REVIEW ARTICLE

Flight Safety and Medical Incapacitation Risk of Airline Pilots

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Background: This paper examines the use of quantitative incapacitation risk assessment for aeromedical decision-making in determining the medical fitness of multicrew airline pilots, and estimates the effect on flight safety should medical standards be relaxed. The use of the "1% rule" for setting limits for aircrew incapacitation risk is re-examined. Human failure (medical incapacitation) is compared with acceptable failure rates in another safety-critical system, the aircraft engines. ***Methods:*** The expected number of cardiovascular incapacitations occurring in flight was modeled by applying an age-related cardiovascular incapacitation risk to the pilot population. The effect on flight safety of relaxing the maximum acceptable incapacitation risk on estimated incapacitation rates in two-pilot operations was also modeled, taking into account a likely increase in the number of pilots who would be allowed to continue to fly with a known medical condition. ***Results:*** The model overestimates cardiovascular incapacitation risk and, therefore, provides a cautious estimate. If the maximum acceptable cardiovascular risk is increased, the model predicts a disproportionately small increase in the number of such incapacitations in flight. ***Conclusions:*** The evidence suggests that the incapacitation risk limits used by some states, particularly for cardiovascular disease, may be too restrictive when compared with other aircraft systems, and may adversely affect flight safety if experienced pilots are retired on overly stringent medical grounds. States using the 1% rule should consider relaxing the maximum acceptable sudden incapacitation risk to 2% per year.

Keywords: aerospace medicine, occupational health, aircrew age, aviation accidents, incapacitation.

IN THE 1930s AND 1940s, the growth of international air traffic demanded a minimum standard of safety be set, and in 1944, an agreement signed in Chicago and known as the Chicago Convention, required signatory states to abide by a common set of minimum standards that are set and revised by the International Civil Aviation Organization (ICAO). The ICAO standards and recommended practices underpin the medical regulation of flight crew around the world (19). These regulatory provisions cannot cover every aeromedical situation, and to facilitate flexibility, "accredited medical conclusion" (a decision by one or more medical experts), operational limitations, and relevant pilot skill and experience can be taken into account in aeromedical decision-making. This provision, ICAO standard 1.2.4.8, is known as the "flexibility standard," and may allow an aircrew member with a significant medical disorder to continue flying, as long as the licensing authority believes this would not jeopardize flight safety.

The Joint Aviation Authorities' (JAA) medical requirements for professional aircrew are currently applied in more than 12 European states, including the United Kingdom. The medical regulations are described by the Joint Aviation Requirements (JAR) and are based on the ICAO standards and recommended practices, but there is no equivalent flexibility standard (23). This has the potential advantage of a commonality of decision-making between states. However, a JAA member state is not normally allowed to issue a medical certificate to a pilot who is outside a requirement, even if the licensing authority considers it safe to do so.

The ICAO flexibility standard has resulted in major differences in aeromedical certification policy around the world. ICAO standard 6.3.2.5 states that "A history of proven myocardial infarction shall be disqualifying," but many ICAO contracting states, using the flexibility standard, permit such individuals to fly professionally, although the limitations imposed can differ. For example, the JAR requires all airline pilots with such a history who can be permitted to continue flying to be restricted to multipilot operations, and to have coronary artery stenosis (except in the vessel supplying the infarcted muscle) of no greater than 50% (30% in the left main and proximal left anterior descending coronary arteries), whereas the Federal Aviation Administration does not impose any operational restrictions and permits greater degrees of stenosis depending on the individual case. Other ICAO contracting states apply the standard as written, do not apply the flexibility standard, and refuse medical revalidation in pilots who have suffered an infarction. Despite wide differences in the application of the flexibility standard, no difference in accident rates (from medically related causes) between contracting states has been demonstrated (9).

Over the last two decades in the United Kingdom and elsewhere, and latterly within the JAA member states, an annual medical incapacitation risk limit of 1% has

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TABLE I. NUMBER OF FLIGHTS, FLIGHT HOURS (INCLUDING TAXIING TIME), AND AVERAGE FLIGHT DURATION FOR UK FIXED WING PUBLIC TRANSPORT OPERATIONS FOR THE YEAR 2000 (7).

Type of Operation	Number of Flights	Flight Hours	Average Flight Duration (h)
Scheduled	743,724	1,620,304	2.2
Charter	168,004	582,998	3.5
Air Taxi	60,409	60,322	1.0
Total	972,137	2,263,624	2.3

been applied in two-pilot public transport operations (32–34). This is known as the "1% rule," and was derived by taking an objective risk assessment approach to human failure. However, since its development, there have been important changes to airline operations. Flights have become longer and aircraft more automated. Although it has been successfully applied in at least one ICAO contracting state, it has not been universally accepted. After 20 yr of experience in its use, it is reasonable to review the basis for its use and consider how it might be applied in the future.

Target Incapacitation Risk and Aircrew Medical Standards: The "1% Rule"

Derivation of the "1% rule": The 1% rule assumes a target all-cause, fatal accident rate for large public transport aircraft of 1 per 10^7 flying hours, not more than 10% of which should be due to one system failure (e.g., pilot failure), and not more than 10% of system failures should be due to a subsystem failure (e.g., medical incapacitation). This gives a target fatal accident rate due to aircrew medical incapacitation of 1 accident per 10^9 hours. This is almost unachievable in single pilot operations, but in two-pilot operations, which comprise the majority of airline flights, if the handling pilot were to suffer an incapacitation, the other pilot should be able to take control and safely continue the flight.

The times during which the aircraft is closest to the ground (i.e., takeoff and initial climb, and approach and landing) are said to be the critical phases, as during these periods a slow or incomplete transfer of control is most likely to result in an accident. At the time the 1% rule was formulated, it was considered that in-flight incapacitation of one of the pilots would result in a fatal accident in about 1 in 1000 such events, as 10% of the then (early 1980s) average 1-h flight time was assumed critical, and in only 1 out of 100 events occurring in this critical period would the other pilot not take control in time to avoid a fatal accident (24). Therefore, in order to achieve the target medical-cause, fatal accident rate of 1 accident per 10^9 hours, neither pilot should have a risk of medical incapacitation greater than 1 in 10^6 hours, i.e., approximately 1% in 1 yr of 8,760 (24 × 365) hours.

