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# COMPILATION OF DATA ON EMISSIONS FROM INTERNATIONAL AVIATION

**Technical paper**

**Summary**

The results of a comparison between preliminary data from the AERO model and the latest available inventory information from Annex I Parties in relation to fuel consumption and $CO_2$ emissions data for domestic and international aviation are presented and discussed. Although the comparison shows relatively good agreement in total fuel consumption and $CO_2$ emissions across all Parties considered, there are large differences between UNFCCC and AERO data for a number of Annex I Parties. An update on the work being undertaken by the International Civil Aviation Organization (ICAO) and brief descriptions of two new models (AERO2K and SAGE) that are currently under development by ICAO are also provided. Initial results from these two new models are expected in spring 2004.

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CONTENTS


| | | Paragraphs | Page |
|---|---|---|---|
| I. | INTRODUCTION | 1 – 4 | 3 |
| | A. Mandate | 1 | 3 |
| | B. Scope of the paper | 2 – 4 | 3 |
| II. | COMPARISON BETWEEN UNFCCC DATA AND DATA FROM THE AERO MODEL | 5 – 15 | 3 |
| | A. Background | 5 – 8 | 3 |
| | B. Comparison of fuel consumption data | 9 – 12 | 4 |
| | C. Comparison of $CO_2$ emission data | 13 | 7 |
| | D. Additional remarks | 14 – 15 | 10 |
| III. | BRIEF DESCRIPTIONS OF THE AERO2K AND SAGE MODELS | 16 – 26 | 10 |
| | A. AERO2K | 17 – 21 | 10 |
| | B. SAGE model | 22 – 26 | 11 |

# I. INTRODUCTION

## A. Mandate

1. The Subsidiary Body for Scientific and Technological Advice (SBSTA), at its eighteenth session, endorsed the elements for future methodological work outlined in paragraph 64 of document FCCC/SBSTA/2003/INF.3,[1] which contained a request to the International Civil Aviation Organization (ICAO) to provide modelled fuel consumption and emissions data arising from the use of validated aviation models for at least 2000 and 2001, before SBSTA 19. This would include data by country, airline and aircraft/engine combinations.

## B. Scope of the paper

2. Because of the on-going development of two new aviation models (AERO2K and SAGE) and the complexity of the calculation of emissions from aviation, it was not possible for ICAO to provide the information mentioned in paragraph 1 above before SBSTA 19. Initial results from the two models are expected in spring 2004. Following their release, these results will be subject to analysis and validation by the ICAO Committee on Aviation Environmental Protection (CAEP).[2] ICAO has provided information on the status and structure of the two models, and a summary of this information is compiled in this paper.

3. Preliminary information from an existing model (AERO) on fuel consumption and $CO_2$ emissions for the years 1992 and 1999 were made available during an expert meeting organized by ICAO in February 2003. For the expert meeting, the AERO data were originally compared with data submitted by Parties included in Annex I to the Convention (Annex I Parties) in 2002. This paper presents the results of the comparison (undertaken by the secretariat) between AERO data and the latest available inventory information, including data submitted by Annex I Parties after February 2003.

4. Since the AERO model was endorsed by ICAO for application for other analytical purposes, the AERO data presented in this paper have not been considered by the CAEP for the purpose of providing specific data on fuel consumption and emissions by country. Therefore the AERO data cannot be regarded as official data from ICAO. They are used here solely as an example of the information by country that this particular model could provide. No conclusions should be derived from the comparison of the results at this stage.

# II. COMPARISON BETWEEN UNFCCC DATA AND DATA FROM THE AERO MODEL

## A. Background

5. In February 2003 an expert meeting was held in Montreal, Canada, to discuss methodological issues relating to emissions from international aviation.[3] In preparation for the meeting UNFCCC data were compared with data on fuel consumption and emissions from the AERO model[4] for the purpose of

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[1] FCCC/SBSTA/2003/10, paragraph 29 (b).

[2] The ICAO data will also be considered during an expert meeting (tentatively scheduled for spring 2004) to be organized by ICAO in accordance with the invitation of the SBSTA (FCCC/SBSTA/2003/10, para. 29 (c)).

[3] FCCC/SBSTA/2003/INF.3.

