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, fuel burn, and emissions based on demand growth met by currently available aircraft types. Noise trends are expressed in terms of population exposed to various day-night average sound levels (DNL). 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.

The trends presented herein were developed to support the 7th Meeting of CAEP in February 2007 and represent an initial assessment against which future developments in technology, operational and air traffic management practice, and changes in demand, can be assessed. In support of the 8th Meeting of CAEP in February 2008, the trends will be updated and will include a number of improvements, including consideration of improvements in aircraft and operational technology as well as a revised traffic forecast. The result will be a more realistic set of trends for CAEP/8. The noise, LAQ, and GHG results presented herein should be considered an upper bound to future trends.

It is envisioned that these types of trends assessments have broad applicability and can be used to support a variety of national and international requirements, including policy establishment.

1 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 (e.g., increased noise/emissions stringency, improved operational procedures, fleet forecasting, etc.). CAEP meets on a triennial basis, with the 7th and most recent meeting (CAEP/7) having taken place in February 2007, and the following meeting (CAEP/8) scheduled for February 2010.

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. Although these goals are somewhat qualitative, it is expected that CAEP may establish quantitative goals, against which the implications of various policy/regulatory decisions can be measured. To better inform the assessment of CAEP's environmental goals, an initial set of environmental trends were developed in support of CAEP/7.

For the purposes of the trends assessment, any emissions released in the atmosphere from 0 to 3000 feet above ground level (AGL) are categorized as LAQ emissions. LAQ is primarily 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, and in the case of particulate matter (PM) emissions, increased mortality [1, 2].

In developing the current environmental trends, any emissions released in the atmosphere above 3000 feet AGL are categorized as GHG emissions. As a general rule of thumb for many aircraft emissions (e.g., CO_2), approximately 90% of the emissions occur above 3000 ft AGL, depending on flight distance [3]. 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 [1,2].

CAEP uses the number of people within a particular sound level contour as a measure of noise impact. The sound level is usually expressed in terms of day-night average sound level (DNL)[1]. For LAQ and GHG, emissions are typically presented in terms of inventories.

In October 2007, CAEP sponsored a workshop on environmental impacts. The final report from that workshop is expected to be available in the second half of 2008. A major outcome of the workshop was that while inventories and population within a noise contour are helpful at characterizing impacts, they are not sufficient. The report is expected to include a number of recommendations for better characterizing noise, LAQ and GHG impacts.

This paper presents trends in aviation-related noise, based on demand growth met by currently available aircraft types. Noise trends are expressed in terms of population exposed to various DNL values. It also presents trends in total aviation fuel burn and emissions inventories, again based on demand growth met by currently available aircraft types. 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.

[1] DNL is a sound level metric commonly used for land-use planning as well as for other purposes. It represents an aggregation of the aircraft sound within a 24-hour period, with aircraft operations occurring between 10PM and 7AM local time penalized by 10 dB.

The trends presented herein were developed to support the 7th Meeting of CAEP in February 2007 and represent an initial assessment against which developments in technology, operational and ATM practice, and changes in demand, can be assessed. CAEP/8 is scheduled for February 2010. In support of the 8th Meeting of CAEP, the trends will be updated and will include a number of improvements, including consideration of improvements in aircraft and operational technology as well as a revised traffic forecast. The result will be a more realistic set of trends for CAEP/8. The noise, LAQ, and GHG results presented herein should be considered an upper bound to future trends. It is envisioned that these types of trends assessments have broad applicability and can be used to support a variety of national and international requirements, including policy establishment.

2 Current and Future Noise Analyses

The Aviation Environmental Design Tool, Model for Assessing Global Emissions of Noise from Transport Aircraft (AEDT/MAGENTA) [4] 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, with the U.S. and U.K. in the lead roles.[5]

AEDT/MAGENTA computes detailed noise exposure for approximately 200 of the world's busiest airports in terms of operations [6], 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* [7]. The most substantial advance in Doc 29 is the adoption of updated guidance 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* [8]. 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 5 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* [9]. Actual increases in contour area are dependent on aircraft fleet mix, runway layout, as well as other factors.

