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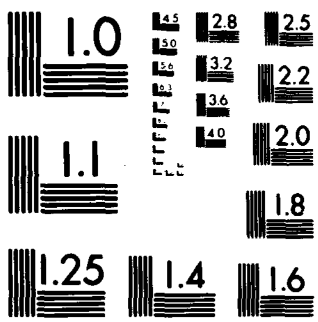

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AGARD ADVISORY REPORT No. 139

Technical Evaluation Report of the Aerospace Medical Panel Working Group WG-08 on Evaluation of Methods to Assess Workload

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NORTH ATLANTIC TREATY ORGANISATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

AGARD Advisory Report No.139

TECHNICAL EVALUATION REPORT

of the

Aerospace Medical Panel Working Group WG-08

on

EVALUATION OF METHODS TO ASSESS WORKLOAD

by

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This Advisory Report was prepared at the request of the Aerospace Medical Panel of AGARD.

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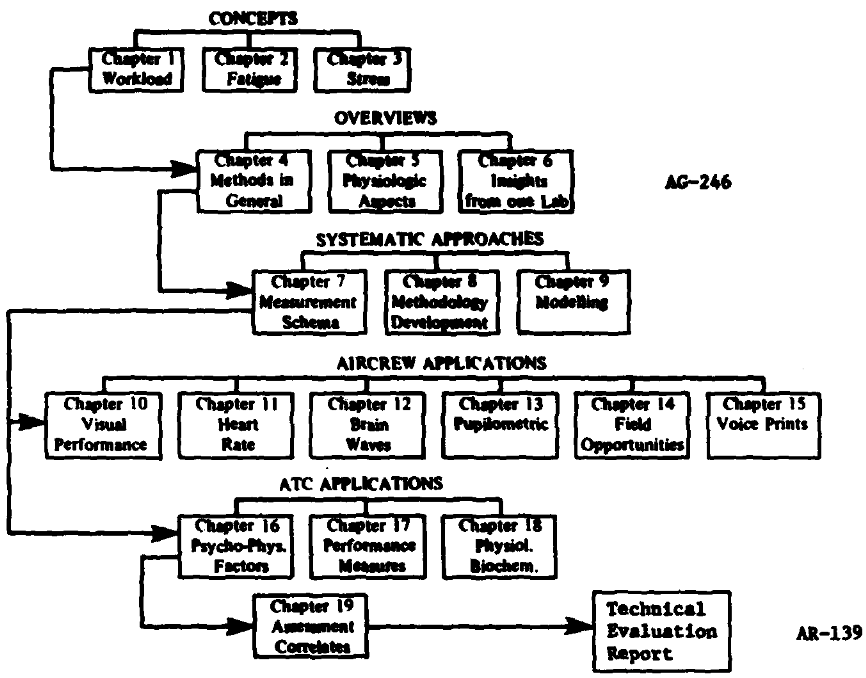
FOREWORD

The Aerospace Medical Panel of AGARD established a working group (AMP-WG-08) on "Evaluation of Methods to Assess Workload" in the fall of 1976 following approval by the National Board of Delegates. Working group meetings were held at Cologne (April 1977), London (October 1977), Fort Rucker, Alabama (May 1978), and Paris (November 1978) concurrent with meetings of the panel. A multi-author report was prepared and published as an AGARDograph (AG-246, "Survey of Methods to Assess Workload") in August 1979. That document contained 19 chapters, which can be viewed graphically as follows:



This technical evaluation report will look across the 19 chapters displayed above, with the goal of providing a critique and overview.

CONTENTS

I. INTRODUCTION

There are few members of the several AGARD Panels who do not have strong interest, firm opinions, and frequently practical experience in problems of pilot workload. It is an area of multidisciplinary concern and activity. Reports, papers, symposia, working groups are as likely to come, for example, from the Flight Mechanics Panel or the Avionics Panel, as from the Aerospace Medical Panel. It is important, therefore, to set the stage for this report. Most of the contributors to AGARDograph No. 246, "Survey of Methods to Assess Workload," had something to say on this issue. Consider the following quotations from that AGARDograph.

Chapter 1: "In ordinary uncritical discourse, the phenomena referred to by the terms "pilot workload" and "fatigue" are easily distinguished. In its broadest and simplest aspect, pilot workload refers to how much a pilot must do to perform a specified flight operation. Fatigue is widely understood as a feeling of tension or weariness, often accompanied by an obvious unwillingness or inability to continue to work or perform. However, when attempts are made to quantify the workload imposed on a pilot by a particular aircraft design, or operational procedure, or to assess the effects of fatigue upon system performance, important unresolved issues arise in regard to the more precise specification of workload and fatigue concepts and to the adequacy of assessment criteria and techniques."

Chapter 2: "Welford (1953) . . . would agree that fatigue is a consequence or concomitant of workload."

Chapter 3: "Mission and operational requirements present the modern pilot and crew with ever-changing complex tasks which provide another form of stress. These major sources of aircrew stress are compounded by the individual's internal psychophysiologic reaction to stress . . ."

Chapter 4: "It would certainly be interesting and important if it were possible to define the degree and limits of psychophysical workload by means of technically valid . . . differential qualitative and quantitative assessments of the various flying specializations. In fact, numerous methods have been proposed periodically for obtaining a measure of workload by quantitatively evaluating the functional changes that fatigue can produce."

Chapter 5: "It is important to recognize that the physiological mechanisms of the organism do not particularly care nor are they necessarily aware that they are reacting to the effects of workload, the effects of fatigue, or the effects of stress. Physiological mechanisms provide a link between the concepts of workload, fatigue, and stress."

Chapter 6: "The term workload is a somewhat ambiguous concept that can be defined in many ways. We feel that workload encompasses the concepts of performance, fatigue, and stress, any one of which can be defined in terms of the other."

