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CHAPTER 13

THE ASSESSMENT OF WORKLOAD IN HELICOPTERS

by

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The value of inflight assessment of pilot workload has been recognised by aviation researchers and designers for over a decade (1) (2). Initially the subjective reporting of workload by experienced test pilots was based upon an application of the Handling Qualities Rating Scale of Cooper and Harper (3). This subjective reporting led to the development of rating scales for the assessment of workload (4). These subjective techniques were later augmented by the recording of physiological variables which could be interpreted as indices of workload (5) (6).

In the last decade, rather than restrict the assessment of workload in aviation to data obtained from test pilots, studies have been reported in which small samples of professional pilots have been used (5) (6). A more recent development has been the employment of workload measures for exploring differences between pilots and to look for correlations between these measures and performance, and success in training (7). Workload estimation has additionally been used to assist in the ergonomic design of systems including crew station geometry, and control and display location (8) (9).

In these, and other cases, the requirement to measure workload has had a practical and 'applied' character. It results from a need to specify and predict the future performance of the operator within a system; to determine what effect will result from changes to an existing system, or evaluate the consequences of entirely new procedures or technology. To this extent workload is fundamental to a wide variety of disciplines.

Although there is broad agreement on the importance of workload, partly as a consequence of the wide range of areas to which the workload concept may be applied, there is no universally agreed definition. In any investigation in which an assessment of workload is to be made, a definition will obviously be required as a basis for both briefing subjects and interpretation of the results. A definition which is frequently used in both aviation and other areas is "the combination of physical and mental effort required to complete the task".

Workload concepts may in fact be refined into 'physical' and 'mental' subsets, represented at extremes by the power output of manual workers to studies of 'decision making' (10). The pilot's task is a combination of the two, with advances in technology emphasising the mental element, ie, monitoring, anticipating, decision making, the need for the pilot to wrestle with the flight controls is largely dated. However, for the military pilot these same technological advances are tending to degrade the physical conditions under which performance is required, eg, increased g, thermal changes, longer duration sorties, more restrictive (albeit more efficient) protective assemblies. Similarly, the air transport pilot encounters more sectors in a duty period, or more rapid change of time zone.

Besides the approaches of different disciplines to the investigation of workload in aviation, there are two other conditions, which at a fundamental level, are extremely difficult to isolate from workload; these are stress and fatigue (10). The concepts if not defined in terms of one another, are implicitly inter-related. Thus if workload is defined in terms of effort (as above), such expenditure cannot be continued indefinitely, hence fatigue. Increased workload will therefore imply the faster onset of fatigue. In turn the mental and physical concomitants of exhaustion may be characterised as stress. Stress results from an excessive demand on the individual.

Workload studies may be employed to determine the current and potential operating capacity of a system. It may be that the material assets are fixed, by that re-scheduling, or re-rostering of crews, or re-defining their duties can allow greater efficiency. For the military, an aim may be to achieve greater combat efficiency, whilst in civil aviation it may be to take on extra routes or services. Other objectives, which are not exclusive may include, increased reliability, efficiency or safety.

Thus workload assessment is frequently a component in a programme with externally defined objectives which tends to follow a particular pattern.

The stages which might be required for a programme of research, and the reasons for their inclusion can best be described by reference to a specific study. One study of this nature, currently being conducted by the authors, is to determine the appropriate allocation of tasks between two pilots manning an Army helicopter.*

The research is undertaken in 5 discrete steps. These are described below and summarised in Figure 1.

STAGE 1: DEFINITION OF PROBLEM AND RESEARCH OBJECTIVES

When any programme of research is required, prior to the actual commencement of work, there is the rather obscure phase of the organisation requiring the research (sponsor) coming together with the researchers (who may be internal or external to the organisation). Initially it may be difficult for the organisation to recognise the true nature of problems which may

* The Army Personnel Research Establishment (UK) have commissioned the College of Aeronautics at Cranfield Institute of Technology to carry out a programme of research in order to determine task allocation between helicopter pilots and to develop Standard Operating Procedures.

