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FINAL REPORT

AN ANNOTATED BIBLIOGRAPHY ON OPERATOR MENTAL WORKLOAD ASSESSMENT

by

Dr. W. W. Wierwille
Ms. B. H. Williges
Systemetrics, Inc.

for

Systems Engineering Test Directorate

March 1980

Approved for Public Release; Distribution Unlimited.

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NAVAL AIR TEST CENTER
NAVAL AIR STATION
Patuxent River, Maryland 20670

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1. Reference (a) authorized NAVAIRTESTCEN to conduct a review of operator mental workload assessment techniques to support the Human Factors Test and Evaluation Methodology Development Program.

2. The work was contracted to Systemetrics, Incorporated, under Navy contract N00421-79-0-2214 with partial funding from the U.S. Army (reference (b)). This final report completes the requirements of the Work Request.

R. L. BRECKON
By direction

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ABSTRACT

An annotated bibliography on operator mental workload is presented with supporting information. This bibliography is based upon two literature searches, one performed in 1977 in support of a survey and analysis catalog (AD A059-501) and one performed in 1979 as an update.

Each literature citation presented contains reference information, an abstract, a numerical workload technique category classification, a numerical operator behavior classification, and a group of word descriptors. Workload methods are divided into 28 specific techniques in four major categories: opinion, spare mental capacity, primary task, and physiological. Applicable operator behaviors are similarly divided into categories.

The descriptors associated with each citation designate the general workload classification, the specific workload classification, the type of presentation, the type of facilities used, and the potential aircrew application. Over 600 citations are presented. Two indexes are also provided. The first is a workload technique index and the second is an experimental facility index. It is concluded that periodic updating of the bibliography will be required and that attention should be directed toward computerizing future workload bibliographies.

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INTRODUCTION

1.1 BACKGROUND

Technological advances in aircraft systems during the past several decades have resulted in sophisticated avionics and weapons delivery subsystems which are available to aid the aircrew in completing specified missions. The ultimate mission success of today's military aircraft, however, still rests on a common factor, the human operator. To be effective, modern aircraft systems, with all of their advanced sensors and avionics, must be compatible with the capabilities and limitations of the aircrew.

During the design, development, test, and evaluation of any new aircraft system, care must be taken to insure that the new system does not place unreasonable demands on the aircrew by overwhelming them with too much information and too little time to process that information. Such considerations are often characterized as assessing mental workload.

It has generally been recognized that mental workload assessment or measurement is a difficult problem. First, there are difficulties in defining mental workload. Second, there are difficulties in finding the available technology and in selecting appropriate techniques for measurement in any given application. And finally, there are difficulties with the workload assessment methods themselves. Problems exist in the areas of sensitivity, intrusion, transferability, reliability, and validity.

The literature of mental workload is diverse and the terminology varies. What one researcher may call mental workload, another may call attentional demand or cognitive load. Most of the work is recent and it appears in proceedings, journals, and reports from many parts of the world. Furthermore, there are numerous studies in progress, requiring that any literature search be updated periodically if it is to remain current.

Because of the importance of workload assessment in test and evaluation of aircraft and avionics systems and because of the diversity of workload literature, the Naval Air Station, Patuxent River, Maryland, tasked Systemetrics, Incorporated, to study the available literature on operator mental workload. That initial study was undertaken in August 1977 and was concluded in September 1978. The project final report contained references to more than 400 workload documents.[1] The report also included workload technique and operator behavior classification schemes along with brief descriptions and typical citations for each known method of workload estimation, some 28 methods in all.

The original survey and analysis report was printed in 150 copies, all of which were distributed among workload researchers and users within a few months. Because of the demand for the document, a second printing in 125 copies was ordered. Almost all of those copies have also been distributed. It is very clear that the demand for documents summarizing and cataloging workload estimation techniques is high.

In preparation for the survey and analysis report, each document selected for inclusion in the reference section was first abstracted and categorized. Numerical indexes and word descriptors were included. Each citation with its abstract, numerical indexes, and word descriptors was then typed on a 5x8 inch index card. The purpose of the cards was to aid in writing the survey and analysis report and to provide a more detailed record that could be edited and published subsequently. Such a record would provide more detailed information on what is contained in each workload document and, if published, would be of substantial value to workload technique users and researchers.

Originally the plan was to publish the abstract cards as a companion document to the survey and analysis report. However, when this task was undertaken in June 1979, it appeared prudent to update the original search and abstract all recently available documents prior to publishing the bibliography. It must be remembered that workload estimation is an active research area and new documents appear frequently. Also, the original cards required updating and editing. Many documents which were cited as presentations at meetings had subsequently been published in journal or book form. Furthermore, experience gained in the abstracting process could be used to increase the uniformity of indexing and descriptor notations.

This report, therefore, contains an updated, annotated bibliography of mental workload estimation techniques. All known documents meeting the selection criteria described in Section 1.3 and available in 1979 or earlier have been included.* There are more than 600 citations.

While it would be helpful to read the earlier survey and analysis report, the present report does stand by itself and contains all necessary formating information regarding the annotated bibliography. It also contains a description of the manner in which the searches were conducted.

[1] Wierwille, W. W. and Williges, R. C., Survey and Analysis of Operator Workload Assessment Techniques, Final Report. Blacksburg, Virginia: Systemetrics, Inc., S-78-101, September 1978 (Contract N00421-77-C-0083) (AD A059-501).

*Certain 1979 dated documents may not be contained, however, because of their publication lags.

1.2 SEARCH PROCEDURE

To accomplish a comprehensive search of the scientific literature dealing with various methods of assessing mental workload, several sources were used. The potential sources of both foreign and domestic literature that were searched included books, scientific journals, technical reports, and proceedings of technical meetings. Computerized information retrieval, library searches, and direct contacts with the scientific community were used to locate relevant documents.

1.2.1 INITIAL SEARCH

Computerized Information Retrieval

To provide an initial pool of workload documents, several computerized information search and retrieval systems were used. Most of these searches are based on key word accessing of documents contained in the files. The user must develop an appropriate key word index and then use various logical expressions in an iterative fashion to combine these key words appropriately. The initial list of key words chosen for use is presented in table I. Subsequently, subsets of these words were used in individual computerized searches.

DIALOG system. First, a nationwide, interactive information system was searched through direct telephone access. The particular system used is called DIALOG and provides 50 computer files pertaining to science, technology/engineering, social sciences (humanities), and business/economics. Complete reference citations, accession numbers for ordering references, and abstracts are readily available on request through the National Technical Information Service (NTIS).

Searches of three files, COMPENDEX (Engineering Index), NTIS including Defense Technical Information Center (DTIC), and PSYCHOLOGICAL ABSTRACTS (American Psychological Association), were conducted on DIALOG. This search provided more than 900 titles that contained potential information on mental workload.

DTIC report bibliography. The literature contained in the dialog system includes primarily reports published within the last 10 years. To provide a more comprehensive survey of the technical report literature, a broad coverage survey of DTIC files was requested covering human operator workload measurement methodology, research, and applications to human operator/machine systems. Specifically, requests were made for annotated bibliographies, including AD numbers, which cover the broad human factors, aircrew systems, man-machine relations, psychology, personnel evaluations, and stress/physiology areas. Three report bibliographies were obtained from DTIC covering the periods 1947-1957, 1957-1967, and 1967-1977, respectively. These three bibliographies combined resulted in a list of over 300 titles.

Table I

List of Key Words

Workload	Difficulty of Operator Tasks
Workload Estimation	Subsidiary Tasks
Spare Mental Capacity	Attentional Demand
Human Information Rate	Pilot Workload
Psychological Stress	Mental Load
Stress Due to Workload	Perceptual Loading
Stress Due to Overloading	Reserve Capacity
Mental Stress	Time Sharing Response of Human Operators
Human Operator Workload	Pilot (Mental) Fatigue
Operator Workload	Task Induced Stress
Secondary Task	Task Difficulty (Measurement Of)
Auxiliary Task	Sensory Overloading
Primary Task	Physiological Stress
Human Information Processing Rate	Information Capacity (Of the Human Operators)
Operator Loading	Time Sharing
Operator Channel Capacity	Pilot Time Sharing
Human Operator Channel Capacity	Secondary Tasks
Extra Task Performance	Residual Capacity
Task Induced Stress	Residual Attention
Physiological Measures of Stress	

CDIC library. A search similar to the one described for DTIC reports was requested from the Control Display Information Center (CDIC) library at the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio. This library has a unique listing of human factors-related documents pertaining to aircrew environments not normally found in the open literature. Abstracts of 27 references were obtained from this search.

Tufts library. Many of the older human factors documents are available through the Tufts library collection which is now housed at Johns Hopkins University. Dr. Stanley Lippert, who developed a computerized search of the complete Tufts bibliography, searched the files according to the key word structure used on the other computerized searches. Unfortunately, these specific terms did not appear in the Tufts bibliography to any great extent. Therefore, the Tufts bibliography published by the Human Engineering Laboratories, Aberdeen Proving Ground, Maryland, was manually searched.

Library Searches

Computerized searches are not exhaustive, largely because many of the reference sources are not included in the files. This is particularly true for proceedings of professional meetings such as the Human Factors Society and the Annual Conference on Manual Control. To supplement the computerized retrieval, an extensive library search was made of several abstracting documents including Ergonomics Abstracts (which includes proceedings of technical meetings), Journal Supplement Abstract Service of the American Psychological Association, Psychological Abstracts, and Dissertation Abstracts as well as selected journals such as Acta Psychologica, AIIE Transactions, American Psychologist, Applied Ergonomics, Aviation, Space, and Environmental Medicine, Ergonomics, British Journal of Psychology, Canadian Journal of Psychology, Human Factors, IEEE Transactions of Man-Machine Systems, IEEE Transactions on Systems, Man, and Cybernetics, Journal of Experimental Psychology, Journal of Motor Behavior, Organizational Behavior and Human Performance, Perception and Psychophysics, Perceptual and Motor Skills, Psychological Bulletin, and Psychological Review.

Two additional library holdings were also included in the literature search. One library was the existing bibliography pertaining to workload assessment methodologies which was maintained by Dr. S. G. Schiflett at the Naval Air Test Center, Patuxent River, Maryland. The other libray was the AGARD index and report holdings maintained by Dr. J. F. Pollard of the Biological and Medical Sciences Division of the Office of Naval Research in Washington, D.C. Over 2000 pages of indexing were searched in this library holding the AGARD Index of Publications from 1952-1976.

Contacts with the Scientific Community

Several direct contacts were initiated with members of the scientific community currently involved in workload assessment methodology. Three subgroups of individuals were mailed requests for reprints of their contributions to the field. Specifically, letters were mailed to six members of the TriService T&E Technical Advisory Group, eight members involved in the TriService/NASA

Operator-Crew Workload activities, and 52 individual scientists who were known to have been involved in workload-related research. The response received from these requests was most gratifying and provided a valuable source of information.

In addition, site visits were made to the Naval Aerospace Medical Research Laboratory (NAMRL) facilities at Pensacola, Florida, and New Orleans, Louisiana, to discuss current workload-related research activities.

1.2.2 UPDATE SEARCH

The update search was planned to provide maximum access to workload literature that had become available between 1977 and 1979. This search was optimized on the basis of experience with the initial search and consisted of three main components: computerized information retrieval, library searches, and inquiries in the scientific community. Each of these components yielded substantial numbers of document citations having a bearing on workload.

Computerized Information Retrieval

A procedure similar to that used earlier was followed for the computerized search. The DIALOG system was again used as the main source of information. Limits, however, were placed on dates of documents retrieved, with documents appearing prior to 1975 being eliminated. Allowance for the years 1975 to 1977 was considered appropriate because of possible lags between document dates and actual appearance, plus time to enter the computerized information data base.

The DIALOG search included searches of COMPENDEX (Engineering Index), NTIS including DTIC files, and PSYCHOLOGICAL ABSTRACTS (American Psychological Association). A set of logical expressions made up from the list of key words appearing in table I was again developed for the search. This was performed on line so that the number and type of titles obtained could be adjusted prior to complete printout of all titles. The procedure increased the efficiency of the search substantially. In total, approximately 300 initial citations were obtained.

In parallel with the DIALOG search, the National Aeronautics and Space Administration was requested to perform a seach of their Scientific and Technical Information Office computerized information system in Washington, D.C. A list of key words was provided. Because NASA had not participated in the initial search, citations dating back to 1970 were requested. This search resulted in another 300 citations. However, because of NASA's extensive, direct experience with pilot and astronaut workload problems, this search provided a high yield of new documents meeting the selection criteria. Several of the documents cited were from foreign sources and had not appeared through the other information retrieval sources.

Library Searches

Because computerized searches cannot be considered exhaustive, a direct library search was instituted again in the update. The search was conducted in the same way as the earlier search, that is, including abstracting documents and journals and proceedings known to be published on the subject of operator workload. The publications and abstracting documents searched were essentially the same as those mentioned in the original library search (Section 1.2.1).

Contacts with the Scientific Community

The list of individuals to whom initial requests for documents had been mailed was updated. In addition, the Human Factors Society Directory was searched for individuals who included operator workload (or similar terminology) as one of their technical specialities. Also, contacts at technical meetings provided the names of additional individuals. In total, approximately 100 letters were sent requesting documents and information on workload publications for the years 1977 through 1979. The cooperation of the workload community was very encouraging and netted approximately 100 technical papers, reports, and citations.

1.2.3 DOCUMENT RETRIEVAL

On the basis of the titles and abstracts obtained from the search, documents appearing to meet the selection criteria were ordered from NTIS or were otherwise obtained in a single copy. Approximately 80% of the documents cited in this bibliography were classified on the basis of the entire document. In the remaining cases, the documents were classified on the basis of the abstract and any other information, such as telephone calls to authors or direct knowledge of the ongoing work. It was felt that classification based on all available information would be more advantageous to the reader than no classification when the full document was not available. While such a procedure may result in some slight inaccuracies in the classifications, these are believed to be minor.

1.3 SELECTION CRITERIA

Given the large pool of documents obtained by the combined search procedures, it was necessary to develop a set of criteria for inclusion of a reference in the final bibliography. Both a general set of criteria as well as a specific set of criteria were adopted.

General Criteria

For a document to be included, it had to satisfy the criteria listed in this section.

A. Topic. Each document had to be applicable to, deal with, or apply workload concepts. Workload here is used in a general sense and includes the terms: spare mental capacity, residual attention, mental load, etc. The term "workload" or similar terms need not explicitly appear in the document provided that a description similar to workload appears and is used.

A.1. Topic discrimination. Each document had to involve mental workload, as opposed to physical workload (physical labor, for example) or hardware workload (computer workload, for example).

A.2. Topic clarification. Mental workload is assumed to occur when a human operator performs perceptual, mediational, communication, or motor processes, or any combination thereof.

A.3. Topic background. A document providing essential background needed for development of a mental workload concept as presented in a later document or a parallel document was included.

B. Subject population. Each document had to describe work with or be applicable to normal adults. Studies dealing with specific groups of normal adults such as drivers, females, trained system operators, and pilots were included. Studies dealing with nonhumans, nonadults, and adults with physical or mental disabilities or debilitating diseases were not included.

C. Application. Each document had to be at least potentially applicable to aircrew mental workload assessment in simulation, in flight test, or as background information.

D. Level of contribution. Each document had to contribute to the scientific understanding of mental workload and its measurement.

E. Existence. A full copy of each document must exist in print or in copyable form. Documents appearing in summary, with sufficient detail to make them usable, and meeting all other necessary criteria as listed here, were included. Documents appearing in short abstract only, personal communications, and verbal presentations were not included.

Specific Criteria

For a document to be included, it also had to meet at least one of the criteria listed in this section.

A. Measurement techniques. A document relating mental workload to any other measurable variable was included.

B. Constructs and models. A document involving philosophical or mathematical constructs or models was included only if mental workload was at least potentially assessable from the constructs or models.

C. Experimental design. A document involving human operator loading was included only if specific implications were made regarding mental workload concepts. (Human operator loading is defined here as an independent variable, that is, any controlled change in experimental conditions that may result in changes in operator behavior.)

D. Design methodology. A document involving design methodologies (methods engineering in industrial engineering, or workspace design in human factors engineering, for example) was included only if specific implications were made regarding mental workload concepts.

E. Physiology. A document involving physiology, physiological measures, medical phenomena, or human body chemistry and functioning was included only if specific implications were made regarding mental workload concepts.

F. Clinical methodology. A document involving clinical, observational, or investigative methodologies was included only if specific implications were made regarding mental workload concepts.

G. Essential background. A document providing essential information on which a workload assessment technique is based was included.

CLASSIFICATION SCHEME

The classification scheme used for the annotated bibliography was developed to provide information to the user or researcher regarding the type or types of workload estimation employed in the cited document and the range of operator behaviors to which the document may be applicable. Additional information in the form of word descriptors also appears. The descriptors provide information on the type of document, facilities used, and potential applications. Once the reader understands the classification scheme, it should be possible to determine whether or not a given document has bearing on a specific workload problem at hand.

2.1 WORKLOAD CLASSIFICATION

The most important dimension in the classification scheme is the workload classification dimension. The literature on workload is so diverse that categorization on the part of the reader of this literature is almost intuitive. It is, however, important to select a categorization which groups the various workload techniques in a logical way so that conflicts and discrepancies on workload concepts are minimized. The taxonomy of workload methods that evolved from the documents reviewed is presented in table II along with a graduated numbering designation. Basically, the various methods are grouped into four major categories (subjective opinion, spare mental capacity, primary task assessment, and physiological measures) which are further subdivided into 28 individual techniques. Each of these specific techniques as well as the higher-order classification terms are described in detail in Section 4 of the earlier survey and analysis report.

In the bibliography which follows, reference to the workload dimension appears directly below the abstract as a numerical classification entitled "W/L Cat. Code." Table III shows a typical citation. The numbers appearing in this classification refer to the workload techniques described in the document. The numbers correspond to the numbers appearing in table II. In the example, two workload techniques are cited. The first is 2.2.4, a secondary task of an adaptive type using either an arithmetic or a logic task. The second is 3.1, measures taken from the primary task, analyzed individually or singly.

It should be noted that in many documents emphasis is on one workload technique, but additional measures are also taken or discussed in detail. When this occurs, all techniques receiving appreciable coverage are included in the workload classification.

Table II

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 III

Example of Annotated Bibliography Format
Using a 5x8 Inch Index Card

Krause, E. F. and Roscoe, S. N., Reorganization of Airplane Manual Flight Control Dynamics. W. B. Knowles, M. S. Sanders, and F. A. Muckler (eds.), Proceedings of the Sixteenth Annual Meeting of the Human Factors Society. Santa Monica, California: Human Factors Society, 1972, 117-126.

Experiments were conducted in a Singer-Link GAT-2 simulator to evaluate the effectiveness of a system providing direct control over aircraft maneuvering performance. Pilots performed complex navigational tasks involving the use of a computer-assisted area navigation system. Changing way-point storage capacity of the simulated navigation system induced variable task loading on subjects. The experiment was replicated with and without an adaptive, digit processing, side task to determine levels of residual attention associated with the control modifications and the varying levels of workload. The flight performance controller yielded greater precision of maneuvering control, fewer procedural blunders, and an increased level of residual pilot attention.

W/L Cat. Code: 2.2.4, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulation
Primary task	Single measures			Flight test

2.2 OPERATOR BEHAVIOR CLASSIFICATION

The purpose of the operator behavior classification is to provide information to the reader on the range of operator behaviors or tasks described or employed in the cited workload document. To attain this purpose, it is necessary to categorize or otherwise classify operator behavior in systems.

The range of operator behaviors and their taxonomies have been investigated for several years. These taxonomies have been used to obtain an understanding of what functions an operator performs in a system and as a basis for task analysis. One widely used listing of operator behaviors was developed by Berlinger, Angell, and Shearer (1964).[2] This approach breaks operator behavior into four major processes (perceptual, mediational, communication, and motor) as shown in table IV. These four major processes are further subdivided into seven activities and then into 47 operator behaviors. This classification yields good agreement among investigators in determining specific behaviors of operators in systems. Consequently, this approach was used to classify operator behaviors.

Early in the process of classifying documents for the survey and analysis report, it became evident that the literature on operator workload did not lend itself to a highly detailed categorization of operator behaviors. Generally, the literature could only be classified down to the second level of detail. Consequently, the literature was classified only according to the four major processes and seven activities shown in table IV, instead of the 47 behaviors. Even at this less-refined level of analysis, classification of the literature according to the operator behaviors dimension appeared more subjective and unreliable than classification in terms of workload technique.

The second line below the abstract designated "Op. Behav. Code" contains the behavior classification. In the example of table III, the general categories of operator behaviors described in the document are 1. Searching and identifying types of perceptual processes, 2. Information processing and problem solving types of mediational processes, and 4. Simple and complex types of motor processes.

[2]Berliner, C., Angell, D., and Shearer, D. J., Behaviors, Measures, and Instruments for Performance Evaluation in Simulated Environments. Paper presented at the Symposium and Workshop on the Quantification of Human Performance, Albuquerque, New Mexico, August 1964.

Table IV

Classification of Universal Operator Behavior Dimension
(After Berliner, Angell, and Shearer, 1964)

Processes	Activities	Specific Behavior
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

2.3 WORD DESCRIPTORS

In addition to the numerical classifications for workload technique and operator behaviors, each citation was also classified according to five categories by means of short word descriptors. The purpose of these descriptors was to convey information to the reader quickly on the details of the cited document.

At the bottom of each citation, five columns of descriptors appear. Going from left to right, the first two columns provide workload technique classification information in easily recognizable form. The first column indicates which of the four major categories of workload estimation are described. The entries in this column correspond exactly to those of the first column of table II. The second column of each citation provides a detailed description of the workload techniques employed and represents a hybrid description of the second and third columns of table II. Consequently, the descriptors in table II have been changed in some cases to provide the maximum information in the least space. Also, in the second column, when five or more workload techniques have been employed or described in one document, the term "multiple" has been used.

The third column specifies the type of presentation, as either Review, Construct, Experimental, or some combination. Documents presenting a brief review prior to developing a construct or describing an experiment were not given the Review designation.

The fourth column lists the experimental facilities used in the experiments described. In the case of review articles, if the review refers in a substantial way to earlier experiments, the facilities associated with those experiments are designated. On the other hand, if the review does not extensively describe earlier experiments, no facilities are designated. Entries in this column consist of None or some combination of Laboratory*, Field, Simulator, Flight simulator, and Flight test.

The fifth column describes the potential aircrew application environment. Those documents providing background information indirectly applicable to aircrew problems were designated by the term Background. The remaining documents were classified as containing information having direct bearing in "Flight simulator" experiments or "Flight test" experiments, or both.

*If the experimental facility was a computer, the designation Laboratory was used.

CONCLUDING REMARKS

The main purpose of the remarks in this section is to aid researchers who may become involved in future workload literature reviews or who wish to gain greater insight into the current review. Several matters have become apparent as a result of completing this annotated bibliography and the earlier survey and analysis report.

First, it is clear that mental workload estimation is an active field of research. The fact that 200 additional references were found between 1977 and 1979 attests to this. It is suggested that search updates should be made in each biennium. While timing is not critical, to wait more than three years to perform an update may again result in a task of enormous magnitude. When performing such a search, it is important to allow time overlap with any previous search. Overlap allows inclusion of publications which are dated prior to actual availability. Also, as indicated earlier, some papers presented at technical meetings eventually appear in journals, proceedings, and books, and it is helpful to the reader to list the most accessible citation.

As the size of this document demonstrates, something should be done to make the workload literature more manageable. Probably this document is the maximum usable size, and future updates should be tied in with computerizing the citations. Initial work in this area is underway using the New Jersey Institute of Technology Telenet System (Electronic Information Exchange System). However, this work represents a feasibility study. A more permanent approach needs to be developed that could be used for the next two decades. The approach should allow additions, editing, indexing, and cross-referencing by authorized personnel as well as accessing, read out, and print out by researchers and users.

Additional work should be done on bounding the topic of mental workload. While the selection criteria presented in Section 1.3 have worked well in most cases, certain problems remain. Foremost among these is the need for a better definition of "essential background." At present, whether or not a document should be included because it represents essential background is entirely a matter of judgment. To illustrate the difficulty, consider the secondary task method of workload estimation and its relationship to dual-task performance studied by experimental psychologists. There are at least a thousand publications dealing with dual-tasks. They address many aspects, including sense modalities, timing, instructions, cognitive processing, and interference. Their relationship to secondary tasks is on a continuum. Some provide more usable background than others, and it is difficult to decide which to include and which to exclude.

Also, in terms of bounding workload, more attention should be given to what might be termed subsidiary definitions. Mental workload itself can be considered as a global term. As an analogy, consider the word "automation." It has distinct meaning and yet conjures up different images to different people. It appears that mental workload has this problem also. By carefully defining subsidiary categories that minimize overlap, progress might be made toward resolving the difficulties in defining workload.

Lastly, a problem remains in terms of applicability of the literature. The survey and analysis report and this annotated bibliography both use the "universal operator behaviors" approach as an applications dimension. However, most literature cuts across two, three, and, in some cases, all four of the major categories of operator behaviors. Consequently, the information contained in the "Op. Behav. Code" notation is quite general. Future reviews should address refinements or alternatives to assessing applicability.

ANNOTATED WORKLOAD BIBLIOGRAPHY

Adams, R. J. and Rich, P. RNAV waypoint charting effects on pilot procedures, training and workload. In Proceedings, National Aerospace Meeting, Denver, Color. April 13, 14, 1977, 31-37. (Washington, D.C.: Institute of Navigation).

A summary is presented of the analytical procedure used to establish waypoint charting requirements. From this theoretical base, the paper introduces several currently used area navigation (RNAV) Standard Instrument Department (SID) and Standard Terminal Arrival Routes (STAR). The advantages gained by both the pilot and air traffic control system through the proper use of pilot procedures is quantified by using detailed flight test results from the Miami, Denver, and Chicago terminal areas and also flight simulator results.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Experimental	Flight simulator	Flight simulator
			Flight test	Flight test

Akhutin, V. M., Zingerman, A. M., Kislitoin, M. M., and Menitskii, D. N. Complex evaluation of the functional state of a human operator in control systems. In Optimization of the professional activity of a cosmonaut. Moscow: Izdatel'stvo Nauka, 1977, 234-244. (in Russian.)

A study of the psychophysiological reactions of human operators performing control operations has indicated two forms of regulation of the heart beat rate by the parasympathetic nervous system. The distinguishing between types of regulation confirms an analysis based on EEG indices and also shows the usefulness of the sensory-motor tracking procedure used in the psychophysiological study. The use of the experimental data to establish regulation information evaluation criteria and to predict the dynamics of operator tension is considered.

W/L Cat. Code: 3.1, 4.1.3, 4.1.5, 4.1.10

Op. Behav. Code: 1.2, 4.2

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	EEG			
	EKG			
	Heart rate, h.r. var.			

Albanese, R.A. Mathematical analysis and computer simulation in military mission workload assessment. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A13-1 - A13-6.

This paper discusses mathematical and computer approaches to the assessment of crew workload during military missions. Three analysis tools are discussed: (1) estimation algorithms, (2) linear models, and (3) nonlinear/hybrid models. These separate but interacting methods provide increasing levels of detail in an analysis, but require increasing levels of effort to obtain a result. A central element in this presentation is emphasis on the notion that a significant measure of crew workload is acceptable accomplishment of the mission plan. Mathematical analysis and computer simulation, properly employed, provide several measures of workload to the investigator, including mission accomplishment measures.

W/L Cat. Code: 3.1, 3.3

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Construct	None	Flight simulator
	Math. modeling			Flight test

Albanese, R. A. Quantitative military workload analysis. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 69-71.

This report discusses a method of tradeoff analysis as applied to workload analysis in the military environment. It is suggested that workload studies be performed in a tradeoff setting which allows the analyst to estimate the return on investment he has earned through his proposed system modifications. The methodologies described employ mathematical modeling techniques. It is emphasized that these techniques are an adjunct to, and not a replacement of, more traditional methods of workload analysis.

W/L Cat. Code: 3.1, 3.3

Op. Behav. Code: 1., 2.

Primary task	Single measures	Construct	None	Background
	Math. model			

Allen, R.W., Jex, H.R., McRuer, D.T. and DiMarco, R.J. Alcohol effects on driving behavior and performance in a car simulator. IEEE Transactions on Systems, Man, and Cybernetics, 1975, SMC-5, 498-505.

A fixed-base simulation was developed to test the effect of alcohol on driving performance. Measurements of both driver control behavior and driver-vehicle performance were obtained for the steering task, and detection and recognition indexes and reaction time were measured on the discrete task. Preliminary results on scanning behavior are also presented. Alcohol causes larger lane and heading deviations, and increases detection and reaction times on the discrete task. Both continuous steering control and discrete peripheral "sign" response tasks were performed, singly and combined, to investigate the effects of divided attention. Performance on the steering contol task was decreased when both tasks were done concurrently, but the sensitivity to alcohol effects was similar.

W/L Cat. Code: 2.2.1, 3.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Simulator	Flight simulator
Primary task	Single measure			Flight test
Physiological	Eye movement			

Allport, D. A., Antonis, B. and Reynolds, P. On the division of attention: a disproof of the single channel hypothesis. Quarterly Journal of Experimental Psychology, 1972, 24, 225-235.

In dichotic listening, subjects are apparently unable to attend simultaneously to two concurrent, auditory speech messages. However, in two experiments reported here, it is shown that people can attend to and repeat back continuous speech at the same time as taking in complex, unrelated visual scenes, or even while sight-reading piano music. In both cases performance with divided attention was very good, and in the case of sight-reading was as good as with undivided attention. There was little or no effect of the dual task on the accuracy of speech shadowing. These results are incompatible with the hypothesis that human attention is limited by the capacity of a general-purpose central processor in the nervous system. An alternative, "multi-channel", hypothesis is outlined.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Alluisi, E. A. and Morgan, B. B., Jr. Effects of practice and work load on the performance of a code transformation task (COTRAN). Moffett Field, California: National Aeronautics and Space Administration, Contractor's Report NASA CR-1261, 1969.

The effects of practice and operator workload on the acquisition and performance of a code-transformation (COTRAN) task are reported. The COTRAN task was developed previously (cf. Alluisi & Coates, 1967) to provide a means for obtaining performance measurements of that part of intellectual functioning which is typically called "non-verbal mediation"; it follows the problem-solving paradigm. The experiment was conducted in two phases. During the first, or acquisition phase, 27 COTRAN problems were solved on each of four (Group-4, with four subjects), eight (Group-8, with twenty subjects), or twelve (Group-12, with four subjects) successive days. Performance reached asymptotic levels in four to six sessions, in general, and the differences in final levels of performance of the three groups (4, 8, and 12) were not statistically significant. During the second, or transfer phase of the study, each of the 28 subjects solved 27 COTRAN problems on each of five successive days while time-sharing the COTRAN task with different combinations of tasks selected from a multiple-task performance battery. The results indicate that skilled COTRAN performance is sensitive to at least two or three levels of workload stress, and that different subjects may tend to adopt different strategies in time-sharing the COTRAN task with other tasks.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 2.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measure

Alluisi, E. A. and Morgan, B. B., Jr. Effects of sustained performance of time-sharing a three-phase code transformation task (3P-COTRAN). Perceptual and Motor Skills, 1971, 33, 639-651.

The 3P-COTRAN task was time-shared with 5 different combinations of tasks selected from a multiple-task performance battery (MTPB) used in a synthetic-work approach to the study of work behavior or sustained performance (Alluisi, 1969). 20 Ss previously trained to a high level of skill on the 3P-COTRAN task were divided at random into 5 groups of 4 Ss, each of which then time-shared the task with a different combination of MTPB tasks. Results were analyzed in terms of both the effects of the time-sharing on the 3P-COTRAN performances, and the effects of 3P-COTRAN on the time-shared MTPB performances. Evidence of the adoption of different response strategies to time-shared tasks, especially under conditions of operator overload, or workload or performance stress, was found, and the methodological implications of this finding are discussed.

W/L Cat. Code: 2.2.1, 2.2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Anderson, D. B. and Chiou, W. C. Physiological parameters associated with extended helicopter flight missions: an assessment of pupillographic data. Fort Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, USARRL no. 77-21, Final report, September, 1977. (AD A052 771).

Six Army aviators were used to study various psychological and physiological parameters of flight fatigue. This study reports the characteristics of the pupillary reflex response to light and of the pupillary amplitude variation. It was found that the waveform characteristics of the pupillary reflex response to light were relatively irregular. Qualitative analyses revealed that the blinking rate increases and the pupillary amplitude varies as a function of loaded flight task. The average pupillary diameter was smaller in the morning than in the evening. Results from this study should be evaluated with other potential flight fatigue parameters such as the blood and urine tests, EKG, etc. to derive more meaningful interpretations of the complex underlying flight fatigue mechanism.

W/L Cat. Code: 4.1.7, 4.1.8

Op. Behav. Code: 1., 2.

Physiological	Eyelid movement	Experimental	Laboratory	Background
	Pupillary dia.			

Anderson, P. A. and Toivanen, M. L. Effects of varying levels of autopilot assistance and workload on pilot performance in the helicopter formation flight mode. Washington, D.C.: US Office of Naval Research, JANAIR 680610, March, 1970.

The objective of this study was to evaluate pilot performance in manual IFR formation flight with varying levels of autopilot assistance and pilot workload. Man-in-the-loop simulations of these vehicles were conducted to evaluate pilot performance under six levels of autopilot assistance, and three levels of pilot workload, consisting of a forced-pace, secondary concomitant task. Results of this study indicated that increasing the level of autopilot assistance resulted in a less demanding task for the pilot and provided greater system stability. This was borne out in terms of both quantitative performance data and pilot opinion. Only at the highest workload level tested did autopilot assistance serve to reduce the position errors from what was experienced under the manual control conditions.

W/L Cat. Code: 1.2, 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion	Questionnaire	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Subsidiary task			Flight test
Primary task	Single measures			

Armstrong, G.C., Sams, D.D., McDowell, J.W. and Winter, F.J., Jr. Pilot factors for helicopter pre-experimental phase. Randolph AFB, Texas: USAF Instrument Flight Center, IFC-TR-74-2, February, 1975.

This investigation was conducted to establish the methods and procedures, to collect pilot factors information, and to obtain firsthand pilot opinions and judgments concerning the present control-display systems installed in helicopters. Four instrument instructor pilots were used as test subjects, and seven data gathering sorties were accomplished. The profiles flown represented typical helicopter instrument maneuvers. The pilot/subject activity required in performance of the maneuver segments was designed to progress from simple tasks to complex tasks. Objective and subjective data were obtained through the use of video, audio, and oscillograph recording equipment. This study documents the characteristics and trends of the control and display devices as installed in a light to medium utility helicopter.

W/L Cat. Code: 1.1, 3.2

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Mult. measures	Experimental	Flight test	Flight simulator
Primary task				Flight test

Asiala, C.F. Advanced man-machine evaluation techniques. Paper presented at the American Defense Preparedness Association, Huntsville, Alabama, November 12-13, 1975.

Recent design/integration efforts have provided an advanced man/machine evaluation technique that focuses on (1) advanced fighter performance, (2) mission analysis, (3) functional allocation analysis, (4) task analysis, (5) anthropometric/visual link analysis, (6) static design aid evaluation, (7) digital pilot simulation model, and (8) flight (man-in-the-loop) simulation. This advanced technique provides a tangible basis for development and assurance of an optimized, integrated cockpit and traceability of man-machine design decisions. Current research efforts have included the development of pilot performance model techniques that evaluate the impact of alternate crew station and weapon delivery configurations on pilot workload. In addition, simulated mission profiles have yielded valuable information on the head and eye motion and workload of operational pilots.

W/L Cat. Code: 2.1.1, 2.1.2, 3.3, 4.1.7

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp.,	Review	None	Flight simulator
Primary task	time assess.			
	Matn. model			

Asiala, C. F., Loy, S. L. and Quinn, T. J. Digital simulation model for fighter pilot workload. St. Louis, Missouri: McDonnell Aircraft Company, MDC A0058, September, 1969.

The Pilot Simulation Model (PSM) was developed by McDonnell Douglas to evaluate workload and mission success factors in developmental aircraft. It has been applied to a number of military system studies such as A-6E TRAM, A-7, F-15, Advanced Tactical System (ATS), Digital Flight Control System (DFCS), Advanced Fighter Technology Integration (AFTI), F-18 and the Harrier. The last two are currently undergoing periodic model iterations in response to design updates. The PSM is used primarily to fill the evaluation gap between paper-and-pencil and manned simulation, in situations where system design status justifies a more comprehensive technique than paper-and-pencil but does not necessarily require a manned simulation approach. The model provides a detailed workload analysis by task by modality (e.g., hand, eye, information processing), and equipment utilized. To accomplish this effectively, both a functional task flow and a task by modality by task time analysis must be performed.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator
		Experimental		

Asset, A. M., Batejat, D., Papin, J. P. and Viard, D. Investigation of pilot behavior in flight-analysis of Japanese studies. Revue de Medicine Aeronautique et Spaciale, 1976, 15, 62-66. (In French.)

This paper describes Japanese investigations involving analysis of pilot behavior during air flight with the purpose of estimating pilot workload and performance complexity. Major aspects discussed concern a description of the activity network in the man/machine system, temporal course of pilot behavior in this system, development of measurement techniques for evaluating pilot behavior, and data analysis and workload estimation.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Review	None	Background
Primary task	Single measures			

Auffret, R. Studies on pilot workload-psychophysiological factors. Proceedings of AGARD Conference on Studies on Pilot Workload, AGARD-CP-217, April, 1977.

The different variables which can influence human performance during the operational use of helicopters or other aircraft having high acceleration loads are assessed to quantify the sum of work which can be provided at each moment during flight.

W/L Cat. Code: 4.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct
Primary task	Single measures	

Auffret, R., Seris, H., Berthoz, A. and Fatras, B. Estimate of the perceptive load by variability of rate of heartbeat: Application to a piloting task. Le Travail Humain, 1967, 80, 309-310.

The load undergone by a subject during aircrew work is essentially perceptive. Its estimate is necessary for the human factors engineering study of an operator station. With this goal in mind we have studied the rate of pulse beat and its variability. This method does not degrade the performance of the subject. The measurement of the variability of the instantaneous cardiac frequency appears a useful criterion in view of the computation of the load or the detection of the variations of load during pilot work. The data reduction should be carried out with a minimum accuracy of 5 ms. Establishing means over long time periods can mask modifications in variability.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Experimental	Laboratory	Flight simulator
			Flight test	Flight test

Bahrick, H. P., Noble, M. and Fitts, P. M. Extra-task performance as a measure of learning a primary task. Journal of Experimental Psychology, 1954, 48, 298-302.

The present study was undertaken to determine whether performance on a secondary task, practiced simultaneously with a primary task, can serve to reveal learning on the primary task that is not revealed by conventional measures on the primary task itself. The study was based on the widely held notion that with continued practice tasks become less susceptible to interference. To test this hypothesis, Ss were trained either in a repetitive or in a random version of a motor task. The two versions were adjusted in such a way that a primary task performance index of the various groups remained at a comparable level at each stage of training. Concurrent performance of an extra task was required either early or late in practice on both versions of the motor task. The results showed that extra-task (arithmetic) performance late in practice was superior to extra-task performance early in practice when the sequence of stimuli in the concurrent motor task was repetitive. No such difference occurred when the motor task was random. Since scores on the motor task itself remained comparable at different levels of training for the random and repetitive groups, these results support the hypothesis that extra-task performance can be used to measure certain kinds of improvement on a primary task which are not evident from conventional scores on that task itself.

W/L C... Code: 2.2.1
Op. Behav. Code: 1., 2., 4.

S... m. capacity Subsidiary task Experimental Laboratory Background

Bainbridge, L. Forgotten alternatives in skill and work-load. Ergonomics, 1978, 21, 169-185.

This paper suggests that the nature of process control skill lies in the changed decision making made possible with increased knowledge of process behavior. During learning, feedback about process output indicates that the process needs correcting, and also that the operator must adjust his choice of action. An experienced operator knows the correct error-action alignment, so has less need to check and correct both the process and his own behavior. He has a lower workload and a larger task capacity. Choice of appropriate control actions requires knowledge of the effects of his own behavior as well as that of the process, and assessment of the task context. If behavior is chosen to maintain the operator's mental and physical state, as well as to maintain the process, this requires further knowledge about his own potential behavior, his internal state, and criteria for acceptability of his own state. High task demands may lead to performance breakdown because they cause unfamiliar decision situations, so the operator is returned to inexperienced, less effective types of behavior.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 3., 4.

Primary task Single measures Construct None Background

Baker, D. L. and Intano, G. P. Helicopter yaw axis augmentation investigation - CDG-PFH-4. Randolph AFB, Texas: USAF Instrument Flight Center, IFC Test Plan 74-11, December, 1974.

A test plan is presented for a flight test. The objectives of the helicopter yaw axis augmentation investigation are to determine the amount of change in performance pilot activity and pilot acceptance by augmenting the yaw axis; determine the value of a heading-hold feature during hover, take-off, climbs, descent, and cruise; and to assess the degree of value of turn coordination when climbing, descending, and level turns are executed. A series of in-flight, postflight, and subject pilot questionnaires will be used.

W/L Cat. Code: 1.2

Op. Behav. Code: 1., 2., 4.

Opinion Questionnaire Construct None Flight test

Flight simulator

Barnes, J. A. Use of eye-movement measures to establish design parameters for helicopter instrument panels. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A3-1 - A3-8.

Recording the pilot's eye-scan paths and fixation points during actual helicopter flight provides an accurate measure of the visual workload imposed by a particular panel design. This tool is not limited to aircraft instrument panels; it can be used to evaluate any operator control panel or even the design of a multi-information display within a panel. Initial work was done in the UH-1 helicopter using experienced instrument-rated pilots flying actual maneuvers on instruments. The knowledge gained from these data allowed for design of a helicopter instrument panel in which the most referred to instruments were placed so that the eye-scan paths were minimized. This design considerably lessens the pilot's visual workload, reduces fatigue, and allows more time for other tasks.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1.1, 2.1, 4.2

Physiological Eye movement Experimental Flight test Flight simulator

Flight test

Baron, S. and Levison, W. H. An optimal control methodology for analyzing the effects of display parameters on performance and workload in manual flight control. IEEE Transactions on Systems, Man, and Cybernetics, 1975, SMC-5, 423-430.

