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# TRENDS IN GLOBAL NOISE AND EMISSIONS FROM COMMERCIAL AVIATION FOR 2000 THROUGH 2025

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## Abstract

In 1983, the International Civil Aviation Organization (ICAO) established the Committee on Aviation and Environmental Protection (CAEP) to assess aviation-related noise and emissions issues. CAEP has established three environmental goals: limit or reduce the number of people *impacted* by noise; limit or reduce the *impact* of aviation emissions on local air quality (LAQ); and limit or reduce the *impact* of aviation greenhouse gas (GHG) emissions on the global climate.

With CAEP goals in mind, this paper presents trends in aviation noise impacts, expressed in terms of population exposed to various day-night average sound levels (DNL). The paper also presents trends in total aviation-related fuel burn and emissions. In both cases, aggregated global data are presented, as well as data on a regional level for baseline years of 2000 through 2005, as well as for the future years of 2010, 2015, 2020 and 2025.

As can be seen in this trends assessment, the input databases and computational methodologies used are migrating in the direction of harmonizing data and methods. It is envisioned that these types of assessments have broad applicability and can be used to support a variety of national and international requirements, including policy establishment.

## Introduction

In 1983, the International Civil Aviation Organization (ICAO) established the Committee on Aviation and Environmental Protection (CAEP) to assess aviation-related noise and emissions issues. CAEP meets on a triennial basis, with the 7th and latest meeting (CAEP/7) scheduled for February 2007. In support of their 7th Meeting, CAEP has established three environmental goals: limit or reduce the number of people impacted by noise; limit or reduce the impact of aviation emissions on local air quality (LAQ); and limit or reduce the impact of aviation greenhouse gas (GHG) emissions on the global climate.

For the purposes of this paper, LAQ is defined as the region in the atmosphere from 0 to 3000 feet above ground level (AGL). LAQ is a concern for the population in the vicinity of an airport. Increased emissions may lead to adverse health effects such as respiratory issues and damage to lung tissue, damage to waterways and vegetation, as well as decreased visibility [1].

GHG is defined as the region typically anywhere above LAQ (greater than 3000 ft AGL). The effects of GHG are related to climate change, in that an increase in GHG may lead to an increase in the overall global temperature [1], but the degree of the effects are much more uncertain compared with the effects of LAQ emissions.

The commonly accepted metric for measuring noise impact has been the number of people within a particular sound level contour, usually expressed in terms of day-night average sound level (DNL).

Unlike for noise, there is no generally accepted metrics for reporting the impact of LAQ and GHG. Additional work is needed to establish a metric for LAQ/GHG.

This paper presents trends in aviation-related noise impacts, expressed in terms of population exposed to various DNL values. In the absence of an accepted metric for determining LAQ/GHG impacts, this paper presents trends in total aviation fuel burn and emissions. In both cases, aggregated global data are presented, as well as data on a regional level for baseline years of 2000 through 2005, as well as for future years of 2010, 2015, 2020 and 2025.

## Current and Future Noise Analyses

The Federal Aviation Administration's (FAA) Aviation Environmental Design Tool, Model for Assessing Global Emissions of Noise from Transport Aircraft (AEDT/MAGENTA) was used to assess global trends in current and future aircraft noise exposure. Various member countries of ICAO/CAEP led the development of AEDT/MAGENTA. The U.S. and U.K. led design and development, and the U.S. provided direct funding support.

AEDT/MAGENTA computes detailed noise exposure for approximately 200 of the world's busiest airports, and provides lower fidelity noise computations for approximately 2000 additional airports. For each airport, a noise contour is combined with population data to compute the number of people within a particular sound level contour, usually expressed in terms of DNL.

The current version of AEDT/MAGENTA is compliant with the recently-approved ECAC.CEAC Doc 29, 3rd Edition, *Report on Standard Method of Computing Noise Contours around Civil Airports*[2]. The most substantial advance in Doc 29 is the adoption of an updated version for computing the lateral attenuation of airplane noise, as prescribed in the Society of Automotive Engineers' (SAE) Aerospace Information Report (AIR) 5662, *Method for Predicting Lateral Attenuation of Airplane Noise* [3]. SAE has shown the algorithms in this AIR are more accurate than those in its predecessor document. They have also shown that the new standard will result in contours that are generally 10 to 20 % larger, than those computed with the older standard, SAE AIR 1751, *Prediction Method for Lateral Attenuation of Airplane Noise During Takeoff and Landing* [4].

For the noise trends assessment, the 2000 through 2004 results were originally computed based on the older SAE AIR 1751 standard, but were adjusted for consistency with the newer SAE AIR 5662 and DOC 29 standards. The 2005 noise results were computed and displayed in two ways: with a Doc 29 compliant AEDT/MAGENTA and with a version of the model based on the older lateral attenuation algorithms of SAE AIR 1751. This way, the effect of migrating to the new Doc 29-compliant standard could be easily quantified.