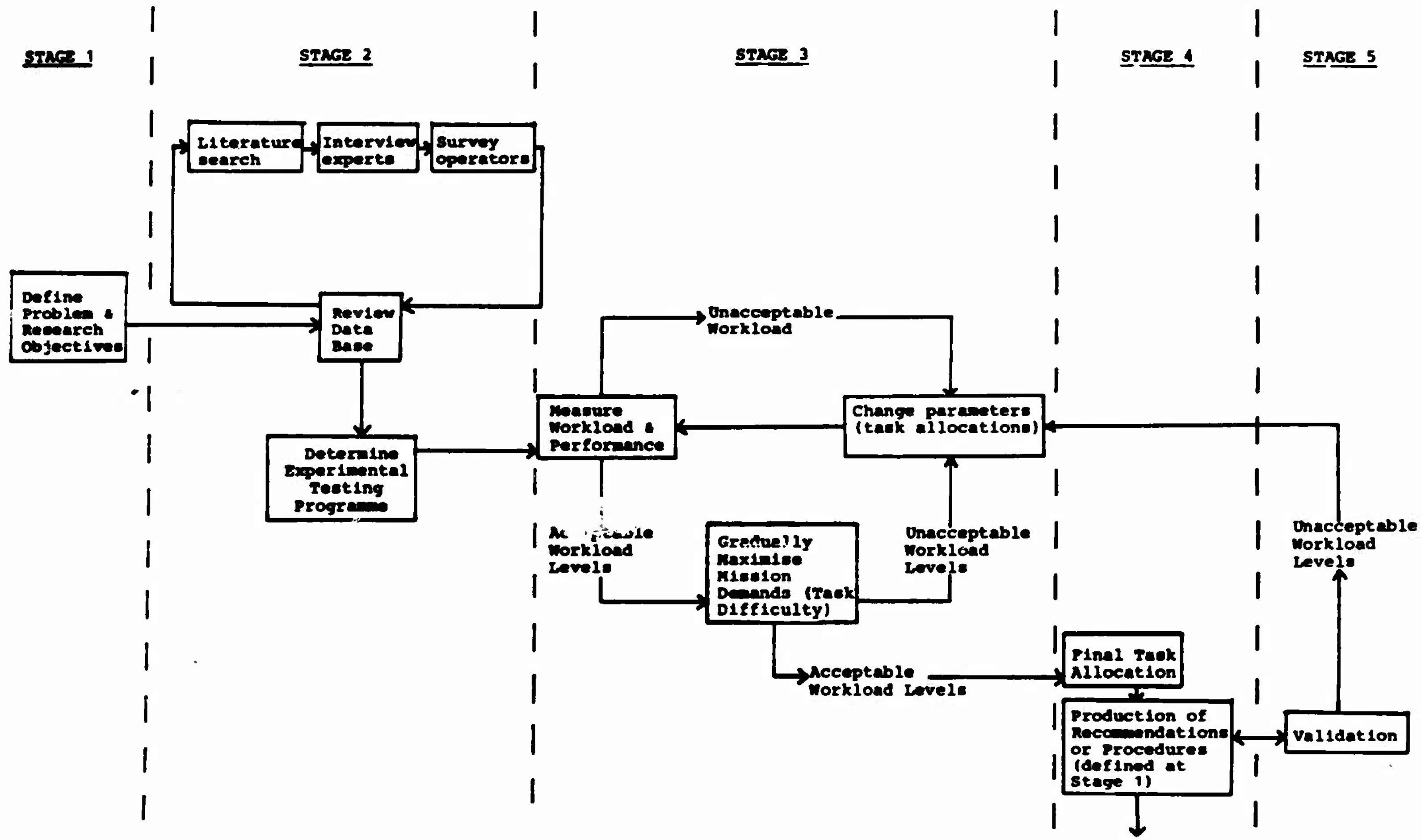

Fig.1 Summary of research stages

have arisen over time or be generated by operational change. The organisation may not be aware of the contribution human factors research and the benefits of rigorously applied techniques can make to resolving such changes; and confusion is likely to exist about what constitutes an optimum resolution.

The ideal case is when an organisation either recognises an existing problem, or foresees one in the future. It is important to realise that the problem may range in scale from a high accident rate through poor crew communication, air traffic procedures, to rostering. The problem may not only involve the flight crew. A problem becomes amenable to human factors research, and particularly to workload assessment techniques, when there is an involvement of people in the process and it is believed that it is the performance of these people which is the limiting factor.

The sponsors, having identified a problem, accepted the need for behavioural analysis, and engaged researchers, must define their objectives. These are the objectives by which a solution derived from workload assessment techniques may be judged. Whilst this is of critical importance to the validation of the study (discussed below), it has the additional advantage of forcing the sponsors to consider fully the implications of their identification of a problem.

