An Ecolabel for Aircraft

Dieter Scholz
Hamburg University of Applied Sciences
AN ECOLABEL FOR AIRCRAFT

including work of:

- **Tim Haß** (Bachelor Thesis)
- **Lynn Van Endert** (Master Thesis)
- ...
Abstract

In attempting to increase the environmental awareness in the aviation sector and to eliminate the green washing phenomenon, an investigation was done into the development and definition of an ecolabel for aircraft. Based on life cycle assessment it was found that aviation affects the environment most with the impact categories resource depletion and global warming (both due to fuel consumption), local air pollution (due to the nitrogen oxide emissions in the vicinity of airports) and noise pollution. For each impact category a calculation method was developed based solely on official, certified and publicly available data to meet the stated requirements of the ISO standards about environmental labeling. To ensure that every parameter is evaluated independent on aircraft size, which allows comparison between different aircraft, normalizing factors such as number of seats, rated thrust and noise level limits are used. Additionally, a travel class weighting factor is derived in order to account for the space occupied per seat in first class, business class and economy class. To finalize the ecolabel, the overall environmental impact is determined by weighting the contribution of each impact category. For each category a rating scale from A to G is developed to compare the performance of the aircraft with that of others. The harmonization of the scientific and environmental information, presented in an easy understandable label, enables the traveling customers to make a well informed and educated choice when booking a flight, selecting among airline offers with different types of aircraft and seating arrangements.
AN ECOLABEL FOR AIRCRAFT

Table of Content

- Idea / Goal & the "Ecolabel for Aircraft"
- Background
- Life Cycle Assessment (LCA)
- Fuel Consumption
  - Source of Information (Payload & Range Diagram)
  - Grouping into A to G Categories
- Global Warming
- Local Air Quality
- Noise
- Summary
- Next Steps
Idea / Goal & ...

- 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**
    - **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**
Background

- **My presentation at the German Aerospace Conference 2012***:
  - Eco-efficiency: Create more with less waste and pollution.
  - Aviation growth does not (and will never) be met by aviation's efficiency gain!
  - Jevson's Paradox: "Fuel Can Not Be Saved from Efficiency Increase!"
  - **ACARE goals** (fuel burn reduction, NOx, ...)
    - are unrealistic and will not be met
    - this without any consequences (see "Vision 2020")
  - **IATA / ATAG goal**: "carbon-neutral growth from 2020"
    - would need massive & effective compensation scheme. CORSIA?
    - Why 2020 and not today?
  - CO2 is not the (major) problem. **The major problem is water!**
  - It is already too late to safe the world. **We need resilience!**
    - Do not bother about aviation, rather increase height of the dikes (Hamburg)

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**Eco-efficiency at every step of the aircraft lifecycle**

**Global Tonne Kilometers Flown**

- **Fleet renewal**
- **Operations**
- **Infrastructure**
- **Engine retrofits**
- **& airframe technology**
- **Biofuels**
- **Offset, credits, etc.**

**Indexed to equal 100 in 2005**

- **CO2 capped at 2020 level**

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Dieter Scholz
An Ecolabel for Aircraft

Aircraft Design and Systems Group (AERO)

Hochschule für Angewandte Wissenschaften Hamburg
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Background

- 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 vehicle/airline (get info from the Ecolable for the Aircraft)
  5. Make sure the vehicle is full and you select an economy seat, unless ...
  6. Compensate (... or maybe just do not compensate, if you do not like the idea)
Background

- **Flybe's Ecolable** (2007):
  - Label not used anymore by Flybe
  - Never used by other airlines (as intended)
  - Detail design shows many deficiencies.
Background

- **Labelling of Tyres** (2009):
  - "Regulation (EC) No 1222/2009 on the labelling of tyres" *
  - An example to learn from

Background

- Other schemes

  1. ICAO Emission Calculator
     http://www.icao.int/env

  2. Atmosfair Emission Calculator

  3. Atmosfair Airline Index
     http://www.atmosfair.de
Background

- 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 labelling)
ISO 14024:1999 Environmental labels and declarations – Type I environmental labelling -- Principles and procedures
ISO 14025:2006 Environmental labels and declarations – Type III environmental declarations -- Principles and procedures

