Improving fuel statistics for Danish aviation

Morten Winther
The National Environmental Research Institute
Department of Policy Analysis
Frederiksborgvej 399
4000 Roskilde
Denmark
Telephone: +45 4630 1297
Fax: +45 4630 1212
E-mail: mwi@dmu.dk

1. Introduction

In Denmark there is a growing need for consistent aviation fuel use statistics in order to meet specific requirements from different statistical bodies, to support emission inventories asked for by international conventions and for environmental monitoring work according to national target plans. In the Danish energy statistics fuel used by flights from Denmark to Greenland and the Faroe Islands are reported as international fuel use, while the United Nations Framework Convention on Climate Changes (UNFCCC) prescribe this fuel use to be reported as a part of the Danish domestic fuel use together with the fuel used in Greenland and the Faroe Islands for domestic flying.

This project aim to 1) develop a method to divide total aviation fuel sold in Denmark into domestic and international numbers from 1985 to 2000, and 2) to estimate the fuel used by flights from Denmark to Greenland and the Faroe Islands, respectively and domestic flights inside Greenland and the Faroe Islands, and 3) to develop a method which allocates domestic and international fuel use into figures for passenger and cargo. Both methods under 1) and 2) should be used in the future to ensure consistent fuel use statistics.

2. Danish energy statistics

The Danish Energy Agency (DEA, 2000) reports in all seven oil companies to supply Danish airports with fossil fuel products. Each company gives up information on a specific reporting scheme. All schemes are summarised for the individual fuel types to give the overall Danish total for fuel used for civil purposes in national airports. In Denmark the fuel used for different purposes is well defined (BKL I/S, the fuel depot at Copenhagen Airport, 2000). In this way JP1 is used by aircraft jet engines, while aviation gasoline is used for small piston engined aircraft. Motor gasoline and Environmental gas/diesel (very low sulphur content) and diesel oil is used for petrol-powered ground handling vehicles. Heating oil is used for special purposes like the pre-heating of aircraft and for heat generation in working areas etc. The other kerosene fuel type is also used for heating purposes.

However large uncertainties are associated with the fuel split (jet petrol and aviation gasoline) used for domestic and international flights. Even though the oil companies give up this information they on the same time make clear that this fuel split is unreliable.

2.1 Domestic/international split made by DEA

Instead the division is made by the DEA by using flight data from Copenhagen Airport for domestic flights. The DEA model is a city-pair model - which means it uses information of aircraft type and destination airport for each flight (Ministry of Transport, 2000a). The model assumes that all flights are return flights. To facilitate the actual calculations all aircraft types are classified according to 10 representative aircraft types. The fuel data are obtained from the Danish TEMA2000 model, see

Ministry of Transport (2000b), and for smaller aircraft types as information from airline companies. The fuel used for international flights is found as the difference between the total fuel sale and the domestic fuel result. Flights for Greenland and the Faroe Islands are regarded as international flights.

Table 1. Danish 1988-1999 Domestic/international jet fuel use (DEA, 2000)

	1988 [TJ]	1989 [TJ]	1990 [TJ]	1991 [TJ]	1992 [TJ]	1993 [TJ]	1994 [TJ]	1995 [TJ]	1996 [TJ]	1997 [TJ]	1998 [TJ]	1999 [TJ]
Domestic	2,464	2,558	2,444	2,262	2,226	2,227	2,239	2,299	2,510	2,562	2,279	1,979
International	25,093	26,045	24,887	23,031	23,838	23,318	25,598	26,244	27,579	28,177	30,282	32,132
Total	27,557	28,603	27,331	25,293	26,064	25,545	27,837	28,543	30,089	30,739	32,561	34,111

2.2 Refinement of DEA domestic/international jet fuel split

The DEA approach does not take into account the division in fuel use between LTO (Landing and Take Off; the flying activity below 3000 ft) and cruise (> 3000 ft) for domestic and international flights. This grouping is essential for the European-wide CORINAIR (COoRdination of Information on AIR emissions) emission inventory system. In CORINAIR country-specific fuel use and emission data is gathered and the emissions are summarised and further reported to international conventions such as the United Nations Framework Convention on Climate Changes (UNFCCC) and United Nations Economic Commission for Europe Convention on Long Range Transboundary Air Pollutants (UNECE CLRTAP).

All Danish environmental data (and underlying fuel use numbers) are organised in CORINAIR and a split in aviation fuel must therefore be made according to the CORINAIR definitions. This yields a consistency between the Danish aviation fuel statistics and the Danish obligations in relation to international conventions. To obtain this fuel split the results from two different models are combined.

2.2.1 The NERI model

For the year 1998 a detailed city-pair fuel use analysis was made at the National Environmental Research Institute (NERI) for all IFR (Instrumental Flight Rules) flights leaving Danish airports (Winther, 2000 and 2001). The NERI model is based on the new detailed CORINAIR calculation principle (CORINAIR, 1999). Air traffic data was provided by EUROCONTROL (The European Organisation for the Safety of Air Navigation) and information on aircraft types and airport codes was obtained from ICAO (International Civil Aviation Organization), see ICAO (1998, 1999). Flights to Greenland and the Faroe Islands was classified as international flights. All aircrafts were grouped into 24 representative aircraft types for which fuel use and emission data were available in the CORINAIR databank (www.eea.int/aegb/) per LTO and for distance classes. Cruise results were estimated for each flight by adjusting for the given flight length.

