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Method for Commercial Aircraft Nitric Oxide Emission Measurements

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Worldwide increases in commercial air traffic have raised concerns about the effects of aircraft emissions on the atmosphere. The purpose of this study was to demonstrate the capability of a remote sensor, developed for the measurement of automobile emissions, in measuring nitric oxide emission indices from in-use aircraft on the ground without interfering with their normal operation. In two days of sampling at London Heathrow Airport, a total of 122 measurements were made of 90 different aircraft in a mix of idle, taxi-out, and takeoff modes. Aircraft measured at idle exhibited little nitric oxide emission. Emission indices measured from aircraft at higher thrust levels were not inconsistent with values from the ICAO Engine Exhaust Emissions Databank.

Introduction

Worldwide increases in commercial air traffic have raised concerns about the effects of aircraft emissions on the atmosphere. In the United States, emissions of nitrogen oxides [(NO_x, denoting the sum of nitric oxide (NO) and nitrogen dioxide (NO_2)] from aircraft have more than doubled during the 25-year period from 1970 to 1995 (*1*). Aircraft engine manufacturers have made considerable improvements in the efficiency of aircraft engines, resulting in lower levels of carbon monoxide (CO) and hydrocarbon (HC) emissions. Due to the fact that this increase in engine efficiency is partly a result of higher combustion temperatures, however, newer aircraft engines emit comparatively higher levels of NO_x (*2*). Nitrogen oxides are known to be a primary precursor in the photochemical formation of ozone, which is a major component of urban smog in the lower troposphere and can act as a greenhouse gas in the upper troposphere (*3*).

Emission indices, reported as grams of pollutant per kilogram of fuel burned, have been tabulated for most modern aircraft engines (*4*), but these values are reported from ground-based tests and do not account for any possible effects of age or maintenance. Recent work by Schulte et al. (*5*) states that age and maintenance effects may be important. They have installed a chemiluminescent NO_x detector and a nondispersive infrared CO_2 detector on a DA-20E chase plane, for the simultaneous determination of NO_x and CO_2 concentrations in the plumes of commercial jet aircraft at cruise altitude. Other workers have also reported on the use of chemiluminescent methods for making cruise altitude measurements of nitric oxide (*6, 7*), and earlier work by Arnold et al. describes cruise altitude measurements of NO by chemical ionization mass spectrometry (*8*). Heland and Schafer have conducted infrared emission measurements of emissions from a research aircraft on the ground (*9*), but we can find no reported work on ground-based measurements of NO emissions from commercial aircraft during normal operation.

In September 1997, a study was undertaken by the University of Denver, with the cooperation of British Airways and the British Airports Authority, to measure commercial aircraft NO emissions by optical remote sensing. The purpose of this study was to demonstrate the capability of a remote sensor, developed for the measurement of automobile emissions, in measuring NO emission indices from in-use aircraft without interfering in their normal operation. The aircraft, ranging in size from Gulfstream executive jets to Boeing 747-400s, were measured in a mix of idle, taxi-out, and takeoff modes. In the case of this feasibility study, the thrust settings of the aircraft were not controlled nor well-known. Where observed load is indicated, the evidence is only that of the experimenters observing the aircraft behavior.

Experimental Section

The remote sensor used in this study was developed at the University of Denver for measuring the pollutants in motor vehicle exhaust and has previously been described in the literature (*10–12*). The system consists of a nondispersive infrared component for detecting carbon monoxide (CO), carbon dioxide (CO_2), and hydrocarbons (HC) and a dispersive ultraviolet (UV) spectrometer for measuring nitric oxide. Due to the relatively low levels of CO and HC emitted by aircraft and the higher than expected noise on the CO and HC detectors, those results are not reported here.

The source and detector units were positioned on the ground to create an open-air sample path between them, approximately 20 ft in length. During operation, the system was manually triggered when the operator determined that exhaust was coming toward the sensor. Once data collection was initiated, the instrument sampled continuously at 100 Hz for a period of 10 s. At the end of the 10-s sampling period, a data file was compiled containing 1000 discreet voltages from each of the IR detectors and 1000 derived NO concentrations from the UV spectrometer. Postprocessing first involves establishing an arbitrary "clean air" baseline, which is taken as the highest voltage recorded on the CO_2 channel during the 10-s data collection period. The IR voltages were converted to CO_2 concentrations, and then the NO/CO_2 ratio in the exhaust was calculated using a correlation plot, as described by Campos et al. (*7*) and Bishop and Stedman (*10*). From the NO/CO_2 ratio and knowledge of the carbon/hydrogen ratio of the fuel being burned, an NO emission index was calculated. To follow convention, the NO emission indices reported in this preliminary study are in units of grams of NO_2 per kilogram of fuel burned.

