British Airways Flightdeck Mortality Study, 1950–1992

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Objective: To study the mortality and life expectancy of male British Airways flightdeck crew and to establish whether proportionate mortality excesses shown earlier for brain/CNS cancer, colon cancer and melanoma remained evident. ***Methods***: A Standardized Mortality Ratio study (SMR) using England and Wales as the comparison population was carried out for 6209 male pilots and 1153 male flight engineers employed for at least 1 yr between January 1, 1950 and December 31, 1992. Internal relative risk comparisons were made between shorthaul and longhaul operations defined broadly as flights within Europe and beyond Europe, respectively. ***Results:*** The all-causes SMR for pilots of 61 (592 deaths) and 56 for flight engineers (127 deaths) confirmed the expected Healthy Worker Effect. In pilots apart from the known excess of deaths from aircraft accidents (SMR 14694), most of the comparisons showed significant deficits in mortality. The SMR's for brain/CNS cancer (143) and colon cancer (111) were no longer statistically significant. The SMR of 333 for melanoma was significantly raised in pilots but was not evident in flight engineers. Life expectancy for longhaul pilots and flight engineers was 4–5 yr better than England and Wales for ages 55–65 while the advantage for shorthaul pilots was reduced to between 2–3 yr. Cases of leukemia and aleukaemia in pilots were less than expected and less than the positive excess predicted from modeling based on radiation dose. ***Conclusion:*** The study confirms that flightdeck crew live longer than the England and Wales population and do not exhibit patterns of death that could be directly attributable to occupation.

Keywords: pilot, flight deck, mortality, life expectancy.

A PREVIOUS PROPORTIONAL Mortality Ratio Study (PMR) (13) identified brain/CNS cancer, colon cancer and melanoma as causes of death among commercial flight crew that needed further study to examine occupational etiology. Since that time, Band et al. (2) described an excess of mortality from aircraft accidents and identified significantly increased incidence for cancer of the prostate and acute myeloid leukemia. Kaji et al. (14) in a smaller study confirmed the mortality excess from aircraft accidents. Grayson (8), who examined cancer incidence for Air Force officers, identified excesses for testes and urinary bladder cancer, and put forward methodological arguments for the lack of consistency with mortality data published for commercial pilot populations.

We revisited our original data set and evaluated the feasibility of carrying out a Standardized Mortality Ratio Study (SMR). We considered this to be impracticable at the PMR stage due to problems of data extraction from hard copy files. Since that time British Airways (BA) Pensions have moved location and transferred all their records onto microfilm.

After a pilot investigation of the available data sources from BA Pensions and the Civil Aviation Authority (CAA) we considered that such a study would indeed be possible, although the detail obtainable from the CAA to identify flight history accurately was in doubt.

METHODS

In excess of 1,000,000 population records at BA Pensions covering the period 1939–1992 were examined, and pilot and flight engineer details for male employees extracted and recorded. With the help of the BA Personnel Department, we examined the level of detail maintained for current and recently terminated male BA pilots and flight engineers. We extracted demographic data and most recent fleet information from the Personnel database. We then examined several sources of data at the CAA to establish flight history information:

1) We looked at the Flight Crew Licensing (FCL) system and extracted details on type of aircraft flown and used the date of the last medical examination as a check on vital status for all individuals on the computer system.
2) The FCL microfiche files were painstakingly reviewed to give historic information on known BA pilots and flight engineers.
3) We searched the main CAA microfiche files independently of the FCL files, but in a manner similar to that in number 2.
4) When no trace was provided through other means we used the CAA archive, although this provided very limited success.
5) The medical department retained some microfiche records of the pilot and flight engineer license

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medical examinations. These provided a cross reference to other sources of data and enabled vital status checks.

6) In the early stages of the research, separate hard copy files (sorted alphabetically) were viewed prior to microfiching for any trace of individuals whose details were not found in the other data sources.

We discovered that years as flight deck crew within BA were discernible but not number of hours flown. Again, because of the dearth of information on flying history, it was not possible to adequately identify years of occupation as flight deck crew in total, particularly where there was a likelihood of employment outside BA. For this reason, we concentrated the analysis on flight type only.

A listing of all the current and recently retired pilots was obtained from FCL within the CAA. This gave all of the aircraft types licensed for each individual in chronological order together with the year in which the license was obtained.

We defined shorthaul operations to mean that of flying within Europe and that of longhaul to cover flying activities to destinations outside Europe which included the Concorde Fleet. Flight engineers were assumed to operate within longhaul operations. This simple differentiation was made to allow mortality patterns to be examined in relation to factors such as altitude and exposure to ionizing radiation. We used aircraft type rating data, when available, to differentiate between shorthaul and longhaul. For those pilots who had a mixture of aircraft types covering both operations we allocated the classification "mainly shorthaul" or "mainly longhaul" based on duration of the license type. We used the information of employer as either British European Airways (Shorthaul) or British Overseas Aircraft Corporation (Longhaul) when no other information existed. We coded pilots who started their careers as navigators, radio operators, flight engineers or helicopter pilots by their predominant aircraft type or final employer.