The "1% rule" reassessed: The airline industry has changed significantly over the past 20 yr and the average flight duration for UK operators is now approximately 2 h (7) (**Table I**). The corresponding figure for the United States is 1.6 h, based on a total flight time of 13,865,596 h for 8,813,518 flights (5). The critical period of flight, 3 min at the beginning and end of each flight, therefore, comprises a lower proportion (nearer 5% than 10%) of the total flight time. Therefore, if the "1% rule" were to be recalculated using a flight time of 2 h, the acceptable risk would be found to be 2% per annum.

Further, the choice of a 3-min critical period at the beginning and end of flight can be challenged, since it is proximity to the ground which better defines the critical period. Because the climb rate after takeoff is greater than the descent rate on the approach, a safe height is reached more rapidly in the former flight phase. A height of 1500 ft could be taken as representative of the height below which an incapacitation might result in an unrecoverable loss of control. This height is consistent with that chosen by the Joint Research Center (European Commission) European Coordination Center for Aviation Incident Reporting Systems as defining the transition from the "takeoff/initial climb" phases to the "climb" phase, and from the "descent/holding" phases to the "approach" phase (15). As the takeoff and climb to this height takes about 1 min and the approach at 120 knots from 1500 ft to the end of the landing roll requires approximately 3 min, this would result in 4 min (rather than 6 min) when the aircraft was in a critical period (3.3% of the 2 h average flight time).

The research on which the estimate of the likelihood of a failed hand-over following an incapacitation during a critical phase of flight was based showed an actual rate, in the simulator, of 1 failure (simulator 'crash') in 400 incapacitations (6). This figure was adjusted for the purposes of developing the 1% rule to a failure rate of 1 in 100 incapacitations to account for real incapacitations being more unexpected than those during simulator details when pilots might be anticipating failures. A failure rate of 1 in 100 may now be rather pessimistic because modern aircraft are less demanding to fly, with fly-by-wire controls, automatic go-around, approach capability to a low height, and autoland becoming commonplace. Further, improved crew resource management training may have reduced the risk of a subtle incapacitation in the handling pilot going unnoticed by the other pilot. Although the assumption needs confirming by means of an up-to-date simulator study, for discussion purposes this paper will assume a failure rate of 1 in 200 (i.e., double the actual rate found during simulator testing).

These revised estimates of the duration of the critical phase of flight (3.3% of the flight, a third of the original assumption) and likelihood of failed hand-over (approximately 1 per 200, half the original assumption) imply that pilots in two-pilot operations could have an annual risk of an incapacitating event of up to 6% (rather than 1%) and the industry could still meet the target medical-cause fatal accident rate of 1 in 10^9 flying hours. This is because the risk per in-flight incapacitation is reduced to 1/6 of the previously calculated value (1/3 × ½ = 1/6), so the acceptable incapacitation risk for an individual pilot could potentially be increased by a factor of 6, from 1% to 6%. Put another way, these new assumptions would result in an anticipated medical incapacitation causing a fatal accident being reduced from 1 in 1000 (1/10 × 1/100) to 1 in 6000 (1/30 × 1/200).

Comparing engine failure with aircrew incapacitation: If an engineering risk assessment approach to medical incapacitation is to be used, target and actual rates for medical incapacitation should be comparable with other system failures such as that of the powerplant. The largest proportion, approximately 75% of the 2.26 million annual hours of public transport flying in the UK, is in twin-engined aircraft. For such aircraft, the failure of one engine might be considered an operationally comparable scenario to the incapacitation of one of the two pilots. The highest engineering standards required for engines are for extended twin-engine operations where an engine type must achieve an in-flight shutdown rate of 0.02 per 1000 h or better (17). To compare with the medical 1% rule approach, if an engine is in the air for 1/3 of the year (2,920 h or 8 hours per day), extended twin-engine operations have an acceptable failure risk of 0.058 (0.02/1000 × 8760 × 1/3) or 5.8% per annum, over 5 times the current acceptable maximum medical incapacitation risk in the UK.

Observed frequency of medical incapacitation: The sudden incapacitation risk of pilots is low on account of the high standards of fitness required at the initial screening medical and during follow-up surveillance. Most potential pilots with a significant and persistent risk of incapacitation (e.g., epilepsy, insulin-dependent diabetes) are screened out at the initial examination. At the time of the development of the 1% rule, most cases (50–100%) of serious prolonged and/or complete in-flight sudden incapacitations reported in public transport aircrew were thought to be due to cardiovascular events, and it has been suggested that the crash of a Trident near Staines in 1972 had cardiovascular incapacitation of the captain as a contributory cause (11,22,26,27,31). Hence, it was considered that the most likely medical conditions in the pilot population most liable to cause sudden incapacity were cardiovascular (primarily coronary artery disease) in origin.

The other group of disorders considered likely to cause sudden unexpected incapacity are neurological, primarily late onset seizure(s). While cardiovascular disease increases in incidence with increasing age, incidence of new seizures is approximately constant, at least up to the normal retirement age of professional pilots. The average annual incidence rate for all types of seizures during adulthood has been estimated to be 50 per 100,000 (0.05%) per year. Therefore, for a population of 10,000 pilots with an annual risk of 0.05%, and an average time in the air of 500 h (1/20 of the year), 0.25 in-flight seizures might be expected per year (10,000 × 0.05% × 1/20). However, the occurrence of a first seizure cannot be accurately predicted in an individual, either by investigation or age-based risk estimation, whereas cardiovascular incapacitation risk increases with age and can be predicted with reasonable accuracy from the results of medical examinations and investigations. For this reason, cardiological surveillance requirements increase with age, and lower thresholds for more detailed cardiovascular assessment are often applied to older pilots. As a result, unfit assessments in professional pilots are most commonly made for reasons of increased cardiac risk and, therefore, tend to occur in experienced, middle-aged pilots (13; Evans ADB. Long term unfit assessments in UK professional aircrew. Presentation to International Congress of Aviation and Space Medicine, 19 September 2001).