For the 2005 Doc 29 – compliant AEDT/MAGENTA runs, results were computed both with and without Commonwealth of Independent State (CIS) airports, which include four from Russia and two from other CIS states. Due primarily to data availability issues, previous global noise exposure trends assessments excluded CIS airports. Their inclusion in the current trends assessment allows for a more consistent comparison with the LAQ/GHG results, since emissions data have traditionally been reported for all global airports. This consistency is a logical evolution in leading to noise/emissions interdependency studies, which reflects the current direction of aviation-related environmental analyses (e.g., ICAO/CAEP analyses, and analyses in support of the Joint Programs Development Office in the U.S. (http://www.jpdo.aero/))

The fleet and operations module (FOM) within AEDT, which is documented extensively in another paper to this conference, *The Fleet and Operations Module (FOM) within the FAA's Aviation Environmental Design Tool (AEDT)* [5], was used to generate future operations data for the years 2010, 2015, 2020, and 2025. The FOM assumed unconstrained growth, such that infrastructure enhancements would keep pace with industry growth.

The FOM also needed to make an estimation for the aircraft being flown (known as the fleet) in the future years of the study. The database used for populating the future aircraft fleet is known as the Best Practices (BP) database, and it is developed with substantial input from the aviation industry. The BP database makes no estimates of noise and emissions for future technology aircraft. It only includes aircraft already designed and planned to be in service.

The process of replacing retired aircraft in the future fleet with aircraft in the BP database is discussed in the FOM paper. It is consistent for both noise and emissions, with the only difference being a slightly different pool of aircraft being used to replace retired aircraft. Work is currently underway to ensure that the replacement database is consistent for both noise and emissions analyses, and that the database will actually reflect what might be achieved in terms of future advances in noise and emissions technologies.

The AEDT/MAGENTA results are presented in terms of population within the 55, 60 and 65 dB DNL contours. Geographically-based, regional totals are presented in Table 1, and also graphically for the 65 dB DNL contour in Figure 1. This chart represents all operations from the specific region, whether within a region or between regions. It also clearly illustrates the sharp decrease in population exposed from 2001 to 2002 due to the events of September 11, 2001, the SARS epidemic, and the accompanying economic downturn.

As discussed above, the 2005 noise results were computed in two ways, first using the Doc 29-compliant AEDT/MAGENTA and then using the older version of AEDT/MAGENTA. In Table 1, these two scenarios are labeled as 2005(A) and 2005(B)(Doc 29 W/CIS). In Figure 1, results for years 2000 through 2004 were adjusted to account for the effects of migrating to a DOC 29-compliant MAGENTA in 2005.

Table 2 summarizes the differences in computed noise when using the Doc 29-compliant version of the model, as compared with the older version, including the impact of including CIS airports. As can be seen, the primary contributor to the change in 2005 results is the use of a Doc 29-compliant AEDT/MAGENTA, which includes the recently-adopted and more accurate lateral attenuation algorithms of SAE AIR 5662 [3], as previously discussed.

## LAQ and GHG Emissions

For the LAQ and GHG emissions trends, the results from four models were considered: (1) U.S. FAA's AEDT System for assessing Aviation's Global Emissions (AEDT/SAGE) [6]; (2) EUROCONTROL's Advanced Emissions Model (AEM) [7]; (3) U.K. Civil Aviation Authority's AERO2K [8]; and (4) U.K.'s FAST Model [9]. A primary driver for including the results from four models is that, unlike with noise, there are currently no internationally accepted standards for computing aircraft emissions.

A summary of the years, which are identical to those used for noise, and models used for the LAQ/GHG trends assessment is presented in Table 3.

Since the GHG models compute emissions and fuel burn from aircraft operating gate-to-gate, they provide LAQ data in addition to data for the en-route portion of flight (GHG). Consequently, for the purposes of the trends assessment, the results from the four models are presented in Table 4 by flight regime, so as to preserve the output of interest for LAQ (the terminal area under 3,000 ft.) and GHG (en-route over 3,000 feet).

Table 4 presents the summary fuel burn and emissions (CO, HC, $NO_x$, and $CO_2$) results for all LAQ/GHG models for all analysis years. Figure 2 presents the base-year (2000 through 2005) actual fuel burn data from each model, as well as the four-model, average fuel burn and 95% confidence interval (CI) for each future year. Figures 3 and 4 present the base-year (2000 through 2005) actual $NO_x$ data, as well as the four-model, average $NO_x$ and 95% CI for each future year, for the LAQ and GHG cases, respectively.

## Observations

In the process of evaluating the environmental goals and conducting this trends assessment, several potential methodological enhancements were identified. These should be considered in any similar trends assessment.

First, enhancements and harmonization of the approaches used for computing emissions for both GHG and LAQ should be researched. The dispersion of pollutants should be considered, as well as the inclusion of emissions contributions from the ground-level support crew. Also, particulate matter was not observed due to insufficient scientific consensus as to proper modeling techniques. If the science is sufficiently mature, then particulate matter should be considered.

