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GROUP OF EXPERTS ON THE ABATEMENT OF NUISANCES CAUSED BY AIR TRANSPORT

Seventy-fifth meeting

(Paris, 4/5 November 2008)

Agenda item 6: Market-based Measures

POLICY OPTIONS TO REDUCE THE CLIMATE IMPACT OF AVIATION NOx EMISSIONS

(Presented by the European Commission)

SUMMARY

This paper presents a summary of a report prepared by CE Delft for the European Commission.

ACTION TO BE TAKEN

The meeting is inviting to note this paper.

(8 Pages)

1. The report sets out to design and evaluate policy instruments to address the climate impact of aviation NO_x emissions. It does so within the context of the proposal to include aviation in the EU ETS. In the proposal, the European Commission stated that ‘by the end of 2008, the Commission will put forward a proposal to address the nitrogen oxide emissions from aviation after a thorough impact assessment’.

2. Before designing and evaluating policy instruments, the' report has conducted a thorough review of the scientific evidence, NO_x formation and control technologies, and the regulatory framework regarding aviation NO_x emissions.

3. Although the study was conducted on the basis of terms of reference formulated by the services of the European Commission, the conclusions of the report are those of the consultant and they are not binding for the European Commission.

Review of the scientific evidence

4. **There is robust scientific evidence that NO_x emissions from the current aviation fleet contribute to global warming.** Aviation NO_x emissions at cruise altitudes result in an enhancement of ozone (O_3) in the upper troposphere and lower stratosphere (UT/LS) and the destruction of a small amount of ambient methane (CH_4), of the order of approximately 1-2% of the background concentrations. The enhancement of O_3 results in climate warming, whereas the reduction in CH_4 is a cooling effect.

5. **The contribution is significant and stronger in the northern hemisphere.** Sausen et al. (2005) estimate the radiative forcing (a proxy measure of the additional amount of heat trapped in the atmosphere due to aviation - RF) for O_3 to be 21.9 mW/m^2 and an RF for CH_4 of -10.4 mW/m^2 for 2000 traffic. This estimate used updated emissions of NO_x from aviation for 2000. For comparison, CO_2 emissions from aviation have an RF of 25.3 mW/m^2 for 2000 traffic. Because O_3 has a much shorter lifetime than CH_4, the warming effects of O_3 are confined to areas with much aviation (i.e. the northern hemisphere) whereas the cooling effects of CH4 decay are global. As a result, the combined O_3+CH_4 forcing is positive in the Northern Hemisphere and negative in the Southern Hemisphere.

6. **However, there is no agreement on the value of a policy-relevant metric to relate the climate impact of NO_x to the impact of other compounds.** The RF metric used above to compare the climate impact of NO_x to CO_2 is a backward looking metric. It measures the forcing from the CO_2 built up in the atmosphere due to aviation emissions, for example. A policy-relevant metric is the global warming potential. This metric shows the integrated RF from a marginal additional emission of a unit mass of emissions (as a pulse) relative to that of CO_2. Thus, it is a measure for the *additional* global warming due to an *additional* emission. GWP is the measure used in the Kyoto Protocol to relate the climate impacts of regulated gases to the impact of CO_2. Although it is possible to calculate a GWP for aviation NO_x, results of these calculations are just beginning to be published in the scientific literature. Currently, there are few reported values and these diverge strongly.

7. **A concerted effort may yield a GWP value of aviation NO_x in about three years.** What is needed is a mobilisation of the international scientific community and a coordinated set of experiments performed so that a robust, consensus analysis of aviation NO_x

GWPs can be undertaken. The outcome cannot be predicted of such a hypothetical study, but all things being equal, if such a study were performed, it is likely to take of the order 3 years. If, however, such a coordinated effort were to produce diverse results it is not possible to predict how long resolution would take. Clearly, such a coordinated experiment should be undertaken as a top priority to formulate a robust policy metric for aviation NO_x emissions.

Review of NO_x inventories and NO_x regulation

8. **Aviation emitted an estimated 1.7 to 2.5 Tg NO_x (as NO_2) per year around 2000.** This report estimates that emissions within, and on flights to and from the EU accounted for 42% of these emissions in 2000.

9. **Emissions are forecast to increase considerably in the future.** Up to 2020, emissions are forecast to double relative to 2000 levels. By 2050, depending on the scenario chosen, emissions could have increased sixfold. If the environmental impacts of the inclusion of aviation in the EU ETS are taken into account, as well as the full benefits of the single European sky, and if one assumes that the voluntary research targets of ACARE are met and if they result in the introduction of new aircraft and engine types in the fleet, emissions could be 6 to 9% lower than the baseline in 2020. Under the same most optimistic scenario, emissions could be around 50% lower in 2050 relative to a sixfold increase in the baseline.