In a review of the UK Civil Aviation Authority's (CAA) Mandatory Occurrence Report (MOR) database for the 10-yr period 1990–1999 for all public transport operations, Evans reported 127 incapacitation events, of which 68 were gastrointestinal and 4 were neurological, including two idiopathic seizures (16). This number of seizures is in keeping with the expected number of 0.25 per annum (2.5 in 10 yr) derived above. There were 3 confirmed cardiac incapacitations (i.e., 0.3 per year), though it is possible that some of the 25 "unknown" events were cardiovascular in origin. Of the total, 20 (2 cardiac, 4 neurological, 6 gastrointestinal, and 8 not known), or approximately 2 per year, were considered "serious," resulting in loss of consciousness or inability to contribute to the flight operation for a prolonged period. In a review of worldwide operations of aircraft above 5700 kg between 1980 and 1996, cardiovascular incapacitation was not cited as a causal or circumstantial factor in any fatal accident (9). This proportionate fall in cardiovascular events is presumably due to the pilot population becoming fitter [between 1979 and 1989–1993, the mortality rates for cardiovascular disease in the general population fell by 40–50% (32,36)], by different reporting criteria, or by increased surveillance identifying those at risk. Further, evidence from the International Federation of Airline Pilots' Associations' survey (22) showed that 29% of those surveyed reported at least one incident of incapacitation on commercial flight decks during their career, the commonest cause being gastrointestinal.

In Evans' survey, the 127 occurrences in the 10,500 aircrew over 10 yr equates to 0.12 events in flight per 100 pilot years in the air (10 × 127/10,500). However, incapacitations in the air represent only 1/20 of the total number of potentially incapacitating events throughout the year as the aircrew, on average, spend only 1/20th of their time in the air. Therefore, the total number of potential incapacitations (in the air and on the ground) would be predicted to be 2.4 (0.12 × 20) events per 100 pilot years or an average pilot risk of 2.4% per annum for an incapacitating event.

These studies indicate that, on average, the annual all-cause pilot incapacitation risk is in excess of 1%, principally due to non-cardiovascular causes, the majority of which do not cause complete incapacity. This illustrates that annual incapacitations in aircrew, in the air and on the ground, do occur, albeit infrequently, and that in two-pilot operations, the risk is successfully mitigated because most incapacitation events occur when the pilot is not flying, and when they do occur in-flight, the presence of another trained pilot on the flight deck greatly enhances flight safety.

Applying Incapacitation Risk Assessment to Flight Operations

The 1% rule considered the risk to a single flight rather than to a crew duty period or operations as a whole. For example, if there are 10,000 'healthy' pilots flying 500 hours per year (approximately 1/20 of the hours in 1 yr), and the average sudden incapacitation risk is 0.1% (or 1/1000) per annum [also the cardiovascular mortality rate at 45 yr of age (36)], the anticipated number of in-flight incapacitations per year is 0.50 ($10{,}000 \times 0.1\% \times 1/20$). At the present time, a proportion of pilots (4% in the UK) having a known medical problem with a higher incapacitation risk (no greater than 1% per annum) are allowed to continue flying, and if this is taken into account, the predicted in-flight incapacitation rate per annum is 0.68 [($96\% \times 10{,}000 \times 0.1\% \times 1/20$) + ($4\% \times 10{,}000 \times 1\% \times 1/20$)]. However, a passenger who happens to be on a flight with a higher-risk pilot at the controls finds that the approximate risk of an incapacitation of the handling pilot during that flight is increased 10 fold, from 0.1 to 1 per 10^6 hours (0.1% to 1% per 10^4 hours).

If the standards are relaxed such that 4% of the pilots have a risk of up to and including 1% per annum (as at present), but a further 1% of pilots are allowed to continue flying with a medical risk of 5% per annum, the predicted in-flight incapacitation rate per annum increases from 0.68 to 0.93 [($95\% \times 10{,}000 \times 0.1\% \times 1/20$) + ($4\% \times 10{,}000 \times 1\% \times 1/20$) + ($1\% \times 10{,}000 \times 5\% \times 1/20$)], only a modest increase in overall rate, but now the passenger who happens to be on a flight with the higher-risk pilot (5% per annum) finds that the risk of a medical incapacitation during that flight is increased 50 fold above the average. However, to put this apparently large increase in risk into context, if, as discussed above, 1/6,000 in-flight incapacitations results in a fatal accident, this 50-fold increase in risk (from 0.1% to 5% per annum) only represents a change in medical-cause fatal accident risk to a 2-h flight from 1 in 3×10^{10} ($2 \times 0.1\%/10{,}000 \times 1/6000$) to 1 in 6×10^8 ($2 \times 5\%/10{,}000 \times 1/6000$). Put another way, if a passenger takes a 2-h flight every day with a handling pilot having a 5% per annum risk of incapacitation, it will, on average, be 1.6 million yr before medical incapacitation of such a pilot results in a fatal accident on one of these flights.

Another approach to risk estimation considers that the two pilots on the flight deck will normally alternate the handling pilot role for the sectors flown during a duty period, i.e., although a pilot may record 500 flying hours in a year, only 250 of these are likely to be as the handling pilot. Therefore, if a pilot has a 1% per annum risk of incapacitation, and the other pilot has a 0.1% per annum risk, the average risk of incapacitation of the handling pilot carried by the crews per flight over their tour of duty together will be midway between their individual risks. Further, under JAA rules, a pilot with an operational multi-pilot limitation (OML) is not allowed to be rostered with another pilot who has an OML (or is over the age of 60), thereby reducing the medical incapacitation flight safety risk during a tour of duty. If the OML limit were to be relaxed from 1% to 5% per annum, assuming the other pilot has the average medical risk of 0.1% per annum, throughout a series ('tour') of flights the average hourly risk of incapacitation would be midway between the risks of the individual pilots, i.e., 2.55%. If incapacitation risk increases with age-related cardiovascular risk, then older pilots are more likely to be retired on medical grounds. However, pilot experience also increases with age and so the effect of retiring experienced pilots on medical grounds should be considered.

