ANALYSIS OF BOEING 737 MAX 8 FLIGHT, IN TERMS OF THE EXHAUST EMISSION FOR THE SELECTED FLIGHT

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AGENDA

• INTRODUCTION
• METHODOLOGY
• RESULTS
• CONCLUSIONS
INTRODUCTION

- Air transport as an economic field,
- Direct impact on the state of the environment,
- Emission requirements,
- Limitations related to emission measurements,
- Estimation of the emission during the flight.

### ICAO ENGINE EXHAUST EMISSIONS DATA BANK

**SUBSONIC ENGINES**

<table>
<thead>
<tr>
<th>ENGINE IDENTIFICATION:</th>
<th>LEAP-12B1</th>
<th>Bypass Ratio:</th>
</tr>
</thead>
<tbody>
<tr>
<td>UNIQUE ID NUMBER:</td>
<td>18C0084</td>
<td>5.6</td>
</tr>
<tr>
<td>ENGINE TYPE:</td>
<td>TF</td>
<td>41.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>130.4</td>
</tr>
</tbody>
</table>

#### REGULATORY DATA

<table>
<thead>
<tr>
<th>CHARACTERISTIC VALUE:</th>
<th>NC</th>
<th>CO</th>
<th>NOx</th>
<th>SMOKE HUDDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dp/T0 (g/4N) or SH</td>
<td>1.2</td>
<td>21.9</td>
<td>67.0</td>
<td>1.5</td>
</tr>
<tr>
<td>As % of Original Limit</td>
<td>5.8</td>
<td>16.6</td>
<td>34.4</td>
<td>6.8</td>
</tr>
<tr>
<td>As % of CA/E/1 Limit (NA)</td>
<td>90</td>
<td>43</td>
<td>34.4</td>
<td>6.8</td>
</tr>
<tr>
<td>As % of CA/E/1 Limit (NON)</td>
<td>94.4</td>
<td>74</td>
<td>54.4</td>
<td>8.8</td>
</tr>
<tr>
<td>As % of CA/E/2 Limit (NA)</td>
<td>9</td>
<td>91</td>
<td>57</td>
<td>8.8</td>
</tr>
<tr>
<td>As % of CA/E/2 Limit (NON)</td>
<td>9</td>
<td>91</td>
<td>57</td>
<td>8.8</td>
</tr>
</tbody>
</table>

#### DATA STATUS

- PRE-REGULATION
- CERTIFICATION
- REVISED (SEE REMARKS)
- OTHER (SEE REMARKS)

**DATA CORRECTED TO REFERENCE**

**ENGINE APPLICATION**

**OUT OF PRODUCTION**

**OUT OF SERVICE**

### MEASURED DATA

<table>
<thead>
<tr>
<th>MODE</th>
<th>POWER SETTING (Nf)</th>
<th>TIME (minutes)</th>
<th>FUEL FLOW (kg/s)</th>
<th>EMISSIONS INDICES (g/kg)</th>
<th>NC</th>
<th>CO</th>
<th>NOx</th>
<th>SMOKE HUDDER</th>
</tr>
</thead>
<tbody>
<tr>
<td>START-UP</td>
<td></td>
<td>0.7</td>
<td>1.051</td>
<td>0.02</td>
<td>0.2</td>
<td>0.4</td>
<td>1.05</td>
<td>0.17</td>
</tr>
<tr>
<td>CLIMB OUT</td>
<td></td>
<td>2.0</td>
<td>0.044</td>
<td>0.04</td>
<td>0.14</td>
<td>0.4</td>
<td>24.8</td>
<td>0.05</td>
</tr>
<tr>
<td>APPROACH</td>
<td></td>
<td>4.0</td>
<td>0.027</td>
<td>0.06</td>
<td>0.12</td>
<td>0.4</td>
<td>24.8</td>
<td>0.05</td>
</tr>
<tr>
<td>T/O TOTAL FUEL (kg) or EMISSIONS (g)</td>
<td>378</td>
<td>2039</td>
<td>7664</td>
<td>-</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUMBER OF ENGINES</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NUMBER OF TESTS</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AVERAGE Dp/T0 (g/4N) or AVERAGE SH (MAX)</td>
<td>0.14</td>
<td>17.94</td>
<td>57.78</td>
<td>1.16</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SMOKE (Dp/T0 in g/4N, or SH)</td>
<td>0.09</td>
<td>0.67</td>
<td>2.29</td>
<td>0.12</td>
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<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**INAIR 2018**
The basis for determining the emission of harmful exhaust gases,
**METHODOLOGY**