Chapter 7: "When one reviews the research literature pertaining to mental workload, two conclusions are readily apparent. Namely, there is no single, agreed upon definition of mental workload, and there is no single, universal metric of it. Mental workload is a theoretical construct, and as such, might best be defined operationally. Clearly, it is related to factors such as operator stress and effort, but these concepts also require operational definitions. Reising (1972) provides an excellent overview of the difficulties and complexities involved in defining and measuring workload. Rather than provide a single definition, one must consider the various operational definitions used in measuring operator mental workload. The systems engineer, for example, may emphasize operational definitions based on time available to perform a task. Psychologists tend to emphasize the information processing aspects of mental workload and operationally define it in terms of measures related to channel capacity and residual attention. Physiologists, on the other hand, emphasize considerations of operator stress and arousal."

Chapter 8: "The principal objectives of a supportive workload research and development program should be (1) estabishment of a set of theoretically-consistent component functions descriptive of the performance of crew members in relevant system tasks; (2) development of quantitative (mathematical) expressions of relationships between input-output parameters for the component functions and appropriate combinations thereof; (3) integration of the results of (1) and (2) above into a task analytic/computer modeling methodology; and (4) validation of the analytic/predictive methodology in a system design, development, and test effort."

Chapter 9: "A central goal of a military workload analyst is to understand the determinants of mission success in a military setting. The emphasis is on the human determinants of mission success with particular consideration to how the human uses the system he is given to accomplish the mission at hand. In quantitative workload analysis, the final goal in many instances is to provide various numerical measures of mission performance. . . A workload analyst studies the system under consideration to determine its capabilities and, when appropriate, he designs system changes or modifications with a view to improving system performance."

Chapter 10: "Operator workload for the task of vehicle manipulation perhaps could be defined as the sum of and cognitive processes. Sensory inputs to the operator are utilized to direct control manipulation, obtain feedback as to degree of effectiveness of the control movements, and to monitor system status. This input workload is combined with the psychomotor workload required to move the vehicle controls as dictated from the sensory inputs and feedback modes. More simply stated, workload measurements can be derived by objectively measuring the input and/or output of the operator."

Chapter 11: "The important and close relationship between aircraft handling qualities and pilot workload has been underlined by several authors."

Chapter 12: "Perhaps more progress has been made toward the utilization of brain wave information for the enhancement of pilot performance in the area of monitoring and assessment of workload than in any other area . . . (to achieve acceptable pilot performance) . . . The available resources must be sufficient to meet the demands imposed by all tasks which challenge the operator at any time: the characteristic of task workload or reserve capacity . . . Even when the resources are adequate, the attention must be allocated properly to the critical tasks, displays, or sources of information, so that important sources are not ignored: the characteristic of attention allocation. The distinction between workload and allocation are crucial."

Chapter 13: "The assessment of pilot workload is a special case of the measurement of information-processing load, the aggregated demands placed upon an individual in the performance of a particular cognitive task or function. Three general approaches have been employed in the measurement of information-processing load. The first is that of subjective estimation. Subjective estimates are involved when workload is estimated from the task engineer's opinion as to the probable magnitude of processing load, an opinion that may be based on previous experience or an analytic theory. However, subjective estimates of workload by the user or participant are the most common form of workload measurement in aircraft design. . . The second major method of measuring processing load employs behavioral measurement. Here the notion is that the information-processing capacity of an individual is limited so that the workload imposed by one task can be estimated by the degree to which it interferes with the simultaneous execution of a secondary measurement task, such as simple reaction time or manual tracking. . . The third major method is physiological, in which the response of the nervous system to the load imposed by an information-processing task is assessed. Momentary increases in processing load induce short-latency, short-lived increases in measures of central nervous system activation. These changes are most evident and most easily measured in the autonomic nervous system."

Chapter 14: "Of prime importance to research workers dealing with aviator workload, stress and fatigue is the intriguing notion of an on-line pilot monitor system during air combat missions. Long considered to be one of the more stressful and demanding pilot tasks, an air-to-air engagement taxes the pilot physically, mentally, and perceptually. The possibility of complementing on-line pilot performance measures with on-line physiological measures such as heart rate, blood pressure, etc., would provide an ideal arrangement for the research team interested in validating laboratory notion of stress, fatigue, or workload in an operational 'real world' environment. A word of caution is advised. Some research teams used to the controls and precision design of experiments in the laboratory will be limited in their attempts to control the real world. But that is exactly the point. Many laboratory studies stress the statistical significance of results without strong support for practical or operational significance. In pilot workload, for example, the amount or severity of workload in either a 24-hour or flight segment is certainly useful to 'describe' the environment but does not by itself have any practical significance unless it can be related to performance effectiveness, short or long term. Our physiological reactions to stress or workload can assuredly be measured but it is only in the context of their relation to performance that they acquire operational significance."

Chapter 15: "The major concern of human engineering has been to develop command and control systems wherein better displays and more functional controls would enable the controller to better perform his demanding task and ultimately render it less stressful. Basic to this concern has been an attempt to define the controller's task and to identify certain aerospace events, such as number of aircraft, aircraft speed, control sector size, etc., which may be crucial factors in the controller's job performance. However, such studies have served only to point out that the real need in evaluating the efficiency of control systems, or of the operator himself, is the establishment of relevant criterion measures. Studies in this area, to date, have demonstrated that simple measures of various aerospace events which comprise the controller's workload do not fully relate to the complex stresses that are experienced in the job performance."

Chapter 17: "The workload experienced by air traffic controllers (ATCS) is difficult to define. One may consider imposed load objectively in terms of numbers of aircraft handled, but the subjective load perceived by the controller may be a greatly different quantity. Many factors may operate as workload modifiers either making the work easier or more difficult: (1) Type of traffic handled. One aircraft in distress may cause more "work" than all the other traffic being handled. (2) Weather. Controllers' perceived workload always increases when pilots cannot maintain visual separation in instruments' meteorological conditions. (3) Equipment outages and malfunctions causing reversion to manual methods of control. (4) Disruption of circadian rhythms caused by rotating shifts, and (5) General physical and emotional conditions resulting from a variety of off-duty activities and on-duty problems with management or peers."