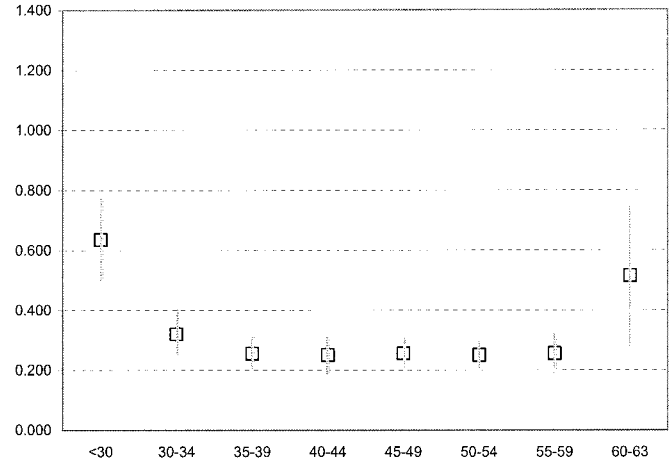

Fig. 1. FAA accident rates per million flying hours by age of pilot in command for FAR 121 (medium/large public transport) and FAR 135 (small commuter/air taxi) operations, adapted from Broach et al. (4).

The Effect on Accident Rates of Retirement on Medical Grounds

Medical retirement: Between 35 and 40 professional pilots in the UK each year are assessed as "long-term unfit" due to a variety of medical reasons, approximately 45% of which are cardiovascular (Evans ADB. Long term unfit assessments in UK professional aircrew. Presentation to International Congress of Aviation and Space Medicine, 19 September 2001.). These figures probably underestimate the total retirement from flying on medical grounds as some pilots will simply not renew their certificate if a clearly disqualifying condition presents. However, because pilots usually need the UK CAA to confirm to an insurance company that a pilot has become unfit before it will pay out on a medical "loss of license" insurance policy, the CAA is generally aware of those who do become long-term unfit. Long-term unfit assessments are made on the basis of the medical risk of the pilot threatening flight safety to an unacceptable level. At the present time under the JAR (which, in order to maintain consistency between contracting states, does not use the ICAO flexibility clause), pilots who are thought to have a risk of incapacitation greater than 1% per annum are considered unfit, regardless of their flying experience.

Pilot-cause accident rates: The two most important pilot factors influencing accident rates are age and flying experience (4,14). **Fig. 1** is taken from the FAA report on pilot age and accident rates (4). It shows a U-shaped curve with the highest accident rates in the youngest pilots. A similar pattern has been observed in fighter pilots (with the nadir in a lower age group). The mishaps in the youngest fighter pilot groups were principally due to lack of experience in handling the aircraft (18). A similar trend has been observed in motor vehicle drivers (12).

Medical fitness and flying experience in accident risk: The concept of the possible detriment to flight safety of retiring experienced pilots on medical grounds and replacing them with younger, less experienced pilots is not new (3). Froom et al. have also considered the effect on the fatal accident rate of replacing experienced fighter pilots (aged 30 to 33) having a 10-fold increase above their peer group in medical risk with younger, less experienced pilots (18). They predicted that although the risk of a medical-cause accident was reduced, the paradoxical effect would be to increase the accident rate because of the effect of flying experience. For the purposes of public transport flying, the FAA accident rates for pilots of 50–54 (or 55–59) years of age can be compared in turn with the rates for those under 30 yr of age and pilots in the age range of 30–34 yr (Fig. 1). Such comparisons may represent a senior captain being medically retired and replaced by a promoted first officer rather than by a pilot of similar age and experience.

Instead of using the actual accident rates shown in Fig. 1, which may overestimate the large public transport aircraft accident rate (as it includes the smaller commuter aircraft and air taxi operations), it may be better to examine relative risk of an accident between the age groups and apply the figures to the UK target public transport fatal accident rate of not more than 1 per 10^7 hours (as used by the 1% rule). The FAA data (Fig. 1) indicate an average relative risk of accident of about 2.5 for pilots under 30, and 1.25 for pilots 30–34 yr old compared with pilots 50–54 yr old. Therefore, if it is assumed that the (all-cause) fatal accident rate for pilots 50–54 yr old is the same as the target fatal accident rate of 0.1 per million hours flown (1 in 10^7 hours), the rate will be 0.125 per million hours for pilots 30–34 yr old, and 0.25 per million hours for pilots under 30. Therefore, if a pilot who is 50–54 yr old is replaced by one who is 30–34, the all-cause accident rate (by subtraction) can be expected to increase by 0.025 per million hours (0.125–0.1). If the pilot is replaced by one under 30 yr old, the accident rate might increase by 0.15 per million hours (0.25–0.1).

From the derivation of the 1% rule, it can be deduced that if a pilot's medical incapacitation risk per annum is 1%, the flight safety risk posed is 1 fatal accident per 10^9 hours, and for every increase of 1% in a pilot's annual incapacitation risk, the additional flight safety risk is 1 accident per 10^9 hours. Therefore, in the hypothetical situation where a pilot of 50–54 yr of age develops a medical condition that increases medical risk to over 1% per annum and is then replaced by a younger pilot of 30–34 yr with the comparatively small average cardiovascular risk of 0.01% per annum (36), the increase in the all-cause accident rate (0.025 per 10^6 hours) can be compared with the perceived benefit of reducing the medical-cause fatal accident risk from 1 per 10^9 to 1 per 10^{11} hours, i.e., a rate reduction of 0.999 in 10^9 ($1 \times 10^9 - 1 \times 10^{11}$), approximately 1 per 10^9 hours or 0.001 per 10^6 hours. It can be seen that flight safety might be eroded by a factor of 25 (0.025/0.001). Similarly, if a pilot under the age of 30 replaces one 50–54 yr old, because of the increased accident rate attributed to the younger age group, if the cardiovascular risk is reduced by 1%, the accident rate will increase by 0.15 per million hours, an erosion in flight safety by a factor of 150 (0.15/0.001). Even if the retired pilot has a risk of 5% per annum, there will still be a potential overall reduction in flight safety if the pilot is replaced by one under 35 yr, although the reduction will be less.