An approach to the analysis of the effects of display parameters on manual control based on an optimal control model of the human operator and a related model for task interference is presented. The methodology allows one to predict the effects of changes in display variables on both performance and attentional demand or workload. The methodology is applied to vertical situation displays for STOL approach-to-landing. Both status displays and displays of command information are examined and compared in teams of approach success probability and workload requirements.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 4.

Primary task Math. model Construct Laboratory Flight simulator

Experimental

Baron, S., Muralidharan, R., and Kleinman, D. Closed loop models for analyzing the effects of simulator characteristics - pilot performance/workload prediction. In Flight Technologies Conference, Arlington, Texas, September, 1978, 138-148. (American Institute of Aeronautics and Astronautics, New York.)

The optimal control model (OCM) of the human operator is used to develop closed-loop models for analyzing the effects of (digital) simulator characteristics on predicted performance and workload. Two approaches are considered: the first utilizes a continuous approximation to the discrete simulation in conjunction with the standard optimal control model; the second involves a more exact discrete description of the simulator in a closed-loop multi-rate simulation in which the optimal control model 'simulates' the pilot Both models predict that simulator characteristics can have significant effects on performance and workload.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 4.

Primary task Math. model Construct None Flight simulator

Baschera, P. and Grandjean, E. Effects of repetitive choice reaction tasks on activation level and subjective state. Paper presented at the 7th Congress of the International Ergonomics Association, Warsaw, Poland, August 27-31, 1979.

The effects of repetitive choice reaction tasks with different degrees of difficulty on activation level and subjective state were investigated. As indices of activation level critical flicker frequency and heart rate variability were used; subjective state was studied with a questionnaire. The task with the lowest degree of difficulty produced the greatest decrease in CFF and the smallest impairment of subjective state. The task with the highest degree of difficulty also produced a large decrease in CFF, but it greatly impaired subjective state. Heart rate variability increased most on the task with the lowest degree of difficulty.

W/L Cat. Code: 1.2, 4.1.1, 4.1.10

Op. Behav. Code: 1., 2., 4.1

Opinion	Questionnaire	Experimental	Laboratory	Background
Physiological	FFF			
	Heart rate, h.r. var.			

Bate, A.J. and Self, H.C. Effects of simulated task loading on side-looking radar target recognition. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, AMRL-TR-57-141, June, 1968. (AD 673873)

This study was conducted to determine the effects of simulated task loads that prevented observers from devoting all of their time to searching a radar display for targets of opportunity. Task loads taking up 0%, 25%, 50% and 75% of observers' screen viewing time were simulated by turning the display on and off in a programmed random pattern. The radar picture depicted a strip of terrain 25-nautical-miles wide and traveled from the top to the bottom of the screen at a simulated aircraft speed of 1300 knots. The number of correct responses and number of false responses were both approximately linear functions of accumulated viewing time. Mean distance traveled down the screen by targets and nontargets prior to responses was also significantly affected by viewing time. Since the numbers of correct and false responses decreased in approximately the same proportion with each decrease in viewing time, overall accuracy of responses was nearly constant for all viewing times.

W/L Cat. Code: 2.3, 3.1

Op. Behav. Code: 1., 2., 3.

Spare m. capacity	Occlusion	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Bateman, R. P. An heuristic approach to work analysis. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29 - November 1, 1979, 554-557.

Nine experienced pilots served as subjects in an experiment designed to evaluate differences between multifunction keyboards by measuring the objective performances of the subjects. Subjects performed tracking tasks and used the keyboards for secondary tasks. Measurements of tracking parameters and of performance time and errors using the keyboards were taken. The results showed that no single variable consistently reflected changes in task difficulty. The observed tendency of subjects to employ different, changing strategies during the multiple task performance led to a tentative hypothesis that work was a composite of all of the parameters. A regression analysis was used to develop an equation with weighting coefficients for the parameters. The equation was found to be in agreement with subjective performance evaluations.

W/L Cat. Code: 1.1, 2.2.1, 3.1, 32.

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Subsidiary task			
Primary task	Single measures			
	Multiple measures			

Baty, D. L. Human transinformation rates during one-to-four axis tracking with a concurrent audio task. Proceedings of the 7th Annual NASA-University Conference on Manual Control, University of Southern California, June, 1971, 293-306. (NASA SP-281).

An experiment was conducted to determine the information processing rates of six subjects performing one-, two-, three-, and four-axis compensatory tracking tasks, with and without a concurrent four-choice auditory task. The purpose was to obtain further evidence concerning the nature of an hypothesized ceiling on human transinformation rates. Interference was found among tasks, but the evidence concerning a ceiling on information processing rates was inconclusive.

W/L Cat. Code: 2.1.2, 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Beatty, J. Pupillometric measurement of cognitive workload. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 135-143. (NASA TM X-73 170).

The momentary workload that is imposed by a cognitive task upon the limited capacity human information-processing system appears to be accurately reflected in the momentary level of central nervous system activation. The utility of pupillometric methods of workload assessment is evaluated and several lines of experimental evidence relating activation and cognitive function are reviewed.

W/L Cat. Code: 4.1.8

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Pupillary dia.	Experimental	Laboratory	Flight simulator
				Flight test

Beatty, J. Pupillometric methods of workload evaluation: present status and future possibilities In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 103-109.

This paper discusses the use of pupillometric measures in the evaluation of pilot workload. First the innervation of the pupil with respect to its connections with brainstem activation systems is described. Modern methods for pupillometric measurement are then described. Next, a series of experiments describing pupillary response in a variety of information-processing tasks is reviewed. Finally some possibilities for the use of pupillometric methods in the measurement of pilot workload are discussed.

W/L Cat. Code: 4.1.8

Op. Behav. Code: 2.

Physiological	Pupillary dia.	Review	Laboratory	Flight simulator

Bell, P. A. Effects of noise and heat stress on primary and subsidiary task performance. Human Factors, 1978, 20, 749-752.

A primary pursuit rotor task and concurrent subsidiary number processing task were performed by 72 male and 72 female paid volunteers who were experiencing ambient temperatures of 22°C, 29°C, or 35°C and noise levels of either 55 dB(A) or 95 dB(A). Performance decrements associated with high noise levels and high ambient temperatures were additive for the subsidiary task. Neither noise nor heat stress affected performance on the primary task. Results are interpreted in terms of an overload framework.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Benel, R. A., Coles, M. G. H., and Benel, D. C. R. Electrodermal lability and individual differences in simultaneous monitoring and tracking. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29 - November 1, 1979, 518-522.

Electrodermal (galvanic skin) responses conveniently index sympathetic arousal. Individuals with high levels of resting electrodermal activity are designated "labiles," while those with low levels, "stabiles." Labiles appear resistant to performance decrement over time in vigilance tasks. Thus, increased electrodermal responsivity may represent enhanced attentional capacity during such tasks. The responses of 10 labiles and 10 stabiles were collected during a simple reaction time task and under single and dual task monitoring and tracking conditions. Subjects monitored an automatic tracking task for dynamic system failures. Tracking was the Critical Task with a subcritical level of instability. The reaction time data paralleled the previously reported findings of inferior performance for stabiles. The data for complex single and dual task conditions did not reveal a similar trend. Generally, stabiles performed better.

W/L Cat. Code: 2.2.2, 3.1, 4.1.2
Op Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Single measures	Single measures			
	GSR			

Benson, A. J., Huddleston, J. H. F., and Rolfe, J. M. A psychophysiological study of compensatory tracking on a digital display. Human Factors, 1965, 7, 457-472.

Comparable performance on a compensatory tracking task was achieved with a purely digital altimeter display and with a combined digital and scale-pointer display. Performance of a subsidiary, light responding, task was degraded significantly when the digital task was employed. In the presence of the subsidiary task a larger change was recorded in a number of physiological variables (heart rate, muscle activity, skin resistance and respiration) with the digital than with the counter-point display. Thus, both performance and physiological measures indicated that parity of performance on the primary task was achieved by increased "effort" when using the digital display.

W/L Cat. Code: 2.2.1, 4.1.2, 4.1.4, 4.1.9, 4.1.10, 4.1.11

Op. Behav. Code: 1.2, 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Flight simulator

Physiological   Multiple

Bergeron, H. P. Pilot response in combined control tasks. Human Factors, 1968, 10, 277-282.

Pilot response in a multi-task simulation, which consisted of a primary control task combined with one or two secondary or side control tasks, was investigated. A general description of the response characteristics of each of these tasks was obtained and this information was used to determine the workload requirements of the tasks. Two different control tasks were used as the primary control task, either a fixed-base simulation of a lunar letdown or a simplified multi-loop tracking task which was similar to the end of the lunar letdown. The simplified tracking task was in lieu of the more complicated lunar letdown because it could be represented and reproduced analytically. The secondary or side tasks consisted of a system-failures task and motor response task. The system-failures task was incorporated from those systems present in a vehicle known as the Mercury Procedures Trainer. The motor response task consisted of using a pencil-like device to make impacts on two separated, restricted columns.

W/L Cat. Code: 2.2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Flight simulator   Flight simulator

Primary task   Single measures

Bergstroem, B. and Arnberg, P. Heart rate and performance in manual missile guidance. Perceptual and Motor Skills, 1971, 32, 352-354.

Earlier stress studies under laboratory conditions show that heart rates from 100 to 110 bpm are associated with significant decrements in missile-tracking performance. Data from real missile tracking by eight operators with no stress deliberately induced indicate, however, that performance is unaffected up to 135 bpm, and only moderately affected in the 135- to 170-bpm region. The disagreement between the two sets of results highlights the difficulties in generalizing from stress experiments.

W/L Cat. Code: 3.1, 4.1.10

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Beringer, D. B. The design and evaluation of complex systems: application to a man-machine interface for aerial navigation. Proceedings of the 23rd Annual Meeting of the Human Factors Soceity, Boston, Massachusetts, October 29-November 1, 1979, 75-79.

Systematic and economic design and evaluation strategies were applied to a computer-generated 4-D serial navigation system. Experienced instrument pilots received training in a PLATO-based digital flight simulator using either a keyboard entry/static map, keyboard entry/dynamic map, or touch entry/dynamic map system. Digital data entry training time was comparable for all three systems but the touch-map proved superior for the plotting tasks, greatly reducing training and task execution times while virtually eliminating errors. Subsequent performance evaluation showed that the touch-map reduced flight path tracking error, increased processing rates on a digit-cancelling secondary task, and increased the accuracy of manual plotting operations. It was concluded that a touch entry system could significantly reduce cockpit workload across a wide range of operational environments.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Bermudez, J. M., Harris, D. A., and Schwank, J. C. H. Peripheral vision and tracking performance under stress. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 402-406.

The complexity of modern aircraft systems places substantial information processing loads on the pilot. Physiological and behavioral evidence for two human visual systems that may differ in susceptibility to psychological stress suggests the possibility of a natural stress resistant information channel that could be used to input information during stressful flight situations. It follows that the extreme peripheral visual fields could be a possible location for adjunct visual displays that serve to orient expeditiously the pilot's focal vision and attention. Two experiments involving male cadets were conducted. The data concern the effects of three types of instrument displays used under varying levels of stress during a simulated instrument landing. Stress was defined as demand for primary task-related cognitive activity. A modified Sternberg memory probe technique was used to impose these demands.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Flight simulator Flight simulator

Primary task Single measures

Beyer, R. A study of pilot's workload in helicopter operation under simulated IMC employing a forward looking sensor. Proceedings of AGARD Conference on Studies on Pilot Workload, AGARD-CPP-217, April, 1977, B6-1 - B6-10.

Various measures of pilot workload are known which are presently applied to human engineering investigations. It is difficult, however, to find a measure which has proved to be universally applicable and adequately validated. Primary task and rating measures tailored to a specific application may be less flexible but can provide relevant and sufficient information on pilot workload. This is demonstrated by referring to experiments with advanced helicopter displays which were tested in flight.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Opinion Rating scale Review Flight test Flight simulator

Primary task Single measure Flight test

Bisseret, A. Analysis of mental processes involved in air traffic control. Ergonomica, 1971, 14, 565-570.

The research which is briefly presented here has been carried out, during the last ten years, by a team of psychologists at the Centre d'Experimentation de la Navigation Aerienne, whose aim is the automation of the air traffic control system. The general topic refers to the operator-computer's interactions in a complex system. The type of contribution that psychology may provide is shown by indicating the three interdependent aspects of the research: 1) the definition of the operator's algorithms; 2) the analysis of his "mental representation"; and 3) the study of the effect of the workload on the mental processes. The general methodology of the studies of mental processes is presented; and an experiment on operative memory is discussed.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct Review	Field	Background

Blaaw, G. J. Godthelp, J. and Morall, J. Driver's lateral control strategy as affected by task demands and driving experience. Society of Automotive Engineers, Paper no. 770876, 1977.

Driving behavior may be described as the result of a process in which performance is optimized to meet several task demands at the same time. The present study investigated how different task demands interact, particularly in combination with driving experience, the latter factor being indicative for driving skill development. The results showed that driving experience as a main experimental factor interacted significantly with task demands for lateral and longitudinal control. The results may be important for the discovery of characteristic performance patterns of experienced and inexperienced drivers and therefore for the development of driver education and training programs.

W/L Cat. Code: 3.1

Op. Behav. Control: 1., 2., 4.

Primary task	Single measures	Experimental	Field	Background

Blosszcynski, R. M. and Kozerenko, O.P. A psychophysiological study of pilot behavior in conditions of combined activity. In Optimization of the professional activity of a cosmonaut. Moscow: Izdatel'stvo Nauka, 1977, 160-169. (In Russian.)

The behavior of pilots performing two different kinds of tasks simultaneously is described. One task involved reception, working, and transmission of oral information, and the other involved visual tracking and psychomotor compensation during control maneuvers using a simulator. Continuous monitoring of psychomotor compensation indices (control hand movements) and of physiological functions (pulse, arterial pressures, oral temperature) is described. It was found that the quality of compensatory tracking during conditions of semantic loading depends on the initial level of performance.

W/L Cat. Code: 2.2.1, 2.2.2, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Blix, A. S., Stromme, S. B., and Ursin, H. Additional heart rate-an indicator of psychological activation. Aerospace Medicine, 1974, 45, 1219-1222.

Heart rate and oxygen consumption of helicopter and transport aircraft pilots were measured. During flight operations, the heart rate accelerated without a corresponding increase in oxygen consumption. This heart rate increase beyond that expected from the oxygen uptake is therefore used as an indicator of psychological activation. This activation did not depend only on the actual task, but also on the experience level of the pilot himself. The levels of heart rate (and blood pressure) recorded indicate that even routine missions may impose a hazard to pilots with unmanifested or latent heart failure. This obviously calls for frequent workload-ECG examinations of flying personnel.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Heart rate, h.r. var.	Experimental	Flight test	Flight simulator
	Blood pressure			Flight test

Boller, H. E. and Kruger, W. Investigation of a control device with force input and displacement feedback in steering-low-frequency system. Paper presented at the 15th Annual Conference on Manual Control, Wright State University, Dayton, Ohio, March 20-22, 1979. (See also Zeitschrift für Arberlswissenschaft, 1978, 32, 254-260, In German).

In manual control information about the vehicle dynamic behavior can be advantageous for the operator. With low frequency systems it must be determined whether the advantage of kinesthetic feedback can be utilized for the slow movements, because technical complexity and costs involved are at a relatively high level. This study compares two two-handed yoke controls with the control functions of (1) displacement input and (2) force input with positional feedback as a kinesthetic display of vehicle response. Eight subjects had to reach command values as quickly as possible controlling the low frequency system output variable and its derivative (depth and vertical rate of a simulated submarine). The values obtained show that the technical complexity involved in a control with force input and positional feedback is not worthwhile for the single-axis vehicle dynamic chosen.

W/L Cat. Code: 2.1.1, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Simulator	Flight simulator
Primary task	Primary task			

Borg, G. Subjective aspects of physical and mental load. Ergonomics, 1978, 21, 215-220.

Methods of measuring subjective difficulty, effort and other aspects of work-load which have been developed by the author and his colleagues are described, and the use of these methods as means of distinguishing between individuals, and their relationships to psychometric measures, are discussed. Applications are noted to both physical and mental work.

W/L Cat. Code: 1.1

Op. Behav. Code: 2., 4.

Opinion	Rating scale	Review	None	Flight simulator
				Flight test

Bowser, D. K. Limiting flight control systems. In AGARD Conference Proceedings No. 199, Stall/Spin Problems of Military Aircraft, (AGARD-CP-199) June, 1976, 11-1 - 11-12. (AD A029 071).

This paper addresses the development and application of various types of automatic flight control systems for high-angle-of-attack augmentation and limiting. Considerations included are improved handling qualities for maximum tracking effectiveness, reduced pilot workload, control-configured vehicles, stall inhibitors, and departure prevention systems.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Single measures			Flight test

Boyce, P. R. Sinus arrhythmia as a measure of mental load. Ergonomics, 1974, 17, 177-183.

This experiment examines the proposition that sinus arrhythmia is a measure of mental load. The experiment involved a subtraction task in which the physical and mental loads could be varied independently. The results indicate that sinus arrhythmia does decrease with an increase in mental load. However, heart rate can also be used to differentiate between the mental loads. In addition it was found that both heart rate and sinus arrhythmia increased for an increase in physical load. This increase in sinus arrhythmia can be explained by the static work component of the physical load and the scoring system used. It is concluded that changes in heart rate and sinus arrhythmia are best regarded as generalized responses to the imposition of a load.

W/L Cat. Code: 1.1, 4.1.3, 4.1.10

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
Physiological	EKG			
	Heart rate, h.r. var.			

Boylan, R. J. A review of crew systems analytic methods. Seattle, Washington: Boeing Aerospace Company, D180-17525-1, January, 1974.

The purposes of crew system analytic methods are to provide a valid methodology for evaluating design/operational requirements, and to pinpoint potential trouble spots early in the design cycle before the system reaches the hardware stage. The implementation of this methodology requires a firm analytic base if the results are to have a bearing on operational performance. It is to this end that the present review was undertaken, attempting to compile, in summary form, a collection of effective, easily adaptible analytic methods for use in man/machine or system analyses. The second purpose of the document is to present the initial development work on a general mission profile, designed for application over a cross section of civilian and military aircraft. Use of the profile by the crew systems analyst will result in a considerable saving in development time, as task and functional commonalities are maximized and prevent needless duplication of effort. In using the general mission profile, the analyst can plug in aircraft specific parameters where applicable, thus approximating the function of contemporary "user-interactive" design programs.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Review	None	Flight simulator

Boylan, R. J. Introduction to Boeing operator workload and workspace evaluation models. Seattle, Washington: Boeing Aerospace Company, D180-17526-1, January, 1974.

The two analytic and computer aiding programs described in this document were developed in response to a growing requirement for a quick, efficient method for designing and evaluating the man/machine interface in contemporary aerospace systems. Not only are the capabilities of such programs in demand today as integral tools in human engineering endeavors, but it is anticipated that they will be contractually required in the near future. In order to meet this challenge, the Boeing Crew Systems Group has pursued a program aimed at the development and refinement of computerized, operator evaluation programs. The two programs presented in this document constitute examples of these efforts, covering workload evaluation of cockpit crews (WECC) based on task performance times, and workspace accessibility (TX-105) based on operator/control distance and movement sequences.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator

Bradshaw, J. L. Load and pupillary changes in continuous processing tasks. British Journal of Psychology, 1968, 59, 265-271.

The interaction of rate of presentation, and number of transforms and possible responses was examined in connection with the effect of cognitive load upon pupillary dilation. The task involved continuous processing of auditorily presented material. The two criteria of task difficulty both contributed to raising pupillary diameters, which were further increased at the moment of button-press responding. That variations in level arousal were involved was further borne out by the tendency for certain regular changes to occur in pupillary dilation in the course of the processing tasks.

W/L Cat. Code: 3.1, 4.1.8

Op. Behav. Code: 2., 3., 4.

Primary task Pupillary dia. Experimental Laboratory Flight simulator

Physiological Single measures

Branscomb, H. H. The development of a measure for task induced stress in speech. Master's thesis, Massachusetts Institute of Technology, Cambridge, Massachusetts, February, 1979.

In an experiment involving responses to instructions presented on a video terminal and clicks presented in a pair of headphones, subjects were tested for changes in speech patterns as a function of task load. Opinion ratings and task scores were also obtained. Results indicate that there is a systematic and reliable, but not very accurate, way to detect the influence of task difficulty on speech. Larger sample sizes and average times appear to be required.

W/L Cat. Code: 1.1, 3.1, 4.3

Op. Behav. Code: 1., 2., 3.

Opinion Rating scale Experimental Laboratory Flight simulator

Primary task Single measures

Physiological Speech part. anal.

Bracht, M. Cardiac arrhythmia and secondary tasks as measures of mental load. Master's thesis, California State University at Northridge, August, 1977.

Five methods of scoring cardiac arrhythmia, and both self-paced and adaptive versions of the secondary-task method were compared as measures of mental load. Each was used to differentiate among easy, medium, and difficult versions of a mental arithmetic task. In this standardized task situation where task difficulty was a function of complexity (load stress), only the secondary-task measures reflected changes in mental loading which corresponded to the increasing difficulty of the arithmetic task. The self-paced and adaptive secondary task versions were quite similar as indices of the mental load imposed. Interference of the self-paced secondary task with the primary loading task was not a problem. None of the cardiac arrhythmia measures consistently nor accurately quantified levels of task difficulty.

W/L Cat. Code: 2.2.1, 2.2.4, 3.1, 4.1.10
Op. Behav. Code: 1., 2., 3.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			
Physiological	Heart rate, h.r. var.			

Brenner, M., Branscomb, H. H., and Schwartz, G.E. Psychological stress evaluator-two tests of a vocal measure. Psychophysiology, 1979, 16, 351-356.

The Psychological Stress Evaluator (PSE), a commercial lie dectector employing voice analysis, was tested on two laboratory tasks. On the guilty knowledge task of Lykken, 20 subjects were interrogated on personal information after being offered a reward to fool the interrogator. PSE analysis failed to identify correct responses beyond chance levels. On the mental arithmetic task of Kahneman, Tursky, Shapior, and Crider and Tursky, Schwartz, and Crider, 16 subjects performed arithmetic problems which varied in difficulty but were performed under identical pacing. According to PSE scoring, stress increased with task difficulty. In addition, the PSE-measured differences occurred with high consistency across subjects. Some aspects of PSE analysis may be valid for the measurement of stress, although the validity of the analysis for practical lie detection is questionable.

W/L Cat. Code: 3.1, 4.3
Op. Behav. Code: 1., 2., 3.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Speech patt. anal.			

Brenner, M., Branscomb, H. H., and Wright, R. A computer based measure of vocal stress. (Unpublished summary report, NASA Ames Research Center, June, 1978-June, 1979.)

The purpose of the program is to develop an automated measure of workload based on the voice. This measure might be employed in aviation situations without attaching moniters to a subject or interfering with cockpit activity. The first year project consisted of three parts: A) automation of the available procedures into a prototype measure ("automation"), B) collection of high-fidelity voice data from a laboratory workload task ("data collection"), and C) initial testing of the prototype measure against the laboratory results "testing").

W/L Cat. Code: 4.3

Op. Behav. Code: 1., 2., 3.

Physiological   Speech patt. anal.   Experimental   Laboratory   Background

Brichcin, M. and Hampejsova, O. Results of two kinds of mental load measurements. Ceskoslovenska Psychologie, 1970, 14, 19-31. (In Czechoslovakian).

The experimental project with 51 men was conceived to verify whether it was possible to differentiate in secondary task conditions the effect of mental load on various types and the degree of difficulty. The model of the mental activity consisted of gradual deduction of number 7 for a 6 minute period (the 7 test) and of searching and ranking of three-figure numbers in a specially constructed numberical square. The secondary activity consisted of a periodic reaction to an acoustic signal (voluntary reaction: the flexion and extension of the right forearm). The course of each reaction was measured by 24 different parameters (position, time, speed and force). The personality traits of the investigated men were tested by Cattell's 16 P.F.Q. Results of the statistical analyses are described in detail.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Flight simulator

Primary task   Single measures

Brictson, C. A. Pilot landing performance under high workload conditions. La Jolla, California: Dunlap and Associates, Contract N00014-73-C-0053, April, 1974. (AD/A 001 802).

A longitudinal study of pilot carrier landing performance was conducted to describe the influence of prolonged operations on pilot performance. A landing performance criterion previously validated in a fleet environment was used to measure and compare pilot and squadron performance variations over time. Three levels of cumulative workload were defined to evaluate concomitant changes in performance associated with each workload. Pilot landing performance improved over time with more improvement found in night performance than day. The influence of practice on carrier landings is discussed in relation to high cumulative workload. The performance criterion was used to identify potential night pilots on the basis of landing proficiency. High and low proficiency pilots also were identified and diagnostic training information provided. A statistically significant increase in night landing performance during high cumulative workload may be due to practice effects as well as workload.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Flight test	Flight simulator
Primary task	Single measure			Flight test

Brictson, C. A. Pilot landing performance under high workload conditions. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD-CP-146, April, 1974, A7-1 - A7-10.

A longitudinal study of pilot carrier landing performance was conducted to describe the influence of prolonged operations on pilot performance. A landing performance criterion previously validated in a fleet environment was used to measure and compare pilot and squadron performance variations over time. Three levels of cumulative workload were defined to evaluate concomitant changes in performance associated with each workload. Pilot landing performance improved over time with more improvement found in night performance than day. The influence of practice on carrier landings is discussed in relation to high cumulative workload. The performance criterion was used to identify potential night pilots on the basis of landing proficiency. High and low proficiency pilots also were identified and diagnostic training information provided. A statistically significant increase in night landing performance during high cumulative workload may be due to practice effects as well as workload.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.

Primary task	Single measure	Experimental	Flight test	Flight simulator
				Flight test

Brictson, C. A. Methods to assess pilot workload and other temporal indicators of pilot performance effectiveness. Proceedings of AGARD Conference on Studies on Pilot Workload, AGARD-CPP-217, April, 1977, B9-1 - B9-7.

A systematic approach to define, measure and describe how certain pilot-related variables influence carrier landing performance during sustained operations is briefly outlined. Previous exploratory research on the interrelations between psychophysiological variables, pilot experience and performance is described. Pilot work activity, mood and sleep are identified as indicators of a pilot's temporal state of readiness. A field study design and techniques to measure and describe temporal readiness during prolonged flight operations are provided to demonstrate the methodology in an operational environment. Potential applications of the research are discussed along with the future role of temporal, psychological and other moderator variables in estimating pilot flight status.

W/L Cat. Code: 1.1, 1.2, 3.2, 4.2

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Construct	Flight test	Flight simulator
Primary task				Flight test
Physiological				

Brictson, C. A. and Ciavarelli, A. P. Aircrew performance research opportunities using the air combat maneuvering range (ACMR). In B. O. Hartman and R.E. McKinzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 111-113.

Three years of aircrew performance measurement related to air combat effectiveness using the Navy's Air Combat Maneuvering Range (ACMR) are presented. Performance assessment methods used to evaluate pilot proficiency are described. The aircrew assessment methods have been used to identify squadron performance differences, evaluate competitive exercises, and provide diagnostic training feedback to operational users. The availability of objective performance criteria promise to be of substantial benefit to both the operational user and the research community in such areas as pilot selection and training, fleet combat readiness, and pilot workload and stress.

W/L Cat. Code: 3.2

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Mult measures	Review	Flight test	Flight simulator
				Flight test

Brictson, C. A., McHugh, W. and Naitoh, P. Prediction of pilot performance: Biochemical and sleep-mood correlates under high workload conditions. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD CP-146, April, 1974, A13-1 - A13-10.

A preliminary longitudinal study of the factors affecting the carrier landing performance of naval aviators under high workload conditions has been carried out. Using stepwise multiple regression techniques, a substantial portion of the variability in landing performance could be accounted for by six factors under zero cumulative workload conditions and by seven factors under moderate cumulative workload conditions. High cumulative workload conditions sharply reduced predictive ability. Although specific aircraft experience and total flight experience were important predictors of average landing performance, blood biochemical levels and emotional states had significant predictive ability. Sleep patterns relate strongly to performance. The factors that determine landing performance change as cumulative workload increases. Suggestions for further research in this area are discussed.

W/L Cat. Code: 4.2

Op. Behav. Code: 1., 2., 4.

Physiological Mult. measures Experimental Flight test Flight simulator

Brigham, F. R. COPTEC-A controller overload prediction technique. Loughborough, England: Human Sciences and Advanced Technology Research Group, Department of Human Sciences, University of Technology, HUSAT Memo. No. 67, February, 1974.

During the course of a number of field studies of control tasks, it became clear that controller overload was an important problem. One of the reasons for controller overload was the occurrence of simultaneous high priority demands. Since the human operator tends to behave as a single channel information processor in situations of this type, he can only satisfactorily attend to one demand at a time. Given the existence and the importance of the problem, it would be useful if this type of overload could be predicted in advance, so that due account could be taken during task design and manpower planning. This is the purpose of the technique described in this report.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Construct Field Flight simulator

Broadbent, D.E. and Heron, A. Effects of a subsidiary task on performance involving immediate memory by younger and older men. British Journal of Psychology, 1962, 53, 189-198.

Most situations devised by psychologists examine either reaction to signals without memory, or memory without reaction. A task has been devised in which both functions are involved. Sets of random numbers are observed through a small slot allowing only a few numbers at a time to be visible. The subject has to cross out particular digits, and has to remember which digit he is seeking at any particular instant. This type of task is compared with a more conventional number crossing task. In the present experiment it was found that the tasks involving memory are very vulnerable to distraction. The older subjects differed greatly among themselves, some being seriously inferior in performance to younger subjects; no such difference in variance appears in the similar task without memory load. When a distracting task is presented together with a main task involving memory, older subjects do very badly at one or the other, whereas young subjects do reasonably at both.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Background

Primary task   Single measures

Bromberger, R. A. LAMPS simulations: VI Pilot performance in the LAMPS simulator. Warminster, Pennsylvania: Naval Air Development Center, NADC-76191-40, October, 1976.

This report examines the pilot's ability to follow a predetermined flight path under five instrument panel configurations. Three variables: (1) presence or absence of a pilot's view of the LAMPS ASW tactics, (2) ground vs. aircraft stabilized format for tactics, (3) traditional flight instruments vs. an electronic presentation of flight information were tested. It was concluded objective measures of performance (deviations from predetermined flight paths) revealed no practical differences in performance. Subjective opinion suggested a preference for traditional instrumentation and a ground stabilized view, if a view of tactics is included.

W/L Cat. Code: 1.2, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion   Questionnaire   Experimental   Flight simulator   Flight simulator
Primary task   Single measure   Flight test

Brown, E. L., Stone, G. and Pearce, W. E. Improving cockpits through flight crew workload measurement. Paper presented at the 2nd Advanced Aircrew Display Symposium, U.S. Naval Air Test Center, Patuxent River, Maryland, April 23-25, 1975. (Douglas Paper 6355).

This project is directed toward developing the capability to measure objectively the flight crew workload with sufficient sensitivity to differentiate between alternative crew station layouts, controls, and displays. The computerized technique concentrates on design factors under the control of crew station designers and provides for quick and low-cost iteration of alternatives. The program provides workload as related to specific equipments and systems, permitting special attention to be given to high workload items during the early development of concepts and hardware before simulation is available. The technique and program is also applicable to integrated displays, including those where programming to meet information requirements is an element.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity | Task comp., time assess. | Construct | Laboratory | Flight simulator

Brown, I. D. Measuring the spare mental capacity of car drivers by a subsidiary auditory task. Ergonomics, 1962, 5, 247-250.

We have attempted to measure spare capacity by giving the driver a subsidiary auditory task to perform when he could. Our first experiment was devoted to finding out whether the method was sufficiently sensitive, and safe, for field studies of driving. As a report of this experiment has already been published (Brown and Poulton 1961), and the experiment is being demonstrated at this congress, I need not go into details. We simply gave drivers an auditory task to perform in two different levels of traffic. In a second experiment the method is being used in a study of fatigue. This experiment also has a second objective, which is to compare two quite different types of subsidiary auditory task. We conclude that relatively small changes in a driver's spare capacity can be detected by scoring his performance on a subsidiary task which has no adverse effect upon driving. We can measure the change in his level of concentration which results from a change in the level of traffic, and we think that we can measure the effect of fatigue upon spare capacity, although better controlled experiments are needed to answer the real questions here.

W/L Cat. Code: 2.2.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity | Subsidiary task | Experimental | Field | Flight simulator, Flight test

Brown, I. D. A comparison of two subsidiary tasks used to measure fatigue in car drivers. Ergonomics, 1965, 8, 467-473.

Car driving has been studied by combining it with a subsidiary task, performance on which is negatively correlated with the perceptual load imposed by changing conditions of traffic. The present experiment compares a subsidiary task which required almost continuous attention to an auditory display, and which involved memory spans of only 3 sec, with an alternative task which did not require continuous attention, but which involved memory spans of up to 55 sec. The former was found to have some advantages. This comparison was combined with a study of men engaged in 8-hour spells of car driving. Some explanations are offered for the finding that performance on the subsidiary tasks was better at the end of the work-spell than at the beginning.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Field Flight simulator

Primary task Single measures Flight test

Brown, I. D. Subjective and objective comparisons of successful and unsuccessful trainee drivers. Ergonomics, 1966, 9, 49-56.

Twenty-two men were tested at weekly intervals during their 5 weeks' course of instruction in bus-driving. The use of the vehicle's controls and time taken over a standard circuit in traffic were recorded at each test, and the trainees' reserve capacity was measured by scoring their performance on a subsidiary auditory task. Details were available of previous driving experience with other vehicles and the trainees were also subjectively assessed at weekly progress checks given by experienced examiners. The object was to compare scores obtained by trainees who passed the independent driving test for Public Service Vehicles, given at the end of their course, with the scores of those who failed. Success on the P.S.V. test was significantly related to previous experience of any kind ($p = 0.004$), and to the result of the progress check given after 14 days' training ($p = 0.0002$). The reserve capacity of the successful group was significantly greater than that of the unsuccessful, at the first test given on the 7th day ($p < 0.025$). At no stage during training could the two groups be discriminated on the objective measurements made directly on driving performance. The relative merits of these methods of assessing driving potential are briefly discussed, with a view to the design of simple selection tests for professional drivers.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Field Flight simulator

Primary task Single measures Flight test

Brown, I. D. Dual task methods of assessing work-load. Ergonomics, 1978, 21, 221-224.

Various applications and design factors of dual task situations are critically surveyed. It is concluded that many applications make questionable assumptions and that many frequently used features of design are unsatisfactory. However, the technique appears to be valid and useful for the study of individual differences in processing resources, when the additional task is secondary, presents discrete stimuli which impose constant load, is carried out at a forced pace and competes with the primary task for processing resources only.

W/L Cat. Code: 2.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Review	None	Flight simulator
				Flight test

Brown, I. D. and Poulton, E. C. Measuring the spare mental capacity of car drivers by a subsidiary task. Ergonomics, 1961, 4, 35-40.

It is impossible to determine the degree to which a driver is absorbed in his driving by measuring his overt responses directly. However, relatively small changes in his spare "mental capacity" can be detected by scoring his performance on a subsidiary task, which has no adverse effect upon driving. This technique is sufficiently sensitive to reveal the higher level of concentration required in a shopping area as compared with that required in a residential area.

W/L Cat. Code: 2.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Field	Flight simulator
				Flight test

Buckley, E. P., O'Connor, W. F. Individual and system performance indices for the air traffic control system. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of Methods to Assess Workload. AGARD-AG-246, August, 1979, 135-136.

This study examined the relationships between field air traffic controller performance indices and system performance measures. The study encompassed performance criteria developed within two distinct environments, the controller's home facility where he controlled live traffic, and a specially designed microsystem or "one-man ATC system" with simulated traffic. This microsystem simulation was done at the National Aviation Facilities Experimental Center. The experiment represented a comparative examination of several quantitative measures of system functioning derived from air traffic control simulation and an investigation of these measures as indices for the objective evaluation of the individual air traffic controller.

W/L Cat. Code:	3.1, 4.1.2, 4.1.10			
Op. Behav. Code:	1., 2., 3., 4.			
Primary task	Single measures	Experimental	Simulation	Flight simulator
Physiological	GSR			Flight test
	Heart rate, h.r. var.			

Burke, J. E. Use of Eye Mark/Sony Videocorder System and related data reduction. Dallas, Texas: LTV Aerospace, Vought Systems Division, VSD Report 2-57110/3R-3107, August, 1973.

Recent VSD experience with in-flight recording of pilot viewing requirements in U. S. Army helicopters has demonstrated the feasibility of the equipment used and the related data reduction procedures. This document summarizes the knowledge gained. It is a compilation of selected portions of the draft version of VSD Report 2-57110/3R-3107, Study to Analytically Derive External Vision Requirements for U. S. Army Helicopters. This effort was conducted for the U. S. Army Aviation Systems Command under contract No. DAAJ01-72-C-0887.

W/L Cat. Code: 3.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Flight test	Flight simulator
Physiological	Eye movement			Flight test

Burke, J. E. In flight acquisition of task sequences and task times. Paper presented at the meeting of the Aerospace Medical Association, Las Vegas, Nevada, May, 1977.

The human engineering of pilot provisions in current aircraft is based upon analytical definition of pilot contribution to system operation. A technique is proposed to gather empirical data on pilot operations, so that follow-on analyses, simulations, and hardware developments will have a solid operational foundation. Vought has demonstrated key features of the proposed system, using existing equipment, in a recent helicopter vision study for the U. S. Army Aviation Systems Command under contract No. DAAJ01-72-C-0887. This study used a single point NAC Eye Mark recorder and Sony video/audio taping system. The helmet mounted Eye Mark recorder provides pilot field-of-view, which also picks up hand motion, and point of visual reference. This visual/audio data needs to be supplemented, complemented, or verified with other system measures which are common to the instrumentation of all new military aircraft. These include: stick/rudder/throttle positions, rates of deflection, and forces; aircraft flight profile; aircraft subsystems moding and performance.

W/L Cat. Code: 3.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Flight simulator	Flight simulator
Physiological	Eye movement		Flight test	Flight test

Burke, M. W. An investigation of visual/tactual multi-modal information processing using dual cross-adaptive critical tracking tasks. Columbus, Ohio: The Ohio State University Aviation Psychology Laboratory, Technical Report No. 2, March, 1979.

This investigation compared performance on a secondary subcritical tracking task using a visual display when the primary subcritical task either also used a visual display or instead used a velocity-aid kinesthetic-tactile (KT) display. The primary and secondary tasks were cross-adaptively coupled. Four visual display conditions were examined to isolate the contributions of peripheral scanning and aiding factors to cross-modal workload relief. After four days of dual-task tracking, the subjects using a KT primary display had significantly higher secondary task workload capability with integrated and separated visual displays indicated that the superiority of the KT display was not simply due to the elimination of scanning.

W/L Cat. Code: 2.2.5, 3.1
Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Butterbaugh, L. C. Crew workload-technology review and problem assessment. Wright-Patterson Air Force Base, Ohio: Flight Dynamics Laboratory, Technical Memorandum, AFFDL-TM-78-74-FGR, January, 1978.

The applications and resulting technical requirements of pilot/crew workload measurement/prediction methods are reviewed and discussed. In addition, existing pilot/crew workload measurement/prediction technology is identified and reviewed. An assessment of the adequacy of these techniques relative to the identified requirements is performed. Generally, the state of workload measurement/prediction technology is not sufficiently developed for measuring/predicting total mission-derived workload, but is sufficient for part-task applications.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Cannings, R. Speech patterns and aircrew workload. In B.O. Hartman and R.E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 115-127.

The use of speech patterns in the analysis of workload is examined. The rather sparse amount of research effort expended in this field is reviewed in terms of a simple model of speech production and the applications of current analysis techniques are considered. There is intuitive evidence to suggest that high work-load or stress may change the fundamental characteristics of speech. Although the voice may not exhibit obvious variations during normal flight profiles, a search for change in speech may prove to be a worthwhile approach in the investigation of workload in air operations. However, central to the possible use of speech patterns is the requirement to reduce complex speech data to parameter sets of a manageable size, and to relate these sets to the psychological and physiological state of the pilot. Optimum choice of parameter sets constitutes a difficult task, but there is an ever increasing literature concerned with speech processing which provides many techniques of analysis.

W/L Cat. Code: 4.3
Op. Behav. Code: 1., 2., 3., 4.

Physiological	Speech patt. anal.	Review	Laboratory	Flight simulator
		Construct		Flight test

Cannings, R., Borland, R. G., Hill, L. E. and Nicholson, A. N. Pitch and formant analysis of the voice in the investigation of pilot workload. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A5-1 - A5-10.

Computer techniques are described which extract parameters from the speech waveform which are amenable to statistical analysis and can be compared to the structure of the pilot's speech waveform at different points in the flight profile. Physiological data and subjective assessment may be used to indicate the workload of the flight profile so that the voice parameters can be correlated with known workload levels. In the present study the call sign of British Airways "Speedbird" was analysed both in terms of pitch and format information. It was concluded from preliminary examination of in-flight recordings that this technique is useful for classifying specific phonemes and is effective despite the noise corruption of the raw data.

W/L Cat. Code: 4.3

Op. Behav. Code: 1., 2., 4.

Physiological   Speech patt. anal.   Experimental   Laboratory   Flight simulator
Flight test

Cantrell, G.K. and Hartman. B.O. Application of time and workload analysis technics to transport flyers. Brooks AFB, Texas: USAF School of Aviation Medicine, Technical Report SAM-TR-67-71, August, 1967.

Two groups of Military Airlift Command aircrewmen reported on their activities in half-hour blocks around the clock--one group for 15 consecutive days, the other for 20 consecutive days--to provide data on the typical transport flyer's workload. Mean times on approximately 50 different activities are presented. Crew availability, level of job-satisfaction, and fatigue are analyzed. It is concluded that: crew availability is nearly 100% and does not limit airframe utilization; certain factors are sources of continuing frustration to aircrewmen; persistent complaints of fatigue appear to arise from frustration rather than overwork; any improvements resulting in a decrease in aircrew frustration should improve aircrew morale and level of job-satisfaction; changes designed to increase airframe utilization rates may increase the level of aircrew frustration; and consideration should be given to training as aircrewmen only those individuals free from excessive sensitivity to frustrating conditions.

W/L Cat. Code: 1.2

Op. Behav. Code: 1., 2., 3., 4.

Opinion   Questionnaire   Experimental   Field   Flight simulator
Flight test

Caplan, R. D. and Jones, K. W. Effects of work load, role ambiguity, and type a personality on anxiety, depression, and heart rate. Journal of Applied Psychology, 1975, 60, 713-719.

