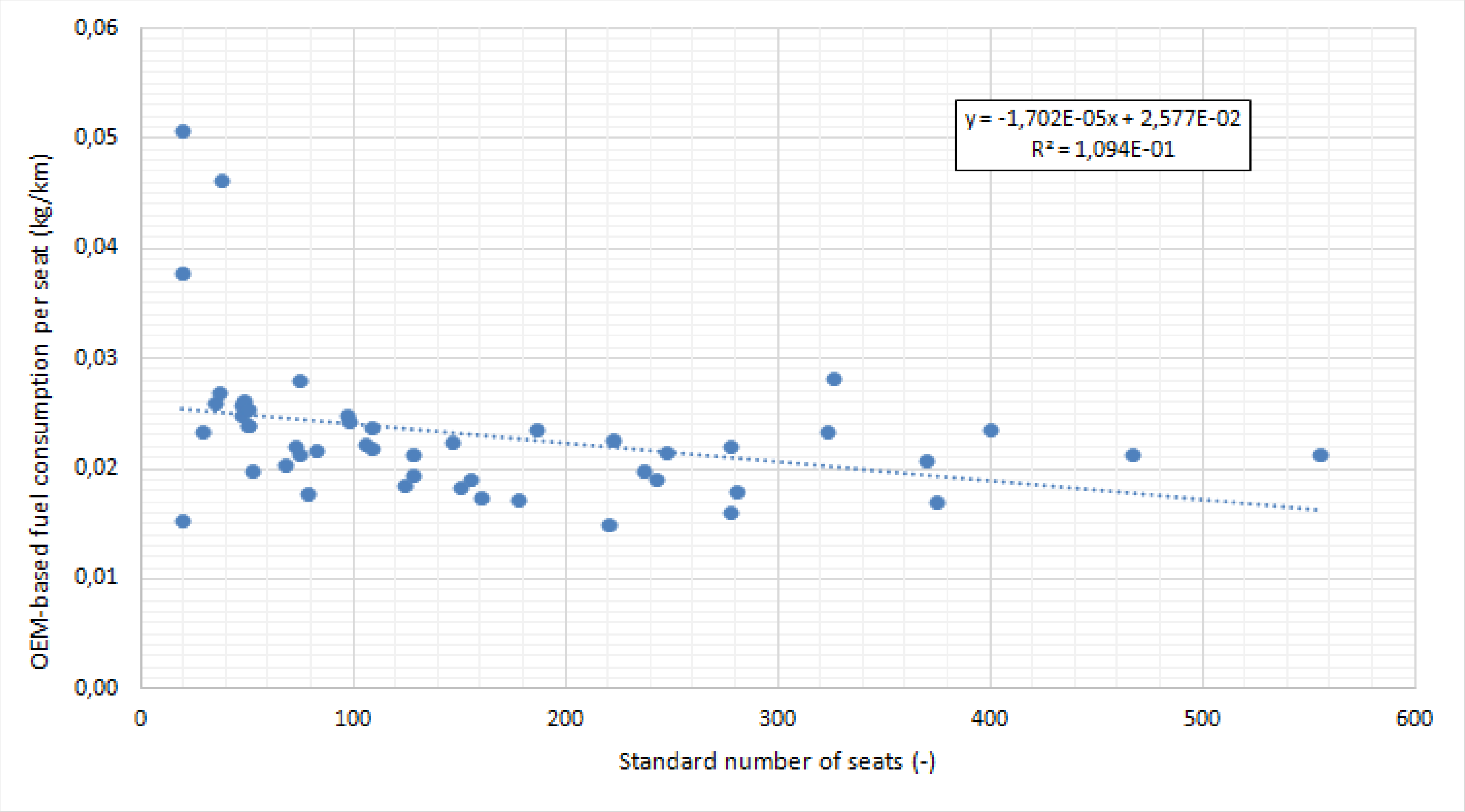
49 payload-range diagrams evaluated

Method to quickly determine cruise altitude from basic data

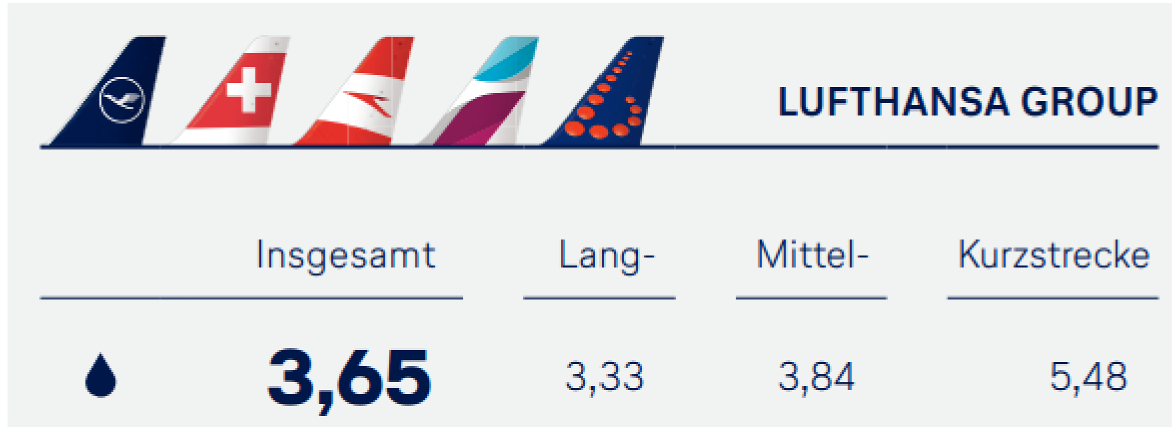
Fuel Consumption

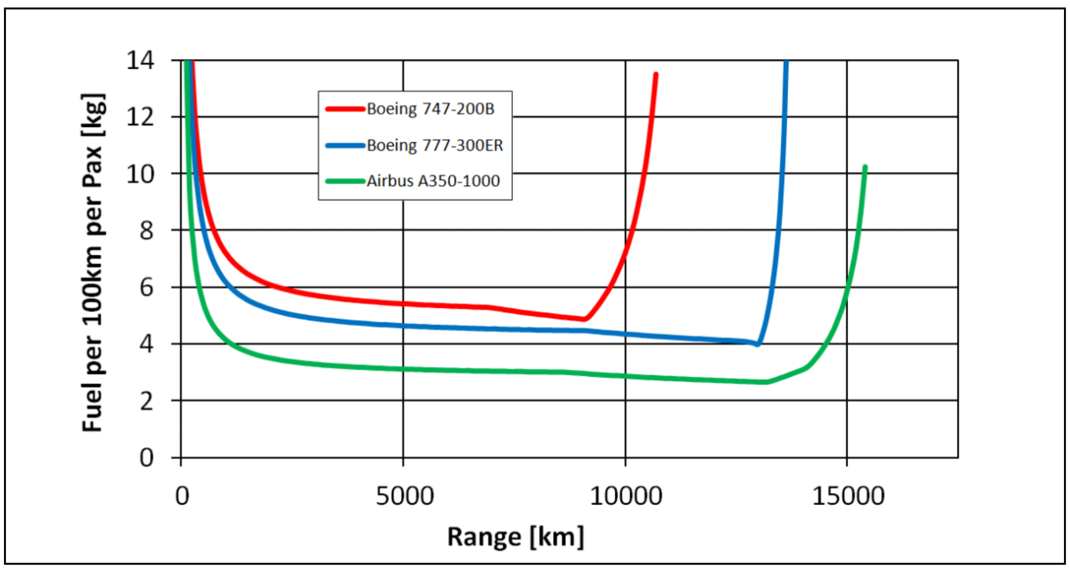


Fuel Consumption



Fuel Consumption





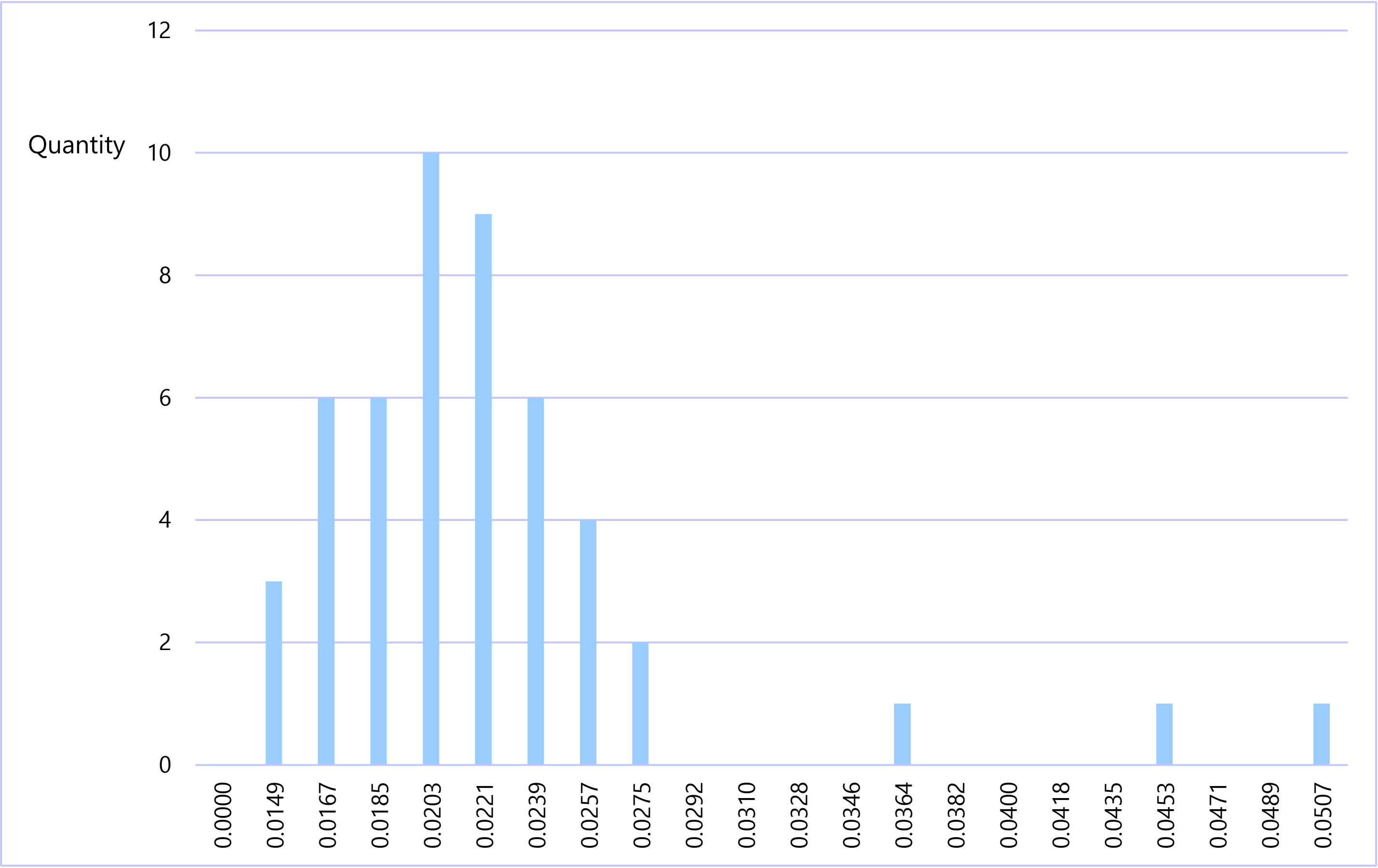
Angabe des spezifischen Treibstoffverbrauchs in **Liter/100 Passagierkilometer** (l/100pkm)

LUFTHANSA, 2019.
BALANCE – Nachhaltigkeitsbericht 2019.
https://perma.cc/L9N6-JHSR

BURZLAFF, Marcus, 2017. Aircraft Fuel Consumption - Estimation and Visualization.
