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## Forecasts of CO<sub>2</sub> emissions from civil aircraft for IPCC

DTI Unique Reference Number 06/2178

Gareth Horton  
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# Administration page

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## Principal author

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Gareth Horton	01252 397792
Cody Technology Park, Farnborough, GU14 0LX	gchorton@QinetiQ.com

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## Executive Summary

QinetiQ has been requested by DTI and DfT to assess the growth of CO<sub>2</sub> emissions from civil aircraft to the year 2030, subject to a set of different scenarios, in support of work for IPCC. A key issue is the effect on these emissions of different levels of “CO<sub>2</sub> cost”, e.g a “Carbon Tax”.

A total of five different scenarios have been analysed, ranging from no aircraft fuel efficiency improvements to a likely technology scenario plus a \$100 per tonne CO<sub>2</sub> cost. In each of these cases, the growth in airline traffic in future years has been derived from the forecasts produced by CAEP’s FESG and an extrapolation previously derived for long term technology goals analyses. The traffic and fuel consumption for 2002 was obtained from the AERO2k database; these two sets of data together with the different scenarios were then used to grow the CO<sub>2</sub> emissions to 2030.

Overall, the total annual distance covered by the global civil aircraft fleet was forecast to grow by 149% from 2002 to 2030, with the seat-kilometres forecast to grow by 229%. The case with the most technological advance (that with \$100/tonne CO<sub>2</sub> cost) was forecast to produce 22% less CO<sub>2</sub> in 2030 than the case without the extra incentives to technology development. However, even this case was forecast to produce nearly twice as much CO<sub>2</sub> in 2030 as in 2002.

This report has been produced for Peter Newton of the DTI and Roger Gardner of the DfT.

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# 1 Introduction

QinetiQ has been requested by DTI and DfT to assess the growth of CO<sub>2</sub> emissions from civil aircraft for the year 2030, subject to a set of different scenarios, in support of work for IPCC. A key issue is the effect on these emissions of different levels of “CO<sub>2</sub> cost”, e.g. a “Carbon Tax”.

A total of five different scenarios have been analysed, ranging from no aircraft fuel efficiency improvements to a likely technology scenario plus a \$100/tonne CO<sub>2</sub> cost. In each of these cases, the growth in airline traffic in future years has been derived from the forecasts produced by CAEP’s FESG [1],[2] and the extrapolation previously derived for long term technology goals analyses [3]. The traffic and fuel consumption for 2002 was obtained from the AERO2k database [4]; these two sets of data together with the different scenarios were then used to grow the CO<sub>2</sub> emissions to 2030.

Further details of the method are given in section 2. The results for the different scenarios are then given and compared in section 3, with some conclusions drawn in section 4.

This report has been produced for Peter Newton of the DTI and Roger Gardner of the DfT.

## 2 Method

The analyses performed covered five different scenarios, as follows.

- Case 1: No technology improvements to fuel efficiency.
- Case 2: Aircraft delivered after 2005 to a “2005 Best Available Technology” standard. Aircraft delivered after 2008 to include Boeing 787/Airbus 350/Airbus 380 technology levels.
- Case 3: Fuel efficiency improvements as per Greene [5] to 2010 and the DTI extrapolation [6] beyond.
- Case 4: As per case 3 but with additional fuel efficiency improvements driven by a \$50 per tonne CO<sub>2</sub> cost.
- Case 5: As per case 3 but with additional fuel efficiency improvements driven by a \$100 per tonne CO<sub>2</sub> cost.

For each of these cases the basic approach was:

- Use the AERO2k database to provide the traffic and fuel consumption by seat class for the year 2002.

- Apply the FESG traffic growth [1], as extrapolated beyond 2020 during the long term technology goals studies [3] to obtain the traffic by seat class in 2030.

- Use the relevant technology assumption to obtain a factor to apply by seat class to the fuel efficiency in 2030.

- Apply the factor to the 2002 fuel consumption, multiply by the traffic growth and aggregate to provide a forecast of the global fuel consumption in 2030.

- Multiply the fuel consumed by the relevant factor (taken as 3.153) to produce a forecast of the global CO<sub>2</sub> production by civil aircraft in 2030.

The approach whereby the calculations were performed by seat class, then aggregated to provide a global figure, was intended to allow the application of different technology trends to different size aircraft. In the event, only Case 2, where specific new aircraft are introduced in 2008, required this approach. The seat classes used were based on those used by FESG:

- 20-49 seats
- 50-99 seats
- 100-150 seats
- 151-210 seats
- 211-300 seats
- 301-400 seats
- 401-500 seats
- 501-600 seats
- 601-650 seats.

