CAUSES OF AIRCREW ERROR IN THE ROYAL AIR FORCE

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SUMMARY

One hundred and forty nine military flying accidents were investigated by psychologists. Inspection of the data collected revealed that nearly half of the accidents involved inadequacies in equipment design, training or administration. Cognitive failure was a major cause of aircrew error and was more often associated with underarousal than with overarousal. Overarousal made a significant contribution to aircrew error, but largely as a secondary factor, i.e. it was generally a consequence of mechanical problems, disorientation, or prior mishandling of the aircraft. Personality factors also made a significant contribution, and the data suggest two distinct types of problem. Life stress and high workload appeared not to play a major part in stress-related accidents. Fatigue was not a major factor, but was closely associated with cognitive failure.

INTRODUCTION

It is widely accepted that flying, particularly military flying, is a stressful occupation. The real significance of the stresses involved in flying is, however, not easily explicated. There are several reasons for this. First, the role of stress is equivocal. Some aviators at least are attracted by the challenge of operating under pressure of whatever kind. And the effects of stress may, under the right conditions, be beneficial. Although the inverted 'U' relationship between arousal and performance, first proposed by Yerkes and Dodson (1) eighty years ago, is by no means a full description of the complexities of stress, it is, nevertheless, a useful reminder of some salient facts: Some stressors raise arousal level, and some depress it, and either action can, at times, improve performance. In addition the experimental investigation of the effects of stress is restricted by obvious ethical and practical difficulties. As a result, the effects of relatively benign stressors in mild doses (eg fatigue, noise, hypoxia) have received attention in the laboratory and, to a lesser extent in simulations and flight tests, but one is left with the suspicion that stressors of great operational significance (particularly varieties of threat) have not yet been adequately investigated in a realistic context, despite some remarkable efforts (2).

The study of aircraft accidents offers the prospect of obtaining some clues to the operational impact of stressors and their relative importance. One may assume, perhaps with little justification but as a useful starting point, that whatever factors are found to be major causes of accidents are also likely to have a deleterious effect on operational effectiveness - perhaps in proportion to their significance in the aetiology of accidents. This gives the investigation of accidents a significance in addition to that derived from the enormous cost of individual accidents. Clues may be sought as to the origins of stress in flying, the nature of the effects of stress, and the relative importance of stress in comparison with other human factors problems.

In 1972 the Royal Air Force started a scheme allowing psychologists to conduct independent investigations of aircraft accidents in conjunction with the established Boards of Inquiry. The data discussed here were collected in the course of these investigations.

METHODS

By the summer of 1988, 149 military flying accidents had been investigated. A few involved Royal Navy or Army aircraft; the majority were RAF accidents. The investigations drew on several sources of information:

- Confidential interviews with survivors and others.
- The personal records of those involved in the accidents.
- Eyewitness reports.
- Analysis of flight data recorder tapes, recordings of radar traces, radio transmissions etc..
- Examination of cockpit equipment, regulations, manuals and other documents.

Data on each accident were recorded in a simple computer data base. In addition to information on aircraft type, phase of flight in which the accident happened, etc., the [illegible] which contributed to the accident are recorded as 'possible', 'minor' or

RESULTS

More than thirty human factors categories have been used in coding the accidents. Some form natural subgroups and have been combined into generic terms in the list in Table 1. The full list is in Appendix A. It is intuitively obvious that the factors do not all have the same logical status: Some are enabling conditions or predispositions, rather than direct causes; others describe the way in which an error occurs. An arbitrary division of the factors has been imposed on Table 1 reflecting this consideration. The three groups are: Aircrew Factors - predisposing conditions some of which are under the control of the aircrew, others being more or less natural or innate; System Factors - enabling conditions engendered by high workload, inadequacies of equipment design or training, etc.; and Modes of Failure - essentially descriptions of types of error. Table 1 shows those factors cited as at least possible contributory causes in more than 10% of the accidents. Most accident investigations revealed three or four human factors problems; some revealed ten or more.