There were two locations used for data collection at Heathrow Airport. The first was the Lima cul-de-sac at Terminal 3, where individual aircraft were measured either idling or lightly accelerating immediately after push-out. The second location was at the west end of runway 09 Right, approximately 100 m northwest of the junction between the taxiway and the runway. Most of the aircraft at this site were measured one at a time during taxi-out as they completed their turn onto the takeoff runway. With appropriate wind conditions at this position, the takeoff plumes of some aircraft

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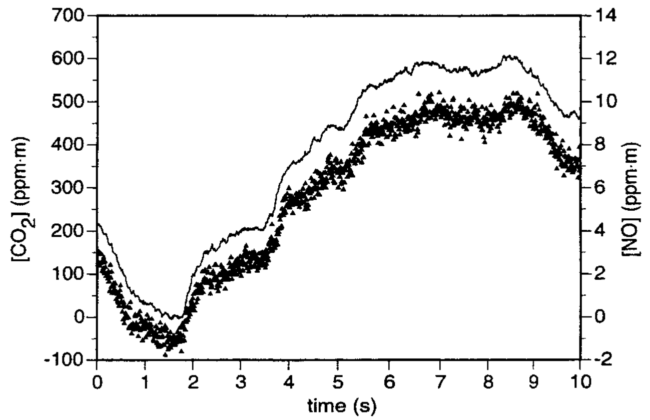

FIGURE 1. Temporal variation of the NO (filled triangles) and CO_2 (solid line) concentrations observed in the plume of a Boeing 777-200 at the beginning of a takeoff run.

would also pass over our instruments. Safety considerations did not allow us to position our equipment directly behind the takeoff runway, nor was it possible to make an accurate measurement of the approximately 100 m distance between the aircraft and the remote sensor.

The distance between the aircraft and the remote sensor was sufficient at both sites to allow for significant plume dilution. The plume measured at the remote sensor was cooled close to ambient temperature, as observed by the instrument operators, and the plume was measured to be optically thin throughout the sampling path. We note that any plume chemistry that converts emitted NO to NO_2 in the few seconds between emission and detection would cause our reported emission index to be a lower limit.

Results and Discussion

During the two days of field measurements at London Heathrow Airport, a total of 181 measurement attempts were made, resulting in 122 valid measurements of 90 different aircraft. A measurement was determined to be invalid if the highest observed CO_2 concentration increase was less than the preset cut point of 160 ppm·m, indicating the lack of an adequate observed plume. Four otherwise valid measurements were excluded because the least squares plot showed an excessive amount of noise in the CO_2 channel.

Sixty-nine of the aircraft measured in this study were at idle and had NO emission indices of less than 5 g/kg (as NO_2). A further 35 of the aircraft had emission indices between 5 and 15 g/kg. The NO emission indices for the remaining 18 aircraft ranged from 15 to 52 g/kg. The aircraft in this last group were measured at the runway position and were either in takeoff mode or observed to be increasing power as they were turning from the taxiway to the runway for immediate takeoff.

Figure 1 shows the temporal variation of the NO and CO_2 concentrations in a typical plume observation, in this case from a Boeing 777-200 (with GE90-76B engines) at the beginning of its takeoff run. From a regression analysis of the NO and CO_2 concentrations in this plot and the NO/CO_2 ratio, the NO emission index was determined to be 49.0 ± 0.15 g/kg. The reported error ($\pm 1\ \sigma$) is the precision returned by the least squares regression routine for the NO/CO_2 ratio. The plot in Figure 1 indicates that the NO concentration appears to go negative for a short period during the plume encounter. This is an artifact of the process by which the ultraviolet reference spectrum is collected during instrument setup and calibration. If background levels of NO decrease during the sampling day, possibly due to changing wind conditions, apparent negative NO concentrations can b recorded. This phenomenon has no deleterious effect on th derived NO/CO_2 ratio, since only relative changes in the N and CO_2 concentrations effect the slope in the correlatio plot.

There were 10 measurements made on seven differer Boeing 767-300 airframes that the operator could confirr were using RB211-524H (or RB211-524H2) engines. One these aircraft was measured three times on 2 consecutiv days, and one of the aircraft was measured twice, all i apparently different operating modes. The observed N emission indices for these aircraft ranged from 1 to 37 g/k These measurements are not inconsistent with the ICA database emissions for this engine, which range from 4.7 g/kg at idle to 65.84 g/kg at 100% thrust. The absolute accura of idle emissions are thought to be ±6 g/kg, based on observe system noise when small plumes were measured. The larg plumes from aircraft under power are estimated to have a overall inaccuracy of ±10%, mostly arising from an analys of the variability of calibrations performed with the inter to simulate large plumes.

The remote sensor used in this study was manned an positioned at ground level, and the data were analyzed i postprocessing. We have reported elsewhere (*13*) that th instrument can be placed below the ground and operate with the use of breakaway periscopes. This configuratio can be operated unmanned, allowing the potential for completely automated system for measuring NO emissio from in-use commercial aircraft at taxi or takeoff. Whe coupled with a video system to record aircraft registratio this system could allow in-use aircraft NO emissions to b characterized in more detail.

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