10. **LTO NO_x emissions of jet engines are regulated and more stringent standards have been introduced repeatedly.** LTO NO_x emissions of jet engines (with the exception of the smallest engines) are regulated by global standards, set by ICAO. Standards are expressed in Dp/Foo, i.e. mass of NO_x emitted per kN of thrust at maximum static sea level thrust. The standards allow engines with a higher pressure ratio (generally larger engines) to emit relatively more NO_x. Turboprops and other engine types are not regulated. All regulated engines have certified values of emissions which are public. For many non-regulated engines, LTO NO_x emission characteristics are known.

11. **Despite more stringent LTO NO_x standards, there has been little progress in the reduction of NO_x emissions per seat kilometre offered**. Although engines and aircraft differ in fuel efficiency and $EINO_x$ (mass of NO_x emissions per unit mass of fuel), and despite increasingly stringent standards, the general historical trend of NO_x emissions per seat kilometre has been flat in the last decades. The reason appears to be that aircraft and engines have become more fuel efficient, partially because of higher pressure and by-pass ratios in the engine. Because of the increase in pressure ratio, $EINO_x$ has increased as permitted under the ICAO standards. The combination of the downward trend in fuel use per seat kilometre and the upward trend in $EINO_x$ has resulted in an almost constant mass NO_x per seat kilometre.

Review of NO_x formation and control technologies

12. **For current technology engines, lower LTO NO_x emissions result in lower NO_x emissions in cruise.** More precisely, if the modification of an engine results in an LTO NO_x increase then it is expected that Cruise NO_x would move similarly. Likewise, if two

engines are compared and one has lower LTO NO_x, then most probably it would also have lower cruise NO_x.

13. **For future technology engines, the correspondence between LTO NO_x emissions and cruise NO_x emissions may break down.** While today there is a reasonable correlation between LTO NO_x: Altitude NO_x future technologies such as lean burn staged combustors and open rotor engines hold the potential for significant change to this relationship. These future technologies will need to be monitored to ensure the relationship holds or is, if necessary, adjusted.

14. **NO_x emissions cannot be monitored in situ but modelling of emissions is possible in principle.** The method considered most accurate is the P3T3 method which relies on proprietary details of engine pressures and temperatures. There are also (at least) two alternative simplified methods which are commonly used, known as the DLR and Boeing2 fuel flow methods with the latter being approved by ICAO CAEP. These methods are thought to be reasonably accurate once the fuel flow is known and could in principle use openly available fuel flow model outputs. The accuracy of fuel flow model outputs is less widely accepted, particularly for new aircraft types.

15. **There is a good correlation between modelled cruise NO_x emissions and LTO NO_x emissions times a distance factor.** As a consequence, it could be possible in principle to use publicly available data on LTO NO_x emissions to approximate cruise NO_x emissions.

Policy instruments to reduce the climate impact of aviation NO_x emissions

15. Drawing on a long list of 15 policy options, six have been selected for further design and analysis after a broad evaluation and stakeholder consultation. These are:

1. An LTO NO_x charge.
2. An LTO NO_x charge with a distance factor.
3. A cruise NO_x charge.
4. Including aviation NO_x allowances in the EU ETS.
5. ICAO LTO NO_x emission standards.
6. A precautionary emissions multiplier on CO_2 allowances in the EU ETS.

1 — An LTO NO_x charge.

16. **An LTO NO_x charge primarily targets local air quality**. Its impact on cruise emissions and hence on the climate impact of aviation NO_x are a co-benefit. The basis of the charge would be the mass of standardised LTO NO_x emissions calculated according to ECAC/ERLIG method. The level of the charge per kg of NO_x would be set at the LAQ

damage costs of NO_x, in line with established EU policy to internalise external costs, and would thus vary in different Member States. The charge would be levied on aircraft operators by all EU airports, in order to align the geographical scope with the scope of the EU ETS. Revenue neutrality, if desired, could be achieved by a simultaneous introduction of the charge and a reduction of landing fees. The charge would be collected by airport operators and would be levied on aircraft operators. The charge would be feasible to implement and is unlikely to raise legal issues, as similar charges are already levied on a number of EU airports.

17. **An LTO NO_x charge based on estimates of LAQ damage costs would reduce aviation NO_x emissions by up to 0.5% relative to the baseline.** At least until 2020, the largest impact would be from reduced demand. Consequently, a revenue neutral charge would hardly impact emissions. Emissions on short haul flights would be reduced more than emissions on long haul flights, even though the latter contribute considerably more to climate change.

