DEVELOPMENTS IN ADMS-AIRPORT TO TAKE ACCOUNT OF NEAR FIELD DISPERSION AND APPLICATIONS TO HEATHROW AIRPORT

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INTRODUCTION

ADMS-Airport is based on the ADMS-Urban system for modelling urban air quality. In the near field it employs a quasi-Gaussian dispersion model and this is nested within a trajectory model. The model includes allowance for airport sources as well as the full range of other source types including road traffic, point, area, volume and grid sources. Aircraft sources are treated explicitly as accelerating jet sources. Result of a detailed sensitivity study of modelled concentrations to the jet source parameters e.g. exit velocity, temperature, the merging of jet plumes downstream of the aircraft and impacts of wake vortices on jet plume trajectories during the take-off roll are presented.

The application of the model to air quality calculations was conducted for the Model Inter-comparison Study (MIC) of the Project for the Sustainable Development of Heathrow (PSDH). The purpose of the inter-comparison was to identify the best available scientific approach that would be used in upcoming studies of Heathrow. ADMS-Airport was compared with monitored air quality data and four other modelling approaches including semi-empirical methods, the Lagrangian model LASPORT and the US Federal Aviation Authority's model EDMS. A range of diagnostic tools were used to compare the models including concentration/wind speed wind-roses, concentrations along transects, source apportionment, variation in concentration as a function of wind speed, variation of diurnal profiles dependent on runway use and areas of exceedence of air quality standards. The key pollutants for this study were NO_x and NO_2. Close to the airport the different treatment of near field dispersion in the models resulted in significant variation between the models.

ADMS-AIRPORT

ADMS-Airport is an air quality model developed by CERC and designed to calculate pollutant concentrations in the vicinity of an airport. The model represents an extension of the well known ADMS-Urban system (*Carruthers et al.*, 1998), also developed by CERC, which models the impact of the complex mix of sources typical of an urban area. The chemical reaction scheme uses explicit reactions for the NO, NO_2, O_3 interactions, and a limited set of surrogate reactions for the impact of VOCs.

The additional features of ADMS-Airport compared to ADMS-Urban relate to its treatment of aircraft sources. The approach is to use a modified version of the ADMS 3 jet model (*CERC*, 2005) to represent the effects of buoyancy and momentum of the jet engines and also the speed of the aircraft on the jet plume dispersion i.e. the aircraft exhaust is represented by an accelerating jet source. Figure 1 shows the plume height, plume vertical spread and plume centreline minus vertical spread for a moving jet with a buoyant exhaust at four different positions on the runway. Meteorological conditions are neutral with a 5m/s westerly wind.

The plots in Figure 1 show that as the aircraft accelerates the buoyant exhaust plume rises less (it is knocked down by the faster oncoming flow) and the vertical spread is slightly greater when the aircraft is moving faster. Modelling the aircraft exhaust as a buoyant plume rather than a volume source is important in capturing correctly the near field behaviour of the exhaust and hence can inform decisions about runway operation.

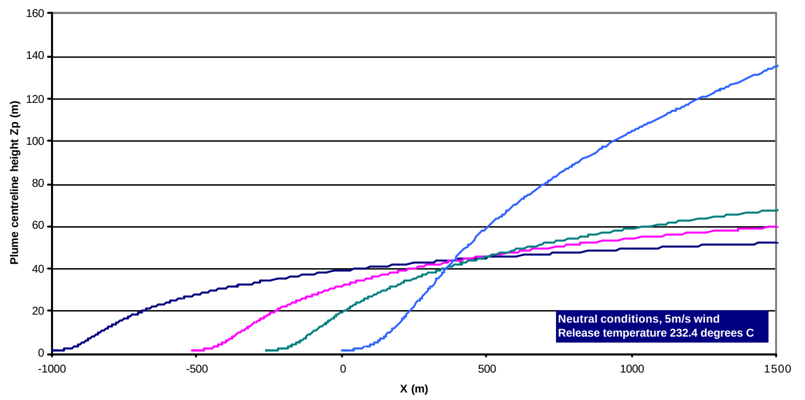


Fig. 1a: Distance (m) vs Plume centreline height (m)

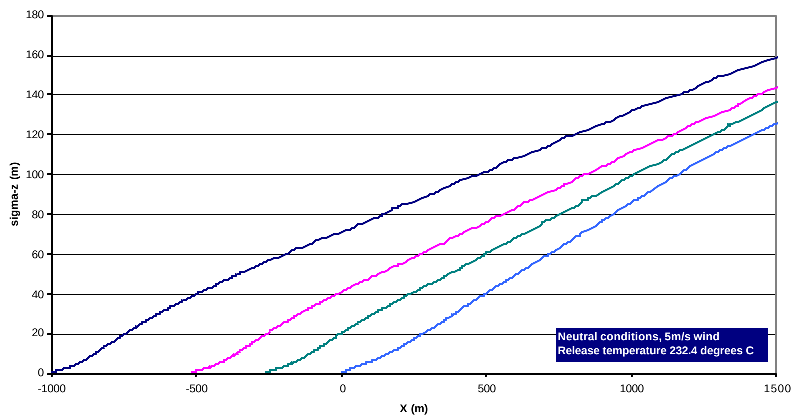


Fig. 1b: Distance (m) vs Plume vertical spread (m).