For the CAEP/7 noise trends assessment, the 2000 through 2004 results were originally computed based on the older SAE AIR 1751 standard. They were adjusted for consistency with the newer SAE AIR 5662 and DOC 29 standards, based on a common 2005 year, sothe guidance in each SAE standard could be compared. 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 States (CIS) airports, which include four airports from Russia and two from other CIS states.

The CAEP fleet and operations module (FOM) [10] 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 demand in capacity. Future AEDT/MAGENTA runs were performed using the Doc 29 – compliant version and included CIS airports

The FOM also needed to account for the aircraft expected to be flown (known as the fleet) in future years. The data used for populating the future aircraft fleet were developed with substantial input from the aviation industry participants within CAEP. Consideration was given to aircraft already designed and planned to be in service, not future-technology aircraft.

The process of replacing retired aircraft in the future fleet is based on historical retirement statistics and equal market replacement, e.g., when both a Boeing and an Airbus model are available for replacement a 50/50% replacement is used. Replacement for CAEP/7 was consistent for both noise and emissions, with the only difference being a slightly different group of aircraft being used to replace retired aircraft. For CAEP/8, a replacement database common to both noise and emissions will be used. This will more appropriately support the assessment of interdependencies between noise and emissions.

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 Figure 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 global economic downturn.

As discussed above, the 2005 noise results are presented in two ways, first using the Doc 29-compliant AEDT/MAGENTA with CIS airports and then using the older version of AEDT/MAGENTA. In Table 1, these two scenarios are labeled as 2005(A) (CAEP/6) 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 [8], as previously discussed.