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

http://www.iso.org
Background

- 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
Background

- 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

Life Cycle Assessment (LCA)

ISO 14040:2006
Environmental Management -- Life Cycle Assessment

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

Johanning (2017): Life Cycle Assessment in Aircraft Design

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:

\[ R_{overall} = 0.4 R_{warming} + 0.2 R_{depletion} + 0.2 R_{localAir} + 0.2 R_{noise} \]
### Fuel Consumption

<table>
<thead>
<tr>
<th>Table 1: Summary of candidate metrics</th>
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<tbody>
<tr>
<td><strong>Full Mission Metrics</strong></td>
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<tr>
<td>Single parameter metric</td>
</tr>
<tr>
<td>Block Fuel</td>
</tr>
<tr>
<td>Range</td>
</tr>
<tr>
<td>Two-parameter metric</td>
</tr>
<tr>
<td>Block Fuel</td>
</tr>
<tr>
<td>Payload * Range</td>
</tr>
<tr>
<td>Block Fuel</td>
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<td>Useful Load * R</td>
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<tr>
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<tr>
<td>MTOW * Range</td>
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<tr>
<td>Floor Area * R</td>
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<tr>
<td>Av. Seats * R</td>
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<tr>
<td>Three-parameter metric</td>
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<tr>
<td>Block Fuel</td>
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<tr>
<td>Payload * R * Speed</td>
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<tr>
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</tr>
<tr>
<td>SAR * Av. Seats * Speed</td>
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</tbody>
</table>

Selecting a Fuel Metric:

\[
\frac{1}{(SAR \cdot n_{\text{seat}})}
\]

Note: \( R = \text{Range} \)

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

### Global airliner fleet by type and operator

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<thead>
<tr>
<th>Aircraft Type</th>
<th>Total</th>
<th>Operator</th>
<th>Operator</th>
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<td>Africa</td>
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<td>EgyptAir</td>
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<td>Asia Pacific &amp; Middle East</td>
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<td>Air Hong Kong (600)</td>
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<td>Qatar Airways (600)</td>
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<td>Unique Air (600)</td>
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<td>Air France</td>
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<td>TAROM</td>
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<td>North/South America</td>
<td>Total 19</td>
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<td>North/South America</td>
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<td>Germania</td>
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<td>S7 Airlines</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SAS</td>
<td>4</td>
</tr>
</tbody>
</table>

147 different aircraft types and 26000 aircraft in database

https://www.flightglobal.com/asset/12798
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 were selected to describe 90% of all passenger aircraft \((n_{\text{seat}} > 14)\).

49 payload-range diagrams evaluated

Method to quickly determine cruise altitude from basic data
Fuel Consumption

![Graph showing relationship between fuel consumption and maximum number of seats.](image)

\[ y = 6.56015E-01x + 2.37971E+01 \]

\[ R^2 = 9.61218E-01 \]
Fuel Consumption

The graph illustrates the relationship between the OEM-based fuel consumption per seat (kg/km) and the standard number of seats (-). The data points are plotted on the graph, with a trend line indicating a decrease in fuel consumption as the number of seats increases. The equation for the trend line is given as:

\[ y = -1.702E-05x + 2.577E-02 \]

with an R² value of 1.094E-01.
Fuel Consumption

![Fuel Consumption Graph](image)

**Lufthansa 2010**

**DLR 2000**

**Graph Description**

- **Verbrauch in Liter Kerosin pro Passagier und 100 km**
  - **Verbrauch in Liter Kerosin pro Passagier und 100 km**
  - **Flugdistanz in Kilometer**
  - **Verbrauch in Liter Kerosin pro Passagier und 100 km**
  - **Graph showing fuel consumption vs. flight distance.**

**Pie Chart Description**

- **Spezifischer Treibstoffverbrauch Passagierbeförderung 2010**
  - **Konzernflotte**
  - **Langstrecke (58%) 3,57 l/100 pkm**
  - **Mittelstrecke (24%) 4,73 l/100 pkm**
  - **Kurzstrecke (18%) 7,46 l/100 pkm**

**Graph Analysis**

- **Fuel Consumption Analysis**
  - **DLR 2000**
  - **Lufthansa 2010**

**Key Points**

- *Key points from the graph and pie chart regarding fuel consumption in various flight distance categories.*