Table 1: The major human factors

AIRCREW FACTORS	
personality	23%
inexperience	20%
life stress	11%
SYSTEM FACTORS	
ergonomics	23%
training and briefing	19%
administration	17%
high workload	14%
MODES OF FAILURE	
overarousal	26%
cognitive failure	17%
distraction	16%
inappropriate model	13%
disorientation	13%
visual illusion	12%

A few of the terms in Table 1 require some explanation:

- Overarousal: The term 'stress' is commonly used in a variety of ways to describe both stressors and the response to them. For convenience 'overarousal' is used here to describe a non-adaptive response to stressors of an exciting or alarming nature. Similarly, 'underarousal' denotes performance degradation due to depression of arousal level.

- Life stress: Any personal or domestic events believed to have a worrying, anxiety provoking or exciting effect on an individual. The personal events may include some arising in the course of professional duties, but not, usually, short term episodes directly connected with flying.

- Administration: This term covers the content of manuals, pilot's guides, instructions and orders, and also features of chains of communication.

- Cognitive failure: A type of error in which actions fail to match intentions, usually because an intended action is omitted or because an unintended action is committed. Such failures are commonly attributed, in lay-man's terms, to 'absent-mindedness'.

- Inappropriate model: This term covers errors due to the formulation of intentions on the basis of incorrect information or assumptions.

The early accidents in the database were selected for their obvious human factors interest. The terms of reference of the scheme have changed, and now an attempt is made to investigate any accident in which aircrew error is considered to be a possible

contributory cause. There are grounds, therefore, for expecting a change in the pattern of results obtained over the years. The data do not, however, fulfill this expectation. A comparison of early and late investigations reveals no significant trends.

Origins and effects of overarousal

Table 2 summarizes a classification of the factors chiefly responsible for a state of overarousal in the aircrew involved in the accidents, and of the effects of that overarousal on their performance. The classification was by no means easy to impose on essentially narrative data describing accidents with complex causes. It is entirely possible that some categories, such as 'disorganised response', are inflated as a result of this difficulty and that of the original investigators, who had to deal with the survivors' understandably confused recollections of alarming events. Nevertheless, the classification allows some broad distinctions to be made.

Of the 39 accidents for which overarousal was cited as a contributory factor, 19 involved a mechanical problem (such as engine failure, hydraulic or electrical failure, bird strike, lightning strike, fire or low fuel state) which was regarded as the stimulus for overarousal. In fourteen of these cases, the emergency was considered to have been in some degree mishandled, thereby increasing the danger. Precipitate and inappropriate action accounted for four cases and disorganised or slow responses for seven. Overarousal was not the only cause of mishandling of emergencies; five other cases were due to a variety of factors other than overarousal.

Table 2: Origin and effects of acute overarousal

Origins of overarousal:	
Mechanical problems	19[1]
Mishandling	6
Disorientation	5[1]
Anxiety or other personality factor	4
Supervisory defects	3
Cognitive failure	2
High workload	1
Effects of overarousal:	
Disorganised response	12
Narrowing of attention	7[2]
Cognitive failure	5[2]
Slow response or inactivity	4
Precipitate action	4
Minor or undetermined effects	9

[1] One accident included in both these categories
[2] Two accidents included in both these categories

In six accidents, overarousal followed mishandling of the aircraft. Limited talent was a predisposing factor in at least half of these.

Five accidents involved overarousal arising from disorientation. All five resulted in the loss of the aircraft. In three instances in which the pilot was killed, it is fair to say that overarousal was assumed to have been a likely concomitant of the disorientation that was believed to be the cause of the accident.

In twelve overarousal-related accidents, a crewmember's personality was thought to have been a contributory factor. Usually, (eight of the twelve) this was due to a lower than average tolerance for stress (see the section on Personality). In four accidents a predisposing personality factor was the cause of overarousal. In three of these, the origins of the overarousal lay in a crewmember's predisposition to anxiety - in one case about test sorties; in another about the possible effects of high intensity radio sources; and in a third, a general unease about fast jet flying may have been heightened and focussed on the possibility of control restrictions. The effects of overarousal in [illegible] which resulted in the omission of an

important action; and, in two cases, precipitate and probably unnecessary ejections.

In two accidents supervisory failings resulted directly in pilots facing novel situations with which they were ill-equipped to deal. In both cases the pilots made errors leading to their losing control of the aircraft. A third accident was similar, except that the overarousal followed the loss of control and hindered recovery; again the necessary enabling conditions included a supervisory factor.