Type A personality (hard driving, persistent, involved in work) was studied as a conditioner of the effects of quantitative workload and role ambiguity (stresses) on anxiety, depression, resentment, and heart rate (strains) among 73 male users of a university computer system that was approaching an imminent 23-day shutdown. Each respondent was his own control. Stress, personality, and psychological strain were assessed by questionnaire, and heart rate was measured. Change scores were then analyzed. Role ambiguity was positively associated with anxiety, depression, and resentment; subjective workload was positively associated only with anxiety. Anxiety was positively related to heart rate. The relationship between workload and anxiety was greatest for Type A persons, and a similar, but nonsignificant trend appeared for the effects of anxiety on heart rate. Response and respondent specificity are discussed.

W/L Cat. Code: 1., 4.1.10

Op. Behav. Code: 1., 2., 3.

Opinion	Rating scale	Experimental	Field	Background
Physiological	Questionnaire			
	Heart rate h.r. var.			

Casey, S. M., Breitmaier, W. A. and Nason, W. E. Cerebal activation and the placement of visual displays. Warminster, Pennsylvania: U.S. Naval Air Development Center, NADC-77247-40, August, 1977.

Previous studies have shown that the human cerebral hemispheres are functionally asymmetrical. In addition, differential hemispheric activation has been brought about by shifts in lateral visual orientation. In view of this information, an experiment was conducted to study the effects of the lateral placement of displays with spatial-type information on human performance. Thirty two right-handed males were required to respond to peripherally-located engine monitoring displays while performing a centrally-located compensatory tracking task. For half of the subjects the engine monitoring displays were presented to the left of the tracking display and for the other half the engine monitoring displays were presented to the right of the tracking display. Performance was found to be better for those subjects who were required to orient to the left than for those who were required to orient to the right. The results of this experiment support the theory that cerebral activation may be an important consideration when locating certain types of visual displays in a high workload cockpit environment.

W/L Cat. Code: 3.1, 4.1.7
Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Construct	Flight simulator	Flight simulator
Physiological		Experimental		Flight test

Catlett, R. L. Application of information theory concepts to study work complex versus operator action time. Red River Army Depot, Texarkana, Texas: USAMC Intern Training Center, USAMC-ITC-2-73-08, March, 1973. (AD 786 286).

Information Theory Concepts are currently being applied to obtain a quantitative measure of work difficulty or complexity. This paper uses information theory to investigate the relationship between information input and operator response time. To investigate this relationship, twelve male subjects were tested for reaction time. Stimuli were any possible pattern of eight lights. Responses were corresponding patterns of stimultaneous key depressions in an eight-key keyboard, (one key for each finger). The conclusion drawn from these experiments was that there seems to be a linear relationship between information input ($\log_2 N$, where N is the number of equally likely alternatives) and operator reaction time for an unlearned task.

W/L Cat. Code: 2.1.2, 3.1

Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Inform. theory	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Cavalli, D. Discrete time modeling of heavy transport plane pilot behavior-workloads during landing. Proceedings of the 13th Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, June 15-17, 1977, 321-328.

A digital computer program simulating the reactions of the pilot of a transport aircraft during final descent is described. Experimental data obtained from monitoring human pilots during simulated final descents permit formulation of a model decision-making strategy involving nine instrument readings (localized deviation, glide path deviation, roll, pitch, yaw, vertical speed, thrust, altitude, and airspeed). Recognition of a difficulty and the sequence of corrective procedures undertaken are also described. It is concluded that a better information display could significantly decrease the pilot's workload and thus improve flight safety.

W/L Cat. Code: 3.1, 3.3, 4.1.7
Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Construct	Flight simulator	Flight simulator
Physiological	Math. model	Experimental		
	Eye movement			

Ceder, A. Driver's eye movements as related to attention in simulated traffic flow conditions. Human Factors, 1977, 19, 571-581.

Drivers' eye-movement amplitude and fixation duration are studied in four simulated traffic flow conditions: (1) within free-flow mode, (2) under maximum flow conditions, (3) within congested-flow mode, and (4) on an urban street between signalized intersections. Of major interest is the possible correlation between eye-movement data and drivers' attention demands. This correlation is based on an uncertainty theoretical model which provides a quantitative approach for evaluating drivers' attention level in various traffic flow conditions. Some applications to traffic flow phenomena are presented.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2., 4.

Physiological Eye movement Experimental Laboratory Flight simulator

Chainova, L. D., Komarova, I. A. and Zonabend, F. I. Complex psychophysiological evaluation of the readability of symbolic information (Kompleksnaya Psikhofiziologicheskaya Otsenka Chitaemosti Znakovoy Informatsii). Voprosy Psikhologii, 1970, 16, 163-168. (Royal Aircraft Establishment Library Translation 1777, 1974).

Slides of conventional cartographic symbols varying in number were exposed for two seconds and their recognition difficulty determined. Twelve such symbols were selected experimentally to cover the range of difficulty. Recordings were then made on ten subjects of their EEG, GSR, EMG and electro-oculogram (EOG) in a recognition task in which the number and difficulty of the symbols were varied. The GSR, EOG and EEG measures were found to reflect the condition of the visual system best. The results obtained make it possible to make decisions regarding information saturation of the visual field, ways of representing symbols, exposure time, and individual differences.

W/L Cat. Code: 3.1, 4.1.2, 4.1.4, 4.1.5, 4.1.7, 4.1.10
Op. Behav. Code: 1., 2., 4.

Primary task Multiple Experimental Laboratory Flight simulator
Physiological Flight test

Childs, J. M. The development of objective inflight performance assessment procedures. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 329-333.

The purpose of this research was to develop procedures for objectively evaluating Initial Entry Rotary Wing (IERW) student performance in flight. Maneuvers of the Basic Instrument phase were addressed. Descriptive inflight scoring procedures to assess absolute deviations of desired values from observed values at designated times, were developed. Desired values were determined on the basis of the rates specified in IERW training guides. Observed values were instrument indications of airspeed, altitude, or heading at those times. Four tolerance categories were incorporated into alternative six-point maneuver scoring algorithms designed to assess aircraft control precision. The criterion for acceptable proficiency was the maintenance of each sampled measure within standard IERW tolerance limits for each sampling point of a maneuver. Tests of the objective scoring procedures were conducted in the UH-1 flight simulator.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.

Primary task   Single measures   Experimental   Flight simulator   Flight simulator

Chiles, W. D. Objective methods for developing indices of pilot workload. Oklahoma City, Oklahoma: Federal Aviation Administration, Civil Aeromedical Institute, FAA-AM-77-15, July, 1977.

This paper discusses the various types of objective methodologies that either have been or have the potential of being applied to the general problem of the measurement of pilot workload as it occurs on relatively short missions or mission phases. Selected studies that have dealt with the workload measurement problem or some similar problem are reviewed in relation to their applicability to securing answers to operational questions. The types of methods are classified as: laboratory, analytic and synthetic, simulator, and in-flight. The paper concludes with a general discussion of the relative merits and some of the cautions to be observed in attempting to apply these methods and in trying to interpret the results with a view toward generalizing to operational situations.

W/L Cat. Code: 2., 3.

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity   Multiple   Review   None   Flight simulator
Primary task   Flight test

Chiles, W.D. Objective methods. In A.H. Roscoe (Ed.) Assessing pilot workload. AGARD-AG-233, February, 1978, 54-77. (AD A051 587).

The general approaches that we have labelled "laboratory methods" are probably best suited to conducting background research on more general questions pertaining to workload. Wherever they are appropriate they are the method of choice because of the typically high degree of control possible and the attendant high levels of reliability. The synthetic work method is especially well suited to examining general workload questions because, by its nature, tasks can be added, removed, and modified with relative ease, and, depending on the overall level of complexity, large investments in training time are not required. The analytic and the synthetic methods both appear to yield reasonable results, but both techniques rest on relatively fragile data bases. Simulators, especially those controlled by general purpose digital computers, have the potential of generating large amounts of very useful information on workload. However, whether the programs that resulted in their acquisition will allow adequate access to such systems for research purposes remains to be seen. Except for some of the safety limitations, in-flight methods can be used on virtually any problem suitable for investigation in a simulator. However, the recording of data of demonstrated reliability is a significant problem.

W/L Cat. Code: 2., 3.
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Multiple	Review	None	Flight simulator
Primary task				Flight test

Chiles, W.D. and Alluisi, E.A. A review of methods for specifying operator or occupational workload. Paper presented at XIXth International Congress of Applied Psychology, Munich, Germany, August, 1978.

Laboratory, analytic, synthetic, simulation, and operational-system methods employed in the specification of performance workloads are reviewed. It is concluded that laboratory methods are the methods of choice, with the synthetic-work technique especially well suited to examinations of general workload. Analytic and synthetic methods yield reasonable results, but both rest on relatively fragile data bases. Simulation methods have the potential of providing quite useful information on operator workload, but simulators have not generally been employed for this purpose, and some of the difficulties implicit to their use are discussed. Operational-system methods can be used on virtually any workload-specification problem suitable for investigation in a simulator, but the problems of data recording can be substantial.

W/L Cat. Code: 2., 3.
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Multiple	Review	None	Flight simulator
Primary task				Flight test

Chiles, W. D. and Alluisi, E. A. On the specification of operator or occupational workload with performance-measurement methods. Human Factors, 1979, 21, 515-528.

Five system-output or performance-measurement methods have been described in the literature for use in operator or occupational workload specifications: laboratory, analytic, synthetic, simulation, and operational-system methods. A review and analysis of these methods indicates that laboratory methods, where appropriate, are the methods of choice, with the synthetic-work technique especially well suited to examinations of general workload questions. Analytic and synthetic methods appear to yeild reasonable results, but both rest on relatively fragile data bases. Simulation methods have the potential of providing quite useful information on operator workload, but simulators have not generally been employed for this purpose, and some of the difficulties implicit to their use are discussed. Operational-system methods, except for some possible safety limitations, can be used on virtually any workload-specification problem suitable for investigation in a simulator, but the problems of data recording can be substantial.

W/L Cat. Code: 2.1, 2.2, 3.1, 3.2
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Multiple	Review	None	Flight simulator
Primary task				Flight test

Chiles, W. D., Jennings, A. E., and Alluisi, E. A. Measurement and scaling of workload in complex performance. Aviation, Space and Environmental Medicine, 1979, 50, 376-381.

A method is developed for scaling different levels of workload on human operators involved in man-machine systems. A multiple task performance battery is used to provide several tasks (monitoring lights, monitoring meters, two-dimensional compensatory tracking, pattern identification, mental arithmetic, and problem solving) in different combinations to generate varying job demands and, presumably, varying levels of workload. A total of 94 volunteer male subjects is tested, divided in two groups tested on one and two days, respectively. A scale of workload is derived for five complex task combination conditions. The scale provided reliable values that were stable on replication. The major restriction to the method's use is the requirement of employing at least 50 subjects to yield stable scale values.

W/L Cat. Code: 2.2, 3.1. 3.3
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Secondary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			
	Multiple measures			

Chu, Y. and Rouse, W. B. Optimal adaptive allocation of decision making responsibility between human and computer in multi-task situations Proceedings of the 1977 International Conference on Cybernetics and Society, Washington, D.C., September, 1977, 168-175.

It is suggested that the computer serve as a backup decision maker in multi-task situations, accepting responsibility when workload becomes excessive and relinquishing responsibility when workload becomes acceptable. A queueing theory formulation of multi-task decision making is used to develop a procedure for determining when the computer should be assigned decision making responsibility. The procedure is illustrated by application to a computer-aided flight management situation.

W/L Cat. Code: 5.3

Op. Behav. Code: 1., 2., 3., 4.

Primary task Math. model Construct Laboratory Flight simulator

Experimental

Clark, D. A., Arnold, E. L., Foulds, E. L., Jr., Brown, D. M., Eastmead, D. R., and Parry, E. M. Aviation, Space, and Environmental Medicine, 1975, 46, 1044-1048.

Studies were conducted to determine the psychological correlates of elevated serum urate and cholesterol levels. Elevations of uric acid level appeared to reflect stress that excited fear or insecurity, while high cholesterol levels seemed to reflect a stress which the individual perceived as requiring a sustained increase in physical and/or mental performance.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Physiological Body fluid anal. Experimental Laboratory Flight simulator

Flight test

Clark, W. E., Jr. and Armstrong, G. C. Three-cue helicopter flight director evaluation. Randolph AFB, Texas: USAF Instrument Flight Center, IFC TR 77-3, July, 1977.

This report covers the work accomplished during an inflight investigation concerning the evaluation of the changes in pilot performance, control activity and biochemical changes while flying with various display configurations of a helicopter Three-Cue Flight Director System. A series of objective, subjective, and physiological measures were used to evaluate the various display configurations.

W/L Cat. Code: 1.2, 3.2, 4.1.10, 4.1.12

Op. Behav. Code: 1.2, 2., 4.

Opinion	Questionnaire	Experimental	Flight test	Flight simulator
Primary task	Mult. measures			Flight test
Physiological	Heart rate h.r. var. Body fluid anal.			

Clement, W.F. Investigating the use of a moving map display and a horizontal situation indicator in simulated powered-lift short-haul operations. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 201-224. (NASA-TMX-73170).

This research investigates the use of a moving map display from enroute through the terminal area, including approach and go-around. Various features of each of the primary STOLAND displays, the electronic moving map multifunction display (MFD), horizontal situation indicator (HSI), and electronic attitude director indicator (EADI), are used in the three phases of flight mentioned above when the STOLAND system is operated in each of three ways: a) flown in the fully automatic mode with the pilot(s) in a monitoring role; b) flown manually using flight director guidance to reduce workload and task requirements to an acceptable level; of c) flown manually using raw instrument situation data. Eye-point-of-regard and workload measurements, coupled with task performance measurements, pilot opinion ratings, and pilot comments are presented. The measurements, ratings, and comments provide an indication of the utility of the MFD as a supplement to the HSI for improving flight safety.

W/L Cat. Code: 1.1, 2.2, 3.2, 4.1.7

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Experimental	Flight simulator	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Clement, W. Annotated bibliography of procedures which assess primary task performance in some manner as the basic element of a workload measurement procedure. Hawthorne, Calif.: Systems Technology, Inc., Technical Report No. 1104-2, January, 1978.

The survey endeavors to include all contributions back to 1970 with special effort to identify papers not contained in formal journals; that is, papers presented at meetings or only available in non-archival proceedings, etc. Major theoretical or bibliographic review articles including sources extending back to 1950 have been included in the search. The annotated bibliography provides complete references to each relevant contribution and an abstract of each with a brief summary of results or findings. Except for the major surveys and conference proceedings, which are arranged chronologically, the contributions within each subtopic are arranged alphabetically by the first author's name.

W/L Cat. Code: 2.2, 3.1, 3.3, 4.1.7

Op. Behav. Code: 1., 2., 4.

Primary task	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Physiological				

Clement, W. F., Hofmann, L. G., and Graham, D. A direct procedure for partitioning scanning workload with a flight director. Proceedings of the IEEE Cybernetics and Society International Conference, Boston, Massachusetts, November, 1973, 38-43.

Recent experimental eye scanning measurements from simulated approaches in a flight-like cockpit representing a contemporary jet transport have made it possible to simplify the procedure for predicting the partition of the pilot's scanning workload required for monitoring and controlling a task with status displays and a flight director. When there is but a single director control display, the new procedure eliminates iteration in the preliminary design computations. The preliminary design computations are based on predictions of closed-loop input-correlated errors in displayed variables with respect to the trimmed flight values. Also included are methods for predicting multiloop error coherence, and for correcting the predicted partition of scanning workload when the pilot's scanning remnant contribution is significant.

W/L Cat. Code: 2.1.1, 3.3
Op. Behav. Code: 1., 2.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator
Primary task	Mach. model			

Clement, W. F., Jex, H. R. and Graham, D. A manual control-Display theory applied to instrument landings of a jet transport. IEEE Transactions on Man-Machine Systems, 1968, MMS-9, 93-109.

This paper presents an illustrative application of a theory for manual control displays to the instrument landing approach of a large subsonic jet transport. A methodical procedure is disclosed for formulation of compensatory display-control systems. Manual approach height and lateral position control are treated in multiloop dynamic analyses so as to select preferred variables for measurement and display. Closed-loop system performance and pilot scanning and workload measures are also evaluated. The example concludes with the "prediction" of a preferred display arrangement. Comparison with an FAA Category II instrument panel arrangement selected by an airline operating the example aircraft shows the predictions to be remarkably accurate. In regard to workload a procedure similar to that of Senders is used. Fractional workload techniques are developed on the basis of summation of fixation frequency-mean dwell time products.

W/L Cat. Code: 2.1.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator
Primary task	Math. model			

Clement, W. F., Jex, H. R. and Graham, D. Application of a systems analysis theory for manual control displays to aircraft instrument-landing. Proceedings of the 4th Annual NASA-University Conference on Manual Control, Ann Arbor, Michigan, March, 1968, 69-94. (NASA SP-192).

This paper presents an illustrative application of a theory for manual control displays to the instrument landing approach of a large subsonic jet transport. A methodical procedure is disclosed for formulation of compensatory display/control systems. Manual approach height and lateral position control are treated in multiloop dynamic analyses so as to select preferred variables for measurement and display. Closed-loop system performance and pilot scanning and workload measures are also evaluated. The example concludes with the prediction of a preferred display arrangement. Comparison with an FAA category II instrument panel arrangement selected by an airline operating the example aircraft shows the predictions to be remarkably accurate.

W/L Cat. Code: 2.1.1 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator
Primary task	Math. model			

Clement, W.F., McRuer, D.T. and Klein, R.H. Systematic manual control display design. Proceedings of the AGARD Conference on Guidance and Control Displays, AGARD-CP-96, 6-1 - 6-10.

A theory of displays, together with validated techniques for analyzing closed-loop pilot-vehicle dynamic performance, provides a systematic procedure for improving the guidance and control display design process. Central to this theory is the notion that display design is fundamentally a guidance and control problem which has interactions with our knowledge of human psychomotor activity. We review the inspirations for eye movement studies in flight control and monitoring tasks and summarize the relationship of eye scanning phenomena to pilot describing functions and remnant. Several measures of pilot workload in control tasks are discussed. One measure, in particular, has great promise in quantifying a practical definition of workload. This is excess control capacity. We conclude by illustrating the further connections with lead equalization, scanning workload, physiological measures of neuromuscular tension, and the effects of additional modalities on visual workload.

W/L Cat. Code: 1.1, 2.2.5, 3.3, 4.1.7, 4.1.9
Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Construct	Laboratory	Flight simulator
Spare m. capacity		Experimental	Flight simulator	Flight test
Primary task				
Physiological				

Cliff, R. C. The effects of attention sharing in a dynamic dual-task environment. Proceedings of the 7th Annual NASA-University Conference on Manual Control, University of Southern California, June, 1971, 307-325. (NASA SP-281).

There are numerous examples of cases where the human operator is confronted with several tasks occurring simultaneously and continuously in time. The current study is an investigation into the nature of attention sharing between two continuous tasks with independent input-output modes. Eleven subjects were tested using a zero order compensatory control task with three levels of difficulty (input bandwidth) for each subject. As a secondary task on half of the trials, the subjects were also required to verbally shadow a random auditory input. Results from an extensive time and frequency domain analysis of the data are presented and discussed. The evidence supports a single channel model for continuous dual-task control.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Cohen, S. I. and Silverman, A. J. Measurement of pilot mental effort. Paris, France: North Atlantic Treaty Organization, Advisory Group for Aeronautical Research and Development, Report 148, May, 1957. (AD 200 672).

This paper discusses the factors which affect a pilot's ability to respond to situations demanding effort and methods of measuring his total psycho-physiologic response. A description is given of some methods and quantitative results obtained in research at the Aeromedical Laboratory of the Wright-Patterson Air Force Base.

W/L Cat. Code: 4.1.2, 4.1.5

Op. Behav. Code: 1., 2., 3., 4.

Physiological	GSR	Construct	Laboratory	Flight simulator
	EEG	Experimental		Flight test

Colle, H.A. and DeMaio, J.C. The use of dual-task performance operating curves to assess workload. Paper presented at the 1978 Review of Air Force Sponsored Basic Research in Flight and Technical Training, U.S. Air Force Academy, Colorado Springs, Colorado, April, 1978.

A preliminary study generated performance operating curves (POC) for two digit transformation tasks (repeat the digit, add three and report the sum) each of which were combined with a tone classification task. Two POCs were generated which allowed the two digit transformation tasks to be equated in attentional demand over a wide range. Pilots also were tested in a formation flying simulator together with the tone classification task. Although the formation flying tasks did make workload demands, they were small in comparison with those made by the digit transformation tasks, as would be expected for an overlearned task. Currently, the additivity of the equivalent demand procedure is being investigated.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Flight simulator

Control-display pilot factors program. Randolph AFB, Texas: USAF Instrument Pilot Instructor School, Instrument Evaluation Project NR.63-1, December, 1963.

Intervening levels of control between full manual and full automatic were examined for the purpose of determining the compatibility of the human pilot with an automatic flight control system using Force Wheel Steering as the link between the two elements. Two identically equipped T-39 aircraft were utilized in the inflight examination. Twenty-six pilots representing commercial airlines, FAA, and the USAF flew every possible combination of the two levels of control in pitch, and three levels of control in roll, a total of five times; two times were for training and three times for record. The standard T-39 panel, featuring the USAF Flight Director Display, was used. The profile consisted of the ILS final approach. All approaches were made under the hood. Standardized briefings and procedures were utilized. Both subjective and objective measures were obtained for describing the effects of intervening levels of control upon performance. Comparable performance was obtained across the intervening levels of control indicating compatibility. A reduction in pilot work load, unburdening, was obtained as a function of increasing levels of automation.

W/L Cat. Code: 1., 3.2
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Questionnaire			Flight test
	Mult. measures			

Cooper, G. E. and Harper, R. P., Jr. The use of pilot rating in the evaluation of aircraft handling qualities. Moffett Field, California: National Aeronautics and Space Administration, Ames Research Center, NASA TN-D-5153, April, 1969.

Pilot rating scales and their use in assessing aircraft handling qualities are reviewed historically, and objections that have been raised to limitations of earlier scales are considered in the development of a revised scale. Terminology used in the evaluation of handling qualities is reviewed and new definitions are proposed to improve communication and international understanding. Of particular significance is the new definition of handling qualities, which emphasizes the importance of factors that influence the selection of a rating other than stability and control characteristics. The experimental use of pilot rating is discussed in detail, with special attention devoted to (1) clarifying the difference between mission and task, (2) identifying what the rating applies to, (3) considering the pilot's assessment criteria, and (4) defining the simulation situation. The important elements of the report are then summarized in a suggested "Briefing Guide," designed for guidance in planning and executing handling qualities experiments.

W/L Cat. Code: 1.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Construct	Flight test	Flight simulator
				Flight test

Corkindale, M.G.G. A flight simulator study of missile control performance as a function of concurrent workload. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD-CP-146, April, 1974, A5-1 - A5-6.

Eight pilots took part in a simulation of the delivery of a stand-off air-to-surface guided weapon. The attack phase of a sortie was simulated. Four levels of workload were studied. The results show that performance at the missile control tasks was degraded by increase in concurrent workload, and manual flight contol and auto-pilot monitoring were adversely affected by concurrent missile control tasks. A small group of non-pilots was put through the same experimental program. A similar pattern of results to those of the pilot group were obtained but the absolute levels of performance were predictably different. Eye movement data and subjective data allow the deterioration in two-task performance to be explained. The results of this study confirm laboratory secondary task experiments in that a deterioration in primary task performance is associated with the occurrence of a secondary task.

W/L Cat. Code: 1.2, 2.2.2, 4.1.7
Op. Behav. Code: 1., 2., 4.2

Opinion	Questionnaire	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Subsidiary task			Flight test
Physiological	Eye movement			

Corlett, E. N. Cardiac arrhythmia as a field technique: Some comments on a recent symposium. Ergonomics, 1973, 16, 3-4.

The seminar on "Heart Rate Variability and Mental Load" at which the papers in this issue were presented was attended mainly by research workers and presented by researchers. The examples given and problem areas posed in these papers are either actual field studies or analogues of field situations. It is not unreasonable therefore to look at the work reported in relation to its contribution to the study of mental work and mental load, not in any carping spirit but to indicate the enormity of the task facing the field worker who is studying mental work. This approach will also indicate the quality of personnel which will be needed in industry if this area is to be adequately treated. To say the least, it seems unlikely that industry will be able to continue with the use of simple techniques and technician level personnel for the study of work loads arising from modern industrial jobs. The seminar gave a clear indication that the study of working stress requires a professional level of training, i.e., one equivalent at least to a chartered engineer in quality, if the effective interpretation of data, which are in themselves reliable, is to be achieved.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Review	None	Flight simulator

Couluris, G. J., Ratner, R. S., Petracek, S. J., Wong, P. J. and Ketchel, J. M. Capacity and productivity implications on enroute air traffic control automation. Washington, D.C.: Federal Aviation Administration, FAA-RD-74-196, December, 1974. (ADA 016 622).

This report documents the work performed by Stanford Research Institute (SRI) to evaluate controller productivity and capacity benefits potentially realizable from postulated evolution of enroute air traffic control (ATC) automation. This work focused on the workload limitations of human controllers and the effects on controllers of various automation applications to National Airspace System (NAS) Stage A3d.2 ATC. Empirical measurements of routine, surveillance, and conflict processing activities were used to develop workload models of control-team operations. These models are extensions of the Relative Capacity Estimating Process (RECEP) previously developed by SRI. They were used to assess the potential benefits of enhancements including an electronic tabular flight data display. The workload models were incorporated into the SRI Air Traffic Flow (ATF) network simulation model to assess the potential benefits of a computerized facility-level traffic flow control method termed planning control.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Field	Flight simulator

Crabtree, M.S. Human factors evaluation of several control system configurations, including workload sharing with force wheel steering during approach and flare. Wright-Patterson AFB, Ohio: USAF Flight Dynamics Laboratory, AFFDL-TR-75-43, April, 1975.

An experiment was conducted to evaluate the performance and workload characteristics of six types of control system configurations during simulated IFR approaches. The six types were, (1) manual ILS, (2) manual approach with flight director, (3) semi-automatic approach with flight director in which the pitch, roll, and yaw axes of the autopilot were controlled by the pilot through force wheel steering, (4) and (5) two workload sharing approaches with force wheel steering and flight directors where, in one case, the pilot controlled pitch and power while the co-pilot controlled roll and yaw and, in the other case, the roles of the pilot and co-pilot were interchanged, and finally (6) a fully automatic approach. Conclusions were that the full automatic mode provided the best performance and lowest workload while the manual ILS mode and the semi-automatic mode provided the worst performance and the highest workload.

W/L Cat. Code 1., 3.2
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Questionnaire			Flight test
	Mult. measures			

Crawford, B. M. Workload assessment methodology development. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 55-67.

This presentation provides a brief review of several concepts useful in workload estimation. The first concept is that of performance theory, including the work of Teichner and Dondus. The second concept is that of divided attention with emphasis on the work of Hick, Knowles, and Sternberg. Experimental results using the Sternberg paradigm are described. Finally, physiological correlates of performance and analytic methodologies are briefly reviewed.

W/L Cat. Code: 2.1, 2.2.1, 3.1, 4.1

Op Behav. Code: 1., 2., 4.

Spare m. capacity	Multiple	Review	None	Flight simulator
Primary task		Construct		Flight test
Physiological				

Crawford, B. M., Pearson, W. H. and Hoffman, M. Multifunction switching and flight control workload. Paper presented at the 6th Psychology in the DOD Symposium, U.S. Air Force Academy, Colorado Springs, Colorado, April, 1978.

Four subjects were tested in a cockpit simulator using a secondary task to measure reserve information processing capacity under two levels of flight control and four levels of multifunction switching. Results suggest that flight control impacts both input-output and central processing stages whereas mere anticipation of switching tasks affects input-output only. Difficult flight control reduced the effective information processing reserve by 54 percent on the average. The corresponding losses attributable to anticipation of multifunction switching were 20 and 31 percent for simple and complex tasks respectively. The study has implications for design of effective processing aids and mental workload measurement.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 2.1, 4.1, 4.2

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Cross, K.D. and Cavallero, F.R. Utility of the vertical contact analog display for carrier landings - a diagnostic evaluation. Proceedings of the AGARD Conference on Guidance and Control Displays, AGARD-CP-96, 21-1 - 21-11. (AD 739-779).

An experiment was performed to evaluate the accuracy with which simulated carrier landings could be performed with the Vertical Contact Analog Display (VCAD), a pictorial vertical situation display generated by a digital computer. A secondary objective was to generate diagnostic data to define the relative magnitude of different potential contributors to total system error. Position and attitude errors were measured under each of five experimental conditions, a full-scale simulated carrier landing task and four part-tasks. The results revealed that all three attitude parameters were controlled with a high degree of accuracy under all conditions. Control of vertical and lateral position in the full-scale simulation condition was accomplished with about the same accuracy and precision as that reported for actual (day) carrier landings in F-4 aircrafts. The part-task data revealed that the largest contributor to lateral error was Control Complexity.

W/L Cat Code: 3.2
Op. Behav. Code: 1., 2., ..

Primary task	Mult. measures	Experimental	Flight simulator	Flight simulator Flight test

Curry, R.E. Mental load in monitoring tasks. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 117-124.

This paper describes issues involved in defining, predicting, and measuring mental workload. Concepts presented include dividing workload into task demands, effort, and performance. Goals of measurement and current methods used are reviewed.

W/L Cat. Code: 1., 2.2, 3.1, 3.3

Op Behav. Code: 1., 2., 3.

Opinion Spare m. capacity Primary task	Multiple	Review Construct	None	Flight simulator Flight test

Curry, R. E., Kleinman, D. L., and Hoffman, W. C. A design procedure for control/display systems. Human Factors, 1977, 19, 421-436.

This paper proposes a design procedure for control and display systems in which levels of automation vary over a significant range. The elements of the primary analysis tool are briefly reviewed, and the use of the model at three levels of specification (information level, display-element level, and display-format level) is discussed. Based on observation and pilot commentary, it is assumed that the pilot allocates his attention to control the aircraft to the desired level of performance, and then, with remaining capacity, to monitor displays. The design procedure is applied to the longitudinal control of a CH-47 helicopter. The procedure points out the need for performance-workload relations for control, which are fairly well understood, and performance-workload relations for monitoring, about which little is known.

W/L Cat. Code: 1.1, 3.1, 3.3
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Construct	Flight simulator	Flight simulator
Primary task	Single measures	Experimental		
	Math. model			

Dahm, A. E. Study of the field use of the psychological stress evaluator. Dektor Counterintelligence and Security, Inc., Springfield, Virginia, Unpublished manuscript, 1974.

This paper summarizes the results of a questionnaire sent to 153 users of the Psychological Stress Evaluator (PSE). Forty-six users responded to the questionnaire. The users were categorized into four groups: (1) privately employed individuals or firms conducting investigations on a hired basis, (2) law enforcement agencies, (3) retail/industrial firms, and (4) clinics and research individuals or firms. The results of the ten questions contained in the questionnaire are individually reported.

W/L Cat. Code: 4.3

Op. Behav. Code: 2., 3.

Physiological	Speech patt. anal.	Review	None	Background

Damos, D. Residual attention as a predictor of pilot performance. Human Factors, 1978, 20, 435-440.

Sixteen student pilots performed a task combination designed to measure residual attention. Scores on this combination were correlated with performances on flight checks administered periodically during flight training. The multiple correlation between performances on the flight checks and the task combination increased as the students progressed through flight training. The usefulness of residual attention as a predictor of pilot performance is discussed.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Damos, D. and Wickens, C. A quasi-linear control theory analysis of timesharing skills. Proceedings of the 13th Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, June 15-17, 1977, 35-43.

Human involvement with complex systems often requires the operator to timeshare or perform several tasks concurrently. While it is apparent that performance under multiple- or dual-task conditions often benefits dramatically from practice, the precise sources of improvement are not clear. One possible source is further mastery of the single-task skills themselves. A second possible source is timesharing skills, which are hypothesized to contribute only to multiple-task performance and which do not develop under single-task conditions. To date, the identity, development, and generality of timesharing skills have not been clearly isolated experimentally. The present study examines performance with practice on two dual-task combinations -- dual axis tracking and two discrete information processing tasks -- in an effort to identify the presence and development of specific timesharing skills, such as parallel information processing or rapid intertask switching. The generality of timesharing skills also is investigated by examining transfer of these skills between the two qualitatively different task combinations.

W/L Cat. Code: 2.2.1, 2.2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures Flight test

Damos, D. L. and Wickens, C. D. Dual-task performance and the Hick-Hyman law of choice reaction time. Journal of Motor Behavior, 1977, 9, 209-215.

The slope, intercept, and linearity of the function relating RT and stimulus information reflect different aspects of information processing. This experiment determined which aspects of information processing are affected by the presence of a secondary task. Subjects (n=12) performed a one-dimensional tracking task concurrently with a choice RT task. Subjects also performed each task singly. Half of the subjects performed under dual-task conditions with adjacent displays, half with separated displays. For the adjacent group the tracking task had no reliable effect on either the slope, intercept, or linearity of the relation. Scanning affected only the intercept for the separated group. Error on the tracking task was found to increase linearly with increased processing load on the choice RT task for both groups. The results are interpreted as supporting a modified single-channel theory.

W/L Cat. Code: 2.2.1, 2.2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measure			Flight test

Danev, S., Radceva, R., Zlatarov, I. Changes in heart rate variability due to informational, physical and emotional load, in laboratory and field conditions. Activas Nervosa Superior, 1975, 17, 187-188.

Results of these experiments corroborate the results of an earlier experiment by G. F. Wartna and S. G. Danev which showed no difference in sinus arrhythmia according to most of the scoring methods in 5 experimental conditions (including physical as well as mental components). The present results do not support the work of J. W. Kalsbeek who found a progressive suppression of sinus arrhythmia and an increase of heart rate when subjects went from rest to higher loading conditions.

W/L Cat. Code: 3.1, 4.1.10

Op. Behav. Code: 1., 2., 4.1

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Danev, S.G. and Wartna, G.F. Information load and time stress: Some psychophysiological consequences. TNO-Nieuws, 1970, 25, 389-395.

An automatisation in industry is progressing, there exists a growing need for objective measures for the mental demands imposed upon the worker. Changes in psychophysiological functioning of the human organism may be an indication of this mental load. Theoretical backgrounds and problems are discussed. In an experimental setting the relative contribution of two groups of factors was studied. These two groups were: emotional (time stress) and informational (arithmetical operations). The results are indicative of the fact that changes in psychophysiological functioning during the task performance are more attributable to the experienced time stress and the induced emotional tension than to the pure processing of information.

W/L Cat. Code: 3.2, 4.2

Op. Behav. Code: 2.

Primary task | Mult. measures | Experimental | Laboratory | Flight simulator

Physiological

Daniel, J. Newer approaches to research of mental load. Proceedings of the 2nd meeting of Psychologists from the Danubian Countries, Smolenice, Czechoslovakia, September, 1970.

In regard to the problem of stress, the terminology can be made more exact: (1) the term stress should be reserved for a heavy physiological and psychological load where, for instance, danger to life is involved. (2) Situations involving the solution of exacting tasks should be spoken of as 'mental load'. (3) Load deriving from current activities should be termed 'light mental load'. This paper deals with results of experimental research which may be sub-headed under the second group of load. It involves stimulation of an operator's activity in a chemical company under normal conditions and under an increased mental load. Correlations of statistical significance were found between results of laboratory research (simulated panel, various modifications of Stroop's interference test, oscillating curve of attentiveness) and rating of the operator at his workplace, done by his foreman

W/L Cat. Code: 1.1, 2.2.1

Op. Behav. Code: 1.1, 1.2, 2.1

Opinion | Rating Scale | Experimental | Laboratory | Flight simulator

Spare m. capacity | Subsidiary task

Daniels, A. F. Crew workload sharing assessment in all-weather, low-level strike aircraft. In Problems of the Cockpit Environment, AGARD Conference Proceedings No. 55, March, 1970, 12-1 - 12-9. (AD 705 369).

This paper describes the first phase of an experimental program undertaken by the British Aircraft Corporation to investigate various aspects of crew workload and workspace assessment. In particular, the use of the time-lapse filming techniques of primary task performance to assist in the evaluation of workspace utilization is detailed. The results obtained and the limitations encountered during a relatively inexpensive study in the early feasibility stages of an aircraft program are discussed.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.

Primary task Single measures Experimental Flight simulator Flight simulator

Defayolle, M., Dinand, J.P., and Gentil, M.T. Averaged evoked potentials in relation to attitude, mental load, and intelligence. In W.T. Singleton, J.G. Fox, and D. Whitfield (Eds.) Measurement of man at work. London: Taylor and Francis, 1973, 81-91.

Various measures of the state of arousal, such as variations in heart rate and rhythm, in skin conductance, and in E.E.G. activity, have been suggested as indicators of mental load. At the very least, we can argue that arousal level varies with the intensity of mental strain the subject accepts, and that is partly reflects the working of some informational processor. This is the quantitative aspect of mental load. But no less important to explore is the qualitative aspect, that is the nature of processed information. Processing of information, to be effective, implies that mental load is mainly devoted to pertinent information. Thus, the notion of mental load seems to involve two components: on the one hand, the level of excitation of some hypothetical mental processor, on the other hand the selective value of the attention focused on the task. This paper describes the role of average evoked potentials (AEP) in dual task paradizms. A vector description of the dual task is developed, and its relation to AEP described.

W/L Cat. Code: 1.1, 2.2.1, 4.1.5, 4.1.6
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
Spare m. capacity	Subsidiary task			
Physiological	EEG			
	ECP			

Dick, A. O. and Bailey, G. A comparison between oculometer data and pilot opinion on the usefulness of instruments during landing. Rochester, New York: University of Rochester, Center for Visual Science, Technical Report No. 3-76, 1976.

A comparison was made between an objective measure of instrument scanning and pilots' opinions about how they used the instruments. The data show a high degree of consistency within and among pilots for both the objective measure and for the opinion measure. The data show much lower agreement between the opinions and actual use.

W/L Cat. Code: 1.2, 4.1.7

Op. Behav. Code: 1., 2., 4.

Opinion	Questionnaire	Experimental	Flight simulator	Flight simulator
Physiological	Eye movement			Flight test

Dick, A.O., Brown, J.L. and Bailey, G. Statistical evaluation of control inputs and eye movements in the use of instrument clusters during aircraft landing. Rochester, New York: University of Rochester, Center for Visual Science, Technical Report 4-76, 1976.

Two different types of analyses were done on data from a study in which eye movements and other variables were recorded while four pilots executed landing sequences in a Boeing 737 simulation. Various conditions were manipulated, including changes in turbulence, starting position, and instrumentation. Control inputs were analyzed in the context of the various conditions and compared against ratings of workload obtained using the Cooper-Harper scale. The results show clear differences as a function of conditions. A major portion of the workload rating variance could be predicted by the number of control inputs. There was also clear evidence for different strategies on the part of the pilots. Overall the results show a differentiation between control inputs and eye-scanning behavior, indicating the need for an improved definition of workload.

W/L Cat. Code: 1.1, 3.1, 4.1.7
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test
Physiological	Eye movement			

Donnell, M.L. The application of decision-analytic techniques to the test and evaluation phase of the acquisition of a major air system: Phase III. McLean, Virginia: Decisions and Designs, Technical Report PR79-6-91, May, 1979.

This report extends the development and application of decision-analytic techniques to assist in the test and evaluation of a major air system, the F/A-18 Hornet multimission fighter/attack aircraft. Early portions of the study dealt with two developments. First was the development of a hierarchial evaluation structure in which missions were decomposed into sets of specific tasks. Second was the development of a rating scale which incorporated considerations for both pilot workload and system effectiveness. The F/A-18 Pilot Task Inventory was modified to make it appropriate for the A-7E, and ratings for the reduced task inventory were gathered from eight pilots. It is the exercising of the computerized evaluation system on the A-7 Echo which is the primary focus of this Interim Report. Refinements in the evaluation mechanism are also discussed.

W/L Cat. Code: 1.1, 2.1.1
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Construct	Flight test	Flight simulator
Spare m. capacity	Task comp., time assess.	Experimental		Flight test

Donnell, M. L. and O'Connor, M. F. The application of decision analytic techniques to the test and evaluation phase of the acquisition of a major air system: Phase II. McLean, Virginia: Decisions and Designs, Technical Report TR 78-3-25, April, 1978.

The purpose of this work was to complete the development and implementation of a prototype computerized Pilot Task Inventory, appropriately structured and applied to the fighter version of the F18 aircraft. In doing so, a general methodology applicable to other system acquisition problems was developed. The two major problems involved in such an effort are: (1) development of a valid, complete, computerized inventory, appropriately structured and readily usable by test pilots; and (2) development of a valid rating scale for use in rating the air system with respect to suitability for task accomplishment.

W/L Cat. Code: 1.1, 2.11

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Construct	Flight test	Flight simulator
Spare m. capacity	Task comp., time assess.			Flight test

Dougherty, D.J., Emery, J.H. and Curtin, J.G. Comparison of perceptual workload in flying standard instrumentation and the contact analog vertical display. Washington, D.C.: Joint Army Navy Aircraft Instrumentation Research, D228-421-019, December, 1964. (Bell Helicopter Co., Fort Worth, Texas.)

Two instrument panels are compared (the JANAIR vertical display and the standard instrument flight display) in terms of the amount of visual free time which was available when performance using these two displays was equal. The task was performed in the JANAIR dynamic flight simulator. Pilots were required to fly a straight and level course maintaining altitude, heading, track and airspeed. A forcing function introduced a rough air component to this task. Performance on both displays was equated in a testing period. The subjects were then tested to determine their free visual time. This was achieved by introducing a secondary visual task which required an oral reading of numbers. These were presented at rates varying from zero to two per second. Results indicated that the pictorial JANAIR display was by far the superior display as the visual work load increased. This was reflected in the decrement of performance on the primary flight or visual task.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Drennen, T.G., Curtin, J.G. and Warner, H.D. Manual control in target tracking tasks as a function of control type, task loading, and vibration. St. Louis, Missouri: McDonnell Douglas Corporation, MDCE 1713, August, 1977.