Chapter 18: "The assessment correlates of workload, performance, and stress can be divided into several areas: those of physiological correlates, psychological correlates, stress correlates, psychophysiologic correlates, and finally, central nervous system (CNS) correlates. We realize that this is an artificial taxonomy and that many areas of overlap exist.

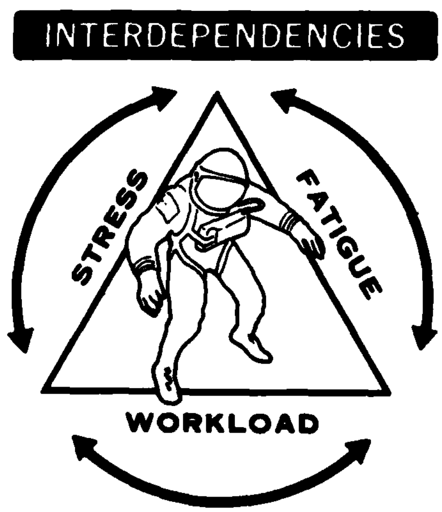
Several problems are demonstrated in these extracts. First, it is immediately apparent that no single definition exists. Second, even when contributors are limited to the biotechnology (aerospace medicine and supporting disciplines) community, a diversity of definitions and approaches emerge. Third, there is a substantial overlap between subelements of a biotechnology definition, e.g., between physiology, psychophysiology, psychology, etc. The range of definitions and approaches will, obviously, increase as the engineering community makes its inputs into the issues of definitions and approaches. This report will, in an attempt to maintain a simple framework, focus on what appears to this writer to be the most common elements of the problem as viewed by aerospace medicine:

a. Workload, fatigue and stress are different aspects of a larger problem; the larger problem is that of maintaining aircrew performance at acceptable levels.

b. There probably is no way to separate workload, fatigue, and stress in terms of definition, measurement approaches, or research strategies.

c. So far as physiologic mechanisms are concerned, the body doesn't know or care which of the three it is responding to.

Our approach to the workload problem can, therefore, be described graphically in figure 1, below.



II. ORGANIZING CONCEPTS

Before proceeding to a technical review of the many measures and methods appropriate to workload, it will be useful to consider some behavioral listings, categories, classifications, metrics, etc. These are offered to give the reader some organizing concepts as well as a preview of the complexity of the measurement problem. Of the following 5 tables, 4 come from Chapter 7 of the AGARDograph (No. 246) to which this technical evaluation report is addressed and the last comes from AGARD Conference Proceedings CP-216. Tables 3 and 4 not only provide overview kinds of matrices, but that each cell is annotated to indicate evaluations by the authors of Chapter 7, W. W. Wierwille, R. C. Williges, and S. G. Schiflett.

Table 1*

Classification of Universal Operator Behavior Dimension

(After Berliner, Angell, and Shearer, 1964)

Processes	Activities	Specific Behaviors
1. Perceptual processes	1.1 Searching for and receiving information	1.1.1 Detects
		1.1.2 Inspects
		1.1.3 Observes
		1.1.4 Reads
		1.1.5 Receives
		1.1.6 Scans
		1.1.7 Surveys
	1.2 Identifying objects, actions, events	1.2.1 Discriminates
		1.2.2 Identifies
		1.2.3 Locates
2. Mediational processes	2.1 Information processing	2.1.1 Categorizes
		2.1.2 Calculates
		2.1.3 Codes
		2.1.4 Computes
		2.1.5 Interpolates
		2.1.6 Itemizes
		2.1.7 Tabulates
		2.1.8 Translates
	2.2 Problem solving and decision-making	2.2.1 Analyzes
		2.2.2 Calculates
		2.2.3 Chooses
		2.2.4 Compares
		2.2.5 Computes
		2.2.6 Estimates
		2.2.7 Plans
3. Communication processes		3.1 Advises
		3.2 Answers
		3.3 Communicates
		3.4 Directs
		3.5 Indicates
		3.6 Informs
		3.7 Instructs
		3.8 Requests
		3.9 Transmits
4. Motor processes	4.1 Simple/Discrete	4.1.1 Activates
		4.1.2 Closes
		4.1.3 Connects
		4.1.4 Disconnects
		4.1.5 Joins
		4.1.6 Moves
		4.1.7 Presses
		4.1.8 Sets
	4.2 Complex/Continuous	4.2.1 Adjusts
		4.2.2 Aligns
		4.2.3 Regulates
		4.2.4 Synchronizes
		4.2.5 Tracks

*This and the next three tables are from AGARD-AG-246, "Survey of Methods to Assess Workload," Chapter 7, "Aircrew Workload Assessment Techniques."

Table 2

Classification of Workload Methodologies Dimension

- 1. Subjective Opinion
  - 1.1 Rating Scales
  - 1.2 Interviews and Questionnaires
- 2. Spare Mental Capacity
  - 2.1 Task Analytic
    - 2.1.1 Task Component, Time Summation
    - 2.1.2 Information-Theoretic
  - 2.2 Secondary Task
    - 2.2.1 Nonadaptive, Arithmetic/Logic
    - 2.2.2 Nonadaptive, Tracking
    - 2.2.3 Time Estimation
    - 2.2.4 Adaptive, Arithmetic/Logic
    - 2.2.5 Adaptive, Tracking
  - 2.3 Occlusion
- 3. Primary Task
  - 3.1 Single Measures
  - 3.2 Multiple Measures
  - 3.3 Math Modeling
- 4. Physiological Measures
  - 4.1 Single Measures
    - 4.1.1 FFF
    - 4.1.2 GSR
    - 4.1.3 EKG
    - 4.1.4 EMG
    - 4.1.5 EEG
    - 4.1.6 ECP
    - 4.1.7 Eye and Eyelid Movement
    - 4.1.8 Pupillary Dilation
    - 4.1.9 Muscle Tension, Tremor
    - 4.1.10 Heart Rate, Heart Rate Variability, Blood Pressure
    - 4.1.11 Breathing Analysis
    - 4.1.12 Body Fluid Analysis
    - 4.1.13 Handwriting Analysis
  - 4.2 Combined Physiological Measures
  - 4.3 Speech Pattern Analysis