To allocate the AERO2k representative aircraft to these seat classes, first each aircraft needed to be assigned a number of seats, as such data are not already defined in AERO2k. The seat numbers assigned were derived from a variety of sources. There

was one change made to the FESG seat classes. In the FESG forecasts, there are no aircraft in the 601-650 seat class in 2002 and very few in the 501-600 seat class. There are no aircraft in either of these two seat classes in AERO2k for the year 2002 (the largest aircraft in AERO2k is the 419-seat Boeing 747-400). As a result of the expected introduction of the Airbus A380 incorporated in the FESG forecasts, the percentage growth rates for the 501-600 and 601-650 seat classes are very high and infinite respectively, yet neither would be captured by simply applying the seat-class growth factors to the AERO2k data. Therefore, the three largest classes were amalgamated into a single 400+ class.

In the above, the fuel efficiency referred to is calculated as the fuel burnt (in kg) per seat-kilometre flown (usually expressed as SKO – seat-kilometres offered – or ASK – available-seat-kilometres). Thus, for a given technology level, the fuel burn is proportional to the seat-kilometres flown.

As described above, the traffic for 2030 was obtained by applying the traffic growth from the FESG models to the AERO2k 2002 traffic, this being done by seat class. The AERO2k and FESG databases allocate slightly different proportions of the fleet in the different classes, particularly the largest (AERO2k has 6.2% of the 2002 fleet with 400+ seats, whereas the equivalent figure for FESG is just 2.4%). Once the traffic on these different seat classes were grown using the FESG traffic growth rates, the growth in the global traffic calculated using the AERO2k model was different from the FESG results. To overcome this problem, the growth in traffic in each seat class (as applied to the AERO2k data) was factored to ensure that the overall global traffic growth was the same as for FESG<sup>1</sup>. As a result, it is possible to use the AERO2k fuel burn and CO<sub>2</sub> production data while obtaining global results which are consistent with the FESG forecasts and, hence, with other analyses using the FESG data.

For Case 1, no fuel efficiency improvements were to be applied, so the above forecasts of the seat-kilometres flown in 2030 gave the factors to apply to the fuel burnt in the 2002 database and hence the CO<sub>2</sub> production could be calculated immediately. In this (artificial) case, fuel burn is directly proportional to traffic growth for a future fleet with an average performance equivalent to that of 2002.

For Case 2, used to establish the fuel burn benefits from anticipated technology developments in the industry, it was necessary to establish the effect of the new aircraft. Each representative aircraft in the AERO2k 2002 database (there are 40 in all) was assigned to a seat class then, for aircraft delivered from 2005 onwards, a factor was derived to transform its fuel consumption (in fuel burn per seat-kilometre) to that of the best in its class. For aircraft delivered from 2008 onwards, additional factors were applied to aircraft in the 210-300, 301-400 and 400+ seat classes to reflect fuel consumption performances equivalent to Boeing 787-3, Airbus A350-900 and Airbus A380 levels respectively, as these aircraft types are assumed to enter the fleet from this date. The fuel consumption levels for these new aircraft were obtained from previous studies of them using the PIANO tool [7]. Rather than using the PIANO values of fuel consumption directly, they were ratioed by the equivalent figures for the “best in class” aircraft to provide the factors to be applied here. This gave an approach which was consistent with that used for the other cases. The aircraft in the smaller seat classes (i.e. less than 210 seats) were assumed to have no further technology improvements beyond the 2005 “best in class” and so the factors applied for the 2008 onwards aircraft were the same as those from 2005. Once these different factors had been generated, the remaining requirement was to determine,

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<sup>1</sup> The previous LTTG studies, which also used the FESG forecasts and the AERO2k 2002 database, amalgamated all the seat-classes together, so this problem did not arise.

for the year 2030, what proportion of the fleet composes aircraft delivered before 2005, from 2005 to 2007 and from 2008 onwards. This was done using the QinetiQ fleet rollover model, based on the work of Greene [5]. This is a global model and it was assumed that the same proportions could be applied to the different seat classes individually. These various factors were then combined to produce a total factor for the fuel consumption for each different representative aircraft in AERO2k. This, together with the traffic forecast for 2030, gave a fuel burn and hence the required CO<sub>2</sub> production figure.

Case 3 should be regarded as the base case from which the effects of further measures should be assessed. It was also based on Case 1, except that a simple factor was applied to the fuel consumption (and hence CO<sub>2</sub> production) for 2030. This factor was derived from the Greene and DTI forecasts of fuel efficiency improvements as described in the IPCC 1999 report [6], i.e.:

1.3% per annum to 2010

1.0% per annum to 2020

0.5% per annum beyond.

These assumptions have been used in the IPCC 1999 special report “Aviation and the Global Atmosphere” [6], along with others, to assess the possible future trends of aviation fuel consumption. For 2030, this produces a factor of approximately 0.775 to apply to the fuel burn per seat kilometre.