Finally we reviewed the dataset and removed from further analysis all pilots whose duration of employment with BA during the study period January 1, 1950 to December 31, 1992 was less than 1 yr or whose finish date was prior to January 1, 1950.

Tracing of vital status and coding of death details to the International Classification of Diseases (ICD) in operation at the time of death, for all those in the study, was coordinated by the (then) Office of Population Censuses and Surveys (OPCS). Deaths that occurred prior to the introduction of the eighth edition (1967) were recoded to the ICD revision in place at the time.

Statistical Analysis

We calculated death rates for the study cohort in 5-yr age bands with some minor exceptions to match the years in which the ICD coding changed, and compared these with death rates from the England and Wales male population. Although we recognize that the pilots represent a heavily screened and healthy population during employment we used national rates to allow broad comparisons to be made against published studies. We relied on specific patterns of mortality and subsequent relative risk (RR) analyses to examine the evidence for occupational etiology.

We used the OCMAP mortality package from the University of Pittsburgh for the SMR and RR analyses (16). For the analyses, we obtained death data for the England and Wales male population from the Medical Research section of the OPCS and re-formatted these to be compatible with the OCMAP package. Additional "diagnostic" ranges were encoded to meet the needs of specific causes of death (e.g., aircraft accidents) experienced by some in the cohort. Life table analyses were performed using the LIFETEST methodology in SAS (18).

TABLE I. VITAL STATISTICS OF PILOT AND FLIGHT ENGINEER POPULATIONS.

	Pilots	Flight Engineers
Currently Employed	2866	397
Terminated	2097	456
Alive	1651	332
Dead	320	73
Unknown	126	51
Retired	1115	284
Alive	972	246
Dead	141	38
Unknown	2	0
Died in Employment	131	16

RESULTS

Pilots (SMR)

The final composition of the 6209 male pilots satisfying the inclusion criteria by aircraft type is as follows: shorthaul = 1802; mainly shorthaul = 1712; longhaul = 1224; mainly longhaul = 1263; helicopter = 168; and unclassified = 40. The vital status of these male pilots who contributed 143,506 person years of observation is shown in **Table I**.

The cause of death for 34 (5.7%) of 592 deaths was unobtainable. A group of 128 (2.1%) of the 6209 in the population could not be traced, reflecting the highly transient nature of the workforce. OPCS classified the reason for "no trace" as "emigration" for the majority of these individuals.

Table II shows the SMR results for all categories of pilot. The all causes SMR of 60.7 (95% confidence interval (55.9, 65.8)), all malignant cancer SMR 64.0 (55.0, 74.1), all heart disease SMR 39.2 (33.0, 46.2), and the non-malignant respiratory disease SMR of 21.3 (12.4, 34.1) represent large and statistically significant deficits when the population is compared with England and Wales data.

The SMR for all external causes of death was significantly elevated at 164.8 (135.7, 198.3) while the SMR for the subcategory of aircraft accidents was as expected highly elevated at 14693.5 (11185.5, 18953.7).

In line with the statistically significant excesses discovered in the earlier PMR (13) study, melanoma was statistically raised at 333.0 (152.3, 632.2) while those of

TABLE II. ALL PILOTS SMR.