An investigation was conducted on the use of fingertip tracking controls which were integrated into an aircraft throttle grip under different levels of task loading and vibration. The experimental variables included two types of control (force and displacement), two levels of task loading (low and high) and four levels of vibration (static, moderate and heavy turbulence and braodband). The low task loading condition required the pilots only to track the displayed targets or to fly the simulated aircraft, while the high task loading condition required simultaneous target tracking and aircraft attitude and airspeed control. In the evaluation 16 pilots performed the target tracking and aircraft control tasks in a motion base simulator. Significant differences between the control types were obtained for only two measures; time-on-target and airspeed scores. The force control provided significantly better tracking performance than the displacement control as indicated by the percent time-on-target scores.

W/L Cat. Code: 3.1
Op. Behav. Code: 1., 2., 4.

Primary task	Mult. measures	Experimental	Flight simulator	Flight simulator
				Flight test

Dunn, R. S., Gibson, R. D. and Sun, P. A simulator study of helicopter pilot workload reduction using a tactile display. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 355-360. (NASA TMX-73-170).

This is a brief report of a limited simulation experiment intended to test the feasibility of a tactile display. It had two objectives: to determine whether the adaptive measurement procedure could be used to evaluate novel display devices in tactical operations; and to determine whether a tactile display could provide useful reductions in visual workload in tactical helicopter operations. To estimate the effect of the tactile display on visual workload a visual secondary task was employed as the dependent variable. As before, the adaptive circuits computed primary task performance and provided a weighted sum of error scores. But the output was not used to alter the vehicle handling qualities and no time delays were applied. Instead, the adaptive measurement procedure was used to alter the difficulty of a secondary task by turning the task on and off. As might be expected, the basic flight task proved to be very difficult with the narrow field of view visual display and no motion cues. It is important to note, however, that the cross-adaptive procedure resulted in stable system performance at or near the error criteria for all these subjects. Each one performed the task six times with the visual cue and six times with the tactile display.

W/L Cat. Code: 2.2.4, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Dyer, R. F., Matthews, J. J., Wright, C. E. and Yudawitch, K. L. Questionnaire construction manual. Fort Hood, Texas: U.S. Army Research Institute for the Behavioral and Social Sciences, Field Unit, Technical Report P-77-1, July, 1976.

This manual has been prepared primarily for the use and guidance of those who are asked to develop or administer questionnaires as part of Army field tests and evaluations. The general content and concepts, however, should be useful to anyone involved in constructing or administering surveys, interviews, or questionnaires. Chapters 2-10 present guidance on preparing, assembling, and arranging items in questionnaires. Chapter 11 discusses the importance of and procedures for pretesting, and Chapter 12 gives respondent characteristics that influence questionnaire results. Chapter 13 deals briefly with analysis and evaluation of responses, and Chapter 14 discusses interview presentation.

W/L Cat. Code: 1.1, 1.2

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Review	Field	Flight simulator
	Interview			Flight test
	Questionnaire			

Edson, R. K. The Dektor psychological stress evaluator (voice stress analyzer) as a research instrument. Unpublished master's thesis, National Graduate University, April, 1976.

This document reviews the actual and potential applications of the voice stress analyzer as a research instrument. The document is intended to provide the potential user with information that will enable him to understand its capabilities, its limitations, and its suitability to his particular research needs. Considerable attention has been given to deception detection, because this has been the primary area of application thus far.

W/L Cat. Code: 4.3

Op. Behav. Code: 2., 3.

Physiological	Speech patt. anal.	Review	None	Flight simulator
				Flight test

Edwards, L. R., Pilette, S. S., Biggs, B.E., and Martinek, H. The effect of workload on performance of operators monitoring unattended ground sensors. Alexandria, Virginia: U.S. Army Research Institute for the Behavioral and Social Sciences, Technical Paper 321, September, 1978. (AD A061 694).

The purpose of this research project was to investigate the effect of workload on operator performance as defined by target activity level and number of unattended ground sensors (UGS) used. Following an orientation and training session, experienced UGS operators monitored, in sequence, each of three event recorder displays showing activations of UGS used in grids. Operators reported each target they detected and estimated speed and direction of movement. The number of sensors monitored and the target activity level significantly affects UGS operator performance. The operators' ability to detect targets decreased as either activity level of number of sensors increased. Operators' ability to estimate target direction also decreased as activity level increased.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Primary task	Single measures	Experimental	Simulator	Background

Egeth, H. E. Perception and attention. Baltimore, Maryland: The Johns Hopkins University, Department of Psychology Report No. 81, August, 1975. (AD A014 215).

The purpose of this paper is to provide the reader with an up-to-date account of the empirical and theoretical status of the concept of attention. The emphasis in this review is on the properties of attention that are manifested in studies of human perceptual processes.

W/L Cat. Code: 2.

Op. Behav. Code: 1., 2.

Spare m. capacity	Multiple	Review	None	Background
		Construct		

Elkin, P. A., Klochkov, A. M., and Zhelezniakov, V. D. Application of EEG spectral characteristics and derivatives in aviation physiology practices. Zhurnal Vysshei Nervnoi Deiatel'Nosti, 1971, 21, 560-565. (In Russian).

In this paper EEG and derivative spectral characteristics are evaluated in an effort to determine pilot mental activity during flight. (Paper was not obtained in time to allow abstracting.)

W/L Cat. Code: 4.1.5

Op. Behav. Code: 1., 2., 4.

Physiological	EEG	Experimental	Flight test	Flight simulator
				Flight test

Ellis, G. A. Subjective assessment. In A. H. Roscoe (Ed.) Assessing pilot workload. AGARD-AG-233, February, 1978, 11-22. (AD A051 587).

Workload should be clearly defined, and the definitions should be operator-related rather than task-related. The most suitable definition comes from Cooper and Harper: "The integrated physical and mental effort required to perform a specified piloting task". The best way to express a subjective assessment is through a simple rating scale amplified by pilots' explanatory comments. Pilot ratings are qualitative, and attempts to subject them to inappropriate forms of numerical analysis should be resisted. Any rating scale should be designed using the principles employed in the Cooper-Harper scale. Pilots should not be overburdened and should be asked to answer only a strictly limited number of questions in any assessment. Subject pilots should be carefully chosen. The best results will be obtained by using experienced evaluation test pilots. Great care should be taken with extrapolating the results of simulator exercises.

W/L Cat. Code: 1.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Review	None	Flight simulator
	Questionnaire			Flight test

Enstrom, K. D. and Rouse, W. B. Telling a computer how a human has allocated his attention between control and monitoring tasks. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 104-123. (NASA TM X-73, 70).

The computer's knowledge of how the human has allocated his attention is posed as an important issue in the design of human-computer systems where the two decision makers have overlapping responsibilities. It is argued that it is inappropriate to require the human to continually tell the computer how he has allocated his attention. Instead, a computer algorithm employing fading-memory system identification and linear discriminant analysis is proposed for real time detection of human shifts of attention in a control and monitoring situation. Experimental results are presented that validate the usefulness of the method.

W/L Cat. Code: 2.1.1, 2.2.4, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Laboratory	Background
Primary task	Subsidiary task			
	Math. model			

Enstrom, K. D. and Rouse, W. B. Real-time determination of how a human has allocated his attention between control and monitoring tasks. IEEE Transactions on Systems, Man, and Cybernetics, 1977, SMC-7, 153-161/

A computer algorithm employing fading-memory system identification and linear discriminant analysis is proposed for real-time detection of human shifts of attention in a control and monitoring situation. Experimental results are presented that validate the usefulness of the method. Application of the method to computer-aided decision-making in multitask situations is discussed.

W/L Cat. Code: 2.1.1, 2.2.4, 3.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Laboratory	Flight simulator
Primary task	Subsidiary task			
	Single measures			
	Math. model			

Ephrath, A. R. Pilot workload during an instrument approach. Storrs, Connecticut: University of Connecticut, Cyberlab, Unpublished manuscript.

This empirical study documents the changes in the instantaneous workload of a pilot executing an Instrument Landing System approach. The results show a marked increase in the pilots' workload (measured by a subsidiary task) as distance to touchdown decreases. This increase in workload is present to different degrees both during coupled (automatic) and manually-flown approaches.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
				Flight test

Ephrath, A. R. Pilot performance in zero-visibility precision approach (NASA CR-137759). Doctoral dissertation, Massachusetts Institute of Technology, June, 1975.

This research consisted of an experimental investigation which was carried out in a static ground simulator. Fifteen airline pilots flew zero-visibility landing approaches with different degrees f automation and at different workload levels which were induced by simulated w . disturbances. The pilots' ability to detect failures and to provide a reliable manual back-up capability was monitored and recorded. To measure the pilot's workload, a "warning light" type subsidiary task was selected. There was a very marked increase in workload scores at altitudes below 500 feet AGL, which was inversely related to distance-to-go.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Questionnaire			Flight test
Primary task	Subsidiary task			
	Single measures			

Ephrath, A. R. A novel approach to the cross-adaptive auxiliary task. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 63-71. (NASA TMX-73,170).

This paper presents a scheme for modulating the difficulty of a primary manual-control task by means of an auxiliary task feedback. The method may find useful applications in operator workload research, in part-task simulation studies and in personnel training. Primary task difficulty was controlled by modulating the noise content of the forcing function, and results suggest that a stable workload level may be achieved by proper selection of the subsidiary task to be used and by proper design of the adaptive logic. Other methods of controlling the primary task's difficulty - such as changing display and control gains or varying an unstable mode - may perhaps also be used. Finally, this study raised an interesting question about human perception of the correlation between control inputs and the output, its dependence on the dynamics of the plant and the effects of the associated time lags. While this question is basic to the study of human performance in manual control tasks in areas such as system identification, adaptation and fault detection, it has never been addressed explicitly, to our knowledge.

W/L Cat. Code: 2.2.5, 3.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	Flight simulator	Flight simulator
Primary task	Single measures	Experimental		

Ephrath, A. R. and Curry, R. E. Detection by pilots of system failures during instrument landings. IEEE Transactions on Systems, Man, and Cybernetics, 1977, SMC-7, 841-848.

The effects of gust disturbances and the pilot's participation mode in the control task on his workload level and failure detection performance during a simulated low visibility landing approach are examined. It was found that the participation mode had a strong effect on the pilot's workload, the induced workload being lowest when the pilot acted as a monitoring element during a coupled approach and highest when the pilot was an active element in the control loop. The effects of differential workload and participation mode on failure detection were separated. The participation mode was shown to have a dominant effect on the failure detection performance, with a failure in a monitored (coupled) axis being detected significantly faster than a comparable failure in a manually controlled axis.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.

Primary task Single measures Experimental Flight simulator Flight simulator

Ettema, J. H. Blood pressure changes during mental load experiments in man. Psychotherapy and Psychosomatics, 1969, 17, 191-195.

Several experiments are discussed showing an increase in systolic and diastolic blood pressure as a function of the amount of information handling per time unit. In short-term experiments, this rise in blood pressure is not very impressive and remains within the normal physiological range. There are some indications, however, that prolonged intensive mental load induces a more important increase in blood pressure. Increase in blood pressure, together with changes in other physiological phenomena such as heart rate, sinus arrhythmia, etc., indicate that mental load may alter the level of activity of the autonomic nervous system. In the experiments, an auditory binary choice task (high or low tone in random sequence and of differing frequency) was used to evoke mental load.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 2., 3., 4.

Physiological Blood pressure Experimental Laboratory Background

Ettema, J.H. and Zielhuis, R.L. Physiological parameters of mental load. Ergonomics, 1971, 14, 137-144.

The essential aspects of the terms "load" and "capacity", as used in work physiology, are valid for mental load in the following ways: the question of the physiological "costs" (biological consequences) of a given performance; external load to be measured in units of performance/time (signals/time, choices/time); capacity, dependent on time of endurance; physiological changes correlating with load,; pathological symptoms due to extreme load. An experiment is discussed, where a simple binary choice task is used with several frequencies of signals to be answered; thus providing different loads. Systematic changes were found in heart frequency, sinus arrhythmia, systolic and diastolic blood pressure, rate of respiration, and so on. Arguments are put forward that these changes are due to a simultaneous rise in sympathetic and in vagal tone.

W/L Cat. Code: 3.1, 4.1.10, 4.1.11
Op Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var. Breathing anal.			

Farber, E. and Gallagher, V. Attentional demands as a measure of the influence of visibility conditions on driving task difficulty. Highway Research Record, 1972, 414, 1-5.

Six drivers were required to negotiate a slalom course at an automatically controlled speed (30 or 45 mph) while wearing goggles fitted with various neutral-density filters and a motorcycle helmet with a gas piston-operated translucent face shield. The face shield could be moved from its normally occluding position for a 1/2-sec "look" by means of a foot switch accessible to the driver. Attentional demand as measured by frequency of looks increased significantly with increasing goggle density at both 30 and 45 mph. The effect of the goggles on attentional demand was stronger at 45 than at 30 mph and for frequently looking than for infrequently looking subjects. Within subjects (error) variability was very low. Other measures of performance were not influenced by the goggles. It was concluded that attentional demand provides a measure of control task difficulty or operator skill to which conventional measurements may be insensitive.

W/L Cat. Code: 2.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Occlusion   Experimental   Field test   Flight simulator

Faulkner, W. H. and Onstott, E. D. Error rate information in attention allocation pilot models. Proceedings of the 13th NASA-University Conference on Manual Control, Massachusetts Institute of Technology, June, 1977, 72-78.

The Northrop urgency decision pilot model was used in a command tracking task to compare the optimized performance of multi-axis attention allocation pilot models whose urgency functions were 1) based on tracking error alone, and 2) based on both tracking error and error rate. A matrix of system dynamics and command inputs was employed, to create both symmetric and asymmetric two-axis compensatory tracking tasks. All tasks were single loop on each axis. Analysis showed that a model that allocates control attention through nonlinear urgency functions using only error information could not achieve performance of the full model whose attention shifting algorithm included both error and error rate terms. Subsequent to this analysis, tracking performance predictions for the full model were verified by piloted flight simulation. Complete model and simulation data are presented.

W/L Cat. Code: 2.2.2, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	Flight simulator	Flight simulator
Primary task	Math. model	Experimental		Flight test

Fergenson, P. E. and Gold, L.S. Perception of task difficulty. Proceedings of the 21st Annaul Meeting of the Human Factors Society, San Francisco, Claifornia, October 17-20, 1977, 48-52.

Twenty male subjects were shown the operation of a rotor-pursuit apparatus under two states of three different task conditions; rotor speed, target shape, and hand used. Pre and post-performance estimates of task difficulty were obtained. The results indicated that subjects had trouble in estimating the relative affects of as few as three different task variables on performance.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Finkelman, J. M. and Glass, D. C. Reappraisal of the relationship between noise and human performance by means of a subsidiary task measure. Journal of Applied Psychology, 1970, 54, 211-213.

Previous research has generally shown that broad-band noise has only minimal effects on task performance. However, this relative absence of effect may be attributable to the way in which earlier investigators measured performance decrements. The present study was based on the notion that where demands imposed by the task and concurrent environmental stress are within the operator's total information-handling capacity, the task can be performed substantially without errors. For performance degradation to occur, the operator's channel capacity must be exceeded. It was assumed that unpredictable noise in combination with multiple task performance would result in such an overload, whereas the introduction of predictable noise would not have such an effect. A subsidiary task method consisting of the delayed recall of randomly presented digits was used to measure overload. As expected, the use of unpredictable, as opposed to predictable noise resulted in performance degradation on the subsidiary task. Performance on the primary task was unaffected by either type of noise. These results were interpreted as reflecting a reduction in spare mental capacity as a function of the aversiveness of the noise stressor.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Firth, P. A. Psychological factors influencing the relationship between cardiac arrhythmia and mental load. Ergonomics, 1973, 16, 5-16.

This paper examines the development and use of cardiac arrhythmia as an index of mental workload in terms of several issues. These include the relevance of autonomic response to the measurement of task difficulty and the implications of general principles of psychophysiology to the application of cardiac arrhythmia as an applied measure. In addition the complexity of the psychological factors which may influence task difficulty is discussed with particular reference to second-by-second changes in heart rate variability. In conclusion it is suggested that the usefulness of global concepts of task difficulty such as mental load may be questionable. Moreover that a greater understanding of what a task entails, with reference to increased psychophysiological knowledge, is necessary in order that global changes in cardiac arrhythmia may be interpreted in relation to task difficulty.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Review	None	Flight simulator

Flora, C. C., Kriechbaum, G. K. L. and Willich, W. A flight investigation of systems developed for reducing pilot workload and improving tracking accuracy during noise-abatement landing approaches. Moffett Field, California: National Aeronautics and Space Administration, Ames Research Center, Contractor's Report NASA CR-1427, 1969.

This study was directed at evaluating various systems developed to reduce the pilot workload while maintaining tracking accuracy under simulated instrument conditions during noise-abatement landing approaches. Preliminary results of the study showed that steeper than normal approaches could not be performed at the same pilot workload level as a conventional approach without improvements in the path guidance system, flight instrument displays, and automatic flight controls. The results of further flight evaluations showed that when the pilot was given an appropriate combination of system aids he was able to perform steep, two-beam or decelerating approaches with workloads and accuracies comparable to those of conventional approaches.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.

Primary task Single measures Experimental Flight simulator Flight simulator

Fowler, R. L., Williams, W. E., Fowler, M. G. and Young, D. D. An investigation of the relationship between operator performance and operator panel layout for continuous tasks. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, AMRL-TR-68-170, December, 1968.

This study defined and evaluated four principles of control panel layout: sequence of use, functional grouping, optimum location by frequency of use, and optimum location by importance. The four principles were evaluated by factorial experiments which included stress conditions and three levels of application of each of the arrangement principles. Systematic procedures for applying each principle in the layout process were developed. Analysis of the final trials indicated that when optimized, sequence of use leads to consistently superior performance. Stress disrupts performance on control panels layed out on the basis of optimum location by frequency of use and on the basis of optimum location by importance of use, but not on panels where the layout principles sequence of use and functional grouping were used. Practical applications of the data to the panel design process are offered.

W/L Cat. Code: 3.2

Op. Behav. Code: 1., 2., 4.

Primary task Mult. measures Experimental Laboratory Background

Frankenhaeuser, M. and Johansson, G. Task demand as reflected in catecholamine excretion and heart rate. Journal of Human Stress, 1976, 2, 15-23.

Immediate effects and aftereffects of exposure to a color-word conflict task were studied in two groups of subjects, one of which performed the task without auditory interference ("single conflict"), the other with auditory interference ("double conflict"). Physiological arousal indices were more susceptible than performance measures to the level of task demand. Thus, the higher demand imposed by the double-conflict task was reflected in relatively larger increases of adrenaline excretion and heart rate, both during the conflict task and during the subsequent arithmetic task, whereas the performance measures remained unaffected.

W/L Cat. Code: 3.1, 4.1.10, 4.1.12

Op. Behav. Code: 1., 2., 3.,

Primary task	Single measures	Experimental	Laboratory	Background
Physiological	Heart rate, h.r. var.			
	Body fluid anal.			

Frolov, N. I. Evaluation of the working capacity of a pilot during flight duty. Voenno-Meditsinskii Zhurnal, July, 1976, 54-68. (In Russian.)

The working capacity of a pilot during the time he is at the controls (in the presence of sufficient level of health, training, and motivation) may be defined as his ability to perform the required tasks with a given efficiency and proper tension of the psychophysiological systems of the body. The paper stresses that the working capacity should be assessed dynamically, based on a complex postflight analysis of the pilot's activities observed by automatic flight parameter recording systems, along with an analysis of the relevant changes in the physiological functions of the pilot's body. Attention should be directed to the evaluation of the pilot's "attention potentiality" and to the structure of his control movements through the use of the stabilizer and manual controls.

W/L Cat. Code: 3.1, 3.2, 4.2

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Mult. measures	Construct	None	Flight simulator
Physiological				Flight test

Fujihara, O., Sakurai, I., and Kakimoto, Y. Measurements of pilot workload during low altitude and high speed maneuvers of F-1 supersonic jet fighter. Tachikawa, Japan: Japan Air Self-Defense Force, Aeromedical Laboratory Reports, 1978, 19, 101-113. (In Japanese.)

In a study designed to reveal the relationships between the mental workload of F-1 jet fighter pilots and flight altitude, four pilots flew four different altitude flights (5000, 2000, 1000, and 500 ft), performing the same mission with the same flight patterns. Changes in heart and voice characteristics of the vibration-space shift rate (VSSR) were measured. The heart rate was found to increase as the flight altitude decreased. The heart rate showed mission-dependent behavior, and in the case of the easiest mission the increase in heart rate as altitude decreases is minimal. The analysis of VSSR showed that the emotional state during flight maneuver had no significant differences at the three higher altitudes, but at 500 ft the psychophysiological tension increased greatly.

W/L Cat. Code: 4.1.10, 4.3
Op. Behav. Code: 1., 2., 3., 4.

Physiological	Heart rate, h.r. var.	Experimental	Flight test	Flight simulator
	Speech patt. anal.			Flight test

Gabriel, R. F., and Burrows, A. A. Improving time-sharing performance of pilots through training. Human Factors, 1968, 10, 33-40.

Even with special display devices in gestation, a pilot must satisfy his complete visual information needs by "time-sharing" between the intra- and extra-cockpit data sources. A sample of sixty military attack pilots, selected with the variable of flying experience in view, was divided into control and trainee groups. Using simple, generalized but adaptive simulation devices, the trainee group was trained over an eight-week period in display reading and in hazard detection. A comparison of the trainee group with the control group in a highly specific and complex simulated flying task, showed that hazard detection (such as collision) was improved significantly without in any way compromising other flying tasks.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 4.2

Spare m. capacity Subsidiary task Experimental Simulator Flight simulator

Gale, A., Davies, R., and Smallbone, A. EEG correlates of signal rate, time in task and individual differences in reaction time during a five-stage sustained attention task. Ergonomics, 1977, 20, 363-376.

The EEG of 20 subjects was monitored continuously while they performed a sustained attention task in which each subject performed five conditions in different order. All conditions involved regular presentation of digits (stimuli). Subjects were required to respond to particular digits (signals) and signal ratios varier between 10 and 50% over the five conditions. The Results were: 1. Mean reaction time to wanted signals increased following the first condition (independent of signal ratio) and was also longest for the 50% signal ratio condition (independent of order of presentation). 2. Errors (false positives and misses) increased as a function of signal ratio but not as a function of order of presentation. Subjects with faster mean reaction time committed more errors. 3. EEG abundance for the lower measured alpha frequencies increased as the task progressed, and mean dominant alpha frequency, decreased. 4. EEG abundance for the higher measured alpha frequencies increased as a function of signal ratio i.e. the higher the ratio, the higher the abundance. 5. Subjects with higher EEG abundance and lower mean dominant alpha frequency were faster (mean RT) than subjects with lower abundance and higher mean dominant alpha frequency. 6. EEG trends were different for fast and slow subjects; fast subjects gave EEG effects for both signal ratio and time in task, whereas slow subjects showed only time effects.

W/L Cat. Code: 3.1, 4.1.5
Op. Behav. Code: 1., 2., 3., 4.
Primary task Single measures Experimental Laboratory Background
Physiological EEG

Gardner, R. M., Beltramo, J. S., and Krinsky, R. Pupillary changes during encoding, storage, and retrieval of information. Perceptual and Motor Skills, 1975, 41, 951-955.

Six subjects were each auditorily presented six lists of 7-digit numbers for retention intervals of 0, 5, and 10 sec. Pupil size was recorded during stimulus presentation, retention interval, and recall of items. Results indicated that pupil dilation occurred during encoding and retrieval of stimulus items. Pupillary constriction was found during the retention interval when rehearsal was presumed to occur.

W/L Cat. Code: 4.1.8

Op. Behav. Code: 1.1, 2., 3.

Physiological Pupillary dia. Experimental Laboratory Flight simulator

Gartner, W. B. and Murphy, M. R. Pilot workload and fatigue: A critical survey of concepts and assessment techniques. Moffett Field, California: National Aeronautical and Space Administration Ames Research Center, NASA TN D-8365, November, 1976.

This study addresses the principal unresolved issues in conceptualizing and measuring pilot workload and fatigue. These issues are seen as limiting the development of more useful working concepts and techniques and their application to systems engineering and management activities. A conceptual analysis of pilot workload and fatigue, an overview and critique of approaches to the assessment of these phenomena, and a discussion of current trends in the management of unwanted workload and fatigue effects are presented. Refinements and innovations in assessment methods are recommended for enhancing the practical significance of workload and fatigue studies.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Gartner, W. B. and Murphy, M. R. Concepts of workload. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 1-2.

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 access 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. This chapter addresses the principle of operator workload concepts, Jahns has found it useful to characterize workload as "an integrative concept for evaluating the effects on the human operator associated with multiple stresses occuring within man-machine environments." While broader conceptions may be considered useful for indicating the range and diversity of workload reference, the purpose here is to outline the principle ways in which investigators have elected to restrict the use of the term.

W/L Cat. Code: 1., 2., 3., 4.
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Construct	None	Background
Spare m. capacity				
Primary task				
Physiological				

Gaume, J.G. and White, R.T. Mental workload assessment, II. Physiological correlates of mental workload: Report of three preliminary laboratory tests. St. Louis, Missouri: McDonnell Douglas Corporation, Report MDC J7023/01, December, 1975.

Describes the results of three preliminary laboratory tests of physiological changes under various types and levels of mental workload. Subjects were tested on two configurations of a mental workload apparatus in a multiple-task situation in which they monitored four or six single-digit light-emitting diode counters to prevent errors. Mental workload was varied by changing the rates of the counters. Repeated readings taken under a single workload level revealed only slight evidence that blood pressure increased as a result of increased workload. No consistent relationships were found between pulse rate and mental workload. Respiration rates were very stable across all levels of workload. Skin resistance tended to decrease with an increase in workload.

W/L Cat. Code: 2.2.1, 4.1.2, 4.1.10, 4.1.11
Op. Behav. Code: 2.1, 2.2

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Physiological	GSR			
	Blood pressure			
	Breathing anal.			

Geer, C. W. Navy manager's guide for the test and evaluation sections of MIL-H-46855. Seattle, Washington: Boeing Aerospace Company, Technical Report D194-10006-2, June, 1977.

Assistance is provided to HFE Navy managers in planning, scheduling, and performing HFE T&E in accordance with the requirements of MIL-H-46855. The emphasis of this guide (as compared to the user's guide) is placed on the planning and scheduling necessary to produce the most cost effective total T&E effort. Both formal and technical T&E program requirements are indicated. Basic T&E considerations such as data inputs, level of detail, timing, and applications are described. Types of HFE T&E techniques are indicated and a system for choosing or evaluating particular techniques is briefly described. 33 techniques are listed along with brief descriptions of each. A fold-out chart, which integrates much of the guide content into a Navy manager's program planning decision tree, is provided and may be used as a checklist to assist him in his job. A list of personnel surveyed to obtain much of the guide material is included in the appendices.

W/L Cat. Code: 1.2.1, 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Geer, C.W. User's guide for the test and evaluation sections of MIL-H-46855. Seattle, Washington: Boeing Aerospace Company, Technical Report D194-10006-1, June, 1977.

Assistance is provided to HF engineers in planning, scheduling, and performing HFE T&E in accordance with the requirements of MIL-H-46855. All appropriate aspects of the total HFE T&E process are indicated with emphasis being given to 33 HFE T&E techniques which may be used. Details of technique selection and use are included along with technique samples where appropriate. The emphasis of this guide (as compared to the Navy manager's guide) is placed on the HFE evaluator's task of performing the most cost effective total T&E effort. Both formal and technical T&E program requirements are indicated. Basic T&E considerations such as data inputs, level of detail, timing, and applications are detailed. Types of HFE T&E are indicated and a system for evaluating and categorizing techniques is presented.

W/L Cat. Code: 1., 2.1, 3., 4.
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Geiselhart, R., Koeteeuw, R. I. and Schiffler, R. J. A study of task loading using a four-man crew on a KC-135 aircraft (GIANT BOOM). Wright-Patterson AFB, Ohio: Aeronautical Systems Division, ASD-TR-76-33, April, 1977.

At the request of Strategic Air Command (SAC), human factors engineers and engineering psychologists participated in this KC-135 crew composition and task load analysis entitled GIANT BOOM. GIANT BOOM, a follow-on study to SAC's earlier GIANT CHANGE, determined the feasibility of a four-man KC-135 crew consisting of two pilots, a boom operator, and an enlisted Flight Systems Operator. This crew complement, with inertial navigation systems and radars for the pilots and Flight Systems Operators, demonstrated significantly reduced task loads on both pilots from those observed in GIANT CHANGE.

W/L Cat. Code: 1.2, 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Questionnaire	Experimental	Flight test	Flight simulator
Spare m. capacity	Task comp., time assess.			Flight test

Geiselhart, R., Schiffler, R. J. and Ivey, L. J. A study of task loading using a three-man crew on a KC-135 aircraft. Wright-Patterson AFB, Ohio: Aeronautical Systems Division, ASD-TR-76-19, October, 1976.

A series of flight tests was conducted to assess the feasibility of reducing the crew size on a KC-135 when a dual Inertial Navigation System (INS) was installed. Test crews consisted of pilot, copilot, and boom operator only. Crew performance during air refueling missions was assessed through questionnaires and inflight observation of crew members. Test missions included Cell, High Latitude, Coronet, and EWO/Mission Change scenarios. During critical phases of the missions, severe task overloading resulted in the deletion or deferral of many normal duties.

W/L Cat. Code: 1.2, 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Questionnaire	Experimental	Flight test	Flight simulator
Spare m. capacity	Task comp., time assess.			Flight test

Gerathewohl, S.J. Definition and measurement of perceptual and mental workload in aircrews and operators of Air Force weapon systems: A status report. In B.O. Hartman (Ed.) Higher Mental Functioning in Operational Environments, AGARD Conference Proceedings No. 181, April, 1976, C1-1 - C1-7. (AD A025 663).

It is recognized that every flight mission places certain perceptual and mental demands on the pilot and the crew, which depend on a variety of variables and conditions. Moreoever, every mission involves certain tasks, which are either flight oriented or combat oriented. This classification lends itself to a definition of activities as primary or secondary tasks, which has been successfully used in experiments for quantitative determinations of workload. The determination of pilot and aircrew workload using psychological, physiological, and operational criteria has yielded valuable results. Methods used in civil aviation can be applied with appropriate modifications to military problems. However, data are not available from actual combat missions. The results obtained by simulation are promising and may be improved by the standardization of methods and the application of statistical approaches and mathematical models.

W/L Cat. Code: 2., 3., 4.
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Primary task Physiological	Multiple	Review	None	Flight simulator

Gerathewohl, S. J., Brown, E. L., Burke, J. E., Kimball, K. A., Lowe, W. F., and Stackhouse, S. F. Inflight measurement of pilot workload: A panel discussion. Aviation, Space, and Environmental Medicine, 1978, 49, 810-822.

A group of U.S. scientists engaged in inflight measurements of pilot workload discussed the problems and aspects of workload; the techniques used for inflight measurements; the various workload models, such as design-oriented, operational, psychological, and physiological concepts; different experimental approaches; and experiences, results and further plans, during the 48th Annual Scientific Meeting of the Aerospace Medical Association in Las Vegas, Nv. on May 10, 1977. The contributions by the chairman and the five panel members are summarized.

W/L Cat. Code: 2.1.1, 2.2.1, 4.1.7, 4.2

Op. Behav. Code: 1., 2.1, 4.2

Spare m. capacity	Task component	Review	Flight simulator	Flight simulator
Physiological	Subsidiary task		Flight test	Flight test
	Eye movement			
	Mult. measures			

Gerathewohl, S. J., Chiles, W. D., and Thackeray, R. I. Assessment of perceptual and mental performance in civil aviation personnel. In B. O. Hartman (Ed.), Higher Mental Functioning in Operational Environments. AGARD Conference Proceedings No. 181, April, 1976, C-7. (AD-A025 663).

Experiments were conducted to study functions of relevance to aircrew, pilot, and ATC performance. They concerned the assessment of mental functions and complex performance on single operators and five man crews while monitoring static and dynamic processes, of perceptual motor tracking ability, as well as group problem solving. Operator proficiency was measured at various levels of demand induced by the simultaneous performance of different combinations of tasks, requiring the exercise of psychological and mental processes. It was found that multiple task performance varied significantly as a function of information input and group interaction. Substantial correlations were obtained between perceptual motor type problem solving and mental ability tests. Moreover, the results obtained from two tracking tasks suggest that a central process exerts a regulatory influence on a variety of physiological variables during increased attention demand.

W/L Cat. Code: 3.1, 3.2

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
	Mult. measures		Flight simulator	

Gilson, R. D., Burke, M. W., and Jagacinski, R. J. Secondary visual workload capability with primary visual and kinesthetic-tactual displays. Proceedings of the 22nd Annual Meeting of the Human Factors Society, Detroit, Michigan, 1978, 293-297.

Subjects performed a cross-adaptive tracking task with a visual secondary display and either a visual or a quickened kinesthetic-tactual (K-T) primary display. The quickened K-T display resulted in superior secondary task performance. Comparisons of secondary workload capability with integrated and separated visual displays indicated that the superiority of the quickened K-T display was not simply due to the elimination of visual scanning. When subjects did not have to perform a secondary task, there was no significant difference between visual and quickened K-T displays in performing a critical tracking task.

W/L Cat. Code: 2.2.4, 2.2.5, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Glenn, F. A., Streib, M. I., and Wherry, R. J., Jr. The human operator simulator volume VIII: Applications to assessment of operator loading. Willow Grove, Pennsylvania: Analytics, Technical Report 1233-A, June 1977.

This study was undertaken as part of a continuing series of studies designed to validate the Human Operator Simulator (HOS). HOS is intended to be used as a system evaluation tool that can be applied to a detailed system design prior to the development of a hardware prototype. Consequently, an assessment of its ability to model operator workload problems realistically was considered to be of prime importance. The study was designed to show that HOS, a general-purpose model of human performance, can accurately simulate the kinds of complex interactions between competing task demands experienced by a human operator performing a complex mission.

W/L Cat. Code: 2.1, 2.2.2, 2.3, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp.,	Construct	None	Flight simulator
Primary task	time assess.			
	Subsidiary task			
	Occlusion			
	Math. model			

Gobuty, D. E. TADRAP: A computer-aided technique for reducing aircrew task analysis data. In AGARD Operational Helicoper Aviation Medicine, AGARD-CP-255, May, 1978, 28-1 - 28-9.

During the design of the YAH-64 advanced attack helicopter, a technique was developed for the computer aided reduction of aircrew task analysis data. The Task Analysis Data Reduction and Analysis Program (TADRAP) begins with the processing of raw data from a classical task analysis which was structured around a five-tiered pyramidal scheme for mission description. TADRAP converts the task analysis data into estimates of operator workload based upon expected task completion time, plus weighted values representing the complexity factors of action cycle, sensory modality, and task position. The TADRAP facilitates task analysis validation and presents workload data in tabular form.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator
		Experimental		

Coerres, H. P. Subjective stress assessment as a criterion for measuring the psycholophysical workload on pilots. Proceedings of the AGARD Conference on Studies on Pilot Workload, AGARD-CP-217, April, 1977, B12-1 - B12-8.

The psychophysiological workload induced by an activity depends not only on the duration and intensity of stressing stimuli, but also upon intra-individual factors in the stressed subject (physical features, functioning of sensory organs, vegetative status, and present state of health as a prerequisite to physical performance; job-related knowledge, abilities, skills, need for achievement, experience, emotional stress resistance as psychic and mental determinants of strain). The results obtained by using standardized interviews and questionnaires to assess these psychophysiological strain parameters in 217 pilots of various type aircraft used by the German Federal armed forces are presented.

W/L Cat. Code: 1.1

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
	Questionnaire			

Goerres, H. P. Subjective stress assessment-a new, simple method to determine pilot workload. Aviation, Space, and Environmental Medicine, 1977, 48, 588-564.

A group comprised of 117 jet pilots, 41 multiple-engine prop pilots, 14 single-engine prop pilots, and 43 helicopter pilots was interviewed and asked to complete questionnaires to provide subjective assessments of workload. The pilots placed the effect of individual stressors and the severity of tension symptoms during different types of missions on a scale of zero to six. They were then asked to respond to the same questions from the point of view of pilots flying different types of aircraft. A combined scoring table was constructed. On a percentage scale, with 100% assigned to jet pilots, who had the highest strain and workload scores, the relative workload for instructor pilots (regardless of aircraft type) is 95%; helicopter pilots, 90%, multiple-engine prop pilots, 75%, and single-engine prop pilots, 60%.

W.L Cat. Code: 1.1, 2.2

Op. Behav. Code: 1., 2., 3., 4.

Opinion   Rating scale   Experimental   Laboratory   Flight simulator
Questionnaire

Goeters, K. M. Relation between pulse rate during the complex coordination test and several psychological measures of effort and stress. Scientific and Technical Aerospace Reports, Report No. DLR-IB-355-75/04, 19[illegible]. (In German.)

The connection between physiological activation in a test situation and psychological measures of effort and stress was investigated for 33 applicants for flight navigator training. The object of this work is to replace psycholgical measures with strong subjective components by objective physiological parameters. Physiological activation was related to pulse rate. It was found that no real correlation exists, and that pulse rate changes are always ambiguous.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological   Heart rate, h.r. var.   Experimental   Laboratory   Background

Goldstein, I. L., Dorfman, P. W., and Price, A. Speed and load stress as determinants of performance in a time sharing task. Human Factors, 1978, 20, 603-609.

The effects of speed and load stress were investigated in a task where operators responded to moving visual stimuli that entered critical zones in each of three visual displays. As expected, increases in either speed or load stress resulted in significantly poorer performance. More importantly, the effects of speed stress were made apparent by a speed by load stress interaction. At the lowest level of load stress where the operator was only required to attend to one display, increases in speed stress did not have any apparent effect. However, as load stress increased to two displays and especially to three displays, increases in speed stress had a significant negative impact on performance. Data concerning the timing of these responses further supported this analysis. Future generalizations about the effects of speed stress much consider the level of load stress present in the task.

W/L Cat. Code: 2.2, 3.1

Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Secondary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Gomer, F. E., Beideman, L. R., and Levine, S. H. The application of biocybernetic techniques to enhance pilot performance during tactical missions. St. Louis, Missouri: McDonnell Douglas Astronautics Company. MDC E2046, Final Report, October 1, 1979.

This report describes a novel means of enhancing man's performance in highly complex, crew station environments. The benefits of on-line evaluation of physiological data are related to projected mission requirements for a 1990 tactical aircraft. The pilot's effectiveness may be monitored for fluctuations in attentiveness and ability to process information. The report summarizes research which has demonstrated that these mental activities are manifest in distinct electrophysiological signals, and that such signals, recorded noninvasively and unobtrusively, can be analyzed and interpreted in real-time.

W/L Cat. Code: 2.1.1, 4.1.5, 4.1.6, 4.1.7
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator
Physiological	EEG ECP Eye movement Eyelid movement			

Gopher, D. Eye movement patterns in selective listening tasks of focused attention. Perception and Psychophysics, 1973, 14, 259-264.

Three experiments are described in which eye movements (Ems) were recorded in conjunction with either monaural of dichotic tasks of focused attention. Two main effects were observed in the Ems records: (1) Listening to auditory messages reduced the occurrence of spontaneous Ems. (2) Selective monitoring of one ear in the dichotic task was accompanied by a consistent pattern of directional Ems characterized by big saccades and long changes of eye fixation in the direction of the relevant ear. The pattern of Ems is affected by the following variables: the presentation rate of the auditory information, the frequency of demands to switch orientation between the ears, and the competition of the irrelevant channel in the dichotic task. It is suggested that the eye-movement mechanism is used in selective listening taske as a general orientation indicator, when the adoption or maintenance of a certain selective set is difficult and demanding of effort. The Ems response is part of a general orientation pattern, although its usual function is in the field of visual perception.

W/L Cat. Code: 4.1.7
Op. Behav. Code: 1., 3.

Physiological   Eye movement   Experimental   Laboratory   Flight simulator

Flight test

Gopher, D. and Navon, D. How is performance limited: testing the notion of central capacity. Haifa, Israel: The Technion, Report No. HEIS-78-11, December, 1978.

A two-dimensional pursuit tracking task was employed in three experiments designed to test three predictions of a central capacity approach to performance limitations under time-sharing conditions. Each of simultaneously performed tracking dimensions (horizontal and vertical) was treated as a separate task and manipulated independently. Tracking difficulty on each dimension and the relative emphasis were jointly investigated. Negatively accelerated effects of task priority and limited tradeoff between tracking dimensions were obtained when frequency and velocity of target movement served as difficulty parameters. Direct linear tradeoffs were observed when control complexity was increased by changing control dynamics. These results cannot be easily accommodated within a strict central capacity model. An alternative interpretation which relies on a multiple capacity approach is outlined.

W/L Cat. Code: 2.2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Background

Primary task   Single measures

Gopher, D. and Navon, D. Can you control your control: on the efficiency of attention allocation between tracking dimensions. Paper presented at the Fifteenth Annual Conference on Manual Control, Wright State University, Dayton, Ohio, March, 1979.

The efficiency of attention allocation between tracking dimensions was investigated in a two dimensional pursuit tracking task where each of the dimensions was treated as a separate task and manipulated independently. Tracking difficulty on each dimension and their relative emphasis were jointly manipulated in a central composite response surface design. Negatively accelerated effects of task priority and limited tradeoff between tracking dimensions were obtained when frequency and velocity of target movement served as difficulty parameters. Direct linear tradeoffs were observed when control complexity was increased by changing control dynamics. These results provide strong evidence of the ability of human subjects to control their responses separately. The differential effects obtained for the three difficulty manipulations suggest that the locus of load in the time-sharing performance of tracking tasks resides primarily in the response selection stage.

W/L Cat. Code: 2.2.2, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Gopher, D., Navon, D., and Chillag, N. Tracking in two dimensions as a function of dimension priorities and tracking difficulty. Proceedings of the 21st Annual Meeting of the Human Factors Soceity, San Francisco, California, Oct. 17-20, 1977, 118-122.

The present paper develops the argument that an effective evaluation of performance under time-sharing conditions requires a joint manipulation of tasks difficulty and operator's resources allocation. An experiment is presented in which each of the dimensions in a two dimensional pursuit tracking task was manipulated and controlled separately. Single and dual task conditions were created by presenting one dimension or two dimensions simultaneously. Time-sharing efficiency was assessed under a joint manipulation of tracking difficulty on each dimension and their relative priorities. Results are discussed in terms of their implications to the problem of measuring capacity, and their contribution to the understanding of tracking behavior.