In the helicopter study currently being undertaken by Cranfield, as part of Stage 1 it was agreed with the Army Air Corps that the primary objective of the research would be to determine the appropriate allocation of tasks between two pilots manning an Army helicopter. This would be derived by separately assigning flight and combat tasks to crew members. The emphasis would be upon the operational employment of the helicopter. This would be achieved by analysing crew workload during flight and subsequently determining which crew member would best perform which tasks. Analysis of current and projected mission profiles would be undertaken to determine how these affect task allocation between the crew. Finally, Standard Operating Procedures would be drafted.

The complexity of the aircrew task together with the need to reproduce with maximum fidelity and conditions prevailing whilst actually flying at ultra low level meant that objective evaluation of aircrew workload had to be taken in the air with representative missions. The use of simulators and non-aircrew subjects of "equivalent" tasks was not considered to be sufficiently representative.

STAGE 2: REVIEW OF THE DATA BASE AND DETERMINATION OF THE EXPERIMENTAL TESTING PROGRAMME

Included in the concept of the Data Base are the abilities, skills and techniques of the researchers themselves, the information that can be derived from the appropriate academic, and organisational literature, and knowledge that is held within the organisation itself. For instance, management may be aware of a problem, but unclear about the details of related processes, these being the province of experts.

This in turn can contribute to the difficulty in identifying a problem: for instance when senior pilots are promoted into management positions this can occur, either because they are cushioned by their status from everyday operations or the system has evolved subsequently.

On the flight deck, the experts are the instructors and training captains. Detailed individual interviews with them will increase the researchers understanding of how the operations proceed, and normally provide clear insight into the scope of the problem under investigation. The other major source of information will be the ordinary flight crews. For this large group a survey of opinion, by questionnaire, is frequently the most appropriate method of data collection.

It is clear that the ways in which the Data Base can be refined are as varied as the operations that are under investigation. Also that the depth of analysis required is variable, whilst the sources of information that could be consulted, freed from constraints of time or cost, are virtually unlimited. The duration and extent of this phase is therefore dependent upon the research team's prior knowledge. Ideally, the research team should include a psychologist and a pilot.

In the helicopter study, this stage involved a literature search and a series of informal and semi-structured interviews with experts in aircrew training, tactics, standards and safety from the Unit which had the requirement for the investigation and who were responsible for the operation of the missions.

The technique of semi-structured interviews involves the use of sequentially structured general questions which lead to choice or branching questions. Having registered a preference in response to a particular question the interviewee is then asked to describe the reasons for their choice. The interview may be recorded on tape in order that the responses from all of the interviewees may be pooled and used to provide information for subsequent stages of the research.

The importance of these interviews should not be underestimated since without their inclusion assumptions may be made regarding organisation and deployment in the operational unit based exclusively on the beliefs of the commissioners of the study and the researchers. Data from this stage provide information regarding current and proposed mission profiles and an exhaustive list of potential crew tasks (and potential allocations) together with priorities and as assessment of criticality to mission success.

This stage also involves the construction of a questionnaire based upon the results of the interviews asking for subjective ratings of workload for the tasks identified on representative missions. This is applied to current aircrew members and to the experts who initially provided the information. This should be supplemented within a small percentage of the former group by short informal interviews. Stage 2 strengthens the representativeness and validity of the data collected.

As part of Stage 2 a representative sample of aircrew who will be required to participate in Stage 3 is determined. Studies are reported in the literature, especially regarding workload and cockpit assessment in which the sample was limited to a number of pilots who were unlikely to represent the full range of the user population.

Helicopter pilots may be called upon to undertaken an almost infinite variety of different sorties, each of which will impose a particular load upon the crew. To utilise workload measurement techniques effectively requires that this variety is reduced into a set of standardised (and hence reproducible) profiles. Within these profiles the facility must be available to change the loading on different crew members, and a promising and quantifiable technique is to vary the communications load according to the level of difficulty that is desired.

Derivation of suitable profiles in the helicopter flight regime follows from the analysis of the aircraft tasks (via interviews and workload questionnaires) and a study of the ways in which such tasks are carried out. This information may be obtained from the Operations Manual of a civil company, or the Tactical Doctrine promologated by a military operator. Shown in Figure 2 is a 'Simple' mission which might be undertaken by a reconnaissance helicopter of the British Army Air Corps. The task briefed might be to look for the enemy, from a defined geographical area, and to report any sightings. The transit to the area can be made more or less demanding of map-reading and low flying skills by imposing "realistic" constraints, such as imaginary artillery positions, drone launches. Radio communications can be required to increase the cockpit activity.

