Abstract

For aero-engines using hydrocarbon fuels, the major exhaust products that are discharged into the atmosphere are carbon dioxide (CO$_2$) and water vapor (H$_2$O). Minor products of combustion may include soot (smoke), carbon monoxide (CO), a variety of unburned hydrocarbons (UHC), nitrogen oxides NO$_x$ (that is, nitric oxide (NO) and nitrogen dioxide (NO$_2$)), and sulfur dioxide (SO$_2$).

A favorable feature of the kerosene fuel used for jet aircraft propulsion is that it contains almost no sulfur. Therefore, the emission of SO$_2$ by aircraft is very low and usually negligible.

The modern high bypass ratio turbofan engines employed for the propulsion of transport airplanes have high compressor pressure ratios and therefore high turbine entry temperatures. Due to the resulting high flame temperatures in the combustion chambers, the NO$_x$-formation rates at takeoff and cruise conditions have been substantially increased during the past decades. When transmitted to or emitted directly into the stratosphere, nitrogen oxides act as catalysts in chemical reactions that contribute to the depletion of the ozone layer [1]. When emitted into the upper troposphere, NO$_x$ may participate in the formation of tropospheric or “bad” ozone. Emissions of NO$_x$ thus affect global warming indirectly through tropospheric ozone formation.

At lower altitudes, aircraft emission products may contribute to the occurrence of acid rain and ground level smog. These effects may cause serious environmental problems in the foreseeable future if the world air fleet increases further and new advanced turbofan engines come into operation. Such engines could have even larger compression ratios and, therefore, may emit increased NO$_x$ emission rates than the present engines.

It seems generally accepted that the bulk of the reduction of the harmful impact of aircraft emissions on the atmosphere is the responsibility of the gas turbine combustor designer [2]. Accordingly, at present, considerable effort is being made to lower the NO$_x$ production in the combustion chamber well below the current levels.

However, in addition, performing a so-called Low NO$_x$ Flight may deliver a noticeable contribution to the reduction of the NO$_x$-emissions. Regrettably, when executed with the current aircraft types, this certainly will result in a considerable increase in fuel consumption and direct operating cost.

Surely, growth of aviation would have to be severely restricted unless one is able to avoid the risk of any perturbation in climate and/or in health.

1 General Introduction

1.1 Earth atmosphere

As one ascends in the atmosphere from ground level, the air temperature normally decreases up to a height of about 10 km (Fig. 1). The region of decreasing temperature is called the troposphere, where due to the negative temperature gradient the air usually is unstable. As a consequence, convective motions occur through which the air normally is well-mixed [3].
Above the troposphere, the temperature at first becomes roughly independent of altitude and then increases with height up to a level of about 50 km. This is the region that is known as the stratosphere.

The dividing plane between the troposphere and the stratosphere is called the tropopause. For average latitudes, this plane is located at a height of about 11 km. Near the polar regions the troposphere extends to about 8 km, while at the Equator it reaches up to approximately 17 km.

1.2 Vertical stability of the atmosphere

The constant temperature as well as the temperature inversion occurring in the stratosphere cause stable atmospheric conditions, which allow existing pollutants in the stratosphere to escape only slowly from this layer. Clearly, aircraft flying in the stratosphere, where they are the only anthropogenic source of pollutants, can leave behind there their effluents, which may remain in the stratosphere for years until they are ultimately transported downwards into the troposphere. Below the tropopause the effluents are readily transferred and removed by processes, such as precipitation and dispersion. It is only the slow downward transport caused by atmospheric mixing that tends to rid the stratosphere of pollutants.

Like the vertical spreading of combustion products, also the horizontal spreading in the stratosphere in the north-south direction is rather slow, while the spreading in east-west direction is faster and notable extensive. This means that most stratospheric effluents produced in the northern hemisphere will remain there and will have a more zonally symmetric distribution.

1.3 Emission altitude and effect on atmosphere

For sound reasons, commercial airliners cruise at altitudes between about 9 and 13 km, that is, well into the stratosphere at middle and high latitudes. However, in that altitude region, their exhaust gases may contribute to both global warming and ozone layer depletion.

Clearly, the concentrations of pollutants occurring in the tropopause region will be greatest near the latitude of the North Atlantic flight corridor, the main flight route between the US and Europe.