[4] A description of the AERO model can be found in *Comparison of UNFCCC Data on Emissions from Domestic and International Aviation with Data from the AERO Model*, SMI-WP/3, ICAO, February 2003, which can be obtained directly from the ICAO secretariat (attention: Secretary of CAEP). More detailed information is published in *Aviation Emissions and Evaluation of Reduction Options/AERO* published by the Directorate General for Civil Aviation, Ministry of Transport, Public Works and Water Management of the Kingdom of the Netherlands, July 2002, ISBN 90-369-1792-1.

highlighting discrepancies between the two data sets. The AERO model was developed by the Dutch Civil Aviation Authority in the period 1994–2000, and is an internationally accepted tool for the computation of emission reduction options. It was designed to evaluate fiscal, regulatory, operational and technical measures to reduce air traffic impacts on the atmosphere and has been applied in a number of international studies.

6. The base year in the AERO model is 1992. AERO computational results with respect to aviation emission levels for 1992, as presented in this paper, are based on the Unified Database.[5] Computational results for the year 1999, as also presented in this paper, are based on a "scenario computation" for the period 1992–1999 for which the growth in aviation demand was computed from observed growth in gross national product, population and exports (for cargo demand) in that period, with the results being verified with actual data for the years 1997 and 1998.

7. The territories of countries in the AERO model are based on the geopolitical situation in 1992 and, hence, fuel consumption and emission data cannot be assessed for some Annex I Parties, in particular the countries in the former Soviet Union (e.g. Estonia, Latvia, Lithuania), the countries in the former Yugoslavia and the Czech Republic and Slovakia.[6] The AERO numbers for the Czech Republic in all tables presented in the next two sections relate to both the Czech Republic and Slovakia.

8. The AERO model computes fuel consumption for aviation and emissions of $CO_2$, $SO_2$, $H_2O$, $C_xH_y$, CO and $NO_X$. The results of the comparison between the AERO model data for the years 1992 and 1999 and the latest available UNFCCC data are presented in this paper only for fuel consumption and $CO_2$ emissions for domestic and international aviation.

## B. Comparison of fuel consumption data

9. Fuel consumption data, as computed by the AERO model for the expert meeting, are presented in tables 1 and 2 for 1992 and 1999, respectively. Fuel consumption is split into domestic and international traffic components and is presented by Annex I Party. All fuel consumption on international flights departing from a particular country is allocated to that country, whereas domestic fuel consumptions relate to all flights within a country. The AERO model computes fuel consumption in mass units (Gg) but Annex I Parties report fuel consumption in energy units (TJ). To facilitate the comparison between the two data sets, the AERO data were converted from Gg to TJ using default conversion factors from the *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories* (1996 IPCC Guidelines).[7]

10. For reference, total fuel consumption from the International Energy Agency (IEA) are also presented in tables 1 and 2. The IEA totals refer to the sum of aviation gasoline, gasoline type jet fuel and kerosene type jet fuel for both domestic and international aviation. The IEA data were converted from mass units to TJ using default conversion factors from the 1996 IPCC Guidelines.[8]

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[5] The Unified Database merges the content of four major aviation databases: the ICAO 1992 "Traffic by Flight Stage" (TFS) data for international scheduled movements; the US Department of Transport 1992 "T-100" data for United States domestic scheduled flights; the July 1992 ABC (now OAG) timetable for scheduled movements; and the ANCAT (Abatement of Nuisances Caused by Air Transport) database for April 1992.

[6] In the AERO model, it is possible to change the mapping of cities to these newly formed countries. However, this involves a considerable amount of work and for the purpose of this comparison this mapping was not done.

[7] The conversion factor used was the default calorific value for jet kerosene. For Parties using net calorific value the factor is 44.59 TJ/Gg (see volume II of the 1996 IPCC Guidelines, page 1.6, table 1.3); for Parties using gross calorific value the factor is assumed to be 5 per cent higher at 46.82 TJ/Gg.

[8] For Parties using net calorific value, conversion factors were 44.80 TJ/Gg for aviation gasoline and gasoline type jet fuel and 44.59 TJ/Gg for kerosene type jet fuel (see volume II of the 1996 IPCC Guidelines, page 1.6, table 1.3). For Parties using gross calorific value the conversion factors were assumed to be 5 per cent higher.

11. Differences in total fuel consumption per country (sum of domestic and international fuel consumption) between UNFCCC and AERO data have been calculated only for those Parties for which both UNFCCC and AERO data are available.