Table 2. Cruise fuel use shares per airport and domestic/international from the Danish 1998 study

Domestic [%]		International [%]		Sum [%]
Copenhagen	Other airports	Copenhagen	Other airports	
2.5	2.5	84.5	10.5	100

An adjustment of the domestic cruise fuel use in other airports was made to adjust for different flight numbers from EUROCONTROL in the NERI model and the national estimates from the current CORINAIR model using take off numbers from the Civil Aviation Agency of Denmark (CAA-DK).

2.2.2 Annual Danish CORINAIR inventories

At present no time series of city-pair flight data are available to support Danish avition fuel use inventory work. So far this information is only available for the year 1998 provided by EUROCONTROL and used in the NERI study described in 2.2.1. Instead the official Danish CORINAIR estimates are based on the number of domestic and international LTOs per aircraft type (LTO/aircraft type statistics) and their respective LTO times-in-mode. The most detailed data are available for Copenhagen Airport, see Copenhagen Airport (1998 and 2001), where an Environmental Impact Assessment (EIA) has proposed 20 aircraft types (with most frequently used engines) to represent all aircraft (Copenhagen Airport, 1996). Other Danish airports only submit their statistics for domestic and international LTOs for large and small aircraft (Statistics Denmark; 1986, 1989-1999 and CAA-DK, 2000, 2001a). Flights to Greenland and the Faroes are regarded as international flights.

2.3 Refinement procedure for domestic/international fuel split

The Danish CORINAIR inventories can be improved both for LTO and cruise. Previously (until 2000) information about the total number of LTOs per aircraft type was obtained from Copenhagen Airport and subsequently NERI made an estimate of the split between domestic and international fuel use. Now the destinction between domestic and international LTOs can be made directly (since 2000) using new flight information from Copenhagen Airport for the years 1991-2000, which improves the precision of the final LTO results. For cruise the estimates also become more accurate by using both the improved LTO results – and in particular the cruise results from the detailed 1998 study.

2.3.1 Refining LTO fuel use

From LTO times-in-modes (approach/landing, taxiing, take off and climb out) the fuel use factors per aircraft type, i, are computed for Copenhagen Airport by using fuel flow indices from the ICAO engine exhaust emission data bank (ICAO, 1995):

$$FC^{i}_{LTO} = \sum_{m=1}^{4} t_m \cdot ff_m \quad (1)$$

Where t_m is the time in s for LTO-mode m and ff_m, the modal fuel flow in kg per s.

Provincial airports are treated in the model as one and for domestic flying aggregated factors for Copenhagen Airport is used slightly modified for lower taxi-times. This assumption can be made since almost all domestic trips (scheduled and charter) is made via Copenhagen Airport. The factors are used in combination with the number of LTOs per aircraft type, i, to estimate the total LTO fuel use:

$$\sum_{i=1}^{20} FC^{i}_{LTO} = N^{i}_{LTO} \cdot FC^{i}_{LTO} \quad (2)$$

2.3.2 Refining cruise fuel use

The total cruise fuel use is estimated as the difference between the total aviation fuel use from DEAs sale statistics and the total LTO fuel use from above. The split of total cruise fuel use into airports and domestic/international flights is based on the findings from the 1998-NERI study (table 2).

The amount of cruise fuel, FC_{CR}^{j}, allocated to j = 1,..,4 (j: Copenhagen/Other airports for domestic/international) in 1998 then becomes:

$$FC^{j}_{CR}(1998) = \%FC^{j}_{CR}(1998, NERI) \cdot FC_{CR}(1998) \quad (3)$$

Where $\%FC_{CR}^{j}$ (1998,NERI) is the share of fuel use by flights from j based on the NERI study from 1998. FC_{CR} (1998) is the total cruise fuel use (based on total sold aviation fuel minus LTO fuel use).

The split in cruise fuel use between Copenhagen/Other airports, for domestic and international flights for a given year, X, is calculated in two steps. The first step estimates the shares in table 2. In the second step these estimated shares are used to distribute the true cruise fuel total in year X, known as the sales figures for total aviation fuel minus the total LTO fuel use in year X. The first step gives:

$$FC^{j}_{CR}(X) = FC^{j}_{CR}(1998) \cdot \frac{FC^{j}_{LTO}(X)}{FC^{j}_{LTO}(1998)} \text{, where j=1,..4} \quad (4)$$

The sum of fuel used for cruise flying is a sum of the four cruise fuel contributions:

$$FC_{CR}(X) = \sum_{j=1}^{4} FC_{CR}^{j}(1998) \cdot \frac{FC_{LTO}^{j}(X)}{FC_{LTO}^{j}(1998)} \quad (5)$$