Even though a reduced level of experience is associated with a higher accident rate (Fig. 1), these data must be regarded with caution as other factors may be important. Older and, therefore, more senior pilots often have greater control over the trips they operate and may choose to fly larger aircraft having longer flight times than their younger colleagues. In consequence, younger pilots may be operating smaller aircraft with a higher number of takeoffs and landings, the flight segments where most accidents occur. Nevertheless, the greater accident rate in younger pilots is in accord with what would be expected from those having more limited experience, and is supported by data from other sources, as mentioned. It can be seen that the accident rate appears to increase for pilots over 60 yr in the FAA data (Fig. 1). This supports a policy of reduced flexibility in aeromedical decision-making when assessing pilots who have a medical problem and are over this age.

Modeling In-Flight Cardiovascular Incapacitations In Aircrew

Any relaxation of the maximum acceptable incapacitation risk is most likely to have its effect on pilots with, or at risk of, cardiovascular conditions, either as a result of decreased surveillance (as assurance of a lower risk is not required) or allowing pilots to fly with a higher risk (under appropriate surveillance). The effects of changes to the incapacitation risk targets can be modeled if the age profile and cardiovascular risk of the pilots are known.

Professional license holder demographics: Fixed wing UK professional pilot licenses are the airline transport pilot's license (ATPL), the commercial pilot's license (CPL), and the basic commercial pilot's license (BCPL). Pilots with a professional license who give flying instruction require a flying instructor rating or an assistant flying instructor rating. Of the UK ATPLs and CPLs issued, approximately 10% are held by active-service military pilots or those working outside the UK. The BCPL confers only limited public transport privileges and is normally used for aerial work, principally flying instruction. Some flying instruction is performed by public transport pilots who hold a CPL or ATPL.

Cardiovascular incapacitation risk in aircrew: At the present time, the majority of pilots are male, and in general, discussions regarding medical and cardiological risk have focused on male mortality/morbidity statistics. This approach is continued in this paper as cardiovascular mortality/morbidity is lower in women under 65 yr of age, and, therefore, using male cardiovascular risk will tend to overestimate risk in the total pilot population.

Coronary artery disease accounts for 90% of sudden death in men aged over 40, and 10–30% of deaths in men under 35 years. Two-thirds of sudden death in those under 35 is due to cardiomyopathy (18). Although the cardiovascular mortality rate in the general population cannot be automatically taken to represent the in-flight cardiovascular incapacitation rate, Tunstall-Pedoe (33,36) has argued that the two can be regarded as roughly equivalent. The incapacitation rate might be expected to be greater than the mortality rate since incapacitating cardiac symptoms do not necessarily result in death, e.g., severe angina. However, this is balanced by the number of cardiovascular deaths which do not pose a flight safety risk because the pilot has developed symptoms or a disease which results in grounding without causing an incapacity, but which subsequently result in death. Therefore, the cardiovascular death rate can be taken to approximate the cardiovascular incapacitation rate (32). Even if potentially disabling nonfatal cardiovascular episodes were to occur more frequently than fatal ones, this factor is liable to be offset by a lower mortality risk in pilots than in the general population, as the standardized mortality ratio for cardiovascular disease in aircrew is between 0.3 and 0.7, probably due to a more favorable socio-economic status and greater health surveillance (1,2,20,25,30). Also, any pilot with a recognized symptomatic disease (50% of people who suffer a myocardial infarction have had prior symptoms) (35) is unlikely to be flying. Therefore, using the male cardiovascular mortality rate as an estimate of the cardiovascular incapacitation rate is a cautious, but reasonable, approach to risk assessment.

The 1% rule was primarily based on cardiovascular incapacitation rates, but cardiovascular incapacitation represents only a small proportion of total incapacitations (10% of serious incapacitations in the UK data), with the commonest known cause of in-flight incapacitation being gastrointestinal illness. However, although gastrointestinal illness can cause loss of consciousness, it usually does not do so suddenly. While loss of consciousness is likely to cause an accident whenever it occurs in solo pilot operations, this is not the case for two-pilot operations. Gastrointestinal illness develops relatively slowly, allowing time for the second pilot to be advised of a deteriorating condition in a colleague, and so, such illness poses little flight safety risk in comparison to the potentially sudden and unheralded incapacitation caused by cardiovascular collapse.

It is true that neurological disease (especially seizures) can occur suddenly, but, like cardiac illness, such incapacitations represent only a small proportion of serious incapacitations (16). However, neurological disease must be considered when attempting to predict the total number of expected sudden in-flight incapacitations. The numbers are likely to be small, in the region of 0.25 per annum, as calculated above. In fact, using cardiovascular mortality data alone to predict all-cause sudden in-flight incapacitations might provide a reasonable approximation.

METHODS

Cardiovascular Incapacitations

The age profiles of UK professional pilot license holders who also held a valid medical were obtained from the data published on the website of the UK CAA Flight Crew Licensing Department (8). The approximate number of airline pilots flying fixed wing public transport operations in the UK in each age group was estimated by subtracting the number of pilots with a flying instructor rating from the number of professional license holders not working abroad or for the military. From the total number of hours flown (Table I), the average number of hours flown per annum was calculated. The annual risk of cardiovascular death in the general male population of the UK was taken from published mortality statistics (32). Assuming cardiovascular mortality rates reflect cardiovascular incapacitations, annual incapacitation rates for each age group was estimated using the mathematical product of the number of pilots in each age group and the cardiovascular mortality rate in that age group.

Effects of Medical Regulation and Relaxation of Acceptable Medical Risk

The crude figures for predicted cardiovascular incapacitations in any year do not take into account the effects of regulatory surveillance. For unrestricted certification, the average individual risk of pilots should not be above that of their peers, which is, for the whole professional pilot population, an average of approximately 0.1% per annum. If, for example, a minor anomaly is identified on the resting ECG, further cardiological investigation is warranted to confirm that the pilot does not have an increased risk of an incapacitating event. If the assessment is not normal, the pilot may continue with a restricted certificate, provided that the risk estimate of an incapacitation is no greater than the target incapacitation risk, currently 1% per annum.