**Table 1. Comparison of fuel consumption data (TJ) for 1992**

| | Domestic | | International | | Total | | | |
|---|---|---|---|---|---|---|---|---|
| **Party** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **Difference as % of UNFCCC value** | **IEA data** |
| Australia | 56 129 | 81 982 | 69 500 | 118 548 | 125 629 | 200 530 | 59.6 | 131 717 |
| Austria | 1 027 | 713 | 14 913 | 14 670 | 15 940 | 15 384 | –3.5 | 16 320 |
| Belgium | | 45 | | 33 220 | | 33 264 | | 40 488 |
| Bulgaria | | 223 | | 3 746 | | 3 969 | | 13 734 |
| Canada | 134 468 | 94 202 | 38 305 | 93 125 | 172 773 | 187 327 | 8.4 | 178 036 |
| Czech Republic | | 1 338 | | 11 683 | | 13 020 | | 7 716 |
| Denmark | 2 664 | 1 561 | 23 539 | 25 372 | 26 203 | 26 932 | 2.8 | 27 780 |
| Finland | 5 442 | 7 982 | 11 452 | 22 027 | 16 894 | 30 009 | 77.6 | 17 435 |
| France | 62 835 | 18 772 | 137 318 | 145 230 | 200 154 | 164 002 | –18.1 | 185 855 |
| Germany | 41 217 | 26 219 | 164 867 | 199 763 | 206 084 | 225 982 | 9.7 | 230 812 |
| Greece | 21 537 | 5 039 | 31 168 | 26 576 | 52 705 | 31 614 | –40.0 | 52 711 |
| Hungary | | 0 | | 4 236 | | 4 236 | | 5 930 |
| Iceland | | 0 | | 3 656 | | 3 656 | | 3 255 |
| Ireland | 807 | 1 338 | 17 405 | 13 422 | 18 213 | 14 759 | –19.0 | 13 422 |
| Italy | | 22 830 | | 67 866 | | 90 696 | | 103 405 |
| Japan | 123 505 | 102 691 | 201 068 | 258 845 | 324 573 | 361 536 | 11.4 | 339 149 |
| Luxembourg | | 0 | | 7 001 | | 7 001 | | 5 797 |
| Netherlands | 2 697 | 490 | 81 000 | 76 293 | 83 697 | 76 784 | –8.3 | 85 613 |
| New Zealand | | 10 956 | 19 450 | 37 503 | 19 450 | 48 459 | 149.1 | 29 688 |
| Norway | | 15 071 | | 7 892 | | 22 964 | | 22 295 |
| Poland | | 312 | | 4 191 | | 4 504 | | 10 256 |
| Portugal | 12 659 | 3 835 | 13 003 | 18 460 | 25 662 | 22 295 | –13.1 | 26 888 |
| Spain | 50 168 | 32 462 | 66 861 | 95 155 | 117 029 | 127 617 | 9.0 | 120 372 |
| Sweden | 8 704 | 12 574 | 12 308 | 25 327 | 21 012 | 37 902 | 80.4 | 35 839 |
| Switzerland | | 4 816 | | 51 903 | | 56 718 | | 50 922 |
| United Kingdom | 30 949 | 24 792 | 224 650 | 239 047 | 255 600 | 263 839 | 3.2 | 298 443 |
| United States | 2 504 850 | 1 636 219 | 705 037 | 664 563 | 3 209 886 | 2 300 782 | –28.3 | 3 213 681 |
| **Comparable totals[a]** | **3 059 659** | **2 061 825** | **1 831 844** | **2 073 926** | **4 891 503** | **4 135 752** | **–15.5** | |
| Subtotal | 3 059 659 | 2 106 460 | 1 831 844 | 2 269 320 | 4 891 503 | 4 375 780 | | |
| All other Parties | | 455 665 | | 1 280 982 | | 1 736 647 | | |
| Total | | 2 562 125 | | 3 550 302 | | 6 112 427 | | |

[a] Total fuel consumption for the Parties for which both the UNFCCC and AERO have data.