https://nbn-resolving.org/urn:nbn:de:gbv:18302-aero2017-12-13.019

Fuel Consumption

21 equal intervals



Normalized OEM-based fuel consumption per seat (kg/km)

Fuel Consumption

Rating scale for the fuel consumption per seat (kg/km)

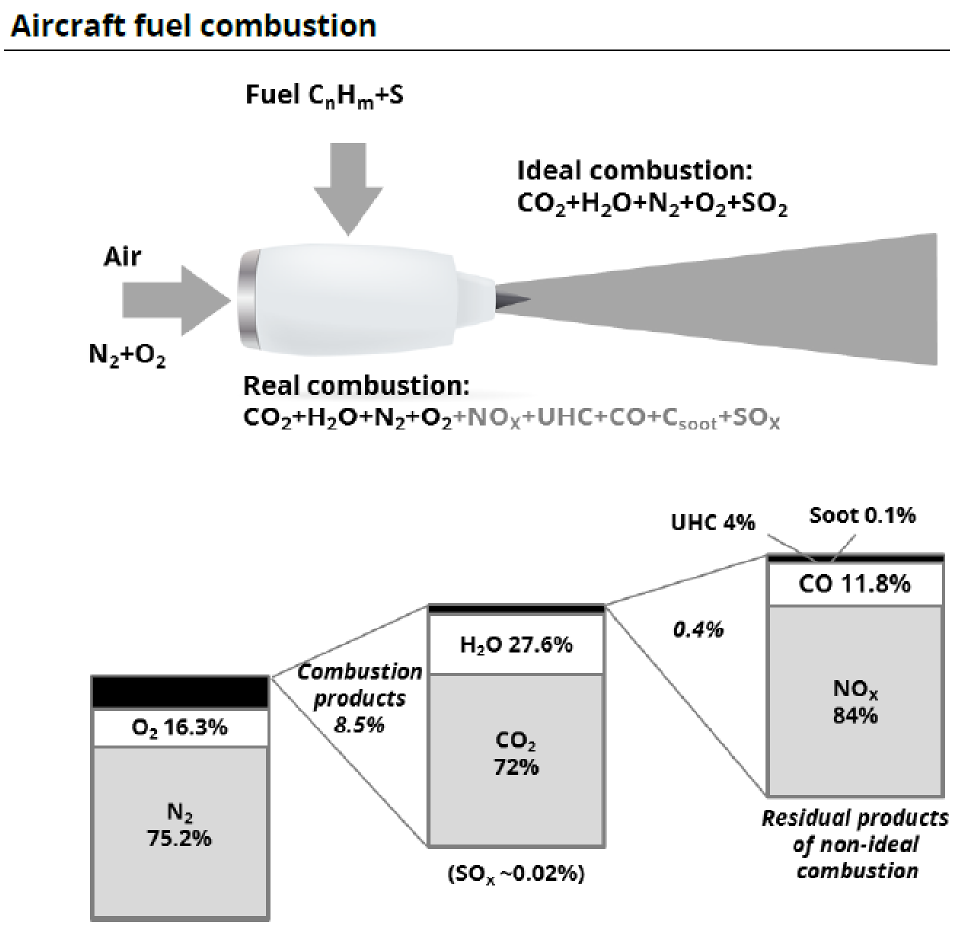
Rating	Range		Normalized to 0-1	
	min	max	min	max
A	0,01493	0,01772	0	0,0781
B	0,01772	0,01983	0,0781	0,1370
C	0,01983	0,02131	0,1370	0,1783
D	0,02131	0,02246	0,1783	0,2106
E	0,02246	0,02392	0,2106	0,2514
F	0,02392	0,02602	0,2514	0,3099
G	0,02602	0,05070	0,3099	1,000

7 unequally spaced intervals for categories A to G with the same number of aircraft in each category