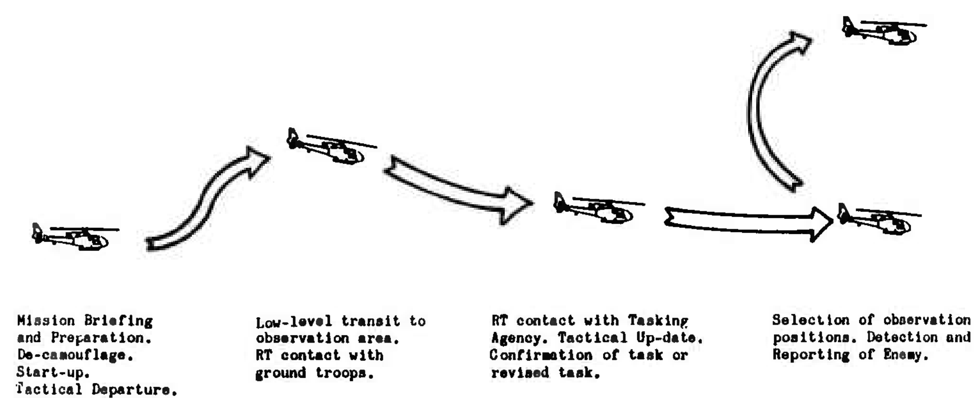

Fig.2 Hypothetical 'simple' mission for reconnaissance helicopter

The selection and occupation of observation positions is a demanding activity in itself, whilst detecting, and subsequently locating the enemy on a map can be varied by using actual vehicles to provide a real target. A further performance measure may involve the 'enemy' using a video system to record occasions when the reconnaissance helicopter is visible, and hence vulnerable, ie occasions of poor performance.

This 'Simple' mission can be extended (as demonstrated in Figure 3) merely by requiring the aircrew to complete the sortie. Thus the helicopter can be relieved by another (probably a notional one), and the crew must be briefed upon the current situation, whilst on the route back the tasking agency must be updated, and further navigation hazards can be introduced.

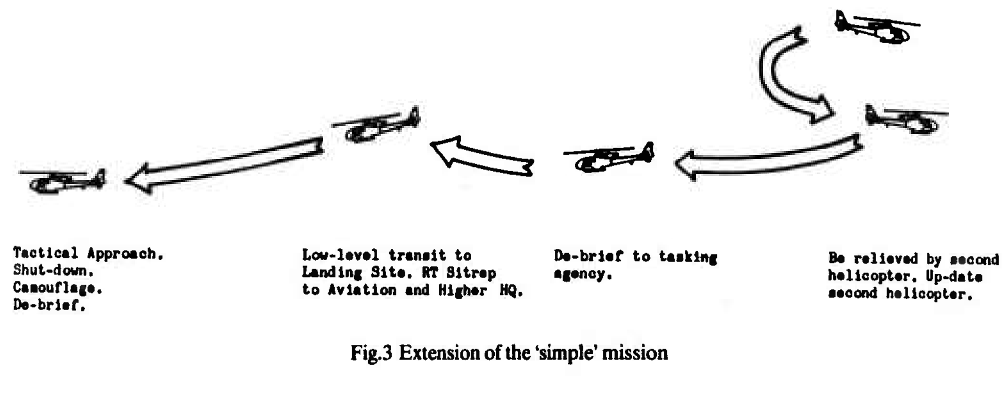

Fig.3 Extension of the 'simple' mission

A major increase in activity can be introduced by requiring the aircrew to make a more comprehensive identification of the enemy, and then assess its suitability for attack by various different weapon systems, eg artillery or Fighter Ground Attack aircraft. In the example in Figure 4 the appropriate system is Anti-Tank Helicopters. By the integration of other aircraft on normal training exercises, into the experimental sortie, the aircrew task can be made as realistic as possible.