The cruise sub-totals and total cruise fuel use found in (4) and (5) take into account the changes in LTO fuel use from the baseline year 1998. This correction expresses the change in aircraft types and number of operations. However, variations in the flight length distribution over the years is not compensated for since no aircraft/city-pair information is available for each calculation year to refine this study. The second step transforms (4) and (5) into the true cruise fuel use shares and the final sum:

$$FC_{CR,TRUE}^{j}(X) = FC_{CR,TRUE}(X)\frac{FC_{CR}^{j}(X)}{FC_{CR}(X)} \quad (6)$$

Finally the true cruise total is found as:

$$FC_{CR,TRUE}(X) = \sum_{j=1}^{4} FC_{CR,TRUE}(X)\frac{FC_{CR}^{j}(X)}{FC_{CR}(X)} \quad (7)$$

Table 3. Refined 1985-2000 fuel results for JP1 in Denmark

Airport	Category	1985 [TJ]	1986 [TJ]	1987 [TJ]	1988 [TJ]	1989 [TJ]	1990 [TJ]	1991 [TJ]	1992 [TJ]	1993 [TJ]	1994 [TJ]	1995 [TJ]	1996 [TJ]	1997 [TJ]	1998 [TJ]	1999 [TJ]	2000 [TJ]
CPH	Dom. LTO	350	377	402	424	453	445	407	426	413	413	450	474	495	420	383	337
Other	Dom. LTO	322	340	356	372	392	368	354	360	347	336	365	392	406	347	320	281
All s	Dom. LTO	672	717	758	796	844	814	760	785	760	749	815	866	901	767	703	618
CPH	Int. LTO	1,678	1,726	1,825	1,908	1,988	1,974	1,865	2,004	2,034	2,093	2,187	2,339	2,514	2,587	2,728	2,756
Other	Int. LTO	75	80	86	92	133	171	138	149	168	175	202	287	296	296	276	281
All	Int. LTO	1,752	1,806	1,911	1,999	2,121	2,145	2,003	2,153	2,202	2,267	2,389	2,626	2,811	2,883	3,004	3,037
CPH	Dom. cruise	687	760	829	889	924	857	775	777	722	773	814	818	814	727	674	603
Other	Dom. cruise	770	835	895	948	974	863	820	799	739	765	804	824	811	731	685	610
All	Dom. cruise	1,457	1,595	1,724	1,837	1,898	1,720	1,595	1,576	1,461	1,538	1,617	1,642	1,625	1,458	1,359	1,213
CPH	Int. cruise	17,966	18,983	20,538	21,789	22,130	20,705	19,379	19,942	19,381	21,350	21,560	22,023	22,522	24,426	26,175	26,827
Other	Int. cruise	867	959	1,050	1,136	1,609	1,947	1,555	1,608	1,740	1,933	2,161	2,932	2,880	3,028	2,869	2,969
All	Int. cruise	18,833	19,942	21,589	22,925	23,740	22,653	20,934	21,550	21,122	23,283	23,721	24,955	25,402	27,454	29,045	29,796
All	Cruise Sum	20,291	21,537	23,313	24,762	25,637	24,372	22,530	23,126	22,582	24,821	25,338	26,597	27,027	28,912	30,404	31,009
Total		22,715	24,059	25,981	27,557	28,603	27,331	25,293	26,064	25,545	27,837	28,543	30,089	30,739	32,561	34,111	34,664

2.3.3 Differences between DEA and refined fuel results

A good accordance exist between the DEAs existing method for domestic fuel use and this study's refined method for domestic jet fuel figures, with the index showing a difference from –2 % to + 7 %.

Table 4. Refined Danish jet fuel statistics and percentage of DEA figures

		1985 [TJ]	1986 [TJ]	1987 [TJ]	1988 [TJ]	1989 [TJ]	1990 [TJ]	1991 [TJ]	1992 [TJ]	1993 [TJ]	1994 [TJ]	1995 [TJ]	1996 [TJ]	1997 [TJ]	1998 [TJ]	1999 [TJ]	2000 [TJ]
New	Dom.	2,129	2,311	2,482	2,633	2,742	2,533	2,355	2,361	2,221	2,287	2,433	2,508	2,526	2,225	2,062	1,831
refined	Int.	20,586	21,748	23,499	24,924	25,861	24,798	22,938	23,703	23,324	25,550	26,110	27,581	28,213	30,337	32,049	32,832
method	Total	22,715	24,059	25,981	27,557	28,603	27,331	25,293	26,064	25,545	27,837	28,543	30,089	30,739	32,561	34,111	34,664
DEA	Dom.	2,031	2,152	2,324	2,464	2,558	2,444	2,262	2,226	2,227	2,239	2,299	2,510	2,562	2,279	1,979	-
Existing	Int.	20,684	21,908	23,658	25,093	26,045	24,887	23,031	23,838	23,318	25,598	26,244	27,579	28,177	30,282	32,132	-
method	Total	22,715	24,059	25,981	27,557	28,603	27,331	25,293	26,064	25,545	27,837	28,543	30,089	30,739	32,561	34,111	-
Diff.	Dom.	105	107	107	107	107	104	104	106	100	102	106	100	99	98	104	-
	Int.	100	99	99	99	99	100	100	99	100	100	99	100	100	100	100	-
	Total	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100	-