Global Warming

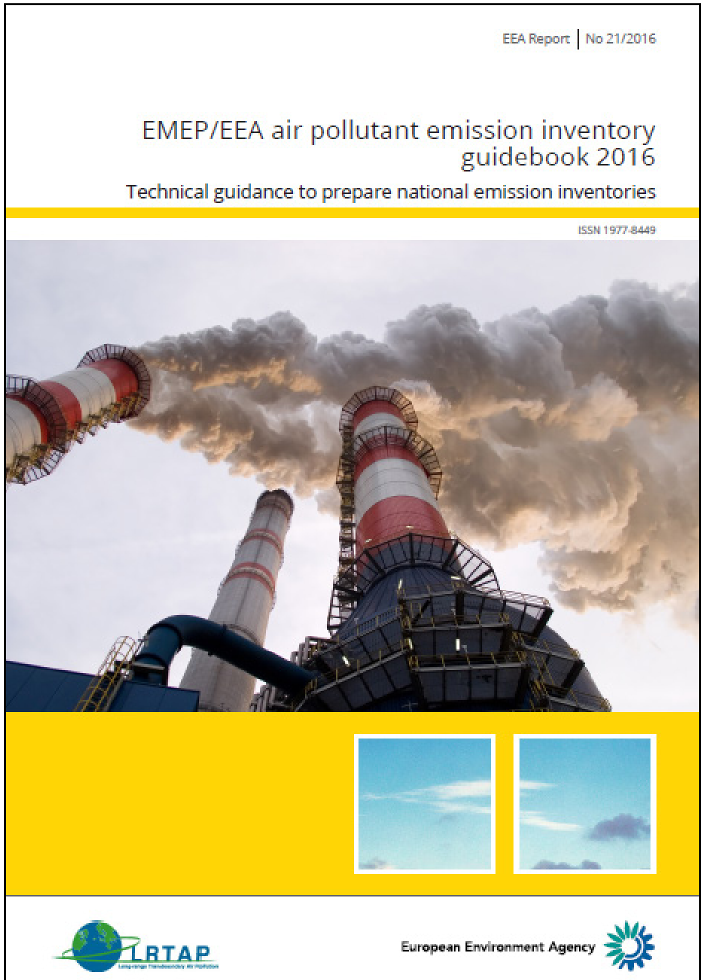
Species	Emission Index (kg/kg fuel)
CO_2	3,16
H_2O	1,23
SO_2	$2{,}00 \cdot 10^{-4}$
Soot	$4{,}00 \cdot 10^{-5}$

IPCC1999
http://www.ipcc.ch/ipccreports/sres/aviation/



EEA 2016
http://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Global Warming



European Environment Agency

European Monitoring and Evaluation Program (EMEP)
http://www.emep.int

European Environment Agency
http://www.eea.europa.eu/publications/emep-eea-guidebook-2016

Users will find two Excel files:
- Master emission calculator
- LTO emission calculator

Height (feet)	Fuel burnt	NO_x, UHCs and CO	CO_2, H_2O and SO_x	VOCs
> 3 000 CCD	BADA	BFFM2	Proportional to the mass of fuel burnt	Proportional to the mass of UHCs generated
≤ 3 000	AEED and other databases			

Global Warming

LRTAP

Aviation emissions calculator. File to accompany
Chapter 1.A.3.a 'Aviation' of the 'EMEP/EEA air pollutant emission inventory guidebook 2016'

European Environment Agency

Disclaimer: The fuel burnt and emission data provided in this spreadsheet are for supporting the European Union and EU Member States in the maintenance and provision of European and national emission inventories. These data should not be used for comparing fuel efficiency and emission data between aircraft models and manufacturers. Fuel burn and emission data in this spreadsheet are modelled estimates and not 'absolute' values. The engine associated to each aircraft type is the most common type of engine used for each aircraft type in 2015. Please refer to Annex 4 'EUROCONTROL fuel burn and emissions inventory system' in the aviation chapter of the 'EMEP/EEA air pollutant emission inventory guidebook 2016' for a description of the method used to produce these data.

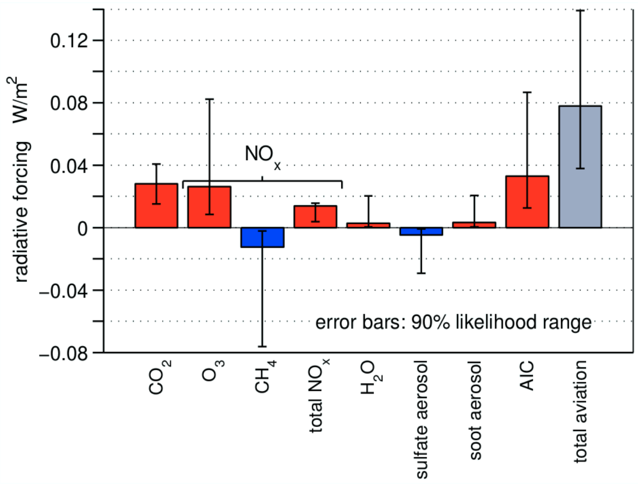
	Aircraft code - designators provided in separate worksheet	Manufacturer	AIRBUS INDUSTRIE	Engine type	Jet
SELECT →	A320	One of the models associated with this aircraft type	A320 233	The most common engine ID in 2015 used for modelling this aircraft type	3CM026
		Category	Landplane	Number of engines	2

Default LTO (1) cycle (hh:mm:ss)		
Phases	ICAO default	Default for a busy European airport, year 2015
Taxi	00:26:00	00:20:06
Take off	00:00:42	00:00:42
Climb out	00:02:12	00:02:12
Approach	00:04:00	00:04:00
TOTAL	**00:32:54**	**00:27:00**

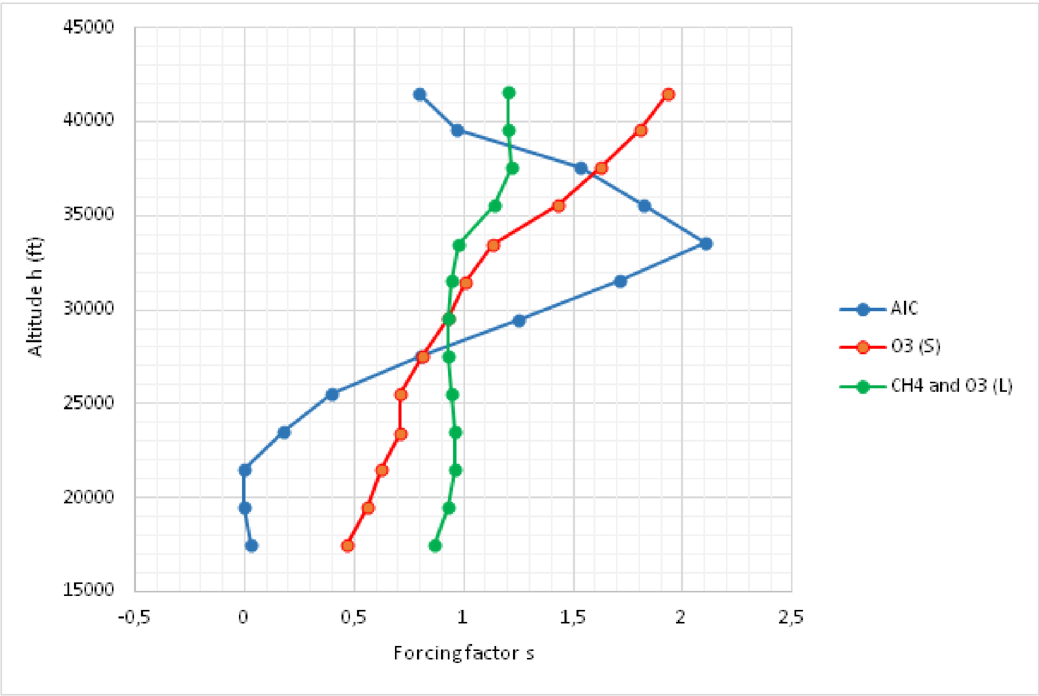
Estimated parameters (based on year 2015)

Aircraft type	A320 / AIRBUS INDUSTRIE	Most frequently observed cruise flight level (100 ft)	Duration (hh:mm:ss)	Fuel burn (kg)	CO_2 (kg)	NO_x (kg)	SO_x (kg)	H_2O (kg)	CO (kg)	HC (kg)	PM non volatile (kg)	PM volatile (organic + sulphurous) (kg)	PM TOTAL (kg) (3)
Default LTO (1) cycle	Default for a busy European airport, year 2015		00:27:00	742,54	2 338,99	10,97	0,62	913,32	6,52	1,30	0,0066	0,0536	0,0602
	ICAO default		00:32:54	816,17	2 570,93	11,28	0,69	1 003,89	8,25	1,64	0,0067	0,0593	0,0661
ENTER → Enter a CCD (2) stage length (NM)	300	280	00:44:21	1 907,10	6 007,38	33,60	1,60	2 345,74	5,48	1,14	0,0250	0,1912	0,2163
TOTAL LTO + CCD 300 nm.			**01:17:15**	**2 723,27**	**8 578,31**	**44,88**	**2,29**	**3 349,63**	**13,72**	**2,77**	**0,0318**	**0,2505**	**0,2823**