Table 3

Applicability Matrix of Workload Methodologies Across Universal Operator Behaviors

UNIVERSAL OPERATOR BEHAVIORS

WORKLOAD METHODOLOGIES		1.1 Searching for and Receiving Information	1.2 Identifying Objects, Actions and Events	2.1 Information Processing	2.2 Problem-Solving and Decision-Making	3. Communication Processes	4.1 Simple/Discrete Motor Processes	4.2 Complex/Continuous Motor Processes
1.1	Rating Scales	3	3	3	3	2	3	3
1.2	Interviews and Questionnaires	3	3	3	3	2	3	3
2.1.1	Task Component, Time Summation	3	3	3	3	3	3	3
2.1.2	Information-Theoretic	1	0	2	0	0	0	1
2.2.1	Nonadaptive, Arith./Logic	3	3	3	2	2	3	3
2.2.2	Nonadaptive, Tracking	3	3	2	2	2	2	2
2.2.3	Time Estimation	0	0	2	0	2	0	1
2.2.4	Adaptive, Arith./Logic	0	0	0	0	0	2	2
2.2.5	Adaptive, Tracking	1	0	1	0	0	2	2
2.3	Occlusion	1	1	1	1	0	1	0
3.1	Single Measure-Primary	1	1	1	1	1	1	1
3.2	Multiple Measure-Primary	1	1	1	2	0	1	2
3.3	Math. Modeling	0	0	1	1	0	1	1
4.1.1	FFF	1	1	1	1	1	0	0
4.1.2	GSR	1	1	1	1	0	1	1
4.1.3	EKG	1	1	1	1	0	2	2
4.1.4	EMG	2	1	2	2	1	2	2
4.1.5	EEG	0	0	1	0	0	0	0
4.1.6	ECP	1	1	1	1	1	1	1
4.1.7	Eye and Eyelid Movement	1	1	1	1	2	0	0
4.1.8	Pupillary Dilation	2	2	2	2	1	2	2
4.1.9	Muscle Tension, Tremor	1	1	1	1	1	2	2
4.1.10	Heart Rate, Heart Rate Variability, Blood Pressure	1	1	1	1	0	0	1
4.1.11	Breathing Analysis	1	1	1	1	1	1	1
4.1.12	Body Fluid Analysis	1	1	1	2	1	1	2
4.1.13	Handwriting Analysis	1	1	2	2	2	0	0
4.2	Combined Physiological Measure	1	1	1	1	1	0	1
4.3	Speech Pattern Analysis	0	0	1	1	1	0	0

Weightings

0 = No research support or only negative support
1 = Limited research support; some conflicting data
2 = Limited research support; no conflicting data
3 = Well documented research support

Table 4

Feasibility of Workload Techniques for In-Flight Environments

CRITICAL CRITERIA

WORKLOAD METHODOLOGIES		Physical Space Required	Portability	Intrusion-Safety	Data Transmission and Recording	Experimental Control	Integration Into Aircraft System	Crew Acceptance
1.1	Rating Scales	S	S	S	S	P	S	S
1.2	Interviews and Questionnaires	S	S	S	S	P	S	S
2.1.1	Task Component, Time Summation	S	S	S	S	S	S	S
2.1.2	Information-Theoretic	S	S	S	S	S	P	S
2.2.1	Nonadaptive, Arith./Logic	S	S	S	S	P	S	S
2.2.2	Nonadaptive, Tracking	S	S	P	S	P	S	P
2.2.3	Time Estimation	S	S	S	S	P	S	S
2.2.4	Adaptive, Arith./Logic	P	S	S	P	S	P	S
2.2.5	Adaptive, Tracking	P	S	P	P	S	P	P
2.3	Occlusion	P	S	P	S	S	P	P
3.1	Single Measure-Primary	S	S	S	S	S	S	S
3.2	Multiple Measure-Primary	S	S	S	S	S	S	S
3.3	Math Modeling	S	S	S	S	S	S	S
4.1.1	FFF	P	S	P	S	S	P	P
4.1.2	GSR	S	S	S	S	S	S	P
4.1.3	EKG	S	S	S	S	S	S	P
4.1.4	EMG	S	S	S	S	S	S	P
4.1.5	EEG	S	S	S	S	S	S	P
4.1.6	ECP	S	S	S	S	S	S	P
4.1.7	Eye and Eyelid Movement	S	P	P	P	S	P	S
4.1.8	Pupillary Dilation	S	P	S	P	P	P	S
4.1.9	Muscle Tension, Tremor	S	P	S	S	S	S	S
4.1.10	Heart Rate, Heart Rate Variability, Blood Pressure	S	S	S	S	S	S	P
4.1.11	Breathing Analysis	S	S	S	S	S	S	P
4.1.12	Body Fluid Analysis	S	S	S	S	S	S	S
4.1.13	Handwriting Analysis	P	S	P	S	P	S	S
4.2	Combined Physiological Measure	S	S	S	S	S	S	P
4.3	Speech Pattern Analysis	S	S	S	S	S	S	S

Weightings

S: Solvable without difficulty; Problem does not exist.

P: Potential problem; Difficulty will be encountered.