In two accidents, problems arising from a cognitive failure caused overarousal which impeded resolution of the problems. In a further five accidents, cognitive failure appears to have been a result rather than a cause of overarousal.

Other sources of stress

Life stress:

In seventeen investigations it was thought relevant to record details of personal and domestic events that might have been a source stress for the aircrew involved. In eight cases overarousal was also considered to be a factor contributing to the accident. In general, however, it was not possible to make any direct link between the life stress recorded and the causes of the accident. In only two cases could personal events be viewed as having a direct causal bearing on the accident: One involved recent experience under fire, which may have caused the pilot to emphasise tactical considerations at the expense of safety; the other involved a terminated engagement to marry and subsequent rather cavalier use of an aircraft. Most of the remaining instances fall into the following groups:

- Domestic problems - five cases: deaths, illness or health problems in the family; intensive and tiring domestic activity immediately preceding the accident (two cases, also listed under fatigue).
- Marital problems - two cases: specifically worries about infidelity or incompatibility.
- Work problems - five cases (two also involve domestic stress): excessive executive responsibilities or secondary duties; conflict between domestic and professional demands.

The mode of failure for five accidents in which life stress was cited as a possible contributory factor was cognitive failure; in three cases a deliberate disregard for rules was a major factor in the accident.

Fatigue:

Although fatigue does not appear in Table 1 as a major cause of accidents, thirteen investigations (9%) did reveal fatigue as a possible contributory factor. Four accidents occurred during night flying, three of them after relatively long periods on duty. In one case night flying over the previous three nights was thought possibly to have caused fatigue on the day of the accident. In five case the fatigue originated at least partly in social or domestic activities. Cognitive failure was the main associated mode of failure (six cases); there were also two cases of apparently controlled flight into the sea, two of failure to avoid rising ground and one mid-air collision.

High workload:

Although 21 accidents implicated high workload as a contributory factor, only seven of these were associated with evidence of overarousal. Four of the seven involved mishandled emergencies, the excess workload arising from mechanical problems. Two of the remainder involved training in demanding operational conditions, which may, of themselves, have generated a degree of excitement. It is not possible to determine whether the high workload or the overarousal made the greater contribution to any of these accidents, but it may be reasonable to assume, in the four cases involving mechanical problems, that the high workload was not itself the primary cause of the overarousal.

Other causes of accidents

Personality:

In 34 investigations the personality of a crewmember or other relevant person was considered a possible contributory factor. Twenty cases fall into one or other of two definable sub-groups, nine in one, eleven in the other. The smaller group is characterised by comments in the subject's personal records such as: "underconfident", "nervous", "prone to over-react". Six of the nine cases involved mishandling of an emergency; one probably involved over-reaction to a mis-identified emergency. The larger group is identified by the following descriptors: "over-confident", "reckless", "disregards rules". The results of this attitude included deliberate excitement seeking (eg illegal low flying) and exhibitionism, as well as pressing on into difficulties without much thought. Two mid-air collisions and four collisions with obstructions, the ground or the sea resulted.

Supervision and ergonomics:

Poor display design accounted for 14 of the 34 accidents in which ergonomic deficiencies played a part. Nine were ascribed to poor cockpit layout and eleven to poor control design. Combining the two supervisory categories (training and briefing and administration) with the ergonomic category reveals that 65 accidents (44%) involved enabling factors generated by the system rather than by the aircrew themselves.

Cognitive failure:

Cognitive failure was a primary or contributory cause of 26 accidents. Nine of these involved actions omitted by the crew, usually from a very familiar drill; 19 involved substitution of inappropriate actions for those intended. In seven cases, distraction provoked or enabled the cognitive failure to happen. In ten cases fatigue or underarousal was considered a predisposing condition. Eight cases of cognitive failure were also associated with life stress. The most common result of cognitive failure was a wheels-up landing - ten cases in all.

DISCUSSION

Overarousal:

The origins of acute overarousal appear to fall into several subgroups. About half of the overarousal related accidents (13% of the total sample) involved mechanical failure, sometimes as a result of operating hazards such as birdstrikes or lightning strikes. Another important subgroup is overarousal due to disorientation. Other specific causes were problems arising from mishandling, cognitive failure or supervisory failings. Overall the first impression is of specific, single causes of overarousal, usually with a sudden onset, rather than a gradual accumulation of several minor stresses. Specific remedies might, therefore, be found in improvements in simulator training - to improve responses to emergencies - and in better presentation of attitude information. Attitude displays that address the ambient visual system rather than central vision could be of real benefit in reducing the probability of disorientation (3).