The effect of regulatory surveillance can be modeled so that the average incapacitation risk is considered to be the age-related cardiovascular risk. Then, as a cautious approach, those with a multicrew limitation are assumed to have, on average, the maximum permitted risk, although in reality their risk may be less than this. For example, if 95% of 10,000 pilots (spending 1/20 of their time in the air) have an average risk of incapacitation (say 0.1%), and 5% have an increased risk (say 1%) and hence a multicrew restriction, the number of in-flight incapacitations per year will be 0.725 [(95% $\times$ 10,000 $\times$ 0.1% $\times$ 1/20) + (5% $\times$ 10,000 $\times$ 1% $\times$ 1/20)]. If the proportion of pilots with a multi-pilot limitation is known for each age group, the number of expected in-flight incapacitations can be predicted for different multi-pilot risk limits.

Increasing the multi-pilot risk limits will allow more pilots to continue flying. Therefore, the proportion with such a limitation will increase. Hence, as a cautious approach, the effect on the number of incapacitations of doubling the number of pilots with a multi-pilot restriction was also calculated.

TABLE II. FIXED-WING PROFESSIONAL LICENCES AND RATINGS HELD IN THE UK ON 1/3/2000 (8).

Age (yr)	ATPL (A)	CPL (B)	BCPL (C)	Total licence holders (A + B + C)	Instruct or Ratings (D)	Estimated licence holders flying public transport {[90% × (A + B) + C] − D}
20–24	24	401	31	456	71	343
25–29	526	950	67	1543	243	1152
30–34	1579	730	91	2400	340	1829
35–39	1909	489	107	2505	454	1811
40–44	1825	284	101	2210	396	1603
45–49	1500	165	108	1771	343	1264
50–54	1824	131	88	2043	292	1556
55–59	897	100	74	1071	242	729
60–64	303	56	34	393	141	216
Total	10387	3306	701	14494	2522	10502

RESULTS

Cardiovascular Incapacitations

The pilot population data for March 2000 are shown in **Table II** (8). The approximate number of airline pilots flying fixed wing public transport operations in the UK was found to be 10,502. More young pilots hold a CPL compared with an ATPL, reflecting the accumulation of additional flying hours and experience necessary to obtain the higher license. The number of professional pilots in the age range of 30–54 is relatively constant, reducing in the subsequent age groups as pilots retire from professional flying.

The annual number of hours flown in fixed wing UK public transport operations is shown in Table I (7). Of the 2.26 million flying hours, 71.5% are scheduled, 25.8% charter, and 2.7% air taxi. All air taxi operations were considered as single pilot, and all scheduled and charter operations were considered 2-pilot. Therefore, the average number of hours flown per pilot per year was 425. $\{[(1 \times 2.7\% \times 2.26 \times 10^6) + (2 \times 97.3\% \times 2.26 \times 10^6)]/10{,}502\}$ Therefore, in a year of 8,760 h, pilots on average spend about one-twentieth (425/8760) of their time operating an aircraft, during which a cardiovascular or other type of incapacitation may pose a risk to safety. The annual risk of cardiovascular death in the general male population of the UK by 5-yr age group (36) is shown in **Table III**. Male cardiovascular death risk increases approximately exponentially with age with values of 0.1% at around age 45 and 1% at around age 65.

For the UK airline pilot population, the total estimated cardiovascular incapacitation rate will be the sum of the estimated incapacitations (number of pilots × cardiovascular risk) for each age group, i.e., 12.7 per year (Table III). Based on the average number of hours flown derived above, the number occurring in flight per annum is estimated at 0.63 (1/20 of the total predicted for the year) and this is shown graphically in **Fig. 2**. This estimate is in good agreement to the figure of 0.68, the predicted in-flight annual incapacitation rate in UK professional pilots, derived earlier when using more general assumptions in applying risk assessment to flight operations. While the highest risk is borne by those over 60 yr of age, the greatest number of incapacitations in any year can be expected to be in the cohort of pilots within the age range 50–59, where the pilot population is most affected by the increasing age-related cardiovascular risk (Table III) and before pilots begin to cease flying as they reach retirement age.

Effects of Medical Regulation and Relaxation of Acceptable Medical Risk

The effect of allowing pilots to continue with a higher risk is shown in Table III where the proportion of pilots

TABLE III. ESTIMATED NUMBER OF INCAPACITATIONS (BY 5-YR AGE GROUP) PER YEAR BASED ON THE MATHEMATICAL PRODUCT OF THE NUMBER OF FIXED-WING PROFESSIONAL LICENCE HOLDERS FLYING PUBLIC TRANSPORT AND THE ANNUAL CARDIOVASCULAR DEATH RISK.

5-year age group (yr)	Estimated licence holders flying public transport (II) (A)*	Proportion (%) with OML (B)†	Annual cardiovascular death risk (%) (C)	Crude estimated number of incapacitations/year (A × C)	Estimated number of incapacitations/year including proportion of pilots with OML limit risk of 1% [A × (100 − B) × C] + (A × B × 1%)
20–24	343	0.2	0.004	0.01	0.02
25–29	1152	0.5	0.006	0.07	0.13
30–34	1829	1.0	0.012	0.22	0.40
35–39	1811	1.2	0.030	0.54	0.75
40–44	1603	2.1	0.063	1.01	1.33
45–49	1264	3.6	0.129	1.63	2.03
50–54	1556	6.3	0.255	3.97	4.70
55–59	729	7.7	0.470	3.43	3.72
60–64	216	9.4	0.842	1.82	1.85
Total	10502			12.70	14.93

*From Table II. †CAA Medical Division data, 2000.

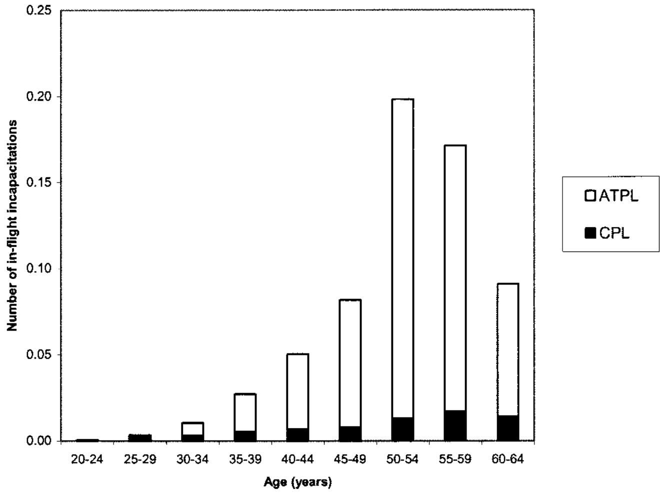

Fig. 2. Estimated annual pilot in-flight incapacitations by 5-yr age group and license type.

with an OML and an acceptable risk limit in such individuals of 1% is taken into account. This has the effect of increasing the estimated number of in-year incapacitations (14.9 compared with 12.7).