W/L Cat. Code: 3.1, 2.2.5

Op. Behav. Code: 1., 2., 4.2

Primary task Single measures Experimental Laboratory Background

Spare m. capacity Subsidiary task

Gopher, D., Navon, D., Chillag, N. and Dotan, H. Tracking in two dimensions as a function of dimension priorities and tracking difficulty. Haifa, Israel: Technion-Israel Institute of Technology, The Center for Industrial Safety Research, Technical Report AFOSR-77-2, December, 1977.

The present report develops the argument that a comprehensive assessment of performance limitations under time-sharing conditions requires an evaluation of the joint effects of task difficulty and operator's resources allocation. An experiment is presented in which each of the dimensions tracking task was treated as a separate time-shared task, and manipulated independently. Tracking accuracy was assessed under a joint manipulation of target frequency on each dimension and their relative priorities. The results showed that the priority variable had the most robust effect on performance. However, this effect was negatively accelerated. Subjects degraded performance on an axis when its priority was reduced, but the released resources could not be effectively transferred to improve performance on the high priority axis.

W/L Cat. Code: 2.2.2, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Flight simulator
Primary task   Single measures

Gopher, D. and North, R. A. Manipulating the conditions of training in time-sharing performance. Human Factors, 1977, 19, 583-593.

A one-dimensional compensatory tracking task and a digit-processing, reaction time task were combined to assess three aspects of training under time-sharing conditions: (1) manipulation of desired levels of dual-task performance; (2) training under equal and unequal task priorities; and (3) repeated sequencing of single/dual-task presentations. Six groups of 10 subjects each participated in the experiment. Larger performance improvements under time-sharing conditions were observed when desired performance indicators were computed relative to a dual-task rather than a single-task reference. Training under unequal task priorities revealed that tracking was more sensitive than the digit-processing task to priority differences. Tracking performance continued to improve during repeated single-task presentation, whereas digit processing improved only in the time-sharing conditions. These findings suggest that improvement on the tracking task is in the specific skill of tracking, while digit-processing improvement results from improved time-sharing ability.

W/L Cat. Code: 2.2.4, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Flight simulator

Primary task   Single measures

Graham, D. K. Transport airplane flight deck development survey and analysis: Report and recommendations. Moffett Field, California: National Aeronautical and Space Administration, NASA CR-145 121, January, 1977.

This document reports results of a survey and analysis of current research and development work in the U.S.A. related to improving transport airplane flight deck equipment and aircrew performance. This survey and analysis was performed for the NASA Langley Research Center's Terminal Configured Vehicle (TCV) program, which was established to study, test, and evaluate concepts for more efficient and more acceptable terminal-area transport operations. Specific recommendations are made for future TCV program work in flight deck development, based on survey results. Methods of workload analysis that seem most appropriate for further development include the oculometer, time-line analysis program, physical cost evaluations of workload which include measures of EKG, muscle activity, and respiration rate.

W/L Cat. Code: 2.1.1, 4.1.3, 4.1.7, 4.1.8, 41.19, 4.1.11, 4.2

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Multiple Review None Flight simulator

Physiological

Green, R. and Flux, R. Auditory communication and workload. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A4-1 - A4-8.

This paper discusses the general problem of assessing how psychomotor workload may interfere with the performance of an auditory communications task. Two experiments are described. The first illustrates that an auditory task from which a cumulative response time measure is taken is affected by changes in signal quality and the second experiment shows that the same auditory task is also affected by a realistic form of workload (flying an aircraft simulator). The implications of these findings are discussed both in terms of assessing the quality required of a communications system and in terms of the use of secondary tasks in the assessment of workload.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 2.1, 3., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures Flight simulator

Greening, C. P. Analysis of crew/cockpit models for advanced aircraft. China Lake, California: Naval Weapons Center, NWC TP 6020, February, 1978.

The purpose of this study was to examine five active computer models of the aircrew/cockpit system, and to determine their relevance to current and future attack aircraft. The models were compared in terms of their general structure, input requirements, output options, and their sensitivity to a wide variety of equipment, mission, and operator characteristics. The models reviewed are similar in several important respects: They all require a detailed mission scenario and task analysis to steer the simulation; all require data on performance time and accuracy as inputs; and all generate outputs related to operator task load. The models differ widely in their sensitivity to significant variables. Recommendations for future work are presented.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Review	Laboratory	Flight simulator
			Flight simulator	

Gregoire, H.G. Is man the weakest link? Proceedings of AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A1-1 - A1-3.

The advantages of small battery-powered video tape analysis during in-flight operations are presented with emphasis on workload relationship to human engineering. Of particular interest are the differences between aircrew debrief accuracy with vs. without the videotape utilization. Data were obtained during passive acoustic submarine search and track operations during actual ASW test flights. These data indicated that during passive acoustic search and tracking, individual control tasks requiring one or more pushbutton operations were performed from 6 to 10 times per minute. Display mode changes occurred at intervals of approximately two minutes. With the exception of a few particular pushbutton inputs, every individual pushbutton operation was guided visually. Keying tasks which occurred with the highest frequency were KEYBOARD numberical entries. The following potential applications are identified: 1) Capability of real time activity recording with slow time analysis, 2) Actual in-flight data sampling, and 3) Capability for accurate and detailed time-line analysis to be correlated with human engineering design limitations of controls and displays.

W/L Cat. Code: 1.2, 2.1.1
Op. Behav. Code: 1.1, 2., 4.1

Opinion	Questionnaire	Experimental	Flight test	Flight simulator
Spare m. capacity	Task comp., time assess.			Flight test

Gunning, D. Time estimation as a technique to measure workload. Proceeding of the 22nd Annual Meeting of the Human Factors Society, Detroit, Michigan, October 16-19, 1978, 41-45.

A secondary task which involves time estimation was used as a measure of workload in a flight simulation study. The results of the time estimation task were compared with performance scores and subjective workload ratings to evaluate the adequacy of the task. The successes and failures of the techniques are discussed.

W/L Cat. Code: 1.1, 2.2.3, 3.1

Op Behav. Code: 1., 2., 3., 4.

Opinion Rating scale Experimental Flight simulator Flight simulator

Spare m. capacity Time estimation

Primary task Single measures

Guttmann, H. E., Easterling, R. G. and Webster, R. G. The effects of flicker on performance as a function of task-loading. Albuquerque, New Mexico: Sandia Laboratories, SC-TM-72 0617, November, 1972.

Subjects performed a tracking task and a search task in a light-tight chamber that was arranged to roll on its longitudinal axis, and were required to maintain the chamber vertical. The tracking task was individually adjusted for each subject to impose a substantial amount of task-load. During the experiment, subjects were exposed to flicker at rates of 3, 7, 11, 15, 19, and 23 pulses per second. At rates of 11 pulses per second and higher, performance on the tracking-task was markedly degraded. No degradation in performance of the search task or maintenance of verticality was observed. Degradation of tracking was greatest when subjects were engaged in the three tasks simultaneously, indicating that task-loading is an important variable in the behavioral response to flicker.

W/L Cat. Code: 3.1, 4.1.1

Op. Behav. Code: 1., 2., 4.

Primary task Single measure Experimental Laboratory Flight simulator

Physiological FFF

Hacker, W. Determining the psychic workload: Present status and perspectives. Socialistische Arbeitswissenschaft, 1974, 18, 17-28. (In German).

Whereas established concepts and measuring methods are available for the physiological workload, no such criteria exist for assessing the load due to mental activity. The author defines the terms (task, demands, load, and stress) from the standpoint of psychic workload and examines the possibilities of determining its effects.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Construct	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Hacker, W. et. al.* Internal representation of task structure and mental workload: approaches and methods of assessment. Le Travail Humain, 1977, 40, 239-248. (In French).

A survey is presented of research designed to elucidate problems of mental load in industrial work, using both laboratory experiments and field studies, and examining relationships between the mental demands of jobs and changes of various indices of performance and of subjective and physiological effects. An initial enunciation of general principles stresses the importance of internal models, strategies and goals in the organization of work activities. This followed by brief accounts of four experimental studies. Of these, one showed that the effects of load are multidimensional, a second gave evidence of shifts of aspiration and motivation, a third illustrated the value of adequate internal models as a means of preventing fatigue, and a fourth indicated that job enrichment which increases the mental demands made by industrial work need not produce undue mental load.

W/L Cat. Code: 1.1, 3.1, 3.3, 4.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	Laboratory	Background
Primary task		Experimental	Field	
Physiological				

*Names of other authors not available at time of publication.

Hacker, W., Plath, H. E., Richter, P. and Zimmer, K. Internal representation of task structure and mental load of work: approaches and methods of assessment. Ergonomics, 1978, 187-194.

A survey is presented of research designed to elucidate problems of mental load in industrial work, using both laboratory experiments and field studies, and examining relationships between the mental demands of jobs and changes during a working spell of various indices of performance and of subjective and physiological effects. An initial enunciation of general principles stresses the importance of internal models, strategies and goals in the organisation of work activities. This is followed by brief accounts of four experimental studies. Of these, one showed that the effects of load are multidimensional, a second gave evidence of shifts of aspiration and motivation, a third illustrated the value of adequate internal models as a means of preventing fatigue, and a fourth indicated that job enrichment which increases the mental demands made by industrial work need not produce undue mental load.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures Review	Laboratory	Flight simulator
		Field	

Hagen, J. F., Moe, P. J., and Woratschek, R. Flight evaluation. MK-2 integrated controller installed in an OH-58A helicopter. Edwards Air Force Base, California: U.S. Army Aviation Engineering Flight Activity 77-11, Final Report, April, 1978. (AD-A-65 072).

This activity conduced a handling qualities and pilot workload evaluation of the MK II integrated controller installed in an OH-58A helicopter. The OH-58A could be safely flown throughout the recommended flight envelope using the integrated controller. The pilot workload when using the integrated controller with two hands was not reduced from and was sometimes greater than the workload when using conventional controls for all maneuvers except level forward fligth. Single hand control during fligth and landing could be safely accomplished, but required increased pilot workload in all cases. The two most serious unsatisfactory characteristics identified were lack of an adequate system-decoupled warning and excessive workload during left sideward flight between approximately 15 to 25 knots true airspeed.

W/L Cat. Code: 1.1, 1.2, 3.1
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Questionnaire			Flight test
	Single measures			

Hale, H. B., Anderson, C. A., Williams, E. W. and Tanne, E. Endocrine-metabolic effects of unusually long or frequent flying missions in C-130E or C-135B aircraft. Aerospace Medicine, 1965, 36, 561-570.

Flight-stress appraisal was made by means of a battery of urinary determinations (epinephrine, norepinephrine, 17-OHCS, urea, uric acid, phosphorus, magnesium, sodium, and potassium) for flyers who participated in (a) 20-hour missions in C-130E aircraft (flights from New Zealand to Antarctica, and back), (b) 6-day missions in C-135B aircraft (earth-circling missions) or (c) 7-week missions in C-135B aircraft (overfrequent transoceanic and transcontinental flying). The adrenal medulla (judging by urinary epinephrine) consistently showed flight-sensitivity, but other endocrine-metabolic functions varied in ways indicative of adaptation. With flight circumstances standardized (particularly with respect to time of day), flight effects tended to be reproducible. With crew rest limited to 2 days, recovery from flight-stress tended to be incomplete. Sleep-deprivation and crew position were shown to be factors which modify flight-stress reactions. Eastbound and westbound earth-circling missions did not induce different degrees of flight-stress, as judged by these endocrine-metabolic indices.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Physiological Body fluid anal. Experimental Flight test Flight simulator Flight test

Hale, H.B., Hartman, B.O., Harris, D.A., Williams, E.W., Miranda, R.E. and Hosenfeld, J.M. Time zone entrainment and flight stressors as interactants. Aerospace Medicine, 1972, 43, 1089-1094.

Physiologic responsiveness to flying was studied, using the members of a double-crew of a C-141 aircraft during six flights, each of which lasted 54 hours and involved bi- or tri-directional transmeridian flying. Responsiveness was quantified by means of endocrine-metabolic indices (urinary epinephrine, norepinephrine, 17-hydroxycorticosteriods, urea, sodium and potassium), using urine specimens which were collected at 4-hour intervals during the flight. Physiologic entrainment was shown to be a factor contributing to responsiveness, for there was rhythmic variability which related to time of day at the crews' home base. The waveforms, amplitudes, time relations and overall levels, however, did not agree with those of unstressed persons. As judged by epinephrine, norepinephrine and 17-OHCS, refractoriness toward flight stressors consistently developed at 2200 hours (Eastern Standard Time), even after the crew had crossed many time zones (flying either eastward or westward). These hormones indicated hyper-responsiveness regularly at 0600 hours EST; at other times responsiveness was shown (by these same indices) to be moderate in grade. Patterns emerged for the other indices as well.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Physiological Body fluid anal. Experimental Flight test Flight simulator Flight test

Hale, H.B., Hartman, B.O., Harris, D.A., Williams, E.W., Miranda, R.E., Hosenfeld, J.M. and Smith, B.N. Physiologic stress during 50-hour double-crew missions in C-141 aircraft. Brooks AFB, Texas: USAF School of Aerospace Medicine, SAM-TR-71-487, October, 1971.

By use of a battery of urinary techniques, the physiologic cost (stress) of prolonged C-141 flying operations (either staged or nearly-continuous) was shown to be mild-to-moderate in degree. Staged missions lasting 5 or 7 days tended to be less stressful than double-crew nearly-continuous 50-hour missions. The two extremely different work/rest schedules, namely, 4/4 and 16/16 hours, induced similar degrees of physiologic stress. Anticipatory stress tended to be higher than the flight stress that followed. Crew position was a contributory factor, slightly modifying flight and postflight trends. Pre-existing circadian periodicity persisted, although flight had modifying influence. Time of day that represented night at home were the times of highest sensitivity to flight. Recovery from prolonged nearly-continuous flying operations appears to require 4-5 days, and it appears to be a multiphasic process, with endocrine-metabolic depression appearing first, after which there was oscillation and final settling at the control level.

W/L Cat. Code: 4.1.12
Op. Behav. Code: 1., 2., 3., 4.

Physiological	Body fluid anal.	Experimental	Flight simulator Flight test	Flight simulator Flight test

Hale, H.B., Hartman, B.O., Harris, D.A., Williams, E.W., Miranda, R.E., Hosenfeld, J.M. and Smith, B.N. Physiologic stress during 50-hour double-crew missions in C-141 aircraft. Aerospace Medicine, 1972, 43, 293-299.

By use of a battery of urinary techniques, the physiologic cost (stress) of prolonged C-141 flying operations (either staged or nearly-continuous) was shown to be mild-to-moderate in degree. Staged missions lasting 5 or 7 days tended to be less stressful than double-crew nearly-continuous 50-hour missions. The two extremely different work/rest schedules, namely, 4/4 and 16/16 hours, induced similar degrees of physiologic stress. Anticipatory stress tended to be higher than the flight stress that followed. Crew position was a contributory factor, slightly modifying flight and postflight trends. Pre-existing circadian periodicity persisted, although flight had modifying influence. Time of day that represented night at home were the times of highest sensitivity to flight. Recovery from prolonged nearly-continuous flying operations appears to require 4-5 days, and it appears to be a multiphasic process, with endocrine-metabolic depression appearing first, after which there was oscillation and final settling at the control level.

W/L Cat. Code: 4.1.12
Op. Behav. Code: 1., 2., 3., 4.

Physiological	Body fluid anal.	Experimental	Flight simulator Flight test	Flight simulator Flight test

Hale, H.B., McNee, R.C., Ellis, J.P., Jr., Bollinger, R.R. and Hartman, B.O. Endocrine-metabolic indices of aircrew workload: An analysis across studies. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations AGARD-CP-146, April, 1974, A10-1 - A10-6.

Endocrine-metabolic measures have been used in field and laboratory studies involving different kinds of military aircraft as well as missions of varying nature and length. The data accumulated in the ten-year period have now been subjected to a cross-sectional analysis in an effort to ascertain the basic relation of endocrine-metabolic activity to the workload in either actual or simulated flights. For the present purpose, load represents degree of flight difficulty multiplied by duration. Difficulty was based upon USAF expert rankings, and duration was based upon fractions of a day. Multiple linear regression analysis was performed on data for urinary epinephrine, norepinephrine, 17-OHCS, urea, Na, K, and the Na/K ratio. This report presents the findings in the first phase of the cross-sectional study.

W/L Cat. Code: 1.1, 4.2
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Review	Flight simulator	Flight simulator
Physiological	Mult. measures		Flight test	Flight test

Hale, H.B., McNee, R.C., Ellis, J.P., Jr., Bollinger, R.R. and Hartman, B.O. Endocrine-metabolic indices of aircrew workload: An analysis across studies. Brooks AFB, Texas: USAF School of Aerospace Medicine, Unpublished report.

During the past decade the USAF School of Aerospace Medicine has conducted, under either field or laboratory conditions, studies of human responses to flight. The working hypothesis has been that flying operations act in the manner of stressors, eliciting interrelated endocrine-metabolic responses which are compensatory in nature, tending to maintain a state of physiologic balance (homeostasis). A battery of urinary determinations was used to assess the physiologic cost in a wide variety of circumstances, including flying operations of various types and durations which took place at various time of day and utilized a variety of aircraft. Statistical evaluation consistently indicated elevation in physiologic "cost" which apparently related to (a) type of aircraft, (b) flight complexity, (c) flight duration, (d) time of day, and/or (e) crew position. Additional factors also seemed to be contributory, affecting some or all of the endocrine-metabolic functions under study.

W/L Cat. Code: 1.1, 4.1.12
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Physiological	Body fluid anal.		Flight test	Flight test

Hale, H.B., Williams, E.W., Smith, B.N., and Melton, C.E., Jr. Excretion patterns of air traffic controllers. Aerospace Medicine, 1971, 42, 127-138.

Twenty air traffic controllers at O'Hare Airport, Chicago, Ill., were studied daily during two t-day work periods. During one of these periods they worked from 1500 to 2300 hours (evening shift); in the other period they worked from 2400 to 0800 hours (morning shift). Traffic density (workload) was maximal during the early part of the evening shift, and it was minimal during the early part of the morning shift. Stress appraisal was made by means of urinalysis, using a battery of determinations which included epinephrine, norepinephrine, 17-hydroxycorticosteroids, urea, inorganic phosphate, potassium and sodium. Direct relationship to workload was indicated for epinephrine, norephinephrine, urea, potassium and sodium. Urinary catecholamines provided evidence of sympathoadrenomedullary hyperactivity during each work shift, with full reversal in the 'postevening' recovery period and incomplete reversal in the 'postmorning' recovery period. Adrenocortical hyperactivity was evident only during the morning shift, and it was late in onset. Relatively high urea output characterized tower work, suggesting high protein catabolism.

W/L Cat. Code: 4.1.12
Op. Behav. Code: 1., 2., 3., 4.1

Physiological	Body fluid anal.	Experimental	Field	Flight simulator Flight test

Hull, T. J., Passey, G. E. and Meighan, T. W. Performance of vigilance and monitoring tasks as a function of workload. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratories, AMRL-TR-65-22, March, 1965. (AD 615 921).

This study investigated performance of 6 tasks. Three of these tasks were passive in nature, requiring only vigilance or monitoring by the operator for detection of a critical signal; these were: auditory vigilance, warning-lights monitoring, and probability meter monitoring. The other 3 tasks--arithmetic computations, target identification, and code-lock solving--required more active attention, and 2 of these tasks (target identifications and code-lock solving) were group tasks requiring interactions among the crewmembers. It was hypothesized that concurrent presentation of active and passive tasks would have a detrimental effect on vigilance and monitoring performance. The principal purpose of this study was the evaluation of vigilance and monitoring performance for 3 such tasks with and without simultaneous presentation of the more active tasks. On the basis of results obtained, the following conclusions seem justified: (1) Presentation of vigilance and monitoring tasks concurrently with tasks requiring more active attention of an operator has a detrimental effect on the operator's monitoring performance. (2) The detrimental effects of increased task load do not appear to be long-term in nature, since removal of the additional (active) tasks from the task program invariably resulted in recovery to previously attained performance on the vigilance and monitoring tasks.

W/L Cat. Code: 2.2.1, 2.2.2, 3.2
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Primary task	Subsidiary task Mult. measures	Experimental	Laboratory	Flight simulator Flight test

Hamilton, P. Process entropy and cognitive control In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 289-297.

While acknowledging the extreme imprecision of information theory formulation it has the twin merits of incorporating into our discussion of mental workload: (1) The contention that internalized thought as well as the stock perceptual/motor skills experiment must be made the province of the workload theorist. (2) Some overdue acknowledgement of the role of effort, or intensive processes, in a field which has had for too long as its goal the portrayal of man as computer.

W/L Cat. Code: 2.1.2

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Inform. theory	Construct	None	Flight simulator

Harris, D.A., Pegram, G.V. and Hartman, B.O. Performance and fatigue in experimental double-crew transport missions. Aerospace Medicine, 1971, 42, 980-986.

Six experimental transport missions using a double crew were flown in a C-141 on routes generating various combinations of long and short legs. Crews followed a 4/4 or 16/16 work/rest schedule. On-board crew-rest facilities were provided so that the plane could fly through the airlift system without crew changes. The flying time averaged around 43 hours. Performance was evaluated by ratings made by an on-board flight examiner. There were no significant differences in flight examiner ratings. Subjective fatigue was measured by a rating scale. There were not significant differences related to work/rest cycles. There were significant differences related to mission profile and crew position. Sleep EEG's were recorded on the two navigators. There was a marked reduction in total sleep as well as Stage 1-REM and deep sleep.

W/L Cat. Code: 1.1, 4.1.5
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Physiological	EEG			Flight test

Harris, R. L., Sr., Mixon, R. W. Advanced transport operation effects on pilot scan patterns. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29 - November 1, 1979, 347-351.

Long straight-in and close-in, curved, descending instrument approaches were made in NASA's fixed-base Terminal Configured Vehicle simulator. The pilot either manually controlled the simulator or monitored the automatic system control of the simulated aircraft during the approach. Tests were performed with or without the display of traffic. The results indicate that the pilots' use of the Electronic Horizontal Situation Indicator (EHSI) increased appreciably for the close-in, curved, descending approach compared to the conventional straight-in approach. When operating as a monitor of the autopilot system, the pilot scanned more with less attention devoted to the Electronic Attitude Direction Indicator (EADI). The pilots preferred the manual mode. The addition of displayed traffic to the EHSI increased the pilots' use of the EHSI. Also, the pilot's pupil diameter increased during the landing flare indicating a higher stress level even though the tests were conducted in a fixed-base simulator.

W/L Cat. Code: 1.2, 4.1.7, 4.1.8
Op. Behav. Code: 1., 2., 4.

Opinion	Interview	Experimental	Flight simulator	Flight simulator
Physiological	Eye movement			Flight test
	Pupillary dia.			

Harris, S. D., North, R. A. and Owens, J. M. A system for the assessment of human performance in concurrent verbal and manual control tasks. Paper presented at the 7th Annual Meeting of the National Conference on the Use of On-Line Computers in Psychology, Washington, D.C., November 9, 1977.

A multi-purpose laboratory system incorporating a voice interactive terminal and graphic display system is described. The facility is designed to investigate some aspects of human performance of concurrent verbal and tracking tasks. The results of a pilot study showing decrements in dual-task performance are reported.

W/L Cat. Code: 2.2.2, 3.1, 4.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measure	Construct		Flight test
Physiological	Speech patt. anal.			

Hart, S. G. Time estimation as a secondary task to measure workload-attention sharing effect on operator performance. Proceedings of the Eleventh Conference on Manual Control, NASA-Ames Research Center, May 21-23, 1975, 64-77. (NASA TMX-62,464).

Variation in the length of time productions and verbal estimates of duration was investigated to determine the influence of concurrent activity on operator time perception. The length of 10-, 20-, and 30-sec intervals produced while performing six different compensatory tracking tasks was significantly longer, 23% on the average, than those produced while performing no other task. Verbal estimates of session duration, taken at the end of each of 27 experimental sessions, reflected a parallel increase in subjective underestimation of the passage of time as the difficulty of the task performed increased. These data suggest that estimates of duration made while performing a manual control task provide stable and sensitive measures of the workload imposed by the primary task, with minimal interference.

W/L Cat Code: 2.2.3
Op. Behav. Code: 1., 2., 4.

Spare m. capacity Time estimation Experimental Laboratory Flight simulation

Hart, S. G. A cognitive model of time perception. Paper presented at the 56th Annual Meeting of the Western Psychological Association, Los Angeles, California, April, 1976.

Four methods have been used extensively to measure individual's ability to estimate or produce specified intervals of clock time. The verbal estimation method requires that one vocalize a judgement of the duration of an operationally presented interval. The method of production requires operational production of an interval whose duration has been specified verbally. The method of reproduction requires the operational production of a standard interval that was operationally presented. The method of comparison involves a relative judgement between the durations of two operationally presented intervals. This paper reviews these methods.

W/L Cat. Code: 2.2.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Time estimation Construct None Flight simulator

Flight test

Hart, S. G. Pilot workload during final approach in congested airspace. Proceedings of the 1978 IEEE Conference on Decision and Control, San Diego, California, January 10-12, 1979, 1345-1349.

Time estimation has been proposed as a measure of pilot workload and it appears that the production method provides a useful measure. The verbal estimation method has also been investigated and it appears that it does not provide as sensitive a measure of workload as does the production method. Overestimation may either reflect boredom during the interval, or the fact that a great deal of activity was performed during the interval that was remembered. Underestimation may either reflect a feeling that time passed quickly because interesting activities were engaged in, or that so little activity was performed or remembered, that very little time passes.

W/L Cat. Code: 2.2.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Time estimation	Experimental	Flight simulator	Flight simulator

Hart, S. G. and McPherson, D. Airline pilot time estimation during concurrent activity including simulated flight. Paper presented at the 47th Annual Meeting of the Aerospace Medical Association, Bal Harbour, Florida, May, 1976.

Human factors researchers have sought an unobtrusive and minimally loading additional task that is sensitive to differences in flying conditions and aircraft instrumentation associated with complex piloting tasks. The present research was aimed at clarifying the functional relationships between the length and variability of time estimates and concurrent task variables. Time estimation is an unobtrusive and minimally loading task. The central tendency, variability, and shape of the distributions of time productions provide indices of concurrent task processing requirements. Thus, time estimates may prove useful to human factors researchers interested in comparing different combinations of displays and controls associated with complex piloting tasks.

W/L Cat. Code: 2.2.2, 2.2.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Time estimation	Experimental	Flight simulator	Flight simulator
Primary task	Single measure			Flight test

Hart, S.G., McPherson, D., Kreifeldt, J. and Wempe, T.E. Multiple curved descending approaches and the air traffic control problem. Moffett Field, California: National Aeronautical and Space Administration, Ames Research Center, NASA TM-78, 430, August, 1977.

The concepts investigated in this study included: 1) multiple curved descending final approaches, 2) parallel runways certified for independent and simultaneous operation under IFR conditions, 3) closer spacing between successive aircraft, and 4) a distributed management system between the air and ground. Piloted simulators were supplied with computer generated traffic situation displays and flight instruments. The controllers were supplied with a terminal area map and digital status information. Intercrossing time variability was greater under centralized, ground-based management, than under distributed, pilot-spaced management. Pilots and controllers also reported that the distributed managem was more orderly than the centralized management. Flying precision increased as the amount of turn required to intersect the outer marker decreased. Pilots preferred the alternative of multiple curved descending approaches with wider spacing between aircraft. Both pilots and controllers felt that parallel runways were acceptable.

W/L Cat. Code: 1., 2.2.3, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Questionnaire			Flight test
Primary task	Time estimation			
	Single measures			

Hart, S. G., McPherson, D., and Loomis, L. L. Time estimation as a secondary task to measure workload: summary of research. Proceedings of the Fourteenth Annual Conference on Manual Control, April 25-27, 1978, University of Southern California, Los Angeles, 693-712. (NASA Conference publication 2060, Ames Research Center, Moffett Field, California.)

Actively produced intervals of time were found to increase in length and variability, whereas retrospectively produced intervals decreased in length, although they also increased in variability with the addition of a variety of flight-related tasks. If pilots counted aloud while making a production, however, the impact of concurrent activity was minimized, at least for the moderately demanding primary tasks that were selected. The effects of feedback on estimation accuracy and consistency were greatly enhanced if a counting or tapping production technique was used.

W/L Cat. Code: 2.2.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Time estimation	Experimental	Flight simulator	Flight simulator

Hart, S. G. and Simpson, C. A. Effects of linguistic redundancy on synthesized cockpit warning message comprehension and concurrent time estimation. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 309-321. (NASA TM X-73 170).

The relative amounts of attention required to comprehend and recognize two types of speech messages that differed in linguistic redundancy were evaluated with two concurrent time estimation tasks. Two-word and sentence-length synthesized-speech cockpit warning messages were presented to 12 commercial airline pilots with and without competing weather broadcast. The pilots had two tasks: a) to read back and write down the warning messages and b) to give two types of time estimates. It was found that the intelligibility of messages presented in a redundant sentence-length format was higher, and that listening time and number of repetitions was less, during the Familiarization Phase. Sentences were also more intelligible than two-word messages when presented in a background of competing weather broadcast for recognition. Differences in verbal estimates of session length and in the length of 10-sec estimates produced by pilots indicated that messages presented in a sentence format required less attention for comprehension than did two-word messages.

W/L Cat. Code: 2.2.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Time estimation	Experimental	Laboratory	Flight simulator
				Flight test

Hartman, B. O., Hale, H. B. and Johnson, W. A. Fatigue in FB-111 crewmembers. Aerospace Medicine, 1974, 45, 1026-1029.

Fifteen biomedically dedicated missions of 8 h duration were flown in the FB-111 as part of its initial operational evaluation. Each two-man crew provided data on subjective fatigue, discomfort, efficiency, and pre- and post-mission sleep. In addition, urine samples obtained from one crew on an unusually demanding mission were analyzed for epinephrine, norepinephrine, 17-hydroxycorticosteroids, sodium, potassium, and urea. The data showed that the crews experienced moderate fatigue and stress, aggravated by physical discomfort, from which they recovered after one night of sleep.

W/L Cat. Code: 1.1, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Rating scale	Experimental	Flight test	Flight simulator
Physiological	Body fluid anal.			Flight test

Hartman, B. O., and McKenzie, R. E. (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979.

This AGARDograph represents an overview of workload assessment. It is current in the sense that each chapter is a condensation or modification of recent papers, prepared by individual authors. The measurement domain has been broken into sensory threshold function tests, motor function and responses to psycho, physio and chemical excitation. The methodology includes a wide range of instrumentation, laboratory, inflight measurement and modeling methods, with the goal of compiling systematically and evaluating the multiplicity of approaches and techniques.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	Flight simulator	Flight simulator
Spare m. capacity		Construct	Flight test	Flight test
Primary task		Experimental		
Physiological				

Hartzell, E. J. Helicopter pilot performance and workload as a function of night vision symbologies. Paper presented at the Conference on Decision and Control, December, 1979, Fort Lauderdale, Florida.

The experiment reported was designed to assess pilot performance, training requirements, and workload as a function of the three symbologies. Pilot workload is addressed in this paper. The results of the time estimation techniques used supported the predicted levels of difficulty designed into the flight scenario. Time estimation provided a relative scale of workload between the hover maneuvers and suggests that there is no significant difference in workload between the three symbology types studied.

W/L Cat. Code: 2.2.3, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Time estimation	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Hatsell, C. P. An information theoretic human operator model. Conference Record, Annual Asilomar Conference on Circuits, Systems, and Computers, Pacific Grove, California, November, 1976. North Hollywood, California: Western Periodicals Co., 1977, 479-483.

By applying information theoretic concepts to control theory, a human operator model is developed which describes the effect of stress on the operator in terms of a partitioning of total information processed by the operator. The model requires very little a priori imposed structure and is consistent with the frequently observed phenomenon of catastrophic failure of the human operator at some critical level of stress.

W/L Cat. Code: 2.1.2, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Inform. theory	Construct	Laboratory	Flight simulator
Primary task	Math. model	Experimental		

Hawkins . L., Church, M., and deLemos, S. Time-sharing is not a unitary abil . Eugene, Oregon: University of Oregon, Center for Cognitive and Perceptual Research, Technical Report No. 2, June 30, 1978, (AD A056 632).

The . objective of the three experiments reported here was to further our under dings of the nature of these limitations. The results of the experiments lead to he conclusion that time-sharing is not a single general ability, but rather dependent upon several more specific processing limitations. These include: (1) an inability early in practice to simultaneously select, or retrieve, multiple responses from memory; (2) a persisting inability to initiate multiple independent responses simultaneously; (3) an inability to process, or at least efficiently process, contiguous inputs from separate modalities owing to the need for modality-specific attentional focus; and (4) an inability to efficiently process multiple inputs from within the same modality owing to the existence of structural interference. It is suggested that the prediction of performance on complex criterion task combinations such as entailed in piloting or air traffic control requires specification of which of these component abilities is required by the criterion situations.

W/L Cat. Code: 2.2., 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Hawkins, H. L. Rodriques, E., and Raicher, G. M. Is time-sharing a general capability? Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 532-535.

The time-sharing ability of subjects was measured under eight separate dual-task conditions. Three distinct task characteristics were systematically varied across conditions in an effort to manipulate the nature of the specific time-sharing demands imposed. Each condition contained two of these characteristics in common with three of the remaining seven conditions, one of the characteristics in common with three others, and none in common with the last condition. Time-sharing efficiency correlated across conditions that impose similar processing demands on the individual, but not across conditions imposing relatively dissimilar demands. We conclude that time-sharing performance under present conditions is determined by several poorly correlated, task-specific subcapacities rather than by a single general ability.

W/L Cat. Code: 2.2.1, 3.1

Op. Bheav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures

Hayashi, E. and Ogawara, Y. A study of the workload of shear line inspectors based on eye-movement analysis. Journal of Human Ergology, 1977, 6, 121-126

The workload involved in inspecting surface defects of cut sheets in a flying shear-line used in the steel industry was studied. The effects of various factors such as workplace conditions and operational and human factors on the visual inspection performance was investigated according to the type and nature of surface defects to be inspected. The results revealed that both pursuing and saccadic eye movements were essential in identifying defects. The pursuing movements apparently played a major role in finding defects on the running steel sheets, while saccadic movements took place at very high rate near the upper limit of eye movements of 3.3 times per second. The line speed was a decisive operational factor for the inspection performance. Further, effects of other factors including defects per se, duration of inspection, and duration of inspection and eye-to-defects distance were studied. The results were suggestive to reducing the inspection workload and establishing optimum conditions for future automation and mechanization of the line inspection.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2.

Physiological Eye movements Experimental Field Background

Helander, M. G. Physiological reactions of drivers as indicators of road traffic demand. In Driver performance studies: Transportation Research Record 530. Washington, D.C.: U.S. Transportation Research Board, Technical Report TRB/TRR-530, 1975, 1-17.

Sixty drivers, all accustomed to a certain make of car, performed test drives along a certain test road. A digital tape recorder was used for real-time recording of the driver's physiological characteristics (electrodermal response, heart rate, and muscle activity), steering, and braking; the vehicle response (accelerations in three directions, velocity, and distance traveled); and traffic events as coded by the experimenter. The characteristics of the test road were measured in the field. Average responses were calculated for the test road, and significant covariations were demonstrated by using the physiological measures as the dependent variable and vehicle behavior on the road as the independent variable. It was also found that the difficulty of a traffic event affects both the driver's brake use and physiological responses. Stress-inducing road characteristics are downhill grades and short sight distances. It is suggested that the driver's capacity to process information varies flexibly as task demand changes. Sudden increases in task demand can be leveled out by modeling the road environment, and this makes the driver more competent at dealing with hazardous situations.

W/L Cat. Code: 3.1, 4.1
Op. Behav. Code: 1., 2., 4.

Primary task | Multiple | Experimental | Field | Flight simulator
Physiological | | | | Flight test

Helm, W.R. Human factors test and evaluation, functional description inventory as a test and evaluation tool development and initial validation study. Volume I and II. Patuxent River, Maryland: U.S. Naval Air Test Center, SY-77R-75, September, 1975.

A new evaluation method was adapted to assist in field testing of the human factors aspects of aircraft man-machine systems. The method is known as the Functional Description Inventory (FDI) and requires a series of investigations analyzing the operational functions of the crew members. The method as tested consists of a series of investigations analyzing the operational functions of each S-3A crew member, with an essential part involving the determination of roles, duties, and tasks performed by each crew member. Next, crew members' judgments were compiled on how important these roles, duties, and tasks are for mission success, how frequently they are performed on a typical mission, how adequate the training has been to insure effective performance of the task, and finally how effective the system is in accomplishing these operational functions. Analysis of roles, duties, and tasks across these four dimensions provides, to a certain degree, an in-depth evaluation of the interrelated problem within the man-machine system. The FDI as developed for the S-3A aircrew has potential as a tool for providing quantifiable assessment of the human factors aspects of aircraft man-machine system.

W/L Cat. Code: 1.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion | Rating scale | Experimental | Flight test | Flight simulator
| | | | Flight test

Helm, W.R. Human factors evaluation of model P-3C UPDATE I airplane: Third interim report. Patuxent River, Maryland: U.S. Naval Air Test Center, SY-122R-75, February 1976.

An evaluation of the P-3C UPDATE I aircraft was conducted to determine the workload implications resulting from design modifications. A method known as the Functional Description Inventory (FDI) was used. This method requires a series of investigations analyzing the selected operational functions of specific P-3C crew members, with an essential part involving the determination of roles, duties, and tasks performed. Next, crew members' judgments were compiled on how important these roles, duties, and tasks are for mission success. It was concluded that for the SENSO 1 and SENSO 2 the design modifications produced a moderate increase in system effectiveness but operator workload requirements were increased substantially; for the SENSO 3 the design modifications produced substantial improvements in system effectiveness while substantially reducing operator workload; and for the TACCO the design modifications produced improved system operation.

W/L Cat. Code: 1.1, 2.1.1, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Construct	None	Flight simulator
Spare m. capacity	Task comp., time assess.			
Primary task	Single measures			

Helm. W.R. Function description inventory as a human factors test and evaluation tool: An empirical validation study. Patuxent River, Maryland: U.S. Naval Air Test Center, SY-127R-76, July, 1976.

The Function Description Inventory (FDI) is a new assessment methodology. In this study the method was modified to augment the traditional human factors engineering field testing on the S-3A airplane. The FDI requires a series of investigations analyzing the operational functions of crewmembers, with an essential part involving the determination of roles, duties, and tasks performed by each crewmember. Subsequent to this analysis, crewmembers' judgments were compiled on how important these roles, duties, and tasks were for mission success, how frequently they were performed on a typical mission, how adequate the training had been to insure effective performance of the task, and finally, how effective the system had been in accomplishing these operational functions. The problems identified by the FDI were then compared to the actual engineering deficiencies reported during the BIS Trials for the S-3A aircraft. The FDI identified the same systems and related problems in which numerous design deficiencies were reported.

W/L Cat. Code: 1.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator Flight test

Helm, W. R. The application of computer aided evaluative techniques to system test and evaluation. Proceedings of the 21st Annual Meeting of the Human Factors Society, San Francisco, California, October, 1978, 92-94.

Adequate assessment of operator workload in a complex system requires a substantial testing program which in turn yields large amounts of data. The different pieces of data regarding operator workload have different relative importance in terms of implications for required decisions such as system redesign or compensatory training. Since no single metric exists that summarizes the data along the relevant dimension, a means must be employed to gather and organize data in a comprehensive fashion that facilitates decision making about such factors. This paper reports on the feasibility of the application of computer aided evaluative techniques in combining precise pieces of test information into summary measures at differing levels of generality to facilitate decisions about operator workload and system acceptability.

W/L Cat. Code: 1.1, 2.1.1, 3.2

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Mult. measures	Construct	None	Flight simulator
Spare m. capacity				
Primary task				

Henry, P.H., Davis, T.Q., Engelken, E.J., Triebwasser, J.H. and Lancaster, M.C. Alcohol-induced performance decrements assessed by two link trainer tasks using experienced pilots. Aerospace Medicine, 1974, 45, 1180-1189.

The degrading effects of ethanol on performance of two separate tasks developed around the Link GAT-1 trainer were studied in 12 USAF instructor pilots. The subjects were tested at three alcohol dose-levels. Statistically significant performance decrements were found for only the moderate and high alcohol doses. The magnitudes of the decrements corresponded closely to those reported for previous experiments using the same test conditions but with subjects who had no previous flying experience. An assessment of the operational significance of the performance measuring scales was also attempted through the use of special questionnaires and by concurrent rating of performance by flight examiners. Limits were established for decrement scores indicative of an operationally significant hazard.

W/L Cat. Codes: 1.1, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Herman, L. M. Study of the single channel hypothesis and input regulation within a continuous, simultaneous task situation. Quarterly Journal of Experimental Psychology, 1965, 17, 37-46.

Subjects performed simultaneously on an auditory tracking and an auditory discrimination task, with each task presented to a separate ear. Information transmitted in the tasks was measured as a function of ability to predict task characteristics, input information-rate, and input discriminability. Based on comparison of single- versus simultaneous-task performance, support was found for a single, central decision-type channel in information processing, having as one primary limit the rate at which information can be accepted. Discriminability of inputs also was found to be a limit on information processing rate. Although ability to predict a task's characteristics facilitated performance on that task, in this experiment it did not result in facilitation of performance in the second task.

W/L Cat. Code: 2.2.1, 2.2.2, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Hess, R. A. and Teichgraber, W. M. Error quantization effects in compensatory tracking tasks. IEEE Transactions on Systems, Man, and Cybernetics, 1974, SMC-4, 343-349.

Experiments were performed to determine the effect of error signal quantization on human operator compensatory tracking performance. Single-axis, dual-axis, and cross-coupled critical tracking tasks were utilized with a variety of quantization formats. The controlled element dynamics were chosen to force the operator to incorporate varying amounts of lead equalization. The single- and dual-axis critical tasks served as sensitive indicators of display format effects, with single-axis task yielding information concerning the operator's effective time delay while tracking. The cross-coupled task allowed measurement of the operator's attentional workload margin while using error quantized displays. The results indicate increased operator time delays and attentional workload when using the quantized displays.

W/L Cat. Code: 2.2.5, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures Flight test

Hickok, J. H. Grip pressure as a measure of task difficulty in compensatory tracking tasks. Master's thesis, Naval Postgraduate School, Monterey, California, September, 1973. (AD 769 744).