## Table 2. Comparison of fuel consumption data (TJ) for 1999

| | Domestic | | International | | Total | | | |
|---|---|---|---|---|---|---|---|---|
| **Party** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **Difference as % of UNFCCC value** | **IEA data** |
| Australia | 59 625 | 109 933 | 105 330 | 172 813 | 164 955 | 282 746 | 71.4 | 182 657 |
| Austria | 1 660 | 981 | 21 246 | 18 772 | 22 906 | 19 753 | –13.8 | 23 544 |
| Belgium | | 89 | | 39 016 | | 39 105 | | 67 464 |
| Bulgaria | 503 | 223 | 4 522 | 4 504 | 5 024 | 4 727 | –5.9 | 5 351 |
| Canada | 193 062 | 118 127 | 44 471 | 119 110 | 237 533 | 237 237 | –0.1 | 238 338 |
| Czech Republic | 187 | 1 516 | 7 610 | 12 084 | 7 797 | 13 600 | | 7 982 |
| Denmark | 2 410 | 2 140 | 31 812 | 37 768 | 34 222 | 39 908 | 16.6 | 36 564 |
| Finland | 6 561 | 9 631 | 14 946 | 28 627 | 21 507 | 38 258 | 77.9 | 22 162 |
| France | 84 548 | 23 053 | 192 219 | 187 144 | 276 768 | 210 197 | –24.1 | 281 142 |
| Germany | 56 271 | 29 652 | 225 083 | 284 752 | 281 354 | 314 404 | 11.7 | 304 417 |
| Greece | 23 722 | 5 797 | 32 016 | 33 933 | 55 738 | 39 730 | –28.7 | 55 738 |
| Hungary | | 0 | 8 424 | 4 727 | 8 424 | 4 727 | –43.9 | 9 097 |
| Iceland | 448 | 0 | 5 134 | 4 727 | 5 582 | 4 727 | –15.3 | 5 574 |
| Ireland | 1 183 | 1 694 | 21 593 | 16 498 | 22 776 | 18 193 | –20.1 | 23 008 |
| Italy | 33 883 | 26 531 | 105 581 | 87 842 | 139 464 | 114 373 | –18.0 | 154 727 |
| Japan | 156 870 | 159 543 | 260 027 | 366 084 | 416 897 | 525 627 | 26.1 | 424 137 |
| Luxembourg | | 0 | | 8 205 | | 8 205 | | 14 402 |
| Netherlands | 5 747 | 669 | 137 949 | 102 780 | 143 696 | 103 449 | –28.0 | 147 324 |
| New Zealand | 11 124 | 13 063 | 28 806 | 52 766 | 39 930 | 65 829 | 64.9 | 41 391 |
| Norway | 15 805 | 18 326 | 12 884 | 9 988 | 28 689 | 28 315 | –1.3 | 32 773 |
| Poland | | 401 | | 6 198 | | 6 599 | | 15 964 |
| Portugal | 18 675 | 4 414 | 12 304 | 22 250 | 30 979 | 26 665 | –13.9 | 32 283 |
| Spain | 71 154 | 39 105 | 106 492 | 120 036 | 177 646 | 159 142 | –10.4 | 182 708 |
| Sweden | 9 563 | 14 269 | 25 710 | 32 417 | 35 273 | 46 686 | 32.4 | 40 979 |
| Switzerland | 3 483 | 6 287 | 61 748 | 71 701 | 65 231 | 77 988 | 19.6 | 67 643 |
| United Kingdom | 38 394 | 30 812 | 369 184 | 319 532 | 407 578 | 350 344 | –14.0 | 443 584 |
| United States | 2 809 136 | 1 992 566 | 884 568 | 836 627 | 3 693 704 | 2 829 192 | –23.4 | 3 696 759 |
| **Comparable totals**[a] | **3 604 012** | **2 608 334** | **2 719 660** | **2 947 481** | **6 323 672** | **5 555 814** | **–12.1** | |
| Subtotal | 3 604 012 | 2 608 824 | 2 719 660 | 3 000 900 | 6 323 672 | 5 609 724 | | |
| All other Parties | | 608 921 | | 1 931 192 | | 2 540 114 | | |
| Total | | 3 217 745 | | 4 932 092 | | 8 149 838 | | |

[a] Total fuel consumption for the countries for which both the UNFCCC and AERO have data.

12. With respect to tables 1 and 2 the following observations can be made:

(a) For Hungary, Iceland and Luxembourg AERO does not compute any domestic fuel consumption. This implies that there are no major flight stages in these countries which are taken into account in the AERO model. Possible minor domestic flight stages in these countries might have been aggregated into one flight stage representing a group of minor flight stages;

(b) According to the AERO computation for 1999 about 80 per cent of the global domestic aviation fuel consumption took place in the Annex I Parties listed in table 2 (i.e. 2,608,824 PJ as a percentage of 3,217,745 PJ). About 60 per cent of the global international aviation fuel consumption in 1999 took place on flight stages departing from the Annex I Parties listed in table 2 (i.e. 3,000,900 PJ as a percentage of 4,932,092 PJ). For 1992 these percentages are somewhat higher, indicating that in the period 1992–1999 aviation traffic within and from other Parties was growing faster compared to that within and from the Annex I Parties listed in tables 1 and 2;