Table IV shows the effect of increasing the maximum acceptable risk limit to 2% and 5% and doubling the number of pilots that are flying with such an increased risk using data (2000) from the CAA Medical Division database for the number of OML limitations for the "current OML profile." It can be seen that there is only a relatively small increase in the predicted number of in-flight incapacitations per year of between 0.15 (0.75 to 0.90) to 0.3 (0.90 to 1.20) for a 2% OML risk and 0.6 (0.75 to 1.35) to 1.2 (0.90 to 2.10) for a 5% OML risk compared with having a 1% OML risk limit.

DISCUSSION

Cardiovascular Incapacitations

Although the figure of 0.63 incapacitations per year would suggest that, over 10 yr, approximately six in-flight incapacitations might be expected, only two serious incapacitations were in fact observed in UK operations during this time period (16). While the numbers are too small to draw substantive conclusions, this supports the view that using the general male population cardiovascular mortality rate for estimating in-flight cardiovascular incapacitation is cautious: actual serious in-flight cardiac incapacitations seem, from the limited data available, to occur at a lower frequency than predicted from this method.

The incapacitation predictions assume that such events occur randomly throughout the year, and that pilots with medical conditions are not rostered to fly more than fitter pilots (and vice versa). It also assumes that the flying environment does not make incapacitation more likely. In civilian pilots experiencing an in-flight myocardial infarction, the event has been said to be more likely to occur during critical stages of flight such as takeoff or landing rather than the cruising phase (10,26,29). However, there is evidence that more angina and myocardial infarctions occur in the early hours, particularly during rapid eye movement (REM) sleep, when the cardiovascular system is not under external stress (21). Also, there are many other everyday life stressors of the cardiovascular system, both physical and emotional, which are likely to occur more frequently to a pilot throughout the year than are stressful flight-related events. Therefore, if the cardiovascular system is going to be sufficiently stressed to cause an incapacitating event, it cannot be assumed that this is more likely to occur in the air than on the ground. In fact, of the two in-flight cardiac deaths of pilots that occurred in UK registered aircraft during 1990–1999, one occurred at 15,000 ft in the descent and the other occurred when the pilot was taking in-flight rest in the crew bunk facility (16).

Effects of Medical Regulation and Relaxation of Acceptable Medical Risk

It can be seen from Table IV that there is only a relatively small increase in the predicted number of in-flight incapacitations per year. This is an important point. It means that the number of in-flight cardiovascular incapacitations per year is not affected as much as might be expected by what would seem to be very significant changes to the maximum risk of incapacitation set by the regulator. This is because whatever maximum acceptable risk of incapacitation is chosen for those who have a known medical condition, the vast majority of pilots will have no such condition and the number of hours flown during flight operations of the latter will dwarf those flown by pilots with a medical problem.

In the United States, the more flexible approach of the FAA has not resulted in an appreciable difference in medical-cause accident rates from symptoms related to a physical condition in two-pilot operations. Further, despite the different interpretations of the ICAO standards and recommended practices, the worldwide lack of any evidence to suggest that increased medical flexibility results in an increased accident rate suggests that the most important aspect of human performance on the flight deck to be addressed is that of human error, which is consistently identified to be the commonest single cause (60–80%) of fatal airline accidents.

CONCLUSIONS

An alternative approach to the use of the 1% rule to the calculation of acceptable aeromedical risk has been

TABLE IV. EFFECT OF INCREASING MAXIMUM ACCEPTABLE RISK LIMITS TO 2% OR 5%.*

	OML risk limit 1%	OML risk limit 2%	OML risk limit 5%
Current OML profile	0.75	0.90	1.35
Double proportion with OML	0.90	1.20	2.10

*Estimated annual in-flight cardiovascular incapacitations per year if cardiovascular risk for unrestricted flying is not more than the average for each pilot age group up to age 65, and the current proportion of pilots with a multicrew restriction (OML) have an incapacitation risk of 1%, 2%, or 5%. The effect of double the proportion of pilots flying with a multicrew restriction (OML) is also shown.

discussed. By adjusting the assumptions made in the original derivation of the 1% rule it has been demonstrated that an aeromedical sudden incapacitation risk of up to 5% might not lead to a decrease in flight safety. If the '1% rule' is simply recalculated with the more appropriate average flight time of two hours, the acceptable risk would be found to be 2% per annum.

The absence of a recorded fatal accident worldwide in a two-pilot commercial aircraft over 5700 kg with cardiovascular incapacitation as a contributing cause for over 20 yr may be testament to the success of medical regulation of pilot fitness. However, the data presented above suggest that medical incapacitation risk, particularly cardiovascular risk, may be over-regulated in some states, especially when compared with another vital aircraft system, the powerplant. Since the most common (60–80%) reason for fatal accidents in airline operations is human error, if experienced pilots are retired on the basis of a relatively small increase in their individual medical incapacitation risk, this could result in an erosion of flight safety.

The estimated increased number of incapacitations that may occur if the incapacitation risk limits are relaxed is small, and is likely to have a negligible effect on flight safety given that the vast majority of operations are performed in multicrew aircraft where the probability of the second crewmember failing to recognize, and successfully deal with, an incapacitation is very low. Consideration should be given to a flexibility clause in the current JAA regulations in line with the ICAO flexibility standard applied in many states, including the United States, and to relaxing the maximum acceptable incapacitation risk for cardiovascular and other physical disorders. A figure of 2% per annum would seem appropriate.