Description	(>2 Observed Deaths) O	E	SMR	CI 95%
All causes	592	975.05	60.7**	55.9, 65.8
All malignant cancer	180	281.13	64.0**	55.0, 74.1
Cancer buccal cavity and pharynx	3	4.74	63.3	13.1, 184.9
Cancer digestive organs and peritoneum	52	82.82	62.8**	46.9, 82.3
Cancer oesophagus	5	10.61	47.1	15.3, 109.9
Cancer stomach	9	23.15	38.9**	17.8, 73.8
Cancer large intestine	20	17.99	111.2	67.9, 171.7
Cancer rectum	8	12.21	65.5	28.3, 129.1
Cancer biliary passage and liver	3	4.35	69.0	14.2, 201.6
Cancer pancreas	6	12.13	49.5	18.2, 107.6
Cancer respiratory system	48	108.90	44.1**	32.5, 58.4
Cancer larynx	2	2.73	73.2	8.9, 264.5
Cancer bronchus trachea and lung	43	103.72	41.5**	30.0, 55.8
Cancer all other respiratory	3	2.44	122.8	25.3, 358.8
Cancer prostate	15	13.48	111.3	62.3, 183.5
Cancer kidney	4	6.18	64.7	17.6, 165.8
Cancer bladder and other genitourinary organs	2	9.29	21.5**	2.6, 77.7
Melanoma	9	2.70	333.0**	152.3, 632.2
Cancer CNS/brain	14	9.80	142.9	78.1, 239.8
Cancer brain	12	9.41	127.5	65.9, 222.7
All lymphatic and haematopoietic tissue	18	21.54	83.6	49.5, 132.0
Hodgkins Disease	4	2.87	139.3	38.0, 356.8
Leukemia and aleukemia	4	7.84	51.0	13.9, 130.7
All other lymphatic tissue	9	8.97	100.3	45.9, 190.4
All other malignant cancer	14	17.15	81.6	44.6, 136.9
Diabetes mellitus	3	8.68	34.6	7.1, 101.0
Diseases of nervous system and sensory organs	13	15.50	83.9	44.7, 143.4
Cerebrovascular disease	34	64.55	52.7**	36.5, 73.6
All heart disease	142	362.47	39.2*	33.0, 46.2
Ischemic heart disease	126	326.53	38.6**	32.1, 45.9
Disease of arteries	14	19.19	73.0	39.9, 122.4
Aortic aneurysm	13	13.14	98.9	52.7, 169.2
Diseases of veins	6	7.38	81.3	29.8, 176.9
Diseases of endocardium	4	7.73	51.7	14.1, 132.5
Hypertension and heart disease	2	6.18	32.3	3.9, 116.8
All other heart diseases	9	14.02	64.2	29.4, 121.9
Non-malignant respiratory disease	17	79.92	21.3**	12.4, 34.1
Influenza and pneumonia	5	23.16	21.6**	7.0, 50.4
Pneumonia	5	21.65	23.1**	7.5, 53.9
Bronchitis, emphysema, asthma	5	30.17	16.6**	5.4, 38.7
Bronchitis	2	22.48	8.9**	1.1, 32.1
Asthma	2	3.76	53.2	6.4, 192.2
Bronchopneumonia	2	15.34	13.0**	1.6, 47.1
Other diseases of respiratory system	5	5.98	83.6	27.1, 195.0
Disease of the digestive system	18	27.68	65.0	38.5, 102.8
Disease of stomach and duodenum	2	7.51	26.6	3.2, 96.2
Duodenal ulcer	2	4.09	48.9	5.9, 176.5
Cirrhosis liver	12	8.23	145.8	75.3, 254.6
Nephritis and nephrosis	4	5.91	67.7	18.4, 173.3
All external deaths	112	67.96	164.8**	135.7, 198.3
Accidents	94	40.73	230.8**	186.5, 282.4
Motor vehicle accidents	13	19.53	66.6	35.4, 113.8
Suicides	11	20.54	53.6**	26.7, 95.8
Homicides and other external	7	6.69	104.6	42.0, 215.5
Aircraft accidents	59	0.40	14693.5**	11185.5, 18953.7

* Significant at 5% level.
** Significant at 1% level.

cancer of the colon and cancer of the CNS and brain are now no longer significant being 111.2(67.9, 171.9) and 142.9 (78.1, 239.8), respectively.

Examination of the category lymphatic and haematopoietic tissue revealed an overall SMR of 83.6 (49.5, 132.0) composed of an SMR of 51.0 (13.9, 130.7) for leukemia and aleukaemia, an SMR of 53.7 (1.3, 299.0) for lymphosarcoma and recticulosarcoma, near expectation for all other lymphatic tissue (100.3; (45.9, 190.4)) and an SMR of 139.3 (38.0, 356.8) for Hodgkins disease.

The results for cancer of the prostate (111.3; (62.3, 183.5)) were non-significant and similar to that of the cancer of the colon, while cancer of the respiratory system and cancer of the stomach were both significantly low at 44.1 (32.5, 58.4) and 38.9 (17.8, 73.8), respectively.

TABLE III. FLIGHT ENGINEERS SMR.