3.1 Fuel use for flights between Denmark, Greenland and the Faroes

In section 2 all Danish jet petrol sold was divided into domestic and international use for the years 1985 to 2000. The underlying flight data was official Danish take off numbers (from CAA-DK) and take off numbers from Copenhagen Airport, and EUROCONTROL city-pair flight data used in the NERI model for 1998. Since in general no city-pair data – with information about destination airport - is available from CAA-DK the method explained in section 2 can not be used to make a special estimation of the fuel used by flights going to Greenland and the Faroes (North-Atlantic flights). Instead city-pair data for North-Atlantic flights must be provided by the airports in question and used as input to special simulations with the NERI model.

From Copenhagen Airport (2001) city-pair data was provided from 1991 and onwards for flights leaving Copenhagen Airport bound for Greenland and the Faroes. For the years before 1991 the flying activity remained constant at the same level as in 1991 (CAA-DK, 2001b). Since 1995 a small number of flights to the Faroes are also made from the airports of Billund and Århus. Exact information from Århus Airport was only provided for the years 1999 and 2000 and from Billund Airport for the years 1998 to 2000 (Billund Airport, 2001). For Århus Airport data from 1999 are likely to represent the years 1995-1998 (Århus Airport, 2001). In the case of Billund Airport the flying activities in 1996 and 1997 equal the 1998 reported figures, while the flight numbers before 1996 are very small and thus not taken into account in this study (Billund Airport, 2001).

Table 5. Fuel use for flights between Denmark, Greenland and the Faroe Islands

Origin	Destination	1985 [TJ]	1986 [TJ]	1987 [TJ]	1988 [TJ]	1989 [TJ]	1990 [TJ]	1991 [TJ]	1992 [TJ]	1993 [TJ]	1994 [TJ]	1995 [TJ]	1996 [TJ]	1997 [TJ]	1998 [TJ]	1999 [TJ]	2000 [TJ]
Denmark	Faroes	140	140	140	140	140	140	140	131	122	129	130	139	138	164	181	184
Faroes	Denmark	(140)	(140)	(140)	(140)	(140)	(140)	(140)	(131)	(122)	(129)	(130)	(139)	(138)	(164)	(181)	(184)
Denmark	Greenland	160	160	160	160	160	160	160	189	186	171	171	182	207	230	270	284
Greenland	Denmark	(160)	(160)	(160)	(160)	(160)	(160)	(160)	(189)	(186)	(171)	(171)	(182)	(207)	(230)	(270)	(284)

Source: NERI model simulations based on flight data from Copenhagen Airport. Numbers in parentheses are estimates based on the assumption that alle flights are return flights.

No air traffic takes place between the Faroe Islands and Greenland. If no other information is available the fuel used by flights between Denmark-Greenland and Denmark-the Faroes respectively can be assumed to represent the fuel use for the opposite flights from Greenland and the Faroes going to Denmark. In terms of flight data this is a precise assumption. Almost all the North-Atlantic flights are return flights and the total fuel use estimate (for flying out and back) is fairly precise. However precautions must be taken in terms of fuel allocation: Due to fuel price differences more fuel is being lifted up in Copenhagen Airport compared with the fuel uplift in Greenland and the Faroe Islands (Greenlandair, 2001 and Atlantic Airways, 2001).

3.2 Fuel use for flights from the Faroe Islands

To get more knowledge of the flying activities at the Faroe Islands city-pair flight information has been obtained from Vagar Airport (CAA-DK, 2001c). Since all flights to and from the Faroe Islands go via Vagar Airport, data encompass all international aviation. The fuel use is calculated with the NERI model. The results for 1999 and 2000 show that around 90% of all international jet fuel is used by flights bound for Denmark (table 6). Flight data from Copenhagen Airport and CAA-DK in Vagar are almost identical as regards number of flights and thus give almost the same amount of fuel computed. Due to this equality for the years 1999 and 2000 and due to the lack of data from CAA-DK in Vagar for the years before 1999 the city-pair information from Danish airports can be used to represent the flying from Vagar to Denmark for the years 1985-1998. Precautions must be taken as before mentioned in relation to fuel allocation: Because of fuel price differences most of the fuel used by return flights between Denmark and the Faroe Islands is being lifted up in Denmark.

Table 6. Fuel use for international flights from the Faroe Islands

Origin country	Destination country	Fuel [TJ] 1999	2000
Faroe Islands	Denmark	176	181
Faroe Islands	Iceland	10	14
Faroe Islands	Norway	1	3
Faroe Islands	Scotland	6	7

Source: NERI model simulations based on flight data from Vagar Airport.