\[ y = 0.3642x^2 + 0.6465x + 0.0507 \]
\[ R^2 = 1 \]

\[ y = 0.0339x^{-0.937} \]
\[ R^2 = 0.8301 \]
\[ y = 4.361e^{2.5027x} \]
\[ R^2 = 0.97 \]

\[ y = 0.1405x^{-1.747} \]
\[ R^2 = 0.9895 \]
METHODOLOGY

\[ y = 3.7058x^3 - 6.5389x^2 + 3.1638x + 0.6093 \]

\[ R^2 = 1 \]
Calculation of the emission of a particular harmful compound:

\[ EPC_{pol, mode} = TIM \cdot FFR \cdot EF \cdot NE \]

Where:
- \( EPC_{pol, mode} \): Emissions per cycle for a particular pollutant during a particular mode [g]
- TIM: Time in Mode [s]
- FFR: Fuel Flow Rate [kg/s]
- EF: Emission Factor [-]
- NE: Number of engines on the aircraft [-]
RESULTS

Emission [g/phase]

Taxi
Approach
Climbout
Take-off
Flight

Phase

HC

INAIR 2018
RESULTS

CO

<table>
<thead>
<tr>
<th>Phase</th>
<th>Emission [g/phase]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi</td>
<td>3500</td>
</tr>
<tr>
<td>Approach</td>
<td>1000</td>
</tr>
<tr>
<td>Climbout</td>
<td>500</td>
</tr>
<tr>
<td>Take-off</td>
<td>10</td>
</tr>
<tr>
<td>Flight</td>
<td>500</td>
</tr>
</tbody>
</table>

INAIR 2018
RESULTS

<table>
<thead>
<tr>
<th>Phase</th>
<th>Emission [g/phase]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi</td>
<td>0</td>
</tr>
<tr>
<td>Approach</td>
<td>100000</td>
</tr>
<tr>
<td>Climbout</td>
<td>80000</td>
</tr>
<tr>
<td>Take-off</td>
<td>20000</td>
</tr>
<tr>
<td>Flight</td>
<td>120000</td>
</tr>
</tbody>
</table>

NOx

INAIR 2018
RESULTS

<table>
<thead>
<tr>
<th>Phase</th>
<th>Emission [g/phase]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Taxi</td>
<td></td>
</tr>
<tr>
<td>Approach</td>
<td></td>
</tr>
<tr>
<td>Climbout</td>
<td>2000</td>
</tr>
<tr>
<td>Take-off</td>
<td></td>
</tr>
<tr>
<td>Flight</td>
<td>3500</td>
</tr>
</tbody>
</table>
RESULTS

- Emission [g/flight]:
  - HC: 484 g
  - CO: 5,665 g
  - NOx: 208,480 g
  - PM: 7,296 g
CONCLUSIONS

• The calculation scheme presented in this article makes it possible to estimate the emission of individual harmful compounds during the flight of an aircraft.

• The highest value of hydrocarbons, nitrogen oxides and particulate matter emissions was recorded for the flight at given ceiling phase.

• The emission of carbon oxides was the highest in the taxiing phase.

• The highest emission values occur for nitrogen oxides, in all phases of the Boeing 737 MAX 8 flight.

• The lowest emission values were observed for hydrocarbons.
\[ \rho = 2 \times 10^{-9} H^2 - 0.0001 H + 1.2034 \]

\[ R^2 = 0.9994 \]

\( \rho \) [Pa]

\( H \) [m]
THANK YOU FOR ATTENTION