Description	(>2 Observed Deaths) O	E	SMR	95% CI
All causes	127	227.62	55.8**	46.5, 66.4
All malignant cancer	47	65.80	71.4*	52.5, 95.0
Cancer digestive organs and peritoneum	10	19.48	51.3*	24.6, 94.4
Cancer large intestine	3	4.22	71.0	14.7, 207.6
Cancer rectum	3	2.88	104.2	21.5, 304.5
Cancer pancreas	2	2.85	70.2	8.5, 253.5
Cancer respiratory system	20	25.71	77.8	47.5, 120.1
Cancer bronchus trachea and lung	20	24.50	81.6	49.9, 126.1
Cancer prostate	3	3.26	92.0	19.0, 268.8
Cancer CNS/brain	3	2.19	136.7	28.2, 399.6
Cancer brain	3	2.11	142.3	29.4, 415.9
All lymphatic and hematopoietic tissue	4	4.84	82.7	22.5, 211.7
Leukemia and aleukemia	2	1.75	114.0	13.8, 411.8
All other lymphatic tissue	2	2.07	96.6	11.7, 348.9
All other malignant cancer	4	4.01	99.9	27.2, 255.7
Cerebrovascular disease	6	15.48	38.8*	14.2, 84.3
All heart disease	35	85.63	40.9**	28.5, 56.8
Ischemic heart disease	31	77.18	40.2**	27.3, 57.0
Disease of arteries	2	4.58	43.6	5.3, 157.6
Aortic aneurysm	2	3.11	64.3	7.8, 232.2
All other heart diseases	2	3.28	60.9	7.4, 220.1
Non-malignant respiratory disease	4	19.27	20.8**	5.7, 53.2
Other non-malignant respiratory disease	2	6.32	31.7	3.8, 114.3
Disease of digestive system	3	6.40	46.9	9.7, 137.0
Cirrhosis liver	3	1.86	161.4	33.3, 471.8
All external deaths	18	14.0	128.5	76.2, 203.2
Accidents	9	8.46	106.4	48.7, 202.1
Motor vehicle accidents	2	4.01	49.9	6.0, 180.3
Suicides	7	4.21	166.3	66.8, 342.6
Homicides and other external	2	1.34	149.5	18.1, 540.0
Aircraft accidents	4	0.08	5072.0**	1382.1, 12986.8

* Significant at 5% level.
** Significant at 1% level.

Although the deaths for cirrhosis of the liver were greater than expected, the SMR was not significantly raised being 145.8 (75.3, 254.6). Suicides were significantly lower than expected at 53.6 (26.7, 95.8).

Among all the extreme deficits from heart disease only aortic aneurysm, at 98.9 (52.7, 169.2), was in line with expectation.

Flight Engineers (SMR)

The vital status of the 1153 male flight engineers who provided 29,094 person-years of observation is summarized in Table I.

Table III shows the SMR data for the flight engineers. For consistency, we will highlight broadly the same causes of death to that for the pilots. We stress though that the data are not directly comparable with those of the pilots, due to the different age distribution of the populations. A direct comparison will be made in the next section when we use a relative risk analysis.

There were significant deficits in mortality for all causes with an SMR of 55.8 (46.5, 66.4), all malignant cancer of 71.4 (52.5, 95.0), all heart disease of 40.9 (28.5, 56.8) and non-malignant respiratory disease of 20.8 (5.7, 53.2). The observed deaths from all external causes of death were not significantly greater than expected with an SMR of 128.5 (76.2, 203.2), but aircraft fatalities were highly in excess at 5072.0 (1382.1, 12986.8) although only based on 4 deaths.

The SMR for cirrhosis of the liver was non-significant at 161.4 (33.3, 471.8) as was the SMR for all deaths due to suicide at 166.3 (66.8, 342.6), the latter being derived from 7 deaths.

Examination of the three main findings from the pilot PMR (13) study showed concurrence for cancer of the brain and CNS with an SMR of 136.7 (28.2, 399.6) but only based on 3 deaths, no significant difference from expectation for cancer of the colon of 71.0 (14.7, 207.6) and an absence of melanoma, which was the most striking finding in the pilot analysis. The unknown vital status of 4.4% (51/1153) and missing diagnoses of 6.3% (8/127) may account for the fact that this cause of death was not represented.

The overall lymphatic and hematopoietic SMR of 82.7 (22.5, 211.7) is of the same order as that for the pilots; it was, however, based on a very small number of deaths and displayed a different composition of causes to that for the pilots.

Relative Risk

Tables IV and **V** compare various occupational groups using a direct relative risk approach to account for the differences in age structure. By the use of two

TABLE IV. LONGHAUL VS. SHORTHAUL RELATIVE RISK.