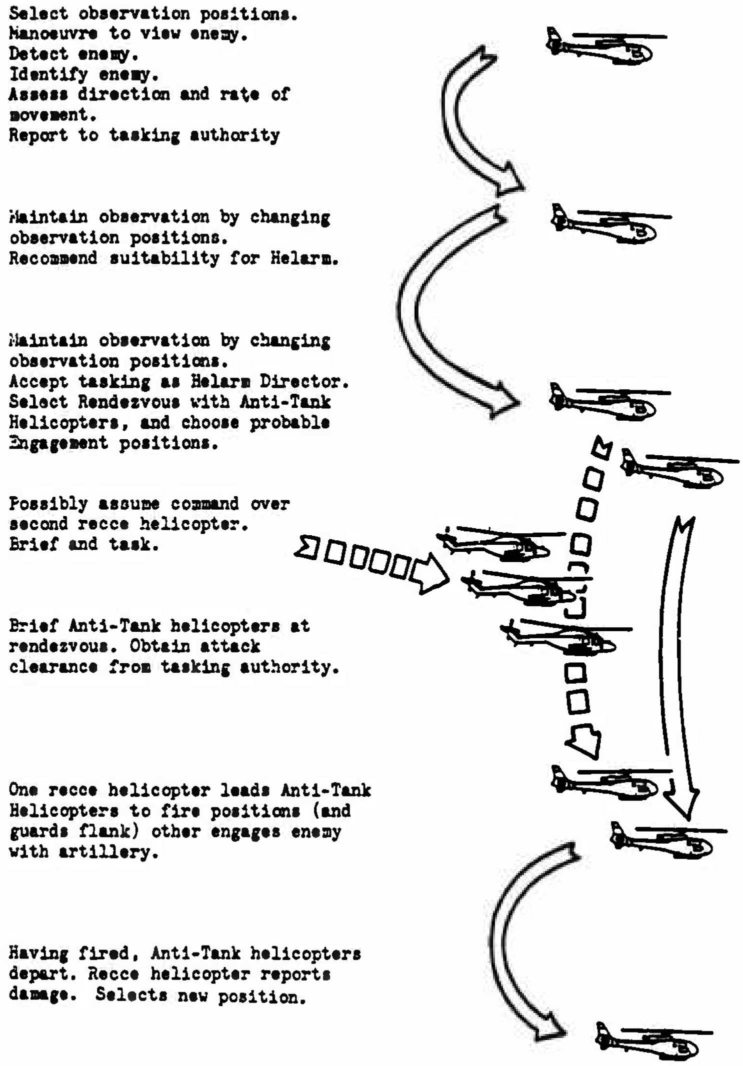

Fig.4 Possible increase in mission difficulty

STAGE 3: MEASUREMENT OF WORKLOAD AND PERFORMANCE

While the variety of techniques devised to study workload is extensive (11) those that may be applied on the flight deck or in the cockpit are few in number, and the methodological and technological restrictions cause severe constraints. Most significant are the safety implications of equipment, compatibility with aircraft systems, and potentially hazardous interference with crew activities (12). Already perhaps encountered in the interview and questionnaire stage may be a misapprehension about the purpose and outcome of the research. From the individual's point of view these fears may be well grounded if, for example, the workload study was to determine whether two crew could do the work previously done by three (13).

This observational stage would involve the inflight assessment and workload measurement of the aircrew task. A member of the research team should fly with typical crews on representative missions determined at the end of Stage 2.

The workload data collected from the aircrew on these sorties falls into two categories:

a. Subjective ratings of pilot workload. It is important that a definition of workload is agreed by the research team and sponsors prior to the commencement of the study and that this definition is given to the crew as part of their briefing before the mission sorties commence. The workload rating used in the helicopter study is based on the Bedford Scale (14).

b. Psychophysiological indices of workload. Although the most widely used method for assessing workload is that of subjective rating, since it cannot be directly observed, the effects of workload may also be inferred from differences in measurable physiological functioning. There is a wealth of evidence that subjective ratings of workload may be usefully augmented by certain physiological indices (5) (15).

The selection of suitable measures will be influenced not only by the theoretical requirement for particular data but also by the feasibility of collection. Agreement between the various measures is frequently tenuous. This results from both the difficulty of obtaining reliable readings, and relating these to real-world events. To a considerable extent the restrictions that must be placed upon data collection in aircraft constrain the researchers' choice of methodology. Comprehensive reviews of the issues may be found in O'Donnell (16) and Wierwille (15).

In the helicopter investigation it was decided to limit the recording of physiological data to that of cardiac activity. The reasons for this choice were that the data can be reliably collected from both members of the aircrew with minimal interference and that such measures have been reported by most researchers as reflecting, to a considerable extent, cognitive as well as physical activity.

