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A PRELIMINARY STUDY OF SURVIVAL RATES IN CIVIL AIRCRAFT ACCIDENTS, 1966 - 1973, WITH PARTICULAR REFERENCE TO FIRE RISK AND FUEL TYPE

BY

A.F. Taylor, BSc CEng MRAeS FInstPet

SUMMARY

To establish whether theoretical and laboratory safety advantages of low volatily fuel, such as that of low rate of flame spread, are reflected in aircraft accident 'statistics' a preliminary study has been made of the ARB's world airline accident summary.

An advantage has been found in that the change to kerosine has apparently halved the death rate in survivable accidents.

In all gas turbine accidents, including those where death was probably due to impact not fire, the death rate seems to be 50% higher with wide cut gasoline than with kerosine.

It has also been found that a higher proportion of gasoline powered aircraft accidents involved impact death and that overall the survival rate has remained virtually unchanged. A critical examination of these preliminary findings, in the light of the relevant accident reports, is planned.

CONTENTS

1. INTRODUCTION

The properties of aviation fuels are well documented and it can be readily appreciated that a large difference in, for example, the rate of flame spread across spilled fuel and the presence or not of an explosive mixture in the tanks must have some effect on accident survival. However the extent to which different fuels have been used has not been widely known and the quantitative effect of these on survival has rarely been considered.

This study has been started as a result of the present fuel shortage, the initial aims being to establish the benefit that has already accrued from the change from gasoline to kerosine and the extent to which this would be lost if a change were now made to wide cut gasoline. Further aims are to see what additional benefits might be expected from the adoption of an anti-misting kerosine and what might be lost if the recently proposed lower flash point kerosine were adopted. However these are outside the scope of the preliminary study.

So far the only reference used, apart from a few reports already held, has been reference 1 the ARB World Airline Accident Summary complete up to Supplement 20 of January 1974 which gives a preliminary listing of last year's accidents.

2. CLASSIFICATION OF ACCIDENTS

As the prime interest is the influence of fuel type on the fire risk the classification has grown from the two standpoints of fuel type and the presence or not of fire. Of the three fuel types in use, gasoline, kerosine and wide cut gasoline a clear distinction exists between gasoline and the other two according to the type of engine. That between kerosine and wide cut is less clear. In fact it can probably never be established with any certainty because very few accident reports make proper reference to the fuel despite clear instructions so to do in the ICAO Manual of aircraft accident investigations. However this does not pose too much difficulty because the fuel policies of most airlines are reasonsably well known. Furthermore the principle distinction to be made is between a fuel above and below its flash point and as it takes only a comparatively small proportion of wide cut to reduce the flash point of a mixture to below common ambient tmeperatures it is reasonable to assume that the tanks of any wide cut user will contain a potentially more hazardous fuel even if the last refuelling or two have been with kerosine. In any case such an assumption would diminish rather than exaggerate the differences, no bad thing in a preliminary study!

The known and assumed users of wide cut fuel are or have been the following:

TCA, now Air Canada	throughout the period
TWA	until January 1965
Pan Am	until January 1965
JAL	until October 1970
Canadian Pacific	sometimes
Sabena	sometimes
KLM	until 1969?
All Nippon	assumed same as JAL

American domestic and other airlines engaged in military transport flights and other flights from military bases, also flights out of Taipei and Seoul where no kerosine is available.

It should be noted that most airlines not only specify kerosine as their usual fuel but also take special precautions should they have to uplift wide cut fuel in an emergency, they are also quite open about their policy. Some wide cut users however have been less than open and it has not always been possible to confirm their policy at any given time, thus a detailed study of actual accident reports is still required.

Russian aircraft have generally been ignored, for two reasons. First because nearly all are operated by Eastern bloc countries who do not necessarily notify the West of their accidents. Thus while there are still a reasonable number of accidents listed it is probable that they do not form a representative sample, the more dramatic accidents are likely to overwhelm the many important minor accidents where no one was hurt. This is probably the principle reason why those listed suggest a record worse than either gasoline or wide cut fuelled Western aircraft. The second reason is that many of the Russian jets and turboprops may be fuelled with kerosine to Russian specifications. These have allowable flash points considerably lower than that of even British kerosine and it is possible that in some cases this could be a further complicating factor. The only such accident where the actual fuel is known to the author is that to a TU 134 at Rijeka in 1971 hence its inclusion in the tables. In this case the aircraft was refuellled at Gatwick with kerosine (DERD 2494) having been previously fuelled in Yugoslavia with wide cut (Jet B). It has been estimated that approximately 10% of the fuel onboard at the time of the accident was wide cut.