In an overview the number of flights bound for Iceland have been constant for many years, though with roughly 10% more flights starting from 1998. Flights for Norway was first opened in 1999. Until 1998 the number of flights for Scotland were only one fifth of todays numbers (CAA-DK, 2001c). Domestic flying in the Faroes are solely helicopter flying with a Bell 212. Average fuel use in kg/hour and the number of flying hours was combined in order to calculate the fuel use (Atlantic Airways, 2001). The domestic flying in the Faroes has been approximately the same in the period 1988-1999.

Table 7. Summary of fuel used by international flights from the Faroe Islands

	1985 [TJ]	1986 [TJ]	1987 [TJ]	1988 [TJ]	1989 [TJ]	1990 [TJ]	1991 [TJ]	1992 [TJ]	1993 [TJ]	1994 [TJ]	1995 [TJ]	1996 [TJ]	1997 [TJ]	1998 [TJ]	1999 [TJ]	2000 [TJ]
Domestic	10	10	10	10	10	10	10	10	10	10	10	10	10	10	10	11
Faroes-DK[1]	(140)	(140)	(140)	(140)	(140)	(140)	(140)	(131)	(122)	(129)	(130)	(139)	(138)	(164)	176	181
Iceland[1]	9	9	9	9	9	9	9	9	9	9	9	9	9	10	10	14
Norway[1]															1	3
Scotland[1]	1	1	1	1	1	1	1	1	1	1	1	1	1	6	6	7
Total	150	150	150	150	150	150	150	141	132	139	140	149	148	180	193	205
Fuel sale[2]											67	73	77	84	97	86

Source: 1) NERI model simulations using flight data from Vagar Airport and Copenhagen Airport. 2) Statistics Faroe Islands.

Information from Statistics Faroe Islands based on reported figures from Statoil, the only oil company supplying fuel in Vagar Airport, gives a total of 86 TJ jet fuel sold in 2000 (Statistics Faroe Islands, 2001). There is a big gap between this total and the simulated figures from the present study; 181 TJ (Denmark) + 24 TJ (Other international) + 11 TJ (domestic) = 216 TJ. It is likely that a major part of the fuel used for Danish flights is actually being lifted up in Denmark.

3.4 Fuel use for flights from Greenland

No official flight statistics for Greenland could be made available for this study. Instead fuel use information in total numbers is gathered by Statistics Greenland as a part of their national fuel sale inventory for 2000 (Statistics Greenland, 2001). This inventory also contains fuel sale figures for the years back to 1982. No distinction is given between domestic and international aviation fuel use, but in practise all fuel is used for civil aviation.

The only way to investigate further where this fuel is being used is to ask the airline companies operating in Greenland. Most of the domestic flying in Greenland are made by Greenlandair (2001a, b), First Air (2001) and Alpha Air (2000) and information on fuel use has been obtained from these airline companies. A few international trips are bound for Canada (First Air and Greenlandair) and Iceland (Greenlandair and Icelandair), although international flying is dominated by flights headed for Copenhagen Airport as the only Danish destination.

Table 8. Jet fuel use information for Greenland obtained by airline companies

Year	Company	Domestic [TJ] [TJ]	International Denmark [TJ]	Other countries [TJ]	Total [TJ]
1999	Air Alpha	10	-	-	
	Greenlandair	340	219[1]	13[1]	232[1]
	First Air	17	-	10	10
	Total	367	219	23	242
2000	Air Alpha	10	-	-	
	Greenlandair	353		2[1]	101[2]
	First Air	-	-	3	3
	Total	363	-	5	104

Source: Airline companies. 1) Also for return flights. 2) Fuel uplift in Greenland.

The majority of domestic fuel is used by Greenlandair. Ressource limitations has been the main obstricle for Greenlandair not to submit fuel use informations for the years before 1999. An overview of the flying activity for the other airline companies in historical years show that First Air had approximately the same domestic fuel use in 1997 and 1998 as given for 1999 – and no domestic flying before 1997. Their international fuel uplift in Greenland in 1995-1998 was marginal (similar size as for the year 2000) and from 1981-1994 even lower (First Air, 2001). Air Alpha began flying in

Greenland in 1994 and the activity and hence fuel use has increased year by year up to todays figures (Air Alpha, 2000). No information has been obtained from Icelandair.

Most of the international fuel is used by flights bound for Copenhagen, though in table 8 only fuel figures from Greenlandair is listed for this route (also for reverse flying). Since in practise all flights between Greenland and Denmark are round trips a comparison with fuel figures from Statistics Greenland could be made in the following way:

1) For 1999 use the domestic and other international fuel figures from table 8 - and take only half of the other international fuel figures by Greenlandair since they report fuel also for the return flights. This yields: 10 TJ+340 TJ+17 TJ+6,5 TJ+10 TJ= 384 TJ. For 2000 the fuel amount is: 10 TJ + 353 TJ + 1 TJ + 3 TJ = 367 TJ.

2) exclude the Greenlandair figure for flights going to Denmark (since it only represents a part of the total fuel used by air traffic on this route) and let the figures from table 5 (1999: 270 TJ and 2000: 284 TJ) represent the fuel use for these flights. The total fuel use from airline companies and NERI model results gets: 384 TJ+270 TJ= 654 TJ (1999); and 367 TJ + 284 TJ = 651 TJ.