Enhancements can also be made to the way future years are modeled. As mentioned previously, there were no assumptions of improving aircraft technology. In addition, the future operational data was computed assuming unconstrained growth. Updated operational procedures that will reduce noise and emissions could also be included, as well as improved land use planning initiatives (e.g., future encroachment trends). Finally, an appropriate metric for fuel efficiency must be considered for assessing trends in fuel burn and emissions against a particular goal.

The data presented here may be underestimating what aviation might expect to be able to achieve thorough continued improvements in technology, operation, and air traffic management. Therefore, proper consideration of the above recommendations will reduce the uncertainty and improve the policy relevance of the results for future trends assessments, as well as policy related assessments.

Note, however, these recommendations will also result in a discontinuity in process compared with previous analyses of noise and emissions. Care will need to be taken in conducting future trends assessments to ensure that the effects of this process discontinuity are adequately quantified. The process undertaken herein to quantify the effects of migrating to a DOC 29-compliant AEDT/MAGENTA may serve as a valuable template.

## Summary

The de facto standard for conducting global assessment of aircraft noise trends is AEDT-MAGENTA. For the assessment of global emissions trends from aircraft, there are several models that are in use throughout the U.S. and Europe. In most cases, the emissions tools utilize common input data and computational methodologies. There is work currently underway in ICAO/CAEP to advance this harmonization process not only within the emissions methodologies, but across noise and emissions. There is a growing desire by environmental policymakers to not only study the effects a particular policy might have on noise or on emissions, but to be able to consider the interdependencies between these two important environmental variables.

As can be seen in this study, the input databases and computational methodologies are migrating in the direction of harmonizing data and methods. However, there is still a lot of work to accomplish in this effort. Similarly, improvements must be made to the overall approach to conducting noise and emissions trends assessments, particularly with regard to fleet forecasting. Finally, it is envisioned that the methods and input data used for these types of trends assessments have broad applicability and can be used to support a variety of national and international requirements.

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## References

[1] Environmental Protection Agency (EPA), "Air and Radiation: Basic Information,", EPA Office of Air and Radiation, http://www.epa.gov/air/index.html, 2006.

[2] European Civil Aviation Conference, "ECAC.CEAC Doc 29: Report on Standard Method of Computing Noise Contours around Civil Airports, Volume 2: Technical Guide," ECAC.CEAC, 3rd Edition, July 2005.

[3] SAE Aerospace Information Report, "AIR 5662: Method for Predicting Lateral Attenuation of Airplane Noise", SAE International, 2006.

[4] SAE Aerospace Information Report, "AIR 1751: Prediction Method for Lateral Attenuation of Airplane Noise During Takeoff and Landing", Society of Automotive Engineers Inc., 1981.

[5] Grandi, Fabio, "The Fleet and Operations Module (FOM) within the FAA's Aviation Environmental Design Tool (AEDT)", Air

Traffic Management Research and Development, 2007.

[6] Federal Aviation Administration (FAA), "Aviation Environmental Models", FAA Office of Environment and Energy, http://www.faa.gov/about/office_org/headquarters_offices/aep/models/ , 2006.

[7] Jelinek, Frank. "European GAES-INVENT Emission Inventory", EUROCONTROL, http://www.eurocontrol.int/eec/public/standard_page/SEE_2004_report_15.html, August, 2005.

[8] Centre for Air Transport and the Environment. "AERO2K", Manchester Metropolitan University, http://www.cate.mmu.ac.uk/aero2k.asp, 2006.

[9] Lee, David S, Owen, Bethan. "Study on the Allocation of Emissions from International Aviation to the U.K. Inventory", DEFRA Global Atmosphere Division, http://www.cate.mmu.ac.uk/project_view.asp?chg=projects&chg2=2&id=2, 2006.

**Table 1: AEDT/MAGENTA Results for 55, 60 and 65 dB DNL**
**Population Above Contour Level**

**55 dB**

| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005(A) (CAEP / 6) | 2005(B) (DOC29 W/CIS) | 2010 | 2015 | 2020 | 2025 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Africa** | 345274 | 346371 | 432600 | 416500 | 408681 | 404635 | 339269 | 308833 | 258711 | 235939 | 240619 |
| **Asia** | 7587786 | 7645920 | 6286438 | 5972194 | 6098674 | 6190149 | 7682065 | 8842866 | 9853990 | 10158369 | 10471078 |
| **Australia** | 86935 | 90061 | 117292 | 115760 | 118132 | 120432 | 166388 | 193162 | 216910 | 230713 | 242984 |
| **Eastern Europe** | 253604 | 255457 | 231480 | 228142 | 228839 | 229476 | 965773 | 1013975 | 1026514 | 1058578 | 1086811 |
| **Middle East** | 2452210 | 2470682 | 1461794 | 1395412 | 1405478 | 1425305 | 2684665 | 2888199 | 3142247 | 3521081 | 3981975 |
| **North America** | 10604625 | 10499088 | 6864415 | 6471512 | 6427769 | 6396417 | 6681386 | 7042005 | 7738542 | 8292456 | 9095908 |
| **South America** | 1229374 | 1210471 | 1154726 | 1098394 | 1089359 | 1076901 | 1039549 | 1111125 | 1136068 | 1180589 | 1220806 |
| **Western Europe** | 1432970 | 1438051 | 1274784 | 1267275 | 1279866 | 1292375 | 1802067 | 2282325 | 2875581 | 3461975 | 3979326 |
| **Total** | 23992776 | 23956101 | 17823529 | 16965188 | 17056798 | 17135691 | 21361161 | 23682489 | 26248563 | 28139699 | 30319506 |