Table 5

Workload Measurement Methodology Matrix

	1. Measures of system Performance	2. Measures of pilot Performance	3. Analogues of pilot Performance	4. Measures of pilot status	Examples
A. in a model					ton-miles kill ratios attrition
B. in a laboratory					reaction time tracking scores perceptual effic.
C. in a simulator					procedural error emergency response glide path deviation
D. in the field					sortie rate in-commission rate cargo pass-thru time
E. in flight					flight path deviations eye movement patterns crew activity
Examples	altitude control navigation gunnery scores	control movements visual scanning communication	pilot opinion synthetic tasks traditional tasks	secondary tasks neurophys. status biochem. status	

III. PSYCHOPHYSIOLOGIC MEASURES

Substantial progress has been made during the past decade in psychophysiologic measurement, methodology, instrumentation, and analytic techniques. Less progress has occurred in elegant explanations of mechanisms. Nevertheless, our considerably improved ability to observe, record, quantify, and interpret psychophysiologic events and activities makes this an area with substantial potential for the assessment of pilot workload. Two significant problems must be resolved, however, before that potential can be realized:

a. Development of field-qualified, cockpit-qualified devices for acquiring data; and

b. Validated relationships between what are sometimes rather subtle psychophysiologic events and important workload conditions and/or effects.

The pace at which these two problems are being investigated, combined with a scattering of recent successes, suggests that we should be optimistic. An important role is being played by present and expanding capabilities provided by mini- and micro-computers as we pursue the application of psychophysiology to operational problems. The following paragraphs will provide short overviews of several areas of psychophysiologic measurement. The interested reader should examine AGARDograph No. 244, "Contributions of Psychophysiologic Techniques to Aircraft Design and Other Operational Problems," by R. D. O'Donnell (July 1979), as well as various chapters in AGARDograph No. 246, "Survey of Methods to Assess Workload," edited by B. O. Hartman and R. E. McKenzie (August 1979), which this Technical Evaluation Report specifically addresses.

EMG. Electromyographic measures have both virtues and limitations. EMG is easy to record, and there is more than enough evidence to support the proposition that with increasing effort there is increasing muscle tone, and therefore increasing EMG. There is reasonable evidence that muscle tone (and EMG) increases as workload increases; the effects can be seen with either mental or physical workload. There is an easily observed relationship between EMG changes and motor activity and/or other "physical" criteria of work. Recent interest and research have focused on biofeedback applications, and the assessment of states of alertness or arousal. Field-qualified instrumentation is within the state-of-the-art. Flight-qualified instrumentation is within reach. Two limitations need to be considered: (a) there is increased muscle tone resulting from "useless" work (consider the difference in muscle tone between a student pilot and an instructor when stalls/spins are first presented); and (b) we do not yet have a "co-linear" scale for EMG changes vs. workload.

GSR/BSR. Some of the comments on EMG can be made regarding the galvanic skin resistance and the related basal skin resistance. GSR/BSR are reasonably easy to acquire and there is a long history to support the proposition that changes in mental and motor activity will be reflected in GSR/BSR. Biofeedback applications are common. Assessment of states of alertness/arousal can be done. Mini- and micro-computer technology will facilitate research progress. Field-qualified instrumentation is within reach; flight-qualified instrumentation will be more difficult. The absence of co-linear scales for GSR/BSR and alertness/arousal/workload is a problem. However, the more significant limitation is the confusion regarding terminology and methodology, coupled with confusion and difficulties on interpretation. Perhaps it is sufficient to say that GSR/BSR reflects some kind of "activation" but there is need for more research before this measure is a good candidate for workload assessment.

Cardiovascular. We will deal with cardiovascular measures as a "package" at this time. Heart rate per se is discussed in detail in Chapters 5, 7, and 11 of AGARDograph 246. The kinds of measures commonly obtained include blood pressure, stroke volume, blood oxygen levels as determined by noninvasive measures such as ear oximetry, and heart rate. These measures are reasonably easy to acquire, field-qualified instrumentation is within the state-of-the-art, and cockpit-qualified instrumentation is within reach, generally speaking. There is controversy regarding theory, mechanisms, findings, and applications when one departs from classical cardiovascular physiology to an applications area as operational as pilot workload, though some skillful applied researchers do well in addressing such controversy. This measurement area is also characterized as one where there is some "elegance" in the analysis procedures, particularly for various fragmentations of the EKG waveform. This author is skeptical about such analyses, which may yield a low payoff for the manhour investment, though analytic power provided by computer technology may resolve this aspect of elegant analyses.

Brain Function. Again, we will deal with these measures as a "package." EEG (electroencephalograph) and ER (evoked responses) are prominent in this package, with interhemispheric assessment showing some progress. This is a measurement domain where elegance in analysis is commonplace and where computer technology is indispensable. There is a marked upsurge in applications of evoked responses, particularly the VER (visual). The changes in this domain frequently relate poorly to changes in other autonomic measures, posing (perhaps) a problem for the investigator with a multi-measure battery. The measures clearly have high utility for low versus normal arousal levels. It is O'Donnell's position (AGARDograph 244) that these are the most powerful of psychophysiologic measures. Field-qualified, and to some extent, cockpit-qualified instrumentation is within the state-of-the-art.

Visual Measures. Measures of visual function have specific utilities and, for most, a reasonably impressive history of successful applications. Included are eye movements (EOG), pupil size, and point of regard. Elegance of instrumentation is customary, though not always essential. Data reduction can be laborious, particularly where simple instrumentation is employed, although the ability of computers to "recognize" wave forms can be profitably employed. Experimental methods and the experimental environment can be demanding, and can pose problems where field-qualified/cockpit-qualified instrumentation is desired. The eye "point of regard," while an extremely specialized measure, usually employed to assess cockpit panel design or the more fundamental scanning pattern, has a real potential for workload applications. Of importance here would be changes in scanning pattern as variations in workload occur, e.g., the elimination of non-essential scanning elements under conditions of high workload. Workload applications have been limited to date, but the potential is good, and the measure has the advantage of high reliability and stability when appropriate instrumentation is employed.