Global Warming



IPCC 1999



Schwartz 2009

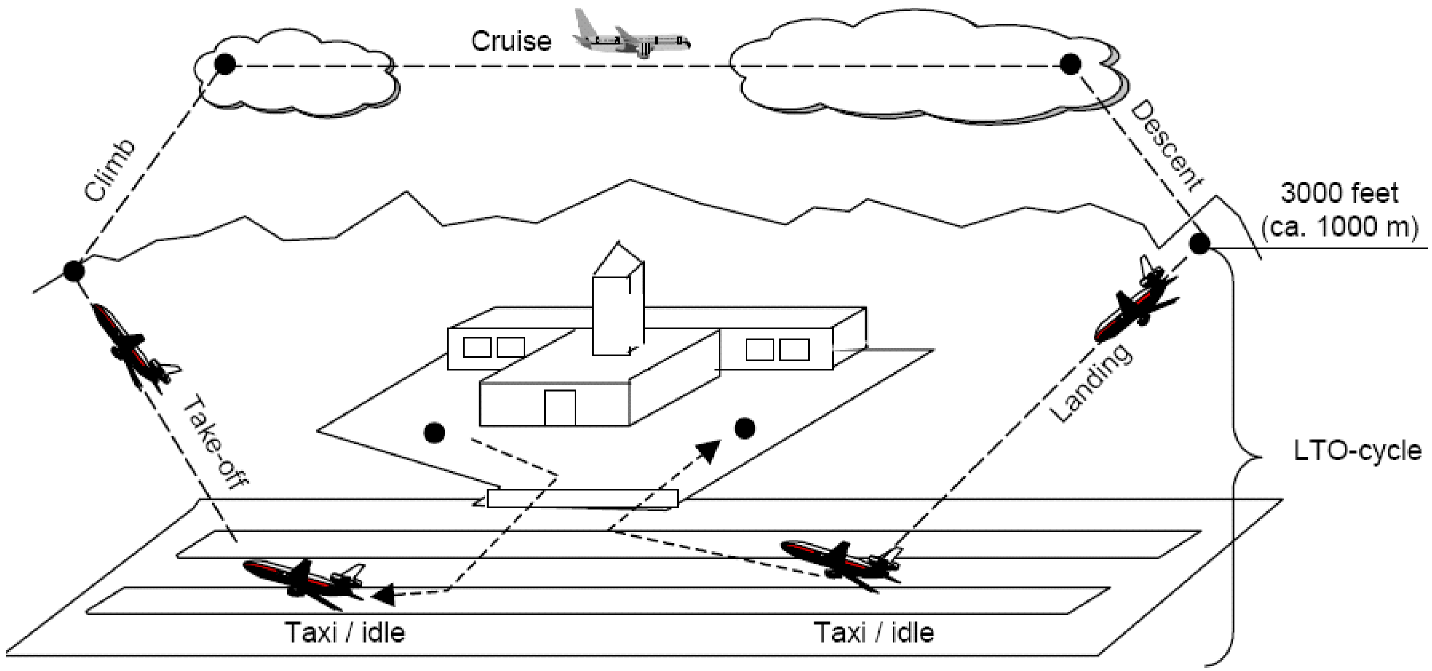
http://www.enu.kz/repository/2009/AIAA-2009-1261.pdf

... more details ...

This added to
ReCiPe
to include the
Altitude Dependency

HAW HAMBURG

Local Air Quality



Definition of the landing and take-off cycle (LTO)

Local Air Quality

Aviation LTO emissions calculator. File to accompany:
Chapter 1.A.3.a 'Aviation' of the 'EMEP/EEA Air Pollutant Emission Inventory Gu

European Environment Agency

Disclaimer: The fuel burnt and emission data provided in this spreadsheet are for supporting the European Union and the Member States of the European Environment Agency in the maintenance and provision of European and national emission inventories. These data should not be used for comparing fuel efficiency and emission data between aircraft types and/or manufacturers. Fuel burn and emission data in this spreadsheet are modelled estimates and not "absolute" values. Where only one type of engine is associated with a particular aircraft type, it is the most common type of engine (as seen in Europe), or the best equivalent type of engine, for that aircraft type. Where several types of engine are associated with a particular aircraft type, the most-common type of engine is marked with "". Please refer to Annex 4 'EUROCONTROL fuel burn and emissions inventory system' in the aviation chapter of the 'EMEP/EEA Air Pollutant Emission Inventory Guidebook 2016' for a description of the method used to produce these data.

Enter aircraft and airport details here (using the drop-down menus in the dark blue boxes)

1) Type of aircraft: A320 (Airbus A-320) with 1CM008 engines

2) Airport
- a) Country: United_Kingdom
- b) Airport: LXGB (Gibraltar International Airport, GIBRALTAR)
- c) Year: 2009

See general engine details here:

- Engine type code: 1CM008
- Engine type name: CFM56-5-A1
- Type of engine: Turbofan/turbojet
- Number of engines: 2

See airport annual average taxi times here

- Taxi out time (s): 712
- Taxi in time (s): 324

See engine fuel burn and emissions data here

	Engine thrust setting (% of maximum thrust)			
	7	30	85	100
Rate of fuel burn (kg/s/engine)	0.1011	0.2910	0.8620	1.051
Rate of emission of CO[2] (kg/s/engine)	0.001779	0.0007275	0.0007758	0.0009459
Rate of emission of HC[3] (kg/s/engine)	0.0001415	0.0001164	0.0001983	0.0002417
Rate of emission of NOX[4] (kg/s/engine)	0.0004044	0.002328	0.01690	0.02585

1 There are no turboprop-engined aircraft.
2 CO is carbon monoxide.
3 HC is unburnt hydrocarbons.
4 NOX are mono-nitrogen oxides (NO and NO_2)

See LTO cycle fuel burnt and emissions totals here

	LTO cycle total												
	Departure phase total						Arrival phase total						
	Taxi out			Take off	Climb out		Approach+landing	Taxi in					
	Average taxi-out time for the selected airport and	ICAO default taxi-out time (=1140 s)	Average taxi-out time for the 25 busiest airports in					Average taxi-in time for the selected airport and	ICAO default taxi-in time (=420 s)	Average taxi-in time for the 25 busiest airports in			
	[7% thrust]			[100% thrust]	[85% thrust]		[30% thrust]	[7% thrust]					
Mass of fuel burnt (kg)	143,941	[illegible]	[illegible]	88,284	227,568	459,793	139,680	65,518	[illegible]	[illegible]	205,198	664,991	Mass of fuel burnt (kg)
Mass of CO emitted (kg)	2,533	[illegible]	[illegible]	0,079	0,205	2,817	0,349	1,153	[illegible]	[illegible]	1,502	4,319	Mass of CO emitted (kg)
Mass of HC emitted (kg)	0,201	[illegible]	[illegible]	0,020	0,052	0,274	0,056	0,092	[illegible]	[illegible]	0,148	0,422	Mass of HC emitted (kg)
Mass of NOX emitted (kg)	0,576	[illegible]	[illegible]	2,171	4,462	7,209	1,117	0,262	[illegible]	[illegible]	1,380	8,588	Mass of NOX emitted (kg)
Mass of CO_2 emitted (kg)	453,415	[illegible]	[illegible]	278,095	716,839	1448,348	439,992	206,382	[illegible]	[illegible]	646,374	2094,723	Mass of CO2 emitted (kg)

Local Air Quality

Characterization factors of ReCiPe

Midpoint category	NO_x	SO_2	PM	CO	HC
Photochemical oxidant formation (ozone)	1	0,081	-	0,046	0,476
Particulate matter formation	0,22	0,20	1	-	-

... more details ...