**60 dB**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Africa** | 198579 | 199421 | 234863 | 226141 | 220675 | 219429 | 104508 | 89518 | 67448 | 58721 | 60780 |
| **Asia** | 2781281 | 2792792 | 1927485 | 1801359 | 1829804 | 1860149 | 2379682 | 2822976 | 3380451 | 3546543 | 3743031 |
| **Australia** | 27780 | 29455 | 44883 | 43803 | 44725 | 45619 | 58143 | 71856 | 85323 | 91668 | 97618 |
| **Eastern Europe** | 159676 | 160458 | 147523 | 145383 | 145636 | 145896 | 437317 | 464085 | 474472 | 483513 | 490875 |
| **Middle East** | 587277 | 592119 | 321184 | 309653 | 313785 | 318036 | 740712 | 806883 | 888768 | 1018441 | 1177921 |
| **North America** | 3730954 | 3692928 | 2524886 | 2367806 | 2345418 | 2334667 | 2491549 | 2560744 | 2812067 | 2985171 | 3301683 |
| **South America** | 527943 | 518075 | 473783 | 443849 | 439598 | 433803 | 394540 | 423169 | 431253 | 449388 | 465380 |
| **Western Europe** | 455588 | 459007 | 421986 | 418290 | 422864 | 427797 | 601859 | 777263 | 989390 | 1204911 | 1411475 |
| **Total** | 8469077 | 8444256 | 6096592 | 5756284 | 5762504 | 5785394 | 7208309 | 8016493 | 9129170 | 9838354 | 10748762 |

**65 dB**

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Africa** | 61030 | 61969 | 76658 | 70608 | 67180 | 66433 | 21004 | 18601 | 14458 | 12769 | 12740 |
| **Asia** | 819958 | 822775 | 619680 | 593786 | 601511 | 609520 | 715427 | 864369 | 994774 | 1048162 | 1113596 |
| **Australia** | 5185 | 5649 | 13756 | 13324 | 13661 | 13997 | 15106 | 20017 | 25761 | 28299 | 30751 |
| **Eastern Europe** | 63335 | 64808 | 66872 | 65382 | 65932 | 66506 | 176537 | 194870 | 205129 | 215464 | 224240 |
| **Middle East** | 137977 | 138741 | 70740 | 68787 | 69718 | 70636 | 243795 | 258929 | 273665 | 301597 | 336819 |
| **North America** | 1303739 | 1294429 | 865205 | 798740 | 790488 | 785664 | 794503 | 798562 | 868745 | 931105 | 1053662 |
| **South America** | 206534 | 202335 | 176799 | 163170 | 161320 | 158714 | 137139 | 148223 | 151210 | 157270 | 163238 |
| **Western Europe** | 119988 | 121617 | 129018 | 127932 | 129495 | 131070 | 165396 | 221938 | 293235 | 370512 | 446849 |
| **Total** | 2717745 | 2712322 | 2018727 | 1901729 | 1899305 | 1902538 | 2268907 | 2525509 | 2826977 | 3065178 | 3381894 |