Psychophysiology and Sensory Function. A variety of psychophysiologic measures are available to assess sensory function. Included are the VER, MTFA (Moderation Transfer Function Area), CFF (Critical Flicker Fusion), visual acuity, contrast sensitivity, color vision, and auditory measures. As indicated earlier, VER instrumentation, methodology, and the experimental environment are fairly demanding. Measures which yield both transient and steady state information are required. Its unique significance is that it is the final representation of a chain of intervening processes (O'Donnell), while also offering the skilled investigator the opportunity to fractionate that process into behavioral aspects of special interest, such as the effect of task errors in central processing. There have been recent applications of VER to the evaluation of different displays, with reasonable success. MTFA is an alternate approach to VER. Visual acuity, contrast sensitivity, and color vision have a long history of clinical applications, but applications in the field on operational problems will require new methods and instrumentation. CFF can be described in a similar way: a long history of successful clinical applications and experimental applications in problems of fatigue and environmental stress, but a need for new methods and instrumentation if field applications are the goal. It is doubtful at this time that a cockpit-qualified capability will emerge. Measures of auditory function demand strict methods and instrumentation. There is the additional problem of a fair degree of intra-subject variability. O'Donnell points out that a variety of "psychophysiologic bridges" are now being employed in auditory measurement, such as GSR and VER. The possibility of "bridged" measures in applications batteries is an intriguing prospect. However, the potential of auditory measures for field applications must be viewed with caution because of the methodologic and experimental demands which such measurement impose.

Psychophysiology and Cognitive Function. It appears that we are on the edge of substantial advances in the ability to assess cognitive function, including field and perhaps even cockpit measurement capabilities. There is presently a fair amount of laboratory activity on GSR, EEG, and pupilometry. VER is emerging as a useful tool for quantifying central processing and decision-making. There is provocative research underway on interhemispheric measurement. Laboratory enhancements of signal detection and reaction time measurement are underway, including physiologic "bridges" to cardia deceleration and evoked potential. VER has good potential for the analysis of subtle response errors which are not quantified by other measurement techniques. The prospects are exciting.

Psychophysiology and Attention/Vigilance. The comments above on cognitive function apply generally to the functional area of attention and vigilance. The use of GSR specifically is a function of how one conceptualizes attention and vigilance. If the concept is a general state of arousal lasting for a fairly long time, GSR has utility. If the concept is more event-related, then GSR is too slow to be of much value. The utility of EMG can be similarly conceptualized. It has particular value as a measure of preparation for motor activity.

Psychophysiology and Workload. The most common of the psychophysiologic measures is heart rate. Particular interest is focused on variability in rate (sometimes identified as changes in sinus arrhythmia). The frequent but not universal finding is a reduction in heart rate variability as workload increases. There are, as was discussed earlier, more elegant analytic treatments of the EKG waveform, but rate per se has the demonstrated value of applicability across a large range of tasks. Brain wave activity is another psychophysiologic measurement domain for workload. Of the several analytic aspects, VER appears most useful, particularly the late positive components. Where VER is coupled with a noninterference secondary task, the utility of VER promises to be even greater. Pupil dilation also holds some promise, probably more for field application than for inflight (cockpit) application. Pupil dilation seems particularly applicable where workload capacity is exceeded, though perhaps graded changes in pupil size can be related to graded variations in workload. The limitations for field application reside in the somewhat demanding requirement to control the visual environment and instrumentation (illumination, eye movement, etc.). Voice analysis has high face validity, with analysis addressing both pitch and formant aspects. To date, however, applications to workload specifically have been limited. There are other problems. The analysis is complex, data collection methods require careful control, and analytic instrumentation and software are demanding. The net result is a substantial possibility that voice analysis can be a source of erroneous data on workload. GSR, EMG, and CFF have yielded mixed results in workload applications, but have good potential. The cautions on these methods which have been stated earlier apply particularly to workload. A promising approach not yet implemented is the application of multiple regression analysis techniques to the psychophysiologic assessment of workload.

IV. SUBJECTIVE MEASURES

In the workload area, subjective measures are a way of obtaining reports from subjects regarding perceptions, effects and feelings concerning the imposed burden. The approaches to soliciting such reports can be broadly categorized as rating scales, questionnaires, and interviews. Each of the three approaches can be further categorized as structured or unstructured. There is a reluctance on the part of some workload researchers to accept subjective measures simply because they are not objective. The counter argument is simply that a significant aspect of workload is one's internal, personal, subjective experience for which a subjective report has high face validity. A second argument against subjective measures is large variance. An appropriate response is to point out the necessity of applying rigorously the psychometric rules for developing such instruments, as well as providing clear instructions and definitions, training subjects, and even calibrating individual subjects against group means. A final argument is that subjective data do not always agree with objective data. True. Perhaps we should examine and try to understand the differences, rather than categorically rejecting the subjective measures. The one argument against which there is little defense concerns the compromise of data when a subject responds with a bias he fully intends to inject into the study, or randomly because he is disinterested.

Rating scales are unique among subjective measures because they yield a score which is a point on a dimension defined by the investigator. Rating scales fall generally into two categories. There are those which add up "scores" on a series of items, with the sum determining that point on the scale (dimension). The subject may have a good qualitative perception of where he scores on that scale, but he usually does not know his score per se. There are those which lead a subject stepwise through a series of reports to a final, standardized appraisal on some workload issue. In this case, the subject knows clearly where he scores on that scale, and might in fact have reported a somewhat less standardized appraisal without the step-wise guidance provided by the rating form. Because of this feature, some investigators eliminate the step-wise guidance and have the subject simply select a standardized opinion equivalent to a point on the scale. There are benefits to be obtained from the step-wise guidance, however. Properly designed, such a rating form also provides insight into what aspects of a task led to the workload rating of "x." The Cooper-Harper scale on handling qualities is the most commonly used example of this approach, and in the hands of trained, "standardized" subjects is a powerful tool with high face validity. It is unquestionably a good model for such an approach. The MIT Flight Transportation Laboratory produced in 1979 a workload rating scale modeled after Cooper-Harper, with some elaborations. The power of rating scales is augmented when other measures are also obtained, particularly where such other measures (e.g., EKG, urine samples, etc.) suggest to the subjects that there is little to be gained from injecting a bias into the data. Before leaving rating scales, we should acknowledge the utility of having subjects simply put a mark on a line (which has well defined anchor points). It is a simple, essentially self-scoring procedure which correlates reasonably well with other subjective reporting approaches.