The feasibility of utilizing the grip pressure exerted on a rigid control stick as a measure of tracking task difficulty was investigated. A device was engineered to measure grip pressure independent of control force. A hybrid computer was used to produce the tracking tasks necessary in the research and on-line data computation. Compensatory tracking tasks using K/s, $K/s(s+2)$ and K/s^2 controlled elements provided the difficulty levels, from easiest to most difficult. Results indicate that grip pressure increases significantly with task difficulty as the operator attempts to reduce his effective time delay. However, grip pressure also appears to be dependent upon the "gain" which a human adopts in a particular tracking task. This gain-related grip pressure may not be related to task difficulty.

W/L Cat. Code: 3.1, 4.1.9

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Muscle tension			Flight test

Hicks, J. A., III and Soliday, S. M. An evaluation of sinus arrhythmia as a measure of mental load. In W. B. Knowles, M. Sanders, and F. Muckler (Eds.) Proceedings of the Sixteenth Annual Meeting of the Human Factors Society, 1972, 191-196.

The primary purpose of this investigation was to provide an evaluation and validation of sinus arrhythmia as a measure of mental workload. Sinus arrhythmia refers to the irregularity in the length of the inter-beat intervals found in the heart rate pattern of a normal individual sitting at rest. Previous research had indicated that this irregularity disappears as a function of the mental load imposed on the individual. A secondary purpose of this investigation was to compare the sinus arrhythmia approach to estimating mental workload with a secondary task loading technique.

W/L Cat. Code: 2.2.2, 4.1.10

Physiological: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulation
Physiological	Heart rate, h.r. var.			

Hicks, T.G. and Wierwille, W.W. Comparison of five mental workload assessment procedures in a moving-base driving simulator. Human Factors, 1979, 21, 129-143.

Five methods of measuring mental workload (secondary task performance, visual occlusion, cardiac arrhythmia, subjective opinion rating scales, and primary task performance) were compared for sensitivity to changes in operator loading. The driving task was produced using an automobile driving simulator with a six-degree of freedom computer generated display, a four-degree of freedom physical motion system, and a four-channel sound system. Subjects were presented with a within-subjects factor of wind gust placement. The results showed significant differences among workload levels for subjective opinion scales and primary performance measures of lateral deviation, yaw deviation, and steering reversals. A relative sensitivity estimate of these would be, from highest to lowest sensitivity, steering reversals and yaw deviation, rating scales, and lateral deviation. The techniques of occlusion, cardiac arrhythmia, and secondary task performance yielded no significant workload effect.

W/L Cat. Code: 1.1, 2.2.1, 2.3, 3.2, 4.1.10
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Simulator	Flight simulator
Spare m. capacity	Subsidiary task			Flight test
Primary task	Occlusion			
Physiological	Mult. measures			
	Heart rate			
	h.r. var.			

Hilgendorf, E. L. Information processing, practice, and spare capacity. Australian Journal of Psychology, 1967, 19, 241-251.

The relationship between information input and response time was studied during extended practice, using visual stimuli of up to ten bits of information per stimulus. Response time was found to be directly related to information input and the relationship was found to persist after practice, contrary to findings reported in several recent studies. On the final trial a secondary auditory task was introduced. Performance on this task was inversely related to the information content of the primary task, which showed a significant decrement when both tasks were performed concurrently. Five hypotheses derived from earlier work are examined in the light of the results obtained.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Hinton, D. A. and Shaughnessy, J. D. Adaptation of time-line analysis program to single pilot instrument flight research. Hampton, Virginia: National Aeronautics and Space Administration (Langley Research Center), NASA-TM-78748, August, 1978.

A data base was developed for SPIRF operation and the program was run. The outputs indicated that further work was necessary on the workload models. In particular, the workload model for the cognitive channel should be modified as the output workload appears to be too small. Included in the needed refinements are models to show the workload when in turbulence, when overshooting a radial or glideslope, and when copying air traffic control clearances.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Laboratory	Flight simulator

Hoffman, E. R. and Joubert, P.N. The effect of changes in some vehicle handling variables on driver steering performance. Human Factors, 1966, 8, 245-263.

The literature on vehicle handling is summarized. Experiments were carried out to determine the effect of vehicle response time, steering gear ratio, and near- and far-sight distances on driver performance on a tracking task consisting of driving through a narrow winding course marked by traffic cones. The vehicle response time was found to affect greatly the number of cones touched by the vehicle during a set testing time. Increasing near-sight distance produced poorer driver performance. This also occurred for the case of decreasing far-sight distances with fixed near-sight distance. Tests with variations of steering ratio and steering torque produced little change in driver performance. Spare mental capacity was measured during the test period. For this indirect measurement of task difficulty, changes in the spare mental capacity of the driver were found to have the same sensitivity to changes in the vehicle, as did the change in the number of cones touched by the vehicle.

W/L Cat Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Field	Flight simulator
Primary task	Single measures			Flight test

Holden F.M., Rogers, D.B. and Replogle, C.R. Simulation of high workload operations in air to air combat. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD-CP-146, April, 1974, A6-1 - A6-4.

General methods and techniques for predicting the mission effectiveness of candidate systems in the preliminary design stage and predicting the human operator's subjective preference for the candidate designs are not generally available. For those techniques which have been used, with some success, there exists the question of validation and general applicability. This report discusses the problems associated with workload measurement, provides a structure for the study and analysis of human performance and describes the tools and techniques used by the 6570th AMRL/EM to provide effectiveness versus design data.

W/L Cat. Code: 3.3
Op. Behav. Code: 2.2, 4.2

Primary task   Math. model   Experimental   Flight simulator   Flight simulator

Holland, M. K. and Tarlow, G. Blinking and mental load. Psychological Reports, 1972, 31, 119-127.

The rate of blinking is related to certain mental activities. One common feature of states associated with low blink rates is the presence of concentrated cognitive activity. The purpose of the present study was to determine how blinking is affected by variations in mental load; it was hypothesized that, for a given nonvisual task, blinking would decrease as mental load increased. The first study reported here manipulated memory load by requiring Ss to retain a sequence of 4, 6, or 8 digits. The second study involved mental arithmetic under time pressure; half the trials contained zeros in the sequence of numbers to be summed. In both studies the rate of blinking was low when mental load was high and the rate was high when mental load was low. It is speculated that blinking may disrupt certain cognitive processes and may therefore be inhibited when these processes are active. When mental load is increased, the inhibition of blinking may be an adaptive mechanism which protects vulnerable cognitive processes from interference.

W/L Cat. Code: 3.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Primary task   Single measures   Experimental   Laboratory   Flight simulator

Physiological   Eye movement

Hopkin, V. D. Mental workload measurement in air traffic control. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 381-385.

Most possible measures of mental workload have been proposed and tried in air traffic control but have not proved to be helpful. This note outlines some of the current practical problems in assessing mental workload in air traffic control, while emphasizing the vital need to have impartial quantitative measures for doing so, both to ensure the safety and efficiency of future systems and to design jobs which have an optimum blend of workload, utilization of skill, and job satisfaction.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3.

Opinion	Multiple	Construct	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Hopkin, V. D. and Napier, A. W. Time estimation in a flight simulator. Farnborough, Hants, England: RAF Institute of Aviation Medicine, IAM-R-232, 1963.

Subjects made their own unaided estimate of time while performing simulated manoeuvres. The entire flight plan had a demanded time of 40 minutes. Each subject performed the whole flight task twice. In one case he was instructed to take all the demanded time to complete each manoeuvre and to set his rate of change accordingly. In the other case he was told to complete the manoeuvres as quickly as possible and then to maintain that position until he thought the demanded time had elapsed since the beginning of the manoeuvres. Deviations from the demanded height, heading and time were used as performance criteria. It was found that time estimates were related to the complexity of the demanded flight manoeuvres, to the subject's previous experience with a flight simulator and to the instructions given, but errors in the time estimation did not relate systematically to the length of the demanded time.

W/L Cat. Code: 2.2.3, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Time estimation	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Hosman, R. J. A. W. Pilot's tracking behavior under additional workload. Delft, The Netherlands: Delft University of Technology, Department of Aeronautical Engineering, Report UTH-199, June, 1975.

An experiment to study the influence of task interference on the information processing of the human pilot is described. Two hypothetical limited capacity models of human information processing, the multi-channel model and the single-channel model, are reviewed and the results of the experiment are discussed in relation to these models. The experimental task consisted of a single axis tracking task under additional workload. The three controlled elements used were a simulated transport aircraft at three different center of gravity positions, at which it was stable, neutral, and unstable, respectively. The forcing function was a gust signal acting on the simulated aircraft. The additional loading task was an auditory binary choice task. The results of the experiment tend to favor the single-channel model of human information processing.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Howells, R. A., Knight, J. L., Jr., Weiss, S. M. Micro-timesharing within a single task. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 523-526.

In continuous, reciprocal Fitts' Law tapping, movement timing and spatial accuracy control may be considered as two micro-tasks within an overall psychomotor task. Usually, timing demands are secondary while the spatial accuracy is stressed. In an experiment in which both timing and spatial demands were manipulated and equally important, subjects were required to divide available attention between these performance dimensions. Results are discussed in terms of current time-sharing models.

W/L Cat. Code: 2.1.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Inform. theory Experiment Laboratory Background

Primary task Single measures

Howitt, J. S. Flight-deck workload studies in civil transport aircraft. Proceedings of the AGARD Conference on Measure of Aircrew Performance, AGARD-CP-56, December, 1969, 1-1 - 1-7.

The term 'Work Load Study' can be interpreted in many ways depending on one's particular interest and point of view. During the past four years a small team has been conducting field studies in civil airlines during both long-haul and short-haul operations. The team have found such studies can be conveniently divided into three main areas: (1) that associated with short term, or instantaneous workload; (2) that associated with accumulated effects of workloads over a particular period; and (3) that associated with the total working environment. Some of the methods used and the indications for further areas of research are discussed.

W/L Cat. Code: 1.1, 2.1.1

Op. Behav. Code: 2.

Opinion	Rating scale	Review	Field	Flight simulator
Spare m. capacity	Task comp time assess.			Flight test

Howitt, J. S., Hay, A. E., Shergold, G. R., and Ferres, H. M. Workload and fatigue-in-flight EEG changes. Aviation, Space and Environmental Medicine, 1978, 49, 1197-1202.

Continuous recordings were made of the EEG and ECG of one pilot during a series of instrument flights in a feeder-type transport aircraft. The flights were arranged to contain epochs of distinctly differing levels of workload. Some flights were made after a night of sleep deprivation and others were made as the second and third flights of the day. Subjectively, there appeared to be marked differences in performance between the two types of tired flight. The EEG analyses showed changes that correlated well with differences in workload. In the highest workload areas during fresh flights, EEG activity increased by approximately a factor of 4 over that of the preflight resting values. This large increase did not occur in the tired flights.

W/L Cat. Code: 1.2, 4.1.3, 4.1.5

Op. Behav. Code: 1., 2., 4.

Opinion	Questionnaire	Experimental	Flight test	Flight simulation
Physiological	EEG			Flight test
	EKG			

Huddleston, J. H. F. Personality and apparent operator capacity. Perceptual and Motor Skills, 1974, 38, 1189-1190.

Twenty-four adults were required to perform a pursuit tracking task and given the opportunity to accept a concurrent second one as soon as they felt themselves capable of doing so. Personality tests showed that the more anxious individuals delayed acceptance of this secondary task. No relationships were found between personality and tracking skill as such.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Flight simulator

Primary task   Single measures

Huddleston, H. F. and Wilson, R. V. An evaluation of the usefulness of four secondary tasks in assessing the effect of a lag in simulated aircraft dynamics. Ergonomics, 1971, 14, 371-380.

Eight male subjects were required to perform a tracking task using an electronic windshield display. The task had two levels of difficulty, an essentially unlagged condition and a condition, chosen to be perceptibility more difficult, having an exponential lag of 0.5 sec. Integrated tracking error scores alone were unable to distinguish between the two difficulty levels. Four secondary tasks were utilized involving a response to digits presented in the forward field of view. The four tasks were arranged to be of comparable difficulty level in pretests using the same subjects. Two secondary tasks indicated a difference between the primary task conditions. The addition of a secondary task also permitted tracking error scores themselves to indicate a difference.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Flight simulator

Primary task   Single measures   Flight test

Hughes, H. M., Hartman, B. O., Garcia, R. and Lozano, P. Systems simulation: A global approach to aircrew workload. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD-CP-146, April, 1974, A1-1 - A1-14.

Aircrew workload can be studied at many different levels of detail. In the most general sense, it is a function of the total workload imposed upon a unit in relation to the number of crews in that unit. An airlift system simulation program has been designed using this global approach and a number of simulation studies have been performed. Outcomes in terms of systems effectiveness measures, crew workload, and crew welfare measures are presented.

W/L Cat. Code: 2.1.1

Op. Behav. Code. 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Flight simulator	Flight simulator
		Experimental		Flight test

Hurst, M. W. and Rose, R. M. Objective workload and behavioral response in airport radar control rooms. Ergonomics, 1978, 21 559-565.

Previous research indicated that peak traffic and the duration of radio-communications were good predictors of behavioural response of air traffic controllers working in air route traffic control centres. In this study we investigated if these two measures of workload were generalizable to controllers (ATCs) working in radar facilities serving major airports. 3,110 observations were made on radar sectors at the [illegible] ra[illegible] control rooms in the U.S.A. A large number of air traffic variables and communication tasks were measured. Behavioural ratings were made by expert observer ATC's. The results replicated previous findings that peak traffic and the duration of radio-communications functioned as behavioural stressors. Careful consideration of these and other results led to the conclusion that peak traffic is the most generalizable environmental stressor for ATC's behaviour whereas the other workload measures are more correctly viewed as concomitants.

W/L Cat. Code: 1.1, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion	[illegible]ing [illegible]e	Experimental	Field	Flight simulator
Primary task	Single measures			

Hurst, M. W. and Rose, R. M. Objective job difficulty, behavioral response, and sector characteristics in air route traffic control centres. Ergonomics, 1978, 21, 697-708.

Observations on 47 radar sectors in Boston and New York were used to determine the principal behavioral stressors in the air traffic control environment. Predictor variables included peak traffic, mean airspeed, sector area. Sector type, radio-communication time, and theoretically derived control load factors. Expert observers rated the degree of activity and behavioral arousal of ATCs working the 47 radar sectors at the same time the objective measures were made. These 'pace' ratings were significantly related to peak traffic count and duration of radio-communications. The control load factors were not related to behavioral responses. Statistical analyses indicated several refinements for the definition and measurement of the control load factors. For example, airspace control load was reliably estimated by sector type and number of transitioning planes, while co-ordination control load was most appropriately estimated by during of radio-communications. The results suggest that estimation of workload may be made by a relatively few objective measures.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Opinion | Rating scale | Experimental | Field | Flight simulator

Primary task | Single measures

Hutcherson, R. C. Statistical analysis of steroid levels in parotid secretions of humans under prolonged mental stress. Master's thesis, Texas A & M University, College Station, Texas, December, 1971. (AD 747 682).

Ten subjects of approximately the same age, size and education group, were exposed to an unchanging mental stress for a two hour period. Using sour candies to stimulate parotid gland activity, parotid fluid samples were collected at thirty minute intervals. Statistical analysis of the steroid levels showed that there was no significant change in cortisol levels in parotid fluid over the two hour sampling period.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2.

Physiological | Body fluid anal. | Experimental | Laboratory | Background

Hyndman, B. W. and Gregory, J. R. Spectral analysis of sinus arrythmia during mental loading. Ergonomics, 1975, 18, 255-270.

A technique is presented for digitally processing cardiac intervals to produce the low-pass filtered cardiac event sequence (LPFCES), a regularly sampled (in time) band-limited signal, representing in a standard form the information contained in the cardiac intervals. The technique takes into account the physiological mechanisms of information transfer across the pacemaker, and thereby produces a signal that has a physiological counterpart: autonomic activity converging on the sino-atrial node. The scoring technique is shown to give a reliable indication of mental loading (and possibly reserve capacity) in decision-making tasks. Possible mechanisms of reduced sinus arrythmia with mental loading are explored.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2.

Physiological	Heart rate, h.r. var.	Experimental	Laboratory	Flight simulator

Inbar, G. F. and Eden, G. Psychological stress evaluators: EMG correlation with voice tremor. Biological Cybernetics, 1975, 24, 165-167.

Temporal measurements of frequency changes in the human voice and tremor in the muscles of the vocal area suggest that these phenomena are correlated. A measure of muscular activity was obtained using a non linear filter on the EMG wave. Frequency changes were detected in the third formant of the voice spectrum. The crosscorrelation results indicate that the voice vibrations are forced oscillations generated by central nervous activity, explaining the detection of stress from voice records.

W/L Cat. Code: 4.3

Op. Behav. Code: 1., 2., 3.

Physiological	Speech patt. anal.	Experimental	Laboratory	Background

Inomata, O. An evaluation of heart rate variability in different levels of mental loading. Journal of Human Ergology, (Studia Psychologica), 1977, 6, 208-210.

Six adult male subjects took part in visual search work demanding four levels of short-term memory. The task was to delete one, two, three, or four kinds of numerals included in a table of 300 two-digit numerals which were randomly arranged in 10 rows. Of 300 numerals, 60 were to be deleted. Those sixty numerals consisted of a single two-digit number in task W1, two numbers in task W2, three numbers in task W3, and four numbers in task W4. Of the four indices, only the irregularity score decreased significantly as the task difficulty increased. This would mean that particular rhythms in heart rate fluctuation could be more sensitive to mental strain than other aspects of heart rate changes. Thus, for application of the evaluation method, exclusion of heart rate fluctuations triggered by physical movements or other external factors seems necessary. In addition, the large inter-individual differences in changes of heart rate variability should be properly taken into consideration.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Phsyiological	Heart rate, h.r. var.	Experimental	Laboratory	Flight simulator

Ioseliani, K. K. Time deficit as a stress factor during an operator's mental activity in the man-flight vehicle system. Kosmicheskaia Biologiia i Meditsina, 1971, 5, 40-43. (In Russian.)

The efficiency in handling combinations of control signals on a panel was evaluated in experiments with a group of 250 healthy subjects performing various task sequences under stress due to time pressure. According to the quality of their operational behavior the subjects were graded in a high performance group of 135, a medium performance group of 95, and a low performance group of 20, with 8 subjects being too hasty and 12 subjects being too slow in the last group.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., times assess.	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Isreal, J. B., Chesney, G. L., Wickens, C. D., and Donchin, E. P300 and tracking difficulty: evidence for multiple resources in dual-task performance. Psycholophysiology (in press).

Subjects performed a visual tracking task while performing a concurrent task in which tones were covertly counted. The P300 component of the event-related potentials elicited by the tones was examined to determine the extent to which its amplitude was affected by variations in the forcing-function bandwidth, or difficulty, of the tracking task. P300 decreased in magnitude when tones were counted in conjunction with the performance of the tracking task, relative to a single-task counting condition. Increasing tracking difficulty failed to reduce P300 amplitude further. A second experiment obviated the possibility that movement-related potentials caused the P300 attenuation resulting from the introduction of the tracking task. In the third experiment, subjects performed a reaction time task in conjunction with tracking to establish the validity of the tracking difficulty manipulation. The results are interpreted in terms of a theory or functionally-specific processing resources.

W/L Cat. Code: 2.2.1, 4.1.6
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Physiological ECP

Isreal, J. B., Wickens, C. D., Chesney, G. L., and Donchin, E. The event-related brain potential as an index of display-monitoring workload. Human Factors (in press).

As an index of task workload, the possible advantages of the event-related brain potential (ERP) over traditional secondary task and physiological measures are described and previous efforts to validate the use of ERPs in this context are discussed. An experiment is then reported in which perceptual load, incurred by monitoring a simulated air-traffic control display for discrete events, is assessed using (a) measures of the P300 component of ERPs elicited by auditory probe stimuli, and (b) a reaction time secondary task. The ERP measures were found to reflect systematically differences in task workload and to vary in agreement with the reaction time measure. The results are discussed within the framework of a multi-dimensional conception of human processing resources and task workload.

W/L Cat. Code: 2.2.1, 3.1, 4.1.6
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures

Phsyiological ECP

Isreal, J. B., Wickens, C. D., and Donchin, E. The event-related brain potential as a selective index of display load. Proceedings of the 23rd Annual Meeting of the Human Factors Society, October 29-November 1, 1979, Boston, Massachusetts, 558-562.

As an index of task workload, the possible advantages of the event-related brain potential (ERP) over traditional secondary task techniques and psychophysiological measures are described and previous efforts to validate the use of ERPs in this context are discussed. A series of six experiments is then reported in which the effects of tracking difficulty and display-monitoring load manipulations on secondary-task reaction time and ERP measures are compared. The results are interpreted within the framework of a "multiple reservoir" conception of processing resources and task workload.

W/L Cat. Code: 2.2.1, 3.1, 4.1.6

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Review	Laboratory	Flight simulator
Primary task	Single measures	Experimental		
Physiological	ECP			

Ivanov-Muromskii, K. A. and Lukianova, O. N. Man in the state of operational stress. Fiziologiia Cheloveka, 1975, 1, 459-568. (In Russian.)

The paper investigates the activity and functional state of individuals under conditions of operational stress induced by time deficit in carrying out a number of algebraic operations. Best results are obtained by the testees characterized by a high lability of nerve processes. In the case where the operation is carried out under conditions of sound noise, selection of operator requires an individual with a high lability and with a high-intensity nervous system with respect to stimulation. Human stress condition is shown to entail changes in functional state, which is reflected in a substantial change in the parameters of different systems in the human body.

W/L Cat. Code: 2.1.1, 3.1, 4.1

Op. Behav. Code: 1., 2.

Spare m. capacity	Multiple	Experimental	Laboratory	Flight simulator
Primary task		Construct		
Physiological				

Jahns, D. W. Operator workload: What is it and how should it be measured? In K. D. Cross and J. J. McGrath (Eds.) Crew System Design. Santa Barbara, California: Anacapa Sciences, July, 1973.

The term "operator workload" generally refers to an integrative concept for evaluating the effects on the human operator associated with the multiple stresses occurring within man-machine operating environments. Viewing the human operator's role in man-machine systems as that of an information transfer and transformation component, a case is made for considering workload as consisting of three functionally relatable aspects: input load, operator effort, and work result. Workload measuring techniques having their basis in time-and-motion analyses, information processing experiments, and direct physiological measurement of the operator state are briefly discussed. The initial conceptualizations of a long-range research program are indicated, where the objective is the systematic investigation of operator effort exerted relative to specifiable input loads and performance criteria.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Jahns, D. W. A concept of operator workload in manual vehicle operations. Meckenheim, Germany: Forschungsinstitut für Anthropotechnik, Report No. 14, 1973.

A conceptual structure (or model) of operator workload relying on the data available in workload literature is presented. The interrelationships among various workload assessment techniques including time-and-motion, information processing, operator activities, and equipment design studies are pointed out systematically. It is concluded that each of the aspects of workload: input load, operator effort, and work result, must be quantitatively scaled before the complex problem of task interference and crew system design criteria in vehicle operations can be treated comprehensibly.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Jenney, L.L., Older, H.J. and Cameron, B.J. Measurement of operator workload in an information processing task. Washington, D.C.: National Aeronautics and Space Administration, Contractor's Report NASA CR-2150, December, 1972.

This was an experimental study to develop an improved methodology for measuring workload in an information processing task and to assess the effects of shift length and communication density (rate of information flow) on the ability to process and classify verbal messages. Each of twelve subjects was exposed to combinations of three shift lengths and two communication densities in a counterbalanced, repeated measurements experimental design. In addition to task-specific measures, subjects were administered a battery of perceptual-motor, cognitive and sensory tests on a pre- and post-shift basis. Physiological measures and subjective magnitude estimates of three workload variables were also obtained. Results indicated no systematic variation in task performance measures or in other dependent measures as a function of shift length or communication density This is attributed to the absence of a secondary loading task, an insufficiently taxing work schedule, and the lack of psychological stress. Subjective magnitude estimates of workload showed fatigue (and to a lesser degree, tension) to be a power function of shift length.

W/L Cat. Code: 1.1, 2.2.1, 4.1.1, 4.1.10

Op. Behav. Code: 1., 2., 3.

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
Spare m. capacity	Subsidiary task			Flight test
Physiological	Heart rate, h.r. var.			

Jennings, A. E. and Chiles, W. D. An investigation of time-sharing ability as a factor in complex performance. Human Factors, 1977, 19, 535-547.

Thirty-nine men were tested on a total of six tasks; performance was measured on each task presented individually and on two complex tasks made up of three-task subsets. A factor analysis performed on the resultant data revealed a factor that showed high loadings for two different monitoring tasks for complex performance but negligible loadings for these tasks for simple performance; separate, orthogonal factors were found for the two monitoring tasks when they were performed under simple-task conditions. The monitoring measures, thus, appear to possess properties that would be expected of measures of a time-sharing ability.

W/L Cat. Code: 2.2.1, 2.2.3, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Jex, H. R. Two applications of a critical-instability task to secondary work load research. IEEE Transactions on Human Factors in Electronics, 1967, HFE-8, 279-282.

This exploratory application of the critical task concepts to the secondary workload problem results in the following main conclusions. 1) A subcritical task makes an easily quantifiable secondary task, whose attentional demand (measured by secondary control activity) is directly, but not linearly, related to the degree of instability. 2) The autopaced critical task score decreases with increasing secondary task instability, and may be used as an alternative index of the secondary task loading. 3) Three very experienced pilots (astronaut candidates) all showed similar decrements in performance with secondary task instability, implying that the effects might be standardized. 4) There was evidence of discrete control actions and display scanning, but the onset of secondary control changes seemed more related to the secondary task error rate and direction rather than the error's magnitude or nearness to the display limit. The gross control motion was, nevertheless, proportional to the delayed error, as predicted.

W/L Cat. Code: 2.2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Jex, H. R. A proposed set of standardized sub-critical tasks for tracking workload calibration. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 179-188.

A set of subcritical tracking tasks are proposed as one portion of a future standardized battery of different types of tasks, each having graded levels of mental workload, against which various investigators could calibrate and validate their measures of workload. This paper provides the recommended task description, mechanization, inputs, operating procedures and evaluation criteria so that measurements made in different locations can be validly made.

W/L Cat. Code: 2.2.5, 3.3.

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Adaptive tracking	Construct	None	Flight simulator
Primary task				Flight test

Jex, H. R. and Allen, R. W. Research on a new human dynamic response test battery. Part I. Test development and validation. Proceedings of the 6th Annual NASA-University Conference on Manual Control, Wright-Patterson AFB, Ohio, April, 1970, 743-766.

A battery of autopaced critical-instability tasks, subcritical tracking tasks, and step reaction-time tests was developed to permit efficient measurement of the limiting human dynamic response properties. Standard test parameters for first-, second-, and third-order controlled elements (the latter requiring double load equalization) are given. Comprehensive "baseline" measurements were made on four well-trained subjects (three were pilots) using a specially built Controlled Element Computer and an on-line Describing Function Analyzer. The resulting data includes: tracking errors, describing functions (and derived loop closure and model-fitting parameters), remnant, critical instabilities, and reaction times. Remarkably simple correlations are shown between the critical instability and various other closed-loop dynamic performance metrics. These tests and results constitute the foundation for a series of continuing experiments on effects of environmental stresses and workload.

W/L Cat. Code: 2.2.5, 3.2, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Math. model Flight test

Jex, H. R. and Allen, R. W. Research on a new human dynamic response test battery. Part II. Psychophysiological correlates. Proceedings of the 6th Annual NASA-University Conference on Manual Control, Wright-Patterson AFB, Ohio, April, 1970, 767-777.

During a comprehensive set of tracking tasks for three orders of controlled element with four trained subjects (reported separately), a number of simultaneous psychophysiological measurements were taken. These included: electrocardiogram, "instantaneous" heart-rate, breath flow, electromyograms, average grip pressure, and palmar skin resistance. These data showed consistent increases in the neuromuscular tension indicators during tracking. Breathing was usually faster and shallower. The average heart rate increased for only two of the four subjects, but distinct increases in the cardiac "sinus arrhythmia" were noted, which were completely correlated with breath flow.

W/L Cat. Code: 4.1.2, 4.1.3, 4.1.4, 4.1.9, 4.1.10, 4.1.11

Op. Behav. Code: 1., 2., 4.

Physiological Multiple Experimental Laboratory Flight simulator

Flight test

Jex, H. R. and Clement, W. F. Defining and measuring perceptual-motor load in manual control tasks. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 125-177.

Basic concepts for defining and measuring the "mental workload" in simple and complex tracking-type tasks are reviewed. The basic concept is that subjective mental effort can only be meaningfully defined in terms of its margin with respect to some form of control-workload limit. The internal allocation of attentional resources to maximize the margin of capacity is assumed to be under the control of a supervisory "meta-control-system." Means for measuring the "excess control capacity" are described (especially the Critical Instability Task and Cross-Coupled-Instability Task), and their application to workload research and practical evaluations of pilot/vehicle/display systems is summarized. Extensions to discrete task workload are discussed, along with implications of sampling errors on task workload and performance. Some examples of psychophysiological measures during tracking tasks are given.

W/L Cat. Code: 1., 2., 4.

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Review	Laboratory	Flight simulator
Spare m. capacity				Flight test
Physiological				

Jex, H. R., Jewell, W. F. and Allen, R. W. Development of the dual-axis and cross-coupled critical tasks. Proceedings of the Eighth Annual Conference on Manual Control, University of Michigan, Ann Arbor, Michigan, May 1972, 529-552.

Multiaxis offspring of the well-established single-axis Critical Instability Task are described. The Dual-Axis Critical Task requires the operator to stabilize simultaneously two identical, increasingly unstable, controlled elements (one in each axis), using identical control and display gains. The dual-axis score, λ_D, is the level of instability at which control is lost in either axis. Pilot experiments show that λ_D is a sensitive indicator of display format and control stick effects. The Cross-Coupled-Instability Task involves any arbitrary primary control task (which may itself be multiloop), with a "subcritical" secondary task whose instability level is adaptively cross-coupled to the primary task performance index. The cross-coupled score, λ_X, is the asymptotic level of secondary task instability, which is shown to be sensitively related to the attentional workload margin of the primary task. Subtle initializing and adaptive logic were needed to permit a single mechanization to handle a wide variety of primary tasks and individual skill levels. Some early applications of these tasks are reviewed.

W/L Cat. Code: 2.2.5, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Jex, H.R., McDonnell, J.D. and Phatak, A.V. A "critical" tracking task for man-machine research related to operator's effective delay time. Proceedings of the 2nd Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, March 1966, 361-377. (NASA-SP-128).

A closed-loop compensatory tracking task has been developed which yields a measure of the human operator's time delay characteristics while tracking, constrains his behavior to within very narrow limits, and provides a low variability indicator of the operator's tracking ability. The procedure is called the critical task because the operator is required to stabilize an increasingly unstable controlled element up to the critical point of loss of control. Based on recent human response research, a theoretical analysis of this man-machine system is performed, and the results of an experimental program are described, which enables describing function and critical task measures to be compared. An "autopaced" critical task mechanization and operating procedure is described which yields consistent, reliable, and very low variance measurements of the critical levels of instability. An analysis of the measured human operator describing functions shows that, when operating near criticality, the subject's behavior is adequately represented by the most recent human-operator describing-function models and adaptation laws.

W/L Cat. Code: 2.2.5, 3.3
Op. Behav. Code: 1., 2., 4.2

Spare m. capacity	Subsidiary task	Construct	Laboratory	Flight simulator
Primary task	Math. model	Experimental		

Johannsen, G. Nebenaufgaben als Beanspruchungsmessverfahren in Fahrzeugführungsaufgaben. Zeitschrift für Arbeitswissenschaft, 1976, 30, 45-50.

A conceptual differentiation between input load and operator effort is stated. Workload measures are contrasted to the performance measures. Methods for workload measurement are classified. Secondary tasks for workload measurement are dealt with extensively and marginal conditions are explained which have to be considered in using secondary tasks. Examples given for secondary tasks are the tapping task, choice reaction tasks and cross-adaptive secondary tasks. Recent results using the tapping task as workload indicator in simulated 6 (grad) landing approaches are presented. The irregularity in tapping increases more, when the primary task gets more difficult.

W/L Cat. Code: 2.2., 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	Flight simulator	Flight simulator
Primary task	Single measures	Experimental		Flight test

Johannsen, G. Workload and workload measurement. In N. Moray (Ed.) *Mental workload: its theory and application*. New York: Plenum Press, 1979, 3-11.

Workload is defined and various measures are classified in terms of time-line analysis, information processing, operator activating-level, and subjective effort ratings. An application-oriented procedure of workload assessment and relationships among measuring techniques are presented.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Johannsen, G., Pfendler, C. and Stein, W. Human performance and workload in simulated landing-approaches with autopilot-failures. In T. B. Sheridan and G. Johannsen (Eds.) *Monitoring behavior and supervisory control*. New York: Plenum, 1976, 83-95.

A fixed-based simulator of a small STOL-aircraft was used to assess a simulated instrument-landing-system (ILS) with autopilot failures of a stability augmentation system (SAS). Various control and monitoring task configurations were evaluated in terms of pilot workload measures and deviations from glidepath. Both subjective pilot ratings on a five point workload rating (WLR) and a tapping task for perceptual motor load (PML) were used to assess workload. The results showed reduced performance and increased workload immediately after failure detection and manual take over.

W/L Cat. Code: 1.1, 2.2.2

Op. Behav. Code: 1.1, 2.2, 4.2

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Subsidiary task			Flight test

Johnston, D. E., Klein, R. H., and Hoh, R. H. Manual and automatic flight control during severe turbulence penetration. Hawthorne, California: Systems Technology, Inc. TR-1049-1, (Final Report, NASA-CR-2677), April, 1976.

An analysis and experimental investigation of possible contributing factors in jet aircraft turbulence upsets was conducted. Major contributing factors identified included autopilot and display deficiencies, the large aircraft inertia and associated long response time, and excessive pilot workload. An integrated flight and thrust energy management director system was synthesized. The system was incorporated in a moving-base simulation and evaluated using experienced airline pilots. The evaluation included comparison of pilot workload and flight performance during severe turbulence penetration utilizing four control/display concepts. Simulation results show improved performance, reduced pilot workload, and a pilot preference for an autopilot system controlling to - flight director command, and manual control of thrust following the trim thrust director.

W/L Cat. Code: 1.1, 3.1, 3.3
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Construct	Flight simulator	Flight simulator
Primary task	Single measures	Experimental		Flight test
	Math. model			

Jones, E. C., Jr. and Schuster, D. H. Design and development of an adaptive, auditory, and distractive stressor. IEEE Transactions on Man-Machine Systems, 1970, MMS-11, 161-163.

An auditory, distractive stressor was developed that automatically adjusts its rate of presenting random digits to human subjects. The rate of digit presentation serves as an inverse index of the amount of attention the subject can spare from a primary task, such as driving a simulated car. The auditory pattern recognition of the device was evaluated under several speaking conditions and for a variety of human speakers. The distractive stressor has a satisfactory digit recognition accuracy, and consequently adapts its digit presentation rate quickly according to how well a subject repeats its given numbers.

W/L Cat. Code: 2.2.4

Op. Behav. Code: 2.1, 4.2

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator

Joslin, R., Ohmiya, H., and Ellis, D. R. A study of simplified methods for longitudinal control decoupling. Society of Automotive Engineers, Reprint number 770468, March, 1977.

Using an inflight simulator, a simple longitudinal decoupling concept was compared with conventional airplane characteristics for the approach and landing tasks. The decoupling system allowed the pilot to command flight path angle changes with the stick with little or no accompanying speed change; likewise, speed changes with only small accompanying flight path changes could be made with throttle only. The unique feature of the concept is that it is an open loop control system. Results indicate that in calm air and up to moderate levels of turbulence the decoupling system provides a su[illegible] reduction in pilot workload.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 1., 2., 4.2

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Single measures			Flight test

Juris, M. and Velden, M. The pupillary response to mental overlaod. Physiological Psychology, 1977, 5, 421-424.

The hypothesis that the pupil constricts below base level in situations of mental overload was tested. Subjects had to perform in a four-alternative forced-choice task at 75%, 100%, and 125% the speed of their maximum processing capacity. No indication of a pupillary constriction in the overload situation was found. The pupil dilated under all three conditions. The pupil diameter of male subjects significantly decreased after the sharp increase at the beginning of the experimental phases, while the female subjects' pupil diameter remained at the same level after the initial increase. The amount of dilation depended on information load for male subjects only.

W/L Cat. Code: 4.1.8

Op. Behav. Code: 1., 2., 4.1

Physiological	Pupillary dia.	Experimental	Laboratory	Flight simulator
				Flight test

Kahneman, D. Attention and effort. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1973.

This book deals with the basic issues in the study of attention and effort. Chapter 1 describes an integration of the intensive and selective aspects of attention. Chapter 2 and 3 discuss some intensive aspects of attention and elaborate on the capacity model of attention and mental effort. Chapter 4 is devoted to looking behavior. Some variants of selective attention are discussed in Chapter 5, which presents a model of the role of attention in perception. A brief review of attention to attributes in Chapter 6 is followed by a more thorough review of focused and divided attention with simultaneous inputs (Chapters 7 and 8). The division of attention between simultaneous or immediately successive speeded responses is discussed in Chapter 9. Chapter 10 returns to the concept of effort and its measurement by task interference.

W/L Cat. Code: 2.2, 3.1

Op. Behav. Code: 1., 2.

Spare m. capacity	Subsidiary task	Review	Laboratory	Background
Primary task	Single measures	Construct		
		Experimental		

Kahneman, D., Beatty, J. and Pollack, I. Perceptual deficit during a mental task. Science, 1967, 157, 218-219.

Subjects monitored for a visual signal while engaged in a demanding mental task. The probability of detecting the signal depends on the time of its presentation during the 8 seconds of the task. A similar time course is observed for failures to detect and for changes of pupil size. Momentary variations in the load that the task imposes on the subject are reflected in both indices. Detection failures are not explained by the pupillary changes.

W/L Cat. Code: 2.2.1, 4.1.8

Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Physiological	Pupillary dia.			Flight test

Kahneman, D., Tursky, B., Shapiro, D. and Crider, A. Pupillary, heart rate, and skin resistance changes during a mental task. <u>Journal of Experimental Psychology</u>, 1969, <u>79</u>, 164-167.

Subjects performed a paced mental task at three levels of difficulty, while time-locked recordings of pupil diameter, heart rate, and skin resistance were made. A similar pattern of sympatheticlike increase was found in the three autonomic functions during information intake and processing, followed by a decrease during the report phase. The peak response in each measure was ordered as a function of task difficulty.

W/L Cat. Code: 4.1.2, 4.1.8, 4.1.10

Op. Behav. Code: 2.

Physiological	GSR	Experimental	Laboratory	Flight simulator
	Pupillary dia.			
	Heart rate, h.r. var.			

Kalsbeek, J. W. H. Objective measurement of mental workload: Possible applications to the flight task. <u>Proceedings of the 55th AGARD Conference</u>, Amsterdam, The Netherlands, 1968, 4.1 - 4.6.

Methods and techniques are developed and applied in simulation experiments to evaluate cockpit workload. Heart beat irregularity patterns are scored as a function of the number of signals per minute answered by six subjects in a laboratory test situation. Distraction stress is evaluated in relation to the step-by-step disintegration of writing performance. A description is given of the mental task simulator which is applied to cockpit design.

W/L Cat. Code: 4.1.10, 4.1.13

Op. Behav. Code: 1., 2.

Physiological	Heart rate h.r. var.	Experimental	Laboratory	Flight simulator
	Handwriting anal.			Flight test

Kalsbeek, J. W. H. Measurement of mental work load and of acceptable load: Possible applications in industry. International Journal of Production Research, 1969, 2, 33-45.

In the assessment of mental workload in which consideration of human brain as an input-output system of information-handling is a prerequisite, the effect of the central choice making system being the weakest link is demonstrated, using a binary choice generator. It was found that increasing the number of binary choices per minute diminished the irregularity of the rest pattern (sinus arrhythmia) without affecting the level of heart rate. A simple scoring method for the use of sinus arrhythmia is put forward and different tasks are scaled according to the progressive suppression of sinus arrhythmia.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 2.

Physiological	Heart rate h.v. var.	Experimental	Laboratory	Flight simulator

Kalsbeek, J. W. H. Standards of acceptable load in ATC tasks. Ergonomics, 1971, 14, 641-650.

Mental load in ATC tasks is described as the brain controlling the controller's controlling performance. A moment of conscious brain control is put forward as a unit to quantify this kind of mental load. New action programs are supposed to require conscious brain control at every step of their execution; with routine this would be less and less the case. The duration of a moment of conscious control varies according to the complexity of the control to be exercised and the number of considerations which have to be taken into account. Propositions are made on how to think about selective attention, identification and cognitive processes in terms of executing programs. A job description method is put forward in terms of such executing programs. Why moments of conscious brain control as units are more suited to the problem of mental load than are units like bits, choices and decisions is discussed. Experiments are described with physiological and psychological variables as a function of the number of moments of conscious brain control per minute.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator

Kalsbeek, J.W.H. Do you believe in sinus arrhythmia? <u>Ergonomics</u>, 1973, <u>16</u>, 99-104.

Problems raised by the use of heart rate irregularity as a dependent variable in experiments are described. Referring to experimental results it is argued that mental load is not an indivisible concept. In laboratory studies a binary choice task is often used to provide the level of mental load as an independent variable. This kind of task is dependent on the capacity of the single channel function. Other types of informational load are conceivable. Special attention is given to the phenomenon of <u>peak load</u>. Finally, heart rate variability is accepted as an indicator of the proportional occupation of an individual's single channel capacity during rest and work. A plea is made that it is necessary to be very careful in using terms like <u>the</u> sinus arrhythmia and <u>the</u> mental load and in using heart rate variability in field applications.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Review	None	Flight simulator
				Flight test

Kalsbeek, J. W. H. Sinus arrhythmia and the dual task method in measuring mental load. In W. T. Singleton, J. G. Fox, and D. Whitfield (Eds.) <u>Measurement of Man at Work</u>. London: Taylor and Francis, 1973, 101-113.

The heart rate pattern of normal healthy subjects sitting at rest is irregular. Momentary irregularity of up to ten or fifteen beats per minute can occur. In the medical literature this phenomenon is generally referred to as sinus and respiratory arrhythmia. If one concentrates one's attention on a perceptual motor task the irregularity of the heart rate pattern tends to disappear as a function of the number of signals per minute one has to deal with. The mean heart rate, however, changes little if at all.