Description	Longhaul		Shorthaul		RR	95% CI
	O	E	O	E		
All causes	277	304	294	267	1.22*	1.03, 1.45
All malignant cancer	87	91	89	85	1.10	0.81, 1.49
Cancer digestive organs and peritoneum	28	27.3	23	23.7	0.95	0.54, 1.60
Cancer large intestine	7	10.1	12	8.9	2.05	0.79, 5.37
Cancer respiratory system	19	24.5	28	22.5	1.66	0.91, 2.93
Cancer bronchus trachea and lung	16	21.7	26	20.3	1.80	0.95, 3.30
Cancer prostate	4	7	10	7	2.47	0.83, 7.65
Cancer CNS/brain	6	7.1	8	6.9	1.37	0.49, 3.90
Cancer brain	6	6.2	6	5.8	1.06	0.35, 3.22
All lymphatic and hematopoietic tissue	10	8.4	8	9.6	0.69	0.28, 1.74
All other malignant cancer	10	7.2	4	6.8	0.43	0.13, 1.24
Diseases of nervous system and sensory organs	7	6.9	6	6.1	0.98	0.34, 2.85
Cerebrovascular disease	18	20.1	16	13.9	1.30	0.66, 2.61
All heart disease	78	77	62	63	0.97	0.69, 1.36
Ischemic heart disease	72	69.3	53	55.7	0.91	0.63, 1.31
Disease of arteries	5	7.4	8	5.6	2.07	0.73, 6.64
Aortic aneurysm	4	6.9	8	5.1	2.76	0.90, 9.44
Non-malignant respiratory disease	7	9.1	9	6.9	1.76	0.66, 4.93
Disease of digestive system	7	9.3	11	8.7	1.70	0.67, 4.28
Cirrhosis liver	5	6	7	6	1.42	0.47, 4.24
All external deaths	34	51.1	70	52.9	2.01*	1.34, 3.07
Accidents	30	43.4	58	44.6	1.92*	1.23, 2.99
Motor vehicle accidents	4	5.9	9	7.1	1.83	0.62, 6.03
Aircraft accidents	17	28.1	38	26.9	2.42*	1.35, 4.24

* Significant at 5% level.

populations, we effectively calculate internal death rates based on the average of the two groups. Relative risks (RR) are then calculated expressing one group relative to the other. In this analysis we have taken the broad definition of longhaul and shorthaul referred to earlier where it can be seen that in addition to those who stayed in a particular operational classification we include those whose main activity was in that grouping. The RR is only shown for those causes of death for which there are sufficient deaths to carry out a meaningful analysis.

Longhaul vs. Shorthaul

We have from Table IV the all causes RR of 1.22 (1.03, 1.45), where 1.0 indicates equality. This implies that the mortality rate in the shorthaul pilots (SH) was higher than that in the longhaul pilots (LH).

The external deaths RR was significantly raised at 2.01 (1.34, 3.07) with the aircraft accidents RR as part of this category similarly showing a significant excess at 2.42 (1.35, 4.24). Although no other comparisons showed statistically significantly raised RRs we will mention some non-significant comparisons for SH against LH which are relevant for the discussion. The RR of prostate cancer for SH over LH was 2.47 (0.83, 7.65), while melanoma, which is not shown in the table, was evenly split between the two groups.

The finding of a RR of 1.37 (0.49, 3.90) for brain and CNS cancer for SH vs. LH leads us to believe there is no real difference in the risk across the groups. Interestingly, the lymphatic and hematopoietic comparison was one of the only cancer RRs to show an excess for LH over SH, with a non-significant RR of 0.69 (0.28, 1.74).

There was no evidence of any difference in relation to

TABLE V. LONGHAUL VS. FLIGHT ENGINEERS RELATIVE RISK.

Description	Longhaul		Flt Eng		RR	95% CI
	O	E	O	E		
All causes	277	279.5	127	124.5	1.03	0.83, 1.27
All malignant cancer	87	91.5	47	42.5	1.17	0.82, 1.67
Cancer digestive organs and peritoneum	28	25.1	10	12.9	0.68	0.34, 1.41
Cancer respiratory system	19	27.1	20	11.9	2.48*	1.30, 4.49
Cancer Bronchus trachea and lung	16	24.9	20	11.1	2.90*	1.47, 5.40
Cerebrovascular disease	18	16.5	6	7.5	0.7	0.29, 1.82
All heart disease	78	78.8	35	34.2	1.03	0.69, 1.54
Ischemic heart disease	72	71.6	31	31.4	0.98	0.64, 1.49
All external deaths	34	35.8	18	16.2	1.18	0.66, 2.10
Accidents	30	27.2	9	11.8	0.70	0.32, 1.44
Aircraft accidents	17	15.1	4	5.9	0.61	0.21, 1.71

* Significant at 5% level.

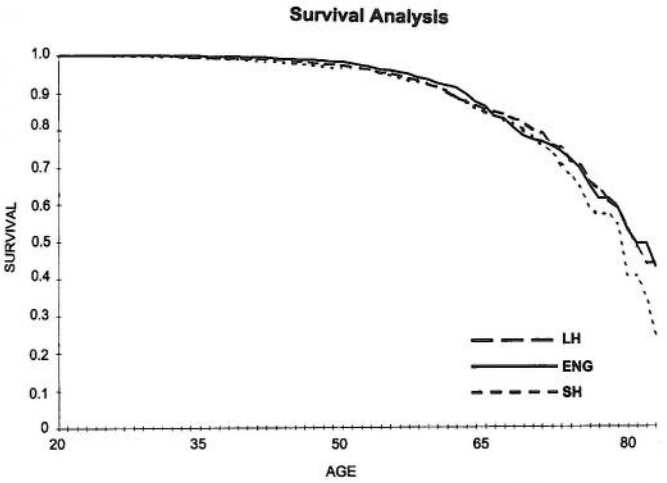

Fig. 1. Survival curves for the flight engineers and the two pilot groups.

heart disease at 0.97 (0.69, 1.36) although the aortic aneurysms were concentrated in the SH 2.76 (0.90, 9.44).