18. **An LTO NO_x charge would incentivise engine manufacturers to reduce LTO NO_x emissions.** This incentive would be stronger for smaller engines which are generally fitted to regional or single aisle aircraft. In the long run, provided that for smaller engines the correspondence between LTO NO_x emissions and cruise NO_x emissions remains intact, this incentive could result in new engines and aircraft with lower LTO and cruise NO_x emissions.

2 — LTO NO_x charge with a distance factor

19. **An LTO NO_x charge with a distance factor would target cruise NO_x emissions and hence its climate impact indirectly.** This is because there is a correlation between cruise NO_x and LTO NO_x times distance. The basis for the charge would be the mass of LTO NO_x emissions calculated according to ECAC/ERLIG method and the great circle distance between the airport of departure and the airport of destination. The level of the charge would be related to the climate damage costs of NO_x, taken to be the GWP of NO_x times the average cost of emission allowances in the EU ETS. The charge would be multiplied by a co-efficient of correlation between LTO NO_x times distance and cruise NO_x. This factor depends on the fleet and would need to be updated every number of years. It can be calculated with relative ease, provided that a dedicated workgroup is established.

20. **The administration of such a charge could be entrusted to EUROCONTROL**, as this organisation has the arrangements in place to calculate the charge and bill the aircraft operators. These are the same arrangements as for the collection of route charges. In this case, the collection of the charges would need to be based on a separate legal basis, e.g. a new agreement between the EU and EUROCONTROL. If the charge would raise revenue, EUROCONTROL could reimburse the funds raised to the EU Member States based on, for example, revenue tonne kilometres to and from airports in these Member States. If the charge would be implemented in a revenue neutral way, EUROCONTROL could reimburse the revenue on the basis of MTOW.km. Effectively, the charge would thus become an incentive to reduce the quotient of mass of LTO NO_x per unit of MTOW.

21. **An LTO NO_x charge with a distance factor could reduce aviation NO_x emissions by up to 3.1% in 2020.** The impacts vary from 0% for a revenue neutral charge or a charge with a low estimate of NO_x GWP to 3.1% for a revenue raising charge using a high estimate of NO_x GWP. At this timeframe, the impacts are mainly due to a reduction in

demand. In contrast to the LTO NO_x charge without a distance factor, the charge with a distance factor reduces NO_x on long haul flights more than NO_x on short and medium haul flights. This is because the combined effect of higher emissions for large aircraft and longer flights.

22. **Like an LTO NO_x charge, this charge would incentivise engine manufacturers to reduce LTO NO_x emissions.** In this case, this incentive would be stronger for larger engines. In the long run, provided that the correspondence between LTO NO_x emissions and cruise NO_x emissions remains intact, this incentive could result in new engines and aircraft with lower LTO and cruise NO_x emissions.

3 — Cruise NO_x charge.

23. **A cruise NO_x charge would be directly aimed at cruise NO_x emissions and thus the climate impact of aviation NO_x.** However this advantage is partly lost because cruise emissions cannot be measured in situ and need to be modelled.

24. **Implementation of a cruise NO_x charge would require building a database to calculate cruise NO_x emissions per aircraft-engine combination and flight distance.** The accuracy of calculations using publicly available data would be 10 to 15% when compared to more sophisticated calculations using proprietary data. With these calculations, a database could be established with cruise NO_x emissions per aircraft type over a range of distances. Each flight under the system could be assigned with a value of NO_x emissions from the database. A charge could be levied based on the emissions and their climate damage costs.

25. **The administration of a cruise NO_x charge could be organised in the same way as an LTO NO_x charge with a distance factor.** EUROCONTROL could be charged with collecting the charges and possibly reimbursing them in a revenue neutral scheme along the same lines as an LTO NO_x charge with a distance factor.

26. **A cruise NO_x charge could reduce aviation NO_x emissions by up to 2.8% in 2020.** The impacts vary from 0% for a revenue neutral charge or a charge with a low estimate of NO_x GWP to 2.8% for a revenue raising charge using a high estimate of NO_x GWP. At this timeframe, the impacts are mainly due to a reduction in demand. The cruise charge reduces NO_x on long haul flights more than NO_x on short and medium haul flights. This is because the combined effect of higher emissions for large aircraft and longer flights.

27. **In contrast to LTO NO_x charges, this charge would incentivise engine manufacturers to reduce cruise NO_x emissions.** As the charge is directly based on cruise emissions (assuming that these can be calculated accurately), the cruise NO_x charge would have the same environmental impacts whether or not the current the correspondence between LTO NO_x emissions and cruise NO_x emissions remains intact.