From the cardiac data two independent indices may be derived.

1 Mean Heart Rate — the instantaneous heart rate derived from measured time intervals between successive ventricular contractions (R-waves of the cardiogram) expressed as beats per minute.

2 Heart Rate Variability — this takes into account the normal physiological trend of mean heart rate and minimises its effect by considering observation order through difference scores.

Although mean heart rate and heart rate variability have been shown to correlate highly with subjective indices of workload, there is evidence to suggest that mean heart rate can be more valuable in situations of high workload whereas in situations of relatively low workload then heart rate variability may be the most sensitive measure.

In any task analysis or assessment of workload it is essential that both subjective and physiological indices of workload are related to objective measures of performance.

The experimenter must have criteria to assess aircrew performance, because it is when performance falls below the specification that one may say that workload is excessive. In the relatively straightforward assessment of performance in, for example, fixed wing public transport aircraft, accuracy in maintaining flight parameters might suffice. In contrast, if the speed height and direction of the combat helicopter are not changing the experimenter must suspect overload.

Video pictures of cockpit activity provide the most accurate and objective recording of events, particularly when compared to either observer or the subject's own reports. In the helicopter study video cameras will be mounted in the cockpit of the helicopter and will be used to provide video recording of the cockpit activity and crew interaction. An additional advantage is that the record is permanent and this will allow the re-analysis of early sorties as the data from subsequent ones is obtained. An adaptation of the methodology developed by Lovesey will be used for the analysis of the video recording.

The member of the research team who is trained both as a pilot and a psychologist, will fly as an observer and record gross crew activities as the sortie progresses. The intercom and radios will be taped to provide a record of crew interaction.

Analysis of the performance data from the observer reports, as well as the recordings from the video, intercom and crew radios will allow an accurate record of crew activities to be compared against objectively specified mission parameters. These parameters will have been developed from the data obtained from Stage 2.

Cardiac recordings time locked to the activity record will permit the independent assessment of pilot workload. This will be correlated with the aircrews' own assessment of the effort involved. It will then be possible to estimate and compare the workload of the crew at succeeding intervals of the flight, and to relate physiological and behavioural measures to mission elements. The recordings may also highlight occasions of under or over loading either crewmember.

Consideration was given to instrumenting the aircraft flight controls or recording flight path data, however a number of factors led to the rejection of this suggestion when using workload techniques to determine crew loading. Not the least of these was the sheer quantity of data which would be collected. Should the data be collected, it may be of limited use, as skilled performance, especially motor performance, does not decline steadily under increasing workload, rather it continues relatively unchanged until catastrophic failure. In addition only the performance of the handling pilot would be recorded.

If the results from the task analysis indicate either decrements in performance or unacceptably high levels of workload, it will be necessary to change a parameter within the operational flight setting, and repeat the observational process. For reasons of safety, the experimental technique will be to increase task difficulty with successive sorties. This will be achieved by increasing the frequency of task related activity.

STAGE 4: PRODUCTION OF RECOMMENDATIONS AND PROCEDURES

When the test conditions are satisfied the research team should specify revised or new procedures or recommendations. These should resolve the problem and meet the objectives initially identified by the project sponsors at Stage 1. In the helicopter study, this will be the appropriate allocation of tasks between two pilots manning the army helicopters and the development of Standard Operating Procedures.

STAGE 5: VALIDATION

The importance of testing the procedures or recommendations derived from Stage 4 on an independent group of subjects for the purposes of validation cannot be overemphasised. In the helicopter study this will be done by replicating certain of the mission sorties using crews from squadrons which were not involved in the original experimental programme. A representative sample of crews would be required to carry out a number of missions which had been included in the original test programme in Stage 3 and to follow the newly developed Standard Operating Procedures. Performance and workload data would be collected throughout the sorties. Any findings of unacceptable levels of workload or performance would indicate a requirement to revert to a Stage 3 and carry out a second phase of observations. Finally, the findings from the research programme should be checked against the objectives determined at Stage 1.

SUMMARY

In aviation an assessment of workload is frequently used as one component in a programme of research. The objectives of the research may vary from an assessment of the activities of the crew to an evaluation of either cockpit modifications or operational changes. Thus workload assessment will form one of a series of stages in the research. A model is presented in which the stages of the investigation which will proceed and follow the workload assessment are described. An application of this approach to the assessment of workload in helicopters is used to illustrate the practical implications of the model.

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