In the stratosphere, molecular oxygen $O_2$ absorbs ultraviolet solar radiation and in this process ozone $O_3$ is formed. The absorption of solar radiation required for the formation of the ozone is the cause of the temperature inversion in the stratosphere. The presence of high ozone concentrations (the ozone layer) in the stratosphere is very important to the protection of the Earth’s biosphere by absorbing harmful short-wave ultraviolet radiation.

A decrease of the amount of ozone in the stratosphere creates an increase of UV-radiation to the Earth and possibly a small change in temperature at its surface.

The substances that especially give rise for concern are nitrogen oxides $NO_x$, which are formed in the high temperature zones of the combustion chamber of aero engines, mainly through the oxidation of nitrogen $N_2$ by oxygen radicals $O$. The latter are formed by dissociation of molecular oxygen $O_2$ at high temperatures (“thermal NOx”).

On the other hand, near the tropopause aircraft emissions are the only source, since emissions of NOx from lightning occur below an altitude of ca 8 km.
ON THE REDUCTION OF NOX-EMISSION LEVELS BY PERFORMING LOW NOX FLIGHTS

When NOx is emitted in the stratosphere, it may participate in the depletion of the ozone layer. When emitted in the upper troposphere, NOx may participate in the formation of tropospheric ozone, which acts as a strong greenhouse gas, and therefore may lead to an enhanced greenhouse effect.

1.4 Low NOx flight

To control possible effects caused by flight operations near to the tropopause, the options available for aero engines, besides improving the combustion process, are reducing fuel consumption and performing a Low NOx Flight.

In aviation the emphasis has always been on fuel conservation. The result of this ambition can be seen from Fig. 2, where the effect of engine technology on the development of specific fuel consumption over the past forty-five years is portrayed.

Fig 2: Development history of specific fuel consumption of engines for commercial aircraft in cruise.

The most fuel-efficient propulsion systems for today’s transport airplanes are turbofan engines with bypass ratios up to about nine. These so-called Ultra High Bypass Ratio (UHBR) engines employ high compressor pressure ratios in combination with high turbine entry temperatures.

Minimizing fuel consumption also implies minimizing the emissions of the greenhouse gases carbon dioxide CO2 and water vapor H2O, because the amounts of these combustion products are directly related to the amount of fuel burned. The emissions of CO2 and H2O in gram per kg of fuel consumed have constant values, which amount to about 3150 and 1250 g/kg, respectively.

This rule does not apply to soot (smoke), carbon monoxide CO, and unburned hydrocarbon UHC, which species are produced by incomplete burning of the kerosene fuel, and are a function of thrust setting (Fig. 3). Fortunately, under cruise conditions, essentially, complete combustion occurs, so that these products have a minor significance.

Consistently with their improved fuel efficiency, the modern turbofan engines show high combustion temperatures and gas pressures, through which especially the NOx formation rates at takeoff and cruise conditions have been substantially increased during the past decades [4]. Besides the peak temperature, the amount of NOx emission also depends on the amount of time the gas mixture of nitrogen and oxygen is at that temperature.

In the early days of aviation environmental considerations used to come a long way after other topics such as safety, reliability, performance, and economics. However, nowadays, environmental considerations have become important design criteria. A reflection of the concern for the environment are the standards set by the ICAO, restricting the emissions of the species: soot, CO, UHC, and NOx [5].

There is reason to expect that also for flight operations near to the tropopause additional regulations are likely to follow.

Fig 3: Emission level versus thrust setting
Currently, no restrictions exist to the production of CO\(_2\) by aircraft. Quoting a statement of the International Civil Aviation Organization given in [6]: “In the case of CO\(_2\), it has been decided not to develop an ICAO standard, since CO\(_2\) production is directly related to fuel consumption and there is already intense economic pressure to keep fuel consumption to a minimum and, in addition, there would be significant difficulties in designing a certification condition”. Therefore, it seems more realistic to expect that taxes will be imposed on the exhaust of CO\(_2\).

Returning to the prevailing standards, it can be said that reductions have been obtained for the emissions of CO and UHC, which pollutants are dominating at low thrust settings. Also soot emission, which dominates at high thrust settings, have been greatly reduced.