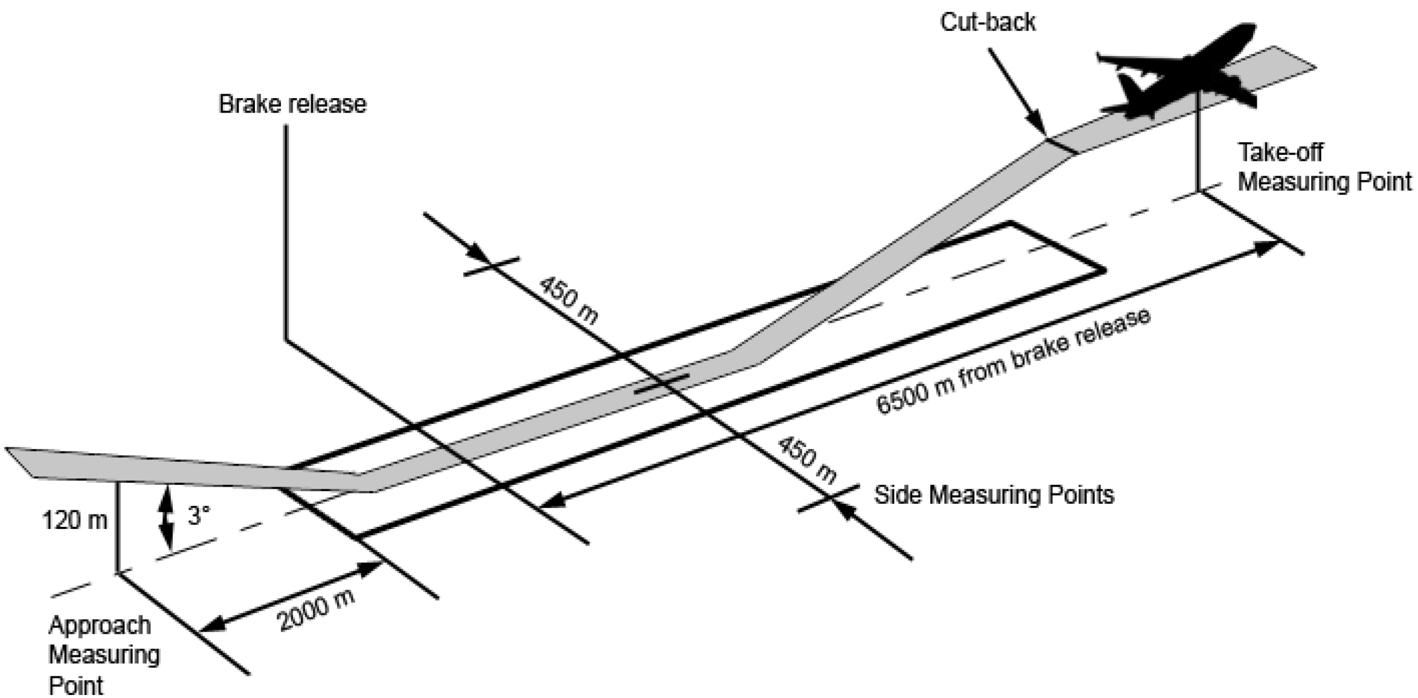
Ozone : $$NMVOC_{LTO} = 1 \cdot (NO_x)_{LTO} + 0{,}081 \cdot (SO_2)_{LTO} + 0{,}046 \cdot (CO)_{LTO} + 0{,}476 \cdot (HC)_{LTO}$$

PM : $$(PM_{equivalents})_{LTO} = 0{,}22 \cdot (NO_x)_{LTO} + 0{,}20 \cdot (SO_2)_{LTO} + 1 \cdot (PM)_{LTO}$$

$(PM)_{LTO}$ calculated from "smoke number"

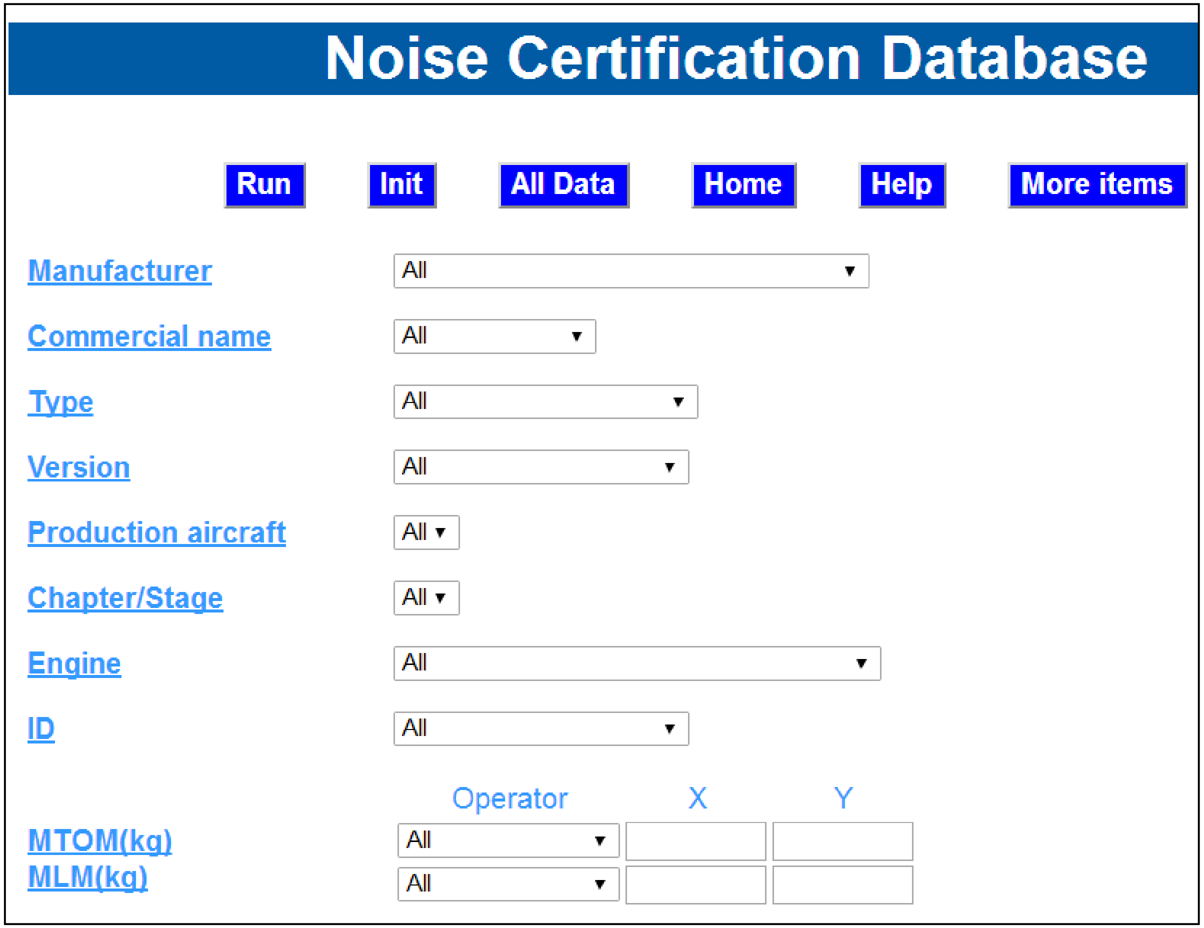
But: Only NOx enters the overall rating

Noise



Reference points for the noise measurement

Noise



Noise Certification Database

... more details ...

http://noisedb.stac.aviation-civile.gouv.fr

HAW HAMBURG

The Tool

General Information	
Aircraft type	A320
Airline	Aeroflot
Engine type	CFM56-5B4/P
Thrust (kN)	120,1
MTOW (kg)	75500
Amount of Seats	140

Travel Class Rating			
Class	Pitch (in)	Width (in)	Seats
Economy	31	18	120
premium economy	0	0	0
Business	38	21	20
First	0	0	0
Total amount of seats			140
S_{EC} (in^2)			558
S_{PEC} (in^2)			0
S_{BC} (in^2)			798

Noise Rating Jets			
	Lateral	Flyover	Approach
Noise Level (EPNdB)	93,5	84,7	95,5
Noise Limit (EPNdB)	96,9	91,6	100,6
Level/Limit	0,964912281	0,924672489	0,949304175
Average	0,9463		
Normalized 0-1	0,7040		

... more details ...