Questionnaires offer an opportunity to probe into multiple aspects of a workload issue. Where multiple choice answers (categories or scaled) are provided, there is the appearance of objectivity. The utility of such questions can be improved by the application of scaling techniques (such as "semantic differential"), which is a technology in its own right. Effective questionnaires must be based on a careful analysis of the task under study, or on extensive background studies of the aspects of a task which present problems to the performers, or on some other method which is exercised with rigor. Open-ended questionnaires are, nevertheless, an option, and have the advantage of offering insights perhaps not otherwise obtained although at the expense of cumbersome scoring (if a score is the objective).

Much of what has been said about questionnaires applies to interviews. In addition, interviews provide further opportunities for insights, since responses which are not entirely clear can be pursued with further questions. There is also the advantage of being able to peruse global feelings and attitudes which might influence responses, but the process is costly in terms of manhours.

V. PERFORMANCE MEASURES

Performance measures can be grouped into the broad classes of mission performance, weapons system (aircraft) performance, primary pilot performance, secondary pilot performance, and laboratory task performance. With the exception of mission performance, these are familiar to workload researchers, and have as their focus the pilot and his tasks.

Mission performance. This class of performance measures is defined as the tasking assigned to a unit (squadron/wing) and refers to unit workload. Therefore, the workload data cannot be traced back to individuals without considerable effort. Examples would be a tactical sortie surge (an exercise requiring "x" number of sorties to be flown over "y" days) or an airlift exercise (move "x" Army troops and equipment from point a to point b in "y" days), or more routinely the monthly flying schedule for any kind of unit. Workload researchers rarely address unit workload, mostly because of the emphasis on the individual pilot and the burden imposed on him by his aircraft systems and sortie tasks. Approaches to unit workload include both field studies, where multi-measure batteries are employed, and computer-based simulation models. While unit workload translates rather concretely into flight schedules and therefore into aircrew schedules, it would not be inappropriate to set it aside in view of the already large problem confronting the workload research. There is, however, one aspect worth considering. Existing models have or can accommodate behavioral and physiologic variables, and can therefore be exercised in a parametric fashion (sensitivity analyses) to identify those variables which potentially compromise unit capability. This, in turn, would provide external criteria to be used to focus and prioritize workload research.

Weapons system performance. The focus here is on task outcomes, e.g., destroy a target, conduct an electromagnetic survey of a potential target area, approach and land. These examples surface an area of controversy: does it matter that pilotage was degraded if the mission or mission element is completed successfully? Is a pilot really overloaded if he successfully performs his task? We will examine this issue more fully in the discussion on primary pilot performance. At any rate, it is clear that objective, quantified measures of success can be acquired. A number of techniques can be used to acquire such measures. The most elaborate uses an instrumental range such as that described in chapter 14, with elaborate ground tracking and recording playback systems, transponders, and telemetering systems in aircraft, etc. The data mass from such a facility can be staggering, but with careful study, one can isolate and acquire measures of direct interest from a workload point of view. A unique advantage is the enhancement of communication with operational personnel, since the measures are meaningful to them. Through close coordination and cooperation, it is possible to create a library of data from such test ranges, though, once again, the mass of data can be overwhelming. Next in level of sophistication is an aircraft-mounted instrumentation pod, frequently available on test aircraft and sometimes with telemetering capability. An extensive range of aircraft and pilot performance measures can be obtained, and frequently recording channels for psychophysiologic or special performance measures can be obtained. The element missing here is what we might call "terminal" mission measures, such as miss distance on missile impact. It should be noted that a computer-driven, aircraft-mounted visual display system under development at the Air Force Aerospace Medical Research Laboratory, called VCASS, has the potential for providing such data, since the computer portion of the system can generate simulated data on these kinds of measures. Chase planes and ground observers are more conventional, but expensive and somewhat gross techniques for obtaining terminal mission measures.

Primary pilot performance. Primary pilot performance measures are those obtained as the pilot performs his tasks. Early versions were measures such as stick and rudder movement, button pressing of various sorts, radio communication activity, and so on. The "goodness" of performance determination is based on comparisons with externally generated standards, with baselines on the same or similar groups of pilots, or on "early vs. late" in the mission. Hypotheses regarding fatigue or workload are employed, perhaps without adequate validation. More recent approaches have involved development of "categories" of pilot performance, such as are shown in Table 1 of this Technical Evaluation Report. What constitutes an adequate ensemble of categories? Some approaches are:

a.	input	a.	perceptual processes
b.	central processing	b.	mediational processes
c.	output	c.	communication processes
		d.	motor processes

a.	preflight activity	a.	activity time
b.	inflight activity	b.	errors
c.	post flight activity	c.	describing functions
		d.	channel capacity

These are only samples from a large family of categories. In that family are factor-analytic and similar kinds of categorization more appropriate to laboratory research. Therefore, this issue will be discussed again. The issue, however, is critical. How does one conceptualize workload measures? What is the relationship between that conceptualization and the measurement battery, the data collection facility or environment, the hypotheses to be tested, and the applications which need to be implemented? There is the very practical aspect raised by many workload researchers--the ability of the pilot to modify his procedures in the face of high workload so as to reduce workload while also successfully completing his tasks. When this occurs, measured performance on some categories (e.g., stick and rudder activity) deviates from the "standard" without apparent cost to task achievement.