(c) For both 1992 and 1999 the AERO results for international fuel consumption (across all countries) are higher compared to the UNFCCC data, whereas for domestic fuel consumption (across all countries) they are lower compared to the UNFCCC data. Despite the relatively small differences for the comparable totals (–15.5 per cent for 1992 and –12.1 per cent for 1999), the differences between UNFCCC and AERO total fuel consumption for individual countries vary between –44 and +78 per cent;

(d) For some countries (for example, Australia, Finland and New Zealand) the differences are rather large, with the AERO model computing the fuel consumption (both domestic and international) at a much higher level compared to the data reported to the UNFCCC;

(e) For most Parties the UNFCCC and AERO data are generally consistent for the two years considered. For a few countries, however, the percentage differences are high; for Finland, for example, the AERO numbers are about 78 per cent higher than the UNFCCC ones, for both 1992 and 1999;

(f) The growth in aviation fuel consumption in the period 1992–1999 is comparable between UNFCCC and AERO. For those countries which reported domestic and international fuel consumption to the UNFCCC for both 1992 and 1999, the growth in fuel consumption over the period is 28 per cent. For the same set of countries the growth in fuel consumption according to AERO is 24 per cent.

## C. Comparison of $CO_2$ emission data

13. Emissions of $CO_2$ based on both UNFCCC reported data and AERO modeled data are presented in tables 3 and 4 for 1992 and 1999, respectively. An implied emission factor (IEF) per country is presented in terms of t $CO_2$/TJ is also shown. Comparing IEFs can show whether differences in emission factors are responsible for differences between UNFCCC and AERO emissions data. Where $CO_2$ emissions between UNFCCC and AERO are different, but IEFs are comparable, the difference in emission data is due to a difference in fuel consumption.

## Table 3. Comparison of $CO_2$ emissions (Gg) for 1992

| | Domestic | | International | | Total | | | Implied emission factor (t $CO_2$/TJ) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Party** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **Difference as % of UNFCCC value** | **UNFCCC** | **AERO** | **Difference as %of UNFCCC value** |
| Australia | 3 880 | 5 527 | 4 796 | 7 993 | 8 676 | 13 519 | 56 | 69.1 | 67.4 | -2.4 |
| Austria | 75 | 51 | 1 077 | 1 039 | 1 152 | 1 090 | -5 | 72.3 | 70.9 | -2.0 |
| Belgium | 8 | 4 | 2 584 | 2 353 | 2 592 | 2 357 | -9 | | 70.9 | |
| Bulgaria | | 15 | | 266 | | 281 | | | 70.8 | |
| Canada | 9 426 | 6 351 | 2 686 | 6 279 | 12 112 | 12 630 | 4 | 70.1 | 67.4 | -3.8 |
| Czech Republic | | 95 | | 828 | | 923 | | | 70.9 | |
| Denmark | 192 | 110 | 1 695 | 1 797 | 1 887 | 1 907 | 1 | 72.0 | 70.8 | -1.7 |
| Finland | 386 | 565 | 811 | 1 560 | 1 197 | 2 125 | 78 | 70.8 | 70.8 | 0.0 |
| France | 4 498 | 1 330 | 9 831 | 10 283 | 14 329 | 11 613 | -19 | 71.6 | 70.8 | -1.1 |
| Germany | 3 050 | 1 857 | 12 200 | 14 142 | 15 250 | 15 999 | 5 | 74.0 | 70.8 | -4.3 |
| Greece | 1 524 | 355 | 1 460 | 1 883 | 2 984 | 2 238 | -25 | 56.6 | 70.8 | 25.0 |
| Hungary | | 0 | | 300 | | 300 | | | 70.8 | |
| Iceland | | 0 | | 260 | | 260 | | | 71.1 | |
| Ireland | 58 | 95 | 1 243 | 950 | 1 300 | 1 045 | -20 | 71.4 | 70.8 | -0.8 |
| Italy | | 1 618 | | 4 805 | | 6 423 | | | 70.8 | |
| Japan | 8 292 | 7 269 | 14 210 | 18 326 | 22 502 | 25 595 | 14 | 69.3 | 70.8 | 2.1 |
| Luxembourg | | 0 | | 495 | | 495 | | | 70.7 | |
| Netherlands | 197 | 35 | 5 910 | 5 402 | 6 107 | 5 438 | -11 | 73.0 | 70.8 | -3.0 |
| New Zealand | 639 | 739 | 1 323 | 2 529 | 1 961 | 3 269 | 67 | | 67.4 | |
| Norway | | 1 069 | | 560 | | 1 628 | | | 70.9 | |
| Poland | | 23 | | 295 | | 319 | | | 70.6 | |
| Portugal | 893 | 271 | 917 | 1 306 | 1 810 | 1 577 | -13 | 70.5 | 70.7 | 0.3 |
| Spain | 3 654 | 2 298 | 4 854 | 6 737 | 8 508 | 9 035 | 6 | 72.7 | 70.8 | -2.6 |
| Sweden | 636 | 890 | 900 | 1 793 | 1 536 | 2 684 | 75 | 73.1 | 70.8 | -3.2 |
| Switzerland | | 340 | | 3 674 | | 4 015 | | | 70.8 | |
| United Kingdom | 2 220 | 1 755 | 16 122 | 16 925 | 18 341 | 18 680 | 2 | 71.8 | 70.9 | -1.2 |
| United States | 167 015 | 110 328 | 47 031 | 44 810 | 214 046 | 155 137 | -28 | 66.7 | 67.4 | 1.1 |
| **Comparable totals[a]** | **206 643** | **139 830** | **129 648** | **146 134** | **336 291** | **285 964** | -15 | | | |
| Totals | 206 643 | 142 990 | 129 648 | 157 591 | 336 291 | 300 580 | | | | |
| All other Parties | | 32 260 | | 90 693 | | 122 953 | | | | |