Having classified as best one can according to fuel type each of these three groups has been divided initially into four sub groups.

(i) fire in survivable or probably survivable accidents

(ii) no fire or no fire mentioned in survivable accidents

(iii) deaths almost certainly by impact

(iv) deaths probably by impact (no survivors)

At this stage sub groups (iii) and (iv) have been presented together as 'probably impact' and these may be compared particularly with the 'probably survivable' and 'total' for each fuel type.

Table 1 shows for each year and group the total number of people (ie passengers and crew but excluding any on the ground) killed, followed by the total number at risk, that is the total number aboard. Note that although the basic period covered is 1966 to 1973 inclusive the accidents that involved or may have involved wide cut have been supplemented from the three previous years to increase the sample size. This earlier period before Pan Am and TWA abondoned wide cut includes the two classic wide cut accidents, at Elkton and at Rome but despite these the fatality rates are all slightly decreased as a result of increasing the sample in this way.

3. ANALYSIS AND DISCUSSION

Before discussing this table it is worth noting that the kerosine sample is so large compared to the wide cut sample that any incorrect classifications can make little difference to the overall kerosine figures. On the other hand one or two 'assumed wide cuts' that turn out to be kerosine could have a considerable effect on the wide cut figures but might either raise or lower them. Table 2 therefore lists all of the 'wide cut' accidents used in this preliminary classification.

Returning to Table 1 several clear patterns imerge that are remarkably consistant from year to year.

In all accidents the fatality rate (as a percentage of those at risk) with gasoline (39.0) is almost twice as high as with kerosine (21.1).

In survivable accidents a similar ratio is evident (18.8 to 10.0) and again in those accidents known to have involved fire (39.2 to 18.9).

Wide cut appears to be similar to gasoline, as one would expect, in terms of survivable accidents (22.7 to 18.8) and in those known to have involved fire (46.2 to 39.2), however overall it lies in between gasoline and kerosine (31.8 as against 39.0 and 21.1). This difference appears to be explained by a different pattern of accidents as between piston engines aircraft and the rest.

Whereas with gasoline (in pistons) 24.9% of all those at risk die in accidents probably as a result of impact the figures for kerosine and wide cut are 12.5% and 11.8% or, combining the latter two for all gas turbines, 12.4%.

Each of these patterns excepting the small wide cut sample is more or less repeated in each individual year giving considerable confidence to the obvious conclusions. In particular the improvement from piston engined to gas turbine engined aircraft appear to be due to two main factors, a higher proportion of accidents are survivable and the chances of continued survival are then higher mainly due to reduced fire risk when using kerosine. With wide cut this second improvement is missing.

Both the similarities and the differences are predictable, qualitatively, but only such an analysis of the accidents involving each fuel can quantitatively assess the different survival rates. Of great interest arethe overall fatality rates of wide cut and kerosine, 31.8% to 21.1% , a ratio of 1.51. That is if wide cut became the standard fuel one might expect fatalities to increase by 51%.

Lest it be thought that the large proportion of only 'assumed' wide cuts is unduly influencing this result it should be noted that in the six confirmed wide cut accidents 45.6% of those at risk died. If the remainder are now assumed to be kerosine then the kerosine fatality rate is increased to 21.6% and the ratio becomes 2.11 an increase in fatalities of 111% ! One may also expect qualitatively, that wide cut would be worse than gasoline because although flame spread rates are similar wide cut also carries with it the additional risk of almost immediate fuel tank explosion, as demonstrated at Elkton and at Rome. However while the figures do tend to confirm that the fire risk is higher than for gasoline the difference shown so far is not very large and it remains to be seen whether this figure remain unchanged when more accident reports are studied.