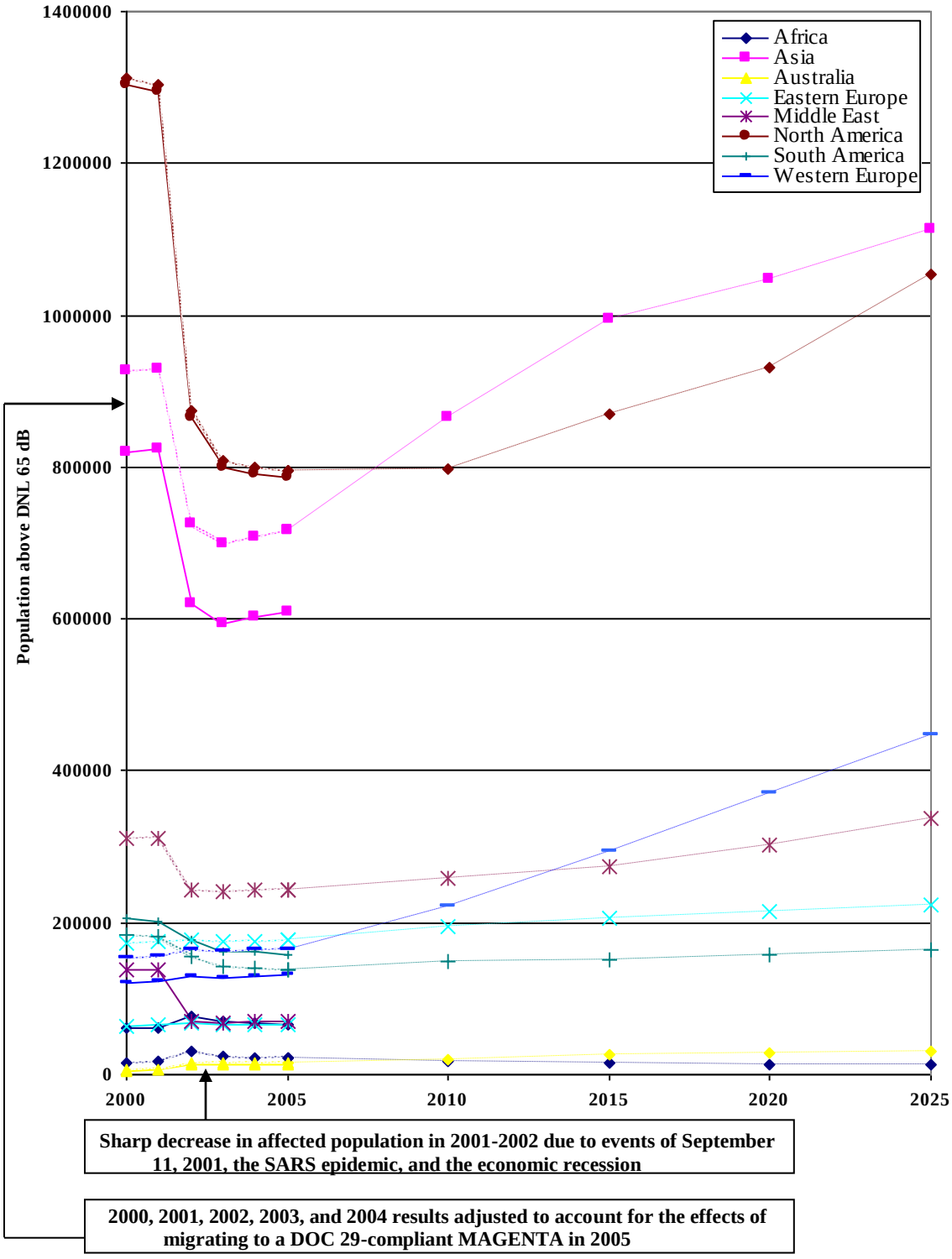
**Table 2: Change in Population, Sensitivity Summary, Doc29 Compliance Contribution**

| | % Change in Population Relative to 2005(A) with CAEP/6 Noise Engine | | |
|---|---|---|---|
| **DNL (dB)** | **2005(A)** | **2005(B) (DOC29 and CIS TOTAL)** | **2005(B) (DOC29 only TOTAL)** |
| **55** | **Ref** | **25%** | **19%** |
| **60** | **Ref** | **25%** | **18%** |
| **65** | **Ref** | **19%** | **11%** |

**Table 3: Summary of Years and Models for Emissions**

| Year of Study | Study Type | Model Notes for Quantifying Fuelburn, Emissions and Fuel Burn Efficiency |
|---|---|---|
| 2000 | Baseline | AEDT / SAGE<br>FAST |
| 2001 | Baseline | AEDT / SAGE |
| 2002 | Baseline | AEDT / SAGE<br>AEM<br>AERO2K |
| 2003 | Baseline | AEDT / SAGE<br>AEM |
| 2004 | Baseline | AEDT / SAGE<br>AEM |
| 2005 | Baseline | AEDT / SAGE<br>AEM<br>FAST |
| 2010, 2015, 2020, 2025 | Future | AEDT/SAGE, AERO2K and AEM using operational deltas generated from the AEDT fleet and operations Module (FOM); FAST method using 2003 predictions and seat-based category aircraft. |