However, the formation of NO\(_x\) has been increased during the past decades [4]. This is caused by the high overall pressure ratios and the high gas temperatures in the combustion chambers of the modern high-bypass ratio turbofan engines. Therefore, the formation of NO\(_x\) mainly occurs at the high power settings applied during takeoff, climb, and cruise.

It should be noted that the ICAO standards include a dependence of the admissible NO\(_x\) levels on the compressor pressure ratio. This is consistent with the fact that the emission of NO\(_x\) increases with increasing compressor pressure ratio.

2 The importance of NO\(_x\) - emissions

The high-altitude gas emissions from air traffic may play a significant role in (future) stratospheric ozone depletion and tropospheric ozone production.

To explain these statements, predictions of the percentage distribution of the pollutant substances, CO, UHC, NO\(_x\), and soot, over the various flight phases are presented in Table 1 of a medium-haul airliner performing a stage length of 500 nautical miles [7].

The quantifications show that NO\(_x\), by far, contributes most to the total emission of the pollutants. For the landing and takeoff cycle, 77.4% of these emissions consist of NO\(_x\), while the contribution from the climb, cruise and descent is even 89.0%. For the whole flight, the NO\(_x\) emissions comprise 85.9% of the total production of pollutants.

Table 1: Percentage distribution of emissions per flight phase for a flight distance of 500 nautical mile

<table>
<thead>
<tr>
<th>constituent</th>
<th>takeoff and landing</th>
<th>climb, cruise, and descent</th>
<th>total flight</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>5.4</td>
<td>7.0</td>
<td>12.4</td>
</tr>
<tr>
<td>NO(_x)</td>
<td>20.6</td>
<td>65.3</td>
<td>85.9</td>
</tr>
<tr>
<td>UHC</td>
<td>0.6</td>
<td>1.0</td>
<td>1.6</td>
</tr>
<tr>
<td>soot</td>
<td>0.1</td>
<td>0.1</td>
<td>0.1</td>
</tr>
<tr>
<td>total</td>
<td>26.6% (77.4% NO(_x))</td>
<td>73.4% (89.0% NO(_x))</td>
<td>100.0% (85.9% NO(_x))</td>
</tr>
</tbody>
</table>

Obviously, if a reduction of the emissions would be desirable, NO\(_x\) is the most appropriate constituent to suppress.

Another study on the emission of NO\(_x\) is reported in [8], where is considered a flight between London and Tokyo with a Boeing 747-400 airplane. Investigated is a cruise climb, i.e., a flight path whose altitude increases continuously as fuel is burned off. Assumed is a flight in International Standard Atmosphere (ISA), at a mean cruise altitude of ca 10.8 km and a constant flight Mach number of 0.85.

Results are specified in Table 2, indicating that on this long-haul flight the airplane produces 1321 kg of NO\(_x\), of which around 85% is emitted during the cruise. The NO\(_x\) - emission at higher altitudes even constitutes about 97% of the total production.

Table 2 NO\(_x\)-emissions per flight phase for B747-400 airplane on the London – Tokyo route

<table>
<thead>
<tr>
<th>flight phase</th>
<th>NO(_x) emissions</th>
<th>kg</th>
<th>% total</th>
</tr>
</thead>
<tbody>
<tr>
<td>takeoff</td>
<td>15</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>climb out to 457 m (1500 ft)</td>
<td>15</td>
<td>1.1</td>
<td></td>
</tr>
<tr>
<td>continued climb (457 m to 9500 m)</td>
<td>158</td>
<td>12.0</td>
<td></td>
</tr>
<tr>
<td>cruise climb (9.5 km to 11.8 km)</td>
<td>1113</td>
<td>84.3</td>
<td></td>
</tr>
<tr>
<td>descent</td>
<td>5</td>
<td>0.4</td>
<td></td>
</tr>
<tr>
<td>approach</td>
<td>7</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>taxi</td>
<td>8</td>
<td>0.8</td>
<td></td>
</tr>
<tr>
<td>total</td>
<td>1321</td>
<td>100.0</td>
<td></td>
</tr>
</tbody>
</table>
As yet, data on the NO\textsubscript{x} - emission levels by applying alternative flight techniques are scarce. Therefore, to obtain an impression of the potential of performing low-NO\textsubscript{x} flights, some results from a “Cruise NO\textsubscript{x} Simulation Model” developed in [9], will be given here. Using this computer simulation model, the effects of variations in cruise conditions on the emission level of NO\textsubscript{x} and the accompanying effects on fuel consumption and direct operating costs of a Boeing 747-400 aircraft are predicted. Anticipating this consideration some attention will be given to the point performance conditions for the flight for minimum fuel, minimum NO\textsubscript{x} - emission, and minimum direct operating cost.