W/L Cat. Code: 2.2, 4.1.10, 4.1.13

Op. Behav. Code: 1., 2.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Kalsbeek, J.W.H. and Sykes, R.N. Objective measurement of mental load. Acta Psychologica, 1967, 27, 253-261.

Two main lines of research are mentioned: 1) the detailed study of deterioration of performance caused by what has been called "distraction stress"; 2) physiological measurements as functions of increasing quantity of information handled. Regarding the first, a simple repetitive task serves to distract the subject from his carrying out a normal task by occupying his information handling capacity. Regarding the second line the best physiological parameter was the scored regularity of the heart rate pattern. The following aspects of the dual task situation are studied: 1) the effect of training and instructions; 2) the effect of increasing demands in the primary task in a dual task situation.

W/L Cat. Code:	2.1.1, 2.2.1, 3.1, 4.1.10, 4.1.13			
Op. Behav. Code:	1., 2., 4.1			
Spare m. capacity	Multiple	Experimental	Laboratory	Flight simulator
Primary task				Flight test
Physiological				

Kantowitz, B. H. and Knight, J. L., Jr. Testing tapping time-sharing. Journal of Experimental Psychology, 1974, 103, 331-336.

A Fitts' law tapping task was combined with a serial digit-naming task having four levels of stimulus-response complexity. Baseline data were also established for tapping and naming tasks performed singly. In simultaneous-task performance, an increase from 3.9 to 10 bits/sec required by the tapping task was accompanied by a decrease in performance on the naming task. When single- and simultaneous-task performance were both analyzed, an interaction between tapping and naming was obtained, supporting a limited-capacity channel. However, when only simultaneous-task performance was evaluated, effects of tapping and naming were additive, supporting a stage model of information processing. Results stressed the processing demands of a response execution and control stage.

W/L Cat. Code:	2.2.1, 2.2.2, 3.1			
Op. Behav. Code:	1., 2., 4.1			
Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Kantowitz, B. H. and Knight, J. L., Jr. On experiments-limited processes. Psychological Review, 1976, 83, 502-507.

Norman and Bobrow have proferred a distinction between data-limited and resource-limited processes. This paper notes some limitations in the application of their framework to data, especially data obtained from dual-task timesharing experiments. Four issues are discussed: (a) the need for single-stimulation baseline control data, (b) problems in the definition of data-limited processes with strong signals, (c) empirical difficulties in distinguishing movement along a performance operating characteristic (POC) from movement between POCs, and (d) the utility of distinguishing between macro- and micro- POCs. Consideration of these issues increases the efficacy of Norman and Bobrow's distinction.

W/L Cat. Code: 2.2, 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Spare m. capacity	Subsidiary task	Construct	None	Background
Primary task	Single measures			

Kantowitz, B. H. and Knight, J. L., Jr. Testing tapping timesharing, II: auditory secondary task. Acta Psychologica, 1976, 40, 342-362.

Two experiments were conducted to extend earlier time-sharing results of Kantowitz and Knight. The simultaneous performance of a paced tapping task and a digit-naming task with auditorally presented digits was required in dual-task conditions. Single-task conditions required only tapping or naming. When a verbal naming response was required (Experiment 1) additivity between tapping and naming was obtained for single- vs. dual-task comparisons and for dual-task comparisons. When the naming response was made by moving a lever (Experiment 2) the additivity for only dual-task comparisons remained while an interaction was obtained for single- vs. dual-task comparisons. Results support a hybrid processing model with serial and parallel arrangements of stages.

W/L Cat. Code: 2.2.1, 2.2.2, 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Kantowitz, B.H. and Knight, J.L., Jr. Testing tapping timesharing: Attention demands of movement amplitude and target width. In G.E. Stelmach (Ed.) Information Processing in Motor Learning and Control. New York: Academic Press, 1977.

A dual task methodology was used to assess attention demands of movement amplitude and target width in a discrete target tapping task. The purpose was to determine if the secondary task, involving digit naming performance, is dependent upon the manner in which the Index of Difficulty (Fitts) was manipulated. It was found that the digit naming scores remained essentially the same whether amplitude or width was changed. It is concluded that the index of difficulty is a better measure of attentional demand than is an index involving a number of movements.

W/L Cat. Code:	2.2.2, 3.1			
Op. Behav. Code:	1.1, 2.1, 4.1			
Primary task	Single measures	Experimental	Laboratory	Flight simulator
Spare m. capacity	Subsidiary task			Flight test

Kantowitz, B. H. and Knight, J. L., Jr. When is an easy task difficult and vice versa? Acta Psychologica, 1978, 42, 163-170.

Lane has argued that Kantowitz and Knight incorrectly predicted an interaction between primary and secondary task difficulty for the variable-allocation model of attention. It is shown that such an interaction is indeed obtained if task-performance difficulty is defined in terms of capacity and only reasonable transformations of data are permitted. This interaction holds for any set of monotonic resource operating characteristics.

W/L Cat. Code:	2.2, 3.1			
Op. Behav. Code:	1., 2., 3., 4.			
Spare m. capacity	Subsidiary task	Review	None	Background
Primary task	Single measures	Construct		

Kelley, C.R. Design applications of adaptive (self-adjusting) simulators. Proceedings of the 2nd Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, March, 1966, 379-401. (NASA SP-128).

Adaptive simulators have been previously applied to problems of training. This study explores their usefulness for manual control system design. The history and development of the field of adaptive vehicle simulation is reviewed. The technique of adaptation most suitable for design studies is one in which operator performance is kept at a preset criterion level by means of adaptive changes in task difficulty. The performance criterion used to measure operator performance is important in adaptive as well as nonadaptive simulation. Time-on-target scores were analyzed and found to be excessively imprecise. The recommended performance criterion for many applications is rms error in one axis and vector error in two or more independent axes. Adaptive system changes are a compromise between speed of adjusting to change in operator performance and stability of the adaptive level achieved. Example design data are presented. The relation of each design variable to forcing function amplitude, with operator error constant, is described for the example task.

W/L Cat. Code: 2.2.4, 2.2.5
Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Kelley, C. R. and Wargo, M. J. Cross-adaptive operator loading tasks. Human Factors, 1967, 9, 395-404.

Performance measures often fail to indicate the amount of effort expended by an operator in reaching various levels of task performance. Secondary or loading task techniques have been developed to overcome this problem. However, with the loading task technique, a problem of interpretation arises when both primary and secondary task measures vary with operator performance. The cross-adaptive operator loading technique, which automatically adjusts the difficulty level of the loading task on the basis of primary task performance, is suggested as a solution to this problem. Data are presented which demonstrate that the cross-adaptive technique effectively standardizes scores on the primary task while casting all the variance in performance to the loading task scores. The cross-adaptive secondary scores thereby become a single unambiguous and sensitive index of effort expended to reach a pre-established level of task performance. Procedures for the implementation of the cross-adaptive technique are discussed and guidelines for its use are suggested.

W/L Cat. Code: 2.2.4, 2.2.5, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures

Kennedy, J. P. Time-sharing effects on pilot tracking performance. Master's thesis, Naval Postgraduate School, Monterey, California, September, 1975. (AD A016 378).

Subjects were required to perform simultaneously a two-dimensional tracking task and respond to a set of lights with toggle switches. Five levels of difficulty and two stimulus presentation rates were involved in the secondary task. The purpose of the experiment was to examine time-sharing performance of experienced military pilots and to investigate differences in performance by pilots of different types of aircraft. Analysis of the data collected from 20 subjects showed that correlation between elements of a complex task is weak, performance levels drop as task load increases, and there was only one difference found between any of the pilot type groups. Dual-crew fighter/attack jet pilots took significantly longer to respond to stimuli when time-sharing.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Kennedy, R. S. Two procedures for applied and experimental studies of stress. Ft. Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, 70-11 NAMI 1099, February, 1970.

To compensate for the low reliability of physiological manifestations of sympathetic nervous system activity two methods are offered. The first method requires a major research program by which a valid criterion of stress would be determined by experimentation, and then predictors of this criterion would be obtained empirically by correlational techniques. These predictors could then be crossvalidated. By using the predictors, the influences of psychological stress and physiological stress could be separated. Whether a functional relationship exists between the magnitude of the response to stress and the probability of its occurrence could then be determined. The second method is similar but less exact. It has been used successfully in motion sickness studies and avoids the necessity of a long exploratory program with numerous pilot studies. A procedure for the control and the regulation of the perception of the magnitude of the stress to the organism (human and infrahuman) is offered for use with the two methods. The lack of suitable control of this factor is discussed in connection with previous research.

W/L Cat. Code: 4.1

Op. Behav. Code: 1., 2., 4.

Physiological	Multiple	Construct	None	Flight simulator
				Flight test

Kennedy, R. S. Bioelectric indicants of diver's ability to perform useful work. Paper presented at the Undersea Medical Society Workshop, Bethesda, Maryland, March, 1978. (AD A060 675).

In the future increasing demands will be made of the diver for information processing and decision making. It was hypothesized that a neglected indicant of an operator's ability to perform useful work in air is eye movement activities. It was felt that aspects of eye movements could provide a useful index of the level of invormation processing or mental load of a diver and secondly, that research into eye movements might aid us in understanding better the effects of the physical environment experienced by a diver. This paper reports recent research in air between eye movements and performance. The findings are positive and offer promise that spectral analysis of eye movement velocities could provide valid early indication of behavioral dysfunction in compressed gas and under water.

W/L Cat. Code: 3.1, 4.1.7

Op Behav. Code: 1., 2.

Primary task	Single measures	Experimental	Laboratory	Background
Physiological	Eye and eyelid movement			

Kerr, B. Processing demands during mental operations. Memory and Cognition, 1973, 1, 401-412.

Man possesses a central system of limited capacity. Theorists at first described this system as a single limited capacity channel. Two current theoretical alternatives to single-channel theory are (1) the undifferentiated capacity hypothesis that man possesses a pool of capacity units so that interference occurs only if the total number of capacity units that mental operations demand exceeds the system limit and (2) the hypothesis that some, but not all, mental operations require space in a limited capacity central mechanism and that any operation that requires space will interfere with any other operation that also demands space. Time on task fails as a sensitive measure of capacity demands because some task components require time but not full processing capacity. The secondary task technique uses the interference between a primary task and a secondary task to assess the extent to which the primary task makes processing demands on the central limited system. Processing demands have been measured for five categories of mental operation: (1) encoding, (2) multiple input, (3) rehearsal, (4) transformation, and (5) responding.

W/L Cat. Code: 2.2, 3.2

Op. Behav. Code: 1., 2., 4.

Spare m capacity	Subsidiary task	Review	None	Background
Primary task	Single measures	Construct		

Kikolov, A. I. Mental work and emotions. Moscow: Izdatel-stvo Meditsina, 1978. (In Russian.)

This book outlines the possibilities for the occurrence of informational neuroemotional stress and mental fatigue using the example of mental and emotional activity of individuals performing high-responsibility tasks, such as traffic controllers. Available data are used to formulate and refine the concept of neuroemotional overstress. Attention is given to a discussion of the characteristics of the development of overstress into a neurotic state upon exposure to chronic informational overload of the brain. A number of methodological approaches are described for assessing subjects engaged in emotionally stressed mental activity. Problems of diagnosis and estimation criteria for the functional state of the human organism exposed to emotional stress are discussed.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Background
Spare m. capacity		Construct		
Primary task				
Physiological				

Kirchner, J.H. and Laurig, W. The human operator in air traffic control systems. Ergonomics, 1971, 14, 549-556.

A system analysis of the air traffic control system with respect to its purpose and realization shows the role which the human operator plays. The task of man in this system is one of information processing. Evaluation of the operator's task is important for selection of personnel, for job evaluation, and for redesigning tasks and jobs. Evaluation of man's task can be regarded from the demands of the job or from their fulfillment and effect for man. Both aspects have to be connected to get objective results which are valid for man. Special research problems arise from the influence of the individual abilities and from the correlation of stress as a workload factor and strain as an effect of this workload on man.

W/L Cat. Code: 2.1., 3.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Background
Primary task	Math. model			

Klein, T. J. A workload simulation model for predicting human performance requirements in the pilot-aircraft environment. Paper presented at the 14th Annual Meeting of the Human Factors Society, San Francisco, California, October 13-16, 1970.

A computerized workload simulation model for relating system performance requirements to task performance requirements is discussed. The model, Continuous Assessment of Task Time-Stress (CATTS), affords a quantitative assessment of instantaneous operator time-stress expected during all segments of a specified aircraft mission. A unique feature of the model is its capability for determining continuous-control error-nulling rate requirements imposed upon the operator by aerodynamic and cockpit design characteristics, by the equations of motion of the aircraft, and by specified tolerances in the continuous-control channels. The paper also discusses the relationship of task difficulty to time-stress threshold levels, and how the model can be applied to multi-crew trade studies as well as to human-automatic functional mix trade-offs.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator

Klein, T.J. and Cassidy, W.B. Relating operator capabilities to system demands. Proceedings of the Sixteenth Annual Meeting of the Human Factors Society. Santa Monica, California, Human Factors Society, 1972, 324-334.

An exploratory study of operator proficiency in tasks analogous to piloting an aircraft is discussed. Task performance was measured while task difficulty (system workload demand) was varied from easy through moderate and hard levels. From these measurements, preliminary workload capability limits were derived for single and two-axis control tasks and for several combinational mixes of control and procedural tasks. The data also provided a basis for development of mathematical equations for (a) predicting work response levels from known system demands, (b) relating tracking accuracy to system workload demands and (c) combining tracking and procedural workload components.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator
Primary task	Single measures	Experimental		

Klein, T. J. and Hall, A. A. An analysis of pilot performance requirements in the A-7E tram. Dallas, Texas: LTV Aerospace, Vought Systems Division, VSD Report No. 2-542201 5R-5777, April, 1975.

This report was prepared by the Human Factors Group of Vought Systems Division, LTV Aerospace, to supplement the Preliminary A-7E TRAM Human Factors Report. The objective of the effort was to assess pilot workload relative to the A-7E TRAM and to compare it with the workload requirements encountered by the pilot during a typical A-7E attack mission. To meet that objective, a common CEP was chosen as the basis for comparison. Dive angles and air speeds are different between the day and night attack modes due to environmental conditions. The 20° night dive angle was used because it proved to be the most realistic and comfortable type of attack during preliminary simulation and flight testing.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator
Primary task	Single measures			

Kleinman, D. I. and Curry, R. E. Some new control theoretic models for human operator display monitoring. Proceedings of the 1976 IEEE Conference on Decision and Control Including the 15th Symposium on Adaptive Processes, Clearwater, Florida, December 1-3, 1976, 1023-1029.

Control theoretic techniques are applied to develop two new models for predicting human operator performance when monitoring an automatically controlled system. In one case it is assumed that the human monitors the instruments in order to rapidly detect failures. The second approach assumes that the instruments are sampled to best reconstruct the system status information. The relation of these models to existing prediction schemes, e.g. equal attention and the Sender's model is explored. It is concluded that a combination of failure detection and status estimation models offers the best potential for human operator application.

W/L Cat. Code: 2.1.2, 3.3

Op. Behav. Code: 1., 2.

Spare m. capacity	Inform. theory	Construct	None	Background
Primary task	Math. model			

Klotzbucher, E. and Roloff, D. The effect of mental work with and without time pressure on selected physiological functions. Zeitschrift fur die Gesamte Hygiene und Ihre Grenzgebiete, 1977, 23, 8-11. (In German).

Methods and results of calculation tests under time pressure with telemetric recording of cardiac and respiratory rates are described. There were no significant changes in cardiac rate and arrhythmia or in catecholamine excretion in tests with and without time pressure. Respiratory arrhythmia increased markedly, to a greater extent with than without time pressure. In contrast to the cardiac rate and arrhythmia which apparently change only on severe mental stress, respiratory arrhythmia appears to respond to differences in stress even when the mental work itself is not impaired.

W/L Cat. Code: 3.1, 4.1.10, 4.1.11, 4.1.12

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var.			
	Breathing anal.			
	Body fluid anal.			

Knowles, W. B. Operator loading tasks. Human Factors, 1963, 5, 155-161.

The purpose of this paper is: (1) To review the rationale of measuring operator workload in terms of auxiliary, or secondary task performance scores; (2) To summarize the important characteristics of suitable loading tasks; (3) To describe several loading tasks which have been used or which are potentially useful; and (4) To suggest the development of a set of standardized tasks which would be useful in obtaining more nearly comparable measures over a wide range of primary tasks.

W/L Cat. Code: 2.2

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Review	None	Flight simulator
				Flight test

Kopala, C. J. The use of color-coded symbols in a highly dense situation display. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 397-401.

The effectiveness of redundant color-coding for displays used by highly-loaded operators performing a series of complex tasks has never been clearly demonstrated. Pilot flight performance and threat recognition performance using two coding conditions for a threat display were compared in a simulated mission. One coding condition consisted of shape-coded symbols, the other of symbols that were both color- and shape-coded. Redundant color-coding was found to significantly reduce both response time and error rate.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Kornstadt, H. J. and Pfennigstorf, J. Evaluation of an integrated flight display for the manual IFR-landing of VTOL-aircraft. Proceedings of the AGARD Conference on Guidance and Control Displays, AGARD-CP-96, 10-1 - 10-8. (AD 739 779).

An integrated flight-display for the hovering-phase of a VTOL-landing was developed. The presentation of information to the pilot has been evaluated in simulation by three criteria: landing performance, pilot rating and measurement of the pilot's mental workload. Adaptation of the display-dynamics and the desired landing-profile lead to higher level of performance at a decreased workload.

W/L Cat. Code: 1.1, 2.2.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Subsidiary task			Flight test

Koym, K. G. Familiarity effects on task difficulty ratings. Brooks AFB, Texas: USAF Human Resources Laboratory, AFHRL-TR-77-25, June, 1977.

This report examines interrater reliability estimates for task difficulty raters having differing levels of familiarity with rated tasks. Data were collected from 455 NCO supervisors who rated the difficulty and familiarity of 424 tasks in the Aircraft Electrical Repair career ladder task inventory. The results showed that the interrater reliability estimates (R_{kk}) decreased from .930 to .802 for six task difficulty rating scale conditions in which ratings were eliminated due to levels of familiarity. This finding suggests that little is to be gained from eliminating task difficulty ratings based upon an experienced judge's level of familiarity with tasks.

W/L Cat. Code: 1.1

Op. Behav. Code: 1., 2., 3., 4.

Opinion Rating scale Experimental Field Flight simulator

Flight test

Kradz, M.P. The psychological stress evaluator. Ellicott City, Maryland: Howard County Police Department, Unpublished manuscript, 1974.

The aim of this study was to investigate the validity of the Dektor Psychological Stress Evaluator (PSE) in law enforcement as a stress measuring device. Supposedly, involuntary physiological response measured directly is related to the degree of psychological stress induced in the subject by the questions contained in a properly constructed "lie detection" examination. Another aim was to compare the validity of the Dektor instrument with that of a polygraph used in the same situation. All other components of the "lie detection" system remained constant, leaving the instrumentation as the only variable. The hypothesis tested, therefore, was that the voice stress reactions indicated by Dektor PSE would correlate with the degree of stress contained in answers to questions regarding a real crime in which the subject was a suspect. It is concluded that the PSE is a valid component worthy of inclusion in the lie dection application system, either in tandem with the polygraph or used as a single measure.

W/L Cat. Code: 4.3
Op. Behav. Code: 2., 3.

Physiological Speech patt. anal. Experimental Field Background

Kraft, C. L. and Elworth, C. I. Flight deck workload and night visual approach performance. In AGARD Measure of aircrew performance. Report No. N70-19786, December, 1969.

Research with a night visual approach simulator has provided data supporting a logical explanation for about 16% of air transport accidents. The explanation is in the form of a two-part hypothesis: a descent path that nulls out some visual information and a delay in relative motion supplement of the same information. The missing topographic information allows incorrect interpretation of altitude and distance. Most operational examples of this class of accidents include information about crew distractions, critical intrusions and workloads. In recent investigations, the flight deck workloads were altered by varying the frequency of appearance of other traffic which the pilot was instructed to detect and report to ground control. Analysis of the effect of workload on performance revealed this to be a significant factor only as it interacted with terrain slope and pilot differences, but not otherwise.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1.1, 1.2, 4.2

Spare m. capacity Subsidiary task Experimental Flight simulator Flight simulator

Krahenbuhl, G. S., Marett, J. R., and King, N. W. Stress and performance in T-37 pilot training. Brooks Air Force Base, Texas: Air Force Human Resources Laboratory, AFHRL-TR-77-3, May, 1977. (AD A041 734).

Catecholamine excretion was determined for student pilots (N = 8) during training conditions. When viewed as the dependent variable, catecholamine excretion patterns support the conclusion that the Basic Cockpit Training Emergency Procedures unit was not stressful. The remaining lesson units, including Power-on Stall and Spin-recovery, First Solo, and Instrument Check lesson units, resulted in a pronounced stress response. When catecholamine excretion data were interpreted for psychological significance, it was concluded that the lesson unit which included Power-on Stalls and Spin-recoveries created the highest arousal, anxiety, and apprehension. Student pilot observations support this interpretation. The relative production of epinephrine and norepinephrine showed changes accompanying pilot training which may be interpreted as demonstrative of successful coping behavior.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Physiological Body fluid anal. Experimental Flight test Flight simulator

Flight test

Krause, E. F. and Roscoe, S. N. Reorganization of airplane manual flight control dynamics. W. B. Knowles, M. S. Sanders, and F. A. Muckler (Eds.) Proceedings of the Sixteenth Annual Meeting of the Human Factors Society. Santa Monica, California: Human Factors Society, 1972, 117-126.

Experiments were conducted in a Singer-Link GAT-2 simulator to evaluate the effectiveness of a system providing direct control over aircraft maneuvering performance. Pilots performed complex navigational tasks involving the use of a computer-assisted area navigation system. Changing way-point storage capacity of the simulated navigation system induced variable task loading on subjects. The experiment was replicated with and without an adaptive, digit processing, side task to determine levels of residual attention associated with the control modifications and the varying levels of workload. The flight performance controller yielded greater precision of maneuvering control, fewer procedural blunders, and an increased level of residual pilot attention.

W/L Cat. Code: 2.2.4, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Krebs, M.J. and Wingert, J.W. Use of the oculometer in pilot workload measurement. Washington, D.C.: National Aeronautics and Space Administration, NASA CR-144951, February, 1976.

This study investigated relationships between eye behavior and pilot workload. A Honeywell Mark IIA oculometer was used to obtain the eye data in a fixed base transport aircraft simulation facility. The data were analyzed to determine those parameters of eye behavior which were related to changes in level of task difficulty of the simulated manual approach and landing on instruments. A number of encouraging trends and relationships between eye variables and pilot ratings were found. A preliminary equation was written based on the results of a step-wise linear regression. High variability in time spent on various instruments was related to differences in scanning strategy among pilots. A more detailed analysis of the obtained data for individual pilots was suggested as the next step in the process of building a model of visual workload.

W/L Cat. Code: 1.1, 3.1, 4.1.7, 4.1.8
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test
Physiological	Eye movement			
	Pupillary dia.			

Krebs, M.J., Wingert, J.W. and Cunningham, T. Exploration of an oculometer-based model of pilot workload. Washington, D.C.: National Aeronautics and Space Administration, NASA CR-145153, March, 1977.

This study investigated relationships between eye behavior and pilot workload. A Honeywell Mark IIA oculometer was used to obtain the eye data in a fixed base transport aircraft simulation. The data were analyzed to determine those parameters of eye behavior which were related to changes in level of task difficulty of the simulated manual approach and landing on instuments. Trends and relationships between eye variables and pilot ratings were found. High variability in time spent on various instruments was related to differences in scanning strategy among pilots. Detailed analysis of individual runs by individual pilots indicated a high degree of intra-pilot variability in instrument scanning. No consistent workload related trends were found. Pupil diameter which had demonstrated a strong relationship to task difficulty was extensively re-examined. It was concluded that the generalized measure which showed this relationship was most likely not purely pupil diameter but a composite index incorporating the influence of other variables such as instrument scanning.

W/L Cat. Code: 1.1, 3.1, 4.1.7, 4.1.8
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test
Physiological	Eye movement			
	Pupillary dia.			

Kreifeldt, J., Parkin, L. and Rothschild, P. Implications of a mixture of aircraft with and without traffic situation displays for air traffic management. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 179-200. (NASA TM X-73 170).

A mixture of aircraft (A/C) with and without traffic situation displays (TSD) was simulated to ascertain its effects on distributed air traffic management in the terminal area. The three simulator A/C and four or five computer simulated A/C were embedded in a terminal area traffic problem with as much realism as possible. All A/C were considered to be STOLcraft. Analyses were made of flight performance measures, verbal communications and subjective evaluations by the professional pilots and controllers who served as subjects. The analyses favor the TSD equipped A/C, and the distributed mode of management permitted by this cockpit capability. However there are indications that an A/C without a TSD in a TSD environment may require or receive considerably more controller attention and pilot disfavor than when it is in an all vectored environment. This may imply that TSD and nonTSD A/C should be segregated and controlled accordingly.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 3., 4.2

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Krivohlavy, J. Physiological correlates of the informational performance. Activitas Nervosa Superior, 1968, 10, 165-171. (In Czechoslovakian).

The relationship between heart and respiratory rate, regularity of pulse, depth of inspiration and the amount of presented information was studied on twenty two subjects under two different conditions: the amount of presented information equalled either 3/4 or 5/4 of the individual capacity (underload and overload conditions). No simple correlation was found, but the subjects with the low heart rate and a small error number during under-threshold performance showed an increase of heart rate during the overload performance,and subjects with higher heart rate and higher error number during underload performance had an opposite tendency. The pulse irregularity increased with the amount of information only during mental reproduction but not during verbal reproduction. In conclusion the importance of the attitude as a regulator of voluntary activity is stressed; physiological functions reflect the changes in the level of mental activation, which is only partially determined by the presented or processed information.

W/L Cat. Code: 4.1.10, 4.1.11

Op. Behav. Code: 1., 2.

Physiological	Heart rate h.r. var. Breathing anal.	Experimental	Laboratory	Flight simulator

Krivohlavy, J. Pulse rate and information load during typing. Activitas Nervosa Superior, 1968, 10, 172-176. (In Czechoslovakian).

The conclusion of G. Gancev, et al. from 1967 was checked. He asserted that the pulse rate can be used as an objective criterion of the degree of tension of higher nervous centers. Experiments of Gancev, et al. were repeated but the results obtained did not confirm this statement. The significance of differences appears to be problematic. These doubts are based on results of other experiments with increasing the input of the flow of information. Even if it is not possible to derive from the lack of significance the non-existence of the relationship, the results would suggest caution. Doubtful is also the a priori identification 'of the degree of tension of higher nervous centers' with 'the magnitude of the required information performance' as stated in the work of Bulgarian authors.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Experimental	Field	Flight simulator Flight test

Krol, J. P. Variations in ATC-work load as a function of variations in cockpit workload. Ergonomics, 1971, 14, 585-590.

The relation between pilots' workload and radar controllers' workload was investigated. Pilots' workload served as the independent variable. It was assumed that a number of levels of workload can be distinguished in a standard airport traffic circuit under visual flight rules. The dependent variable (controllers' workload) was measured by response frequency on an auditory binary choice task. Results indicate a rise in radar controllers' workload in a predicted direction for a number of pilots' workload levels.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity   Subsidiary task   Experimental   Flight test   Flight simulator

Primary task   Single measures   Flight test

Krzanowski, W. J. and Nicholson, A. N. Analysis of pilot assessment of workload. Aerospace Medicine, 1972, 43, 993-997.

In a previous study on the activity of the nervous system during the let-down, approach and landing of a transport aircraft the workload was assessed by the pilot. Correlations were established between overall workload of the let-down and individual factors which influence the workload pattern and between the subjective assessments of workload and physiological change in the pilot. In the present paper assessments of workload over a four-year period have been examined to determine the technique used by the pilot to evaluate workload from the various factors of the let-down and to assess the consistency of his technique.

W/L Cat. Code: 3.1, 4.2

Op. Behav. Code: 1., 2., 4.

Primary task   Mult. measures   Experimental   Field   Flight simulator

Physiological   Flight test

Kuhar, W. T., Gavel, P. and Moreland, J. A. Impact of automation upon air traffic control system productivity/capacity (ARTS-III). Washington, D.C.: Federal Aviation Administration, FAA-RD-77-39, November, 1976. (AD A038 659).

This report documents the results of a study to assess the impact of the Automated Radar Terminal System (ARTS 3) upon air traffic control system capacity. It is based upon on-site measurements of air traffic activity, controller work pace, controller workload indicators, and staffing at the San Antonio, Texas and San Francisco/Oakland, California TRACONS. Measurements were taken of both the pre-ARTS 3 and post-ARTS 3 environments and comparisons made to determine the direction and degree of change attributable to ARTS 3. The results indicate that the ARTS 3 system has reduced controller workload and increased system capacity by 10.5%. A reasonable estimate of the productivity increase is 8.5%.

W/L Cat. Code: 1.1, 2.1.1

Op. Behav. Code: 1., 2., 3 , 4.1

Opinion	Rating scale	Experimental	Field	Flight simulator
Spare m. capacity	Task comp., time assess.			Flight test

Kundiev, I. I., Navakatikian, A. O., Tomashevskaia, L. I., Derkach, V. S., and Kovaleva, A. I. Stressful mental activity and the regulatory state in the cardiovascular system. Fiziologiia Cheloveka, 1976, 2, 433-440. (In Russian.)

In-vivo and in-vitro experiments were conducted on subjects to study relevant regulatory parameters of cardiovascular functions during stressful mental activity involving such elements as time pressure, risk, and threat of electroshock penalty. The measurements were obtained by radiotelemetric recording of the cardiac rhythm, polycardiography, and mechanocardiography, along with evaluation of circadian rhythm for excretion of epinephrine, norepinephrine, and corticosteroid-17. Subjective evaluation of stress was made by a ranking method. It is shown that mental activity involving high stress is accompanied by changes in the intra-systemic coordination of the functions of the cardiovascular system and returning of the rhythmic regulation of cardiac activity.

W/L Cat. Code: 1.1, 4.1.3, 4.1.10, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var. Body fluid anal.			Flight test

Kuroda, I., Fujiwara, O., Okamura, N., and Utsuki, N. Method for determining pilot stress through analysis of voice communication. Aviation, Space, and Environmental Medicine, 1976, 47, 528-533.

Factors inherent in aircraft communication systems hinder customary approaches to voice analysis in the determination of the degree of stress experienced by a pilot during an inflight emergency. By means of a sound spectrogram, the mean vibration space of a voice can be analyzed if the space between the vertical deflections of the vowel sounds is calculated in micrometers. The vibration space shift rate (VSSR) is calculated by comparing the widest vibration space of the voice during the normal phase of the same flight (standard vibration space: SVS) with that encountered during the emergency situation (EVS). The number of measuring points in each case differs in regard to the length of communication during the emergency. The VSSR can be divided into three phases--normal, urgent, and emergency--each with three grades of 0.5 S.D. apiece.

W/L Cat. Code: 4.3

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Speech patt. anal.	Experimental	Laboratory	Flight simulator
			Flight test	Flight test

Lane, D. M. Attention allocation and the relationship between primary and secondary task difficulty. A reply to Kantowitz and Knight. Acta Psycholgica, 1977, 41, 493-495.

Kantowitz and Knight have argued that Kahneman's attention-allocation theory requires primary and secondary task difficulty to interact. It is shown that whether or not these two variables interact depends upon (1) the shape of the function relating task difficulty and available capacity to performance and (2) the difficulty levels of each task.

W/L Cat. Code: 2.2.1, 2.2.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	None	Background
Primary task	Single measures			

Lane, N.E. and Streib, M.I. The human operator simulator: Workload estimation using a simulated secondary task. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CP-216, April, 1977, A11-1 - A11-12.

This paper describes the use of the Human Operator Simulator (HOS) for identifying potential workload problems. HOS is applicable during the midrange of system development, between early analytic prediction methods and later simulator evaluations. The HOS system creates a software simulation of a trained human operator, his system hardware/software and required interfaces. Previous HOS applications have indicated a close correspondence in the behavior of HOS operators and human operators on the same tasks. The results of this work demonstrate the applicability of HOS for workload evaluation and explores HOS operator behavior under varying conditions of task demand. Problems of definition and methodology for current workload measures are discussed and alternatives identified using HOS to control task difficulty and task demand parameters. The implications of HOS application for cost and flexibility improvements are examined, and further developments of the model for workload evaluation are proposed.

W/L Cat. Code: 2.1.1, 2.2.1, 2.2.2
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess. Subsidiary task	Experimental	Laboratory	Flight simulator

Lane, N.E., Wherry, R.J., Jr. and Streib, M. The human operator simulator: Estimation of workload reserve using a simulated secondary task. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April 1977, A11-1.

This paper describes an extension of the Human Operator Simulator (HOS) to estimate workload. The HOS is a design technique which provides the relative precision and accuracy of dynamic simulation but which can be applied early enough in design to allow for needed system changes. The HOS system creates a software analog of the human operator, the hardware he will operate, and the required interfaces. Previous simulations have indicated a close correspondence between HOS performance and that of a human operator on the same task procedures. Work described here discusses the potential of HOS as a workload assessment technique during system design, using the concept of secondary task loading to determine operator reserve. By varying primary/secondary task demands and the priorities assigned to each task level, statements about reserve time available can be used to establish potential overload problems and to provide a workload "figure of merit" for alternative crewstation/task configurations.

W/L Cat. Code: 2.1.1, 2.2.1, 2.2.2
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator

Laurell, H. and Lispar, H. O. A validation of subsidiary reaction time against detection of roadside obstacles during prolonged driving. Ergonomics, 1978, 21, 81-88.

Indirect psychological or physiological measures of driving performance are often used without supporting evidence or even comment on their validity. In this validation the performance of ten subjects on a subsidiary reaction time (RT) task and a visual detection task was correlated. On the RT task 93 dB auditory signals were presented with an average intersignal interval of 50s. On the detection task, the subjects had to brake as fast as possible when they perceived a 40 x 40 cm obstacle at the side of the road. Over the test of three hours, in night driving conditions on a closed 5 km track, the correlation between group averages was -0.78 and the average within-subject correlation was -0.47. From these results and a discussion of the predictive and the construct validity of the RT-task, it is concluded that subsidiary RT may be used as a valid indicator of changes in efficiency of driving performance.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Field	Flight simulator
Primary task	Single measures			Flight test

Laurig, W. and Phillip, U. Changes in the pulse frequency rhythm in relation to the workload. (Veränderungen der Pulsfrequenzarrhythmie in Abhängigkeit von der Arbeitsschwere). Arbeitsmedizin Sozialmedizin, Arbeitshygiene, 1970, 5, 184-188. (Royal Aircraft Establishment Library Translation 1586).

Starting with a phenomenononological description of the heart rate rhythm, an arrhythmia condition has been derived theoretically. Experimental results from physical and mental work have given values for the average behavior of the arrhythmia quotient in relation to the intensity of the work of a large collection of male subjects. A regression calculation over the individual results of all the experiments shows a reduction in the arrhythmia quotient with the workload. A control theory description is used for the behavior of the arrhythmia on rest. The significance of heart rate measurements in medical practice is discussed.

W/L Cat. Code: 4.1.3, 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	EKG	Construct	Laboratory	Flight simulator
	Heart rate, h.r. var.	Experimental		Flight test

Lauschner, E. A. (Ed.) Measurement of aircrew performance: The flight deck workload and its relation to pilot performance. AGARD Aerospace Medical Panel, AGARD-CP-56, May, 1969.

Contents: Flight-deck workload studies in civil transport aircraft; Energy cost of piloting fixed and rotary wing army aircraft; Psychomotor performance under thermal stress-A critical appraisal; Operational measures of pilot performance during final approach to carrier landing; Aircrew task loading in the Boeing multimission simulator; Physiological assessment of pilot stress during landing; Exploratory study of pilot performance during high ambient temperatures and humidity.

W/L Cat. Code: 1., 2., 3., 4

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	Flight simulator	Flight simulator
Spare m. capacity		Construct		
Primary task		Experimental	Flight test	Flight test
Physiological				

Laville, A., Teiger, C., and Duraffourg, J. An attempt to evaluate workload in a repetitive task. Paper presented at the annual conference of the Ergonomics Research Society, April, 1972.

The study of performance is not sufficient to evaluate workload, especially in an industrial situation where the organization of the work does not allow large variations in quantity or quality of the work done. The first approach to an evaluation of workload in this type of task is an analysis of the mechanisms used by the operators. We have attempted this analysis, in the study of a work-station on a television assembly line, in conjunction with certain measures of physiological parameters, notably those related to posture. The results obtained show important changes in method of operation used as a function of certain difficulties in the task. The modifications can be interpreted as the bringing into play of adaptive mechanisms to a situation variables, where these coexist requirements of speed and accuracy in execution of this type of task, the variation in certain parameters of posture can be shown to have a relationship with the results obtained from an analysis of work.

W/L Cat. Code: 2.1.1, 4.1.9
Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Task comp., time assess.	Experimental	Field	Flight simulator
Physiological	Muscle tension			

Lawrence, G. H. Brain waves and the enhancement of pilot performance. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 93-102.

The use of brainwaves (EEG) for the enhancement of the performance of aircraft pilots is an idea which requires, for its development, the integration of two previously independent lines of research endeavor: human performance assessment and central nervous system neurophysiology. A human performance research paradigm specifically relevant to the study of pilot performance, in the context of which the use of brain waves may feasibly be studied, will be discussed later. Attention is now directed to the state of the art of brain wave research and brain-behavior relationships, specifically those aspects which are considered to be feasibly and usefully applicable for potential use in simulated aircraft crew stations or eventually in a real-world environment.

W/L Cat. Code: 4.1.5, 4.1.6

Op. Behav. Code: 1., 2.

Physiological	EEG	Review	Laboratory	Flight simulator
	ECP			

Lebacqz, J. V. and Aiken, E. W. A flight investigation of control, display, and guidance requirements for decelerating descending VTOL instrument transitions using the X-22A variable stability aircraft. Volume I. Buffalo, New York: Calspan Corporation, AK-5336-F-1, September, 1975.

A flight research program using the variable stability X-22A aircraft was undertaken to investigate control, display, and guidance requirements for VTOL instrument transitions. The primary purpose of the experiment was to provide meaningful data related to the interaction of aircraft control system and displayed information characteristics on pilot rating and performance. Primary results of the program include the demonstration of an inverse relationship between control complexity and display sophistication, as was hypothesized in the experiment design, and the definition of acceptable and satisfactory control/display combinations. Analysis of the results in terms of simple pilot-in-the-loop considerations and measured performance and workload provide initial guidelines for the design of future VTOL control-display characteristics.

W/L Cat. Code: 1.1, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight test
Primary task	Single measures			Flight simulator

Leplat, J. Factors determining work-load. Ergonomics, 1978, 21, 143-149.

In this short introduction to the topic of the symposium, some analytical elements are suggested for the concept of work-load, the large variety of work-load categories is recalled, and mention is made of some factors determining work-load, which will be elaborated on in the papers presented by other authors.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Construct	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Leplat, J. and Pailhous, J. The analysis and evaluation of mental work. In W. T. Singleton, J. G. Fox, and D. Whitfield (Eds.) Measurement of man at work. London: Taylor and Francis, 1973, 51-56.

Mental work, which is essentially non-observable, presents serious difficulties to the analyst who wishes to evaluate it. This kind of work is found increasingly in our society, even where the task requires a relatively low level of skill, and interest in its study is increasing. In this paper we consider various analytical procedures of analysis and evaluation and assess the results obtained. The analysis provides an opportunity to compare the methods of the applied psychologist and the work physiologist and to expose the differences involved. The distinction which we shall propose in terms of load or intellectual mechanisms appears to be quite fundamental; it covers many totally different scientific attitudes; it leads to distinct types of techniques, even if in practice they may be utilized successively at two different periods of an investigation. Such an analysis should contribute to the dialogue with our physiologist colleagues.

W/L Cat. Code: 2.2, 4.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Review	None	Background
Physiological	EEG			
	EMG			

Levine, J. M., Ogden, G. D. and Eisner, E. J. Measurement of workload by secondary tasks: A review and annotated bibliography. Washington, D.C.: Advanced Research Resources Organization, Contract No. NAS2-9637, January, 1978.

An annotated bibliography of the post - 1965 behavioral science literature concerned with the use of secondary tasks in the measurement of operator workload was prepared, and an organization of this literature was accomplished. The bibliography contains 146 empirical references and 17 review or theoretical papers. The references were categorized according to the type of primary and secondary tasks used. Methodological and theoretical issues in the use of a secondary task technique are discussed and suggestions for further research efforts are made.

W/L Cat. Code: 2.

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Review	None	Flight simulator
				Flight test

Levison, W. H. A model for task interference. Proceedings of the 6th Annual NASA-University Conference on Manual Control, Wright-Patterson AFB, Ohio, April 7-9, 1970, 585-616.

A model is presented for interference among multiple continuous manual control tasks. This model is based upon the assumption that multiple tasks are performed in parallel and that the human must share a fixed amount of central-processing capacity among the tasks. The equivalent observation noise associated with a subtask is shown to be related to the fraction of the controller's capacity allocated to that task. The model is able to predict with great accuracy the total performance scores measured in a set of multivariable tracking experiments. The model structure also accounts for the effects of multivariable tracking on the controller's describing function and remnant.

W/L Cat. Code: 2.2.2, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	Laboratory	Flight simulator
Primary task	Math. model	Experimental		Flight test

Levison, W.H. A model for mental workload in tasks requiring continuous information processing. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 189-218.

This paper provides a unified treatment of theory, validation, and application of the model for workload and attention. The section on theoretical development presents the basic assumptions underlying the proposed workload model, shows the equivalence of time-sharing and capacity-sharing notions of attention, presents the basic model of workload, and reviews a human operator model that allows one to predict the relationship between performance and workload. The reader is then directed to the literature for results that validate the basic human operator model as well as the specific model for mental workload, and some pilot-opinion results are cited to support the argument that response randomness can be related to workload and attentional demand. The third major section of the paper discusses predictive and diagnostic applications of the workload model. Finally, some thoughts are offered relating the concepts and techniques discussed in this paper to the goals of the workload symposium to which this paper is submitted.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 3., 4.