**References**

- **Hochschule für Angewandte Wissenschaften Hamburg**
- **Hamburg University of Applied Sciences**
Fuel Consumption

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

21 equal intervals
# Fuel Consumption

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

<table>
<thead>
<tr>
<th>Rating</th>
<th>Range</th>
<th>Normalized to 0-1</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>max</td>
</tr>
<tr>
<td>A</td>
<td>0.01493</td>
<td>0.01772</td>
</tr>
<tr>
<td>B</td>
<td>0.01772</td>
<td>0.01983</td>
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<td>0.02131</td>
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</tr>
<tr>
<td>G</td>
<td>0.02602</td>
<td>0.05070</td>
</tr>
</tbody>
</table>

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

Aircraft fuel combustion

Fuel $C_nH_m+S$

Air $N_2+O_2$

Ideal combustion:
$CO_2+H_2O+N_2+O_2+SO_2$

Real combustion:
$CO_2+H_2O+N_2+O_2+NO_X+UHC+CO+C_{soot}+SO_X$

<table>
<thead>
<tr>
<th>Species</th>
<th>Emission Index (kg/kg fuel)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$CO_2$</td>
<td>3.16</td>
</tr>
<tr>
<td>$H_2O$</td>
<td>1.23</td>
</tr>
<tr>
<td>$SO_2$</td>
<td>$2.00 \cdot 10^{-4}$</td>
</tr>
<tr>
<td>Soot</td>
<td>$4.00 \cdot 10^{-5}$</td>
</tr>
</tbody>
</table>

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

EEA 2016

Dieter Scholz
An Ecolabel for Aircraft

German Aerospace Congress
Munich, 05.-07.09.2017

Aircraft Design and Systems Group (AERO)
Global Warming

European Environment Agency

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

European Environment Agency

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

<table>
<thead>
<tr>
<th>Height (feet)</th>
<th>Fuel burnt</th>
<th>NOx, UHCs and CO</th>
<th>CO2, H2O and SOx</th>
<th>VOCs</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt; 3,000</td>
<td>BADA</td>
<td>BFFM2</td>
<td>Proportional to the mass of fuel burnt</td>
<td>Proportional to the mass of UHCs generated</td>
</tr>
<tr>
<td>CCD</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>≤ 3,000</td>
<td>AEED and other databases</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Global Warming

IPCC 1999

... more details ...

Schwartz 2009

This added to ReCiPe to include the Altitude Dependency

Local Air Quality

Definition of the landing and take-off cycle (LTO)
### Local Air Quality

#### Aviation LTD emissions calculator: File to accompany

**Chapter 1.3: "Aviation" of the "TIMP/EC AA Pollutant Emission Inventory Guide"**

**Disclaimer**: The fuel burned and emissions data provided in this spreadsheet are part of the European Union and have been obtained from the European Environment Agency. The data is intended to aid and facilitate assessment of aircraft performance in terms of emissions. The data includes information on fuel consumption, emissions, and performance metrics. The user should exercise caution when interpreting the data, as it may contain errors or omissions.

#### Aircraft Details

- **Type of aircraft**: [Select Type]
- **Engine type code**: [DD500]
- **Engine type name**: [DD500]
- **Type of engine**: [Jet engine]
- **Number of engines**: [2]

#### Departure phase total

- **Average fuel burn (kg)**: [143,441]
- **Departure phase fuel burn (kg)**: [21,214]
- **Average fuel burn (kg)**: [227,564]
- **Departure phase fuel burn (kg)**: [459,753]
- **Total fuel burn (kg)**: [159,610]
- **Total fuel burn (kg)**: [459,753]
- **Total fuel burn (kg)**: [519,363]
- **Total fuel burn (kg)**: [245,192]
- **Total fuel burn (kg)**: [519,363]
- **Total fuel burn (kg)**: [664,511]

#### Arrival phase total

- **Average fuel burn (kg)**: [219,987]
- **Approach fuel burn (kg)**: [37,524]
- **Climb fuel burn (kg)**: [39,141]
- **Total fuel burn (kg)**: [245,192]
- **Total fuel burn (kg)**: [519,363]
- **Total fuel burn (kg)**: [664,511]