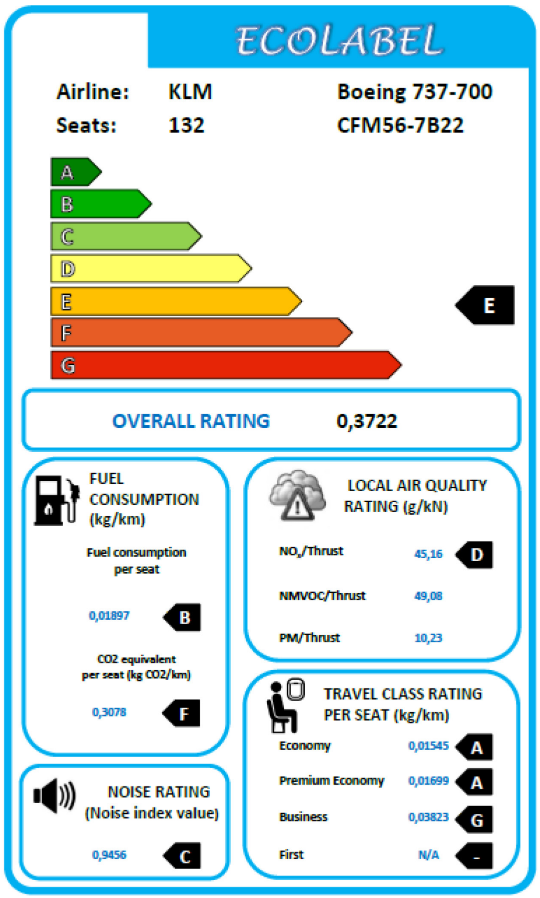
Local Air Quality Rating	
Fuel LTO cycle (kg)	408
LTO NO_x (g)	5641
LTO SO_x (g)	81,6
LTO HC (g)	818
LTO CO (g)	4123
Smoke number T/O	5,4
Smoke number C/O	4,1
Smoke number App	0,2
Smoke number Idle	0,5
Fuel Flow T/O (kg/sec)	1,132
Fuel Flow C/O (kg/sec)	0,935
Fuel Flow App (kg/sec)	0,312

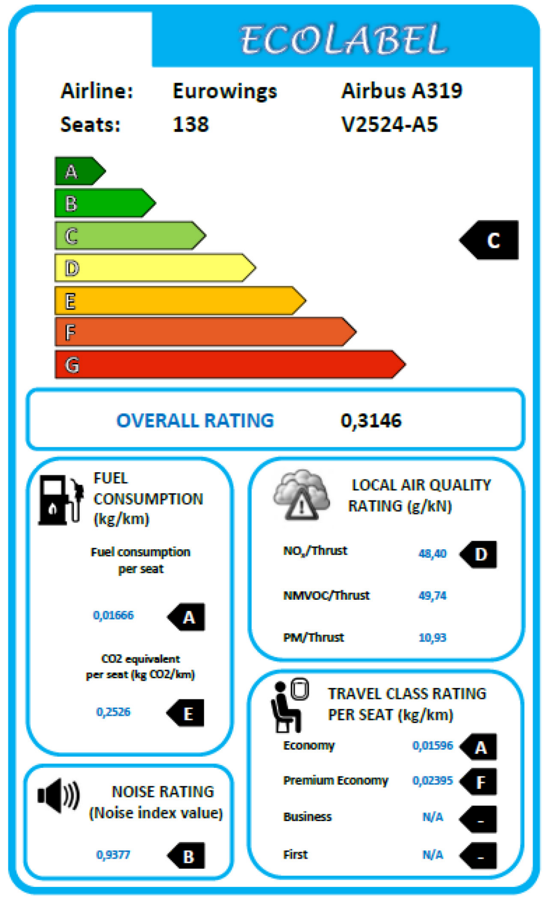
... more details ...

Fuel Consumption Rating	
R_1 (km)	3882
m_1 (kg)	19750
R_2 (km)	5200
m_2 (kg)	16125
dr (km)	1318
dm (kg)	3625
1/SAR (kg/km)	2,750379363
Fuel consumption (kg/km/seat)	0,01965
Normalized 0-1	0,1318

Ecolabels for Aircraft – Application of the Tool

Same Aircraft Size from Different Manufacturers – Boeing 737 Family vs. Airbus A320 Family





Same Aircraft Size from Different Manufacturers – Boeing 737 Family vs. Airbus A320 Family

Comparison of Boeing 737-700 vs. Airbus A319

Aircraft type **Airline**	**Boeing 737-700** **KLM**		**Airbus A319** **Eurowings**	
Engine type	CFM56-7B22		V2524-A5	
Overall rating	0.3722	(E)	0.3146	(C)
Fuel consumption				
Fuel consumption per seat	0.01897	(B)	0.01666	(A)
CO_2 equivalent per seat (kg CO_2 / km)	0.3078	(F)	0.2526	(E)
Local air quality				
NO_X / thrust (g / kN)	45.16	(D)	48.40	(D)
NMVOC / thrust (g / kN)	49.08		49.74	
PM / thrust (g / kN)	10.23		10.93	
Noise rating				
Noise index value	0.9456	(C)	0.9377	(B)
Travel class rating				
Economy (kg / km)	0.01545	(A)	0.01596	(A)
Premium economy (kg / km)	0.01699	(B)	0.02395	(F)
Business (kg / km)	0.03823	(G)	-	

Fleet Comparison – KLM vs. Lufthansa

$$AR = \frac{\sum N_{A/C,i} S_{A/C,i} O_{A/C,i}}{\sum N_{A/C,i} S_{A/C,i}}$$

- AR: airline rating
- $N_{A/C}$: number of aircraft type in fleet
- $S_{A/C}$: number of seats per aircraft
- $O_{A/C}$: overall aircraft rating
- i: ID

Fleet Comparison – KLM vs. Lufthansa

KLM aircraft fleet

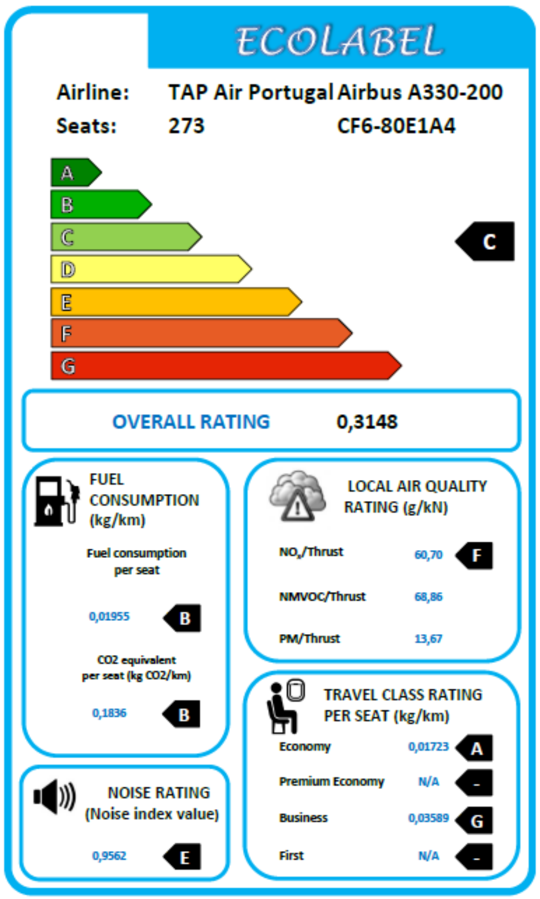
ID (I)	Aircraft type	No. of A/C (*N*)	Seats per A/C (*S*)	Overall rating (*O*)	*N S*	*N S O*
1	Airbus A330-200	8	268	0.3217	2144	712.88
2	Airbus A330-300	5	292	0.2810	1460	410.26
3	Boeing 737-700	18	132	0.3722	2376	835.64
4	Boeing 737-800	27	170	0.3008	4590	1381.13
5	Boeing 737-900	5	178	0.3382	890	300.99
6	Boeing 747-400	15	408	0.3198	6120	2003.69
7	Boeing 777-200ER	15	316	0.3327	4740	1471.29
8	Boeing 777-300ER	14	408	0.3042	5712	1699.32
9	Boeing 787-9	11	294	0.2160	3234	641.95
				∑:	**31266**	**9637.04**
				Average Rating		**0.3082 (C)**