The only two other studies of survival rates referred to at this stage are the CAB's of 1965 (ref.2) and the Air Safety Group's of 1966 (ref.3). The former deals only with American operators and doesn't distinguish between fuel types at all, yet during the period considered.1955 to 1964.the majority were gasoline (plus the two classic wide cut accidents) so it is interesting to note that the overall fatality rate was 1955 from a total of 4559, that is 42.9% , a figure not far removed from that of gasoline in this study. The Air Safety Group used this same report together with reference 4 and others and concluded that the fire risk was roughly halved in changing from gasoline to kerosine, a conclusion that the present study's much larger sample tends to confirm.

However in accepting that the indicated correlations between aircraft type and between fuel type mean what they appear to mean and are not just a coincidence one has to look also at the 'other' survivable accidents, those where there was either no fire or fire was not mentioned in the summary. Table 1 shows considerable differences between fuel types both in the number of people at risk and the percentage killed, this must be explained. In the 45 accidents of Table 2, assumed to have involved wide cut there are only about two where any real doubt exists about the presence of fire. Even with these two it is reasonably certain that there was no fire so in this category 'other' means 'no fire'. Thus 47% of those involved in survivable accidents were also subjected to a real fire risk.

On the other hand kerosine and gasoline both show far more in the no <u>known</u> fire column yet the fatality rate in each is also much higher. A brief look at the summaries will confirm that there are far more accidents where there might well have been a fire but none is mentioned, to the extent that one suspects that with gasoline a fire was considered normal and therefore was omitted from the summary. While an alternative to the assumption that there are many unreported gasoline fires is that piston engined aircraft passengers are far more subject to impact deaths in accidents with no fire it should be noted that use of the proportion derived from the wide cut results does predict a figure close to the actual.

Putting R = number at risk, S = proportion of survivable accidents, and F = proportion who die in accidents known to have involved fire, one can obtain D the total number of deaths from the expression

$$D = R \left\{1 + S(0.47\ F - 0.99)\right\}$$

So by using the average value for S of 0.876 we obtain for wide cut gasoline

$$D_W = 2716 \left\{1 + 0.876(0.47\ 0.462 - 0.99)\right\}$$

$$= 878 \quad 1.5\% \text{ high}$$

for kerosine

$$D_k = 33313 \left\{1 + 0.876(0.47\ 0.189 - 0.99)\right\}$$

$$= 7015 \quad 0.3\% \text{ low}$$

and for gasoline with S = 0.751

$$D_g = 6008 \left\{1 + 0.751(0.47\ 0.392 - 0.99)\right\}$$

$$= 2372 \quad 1.2\% \text{ high}$$

Alternatively one can use the average value of F for gasoline and wide cut, 0.431, this gives D_g 4.7% high and D_W 2.6% low, not so good but a reasonable approximation. Of course such results may be quite coincidental but such good agreement for kerosine and gasoline suggests that there may be something in this approach.

While with wide cut the actual accident figures show that 60% of all deaths are in accidents involving fire. This approach predicts that the corresponding proportions for gasoline and kerosine are about 35% and 37% , rather higher than expected and as yet unconfirmed. Not all deaths in accidents involving fire are actually as a result of fire but these figures do emphasise the importance of reducing fire risk. The gasoline figure is of course lower because a smaller percentage survive in the first place, thus as the number of survivors increases so does the importance of decreasing the fire risk.

4. CONCLUSIONS

4.1 During the period considered the overall survival rate in all listed accidents has remained virtually constant at about 75.6% of those at risk in these accidents. A possible slight improvement due to the continued phasing out of gasoline fuelled aircraft is offset by several losses due to bombs with 1972 being a particularly bad year.

4.2 The change from piston engines to gas turbines has approximately halved the death rate. This is partly due to an increase in the proportion of survivable accidents from 75.1% to 87.6% .

4.3 It is possible that fire occurs in 47% of all survivable accidents, however this figure may be modified by study of the full accident reports.

4.4 In accidents where fire definitily occurred (ie it is mentioned in the summary or is otherwise known) the death rate is more than twice as high with the volatile fuels (43.1 %) as with kerosine (18.9 %).

4.5 The death rate in all survivable accidents is twice as high with the volatile fuels (20.2 %) as with kerosine (10.0 %).