For Cases 4 and 5, the Case 3 fuel efficiency factors were applied together with additional factors intended to represent the effect of \$50/tonne and \$100/tonne CO<sub>2</sub> additional costs. These additional factors were produced by Ron Wit of Stichting Natuur en Milieu, based on the work reported in reference [8]. In generating these factors it was assumed that the additional costs would have no impact on demand for air travel (“zero elasticity”) and, hence, that the forecast traffic growth would be unchanged. The factors produced were 0.5% and 1.0% improvement in fleet fuel efficiency per annum for the two cases, respectively. These additional costs (and the respective improvements in fleet efficiency) were assumed to apply from 2005 and so, for 2030, these gave additional factors (above the Case 3 levels) of 0.882 and 0.778 when applied to the 2002 baseline.

### 3 Results

As noted above, the same growth in global traffic was applied to all five cases. The growth calculated to 2030 is given in Table 1.

	Global distance flown (10 <sup>9</sup> km)	Global SKO (10 <sup>9</sup> km)	Ratio of distance to 2002	Ratio of SKO to 2002
2002	32.95	5490.5		
2030	82.16	18063.4	2.493	3.290

*Table 1 Distance and SKO (seat-kilometres offered) for 2002 and 2030*

The global fuel burns and CO<sub>2</sub> emissions in Teragrams (tonnes x 10<sup>6</sup>), calculated using these growths in traffic, are shown in Table 2 and Table 3.

	Fuel Burn 2002 (Tg)	Fuel Burn 2030 (Tg)	Ratio of Fuel Burn to 2002
Case 1	155.18	510.54	3.290
Case 2	155.18	442.45	2.851
Case 3	155.18	395.50	2.549
Case 4	155.18	348.92	2.248
Case 5	155.18	307.63	1.982

*Table 2 Fuel burn calculated for each case for years 2002 and 2030*

	CO <sub>2</sub> production 2002 (Tg)	CO <sub>2</sub> production 2030 (Tg)	Ratio of CO <sub>2</sub> production to 2002
Case 1	489.29	1609.74	3.290
Case 2	489.29	1395.06	2.851
Case 3	489.29	1247.02	2.549
Case 4	489.29	1100.15	2.248
Case 5	489.29	969.96	1.982

*Table 3 CO<sub>2</sub> production calculated for each case for years 2002 and 2030*

From these results, it is possible to calculate the reduction in CO<sub>2</sub> emissions which would occur for Cases 4 and 5 relative to a base case of Case 3, to show the effect of the extra incentives to technology. These reductions are shown in Table 4

Case 2	Case 3	Case 4	Case 5
13.3%	22.5%	31.7%	39.7%

*Table 4 Reductions in CO<sub>2</sub> production in 2030 from the different scenarios relative to Case 1*

Thus, it can be seen that Case 5, using the Greene and DTI forecasts of technology improvements and an additional \$100/tonne CO<sub>2</sub> incentive to technology acceleration, gives a nearly 40% reduction in CO<sub>2</sub> emissions in 2030 relative to a frozen technology case. As described in section 2, the additional technology improvements associated with the CO<sub>2</sub> costs of Cases 4 and 5 should be compared to the results from Case 3 (which has the same technology assumptions except for the additional incentives). The results, expressed as reductions in CO<sub>2</sub> production in 2030 relative to Case 3, are shown in Table 5.

Case 4	Case 5
11.8%	22.2%

*Table 5 Reductions in CO<sub>2</sub> production in 2030 from the different scenarios relative to Case 3*

From this, it can be seen that Case 5 gives a 22% reduction in CO<sub>2</sub> production in 2030 compared to the base case (of just the Greene and DTI forecasts). Alternatively, it reduces the growth in CO<sub>2</sub> emissions by 37% of what it would be for the case without the additional incentives. However, it should be noted that, even with these improvements, the CO<sub>2</sub> emissions in 2030 are very nearly twice the 2002 values.

## 4 Conclusions

QinetiQ has been requested by DTI and DfT to assess the growth of CO<sub>2</sub> emissions from civil aircraft for the year 2030, subject to a set of different scenarios, in support of work for IPCC. A key issue is the effect on these emissions of different levels of “CO<sub>2</sub> cost”, e.g. a “Carbon Tax”.

A total of five different scenarios have been analysed, ranging from no aircraft fuel efficiency improvements to a likely technology scenario plus a \$100 per tonne CO<sub>2</sub> cost. In each of these cases, the growth in airline traffic in future years has been derived from the forecasts produced by FESG and an extrapolation previously derived for long term technology goals analyses. The traffic and fuel consumption for 2002 was obtained from the AERO2k database; these two sets of data together with the different scenarios were then used to grow the CO<sub>2</sub> emissions to 2030.

Overall, the total annual distance covered by the global civil aircraft fleet was forecast to grow by 149% from 2002 to 2030, with the seat-kilometres forecast to grow by 229%. The case with the most technological advance (that with \$100/tonne CO<sub>2</sub> cost) was forecast to produce 22% less CO<sub>2</sub> in 2030 than the case without the extra incentives. However, even this case was forecast to produce nearly twice as much CO<sub>2</sub> in 2030 as in 2002.

## 5 References

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*Initial distribution list*

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