3 Point performance conditions

3.1 Minimum fuel for a fixed cruise distance

Since the mass of an airplane decreases continuously with time due to the consumption of fuel by the engines, we can write for the fuel mass flow rate F:

$$F = \frac{dM_f}{dt} = -\frac{dM}{dt}$$ (1)

where M\textsubscript{f} and M is fuel and airplane mass, respectively.

Assuming still air, the range of the airplane (R) is obtained from the following integral:

$$R = \int_{t_1}^{t_2} Vdt = \int_{M_1}^{M_2} \frac{V}{F} dM = \int_{M_1}^{M_2} \frac{V}{F} dM_f$$ (2)

where V/F is the distance flown per unit mass of fuel or specific air range (SAR) in km/kg. The subscripts “1” and “2” refer to the initial and final conditions at the beginning and end of cruise, respectively.

Obviously, for a minimum amount of fuel to cover a given cruise distance, the specific air range should be maximum for each momentary flight condition.

3.2 Minimum NO\textsubscript{x} emission for a fixed cruise distance

The emitted mass of pollutant substance dQ\textsubscript{x} after consuming an amount of fuel mass dM\textsubscript{f} is given by:

$$dQ = EI dM_f$$ (3)

where EI is the emission index of the pollutant in gram per kilogram of fuel consumed, and Q\textsubscript{x} is in gram.

With dR = (V/F) dM\textsubscript{f}, we obtain:

$$Q = \int_{0}^{R} \frac{EI}{V/F} dR$$ (4)

The parameter [EI/(V/F)] is called pollution number, P. For the emission of NO\textsubscript{x} we can write:

$$P_{NO_x} = \frac{EI_{NO_x}}{V/F}$$ (5)

Apparently, for a given range R, the amount of pollutant Q is minimum if the pollution number is as low as possible for each momentary flight condition. Clearly, for a given emission index, a high specific air range (high fuel efficiency) results in a low amount of NO\textsubscript{x} emitted.

3.3 Minimum direct operating costs for a given range

The direct operating costs (DOC) are those costs which are directly related to the operational characteristics of the airplane. They may comprise the costs of fuel and oil, crew, landing fees, depreciation of capital invested, insurance, interest and maintenance.

For analysis, the direct operating costs can be subdivided into costs of time and fuel:

$$DOC = CT \times E + CF \times M_f$$ (6)

where CT designates the costs of time in $/h, E the endurance of the flight in hour, CF
the cost of fuel in \$/kg, and \( M_f \) the mass of the fuel consumed for a given range.

A criterion employed to express the relative costs of time and fuel is the cost index, CI, defined as the ratio of time cost to fuel cost [10]:

\[
CI = \frac{CT}{CF}
\]  

(7)

where CI is expressed in \((\$/h)/(\$/kg) = \text{kg/h}\).

Application of the cost index combines time cost and fuel cost to an equivalent fuel mass, \( M_{f,\text{eq}} \), which is used as a measure for the direct operating costs:

\[
M_{f,\text{eq}} = CI \times E + M_f
\]  

(8)

Since \( \text{DOC} = M_{f,\text{eq}} \times CF \), the mass \( M_{f,\text{eq}} \), in fact, is the fuel mass that could be purchased for the direct operating cost.

In order to investigate the minimum \( \text{DOC} \) for a given range, the specific economic range, (SER), is introduced, which parameter is defined as the ratio of the rate of change of distance to the rate of change of equivalent fuel mass.

In still air, the rate of change of distance is the airspeed \( V \), and the rate of change of equivalent fuel mass is given by:

\[
\frac{dM_{f,\text{eq}}}{dt} = CI \times F
\]  

(9)

where \( F = \frac{df}{dt} \) is the fuel mass flow rate in kg/h. This results in the following expression for the specific economic range:

\[
\text{SER} = \frac{V}{CI \times F}
\]  

(10)

where SER has the unit km/kg.