Secondary pilot performance. In Chapter 7, secondary pilot performance measures (secondary tasks) are carried under the major heading of Spare Mental Capacity. That is appropriate in the sense that spare capacity provides a conceptual umbrella for measurement approaches, of which a secondary task is one. To quote from Chapter 14, "Spare mental capacity . . . is the difference between the total workload capacity of the operator and the capacity needed to perform the task." Among the elements of this cluster are:

a. measurement of multi-channel processing

b. measurement of switching attention among channels

c. identification of conflicts and bottlenecks in information processing

d. variations in the overload point

The authors then address in some detail three approaches: task analytic; secondary task; and occlusion procedures. Task analytic measurement derives from systems engineering, using modeling in various forms, manipulating empirical data from laboratory and simulator studies. It adopts the single channel concept of man as an information processor and responder, though this review has already highlighted various ways in which the pilot may deviate from that mode. Therefore, there is always the need for empirical verification of task analytic studies. However, mathematical modelling has two unique virtues: an operation (task) can be examined parametrically with values for each step ranging from artificial clear minimums to artificial clear maximums, thereby identifying worst case/best case analyses of each step and "choke points;" and a model can generate tenable findings using fragmentary data. These two virtues are not unrelated, since each supports the other in the nature of the data being manipulated (artificial vs. empirical) and in the kinds of findings which can be generated. The behaviorists in workload research, in contrast to mathematically oriented analysts, prefer secondary tasks to assess space capacity. "Performance on the secondary task theoretically decreases as the attentional demands of the primary task increase. Secondary task performance, then, becomes an indirect measure of operator workload" (Chapter 7). Methodology and the design of tasks vary considerably, although the Sternberg task is widely recognized and frequently used. The Sternberg task is an item recognition task with a strong supporting analytic model. Graphic representation of a least-squares, linear regression line is the common way of presenting Sternberg task data. The underlying hypothesis holds that the slope of this line reflects the information processing aspect of the task and the intercept depicts the input/output aspect of the task. Secondary tasks have high potential for becoming field qualified and even becoming cockpit qualified when installation of this additional piece of hardware in a cockpit is permissible. Occlusion is a technique where visual information is presented in samples rather than continuously, and inferring workload from performance changes. Its utility for aircrew workload studies in flight is questionable, though it may have merit for laboratory and simulator studies.

Laboratory task performance. The strategies available to the laboratory researcher on workload are extensive. They range all the way from a simulation of a specific piloting task or subtask, through multi-task batteries, the use of a collection of conventional psychomotor tasks, to the use of a single psychomotor task. In addition, there is the manipulation of test conditions, such as work/rest schedules or day versus night or schedules which disrupt normal sleep. Finally, all of the workload measures discussed earlier in this report can be used. How one conceptualizes the real world task being studied and, more important, how one conceptualizes the relationship between real-world task and the tasks being used in the laboratory are significant issues. There are even issues which should be addressed on the choice of the analysis technique and how one chooses to explain variations in results where more than one measure is taken. Even a high fidelity laboratory simulation is open to debate, since many researchers and operational personnel challenge a laboratory simulation on the grounds that the hazards of flying cannot be duplicated. The choice of subjects, especially the kind usually available for laboratory studies and frequently with a restricted age range and no piloting experience, also poses problems in applying results to the operational world.

Major benefits, at least in terms of face validity, derive from approaching the selection of laboratory tasks in a systematic fashion. Some investigators develop task batteries on the basis of prior factor analytic studies, where an array of tasks can be analyzed so as to yield a smaller number of factors. A term in current use is "universal operator behaviors" (see Chapter 7 in AGARDograph No. 246), which capture real-world tasks with terms like "tracking," "arithmetic," "logic," etc. A similar approach is to develop multi-task batteries where tasks are chosen for independence from each other while still reflecting real-world task elements with reasonable face validity. A US Navy approach involves creating a battery by selecting tasks from well-standardized published tests. In this latter case, measures were selected from intelligence tests, cognitive tests, factor analyses of tests of manual dexterity, information processing tests, tests of central nervous system status, and so on. All three of these approaches have a double goal: (a) provide data on the problem being studied, and (b) develop a data base across a series of studies for the purposes of norms, reliability, and consensual validation. This last term was in vogue more than a decade ago and still provides some basis for asserting that a test or battery or concept has validity because numerous studies with similar approaches yielded similar results. There is some merit to this concept, though a direct field validation with "real" subjects flying real missions is clearly more impressive. At any rate, a single test, no matter how good, is less impressive than a well thought out battery of tests based on a convincing rationale, because the real-world task of flying military missions is indeed complex. What is needed badly in the area are standardized tests with convincing reliability and validity and a task taxonomy (the anatomy of psychomotor skills) which is widely accepted in the scientific community.

VI. SUMMARY

This report has provided an overview and evaluation of the measurement of pilot workload using AGARDograph 246, supplemented by AGARDograph 244, as primary sources. The broad measurement areas of psychophysiology, subjective reports, and performance testing have been addressed. The concept of workload and its relation to fatigue and stress have been discussed. By way of summary, we can review the following as issues and/or needs for workload measurement technology:

a. We need a widely accepted definition of pilot workload which goes beyond the definition implicit in the selection of a specific measure.

b. We need strong bridges of reliability and validity for second order measures such as are characteristic with psychophysiologic or biochemical measures, for example.

c. We need to accept more readily the utility of subjective measures.

d. We need better standardization of psychomotor tests and more validity and reliability data for psychomotor tests which constitute "synthetic" tasks.

e. We need field-qualified and/or cockpit qualified instruments.

f. We need convincing, successful field studies which provide the operational community with applications which demonstrably reduce pilot workload.

g. We need better models which can cope with fragmentary data and, in addition, provide information on the operational utility of test results, as well as clues on where to focus our workload research.

There are studies and developments ongoing in research groups across the NATO community which are promising. Investigators are adopting the broad view at an increasing rate. Significant progress is being made in workload measurement technology.

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14. Abstract

Military aircraft are becoming increasingly complex, the associated avionics systems more sophisticated, and the mission profiles more demanding. The problem is to establish if such an increase in aircrew workload has become a limiting factor in the operational employment of some aircraft and to select viable methods to assess it.

The methods of assessing workload are set forth in AGARDograph AG-246 "Survey of Methods to Assess Workload" which was published in August 1979. This companion document sets forth conclusions on workload measurement methodology.

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