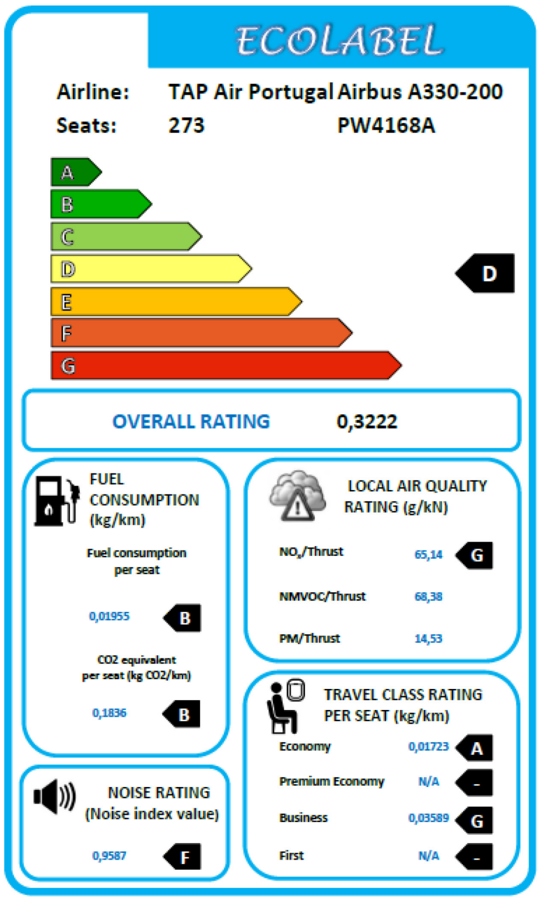
Fleet Comparison – KLM vs. Lufthansa

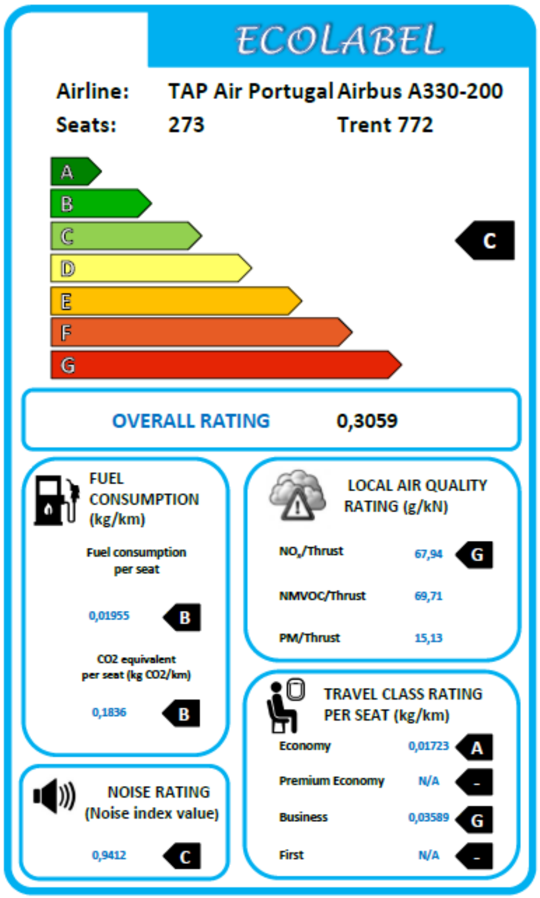
Lufthansa aircraft fleet

ID (I)	Aircraft type	No. of A/C (N)	Seats per A/C (S)	Overall rating (O)	$N\,S$	$N\,S\,O$
1	Airbus A319	30	122	0.3601	3660	1317.97
2	Airbus A320	68	166	0.3121	11288	3522.98
3	Airbus A320neo	10	166	0.2201	1660	365.37
4	Airbus A321	63	190	0.3342	11970	4000.37
5	Airbus A330-300	19	255	0.2998	4845	1452.53
6	Airbus A340-300	17	298	0.3067	5066	1553.74
7	Airbus A340-600	20	281	0.4425	5620	2486.85
8	Airbus A350-900	8	319	0.2303	2552	587.73
9	Airbus A380-800	14	509	0.3117	7126	2221.17
10	Boeing 747-400	13	371	0.3457	4823	1667.31
11	Boeing 747-8	19	364	0.3093	6916	2139.12
				∑:	**65526**	**21315.14**
				Average Rating		**0.3253 (D)**

Engine Comparison on Same Aircraft – TAP Airbus A330-200





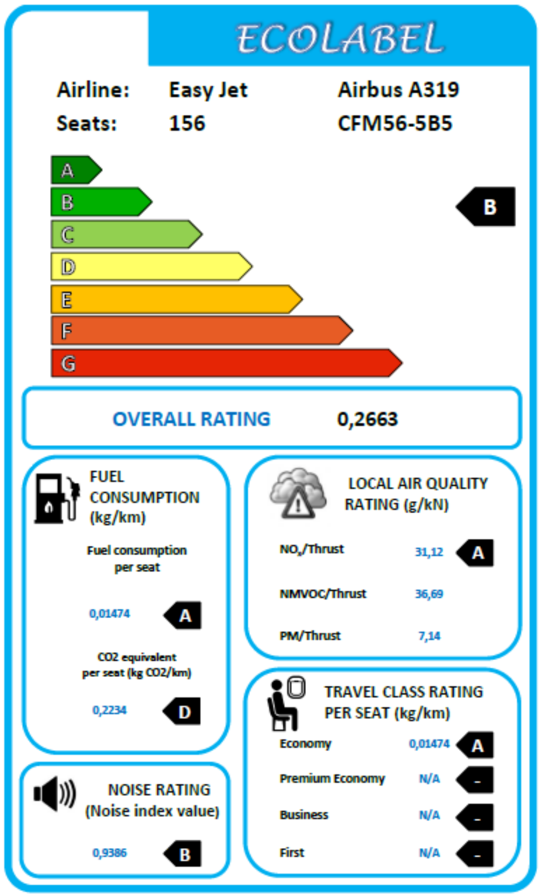


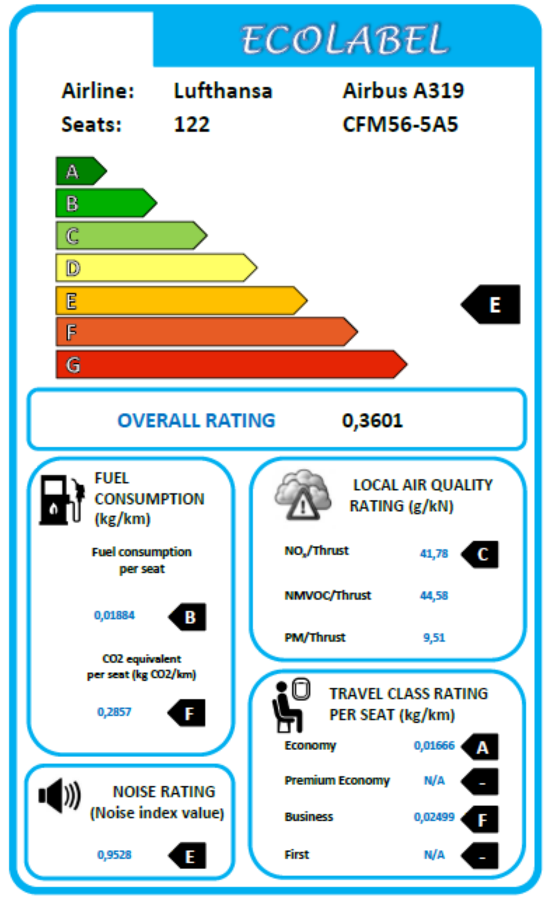
Engine Comparison on Same Aircraft – TAP Airbus A330-200

Ecolabel comparison on A330-200 TAP Portugal with three different engine types

Engine type	**CF6-80E1A4**	**(1)**	**PW4168A**	**(2)**	**Trent 772**	**(3)**
Overall rating	0.3148	(C)	0.3222	(D)	0.3059	(C)
Fuel consumption						
Fuel consumption per seat	0.01955	(B)	0.01955	(B)	0.01955	(B)
CO_2 equivalent per seat ($kg\ CO_2$ / km)	0.1836	(B)	0.1836	(B)	0.1836	(B)
Local air quality						
NO_X / thrust (g / kN)	60.7	(F)	65.14 (G)		67.94 (G)	
NMVOC / thrust (g / kN)	68.86		68.38		69.71	
PM / thrust (g / kN)	13.67		14.53		15.13	
Noise rating						
Noise index value	0.9562	(E)	0.9587	(F)	0.9412	(C)
Travel class rating						
Economy (kg / km)	0.01723	(A)	0.01723	(A)	0.01723	(A)
Business (kg / km)	0.03589	(G)	0.03589	(G)	0.03589	(G)