Life stress and personality:

Indications that specific, single causes of stress do not constitute the whole picture come from the data associating personality characteristics and life stress with aircrew error. Life stress has commonly been assumed to contribute to stress-related errors and has been the subject of some attention in recent years. Alkov and Borowsky (4) and Alkov et al (5) found a number of life events to be associated with involvement in aircrew error accidents. These included:

- Recent engagement to be married.
- Recent loss of a friend or relation through death.
- Marital problems.
- Recent major career decision.
- Recent trouble with peers, subordinates or senior officers.

Some additional factors seemed to be more descriptive of personality characteristics than life events:

- Lacking in maturity or stability.
- Lacking in a sense of humour concerning self.
- Experiencing difficulty with interpersonal relationships.
- Slow to assess potentially troublesome situations.
- Lacking professionalism in flying.

It is possible to interpret two of the five life events listed above (marital problems, trouble with other officers) as also reflecting immaturity or inadequacy in coping with interpersonal relations. In fact, Alkov et al interpret the findings of the two studies as indicating that social maladjustment may be a good predictor of aircrew error and they place little weight on the remaining life events. What, then, is the role of life stress? As indicated above, in only two of the 17 cases where life stress was recorded as a possibly relevant background variable was it possible to see a direct relationship between the life events and the behaviour that caused the accidents. These may be regarded as rather special cases. It is, of course, inevitable that any sizeable sample of aircrew should carry a burden of some marital disharmony, some illness, domestic upheavals and problems at work. Without a control group, it is impossible to know whether these problems are over-represented in our sample of accident victims. For the moment, the case for life stress as a direct contributor to aircrew error is, at best, not proven, and must be regarded with some suspicion until more substantial evidence becomes available. McCarron and Haakonson (6) came to a similar conclusion after surveying life events among Canadian pilots. This would probably represent the attitude

of many aircrew themselves. For many the cockpit of a high performance aircraft provides a welcome refuge from down-to-earth pressures and annoyances.

The role of personality in aircrew error accidents appears to have at least two discernible aspects which account for 20 out of the 34 personality-related accidents. One aspect has a bearing on stress. Some individuals previously described by their supervisors as underconfident or nervous failed to cope when presented with emergencies or unusually demanding conditions. Precipitate, inappropriate action was a common style of error. The second group, described as overconfident or reckless, either sought excitement in unauthorised ways, or was oblivious of or slow to recognise risks. Levine et al (7) found that questionnaire items concerned with adventurousness or risk taking were associated with accident occurrences among U.S. Navy aviators. However, in a review of personality studies, Farmer (8) found that despite the existence of some evidence implicating extraversion and neuroticism, overall the evidence was inconclusive and contradictory. The two studies by Sanders and Hoffman (9) and Sanders et al (10) provide an instructive example of the difficulty of obtaining stable correlations between personality data and accident statistics. If the data presented here are any guide, it seems likely that both unstable introverts and unstable extraverts have their own idiosyncratic risks. This would certainly make it harder to demonstrate a simple correlation between extraversion/introversion, as measured by personality tests, and accident-proneness. There seems little prospect of identifying the high risk personalities with a useful degree of validity at the selection stage. However, given that supervisors are already demonstrating some awareness of relevant personality characteristics, it may be worthwhile attempting to supplement their observations with formal personality tests. These could provide the basis both of guidance for supervisors and of counselling for individuals.

Fatigue and workload:

Fatigue and high workload were both associated with relatively few stress-related accidents. It is no surprise that nearly 40% of the fatigue-related accidents involved night flying. Perhaps more interesting is the fact that domestic activities contributed to fatigue in a similar number of accidents. Both sources of fatigue should be controllable by suitable supervisory action.

Cognitive failure:

The largest homogeneous class of immediate causes of accidents appears to be cognitive failure (17%). This represents a peculiarly difficult problem to tackle, because, to a large extent, being well trained and experienced is a requirement for this type of error. Reason and Mycielska (11) found that people reporting cognitive failures were more often preoccupied (at the time of the mistake) than not, and also tended to be tired or sleepy rather than emotional or excited. There are parallels in the present data. Ten out of 26 cognitive failures were associated with fatigue or underarousal (five resulted from overarousal); eight were associated with life stress - a possible source of preoccupation. There is a more complicated link between cognitive failure and life stress, however, and one that takes account of the intuitively obvious fact that individuals differ in their response to life stress.