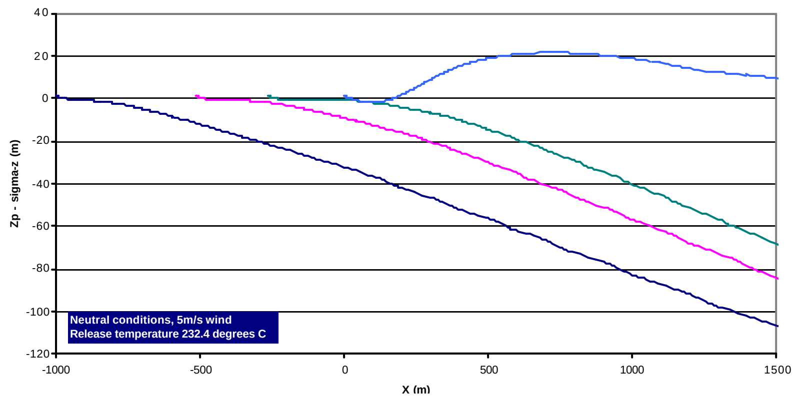


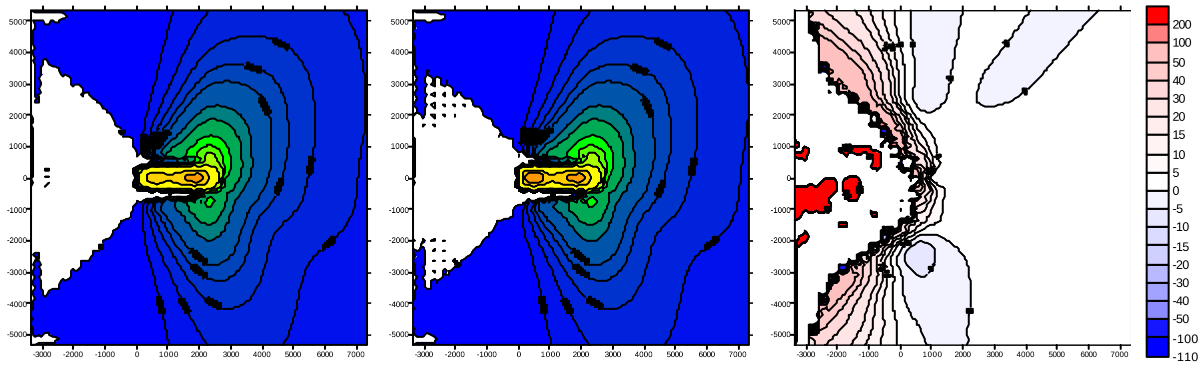
Fig. 1c: Distance (m) vs Plume centreline height minus vertical plume spread (m).

MODEL SENSITIVITY

A detailed set of sensitivity tests has been carried out into the ADMS-Airport modelling of aircraft engines exhausts as moving jet sources. It arose from PSDH discussions about possible modifications to ADMS-Airport modelling in the light of LIDAR studies and considerations regarding the effect of wake vortices and surface effects on jet plume dispersion. The sensitivity tests included changes to illustrate both the impact of adjustment to model parameterisation and the effect of imprecision in the model input data. All the tests use the same airport runway set-up with the runway located at ground level (z=0m) lying east-west. The aircraft take-off towards the west (negative x) with ‘wheels off’ at x=-1000. As they have different take-off lengths the starting point varies for each plane. The results shown here are annual averages. The emissions used are not real emissions and so the magnitude of the predicted concentrations should be ignored. It is the percentage changes in concentration that are of interest.

Vortex shedding

One set of tests looked at the effect that the buoyancy of the release has on ground level concentrations for emissions during the take-off roll. It had been suggested that the effect of wake vortices produced in the later stages of take-off (vortex shedding) is to suppress the lift of the jet plume and that this may be modelled by reducing the jet plume buoyancy. A comparison was made between modelling with buoyant release during all of the take-off roll, during none of the take-off roll and during the first two thirds length of roll. Figure 2 shows some of the results for a B747. It was found that the difference between some and all of the take-off roll being modelled as buoyant is relatively modest except close to the runway where increases of up to 50% occur. By comparison, turning off buoyancy for all of the take-off roll has a significant impact over a wider area.