**Figure 1: Summary of AEDT/MAGENTA Results for 65 dB DNL**



## Table 4: Summary of LAQ and GHG Fuelburn and Emissions

| | | Fuelburn (Tg) | | | CO (Tg) | | | HC (Tg) | | | NOx (Tg) | | | CO2 (Tg) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | < 3000 ft. | > 3000 ft. | Total | < 3000 ft. | > 3000 ft. | Total | < 3000 ft. | > 3000 ft. | Total | < 3000 ft. | > 3000 ft. | Total | < 3000 ft. | > 3000 ft. | Total |
| 2000 | AEDT / SAGE | 12.904 | 168.418 | 181.322 | 0.084 | 0.390 | 0.474 | 0.016 | 0.060 | 0.076 | 0.197 | 2.308 | 2.505 | 40.713 | 531.358 | 572.071 |
| | AEM | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | AERO2K | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | FAST | 19.000 | 133.000 | 152.000 | n/a | n/a | n/a | n/a | n/a | n/a | 0.270 | 1.710 | 1.980 | 59.000 | 421.000 | 479.000 |
| 2001 | AEDT / SAGE | 12.350 | 158.106 | 170.456 | 0.076 | 0.333 | 0.409 | 0.014 | 0.049 | 0.063 | 0.192 | 2.166 | 2.358 | 38.965 | 498.824 | 537.789 |
| | AEM | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | AERO2K | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | FAST | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| 2002 | AEDT / SAGE | 12.239 | 158.587 | 170.826 | 0.076 | 0.347 | 0.423 | 0.013 | 0.051 | 0.064 | 0.194 | 2.219 | 2.414 | 38.615 | 500.341 | 538.956 |
| | AEM | 16.768 | 157.536 | 174.303 | 0.054 | 0.424 | 0.478 | 0.007 | 0.053 | 0.060 | 0.250 | 2.020 | 2.270 | 52.802 | 496.080 | 548.882 |
| | AERO2K | 18.494 | 136.688 | 155.183 | 0.199 | 0.304 | 0.503 | 0.027 | 0.036 | 0.063 | 0.248 | 1.800 | 2.047 | 58.055 | 430.911 | 488.966 |
| | FAST | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| 2003 | AEDT / SAGE | 12.415 | 164.011 | 176.427 | 0.074 | 0.354 | 0.429 | 0.013 | 0.049 | 0.062 | 0.199 | 2.294 | 2.493 | 39.171 | 517.456 | 556.627 |
| | AEM | 16.768 | 161.283 | 178.052 | 0.054 | 0.426 | 0.480 | 0.007 | 0.051 | 0.058 | 0.248 | 2.088 | 2.336 | 52.804 | 507.881 | 560.685 |
| | AERO2K | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | FAST | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| 2004 | AEDT / SAGE | 12.881 | 175.473 | 188.354 | 0.076 | 0.373 | 0.450 | 0.013 | 0.050 | 0.063 | 0.210 | 2.476 | 2.686 | 40.640 | 553.618 | 594.258 |
| | AEM | 17.795 | 170.300 | 188.095 | 0.056 | 0.450 | 0.506 | 0.007 | 0.052 | 0.059 | 0.261 | 2.179 | 2.440 | 56.036 | 536.275 | 592.310 |
| | AERO2K | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| | FAST | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |
| 2005 | AEDT / SAGE | 14.980 | 178.566 | 193.546 | 0.133 | 0.341 | 0.474 | 0.016 | 0.045 | 0.061 | 0.211 | 2.788 | 2.999 | 47.261 | 563.376 | 610.637 |
| | AEM | 18.414 | 174.352 | 192.766 | 0.058 | 0.465 | 0.523 | 0.007 | 0.053 | 0.060 | 0.269 | 2.224 | 2.493 | 57.987 | 549.033 | 607.020 |
| | AERO2K | 21.837 | 162.996 | 184.833 | 0.235 | 0.363 | 0.597 | 0.031 | 0.043 | 0.074 | 0.297 | 2.166 | 2.463 | 68.548 | 513.846 | 582.394 |
| | FAST | 18.802 | 138.198 | 157.000 | n/a | n/a | n/a | n/a | n/a | n/a | 0.270 | 1.800 | 2.070 | 59.281 | 435.740 | 495.021 |
| 2010 | AEDT / SAGE | 18.560 | 227.587 | 246.146 | 0.160 | 0.425 | 0.585 | 0.018 | 0.050 | 0.068 | 0.267 | 3.579 | 3.846 | 58.555 | 718.036 | 776.591 |
| | AEM | 23.060 | 222.291 | 245.351 | 0.072 | 0.586 | 0.658 | 0.009 | 0.068 | 0.077 | 0.340 | 2.859 | 3.200 | 72.616 | 699.996 | 772.612 |
| | AERO2K | 28.075 | 212.377 | 240.452 | 0.301 | 0.468 | 0.770 | 0.040 | 0.055 | 0.095 | 0.392 | 2.854 | 3.245 | 88.131 | 669.526 | 757.657 |
| | FAST | 22.000 | 172.000 | 192.000 | n/a | n/a | n/a | n/a | n/a | n/a | 0.340 | 2.310 | 2.650 | 71.000 | 534.000 | 605.000 |
| 2015 | AEDT / SAGE | 22.678 | 291.458 | 314.136 | 0.192 | 0.515 | 0.707 | 0.020 | 0.056 | 0.077 | 0.331 | 4.593 | 4.924 | 71.550 | 919.551 | 991.101 |
| | AEM | 28.863 | 280.598 | 309.460 | 0.089 | 0.732 | 0.820 | 0.011 | 0.086 | 0.098 | 0.435 | 3.631 | 4.067 | 90.889 | 883.602 | 974.491 |
| | AERO2K | 35.706 | 272.519 | 308.225 | 0.383 | 0.598 | 0.981 | 0.051 | 0.069 | 0.120 | 0.509 | 3.693 | 4.201 | 112.085 | 859.131 | 971.216 |
| | FAST | 28.000 | 214.000 | 242.000 | n/a | n/a | n/a | n/a | n/a | n/a | 0.410 | 2.930 | 3.340 | 88.000 | 675.000 | 763.000 |
| 2020 | AEDT / SAGE | 26.398 | 318.732 | 345.130 | 0.217 | 0.575 | 0.793 | 0.023 | 0.059 | 0.082 | 0.396 | 5.051 | 5.447 | 83.286 | 1005.600 | 1088.886 |
| | AEM | 36.234 | 350.272 | 386.506 | 0.109 | 0.896 | 1.004 | 0.014 | 0.107 | 0.121 | 0.557 | 4.605 | 5.161 | 114.100 | 1103.008 | 1217.108 |
| | AERO2K | 44.275 | 325.388 | 369.663 | 0.477 | 0.726 | 1.203 | 0.063 | 0.085 | 0.148 | 0.643 | 4.491 | 5.135 | 138.982 | 1025.784 | 1164.766 |
| | FAST | 36.000 | 282.000 | 318.000 | n/a | n/a | n/a | n/a | n/a | n/a | 0.530 | 3.910 | 4.440 | 114.000 | 888.000 | 1003.000 |
| 2025 | AEDT / SAGE | 30.556 | 358.963 | 389.520 | 0.246 | 0.655 | 0.901 | 0.025 | 0.064 | 0.090 | 0.467 | 5.701 | 6.168 | 96.405 | 1132.530 | 1228.934 |
| | AEM | 43.972 | 428.614 | 472.586 | 0.129 | 1.080 | 1.210 | 0.017 | 0.129 | 0.146 | 0.685 | 5.683 | 6.368 | 138.469 | 1349.706 | 1488.175 |
| | AERO2K | 54.296 | 391.315 | 445.611 | 0.587 | 0.880 | 1.466 | 0.078 | 0.104 | 0.182 | 0.799 | 5.461 | 6.260 | 170.437 | 1233.608 | 1404.045 |
| | FAST | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a | n/a |