Table 9. Fuel use from Statistics Greenland, airline companies and NERI estimates

Year	Statistics Greenland	Airline companies		NERI simulations	Airline companies/ NERI simulations
	Total TJ	Domestic TJ	International TJ	DK-Greenland TJ	Total calculated TJ
1999	721	367	17	270	654
2000	830	363	4	284	651

The fuel use data behind this study has been validated by SAS in Copenhagen (2001) per flight for the aircraft type B767 and by flight numbers by SAS in Copenhagen and in Søndre Strømfjord (SAS, 2001). As regards the aircraft type B757 Greenlandair reports a fuel use around 20% higher for a Søndre Strømfjord-Copenhagen-Søndre Strømfjord return flight compared with the fuel use behind the NERI model (Greenlandair, 2001b). Inspite of this difference the total NERI results are close to the fuel use in real world flying, since the total B757 fuel use is less than half of the grand fuel use total for the Greenland-Denmark flights. The discrepancy between Statistics Greenland and airline companies/NERI simulation figures is moderate in 1999 (around 9%), however increases to 22% in 2000. The missing fuel amount from Icelandair international flights plays no role in the total budget.

If extra fuel were added to the NERI B757 simulated figures – as indicated by the Greenlandair B757 fuel use – the fuel sale/simulated fuel use discrepancies would be somewhat smaller. However one important fact would tend to once again widen the gap between simulated fuel use and fuel sale figures: Under actual flying conditions the experience is that 2/3 of all fuel is being lifted up in Copenhagen Airport while only 1/3 is lifted up in Greenland (Greenlandair, 2001a).

For the years 1985-2000 a time series of fuel use can be established from the fuel sale figures reported by Statistics Greenland (2001). The JP1 sales are reported directly in the statistics for 1993 to 2000. To make an approximation of the JP1 fuel sales for the years 1985-1992 fractions of the total kerosene sales are found by using the known 1993 JP1 percentage share (73.9%). The next step is to subtract the fuel used by flights from Greenland to Denmark and other international flights, and in this way obtain figures for domestic fuel use. Even though big uncertainties exist as regards fuel sold versus fuel used by international flights, the procedure for making a split in fuel use as outlined above is the only feasible way forward with the present data available.

Table 10. Time series of total fuel sales and per flight category in Greenland

	1985 [TJ]	1986 [TJ]	1987 [TJ]	1988 [TJ]	1989 [TJ]	1990 [TJ]	1991 [TJ]	1992 [TJ]	1993 [TJ]	1994 [TJ]	1995 [TJ]	1996 [TJ]	1997 [TJ]	1998 [TJ]	1999 [TJ]	2000 [TJ]
Total sale	179	207	230	227	243	518	528	521	309	265	291	345	375	905	721	830
Greenland-DK	160	160	160	160	160	160	160	189	186	171	171	182	207	230	270	284
Other int.													3	3	17	4
Domestic.	20	48	71	67	84	358	369	332	123	93	120	163	165	672	434	542

The large fluctuations in reported fuel sold suggest that the statistics are still unprecise. The large figures for the years 1990-1992 might occur because the JP1 percentage share for 1993 was used for these years to extract JP1 from the kerosene total. Possibly the 1993-1997 figures are to low whereas the figures for 1998-2000 might be higher than accurate numbers. Two arguments motivate this: The air traffic has increased in Greenland during the time period; however not in a rate which explains the JP1 fuel sales increase from 1997 to 1998 as can be seen in table 10. Also the differences in 1999 and 2000 between fuel sold and fuel information/simulations (table 9) causes concern - given the fact that the differences would become real if the effect of fuel price differences on fuel used by international flights could be accounted for in the simulations (as mentioned previously in this paragraph).

4. Dividing fuel use by passenger and freight

Depending on the flight data available fuel use inventories for air freight transportation can be made with an increasing level of details. In Denmark a fuel use inventory for sole domestic cargo flights in the years 1991-1999 has been made as a part of the DEA model, DEA (2000). In the present project the city-pair data behind the DEA model will be updated with year 2000 data and further used as input to the NERI city-pair model. On the same time a correspondent inventory will be made for international cargo flights in the year 2000 to ensure a consistency with the other results of this study.

Ideally the fuel use results for specific cargo flights could be used to make an approximation of the fuel use allocated to cargo transport on passenger flights. Needed is data for the total amount of cargo handled in Danish airports and the cargo part handled in relation to specific cargo flights. This fuel use would be calculated as the ratio between total cargo weight on passenger flights and the total cargo weight flown on specific cargo flights, multiplied with the total fuel use for specific cargo flights.

$$FC_{P.F.}(C\arg o) = \frac{M_{T,P.F.}}{M_{T,C.F.}} \cdot FC_{C.F.} = \frac{(M_T - M_{T,C.F.})}{M_{T,C.F.}} \cdot FC_{C.F.} \quad (8)$$

Where $FC_{P.F.}$(Cargo) and $FC_{C.F.}$ is the total fuel use associated with cargo transportation on passenger flights and the fuel used by specific cargo flights, respectively. M_T, $M_{T,P.F.}$, and $M_{T,C.F.}$ are the weights for 1) all cargo transported, 2) cargo on passenger flights and 3) cargo on specific cargo flights.