Finally, the non-malignant respiratory disease comparison produced a RR in the region of that for malignant respiratory cancer being 1.76 (0.66, 4.93) and 1.66 (0.91, 2.93), respectively suggesting a common component, perhaps smoking, may be involved in both.

Longhaul vs. Flight Engineers

The all causes RR from Table V was 1.03 (0.83, 1.27) showing near equality. The overall malignant cancer RR was 1.17 (0.82, 1.67) with cancer of the respiratory system demonstrating a significant excess for flight engineers (ENG) over LH with an RR of 2.48 (1.30, 4.49).

All heart disease was very similar between the LH and ENG at 1.03 (0.69, 1.54), the picture being the same for the category of ischemic heart disease.

The external causes of death RR of 1.18 (0.66, 2.10) showed a non-significant increase in risk for ENG over LH which was inflated by deaths from suicide. The difference in the RR for aircraft fatalities was well within the bounds of chance at 0.61 (0.21, 1.71) and was also affected by some deaths in pilots during solo operation.

Life Expectancy

Fig. 1 shows the survival curves for the flight engineers and the two pilot groups.

The median residual lifetime, derived from these data, which for any particular age is the length of time until half of the population alive at that point have died, is displayed in **Table VI** for the ages 55, 60 and 65.

The analyses were hindered by extensively censored data representing 88.9%, 91.6%, and 89.0% of the available data for LH, SH and ENG, respectively. Nevertheless, a qualitative comparison suggesting little difference between LH and ENG but an increasing divergence in the region of 2–3 yr over this range of ages between LH and SH is confirmed using the -2 log (LR) test. This test which assumes an exponential shape for the survival curve produced a non-significant result for LH vs. ENG ($\chi^2 = 0.09$, $Pr > \chi^2 = 0.76$) and a significant result at the 5% level for LH vs. SH ($\chi^2 = 4.73$, $Pr > \chi^2 = 0.03$).

DISCUSSION

We will examine the evidence from this study in relation to the prior hypotheses generated from the earlier PMR study (13). We will then explore our data in relation to additional causes of death thought to be associated with the hazards of the flying environment, namely flying accidents and exposure to ionizing radiation.

One of the key reasons for considering a follow up to our PMR study (13) was to examine in more detail the excess found for cancer of the brain and CNS, and its possible etiological relationship with the working environment. Since that time, a very comprehensive review of the literature of brain cancer has been carried out by Inskip (12) in which he concluded for electromagnetic forces (EMF) "the mechanism by which cancer could be initiated was unclear given that there is insufficient energy to ionize molecules or damage DNA." On the basis of the available evidence he indicated that the data are insufficient to support the conclusion that EMF causes cancer.

A more recent case control study of brain cancer among U.S. Air Force personnel by Grayson (9) suggested that there was a small association of brain cancer with extremely low frequency EMF, the pilots within that study being classified as having possible exposure. Contrary evidence to such an association was displayed in a another smaller investigation looking at the mortality of submariners, many of whom would have been exposed to EMF of varying intensities in which a deficit of brain cancer was seen not quite significant at the 5% level (11). For ionizing radiation, Inskip (12) suggested there was no consistent evidence to support this as a major cause of brain cancer.

Our earlier (13) data showed a statistically significant PMR of 268 (123, 508) for brain and CNS cancer but this is now superseded by a non-significant SMR of 142.9 (78.1, 239.8) which is remarkably similar to that of the recent paper by Band et al. (2) of 142 (56, 298),where the confidence intervals quoted are 90%. Although based on only three deaths the finding is also consistent with that of the flight engineers within our study providing an almost identical SMR of 136.7 (28.2, 399.6). The numbers of deaths are too small to detect any change in risk over the study period but the shorthaul and longhaul relative risk comparison points to a non-significant elevation for shorthaul where ionizing radiation exposure would have been less than that of longhaul. If there

TABLE VI. MEDIAN RESIDUAL LIFETIME FOR PILOTS AND FLIGHT ENGINEERS.

	Age		
	55 yr	60 yr	65 yr
All Pilots	25.37	20.87	16.57
Longhaul	26.13	21.58	18.32
Shorthaul	24.49	19.61	14.86
Flight Engineers	27.17	22.44	17.95

is a risk associated with cosmic radiation exposure then it is very small.