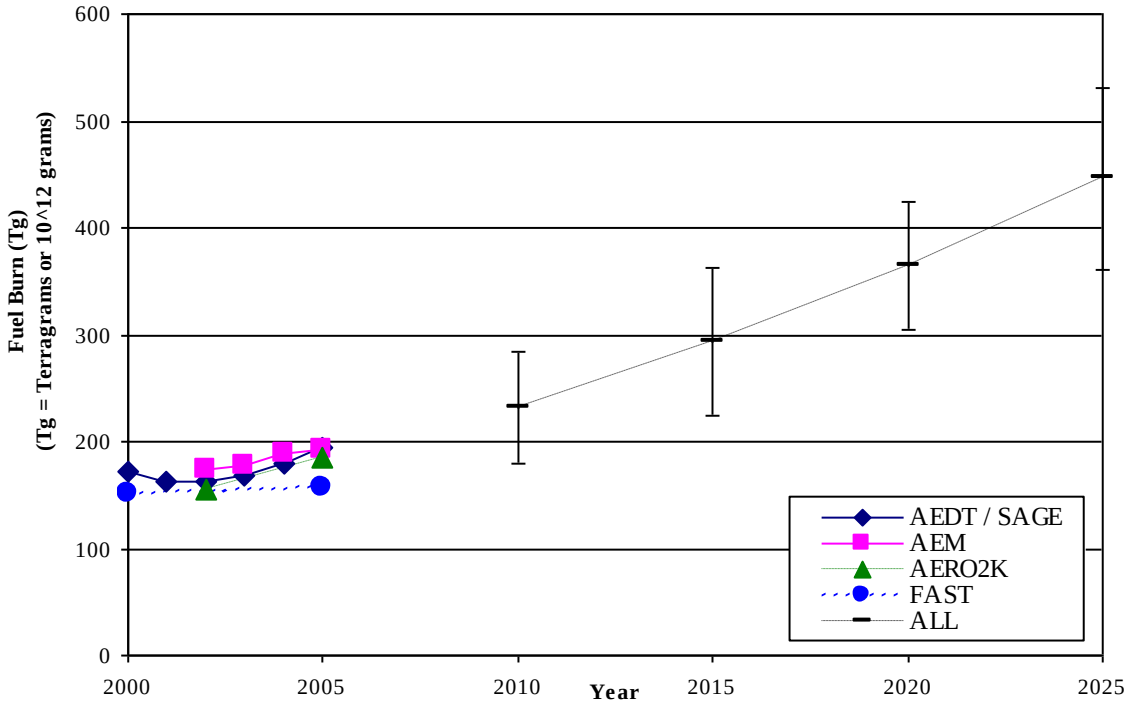



**Figure 2: Summary of Total Fuel Burn. Represents four individual model results for actual fuel burn data, and four-model-average fuel burn with 95% confidence intervals for each future year.**