All take-off roll buoyant Buoyant for first 2/3 length roll Percentage difference

Fig. 2: A320. The left hand and central plots shows predicted annual average concentrations and the right hand plot shows the percentage difference plot with 'All take-off roll buoyant' as the base scenario.

Number of engines

Most of the aircraft studied have two engines, one on either wing. The A340 and B747 are the only exceptions with four engines, two engines on either wing. The study investigated the impact of representing twin or 4-engined aircraft with a smaller number of representative sources, i.e. representing a twin-engined jet with one source and a 4-engined jet with two sources or one source. The need for this arises from the observation (e.g. LIDAR study) that the jet exhausts may combine within a few wingspans of the aircraft with twin-engined aircraft exhibiting only one plume and 4-engined aircraft, two at most. Thus, representing the sources with a reduced number of effective sources may provide a more accurate representation of the effect of momentum and buoyancy on the jets. The position of the new combined engine is taken as the average of the original engines and the engine diameter is set equal to the sum of the two original engines, so the exhaust velocity is unchanged.

Figure 3 shows the plots of percentage difference in concentration modelling an A340 as 4-engined, twin-engined or 1–engined. They show that if the exhaust plumes combine concentrations significantly reduce due to the increase in plume elevation.

Velocity

The effects of uncertainty in the input parameters was investigated in a series of sensitivity tests in which the exhaust temperature, engine velocity and engine diameter are varied by 50%. Figure 4 shows the plots of percentage difference in concentration for an A320 when the exhaust velocity is increased or decreased by 50%. It was found that the predicted concentrations for the twin-engined plane studied, the A320, were less sensitive to the change in any of the three parameters, than those for the 4-engined plane, the B747.

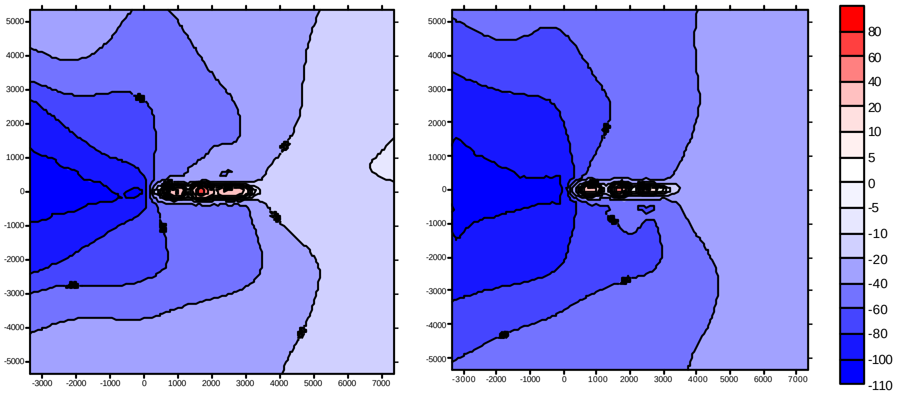


Fig. 3: A340. Percentage difference in annual average ground level concentration between an A340 modelled as twin-engined and 4-engined (left) 1-engined and 4-engined (right). Only wind directions from 180° to 360° have been modelled.

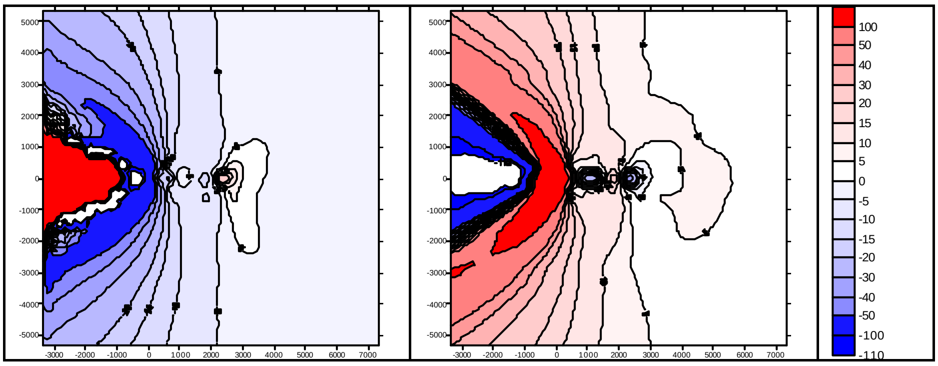


Fig. 4: A320 Percentage difference in annual average ground level concentration between an A320 with jet exhaust increased by 50% (left) decreased by 50% (right) compared with concentration due to a jet with the unmodified velocity.