#### Additional Notes

1. **Fuel burned per aircraft**
2. **NOx emissions per vehicle**
3. **CO2 emissions per vehicle**
4. **GHG emissions per vehicle**

---

**Dieter Scholz**

**An Ecolabel for Aircraft**

#### German Aerospace Congress

**Munich, 05.-07.09.2017**

**Aircraft Design and Systems Group (AERO)**

**07.09.2017, Page 35**
Local Air Quality

Characterization factors of ReCiPe

<table>
<thead>
<tr>
<th>Midpoint category</th>
<th>NO\textsubscript{x}</th>
<th>SO\textsubscript{2}</th>
<th>PM</th>
<th>CO</th>
<th>HC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photochemical oxidant formation (ozone)</td>
<td>1</td>
<td>0,081</td>
<td>-</td>
<td>0,046</td>
<td>0,476</td>
</tr>
<tr>
<td>Particulate matter formation</td>
<td>0,22</td>
<td>0,20</td>
<td>1</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

... 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)\textsubscript{LTO} calculated from "smoke number"

But: Only NOx enters the overall rating
Reference points for the noise measurement
Noice

Noise Certification Database

- Run
- Init
- All Data
- Home
- Help
- More items

Manufacturer: All
Commercial name: All
Type: All
Version: All
Production aircraft: All
Chapter/Stage: All
Engine: All
ID: All

MTOM(kg)
MLM(kg)

Operator X Y
All

The Tool

### General Information

<table>
<thead>
<tr>
<th>Aircraft type</th>
<th>A320</th>
</tr>
</thead>
<tbody>
<tr>
<td>Airline</td>
<td>Aeroflot</td>
</tr>
<tr>
<td>Engine type</td>
<td>CFM56-5B4/P</td>
</tr>
<tr>
<td>Thrust (kN)</td>
<td>120.1</td>
</tr>
<tr>
<td>MTOW (kg)</td>
<td>75500</td>
</tr>
<tr>
<td>Amount of Seats</td>
<td>140</td>
</tr>
</tbody>
</table>

### Travel Class Rating

<table>
<thead>
<tr>
<th>Class</th>
<th>Pitch (in)</th>
<th>Width (in)</th>
<th>Seats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy</td>
<td>31</td>
<td>18</td>
<td>120</td>
</tr>
<tr>
<td>premium economy</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Business</td>
<td>38</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>First</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total amount of seats</td>
<td></td>
<td></td>
<td>140</td>
</tr>
</tbody>
</table>

### Noise Rating Jets

<table>
<thead>
<tr>
<th>Noise Level (EPNdB)</th>
<th>Lateral</th>
<th>Flyover</th>
<th>Approach</th>
</tr>
</thead>
<tbody>
<tr>
<td>93.5</td>
<td>96.9</td>
<td>96.9</td>
<td>100.6</td>
</tr>
<tr>
<td>Noise Limit (EPNdB)</td>
<td>94.67</td>
<td>924672489</td>
<td>949304175</td>
</tr>
<tr>
<td>Level/Limit</td>
<td>0.964912281</td>
<td>0.924672489</td>
<td>0.949304175</td>
</tr>
<tr>
<td>Average</td>
<td>0.9463</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Normalized 0-1</td>
<td>0.7040</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Fuel Consumption Rating

<table>
<thead>
<tr>
<th>R₁ (km)</th>
<th>3882</th>
</tr>
</thead>
<tbody>
<tr>
<td>m₁ (kg)</td>
<td>19750</td>
</tr>
<tr>
<td>R₂ (km)</td>
<td>5200</td>
</tr>
<tr>
<td>m₂ (kg)</td>
<td>16125</td>
</tr>
<tr>
<td>dr (km)</td>
<td>1318</td>
</tr>
<tr>
<td>dm (kg)</td>
<td>3625</td>
</tr>
<tr>
<td>1/SAR (kg/km)</td>
<td>2.750379363</td>
</tr>
<tr>
<td>Fuel consumption (kg/km/seat)</td>
<td>0.01965</td>
</tr>
<tr>
<td>Normalized 0-1</td>
<td>0.1318</td>
</tr>
</tbody>
</table>
Summary & What Next?

Summary

- An "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

What Next?

- Final check; final ideas; finalizing the method
- More Examples
- "Governing Body" ???
- To go "massive" public ???