[a] Total emissions for the countries for which both the UNFCCC and AERO have data.

## Table 4. Comparison of $CO_2$ emissions (Gg) for 1999

| | Domestic | | International | | Total | | | Implied emission factor (t $CO_2$/TJ) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Party** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **UNFCCC** | **AERO** | **Difference as % of UNFCCC value** | **UNFCCC** | **AERO** | **Difference as % of UNFCCC value** |
| Australia | 4 691 | 7 412 | 7 268 | 11 654 | 11 959 | 19 066 | 59 | 72.5 | 67.4 | -7.0 |
| Austria | 121 | 68 | 1 542 | 1 330 | 1 662 | 1 398 | -16 | 72.6 | 70.8 | -2.5 |
| Belgium | | 5 | 4 381 | 2 762 | 4 381 | 2 767 | -37 | | 70.8 | |
| Bulgaria | 35 | 16 | 319 | 318 | 355 | 334 | -6 | 70.6 | 70.7 | 0.1 |
| Canada | 13 168 | 7 965 | 3 032 | 8 031 | 16 200 | 15 997 | -1 | 68.2 | 67.4 | -1.1 |
| Czech Republic | | 107 | 539 | 857 | 539 | 964 | 79 | 69.1 | 70.9 | 2.6 |
| Denmark | 174 | 152 | 2 290 | 2 674 | 2 464 | 2 826 | 15 | 72.0 | 70.8 | -1.7 |
| Finland | 465 | 681 | 1 058 | 2 026 | 1 523 | 2 706 | 78 | 70.8 | 70.8 | -0.1 |
| France | 6 053 | 1 631 | 13 761 | 13 250 | 19 814 | 14 881 | -25 | 71.6 | 70.8 | -1.1 |
| Germany | 4 164 | 2 099 | 16 656 | 20 159 | 20 820 | 22 258 | 7 | 74.0 | 70.8 | -4.3 |
| Greece | 1 679 | 409 | 2 881 | 2 402 | 4 560 | 2 811 | -38 | 81.8 | 70.8 | -13.5 |
| Hungary | | 0 | 596 | 334 | 596 | 334 | -44 | 70.8 | 70.7 | -0.2 |
| Iceland | 32 | 0 | 363 | 335 | 395 | 335 | -15 | 70.8 | 70.9 | 0.2 |
| Ireland | 84 | 119 | 1 542 | 1 168 | 1 626 | 1 287 | -21 | 71.4 | 70.7 | -0.9 |
| Italy | 2 397 | 1 877 | 7 468 | 6 219 | 9 865 | 8 096 | -18 | 70.7 | 70.8 | 0.1 |
| Japan | 10 532 | 11 297 | 18 377 | 25 918 | 28 909 | 37 215 | 29 | 69.3 | 70.8 | 2.1 |
| Luxembourg | | 0 | 1 019 | 580 | 1 019 | 580 | -43 | | 70.7 | |
| Netherlands | 420 | 47 | 10 070 | 7 276 | 10 490 | 7 323 | -30 | 73.0 | 70.8 | -3.0 |
| New Zealand | 757 | 880 | 1 959 | 3 556 | 2 716 | 4 437 | 63 | 68.0 | 67.4 | -0.9 |
| Norway | 1 155 | 1 297 | 942 | 706 | 2 097 | 2 003 | -4 | 73.1 | 70.7 | -3.2 |
| Poland | | 29 | 346 | 438 | 346 | 467 | 35 | | 70.8 | |
| Portugal | 1 317 | 312 | 868 | 1 577 | 2 185 | 1 888 | -14 | 70.5 | 70.8 | 0.4 |
| Spain | 5 188 | 2 769 | 7 737 | 8 498 | 12 924 | 11 267 | -13 | 72.8 | 70.8 | -2.7 |
| Sweden | 699 | 1 009 | 1 879 | 2 295 | 2 578 | 3 305 | 28 | 73.1 | 70.8 | -3.2 |
| Switzerland | 255 | 444 | 4 520 | 5 076 | 4 775 | 5 520 | 16 | 73.2 | 70.8 | -3.3 |
| United Kingdom | 2 753 | 2 181 | 26 494 | 22 624 | 29 247 | 24 806 | -15 | 71.8 | 70.8 | -1.3 |
| United States | 186 771 | 134 357 | 58 833 | 56 412 | 245 604 | 190 768 | -22 | 66.5 | 67.4 | 1.4 |
| **Comparable totals**[a] | **242 908** | **177 022** | **196 740** | **208 476** | **439 648** | **385 496** | -12.3 | | | |
| Totals | 242 908 | 177 164 | 196 740 | 208 476 | 439 648 | 385 640 | | | | |
| All other Parties | | 43 113 | | 136 729 | | 179 842 | | | | |