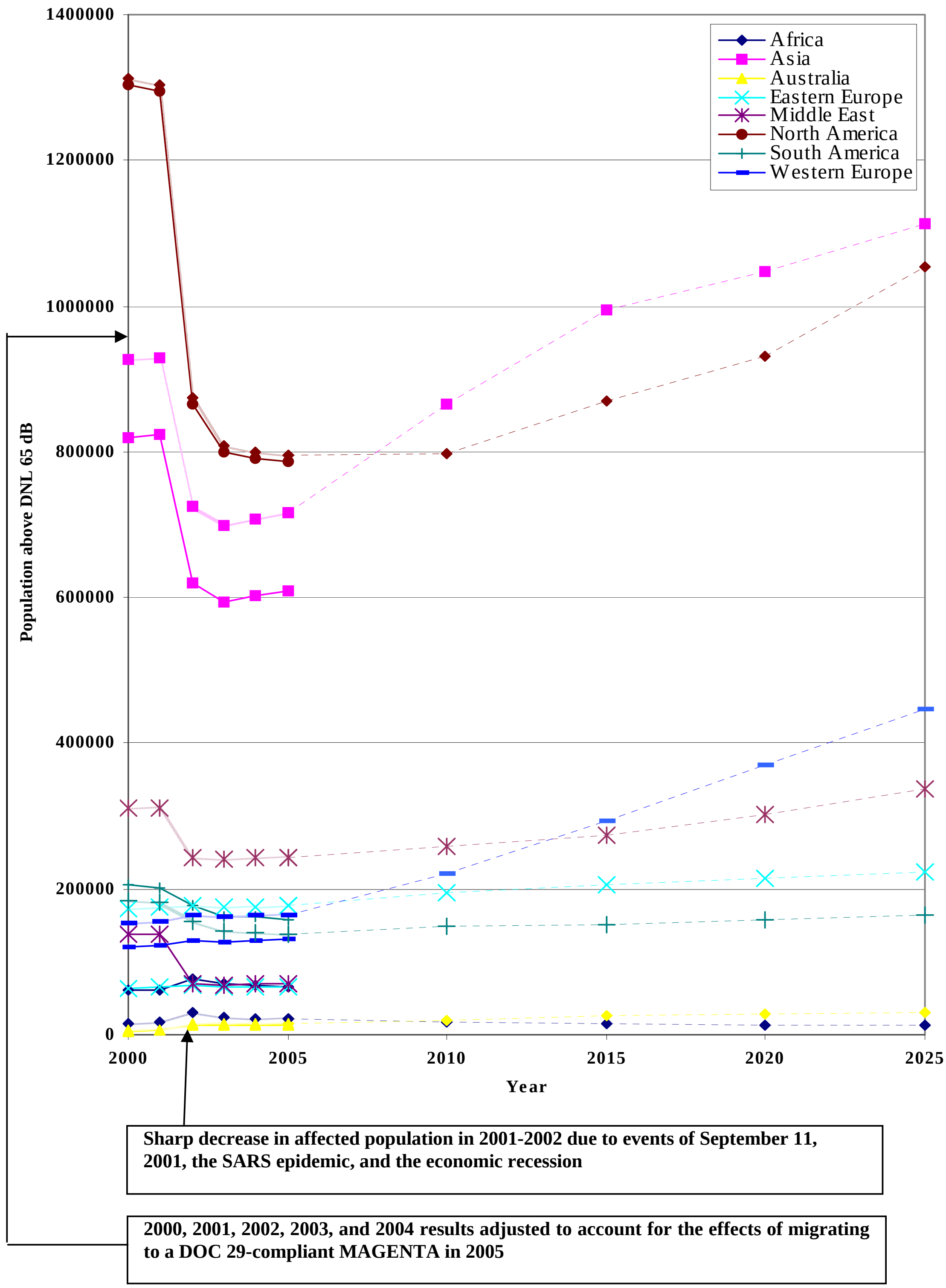

Fig. 1: Summary of AEDT/MAGENTA Results for 65 dB DNL

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

	2000	2001	2002	2003	2004	2005(A) (CAEP / 6)	2005(B) (DOC29 W/CIS)	2010	2015	2020	2025
55 dB											
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%**

3 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) [3,5]; (2) EUROCONTROL's Advanced Emissions Model (AEM) [11]; (3) EC/QinetiQ's AERO2K [12]; and (4) U.K.'s FAST Model [13].

A primary driver for including the results from four models is to provide a check of results between models. This was not possible for noise, since no other models are currently available for conducting a global assessment of aircraft noise. In support of CAEP/8, it is expected that airport/regional-level comparisons of noise from other models will be included to perform checks of AEDT/MAGENTA, as is being done using the four LAQ/GHG models.

A summary of the years included in the LAQ/GHG trends assessment for each of the four models is presented in Table 3.

Table 3: Summary of Years and Models for Emissions

Year of Study	Study Type	Model Notes for Quantifying Fuelburn and Emissions
2000	Baseline	AEDT / SAGE FAST
2001	Baseline	AEDT / SAGE
2002	Baseline	AEDT / SAGE AEM AERO2K
2003	Baseline	AEDT / SAGE AEM
2004	Baseline	AEDT / SAGE AEM
2005	Baseline	AEDT / SAGE AEM 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.

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 this 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. CO, HC and NO_x are included in the trends assessment as they are emissions currently regulated by CAEP, while CO_2 is included for climate change considerations. It is expected for CAEP/8 that the assessment will be expanded to include PM emissions.

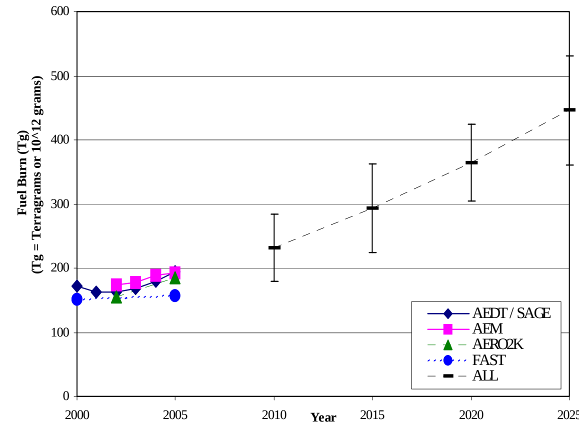

Figure 2: Summary of Total Fuel Burn. Represents four individual model results for actual fuel burn data, and four-model-average fuel burn with 95% confidence intervals for each future year.