HEATHROW AIRPORT MODEL INTER-COMPARISON

The annual mean nitrogen dioxide objective of 40 $\mu g\ m^{-3}$ for nitrogen dioxide proved the central focus of the study but short term (hourly) NO_X concentrations were combined with hourly flight information and hourly wind data to investigate the performance of the model. The analysis carried out fell into two broad categories: direct comparison with measured concentrations and diagnostic tests that aim to reveal important dispersion characteristics. At Heathrow airport there are two parallel runways and they are operated such that when aircraft take off on one runway, landings are on the other runway. This runway alternation provided an opportunity to test various aspects of the models.

The short term analysis focussed on measurements and predictions at monitoring site LHR2, which lies within 200m of the start of roll on runway 27R and 1.6km of the start of roll on the parallel runway, 27L. The year used for the comparison was 2002 and the sources of data are described in the inter-comparison report (*DfT*, 2006). Hourly mean NO_X estimates at LHR2 were calculated as a function of wind speed and wind direction to produce polar plots of predicted concentration that were compared with polar plots of the monitored concentration, Figure 5. The pattern of the monitored polar plot shows the highest concentrations when the wind speed is medium to high and from the south-west, where the take-off roll starts. A nearby passive source would be expected to give the highest concentrations under low wind speeds. That the highest concentrations do not occur at low wind speeds indicates that the significant sources are buoyant. The ADMS-Airport results represent the overall pattern of concentration well; but there is some evidence of concentrations being too high at low wind speeds possibly due to over-estimating the impact of nearby passive sources such as the airport perimeter road.

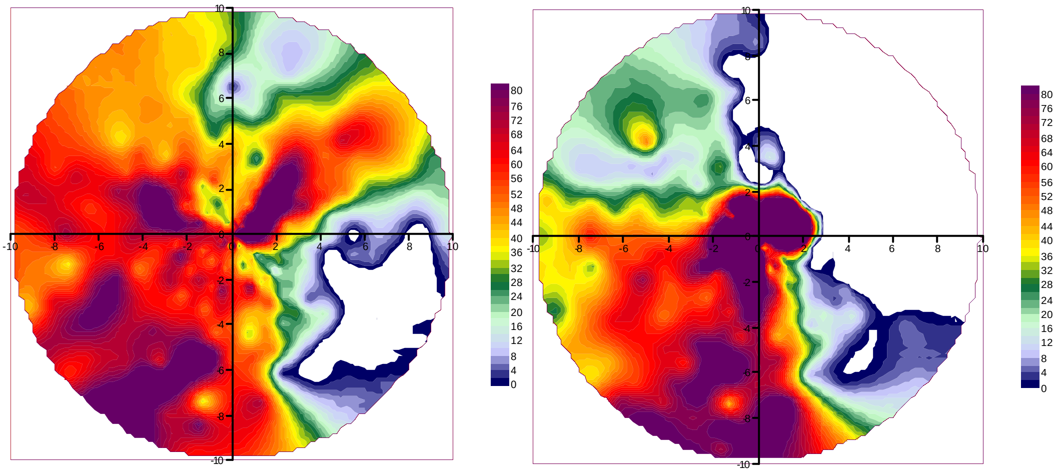


Fig. 5: Polar plots of mean NO_X concentration at monitor LHR2. (Left) Monitored concentration (Right) ADMS-Airport concentration. Axes show wind speed from 0-10m/s.

DISCUSSION

ADMS-Airport models aircraft exhausts as buoyant moving jet sources. We have presented some results from a detailed sensitivity study that included changes to illustrate both the impact of adjustment to model parameterisation and the effect of imprecision in the model input data. Suppression of buoyancy at the end of take-off roll was found not to be very significant, but the enhanced plume rise due to modelling the exhausts combining within several wingspans of the jet exit was more significant.

In the Heathrow airport Model Inter-Comparison the difference in near field treatment of the jet exhausts, with ADMS-Airport modelling the exhausts as buoyant jets rather than volume sources, resulted in significant variation in predicted concentrations at receptors nearest to the airport. The diagnostic tools used in the inter-comparison suggested that the modelling by ADMS-Airport did correctly capture the important features of the behaviour of the aircraft emissions, such as the behaviour with wind speed and runway alternation. As the model is physically based it is possible to model effects such as the impact of vortex shedding through reduced buoyancy, the influence of ground on the jet through increased surface drag and asymmetrical entrainment, and possible convergence of the plumes within the framework of the model and this was identified as a model strength by the Heathrow study.

ACKNOWLEDGEMENT

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