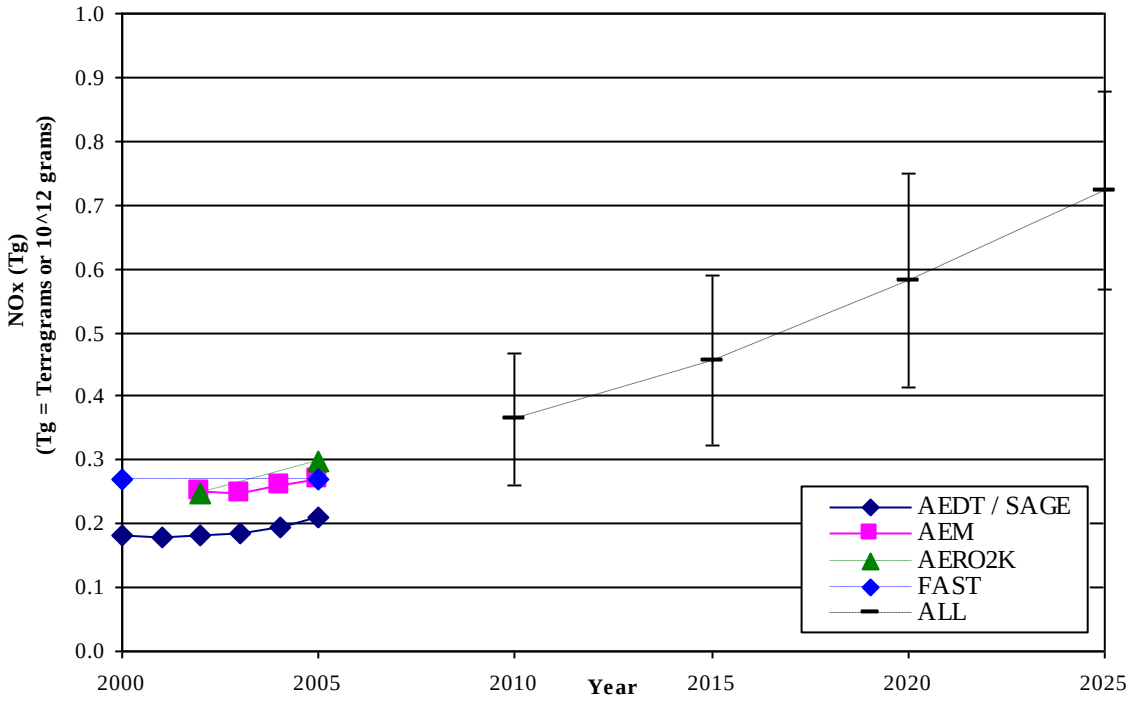



**Figure 3: Summary of NOx < 3000 Ft (Local Air Quality). Represents four individual model results for actual fuel burn data, and four-model-average fuel burn with 95% confidence intervals for each future year.**

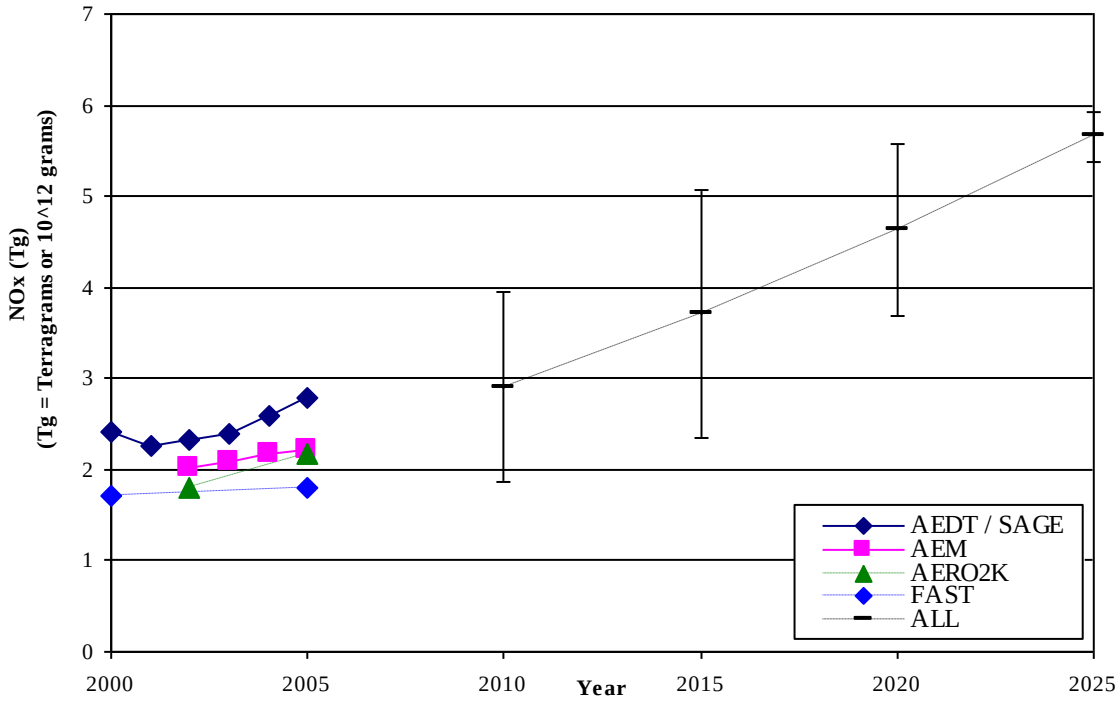



**Figure 4: Summary of NOx > 3000 Ft (Green House Gases). Represents four individual model results for actual fuel burn data, and four-model-average fuel burn with 95% confidence intervals for each future year.**