Low Cost Carrier vs. Legacy Carrier – Easy Jet vs. Lufthansa



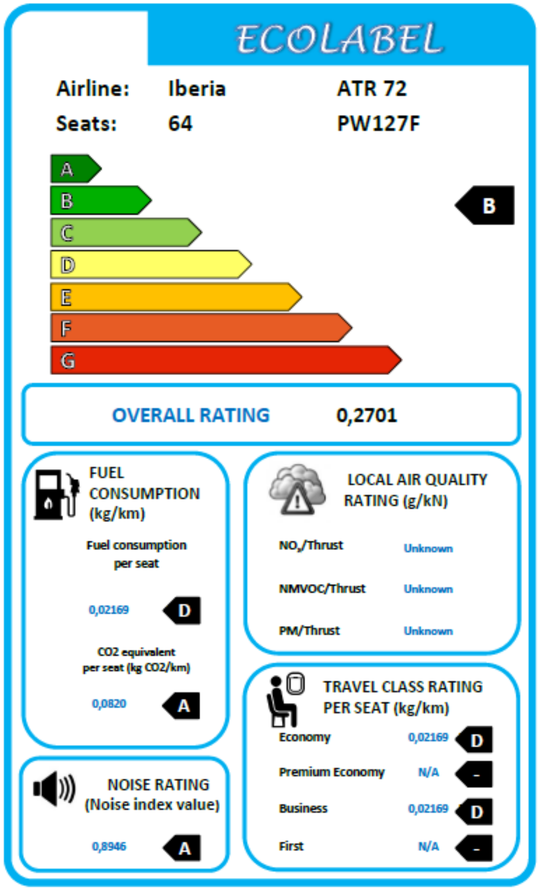


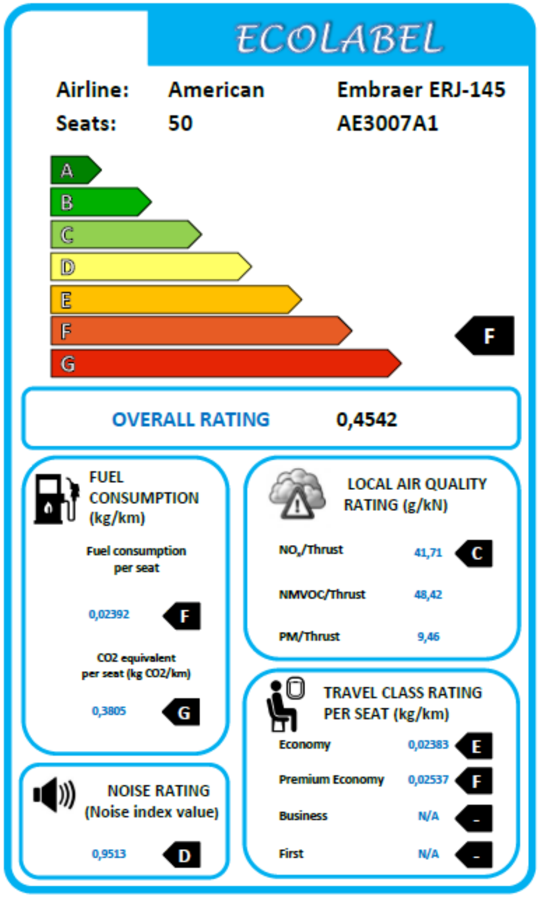
Low Cost Carrier vs. Legacy Carrier – Easy Jet vs. Lufthansa

Low cost carrier vs. Legacy carrier - Ecolabel comparison

Aircraft type	**Airbus A319**		**Airbus A319**	
Airline	**Easy Jet**		**Lufthansa**	
Engine type	CFM56-5B5		CFM56-5A5	
Overall rating	0.2663	(B)	0.3601	(E)
Fuel consumption				
Fuel consumption per seat	0.01474	(A)	0.01884	(B)
CO_2 equivalent per seat (kg CO_2 / km)	0.2234	(D)	0.2857	(F)
Local air quality				
NO_X / thrust (g / kN)	31.12 (a)		41.78 (c)	
NMVOC / thrust (g / kN)	36.69		44.58	
PM / thrust (g / kN)	7.14		9.51	
Noise rating				
Noise index value	0.9386	(B)	0.9528	(E)
Travel class rating				
Economy (kg / km)	0.01474	(A)	0.01666	(A)
Business (kg / km)	-		0.02499	(F)

Turboprop vs. Turbofan – ATR 72 vs. Embraer ERJ-145



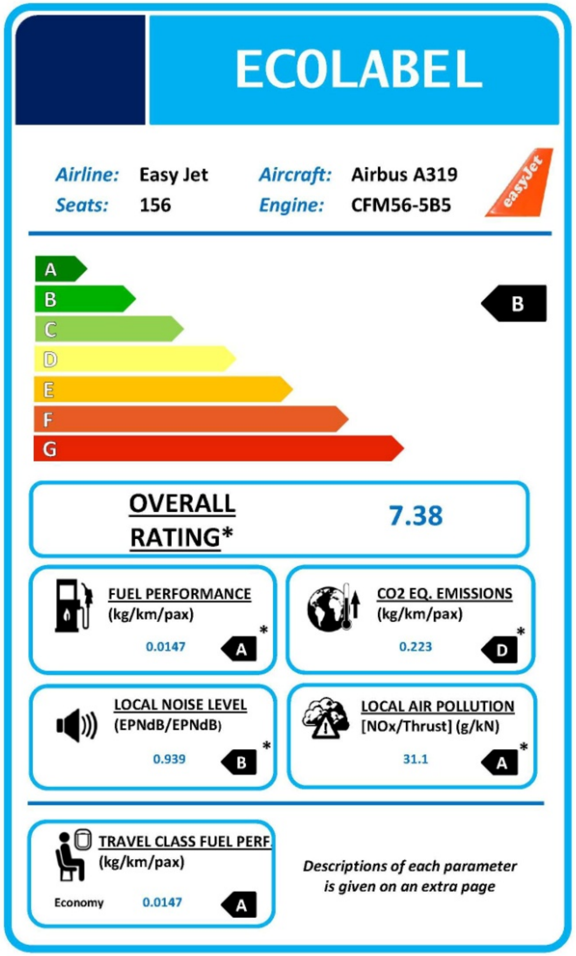


Turboprop vs. Turbofan – ATR 72 vs. Embraer ERJ-145

Turboprop vs. Turbofan - Ecolabel comparison

Aircraft type	**ATR 72**		**Embraer ERJ-145**	
Airline	**Iberia**		**American**	
Engine type	PW127F		AE3007A1	
Overall rating	0.2701	(B)	0.4542	(F)
Fuel consumption				
Fuel consumption per seat	0.02169	(D)	0.02392	(F)
CO_2 equivalent per seat (kg CO_2 / km)	0.0820	(A)	0.3805	(G)
Local air quality				
NO_X / thrust (g / kN)	-		41.71	(C)
NMVOC / thrust (g / kN)	-		48.42	
PM / thrust (g / kN)	-		9.46	
Noise rating				
Noise index value	0.8946	(A)	0.9513	(D)
Travel class rating				
Economy (kg / km)	0.02169	(D)	0.02383	(E)
Premium economy (kg / km)	-		0.02537	(F)
Business (kg / km)	0.02169	(D)	-	

A More Comprehensible Design of the Ecolabel?



Summary & What Next?

Summary

- New Motivation: Flygskam, EASA Workshop, CS-CO2 not to be used
- **Ecolabel for Aircraft** has been **defined** (ISO, ICAO, ...)
- **Based on simplified Life Cycle Assessment (LCA)**
  - **Fuel Consumption**
    - Source of Information: Payload & Range Diagram (directly from OEM)
  - **Global Warming, Local Air Quality, Noise**
- **Ecolabel for Aircraft** has been **applied:**
  - Airbus A320 Family better than Boeing 737 Family
  - KLM better than Lufthansa
  - Three engines on Airbus A330-200 identical related to environment
  - Low Cost Carrier better than Legacy Carrier
  - Turboprop much better than Turbofan

What Next?

- Systematic Application
- "Governing Body" ?
- To go "massive" public ?

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