The etiology of melanoma of the skin is multifaceted and complicated. The results from this cohort reinforced the earlier PMR finding and produced the only significant excess SMR for a form of cancer, at 333.0 (152.3, 632.2). There was no difference between shorthaul and longhaul in the relative risk analysis lending support to the suggestion this is due to exposure to the sun at ground level rather than at altitude. The lack of cases among flight engineers is surprising and may well point to missing or unclassified deaths, as only one death would be needed to reach the lower 95% confidence bound of risk for pilots.

The statistically significant excess for colon cancer demonstrated in our previous study (13) is now non-significant at 111.2 (67.9, 171.7) and is broadly in line with that of the mortality data in Band et al. (2) at 123 (67, 209) and the results from Grayson (8), whether internal or external comparison populations are used within his study.

The SMR from air accidents showed a 150-fold increase in risk (SMR = 14693.5 (11185.5, 18953.7)). This was mainly concentrated in the shorthaul group (RR = 2.42 (1.35,4.24)) during the early part of the study period, the causes of which were many and varied. The difference in risk between longhaul pilots and flight engineers was well within the bounds of chance (RR = 0.61 (0.21, 1.71)) and was influenced by some off-duty pilot deaths. Although Band et al. (2) confirmed the expected excess from this cause their SMR data at 2657 was lower and probably reflects a different operating environment during the first two decades of the BA study when most of the deaths occurred. The death rates within year-of-birth cohorts grouped into 10-yr bands within our study confirm the acknowledged reduction in mortality across the decades.

An early review of the literature (17) on prostate cancer pointed to the need for further research on ionizing radiation hazards in part due to the exposure in the atomic energy industry. Band et al. (2) in their study of Canadian pilots have highlighted a significant two-fold increase in cancer incidence. More recent analysis among U.K. Atomic Energy Authority employees confirmed the highest risk was concentrated in men aged 45–54 and showed dose response relationships in one location mainly restricted to workers who had also been exposed to radionuclides (6). The prostatic cancer SMR derived from the 15 deaths in our study is non-significant at 111.3 (62.3, 183.5). There was no difference in risk between the longhaul and flight engineers and only a suggestion, no more, that the risk was higher in the shorthaul group. The evidence from our study militates against there being an increase in risk of prostate cancer related to ionizing radiation.

The pilots SMR and that of the flight engineers for total cancer of the lymphatic and hematopoietic tissue were similar at 83.6 (49.5, 132.0) and 82.7 (22.5, 211.7), respectively, but the composition of types was different. The SMR data from the Band et al. study (2) showed a finding consistent with the overall data from the pilots, but the composition was again different with a greater proportion of acute myeloid leukemia, thought to be associated with ionizing radiation.

From dosimetric evaluations that we have carried out on transpolar routes (1), derivation of dose from Concorde in-flight monitors and use of CARI-3 modeling (7) we calculate that the yearly average exposure to ionizing radiation for shorthaul and longhaul is 2.5 mSv and 5 mSv, respectively, using typical schedules and conservative estimates of hours flown. With the use of these data, the cumulative dose for the pilot cohort was 445 Sv, which leads to estimates of either 0.09 or 0.22 additional leukemia deaths in the population dependent on whether nuclear industry worker or atomic bomb survivor data (10) are used to provide the estimate of excess relative risk per Sv of dose. In this calculation we have assumed that the end-of-flying date for missing data is either the study end-date or the date of normal retirement, whichever comes first. Our SMR data, rather than showing an excess, shows an overall non-significant deficit for leukemia and aleukaemia (4 vs. 7.84). The comparison between operation types did show a slight non-significant excess for longhaul over shorthaul but when viewed in the light of the overall non-significant deficit this does not support a major leukemia problem associated with ionizing radiation.

We did not see any excesses for cancer of the testes or bladder that were exhibited in the U.S. aviator population (8) but suspect this is a direct consequence of contrasting mortality data from a maturing population with those of incidence data from a relatively young population in active service.

The life expectancy analyses confirm the difference displayed in the raw all causes SMR data for shorthaul of 64.6 (57.4, 72.4) when compared with longhaul of 54.7 (48.5, 61.6) which is also reflected in the relative risk calculations of 1.22 (1.03, 1.45). The analysis showed that the shorthaul pilots have a shorter life expectancy than the longhaul pilots and flight engineers, in the order of 2–3 yr at ages between 55 and 65. Comparison with England and Wales data over the years 1970–90 (3,4,14), where life expectancy varied from 19.1 to 21.8 yr at age 55 and 12.2 to 14.3 yr at age 65, showed the longhaul and flight engineer groups live around 4–5 yr longer while the differential for shorthaul reduces to between 2 and 3 yr.