Broadbent et al (12) showed that proneness to cognitive failure is a relatively stable trait and that those who are prone to cognitive failure are more likely to develop minor symptoms in response to stress than those who are not. Broadbent later argued (Broadbent et al (13)) that the basis of the trait lay in differences in cognitive style, those with a more obsessional style being both less vulnerable to chronic stress and less subject to cognitive failure. He also suggested that cognitive styles become more extreme under stress. Thus, although the evidence for life stress as a direct cause of accidents is doubtful, it may have a relevance in identifying those who are most liable to cognitive failure, and, possibly, their times of highest risk. Some piecemeal remedies for cognitive failure, involving redesign of equipment, are possible. There is also a clear need for a valid, objective test of liability to cognitive failure, and for techniques of remedial training in cognitive style.

System factors:

It is a truism that complex systems, like aviation, can never be free of human error. The present data indicate that, in a substantial proportion of accidents (44%), significant errors were made by people remote from the critical events. These errors included design of equipment, inadequacies in training and briefing and administrative failures. Often the errors were not obscure or complex. Many of them were surely identifiable as potential hazards before they caused an accident. The only practical remedy for system errors of this type requires aviators to take a closer interest in the way their system operates and, perhaps more important, the relevant authorities should encourage a questioning attitude and be prepared to support changes to the system in the interests of flight safety.

CONCLUSIONS

Although overarousal makes a significant contribution to aircrew error accidents, it appears, in general, to result less from generally high levels of stress or the cumulative effects of small stressors than from specific, provocative events. Mechanical failure and disorientation are two significant classes of provocation. Specific remedies in the form of improved simulator training and enhanced presentation

of attitude information are at least conceptually feasible.

The role of life stress in accidents appears ill-defined. It seems unlikely to be a direct causal agent, and whatever significance it has may be related to some aspects of personality (social maladjustment) or cognitive style. Fatigue made a small contribution to the accidents investigated, largely in connection with night flying and, interestingly, tiring domestic activities. Nearly half the accidents involving fatigue were due to cognitive failure.

Two distinct classes of personality problem are discernible in the data. One involves overarousal in response to emergencies or other demanding circumstances, and appears to be the province of unstable introverts. The other involves excitement seeking and disregard of risks by unstable extraverts. The use of personality tests to provide guidance for supervisors and counselling for aircrew is a possible remedy.

A major cause of aircrew error was cognitive failure. Although some cognitive failures occurred in stressful conditions, they were more likely to happen in normal, undemanding circumstances, or when the aircrew were fatigued or underaroused. General remedies for this type of failure are not available and should be a priority for future research.

Nearly half of all the aircrew error accidents involved some contribution from design deficiencies, inadequacies in training or briefing, or administrative failures. Such errors represent a significant challenge for both designers of equipment and those authorities responsible for the training of aircrew and the control of flying activities.

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Appendix A: Human factors classification

AIRCREW FACTORS

- alcohol
- disregard for rules
- excess of zeal
- fatigue
- hypoglycaemia
- inexperience
- joie de vol (unnecessarily spirited or adventurous manoeuvring)
- lack of airmanship
- lack of talent
- life stress (exciting or worrying personal or domestic events)
- low morale
- personality
- QFI checking another QFI; reluctance to take control
- sensory limitations - visual
- social factors/crew co-ordination
- underarousal

SYSTEM FACTORS

- aircraft handling characteristics
- ergonomics - displays
- ergonomics - cockpit layout
- ergonomics - controls
- logic errors in automatic systems
- noise/communication
- operational pressures
- time pressure
- training/briefing
- administration
- physiological stress (usually heat)
- high workload
- under fire

MODES OF FAILURE

- cognitive failure - inappropriate action
- cognitive failure - omission
- disorientation
- distraction
- 'giant hand' experience
- inappropriate decision
- inappropriate model
- inappropriate spatial model
- overarousal
- slow response
- stress
- unawareness episode
- visual illusion