4 — Including NO_x allowances in the EU ETS

28. Requiring aircraft operators to surrender NO_x allowances in the EU ETS for their emissions would target cruise NO_x emissions and hence its climate impact indirectly. The amount of NO_x for which allowances have to be surrendered can be calculated for each flight with the same formula as the LTO NO_x charge with a distance factor. The value of NO_x

allowances would be related to the value of CO_2 allowances by the GWP of NO_x. In this way, there would be full fungibility between aviation NO_x allowances and aviation CO_2 allowances.

29. The administration of the inclusion of aviation NO_x emissions in the EU ETS would be identical to the administration of the inclusion of aviation CO_2 emissions. The only additional requirement would be the establishment of a baseline. A historical baseline can be calculated for every year for which detailed flight data are available, using the same formula that will be established for calculating NO_x emissions of flights.

30. Inclusion of aviation NO_x emissions in the EU ETS could reduce aviation NO_x emissions by up to 2.8% in 2020. The impacts depend on the allocation method. With full auctioning, the environmental impact would be highest; with updated benchmarking, it could be considerably lower depending on the baseline and emission growth.

31. Like LTO NO_x charges with a distance factor or cruise NO_x charges, inclusion in the EU ETS would incentivise engine manufacturers to reduce cruise NO_x emissions. The risk of a negative design trade-off between CO_2 and NOx emissions would be absent, as the value of reducing emissions for both is related by their climate impact as expressed in GWP.

5 — ICAO LTO NO_x emission standards.

32. **ICAO LTO NO_x emission standards have been the predominant instrument to reduce LTO NO_x emissions for decades.** ICAO has regulated LTO NO_x of large jet engines since 1986. Standards have been progressively tightened, about every 6 years since the mid 1990's; the most recent standards became effective as of 1 January 2008. An EU NO_x standard could in principle be implemented and enforced by EASA, but there is a serious risk of competition distortions in the event of an EU standard exceeding ICAO standards.

33. **The relation between LTO NO_x standards and cruise emissions is complex.** Although there is a correlation between LTO NO_x and cruise NO_x for current engines, increased stringencies have not reduced cruise emissions per seat kilometre. The main reason is that standards allow engines with higher pressure ratios to emit more NO_x per unit of thrust. Engines with higher pressure ratios have better fuel efficiency performance, so there have been strong incentives to increase pressure ratios, resulting in higher absolute NO_x emissions. Furthermore, for new engine technologies, the current relation between LTO NO_x and cruise NO_x may break down. This would render LTO NO_x emission standards an unsuitable instrument to control the climate impact of aviation NO_x emissions in the absence of continuous review.

34. **Depending on the level to be agreed by international consensus in CAEP, increased stringency of standards could reduce aviation NO_x emissions by 2.3 to 5.2% in 2020.** These results are based on the assumption that the current relation between LTO and cruise emissions remains intact. Of course, the impacts depend on the outcome of international political negotiation processes.

6 — Precautionary emissions multiplier.

35. **A robust value for an emissions multiplier cannot be proposed, based on the current scientific evidence.** A commonly proposed metric to base the multiplier on, RFI, is unsuitable as it is a backward looking metric and does not assess the climate impact of an additional amount of emissions.

36. **A precautionary emissions multiplier would give the wrong incentive to technological development without some signal of an intended future revision that addresses NO_x directly.** In engine design, there is a trade-off between CO_2 and NO_x. Therefore, increasing the incentive to reduce CO_2 emissions may lead to NO_x emissions that are higher than they would have been without the multiplier. Of course, this would only result in higher NO_x emissions in the long run as new engines are introduced into the fleet.

37. **A precautionary emissions multiplier can be readily implemented, as it shares most of the design features of the inclusion of aviation in the EU ETS.**

38. **The precautionary emissions multiplier could reduce aviation NO_x emissions by 4.7% in 2020 maximally.** The impacts vary from 0.3% for an emission multiplier of 1.1 to 4.7% for a value of 2.0. The impacts are mainly due to a reduction in demand and to a further reduction of fuel burn.

Overall conclusion

39. The report demonstrates that it will take three to five years to design policy instruments that are both well-founded in scientific evidence and provide the right incentives to reduce emissions both in the short term and in the long term. The two main issues that will have to be resolved before such an instrument can be developed are:

- Establish a value for a policy-relevant metric for aviation NO_x climate impact, such as a GWP for NO_x.
- Either establish a way to model cruise NO_x emissions or establish the correlation coefficient between LTO and cruise emissions.

40. Both issues should be capable of being resolved in three to five years. In the meantime, the policy instruments that could be introduced would either have very limited environmental impacts but a solid scientific foundation, or a questionable scientific basis but a significant impact.

— END —