At present the total air cargo weight M_T is known from official CAA-DK statistics. These data are printed in Statistics Denmark (2000); by this source the cargo weight is given for both domestic and international air transport from 1989 to 1999, while only total figures is given for 1987 and 1988. If information could be provided also for the total cargo weight transported on sole cargo flights, the fuel use approximation could be made. At this level two factors would influence the precision of the final result. First of all the aircraft type distribution for cargo flights is assumed to equal the one for passenger flights also carrying cargo weight. Secondly the total cargo amount also comprise a part of the cargo being transported on trucks to airports in other countries from where it is flown out.

Several obstricles render a fuel use inventory in which the fuel use allocated to cargo is estimated on every flight. Flight data can be made available on a city-pair level, but at present the number of passengers and gross cargo weight can not be provided to support a total fuel use inventory for cargo transportation. Nevertheless the method is explained in the following; by all accounts from 2001 and onwards the CAA-DK will be able to provide the input data sought for.

For each flight the passenger and cargo part can be derived as a direct split in the specific flight fuel use by passenger:cargo weight ratio:

$$FC(i) = FC_C(i) + FC_P(i) = \frac{M_C(i)}{M_C(i) + M_P(i)} \cdot FC(i) + \frac{M_P(i)}{M_C(i) + M_P(i)} \cdot FC(i) \quad (9)$$

Per flight, i, FC(i) FC_C(i) and FC_P(i) is the total fuel use and the fuel use associated with cargo and passenger transportation, respectively. M_C(i) and M_P(i) is the weight of cargo and passengers. With the number of passengers, N_P(i), and the average weight per passenger, M_N(i), inserted (9) becomes:

$$FC(i) = \frac{M_C(i)}{M_C(i) + N_P(i) \cdot M_N(i)} \cdot FC(i) + \frac{N_P(i) \cdot M_N(i)}{M_C(i) + N_P(i) \cdot M_N(i)} \cdot FC(i) \quad (10)$$

The cargo and passenger part of the total fuel use can be found by adding up the fuel use contributions for all domestic and international flights. Major benefits from making a cargo/passenger fuel use inventory as explained are achieved in important areas: The real aircraft type distribution is behind the estimations and the cargo figures have been filtered for the amount of cargo transported by road, since the cargo weight is related to the specific flights.

The total weight of cargo handled in Danish airports is known for historical years. For a given year, X, the fuel use associated with domestic and international cargo transportation is found as the ratio between the total cargo weight in year X and year 2001 multiplied with the fuel used for cargo transportation in 2001. The fuel used for domestic and international passenger transportation is derived as the difference between the total fuel use and the fuel used for cargo transportation.

Mainly two factors influence the precision of the final result. First of all the aircraft type distribution for cargo flights in historical years is assumed to equal the one for 2001. Secondly the total cargo amount for historical years also comprise a part of the cargo being transported on trucks to airports in other countries from where it is flown out.

5. Conclusion

In this study a consistent split in jet fuel for domestic and international use has been made in a time series from 1985 to 2000. The task has been to develop a method which breaks down the fuel use into domestic and international LTO (< 3000 ft) and cruise (>3000 ft) as required by the UNFCCC and UNECE conventions. Two major improvements have been achieved: As a basis it is now possible to distinguish directly between domestic and international flights from Copenhagen Airport. The improved LTO/aircraft type data is provided by the airport itself and the overall national LTO numbers come from CAA-DK. In step two more accurate cruise fuel use estimates have been calculated based on city-pair model results for the year 1998 estimated with the detailed NERI model.

A fine harmony exist between the new fuel use split and the current split made with the DEA city-pair model for domestic flights; result deviations are between + 7 % and –2%. To make the split in domestic and international fuel use in the future three kind of information must be obtained; 1) the total JP1-fuel sale figure, 2) the number of domestic and international LTOs per aircraft type from Copenhagen Airport and 3) the official Danish LTO numbers from CAA-DK.

In order to estimate the fuel used in future years by flights from Denmark to Greenland and the Faroe Islands, respectively, city-pair flight data must be obtained directly from the airports of Copenhagen, Billund and Århus. In this study this has been done for historical years: With some modifications a consistent time series of fuel use by North-Atlantic flights has been produced for the years 1985 to 2000. In situations where no other information is available these results can also represent the flights from Greenland and the Faroe Islands arriving to Denmark. The reverse sum gives a fairly accurate estimate. However it must be stated that airline companies tend to take up more fuel in Denmark. Fuel price differences have a big influence on the precise fuel allocation.

