Discussion paper: BC fractions of PM emissions from aviation

The update of the EMEP/EEA Emission Inventory Guidebook with emission data for BC, must be based on studies reporting both total PM and BC in order to derive consistent BC fractions of PM (f-BC).

Table 1 presents an overview of the five studies which have been regarded as relevant for the present literature review. Apart from f-BC fractions, for each study the engine type and emission test modes are listed, as well as the PM emission sampling conditions, as far as information is available. Some of the following references also report figures for OC which can be input for the further assessment of OC fractions of PM (f-OC) in a future project.

Petzold et al. (2009) carry out test rig measurements of the emissions from four engine operational conditions in the SAMPLE (Study on sampling and measurement of aircraft particulate emissions) project. The measurements of PM are adjusted to include the particulate emissions in form of water bound sulphate. BC and EC values are also measured. Petzold et al. (2009) find that BC equals EC. No trend in emission could be observed for variations in engine test modes.

Petzold et al. (2003) simulates in a test rig for cruise power settings the emission influence from low, medium and high fuel sulphur content used by old and new engine technologies, respectively. BC and TC (total carbon) emissions are measured. Subsequently, the TC emissions are adjusted with 30 % in upwards direction (c.f. Petzold et al. (2009)) in order to calculate the total mass of PM and determine the f-BC fraction. No trend in emission could be observed for variations in engine test modes.

Rogers et al. (2005) carried out ground based plume measurements of the emissions from a jet engine military fighter and a turbo shaft engine being used by military helicopters. Rogers et al. (2005) measures EC, OC and total PM mass emissions, and mention the measured EC factor as the “black factor”. Based on one test run they derive BC factors which can be related to the PM mass emission factors.

Kinsey et al (2010) reports ground based plume emission measurements for nine commercial aircraft engines in three field campaigns of the Aircraft Particles Emissions eXperiment (APEX) 1-3 study. In the supplementary material for Kinsey et al. (2010), EC emissions are interpreted as BC and further it is noted that volatile PM emissions consist of sulphur and organic PM. In Kinsey et al. (2010) for five aircraft engines, the total PM mass emissions are split into volatile (PMvol) and non volatile (PMnon vol) fractions. For the present discussion note, the non volatile share of total PM is assumed to be equivalent to the f-BC fraction.

Agrawal et al. (2008) measured the emissions of e.g. PM, EC and OC from four commercial aircraft. No trend in emission could be observed for variations in engine test modes. For the present discussion note EC values are used for BC, following the assumptions made by e.g. Rogers et al. (2005) and Kinsey et al. (2010).

BC:PM emission ratios derived from the above mentioned studies are listed in the following Table 1.

Winther et al. (2012) calculated the emissions of PM for aircraft engines in Copenhagen Airport based on actual flight operational data and aircraft/engine combinations. The FOA3 method (ICAO, 2008) was used to estimate the PM emissions, split into volatile PM coming from the sulphur in the fuel and exhaust VOC, and non volative PM from soot. Subsequently, a fuel weighted f-BC fraction (non volatile share of total PM)

was derived taking into account the landing, take off and taxi engine power modes. The f-BC fraction for Copenhagen Airport was similar to the f-BC fraction calculated for LTO for Shiphol Airport in Amsterdam also using the FOA3 method (pers. comm. Andreas Petzold, DLR, 2012).

Study	Aircraft/Engine types	Test conditions	f-BC
Petzold et al. (2003)	Old engine	Cruise, low sulphur	61
		Cruise, medium sulphur	44
		Cruise, high sulphur	50
	New engine	Cruise, low sulphur	75
		Cruise, medium sulphur	31
		Cruise, high sulphur	40
Agrawal et al. (2008)	CFM56-7B22	Mode 1 (4 & 7 %)	31
		Mode 2 (30 & 40 %)	8
		Mode 3 (65 %)	59
		Mode 4 (85 %)	59
	CFM56-3B1	Mode 1 (4 & 7 %)	48
		Mode 2 (30 & 40 %)	60
		Mode 3 (65 %)	26
		Mode 4 (85 %)	85
	CFM56-3B2	Mode 1 (4 & 7 %)	55
		Mode 2 (30 & 40 %)	69
		Mode 3 (65 %)	74
		Mode 4 (85 %)	79
	CFM56-7B22	Mode 1 (4 & 7 %)	47
		Mode 2 (30 & 40 %)	72
		Mode 3 (65 %)	86
		Mode 4 (85 %)	68
Rogers et al. (2005)	Military F404-GE-400, T700-GE-401	65%-80%, 67%-98%	56
Kinsey et al. (2010)	CFM56-2C1	Various power modes	38
	CFM56-3B1	Various power modes	21
	AE3007A1E	Various power modes	38
	P&W4158	Various power modes	46
	RB211-535E4B	Various power modes	59
Petzold et al. (2009)	Test rig	Condition1	66
		Condition2	33
		Condition3	54
		Condition4	36
Winther et al. (2012)	Copenhagen Airport fleet/engine	Landing	33
		Take off	54

	Taxi	30
Petzold et al. (2003)		50
Agrawal et al. (2008)		58
Rogers et al. (2005)		56
Kinsey et al. (2010)		40
Petzold et al. (2009)		47
Winther et al. (2012)		39
Average (All)		48

Recommendation

The amount of available data is regarded as being too scarce to propose different f-BC fractions for different Tiers and explicitly for LTO and cruise in the guidebook chapter for aviation. Hence, the same f-BC fractions will be proposed for the simple LTO and cruise methodology in Tier 1, the aircraft type specific Tier 2 methodology, the aircraft type city-pair based Tier 3 methodology, and for military aircraft. For piston engined aircraft data from Winther and Nielsen (2011) will be used (f-BC = 0.15) based on information from Kupiainen and Klimont (2004).

The tables in the Guidebook being updated with f-BC fractions (or BC factors calculated from the existing PM factors and the examined f-BC fractions) are listed in Table 2. These fractions must then be combined with the existing PM factors in GB in order to establish the final BC emission factor in each case.

Table 2 Tables relevant for f-BC updates in the GB aviation chapter

Table no.	Tier	Detail	f-BC source
3-3	1	Old/average fleet; LTO and cruise emf.	Present survey
3-5	2	LTO emf. per aircraft type	Present survey
3-4	1	Piston engined aircraft	Winther et al. (2011) – IIASA
3-15	2	Military	Present survey

Inclusion of f-BC values in the guidebook

The inclusion of the new f-BC information in the guidebook can be made in several ways and needs to be agreed by the transport expert panel prior to the update of the individual chapters. For aviation, one approach can be to place the final version of the present note as an annex to the guidebook chapter, and make references to the relevant PM emission factor tables in the chapter. Another approach can be to include directly the f-BC fractions in the relevant PM emission factor tables, or as foot notes to the tables. References can then be made to the annex description, or alternatively a brief summary of the discussion note can be put somewhere central in the chapter.

Acknowledgment

Andreas Petzold, DLR, must be thanked for technical discussions during the project.

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