[a] Total emissions for the countries for which both the UNFCCC and AERO have data.

### D. Additional remarks

14. The AERO model offers the potential to provide fuel consumption and emissions data by country as requested by the SBSTA, subject to further improvements of the model input parameters and data. In relation to data by airlines and aircraft/engine combinations the following remarks can be made:

(a) The AERO model calculations are based on the Unified Database, which holds data on civil aircraft movements and air passenger and cargo demand for the base year 1992 covering flights between over 50,000 city pairs. After a grouping of minor city pairs, this results in some 19,000 city-to-city flight stages being explicitly distinguished in the AERO model. The Unified Database also holds information on the operators of the flights;

(b) In the AERO model, aircraft flights are specified by 10 generic aircraft types (based on relevant combinations of range and capacity) and two technology levels, ‘older’ and ‘current’, which are defined by certification age. The older fleet consists of all aircraft with a certification age of 12 years or more prior to the review year (baseline or scenario year). Different fuel use characteristics are computed for the 10 generic aircraft types based on the weighted average fuel use characteristics of all aircraft belonging to a particular aircraft type.

15. The information above suggests that it is probably possible for the AERO model to provide the additional data requested by the SBSTA. However, extracting this information in a usable form would require additional effort and resources. Other models, currently being evaluated, could possibly provide more accurate information to supplement data collection and analysis for national inventories of greenhouse gases, particularly for $CO_2$ and $NO_X$ emissions.

## III. BRIEF DESCRIPTIONS OF THE AERO2K AND SAGE MODELS

16. The SBSTA has noted the need for ICAO modelled data by country, airline and aircraft/engine combinations.[9] As mentioned above, ICAO expects to receive data generated by the AERO2K and SAGE models in spring 2004. Both models will be important in providing data to the secretariat and although their capabilities differ, the model developers have agreed to share data to ensure the consistency of the results. The following sections provide information on these two tools.

### A. AERO2K

#### 1. Introduction

17. The AERO2K project is supported through the European Commission Fifth Framework programme and is under development by a consortium led by QinetiQ (United Kingdom) with DLR (Germany), NLR (Netherlands), Eurocontrol, Airbus (France), Manchester Metropolitan University (United Kingdom) and the Department of Trade and Industry (United Kingdom).

#### 2. Objectives

18. The objective of AERO2K is to develop a new four dimensional (4-D: latitude, longitude, height and time) gridded database of global aircraft emissions of priority pollutants and to improve methodologies and analytical tools that facilitate novel and improved evaluations of the impact of aircraft emissions on the global atmosphere. Within this overall objective, the current AERO2K project will provide improved routing assumptions for present day traffic (e.g. using radar data); improved methodologies for establishing flight profiles and fuel usage for engine/aircraft combinations; new inventory parameters e.g. distances flown per grid cell per hour, needed for contrail impact analysis; and a new 25-year forecast of aviation emissions which encompasses the parameters identified above.