For Greenland and the Faroe Islands domestic and international fuel use estimates have been made for 1985-2000. Internal flying in the Faroe Islands is solely helicopter flying. To make future estimates Atlantic Airways must be asked each year for data on flying hours and specific fuel use. For international flights city-pair flight data must be provided by CAA-DK in Vagar Airport and used as input in the NERI model for fuel use simulations. For Greenland efforts still needs to be made in order to establish a consistent aviation fuel use statistics. Considering the data available a time series of fuel use in Greenland should be made in three steps. First of all the total fuel sale figures must be obtained from Statistics Greenland. Secondly the fuel used by international flights for Denmark and other countries, respectively, should be simulated with the NERI model. The final step is to let the difference between fuel sold and simulated figures represent the fuel use for domestic flying.

A fuel use inventory for Danish domestic cargo flights for the years 1991-1999 already exist. The underlying flight data will be updated with year 2000 data (also comprising international flights) and used in the NERI model to obtain a consistent fuel use estimate for sole cargo flights. Based on these results a fuel use approximation for cargo transportation on passenger flights could be made: The demand for input data is the total cargo amount handled in Danish airports (already available) and the total amount of cargo flown on specific cargo flights (still missing from the CAA-DK). The future prospects of making a detailed and complete fuel use inventory for air cargo transportation become increasingly better. By all accounts the flight statistics gathered by CAA-DK from 2001 and onwards contain information on destination airport, the number of passengers and cargo weight for each flight leaving large Danish airports. These data are well fitted for calculations made with the NERI model.

6. References

Alpha Air (2000): Unpublished data material and pers. comm. Inge Merete Friis.
Atlantic Airways (2001): Unpublished data material. e-mail from Hans Erik Jakobsen.
Billund Airport (2001): Unpublished data material and pers. comm., Jette Giørtz/Ronny Lilienvald.
BKL I/S (2000): Pers. comm., Finn Poulsen, the fuel depot at Copenhagen Airport.
CAA-DK (2000): Statistik over luftfartsaktiviteter 1999, www.slv.dk
CAA-DK (2001a): Statistik over luftfartsaktiviteter 2000, www.slv.dk
CAA-DK (2001b): Pers. comm., Henrik Gravesen.
CAA-DK (2001c): Unpublished data material and pers. comm., Torfinn Jacobsen.
Copenhagen Airport (1996): VVM Fagprojekt - Luftforurening, Copenhagen Airport, Copenhagen.
Copenhagen Airport (1998): Traffic Statistics 1985-1990, Copenhagen Airport, Copenhagen.
Copenhagen Airport (2001): Traffic Statistics 1991-2000, Lars H. Hansen, Copenhagen Airport, Copenhagen (unpublished data material).
CORINAIR (1999): Atmospheric Emission Inventory Guidebook Vol. 3, Second Edition, EMEP Task Force on Emission Inventories, European Environmental Agency, Copenhagen.
DEA (2000): Danish Energy Agency, End-use statistics (unpublished data material).
First Air (2001): Unpublished data material and pers. comm., Gary Plexman.
Greenlandair (2001): Unpublished data material and pers. comm., Thomas Jørgensen/Hanne Bertels.
ICAO (1995): ICAO Engine Exhaust Emissions Data Bank, Doc 9646-AN/943, First Edition - 1995, ICAO, Montreal.
ICAO (1998): Aircraft Type Designators, Doc 8643/26, 26th Edition, ICAO, Montreal.
ICAO (1999): Location Indicators, Doc 7910/93, 93th Edition, ICAO, Montreal.
Ministry of Transport (2000a): Notat om energiforbrug til indenrigsluftfart, Copenhagen (in Danish).
Ministry of Transport (2000b): TEMA2000. Technical report, Copenhagen (in Danish).
SAS (2001): Pers. comm. Karl-Erik Kjøller (Copenhagen)/Leif Pedersen (Søndre Strømfjord).
Statistics Denmark (1986): Statistical Yearbook 1986, Statistics Denmark, Copenhagen (in Danish).
Statistics Denmark (1989-1999): Statistical Yearbook 1989-1999 editions, Statistics Denmark, Copenhagen (in Danish).
Statistics Denmark (2000): Transport 2000, ISBN 87-501-1134-5, Statistics Denmark, Copenhagen.

Statistics Faroe Islands (2001): Pers. comm., Simona Nielsen, Argir.
Statistics Greenland (2001): Unpublished data material and pers. comm., Andreas Vedel, Nuuk.
Statoil (2001): Pers. comm., Jens Bjørnmose, Copenhagen.
Winther, M.(2000): A Model for Calculating the Fuel Use and Emissions from IFR Flights Using the New CORINAIR Guidelines. In: Joumard, R. (ed): 9th Symposium Transport and Air Pollution. Report of INRETS. Vol. 2.
Winther, M. (2001): 1998 Fuel Use and Emissions for Danish IFR Flights. Environmental Project xxx, 2001. 100 p. Danish EPA. Prepared by the National Environmental Research Institute, Denmark.
Århus Airport (2001): Unpublished data material and pers. comm., Thomas Sigvardt.