4.6 The overall death rate in gas turbine engined aircraft is approximately half as high again with wide cut gasoline (31.8 %) as with kerosine (21.1 %). In piston engined aircraft it is even higher (39.6 %) because of the extra 'impact' deaths.

4.7 Should wide cut be used as standard a reduction in deaths of one third could be achieved by a change to kerosine (ie by raising the fuel flash point to above operational fuel and ambient temperatures). It is considered unlikely that such an improvement could be achieved as easily and as cheaply in any other way.

4.8 Supersonic transports are often likely to land with fuel above flash point so a compensating improvement must be found if present safety levels are to be maintained.

4.9 Despite recommendations in the ICAO 'Manual of Aircraft Accident Investigation' details of the fuel type(s) and distribution within the aircraft are often omitted. This shortcoming should be remedied.

5. REFERENCES

1. 'World airline accident summary'
   Air Registration Board

2. 'A study of United States air carrier accidents involving fire, 1955 - 1964'
   Civil Aeronautics Board, Bureau of Safety Pamphlet, BOSP 7-6-3

3. 'A review of the aviation fuel controversy'
   Air Safety Group, ASG 101, December 1966

4. 'Report of the working party on aviation kerosine and wide cut gasoline.
   Ministry of Aviation Report CAP 177, 1962

TABLE 1

key to figures in each row
a number dead/number at risk
b percentage dead/at risk
c percentage at risk/total at risk

year	GASOLINE survivable accidents fire	other	total	probably impact	overall total	KEROSINE survivable accidents fire	other	total	probably impact	overall total	WIDE CUT GASOLINE survivable accidents fire	other	total	probably impact	overall total	year	GRAND TOTAL each year	moving 3yr. ave
1963											81/242 33.5	1/107	82/349 23.5	118/118	200/467 42.8	1963		
1964											50/211 23.7	0/358	50/569 8.8	-	50/569 8.8	1964		
1965											0/6 0	-	0/6 0	-	0/6 0	1965		
1966	21/107 19.6	125/730 17.1	146/837 17.4 80.5	203/203	349/1040 33.6	26/461 5.6	99/1917 5.2	125/2378 5.3 86.9	357/357	482/2735 17.6	152/215 70.7	1/66	153/281 54.4	183/183	336/464 72.4	1966	1167/4239 27.5	
1967	122/233 52.4	94/603 15.6	216/836 25.8 77.6	241/241	457/1077 42.4	212/1229 17.2	180/1801 10.0	392/3030 12.9 90.9	303/303	695/3333 20.9	-	0/15	0/15 0	3/3	3/18 16.7	1967	1155/4428 26.1	24.6
1968	66/71 93.0	50/450 11.1	116/521 22.3 76.6	159/159	275/680 40.4	291/750 38.8	72/3092 2.3	363/3842 9.4 90.0	425/425	788/4267 18.5	-	22/231	22/231 9.5	7/7	29/238 12.2	1968	1092/5185 21.1	24.6
1969	52/197 26.4	81/538 15.1	133/735 18.1 63.9	416/416	549/1151 47.7	136/728 18.7	65/2149 3.0	201/2877 7.0 84.0	548/548	749/3425 21.9	4/26 15.4	0/196	4/222 1.8	-	4/222 1.8	1969	1302/4798 27.1	22.5
1970	36/131 27.5	11/403 2.7	47/534 8.8 81.5	121/121	168/655 25.6	39/1071 3.6	270/3135 8.6	309/4206 7.3 88.8	532/532	841/4738 17.8	156/338 46.2	0/147	156/485 32.2	3/3	159/488 32.6	1970	1168/5881 19.9	23.2
1971	37/113 32.7	38/362 10.5	75/475 15.8 87.6	67/67	142/542 26.2	50/365 13.7	137/2538 5.4	187/2903 6.4 83.3	584/584	771/3487 22.1	78/87 89.7	0/148	78/235 33.2	-	78/235 33.2	1971	991/4264 23.2	24.5
1972	0/3 0	76/317 24.0	76/320 23.8 64.8	174/174	250/494 50.6	369/1280 28.8	177/3059 5.8	546/4339 12.6 81.2	971/1004	1517/5343 28.4	0/3 0	-	0/3 0	-	0/3 0	1972	1767/5860 30.2	24.9
1973	12/28 42.9	27/225 12.0	39/253 15.4 68.[illegible]	116/116	155/369 42.0	304/1650 18.4	480/3926 12.2	784/5576 14.1 93.2	409/409	1193/5985 19.9	-	-	-	6/6	6/6 100	1973	1354/6360 21.3	
Totals	346/883 39.2	502/3628 13.8	848/4511 18.8 75.1	1497/1497 100	2345/6008 39.0	1427/7534 18.9	1460/21617 6.8	2907/29151 10.0 87.5	4129/4162 99.2	7036/33313 21.1	521/1128 46.2	24/1268 1.9	545/2396 22.7 88.2	320/320 100	865/2716 31.8		10246/42037 24.4	
wide cut and gasoline	867/2011 43.1		1393/6907 20.2															