Figure 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.

Table 4: Summary of LAQ and GHG Fuelburn and Emissions

		Fuelburn (Tg)			CO (Tg)			HC (Tg)			NO_x (Tg)			CO_2 (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

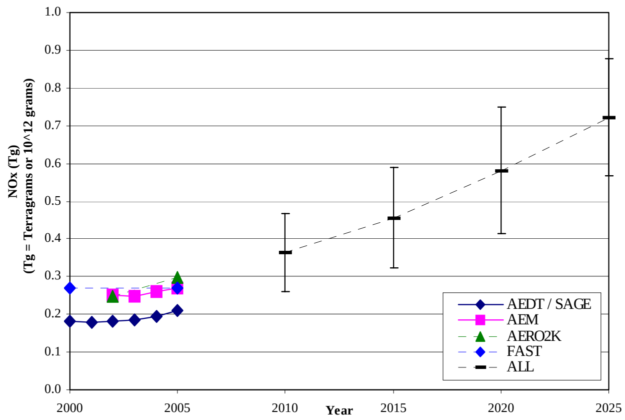

Figure 3: Summary of NOx < 3000 Ft (Local Air Quality). Represents four individual model results for actual fuel burn data, and four-model-average fuel burn with 95% confidence intervals for each future year.

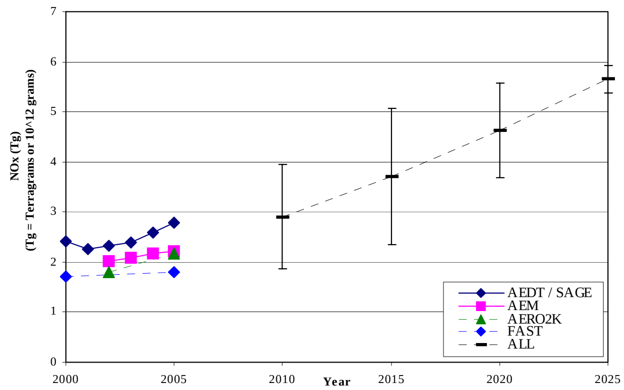

Figure 4: Summary of NOx > 3000 Ft (Green House Gases). Represents four individual model results for actual fuel burn data, and four-model-average fuel burn with 95% confidence intervals for each future year.

4 Summary Discussions

It is anticipated that CAEP may establish measureable environmental goals for noise, LAQ and GHG, against which the implications of various policy/regulatory decisions can be measured. For example, a measurable goal for CO_2 might be no increase in emissions relative to a specific base year.

In developing this initial set of environmental trends presented in this paper, a number of potential methodological enhancements were identified. The planned inclusion of these enhancements will result in a more realistic set of environmental trends.

Of particular note is the need to include assumptions related to planned improvements in aircraft/engine technology, e.g., better aerodynamics and lighter materials, which will result in fuel burn improvements. Likewise, it is critical to include anticipated operational improvements. These may result from: (1) navigational technologies such as RNAV, which enables more direct routing of aircraft, and thus lower total flight fuel burn and emissions; or (2) operational procedures such as continuous descent arrivals, which result in reductions in noise, emissions and fuel burn.

In addition, emissions inventories need to be augmented with better measures of quantifying overall improvements in fleet-level fuel burn. For example, fleet-wide traffic efficiency will better quantify the improvements in overall system efficiency. A complementary paper to this Congress discusses work currently underway to develop a fleet-level traffic efficiency metric.

The trends assessment presented herein was an initial step to better inform the CAEP environmental goals process. These data are underestimating what aviation might expect to be able to achieve through continued improvements in technology, operations, and air traffic management. The noise, LAQ, and GHG results presented herein should be considered an upper bound to future trends.

Improvements are planned for the overall approach to conducting noise and emissions trends assessments in support of CAEP's environmental goals. It is envisioned that these types of trends assessments have broad applicability and can be used to support a variety of national and international requirements, including policy establishment.

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