The shape of the survival curve was greatly influenced by the death rates in the more elderly pilots, and less so by removal of accidental deaths in the earlier part of the study period. Examination of the year-of-hire data and patterns of person years at risk did not indicate a significant misclassification of shorthaul pilots as longhaul pilots, which might have explained the difference in death rates. Further evaluation of the proportion of cancer and circulatory diseases beyond age 60 did not reveal any major difference between the groups.

The all causes SMRs and life expectancy calculations for all the flight deck crew groups are consistent with the phenomenon known as the "Healthy Worker Effect" originally identified by Fox and Collier (5) and referred to extensively since. In simple terms, the effect refers to the bias resulting from the comparison of a

population selected for employment because of their good health with that of a population composed of one containing the ill and disabled. Other factors such as the changes associated with employment status and the methodological aspects of the SMR calculation have been incorporated in an explanation of the magnitude of the effect.

In an attempt to place the size of the Healthy Worker Effect in context within our study we wished to compare the mortality experience of the cohort with that of a comparable social class grouping. Although there are problems with classifying social class from an occupational coding that has changed over time, we approached the Office for National Statistics to determine the availability of such data. They provided all causes mortality and population data for 20–64 yr olds for social class 2 around the 10 yearly census points from 1951 to 1991.

Use of these data for the 205 deaths in the pilot cohort produced an SMR of 81 compared with that of 61 derived from England and Wales data. Extension to the 41 flight engineer deaths during this period, for the same age categories, assuming the same social class classification, gave an SMR of 70 as opposed to 53 from the general population. On the basis of these data we would see the additional life expectancy already quoted reduce by between 1 and 2 yr.

In summary, the study confirms that the flight deck crew live longer than the general England and Wales population and do not exhibit any patterns of death, apart from aircraft accidents, that could be directly attributed to occupation. The excess of melanoma could well be due to direct sun exposure, while small differences in risk between the shorthaul pilots, longhaul pilots and flight engineers may be due to chance or to variations in lifestyle.

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REFERENCES

1. Bagshaw M, Irvine D, Davies M. Exposure to cosmic radiation of British Airways flying crew on ultralonghaul routes.Occupat Environ Med 1996; 53:495–8.
2. Band PR, et al. Cohort study of Air Canada pilots. Mortality, cancer incidence and leukaemia risk. Am J Epidemiol 1996; 143(2):137–43.
3. English Life Tables number 14, 1980–1982. London, England: Office Population Censuses and Surveys. Series DS Number 7.
4. English Life Tables number 14, 1990–1992. London, England: Office Population Censuses and Surveys. Series DS Number 14.
5. Fox AJ, Collier PF. Low mortality rates in industrial cohort studies due to selection for work and survival in the industry. J Prev Soc Med 1976; 20:225–30.
6. Fraser P, et al.Cancer mortality and morbidity in employees of the United Kingdom Energy Authority, 1946–86. Br J Cancer 1993; 67:615–24.
7. Friedberg W, et al. The cosmic radiation environment at air carrier flight altitudes and possible associated health risks. Luxembourg: Proceedings of workshop on radiation exposure of civil aircrew, June 25–27,1991. EUR 14964 EN; ISBN 1 870965.
8. Grayson JK, Lyons TJ. Cancer incidence in United States Air Force aircrew, 1975–89. Aviat Space Environ Med 1996; 67:101–4.
9. Grayson JK. Radiation exposure, socioeconomic status, and brain tumor risk in the U.S. Air Force: a nested case control study. Am J Epidemiol 1996; 143(5):480–6.
10. IARC Study Group on Cancer Risk Among Nuclear Industry Workers. Direct estimates of cancer mortality due to low doses of ionising radiation: an international study. Lancet 1994; 344: 1039–43.
11. Inskip H, Snee M, Styles L. The mortality of Royal Naval submariners, 1960–89. Occupat Environ Med 1997; 54:209–15.
12. Inskip PD, Linet MS, Heineman EF. Etiology of brain tumors in adults. Epidemiol Rev 1995; 17:382–404.
13. Irvine D, Davies M. The mortality of British Airways pilots, 1966–1989: a proportional mortality study. Aviat Space Environ Med 1992; 63:276–9.
14. Kaji M, et al. Mortality experience of cockpit crew members from Japan Airlines. Aviat Space Environ Med 1993; 64:748–50.
15. Life tables. The Registrar General's decennial supplement for England and Wales 1970–1972. London, England: Office Population Censuses and Surveys. Series DS Number 2.
16. Marsh GM, Preininger M. OCMAP: a user-oriented occupational cohort mortality analysis program. Am Stat 1980; 34:245.
17. Nomura AMY, Kolonel LN. Prostate cancer. A current perspective. Epidemiol Rev 1991; 13:200–27.
18. SAS/STAT User's Guide. Cary, NC: SAS Institute Inc. 1994.