TABLE 2

Accidents where wide cut gasoline is assumed to have been used.

date	aircraft	airline		dead	aboard	comments
1.1.63	CV 880	TWA		0	64	engine FIRE warning
5.1.63	Viscount	TCA		0	32	nose wheel retracted
6.5.63	Vanguard	TCA		1	69	turbulence
9.6.63	Argosy	Capitol		0	3	u/c collapse. AFB
6.11.63	DC8	TCA	*	0	97	overrun, small FIRE
29.11.63	DC8	TCA		118	118	impact
8.12.63	707	Pan Am.	*	81	81	Elkton, lightning, FIRE
30.12.63	DC8	JAL		0	3	oo engines lost
1.1.64	CV 880	TWA		0	66	landing
7.4.64	707	Pan Am.		0	145	overrun, no fire
29.5.64	707	TWA		0	103	nose u/c collapse
13.6.64	Viscount	TCA		0	44	landed short
26.8.64	707	TWA		0	138	undershoot, small FIRE
23.11.64	707	TWA	*	50	73	Rome, abort T.O. FIRE
27.2.65	CV 880	JAL		0	6	landing, FIRE
4.2.66	727	All Nippon		133	133	impact
4.3.66	DC8	Can.Pacific		64	72	undershoot, FIRE
22.4.66	Electra	Am.Flyers		83	98	approach, FIRE, AFB
5.8.66	DC8	KLM		1	64	pilot collapse
26.8.66	CV 880	JAL		5	5	after T.O. FIRE
18.9.66	F.27	All Nippon		0	2	overrun
13.11.66	YS-11	All Nippon		50	50	impact
17.12.66	Viscount	Air Canada		0	40	engine FIRE
20.1.67	YS-11	All Nippon		0	15	u/c collapse
20.5.67	DC8	Air Canada		3	3	approach
7.2.68	707	Can.Pacific		1	61	landing veer off
16.2.68	727	C.A.T. Co		21	63	approach, Taipei
13.7.68	707	Sabena		7	7	undershoot, FIRE
22.11.68	DC8	JAL		0	107	undershoot, no fire
4.4.69	CV 880	JAL		0	92	overrun
7.4.69	Viscount	Air Canada		1	21	engine FIRE
24.6.69	CV 880	JAL	*	3	5	T.O. FIRE
20.11.69	YS-11	All Nippon		0	53	overrun
14.12.69	YS-11	All Nippon		0	51	collision, minor damage
1.3.70	Viscount	Air Canada		0	33	collision, minor damage
14.3.70	DC8	Air Canada		0	111	u/c collapse
3.5.70	YS-11	All Nippon		0	3	u/c retracted
5.7.70	DC8	Air Canada		109	109	overshoot, FIRE
10.10.70	Hercules	Saturn		3	3	undershoot, AFB
27.11.70	DC8	Capitol	*	47	229	abort. T.O. FIRE, AFB
29.1.71	DC8	Can.Pacific		0	148	collision, 727 hit fin
18.3.71	Hercules	Saturn		0	4	landing, FIRE, AFB
23.5.71	Tu 134	JAT	*	78	83	landing, FIRE
19.3.72	Electra	Universal		0	3	landing, FIRE, AFB
8.9.73	DC8	World Airways		6	6	hit hill, FIRE, AFB

*Wide cut confirmed