REFERENCES

1. Band P, Lee N, Fang R, et al. Cohort study of Air Canada pilots: Mortality, cancer incidence, and leukaemia risk. Am J Epidemiol 1996; 143:137–43.
2. Band P, Spinelli J, Ng V, et al. Mortality and cancer incidence in a cohort of commercial airline pilots. Aviat Space Environ Med 1990; 61:299–302.
3. Bennett G. Aviation accident risk and aircrew licencing. Eur Heart J 1984; 5(Suppl A):9–13.
4. Broach D, Joseph KM, Schroeder DJ. Pilot age and accident rates report 4: An analysis of professional ATP and commercial pilot accident rates by age. September 2000; Retrieved on 13 March 2003 from www.cami.jccbi.gov/AAM-400A/AGE60/age60_4.pdf.
5. Bureau of Transportation Statistics. Bureau of Transportation Statistics (BTS) activity data for U.S. air carriers. 2000; Retrieved on 16 September 2003 from http:www.nasdac.faa.gov/bts/btsfrm41.xls.
6. Chapman PJC. The consequences of in-flight incapacitation in civil aviation. Aviat Space Environ Med 1984; 55:497–500.
7. Civil Aviation Authority. UK airline statistics 2000 annual. 2000; Retrieved on 13th March 2003 from http://www.caa.co.uk/docs/80/airline_data/2000annual/209_Total_Scheduled_and_Non-Scheduled_Services_Operating_and_Traffic_Statistics_for_the_Financia_%20Years_of_Reporting_Airlines.xls.
8. Civil Aviation Authority. Professional licences held by age. 31 March 2000; Retrieved on 13th March 2003 from http://www.caa.co.uk/docs/175/srg_fcl_Age2000StatsProfessional.pdf.
9. Civil Aviation Authority. CAP 681: Global fatal accident review 1980–1996; Gloucestershire, UK: Westward Digital Limited; 1998.
10. Cullen SA, Drysdale HC, Mayes RW. Role of medical factors in 1000 fatal aviation accidents: Case note study. Br J Med 1997; 314:1592.
11. Department of Trade and Industry. Civil aviation accident report 4/73. Trident G-ARPI. Report of the public inquiry into the causes and circumstances of the accident near Staines on 18 June 1972. London: The Stationery Office; 1973.
12. Dionne G, Desjardins D, Laberge-Nadeau C, Maag U. Medical conditions, risk exposure, and truck drivers' accidents: An analysis with count data regression models. Accid Anal Prev 1995; 27:295–305.
13. Downey LE, Dark SJ. Medically disqualified airline pilots in calendar years 1987 and 1988. Washington, DC: FAA Office of Aviation Medicine; 1990. Technical Report No: DOT/FAA/AM-90/.
14. Erruad MY, Borowsky MS. Age and pilot performance. Aviat Space Environ Med 1985; 56:553–8.
15. European Co-ordination Centre for Aviation Incident Reporting Systems. ECCAIRS4 data definition standard. 2003; Retrieved 8 March2003fromhttp://eccairs-www.jrc.it/Support/Downloads/Files/Documentation/Release40Taxonomy/R4CDEventPhases.pdf.
16. Evans ADB. Inflight incapacitation in United Kingdom public transport operations: Incidence and causes 1990–1999 [abstract]. Aviat Space Environ Med 2002: 73:242.
17. Federal Aviation Administration. Extended range operation with two-engine airplanes (ETOPS). Oklahoma City, OK: FAA; 1998. Advisory Circular 120–42A 20/12/1998.
18. Froom P, Benbassat J, Gross M, et al. Air accidents, pilot experience, and disease-related inflight sudden incapacitation. Aviat Space Environ Med 1988; 59:278–81.
19. ICAO Standards and Recommended Practices. Personnel licensing, annex 1, chapter 6, medical requirements. Montreal: ICAO; 1988.
20. Irvine D, Davies DM. British Airways flight deck mortality study, 1950–1992. Aviat Space Environ Med 1999; 70:548–55.
21. ISIS-2 (Second International Study of Infarct Survival) Collaborative Group. Randomised trial of intravenous streptokinase, oral aspirin, both, or neither among 17,187 cases of suspected acute myocardial infarction. Lancet 1988; 2:349–60.
22. James M, Green R. Airline pilot incapacitation survey. Aviat Space Environ Med 1991; 62:1068–72.
23. Joint Aviation Requirements JAR-FCL 3 Flight Crew Licensing (Medical). Hoofdorp, Netherlands: JAA; 2000.
24. Joy M. Cardiological aspects of aviation safety: The new European perspective. Eur Heart J 1992; 13(Suppl H):21–6.
25. Kaji M, Tango T, Asukata I, et al. Mortality exerience of cockpit crewmembers from Japan Airlines. Aviat Space Environ Med 1993; 64:748–50.
26. Leighton-White RC. Airline pilot incapacitation in flight. Aerosp Med 1972; 43:661–4.
27. Manning GW. Aviation cardiology in Canada. Am J Cardiol 1975; 36:576–83.
28. Mc Fadden KL. Predicting pilot-error incidents of US airline pilots using logistic regression. Applied Ergonomics 1997; 28:209–12.
29. Mohler SR, Booze CF. US fatal general aviation accidents due to cardiovascular incapacitations 1974–1975. Aviat Space Environ Med 1978; 49:1225–8.
30. Nicholas JS, Lackland DT, Dosemeci M, et al. Mortality among US commercial pilots and navigators. J Occup Environ Med 1998; 40:980–5.
31. Raboutet J, Raboutet P. Sudden incapacitation encountered in flight by professional pilots in French civil aviation, 1948–1972. Aviat Space Environ Med 1975; 46:80–1.
32. Tunstall-Pedoe H. Risk of a coronary heart attack in the normal population and how it might be modified in flyers. Eur Heart J 1984; 5(Suppl A):43–9.
33. Tunstall-Pedoe H. Introduction to section 1: Acceptable cardiovascular risk in aircrew. Eur Heart J 1988; 9(Suppl G):9–11.
34. Tunstall-Pedoe H. The concept of risk. Eur Heart J 1988; 9(Suppl G):13–5.
35. Tunstall-Pedoe H. Cardiovascular risk and risk factors in the context of aircrew certification. Eur Heart J 1992; 13(Suppl H):16–20.
36. Tunstall-Pedoe H. How cardiovascular risk varies with age, sex, and coronary risk factors: Do standard risk scores give an accurate perspective? Eur Heart J 1999; 1(Suppl D):25–31.