Similar to the condition for minimum fuel, i.e., maximum specific air range \((V/F)_{\text{max}}\), the condition for minimum \( \text{DOC} \) in cruise flight is that SER should be maximum for each momentary flight condition. Then the equivalent fuel mass is minimized, and therefore the total cost for the distance flown.

### 4 Low NOX Flight

The calculation procedure reported in [9] is aimed at the determination of the effect of cruise conditions on the emission of NO\(_x\) and the accompanying effects on fuel consumption and \( \text{DOC} \). Varying cruise conditions include variations of flight altitude, cruise Mach number or airspeed and atmospheric conditions. The cruise is taken as a continuous succession of quasi-steady state motions.

Considered is a cruise range of 5800 km with a Boeing 747-400 aircraft, powered by a fictitious turbofan engine model. Some characteristic data of this typical wide-body airplane are given in Table 3.

<table>
<thead>
<tr>
<th>Table 3: Characteristic data of Boeing 747-400 airplane.</th>
</tr>
</thead>
<tbody>
<tr>
<td>year of introduction</td>
</tr>
<tr>
<td>wing loading</td>
</tr>
<tr>
<td>wingspan</td>
</tr>
<tr>
<td>wing area</td>
</tr>
<tr>
<td>maximum thrust</td>
</tr>
<tr>
<td>cruise Mach number</td>
</tr>
<tr>
<td>maximum takeoff weight</td>
</tr>
<tr>
<td>operating empty weight</td>
</tr>
<tr>
<td>fuel capacity</td>
</tr>
<tr>
<td>range</td>
</tr>
<tr>
<td>initial cruise altitude</td>
</tr>
<tr>
<td>takeoff field length</td>
</tr>
<tr>
<td>landing field length</td>
</tr>
<tr>
<td>maximum lift-drag ratio</td>
</tr>
</tbody>
</table>

The emission indices \( E_{\text{INOx}} \) are calculated according to the empirical relation suggested in [11]:

\[
E_{\text{INOx}} = 10^{1.0032(T_{\text{c}} - 581.25)} \frac{p}{p_0}
\]  

(11)

where \( T_{\text{c}} \) is the combustor inlet total temperature, \( p \) is the atmospheric pressure and \( p_0 \) is sea-level atmospheric pressure in ISA. It
may be noted that the above expression for \( EINOx \) reflects the well-known Lipfert plot given in [12].

The following point performance capabilities for flight in ISA, taken from [8], are shown here: specific air range \( SAR = V/F \), specific economic range \( SER = V/(CI+F) \), and \( NOx - pollution number \( PNOx = [EI / (V/F)] \).

Fig. 4 presents the effects of flight Mach number and altitude on specific air range. At a given airplane weight \((W = 2800 \text{ kN})\) an optimum Mach number as well as an optimum cruise altitude occurs for maximum specific range, \((V/F)_{max}\).

Fig. 5 indicates that at a given cruise speed \((V = 860 \text{ km/h})\), the altitude for \((V/F)_{max}\) increases with decreasing weight. Hence, when minimum fuel consumption is aimed for, the airplane should ascend in altitude during the cruise.

Fig. 6 displays the effects of flight Mach number and cruise altitude on specific economic range at a given airplane weight \((W = 2800 \text{ kN})\). Used is a cost index of \( CI = CT/CF = 3220 \text{ kg/h} \), where the time cost \( CT = 1288 \text{ $/h} \) and the fuel cost \( CF = 0.40 \text{ $/kg fuel} \).

Consistent with Fig. 4, the curves in Fig. 6 emphasize the importance of a relatively high flight Mach number and cruise altitude (up to 11 km) for an economic operation of the aircraft. If a cruise for minimum cost is aimed for, then similar to minimum fuel consumption, the aircraft should ascend in altitude.

In Fig. 7 are shown the effects of cruise altitude and aircraft weight on the \( NOx - emission index for given airspeed (V = 860 \text{ km/h}) \). The plot reveals that at a given weight and airspeed, an optimum cruise level occurs for minimum emission index.

The curves also manifest that when at a given airspeed and altitude, weight is reduced, a
lower NO\textsubscript{x} production is obtained due to the lower thrust setting required. Clearly, aircraft empty weight and trip fuel are challenging parameters for aircraft designers and airline operators, since restricting them will have a direct effect on fuel consumption as well as on the emission of NO\textsubscript{x}.