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[9] FCCC/SBSTA/2003/INF.3, paragraph 64.

### 3. Design

19. The inventory software package includes an MS Access database which stores data on aircraft flight movements over a specified period and geographical area. The emissions can be displayed in a 4-D grid. Grid sizes are flexible to suit the application and the emissions are calculated from knowledge of flight routing, flight phase, aircraft and engine type, thrust settings, fuel consumption and emissions factors. Although this approach is not in itself novel, the techniques used in generating the input information will provide a substantially more reliable data set than has previously been available. Such techniques include use of actual radar tracking data (as opposed to great circle data); increased number of representative aircraft types; calculation of aircraft in-flight weight changes with consequent variations in fuel burn and emissions; characterization of landing and take-off (LTO) times by airport; and use of latest available information and methodology for calculation of LTO and altitude emissions.

### 4. Outputs

20. The main outputs of the current project will be a new civil air traffic movements database for 2002 based upon improved routing assumptions and methodologies; emissions inventories for pollutants ($CO_2$, $H_2O$, CO, $SO_2$, $NO_X$, soot (mass) and hydrocarbons) from aircraft; uncertainty analyses; an inventory of distances flown in and between regions of the world; and a new 2025 emissions forecast. In addition, emissions inventory software tools are expected to be created and integrated into the software package, which will then be capable of developing and analysing a range of allocation scenarios for aviation emissions.

### 5. Validation

21. Currently (October 2003), the inputs to the inventory software package have been specified and initial testing of the integrated software has been carried out. Results in terms of the 2002 inventory and the 2025 forecast are expected in spring 2004. Further work under consideration includes wider validation and comparison of the model output with other models and data; integration of additional modules to provide information, for example, on atmospheric and climate impacts; addition of further pollutants (e.g. particulates) as information becomes available; and additional runs of the model.

## B. SAGE model

### 1. Introduction

22. The United States Federal Aviation Administration Office of Environment and Energy has developed the **S**ystem for assessing **A**viation's **G**lobal **E**missions (**SAGE**), with support from the Volpe National Transportation Systems Center, the Massachusetts Institute of Technology and the Logistics Management Institute.

### 2. Objective

23. The objective is for SAGE to be an internationally accepted computer model that is based on the best available data and methodologies, and used for estimating aircraft emissions ($CO_2$, CO, HC, $NO_X$, $H_2O$, and $SO_X$ modelled as $SO_2$) over the whole flight regime including the landing and take-off cycle, and cruise. With regard to scope, the model is capable of analyses on an aircraft, airport, regional, and global level. Various operational, policy and technology-related scenarios can be evaluated using this model to assess their potential effects on global aircraft emissions.

### 3. Model structure

24. SAGE comprises four basic computational modules: aircraft movements; capacity and delay; fuel burn and emissions; and forecasting. These modules encompass both the methods and the input data requirements to run the model. SAGE was developed using the best available data and methods that

allow high-resolution and high-fidelity modelling of aircraft fuel burn and emissions during all phases of flight. Similar to AERO2K, the emissions can be displayed in a 4D grid (latitude, longitude, height and time). Grid sizes are flexible to suit the application and the emissions are calculated from knowledge of flight routing, flight phase, aircraft and engine type, thrust settings, fuel consumption and emissions factors.

### 4. Outputs

25. The model has generated an inventory of aircraft fuel burn and emissions for the years 2000 to 2002, based upon detailed knowledge of worldwide aircraft movements. These inventories and those for subsequent years will help to determine trends in aircraft emissions on a regional and global level, allow for more accurate comparisons to emissions from other industries, and provide a basis for forecasts of future aircraft greenhouse gas emissions. Detailed knowledge of aircraft movements allows for analysis of fuel burn and emissions within regions and between regions using SAGE.

### 5. Validation

26. Preliminary validation work has shown good agreement on both modular and system levels. It is expected that additional validation work will be conducted to determine areas for model improvement and to better understand areas of uncertainty. Model improvements that incorporate higher-resolution inputs will allow for SAGE to provide higher-fidelity results. Emission reduction options relating to new emissions reduction technologies and new operational procedures and strategies could be analysed with SAGE once the appropriate input data are made available.

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