Another observation from Fig. 7 is that the optimum altitude at which \((EINOx)_{\text{min}}\) occurs, is almost independent of aircraft weight.

Fig. 8 shows that when at a given airplane weight the higher the airspeed, the higher the NO\textsubscript{x} production and the lower the optimum cruise altitude.

![Fig 8. NOx – emission index as functions of altitude and airspeed.](image)

According to the definition of the pollution number, the effect of varying cruise conditions on PNO\textsubscript{x} \((= EINOx / (V/F))\) is the combined effect of NO\textsubscript{x} - emission index and specific air range. From these two influences the curves shown in Fig. 9 result.

![Fig 9: NOx – pollution numbers as functions of Mach number and altitude.](image)

It can be seen that at an altitude of approximately 11 km, a minimum for PNO\textsubscript{x} will occur. Apparently, hardly any variation of \((PNOx)_{\text{min}}\) with flight Mach number is found. It appears that the altitude yielding the lowest pollution number is virtually independent of cruise Mach number. Beyond a Mach number of 0.86, the pollution number increases sharply.

The effects of flight Mach number on range performance for low-NO\textsubscript{x} emission, are shown in Fig. 10. The NO\textsubscript{x} - reductions and associated changes in cost and fuel are expressed in terms of percentages. The data are obtained by considering the cruise part of the flight only and assuming that the airplane is allowed by ATC to perform a cruise climb. Also, the additional fuel consumption, NO\textsubscript{x} emission, and cost change due to an extended climb to a higher initial cruise altitude, are neglected.

![Fig 10: Effect of flight Mach number on changes in NOx, fuel and cost for low NOx flight of 5800km.](image)

The diagram shows, as an almost general result, that NO\textsubscript{x} - reductions up to 10% are achievable as the cruise Mach number is lowered. However, this measure is accompanied by a considerable cost increase and also penalizes the flight time. Obviously, a reduction in NO\textsubscript{x} is also attended by an increase in fuel consumption, leading to an increase in CO\textsubscript{2} and H\textsubscript{2}O emissions. The harmful effect of these pollutant species should be carefully weighted against the harmful effects of NO\textsubscript{x}.

As mentioned before, emissions of NO\textsubscript{x} affect global warming indirectly through tropospheric ozone formation. This process is
highly dependent on altitude, latitude, and season, as different chemical regimes will produce different amounts of ozone for the same amount of NO\(_x\). Therefore, the resulting environmental harm may be represented by the product of NO\(_x\) and its Global Warming Potential (GWP) value as a weighing factor [3].

To this end, use may be made of the curve shown in Fig. 11, which would be valid at mid-latitudes and summer atmospheric conditions. The curve is established originally in [13], where it is stated that they must be seen as a first approximation only.

4 Epilogue

The production of NO\(_x\) can be affected by changing the cruise conditions of the aircraft, however, at the expense of a considerable cost increase. This fact makes that the magnitude of the improvements predicted in [9] are of a limited significance for solution to the problem.

Doubtless, implementation of environmental design criteria focused on preventing NO\(_x\) emissions, may demand for drastic changes of future aircraft configurations, introducing a lot of attendant problems. Moreover, it will require several aircraft related technological developments having large influence on the aviation system as a whole.

Therefore, it is hoped so that also combustor design changes will yield a substantial reduction of NO\(_x\) production.

The principle of the latter approach is to prevent the gases in the combustion chamber of the engine from exceeding a temperature critical to the formation of nitric oxide NO. Today, the most advanced concept is a lean combustion process, which is achieved by feeding the whole of the compressor air directly to the combustion chamber. One of the real problems in its application is that a weak mixture is more difficult to light, especially a relight after a flame blow-out under high-altitude conditions. The challenge right now is to develop injector designs that are able to cope with such conditions while meeting targets for low emission [6].

Obviously, of vital importance is the fact that the latter solution would have no major effects on the operation of existing airliners and on the design of future aircraft.

References


**Copyright Statement**

The authors confirm that they, and/or their company or institution, hold copyright on all of the original material included in their paper. They also confirm they have obtained permission, from the copyright holder of any third party material included in their paper, to publish it as part of their paper. The authors grant full permission for the publication and distribution of their paper as part of the ICAS2008 proceedings or as individual off-prints from the proceedings.