Primary task | Math. model | Review Construct | Laboratory | Flight simulator

Lieberman, P. and Michaels, S. B. Some aspects of fundamental frequency and envelope amplitude as related to the emotional content of speech. Journal of the Acoustical Society of America, 1962, 34, 922-927.

Pitch pulses were derived from the utterances of three male speakers who each read eight neutral test sentences in certain "emotional: modes, i.e., as a question, an objective statement, a fearful utterance, a happy utterance, etc. Tapes were recorded and presented to separate groups of naive listeners who categorized the emotional modes in forced judgment tests. Results of the tests show that with unprocessed speech, the listeners were able to correctly identify the emotional content 85% of the time. When only pitch information was presented, correct identification was made 44% of the time. When amplitude information was added to the pitch information, the identification rose to 47%. Smoothing the pitch information with a 40-msec time constant reduced the identifications to 38%, while 100-msec smoothing reduced the identification to 25%. A 120-cps monotone with amplitude information derived from the original speech envelope amplitude resulted in 14% identifications.

W/L Cat. Code: 4.3

Op. Beahv. Code: 1., 2., 3.

Physiological | Speech patt. anal. | Experimental | Laboratory | Background

Lindquist, O. H. Design implications of a better view of the multichannel capacity of a pilot. Proceedings of the AGARD Conference on Guidance and Control Displays, AGARD-CP-96, 5-1 - 5-6, February, 1972. (AD 739 779).

A major result of a recently completed study has been the prediction and measurement of multichannel pilot performance, which significantly increased his information-handling capability beyond that predicted by today's techniques. Current techniques of predicting man/machine interactions were shown to be in error by an order of magnitude in some measurements related to human channel capacity. The results of this experimental work are presented and system design implications for pilot capability and limitations are discussed.

W/L Cat. Code: 2.1.

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct Experimental	Flight simulator	Flight simulator

Linn, V. C., Jr. The parotid fluid technique for the evaluation of mental stress in a production situation. Texarkana, Texas: US Army Logistics Management Center, USAMC Intern Training Center, USAMC-ITC Report No. 2-72-05, July, 1972. (AD 761 025).

This paper presents a method for the evaluation of mental stress in production situations where mental fatigue is considered a significant problem. The level of mental stress which the operator experiences is reflected in the concentration of 17-hydroxycorticosteroid in his parotid fluid. Included is a discussion of the theory behind the technique and its procedural application. The use of the technique to reduce mental stress and the effects of mental fatigue in a production facility is also discussed.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2., 4.

Physiological	Body fluid anal.	Construct Experimental	Field	Flight simulator Flight test

Linton, P. M. VFA-V/STOL crew loading analysis. Warminster, Pennsylvania: U.S. Naval Air Development Center, NADC-75209-40, May, 1975.

The purpose of this study was to determine whether a single crew member could effectively execute proposed VFA-V/STOL missions or whether a two man crew would be necessary. The question was addressed primarily through the determination of workload imposed upon a single operator during selected missions. Scenarios were generated for a deck launched intercept fighter mission and a close air support attack mission. Functional flow block diagrams were determined and detailed task analyses completed for the high workload phases of these missions. A representative VFA-V/STOL cockpit was designed and fabricated to assist in the calculation and later validation of crew loading. The data were analyzed by the statistical workload assessment model (SWAM) of the computer-aided function allocation evaluation system (CAFES) and the results suggest that a one man crew should be sufficient for the VFA-V/STOL aircraft.

W/L Cat. Code: 2.1.

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Flight simulator	Flight simulator
	Inform. theory	Experimental		

Linton, P. M., Jahns, D. W. and Chatelier, P. R. Operator workload assessment model: An evaluation of a VF/VA-V/STOL system. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A12-1 - A12-11.

By systematically describing the steps undertaken to estimate the workload in a conceptual fighter/attack V/STOL aircraft, meeting Navy mission requirements, this paper shows that while a single crewmember can probably manage the V/STOL in its primary mission phases, additional and refined workload assessment evaluations will be required to conclusively settle the issue for all aspects of deployment. In addition, it is suggested that an integrative concept of operator workload be developed to more accurately reflect the psychological/physiological demands made of the operator in the course of system operations.

W/L Cat. Code: 2.1.

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Flight simulator	Flight simulator
	Inform. theory	Experimental		

Lisper, H. O., Laurell, H. and Stening, G. Effects of experience of the driver on heart-rate, respiration-rate, and subsidiary reaction time in a three hours continuous driving task. Ergonomics, 1973, 16, 501-506.

From accident statistics a difference was hypothesized between experienced and inexperienced drivers in vulnerability to continuous driving. This difference was used as a basis for a comparison of changes in autonomic measures and reaction time over driving time. The result showed significant effects of experience on both types of measures. Heart-rate pointed to experienced and reaction time pointed to inexperienced drivers as being the most vulnerable to continuous driving. This contradiction was solved with reference to statistical data and validation of the reaction time task. Thus in this study reaction time was preferred to the autonomic measures.

W/L Cat. Code: 2.2.1, 4.1.10, 4.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Field	Flight simulator
Physiological	Heart rate h.r. var. Breathing anal.			Flight test

Logan, G. D. On the use of a concurrent memory load to measure attention and automaticity. Journal of Experimental Psychology: Human Perception and Performance, 1979, 5, 189-207.

The concurrent-memory-load technique identifies attention demands with interactions between reaction-time-task parameters and the size of the load on memory. Three experiments are reported in which a multiple-choice, reaction time task involving two, four, and eight stimulus-response (S-R) alternatives was performed alone and in the retention interval of a short-term-memory task involving ordered recall of eight digits. The experiments have validated the concurrent-memory-load technique by showing that interaction, additivity, and a transition from interaction to additivity can all occur in real data. The tentative conclusion that practice with consistent mapping seems to be a necessary and sufficient condition for producing the transition relates the technique to other theory and data on attention and automaticity and attests further to its validity.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Lorens, S. A., Jr. and Darrow, C. W. Eye movements, EEG, GSR, and EKG during mental multiplication. Electroencephelography and Clinical Neurophysiology, 1976, 14, 739-746.

Physiological measures were taken for ten subjects before and during mental multiplication tasks. Each of the ten subjects showed a significant increase in eye movement rate (EMR) during mental multiplication. These data suggest that rapid ocular movement is a consistent concomitant of mental multiplication under the conditions described. The increase in EMR during mental multiplication was not related to changes in heart rate, conductance level (CL), percent time occipital alpha, or to the presence of a palmar galvanic skin response (PGR) following presentation of a problem, although a tendency was observed for those individuals with high CL's to have both PGR's and high EMR's. Records of the six subjects scored for per cent time occipital alpha each showed a significant decrease in occipital alpha acitivity during mental multiplication attributable primarily to "blocking". No unique EEG wave forms were identified.

W/L Cat. Code: 4.1.2, 4.1.5, 4.1.7, 4.1.10

Op. Behav. Code: 1.1, 2., 3.

Physiological	GSR EEG Eye movement Heart rate, h.r. var.	Experimental	Laboratory	Flight simulator

Lovesey, E. J. In-flight recording of helicopter pilot activity. Proceedings of AGARD Conference on Studies on Pilot Workload, AGARD-CPP-217, April, 1977, B3-1 - B3-10.

Head and hand activity patterns have been established for UK Army and Air Force helicopter pilots under a variety of operational flight conditions using a cine filming technique. A fully portable cine camera fitted with a "fish eye" or wide angle lens has been used to record pilots' head and hand movements in 6 different helicopters and 2 fixed wing aircraft types during nap-of-the-earth, low level and other flight phases. Apart from highlighting problem areas in the cockpit, the film records show that activity patterns depend more upon the flight profile than upon the helicopter type or the individual pilot. Subsequent film analysis has shown that the pilot work-load tends to increase with decreasing height above the ground. During nap-of-the-earth tactical flying, a pilot may spend over a third of the time looking inside the cockpit at maps, instruments and radios. This is precisely the time when he needs to spend the maximum time looking outside to detect and evade potential hazards such as wires, trees, enemy positions etc. Reasons for the apparently paradoxical behavior and the effect upon pilot work-load are discussed.

W/L Cat. Code: 3.1

Op. Behav. Code: 4.2

Primary task	Single measure	Experimental	Flight test	Flight simulator
Physiological	Eye movement			Flight test

Luczak, H. The use of simulators for testing individual mental working capacity. Ergonomics, 1971, 14, 651-660.

The operator, who determines the functional relationship between stress and strain, is interpreted as the unit of individual mental working capacity. A theory of mental stress built up with concepts from formal logic, systems theory, and information theory is presented. Three simulators of mental stress, constructed from the theoretical concept, are introduced, and attention is given to a measurement of strain with cardiac parameters. Several concepts for the evaluation of individual mental working capacity are considered.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 4.

Primary task	Math. model	Construct	None	Background

Luczak, H. and Laurig, W. An analysis of heart rate variability. Ergonomics, 1973, 16, 85-97.

Proceeding from a formal definition of heart rate variability, some mathematical and statistical techniques from sampling statistics and time series analysis for the analytical evaluation of heart rate variability for ergonomics purposes are presented and compared. The concept of sampling statistics gives a measure of heart rate variability, arrived at by combining two measures, which were chosen according to a definite criterion. The applicability of this measure is discussed, especially with respect to serial correlation influences when using statistical tests. The two main methods of spectral analysis-the calculation of the transformed autocovariance function and of harmonic analysis-are presented. The influences of interpolations, algorithms and physiological effects are discussed. A possible measure of heart rate variability, calculated by spectral estimates, is proposed and some results are given.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Construct	Laboratory	Flight simulator
		Experimental		Flight test

Luczak, H. and Rohmert, W. Adaptation reactions of workers in ergonomic field studies of information processing work potentials. European Journal of Applied Physiology, 1976, 35, 33-47. (In German.)

Adaptation processes in the performance of information processing tasks were measured in 18 subjects in terms of performance parameters - cycle times, variance of cycle times, informational content of time and errors - and in terms of physiological strain parameters - electromyograms of musculus extensor digitorum and musculus rhomboideus, horizontal and vertical electrooculogram, heart rate and heart rate variability - and are described according to type and frequency. Simultaneous and successive reactions of all measured quantities over the course of the work shift and three successive days are described. They are classified as being due to either training or emotional habituation and are discussed in terms of an experimenter-experimental situation model.

W/L Cat. Code: 2.1.2, 3.1, 4.1.4, 4.1.7, 4.1.9, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Multiple Experimental Laboratory Flight simulator

Primary task

Physiological

Machac, M. Mental load, fatigue, and recovering. Psychologie, 1971, 6, 72-79. (In Czechoslovakian).

This article is concerned with the influence of civilization processes on man, especially with regard to the sensation of fatigue. It is based on the fact that man has learned to change the material world far more quickly than to adapt himself to such changes. The problem of mental load and fatigue are at present at the center of attention in scientific research. The author deals with the causes of sensation of fatigue and characterizes the development of artificial recovering methods.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion Multiple Construct None Background
Spare m. capacity
Primary task
Physiological

Madero, R. P., Sexton, G. A., Gunning, D., and Moss, R. Total aircrew workload study for the AMST, Volume I, Results. Wright-Patterson Air Force Base, Ohio: Flight Dynamics Laboratory, Final Technical Report, AFFDL-TR-79-3080, Vol. I, February, 1979.

There is a growing realization within the USAF that state of the art crew systems may allow cost effective reductions in crew complements. The present study addresses the minimum crew complement required and conceptually, the crew systems required to support the minimum crew of an Advanced Medium STOL Transport (AMST) in the accomplishment of the tactical transport mission. The study involved the simulation of a total tactical airlift mission which was flown by operational (C-130) tactical airlift aircrews to further refine crew complement and crew system concepts established in earlier mockup studies. The results of this study indicate that two pilots, a loadmaster and a crew chief type additional crew member can fly the total AMST mission if provided with adequate state of the art crew system capabilities.

W/L Cat. Code: 1., 2.2.3, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Spare m. capacity	Questionnaire			Flight test
Primary task	Time estimation			
	Single measures			

Markeiwicz, L., Koradecka, D., and Konarska, M. Retention of selected physiological indicators in pilots in the course of agricultural flights. Washington, D.C.: National Aeronautics and Space Administration, Technical Translation TT-F-17441, August, 1977.

Stress on the organism of pilots maneuvering fixed-wing or rotary-wing aircraft in crop-dusting and sowing operations, with abrupt changes in terrain and sharp turns required, is studied on the basis of telemetered heart rate, tremorgrams, indications of muscle fatigue (particularly, flexor muscles of the fingers), and response to vibrations. Comparisons are made of data for low-level flight over even terrain and nap-of-the-earth flight over hilly terrain. Responses in fixed-wing flight and helicopter flight are also contrasted. Criteria are proposed for optimization of piloting conditions in this type of service.

W/L Cat. Code: 1.2, 4.1.3, 4.1.9, 4.1.10

Op. Behav. Code: 1., 2., 4.

Opinion	Interviews	Experimental	Flight test	Flight simulator
Physiological	EKG			Flight test
	Muscle tension, tremor			
	Heart rate, h.r. var.			

Mashhour, M. The effect of motion on attention in man-machine systems. Stockholm, Sweden: University of Stockholm, The Psychological Laboratories, April, 1969. (AD 862 320).

Attention, particularly visual attention, is defined and treated in terms of information processing concepts through a consideration of the "single-channel" hypothesis which holds that the central information processing mechanism treats messages (signals) one at a time. (1) It is pointed out that the selection of a message in the visual system is most likely to be based on factors other than the statistical nature of the source (the number of alternative messages, as defined in information theory). Among these factors are those which activate the "orientation reactions". (2) The effect of the motion of a moving man-machine system on the human operator's attention is studied on the basis of a model where the operator is considered as a servo-component. It is shown, among other things, that by increasing the velocity of locomotion of such systems (a) the sensitivity of the visual system decreases, (b) human performance for error detection and error correction deteriorates and (c) the perceptual and motor overloads increase. The relevance of these relationships in the design of man-machine systems and in the analysis of accidents is emphasized. And finally, (3) supporting data concerning engine drivers' shifts of attention are given and commented on.

W/L Cat. Code: 2.1.1, 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	None	Flight simulator
Primary task	Single measures			Flight test

McCauley, M. E., Kennedy, R. S., and Bittner, A. C., Jr. Development of performance evaluation tests for environmental research (PETER): time estimation test. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 513-517.

A time estimation task was considered for inclusion in the Performance Evaluation Tests for Environmental Research (PETER) battery. As part of this consideration the effects of repeated testing on the reliability of time judgments, using the method of production, was studied. Forty trials per day were administered individually to each of 19 subjects for 15 consecutive weekdays. Descriptive statistics are reported and the need for knowledge about the reliability coefficient over repeated test administrations in the context of performance testing in exotic environments is discussed.

W/L Cat. Code: 2.2.3, 3.1

Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Time estimation	Experimental	Laboratory	Background
Primary task	Single measures			

McDonald, L. B. and Ellis, N. C. Driver work load for various turn radii and speeds. In Driver performance studies: Transportation Research Record 530. Washington, D.C.: Transportation Research Board, TRR 530, 1975, 18-30.

The need exists for a method by which a highway designer can determine, during the design stage, whether a highway design will demand so much of a driver's attention that there is insufficient time to look for and avoid accidents. One aspect of attentional demand is tracking the lane in curves and tangent sections. A study was done to determine (by use of a secondary task) what percentage of a driver's attention is required to track a lane while various curves are negotiated at various speeds. In addition, data were gathered about how drivers control their lane position. Results indicated that lane tracking in a 17-deg. turn demanded 26 percent of the subject's attention at 20 mph (32 km/h) and 42 percent at 40 mph (64 km/h) and that attentional demand in the straightaway remained around 23 percent for speeds from 40 to 80 mph (64 to 129 km/h). Lane-tracking data indicated that the median location was 5 in. (13 cm) to the left of the lane center in straightaways, 7 in. (18 cm) to the left in left turns, and 6 in. (15 cm) to the right in right turns. Distributions of drift distances from these three median locations were also determined.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Field	Flight simulator
Primary task	Single measures			Flight test

McDonald, L.B. and Ellis, N.C. Stress threshold for drivers under various combinations of discrete and tracking workload. Proceedings of the 19th annual meeting of the Human Factors Society, Dallas, Texas, October, 1975, 488-493.

Stress thresholds were determined for drivers under various combinations of discrete and tracking workload. The fifteen subjects in the study first carried out a series of tracking tasks, and the workload on each difficulty level was measured with a secondary task. They then executed a number of discrete tasks, and the workload on each difficulty level was measured. Various workload levels were then combined in an effort to discover the stress threshold for different combinations of discrete and tracking tasks. Study results indicate that subjects are unable to simultaneously execute two tasks, each of which occupies 50% of their attention when executed alone. A regression analysis was performed on the data to determine what levels of tracking workload can be executed simultaneously with various levels of discrete task workload.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 2.1, 4.2

Spare m. capacity	Subsidiary task	Experimental	Field	Flight simulator
Primary task	Single measures			Flight test

McDonnell, J. D. Pilot rating scales for the estimation and evaluation of handling qualities. Wright-Patterson Air Force Base, Ohio: AFFDL-TR-68-76, December, 1976.

This document reviews existing rating scales used in estimating aircraft handling qualities and workload. Based on background data a new scale is proposed which more nearly meets the criteria of an interval scale.

W/L Cat. Code: 1.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Construct	Laboratory	Flight simulator
		Experimental		Flight test

McFeely, T. E. Pupil diameter and the cross-adaptive critical tracking task; A method of workload measurement. Master's thesis, Naval Postgraduate School, Monterey, California, June, 1972. (AD 749 075).

Two new applications of established techniques for measuring an individual's level of stress (workload) in tracking tasks are presented. An indirect technique of measuring "reserve capacity" is utilized in a two-axis cross-coupled compensatory tracking task. A direct psychophysiological measurement is made by recording time histories of operator pupil diameter. Results obtained indicate that each method yields a good index of workload, although considerable variance in the data is observed. The level of instability in the second axis of the cross-adaptive method is shown to be related to the level of workload in the primary axis. Increased pupil diameter is shown to be similarly related to operator workload. The simultaneous application of both techniques is determined to be inappropriate.

W/L Cat. Code: 2.2.5, 3.1, 4.1.8

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			
Physiological	Pupillary dia.			

McGrath, J. J. Temporal orientation and task performance. Goleta, California: Human Factors Research, 719-IC, January, 1969. (AD 758 909).

This report summarizes a three-year program of research on temporal orientation and task performance. The objective of the program was to demonstrate the feasibility of relating man's perception of time to his performance on the job. Three methods of manipulating temporal orientation were used: measuring individual differences, varying the display of time information, and altering the physiological state of the subject. Criterion tasks were signal detection, anticipatory timing, and elementary visual perception. The results demonstrated the feasibility of manipulating temporal orientation as an independent variable and demonstrated several relationships between these manipulations and task performance.

W/L Cat. Code: 2.2.3, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Time estimation	Review	Laboratory	Background
Primary task	Single measures			

McHugh, W. B., Brictson, C. A. and Naitoh, P. Emotional and biochemical effects of high work-load. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD-CP-146, April, 1974, A12-1 - A12-9.

A preliminary longitudinal multifactorial study of the interrelationships of biochemical, mood, biographical factors and landing performance under high work load conditions has been carried out with U. S. Naval Aviators. Levels of serum cholesterol, serum uric acid, blood lactate, pyruvate, and mood assessments were made during periods of non-flying activity and during periods of increased cumulative workload. Uric acid values fell during moderate cumulative workload and cholesterol values fell during high cumulative workload. Increased variability of pyruvate and lactate were noted with increased cumulative work load. Increased cumulative workload did not affect emotions or performance but altered mood association patterns and altered the relationships of mood and performance. Experience was correlated with performance under zero cumulative workload conditions. Emotion correlated with performance under high cumulative workload conditions.

W/L Cat. Code: 4.2

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Mult. measures	Review	Flight test	Flight simulator
				Flight test

McKenzie, R. E. Assessment correlates of workload and performance. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 145-159.

This paper reviews assessment correlates, with separate emphasis on workload, performance, and stress. The correlates can be divided into several groups: physiological correlates, psychological correlates, stress correlates, psychophysiologic correlates, and central nervous system (CNS) correlates. Each group is examined with respect to specific applicable techniques.

W/L Cat. Code: 3.1, 4.1

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Multiple	Review	None	Background
Physiological				

McKenzie, R. E., Buckley, E. P., and Sarlanis, K. An exploratory study of psychophysiological measurement as indicators of air traffic control sector workload. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 129-133.

There has been an ever-increasing concern within the Federal Aviation Agency for the possible adverse effects of stress inherent in the character of the work of Air Traffic Control Specialists (ATCS). Since external job-related measures do no appear to offer satisfactory criteria, attention has been turned to internal operator-related measures in an effort to determine their usefulness in evaluating the stressors inherent in the work of the ATCS. This study was designed to explore the possibility that certain physiological measures could be related to some aspects of the controller's task, namely, workload defined in terms of number of aircraft (traffic density), and the occurrence of aircraft conflicts. Results of this study show that significant differences exist in conflict detection, heart rate, and GSR for the two traffic densities examined.

W/L Cat. Code: 3.1, 4.1.2, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Experimental	Simulator	Flight simulator
Physiological	GSR Heart rate, h.r. var.			Flight test

McLean, J.R. and Hoffmann, E.R. Steering reversals as a measure of driver performance and steering task difficulty. <u>Human Factors</u>, 1975, <u>17</u>, 248-256.

Steering reversal rates, used as a measure of driver performance, are reviewed. The data from two previously reported experiments, carried out in a controlled situation, are used to compare steering reversal rates with other performance measures. While steering reversal rates correlate with other measures of control frequency, they do not necessarily correlate with measures of absolute steering performance. This result is consistent with the view that frequency characteristics provide a measure of steering task difficulty rather than steering performance. The general problems of selecting measures of steering performance and steering task difficulty are discussed. It is shown that, when considering steering task difficulty, care must be taken to differentiate between the difficulty imposed by the task constraints, and the factors which affect the driver's ability to maintain a level of performance commensurate with those constraints.

W/L Cat. Code: 3.1
Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Construct Experimental	Field	Flight simulator Flight test

Melton, C. E. Workload and stress in air traffic controllers. In B. O. Hartman and R. E. McKenzie (Eds.) <u>Survey of methods to assess workload</u>. AGARD-AG-246, August, 1979, 137-144.

Data collected at 14 air traffic control facilities regarding air traffic controller (ATCS) workload and urinary stress indicator hormone (SIH) excretion is reviewed. The data show a significant relationship between objective workload measures (radio transmission time and traffic counts) and indexes of catecholamine excretion. Mean epinephrine excretion by ATCSs at six air traffic control towers ranging from very low to very high traffic density was significantly ($r = 0.96$) related to annual traffic counts at those towers. The sympatho-adrenomedullary axis that prepares the organism for "fight or flight" described by W. B. Cannon in 1929 apparently is applicable to ATCSs. The question of underload, optimum load, and overload is discussed.

W/L Cat. Code: 3.1, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Experimental	Field	Flight simulator
Physiological	Body fluid anal.			Flight test

Melton, C. E., Smith, R. C., McKenzie, J. M., Hoffmann, S. M., and Saldivar, J. T. Stress in air traffic controllers-effects of ARTS III-automated radar terminal systems. Aviation, Space, and Environmental Medicine, 1976, 47, 925-930.

Physiological, biochemical, and psychological assessments of stress in air traffic controllers were made at Los Angeles (LAX) and Oakland (OAK) Terminal Radar Approach Control TRACON) facilities before and after installation of Automated Radar Terminal Systems-III (ARTS-III). Heart rates of controllers on duty or at rest scarcely changed from before to after ARTS-III installation. Total stress increased at both TRACONs, and the increase was entirely due to elevated catecholamine excretion. Steroid excretion was significantly reduced at both facilities after ARTS-III installation. Scores on the A-State scale of the State-Trait Anxiety Inventory indicated that introduction of ARTS-III had no appreciable effect on work-related anxiety levels of controllers. The post-ARTS-III A-State means for both facilities were not significantly elevated.

W/L Cat. Code: 1.1, 4.1.10, 4.1.12
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Field	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test
	Body fluid anal.			

Melton, C. E., Smith, R. C., McKenzie, J. M., Wicks, S. M., and Silver, J. T. Stress in air traffic personnel: low-density towers and flight services. Oklahoma City, Oklahoma: Federal Aviation Administration, FAA-AM-72-73, September, 1977. (AD A046 826).

Stress and anxiety levels were measured in 10 air traffic control specialists (ATCS) at two low-traffic-density towers and in 24 flight service (FS) specialists. Physiological measurements consisted of heart rate and urine biochemical analysis for 17-ketogenic steroids, epinephrine, and norepinephrine. On-duty arousal in ATCS's and FS specialists was evident both physiolgically and psychologically; such arousal was within psychologically normal limits and was generally low physiologically. It is concluded that it is inappropriate to describe all air traffic control work, as is commonly done in the popular press, as unusually stressful.

W/L Cat. Code: 1.1, 4.1.3, 4.1.10, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Field	Flight simulator
Physiological	EKG			
	Heart rate, h. r. var.			
	Body fluid anal.			

Merhav, S. J. and Ya'acov, O. B. Control augmentation and workload reduction by kinesthetic information from the manipulator. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 361-379. (NASA TM X-73 170).

This paper is concerned with control augmentation and workload reduction by means of kinesthetic information provided by the manipulator. The control stick is loaded by a torque motor and the system is so interconnected that it presents complete kinesthetic input and output information from the controlled plant. Thus, the control task involves the same kinesthetic cues and the low workload as in nonintermediary handling of objects. It is demonstrated that within 20 rad/sec, which is the effective bandwidth in manual control, the method is realizable for a large variety of plants which may be unstable and time varying. Tracking and regulating tests demonstrate that very substantial improvements in accuracy and reduction in workload are obtained in comparison with ordinary isotonic, isomorphic or isometric manipulators. A test for the fixed set point regulation task involving a second order plant reveals that the control force law involved is strikingly similar to that of a linear regulator with an energy constraint obeying a quadratic performance criterion. The corresponding theoretical closed loop transfer function is in agreement with known linear models of the manual neuro-muscular system.

W/L Cat. Code: 2.2.4, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Meyer, R. E. Stress and the air traffic controller. Revue de Medicine Aeronautique et Spaciale, 1974, 13, 97-106.

The flight controller's task requires continuous vigilance, possibly for extended periods without a break. A significant factor to be borne in mind is that the individual controller has no control over his rate of work. It has been recorded that with increasing traffic density, controllers are able to maintain a high performance level but that as they do, the stress level rises accordingly and the ultimate safe tolerance level becomes the limiting factor on the system. It is shown that this task level is not the only serious source of stress but that other factors such as noise, the effects of shift work, family problems, and others all contribute in varying degrees to the operator's workload. It must be kept firmly in mind, however, that whatever his loading is, he must still attain the highest degree of safety that is humanly possible.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Review	None	Background

Michon, J. A. A note on the measurement of perceptual motor load. Ergonomics, 1964, 7, 461-463.

This note describes a method of measuring the perceptual motor load (PML) of tasks in which activity is negligible, and the input and processing of perceptual data is the important thing. The method involves a tapping (interval production) task that is measured for regularity. Comparisons are made between task scores and both subject and expert ratings. Agreement is good.

W/L Cat. Code: 1.1, 2.1.2, 2.2.2

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
Spare m. capacity	Inform. theory			Flight test
	Subsidiary task			

Michon, J. A. Tapping regularity as a measure of perceptual motor load. Ergonomics, 1966, 9, 401-412.

Numerous methods have been devised to measure perceptual load. Unfortunately the concept itself is ill-defined, which makes different approaches practically incomparable. The central problem is the ordering of tasks of different types. Most methods compare tasks that differ only in one variable, such as speed or input/output uncertainty. There are however methods which can be applied to a wider range of tasks. One such approach observes the timing of successive actions: load will cause "traffic control" problems in the central nervous system, so that actions will be executed in an irregular fashion. The use of irregularity as a measure of perceptual load depends on the availability of a "functional" descriptive system of behaviour, as opposed to current "phenomenal" systems like those of time and motion study. A convenient substitute is that of measuring the irregularity of a subsidiary performance. Key tapping was found to satisfy certain methodological requirements. Some experiments evaluating this method are discussed.

W/L Cat. Code: 2.2.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
				Flight test

Michon, J. A. and Doorne, H. van Equipment note: A semi-portable apparatus for the measurement of perceptual motor load. Ergonomics, 1967, 10, 67-72.

A device is described which makes it possible to record the intervals produced by a subject in a method for measuring perceptual motor load. The system is specially adapted for field work and operating under difficult electrical conditions.

W/L Cat. Code: 2.2.2

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Construct Field Flight simulator

Flight test

Miller, R. G. and Rubin, R. T. Stress of aircraft carrier landings. 1. Corticosteroid responses in Naval aviators. San Diego, California: Navy Medical Neuropsychiatric Research Unit, Report No. NMNRU-70-16, April, 1970.

Serum and urine cortisol levels were measured in Navy pilots and their flight officers during aircraft carrier landing practice in the two-man F-4B jet aircraft. The pilots showed a considerably adrenal cortical stress response; the flight officers did not. The complex and dangerous task of carrier landing appears to be a greater stress on the pilot in control of the aircraft than on his passive partner. These findings suggest that in acute stress situations, assigned role and responsibility may become dominant factors in the hierarchy of psychoendocrine control of adrenal cortical responses. As a possible reflection of central norepinephrine metabolism urine MHPG excretion was measured in naval aviators during aircraft carrier landing practice, a complex task and a stress of considerable magnitude. Mean urine MHPG was significantly increased after both day and night carrier landings compared to a nonflying control day. These findings suggest that there may be an accelerated metabolism of brain norepinephrine under conditions of heightened arousal and concentration compared to the normal waking state.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2., 4.

Physiological Body fluid anal. Experimental Flight test Flight simulator

Flight test

Milord, J. T. and Perry, R. P. A methodological study of overload. Journal of General Psychology, 1977, 97, 131-137.

The purpose of this research is to establish a methodology for studying stimulus overload in the psychological laboratory. It is argued that to maximize the conditions of overload in simulation, the dimensional criteria of maximal intensity, maximal diversity, and minimal patterning must be included in the methodology. In addition, it is suggested that the psychological phenomenon of overload be operationally defined in terms of the individual's perception of overload rather than the input-output capacity of the system. College students performed either an overload or no overload version of a proofreading-vigilance task, a driving-memory task, or a computation-interruption task. The driving-memory task, which was intended to be most extreme on the dimensions of intensity, diversity, and patterning, was perceived as the most overloading of the three experimental tasks. This led to the conclusion that this driving-memory task represented a substantial improvement over existing methods.

W/L Cat. Code: 1.1, 2.2.1, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Laboratory	Background
Spare m. capacity	Subsidiary task		Simulator	
Primary task	Single measures			

Mobbs, R.F., David, G.C. and Thomas, J.M. An evaluation of the use of heart rate irregularity as a measure of mental workload in the steel industry. London, England: British Steel Corporation, BISRA, OR/HF/25/71, August, 1971.

An experiment is reported in which heart rate was recorded while subjects performed a mental task that was varied in "complexity" and presented in several paced and unpaced conditions. The relationships between twelve conditions of mental load and heart rate irregularity are discussed. Another experiment examines the relationship between heart rate irregularity and physical load on a bicycle ergometer. A third experiment is reported in which subjects repeated the same exercises on a bicycle ergometer on 3 separate days. The results of these experiments are discussed, with special reference to previously reported influences of respiratory rate and depth on heart rate irregularity.

W/L Cat. Code: 4.1.3, 4.1.10, 4.1.11
Op. Behav. Code: 1., 2., 4.

Physiological	EKG	Experimental	Laboratory	Flight simulator
	Heart rate, h.r. var.			Flight test
	Breathing anal.			

Monty, R. A. and Ruby, W. J. Effects of added workload on compensatory tracking for maximum terrain following. Human Factors, 1965, 7, 207-214.

The relative merits of presenting each of two command signals (δ_e, the elevator deflection angle, and γ, the aircraft flight-vector angle) on a compensatory display for manual control of a simulated aircraft on a terrain-following mission were examined. It was found that imposing additional workloads on the pilot led to a greater decrement in tracking performance with the γ command than with the δ_e command. Further, the workload task itself was performed with greater proficiency while tracking with the δ_e command. The apparent merits of the δ_e command warrant further investigation.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures

Moray, N. Where is capacity limited? A survey and a model. Acta Psychologica, 1967, 27, 84-92.

A model is presented for the limitations of processing information by the human operator which proposes that he acts not as a limited capacity channel with fixed capacity, but as a limited capacity processor. The total capacity of the brain can be allocated to the separate aspects of the tasks, such as reception, recoding, emission, storing, etc. Hence from moment to moment the size of the 'channel' in the Shannon sense will appear to vary. In particular parallel processing is possible where the total capacity is not exceeded, and where there is high compatibility. Experimental evidence in support of the model is presented.

W/L Cat. Code: 2.1.2

Op. Behav. Code: 1., 2.

Spare m. capacity Inform. theory Construct Laboratory Background

Experimental

Moray, N. Attention, control, and sampling behavior. In T. B. Sheridan and G. Johannsen (Eds.) Monitoring behavior and supervisory control. New York: Plenum, 1976, 221-243.

A critical review of attention and sampling behavior is presented. The two approaches, cognitive psychology and information processing are first reviewed. It is then suggested that by developing internal models of the human operator, differences in the two approaches can be reconciled. One of the major problems confronting internal model formulation is that of parameter measurement. It is suggested that spectral techniques are among the most powerful in parameter determination.

W/L Cat. Code: 3.1, 3.3

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Review	None	Flight simulator
	Math. modeling	Construct		

Moray, N. Models and measures of mental workload. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 13-21.

Systematic and careful study of the formal relation between normative measures, and a corresponding empirical analysis of the interrelation of the scores of the different empirical measures (including physiological ones) are needed. Just as each normative model gives an "ideal" score, so should they provide normative intercorrelations. An enormous practical step would have been taken if one could specify the boundary conditions within which measures, models, and intercorrelations are effective and can be relied on.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Math. model	Construct	None	Flight simulator

Morgan, B. B., Jr., Coates, G. D., Alluisi, E. A., and Kirby, R. H. The team-training load as a parameter of effectiveness for collective training in units. Norfolk, Virginia: Old Dominion University, Performance Assessment Laboratory, Technical Report ITR-78-14, May, 1978.

This report summarizes the results of two groups of studies of team training. In each of ten studies, five subjects worked together as a team for eight hours per day over six consecutive days; during their first 48 hours of work, each team was trained to perform the six tasks that constitute the synthetic work presented with the Multiple-Task Performance Battery. The teams consisted of different combinations of the total of 20 undergraduate male volunteer subjects to provide team-training loads (percentages of untrained team personnel) ranging from 0 to 100 percent in 20 percent steps. The data of the 10 studies were combined to permit analysis of the effects of team-training loads ranging from 0 to 100 percent in 10 percent steps, and the effects of team-training load on training and performance effectiveness were therby assessed.

W/L Cat. Code: 5.2

Op. Behav. Code: 1., 2., 4.

Primary task Single measures Experimental Laboratory Flight simulator

Flight test

Morgan, T. R. Inflight physiological data acquisition system. Brooks AFB, Texas: USAF School of Aerospace Medicine, SAM-TR-75-46, December, 1975.

An inflight physiological data acquisition system, for use in recording selected biomedical and environmental parameters of flight, has recently completed final development. The system employs an instrumented oxygen mask which inputs to signal-processing and recorder packages positioned in conveniently accessible cockpit areas, or in pockets of the crewmember's survival vest. These subunits are of sufficiently flexible configuration to be fully compatible with the broad spectrum of military cockpits and can monitor a variety of parameters, including accessible lung volumes (such as tidal volume, minute volume, and forced vital capacity), oxygen consumption, ECG activity, G_z, cabin pressure, an internally generated time-code signal, and voice communications. Information is recorded on cassette tape for subsequent retrieval and analysis by ground-based data reduction equipment. The system is expected to prove useful in establishing breathing-system design criteria and assessing biomedical stresses of flight.

W/L Cat. Code: 4.1

Op. Behav. Code: 1., 2., 3., 4.

Physiological Multiple Experimental Flight test Flight simulator

Flight test

Morrissette, J.O., Crannell, C.W. and Switzer, S.A. Group performance under various conditions of work load and information redundancy. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, AMRL-TR-65-16, April, 1965. (AD 615 376).

The objective of the present study were: (a) to determine the counteracting effect of work load (W) and informational redundancy (R) on performance, and (b) to determine the performance of groups of individuals working cooperatively with groups of individuals working independently, under various conditions of work load and informational redundancy (W-R). Sex differences were also considered.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 3., 4.1

Spare m. capacity | Subsidiary task | Experimental | Laboratory | Background
Primary task | Single measures

Mourant, R. R. and Rockwell, T. H. Mapping eye-movement patterns to the visual scene in driving: an exploratory study. Human Factors, 1970, 12, 81-87.

Eye movements of eight drivers were filmed as the drivers traveled on a local expressway at 50 mi. per hour. Search and scan patterns of the drivers became more compact and the center of location shifted down and to the left as the drivers became more familiar with the route. The center of the final pattern was located above the right road edge marker and slightly higher than the horizon. The search and scan patterns verified that the peripheral area of the eye is used for monitoring lane position, other vehicles, and road signs so that the fovea may be directed for a closer examination when the situation demands it.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2., 4.

Physiological | Eye movement | Experimental | Field | Background

Mulder, G. Mental load, mental effort and attention. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 299-325.

This paper provides a summary of many of the widely-used techniques of workload estimation. Conceptually, mental workload can be compared with physical workload. Whereas in physical workload maximum intake of oxygen is an important limiting factor, in mental workload processing capacity is a limiting factor. To measure mental workload secondary tasks may be used. Additionally mental workload may be measured by "strain", that is physiologically. Newer concepts involve information processing models and other "internal" models of humans.

W/L Cat. Code: 2.2, 3.3, 4.1

Op. Behav. Code: 1., 2.

Spare m. capacity	Multiple	Review	None	Flight simulator
Primary task		Construct		
Physiological				

Mulder, G. Sinusarrhythmia and mental work load. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 327-343.

Sinusarrhythmia has been associated with respiration. In the last decade insight has been obtained into the mechanisms underlying this phenomenon. Spectral analysis has been applied and reveals the different mechanisms involved. This paper reviews and integrates the present state of knowledge of sinusarrhythmia and its relationship to certain classes of mentla workload.

W/L Cat. Code: 4.1.3, 4.1.10, 4.1.11

Op. Behav. Code: 1., 2.

Physiological	Heart rate, h.r. variability	Review	None	Flight simulator
	Blood pressure			Flight test
	Breathing analysis			

Mulder, G. and Mulder-Hajonides van der Meulen, W. R. E. H. Mental load and the measurement of heart rate variability. Ergonomics, 1973, 16, 69-83.

A number of studies concerning heart rate variability and mental load are reviewed. It is concluded that in paced choice reaction tasks the number of reversal points in the cardiotachogram is the most sensitive measure of the load of the task. This measure was strongly correlated with respiration. Spectral analysis of heart rate variability revealed the existence of a frequency component at about 0·10 Hz, a respiration frequency and sometimes a task frequency. In a number of tasks the respiration frequency increased, and the amplitude of energy in the lower frequencies decreased (i.e., there was a decrease in heart rate variability).

W/L Cat. Code: 4.1.3, 4.1.10, 4.1.11

Op. Behav. Code: 1., 2., 4.

Physiological	EKG	Construct	Laboratory	Flight simulator
	Heart rate, h.r. var.	Experimental		Flight test
	Breathing anal.			

Murphy, J.V. and Gurman, B.S. The integrated cockpit procedure for identifying control and display requirements of aircraft in advanced time periods. Proceedings of the AGARD Conference on Guidance and Control Displays, AGARD-CP-96, 4-1 - 4-7. (AD 739 779).

The Integrated Cockpit Research Procedure (ICRP) was used to define cockpit control and display requirements for the next generation utility transport helicopter. A control and display requirements analysis was conducted based upon the derivation of specific functions necessary for accomplishing four specified missions. In turn, control/display mechanization was derived from specific mission functions. A Time-Based Load Analysis (TBLA) was used as an evaluation tool to provide a quantitative index of operator load. A Load Analysis was performed utilizing computer processing techniques to make task adjustments in real time. The technique also provided an analysis of contingency situations and denoted overload conditions that occurred. The hard copy mock-up was a full-scale cockpit shell in which the alternative mission control/display configurations could be illustrated.

W/L Cat. Code: 2.1.1
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator

Murphy, M. R. Coordinated crew performance in commercial aircraft operations. Proceedings of the 21st Annual Meeting of the Human Factors Society, San Francisco, California, October, 1978, 416-420.

A critical need for an improved system of coding and analyzing crew member interaction is identified and a specific methodology suggested. The complexity and lack of precision of many crew and task variables suggest the utility of fuzzy linguistic techniques for modeling and computer simulation of the crew performance process. Other research methodologies and concepts that have promise for increasing the efficacy of research on crew performance are identified.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Math.model	Construct	None	Background

Murphy, M. R. Analysis of eighty-four commercial aviation incidents: implications for a resource management approach to crew training. Proceedings of the 1980 Annual Reliability and Maintainability Symposium, San Francisco, California, June, 1980.

A resource management approach to air crew performance is defined and utilized in structuring an analysis of 84 exemplary incidents from the NASA Aviation Safety Reporting System. The distributions of enabling and recovery factors between and within five analytic categories suggest that resource management training be concentrated on: 1) interpersonal communications, with Air Traffic Control (ATC) information of major concern; 2) task management, mainly setting priorities and appropriately allocating tasks under varying workload levels; 3) planning, coordination, and decisionmaking concerned with preventing and recovering from potentially unsafe situations in certain aircraft maneuvers. Problem solving and leadership skills were implicated as factors in a sufficient number of incidents to require further study. Leadership, social skills, and role-issue effects may be under-reported in voluntarily submitted incident data; more systematic study is recommended. Some problem areas are identified for which design changes are apparently in order, particularly the ATC interface.

W/L Cat. Code: 2.1.1, 4.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct Experimental	Field	Background
Primary task	Single measures			

Murphy, M.R., McGee, L.A., Palmer, E.A., Paulk, C.H. and Wempe, T.E. Simulator evaluation of three situation and guidance displays for V/STOL zero/zero landings. Proceedings of the 10th Annual NASA-University Conference on Manual Control, Wright-Patterson AFB, Ohio, April 9-11, 1974.

A simulator study was conducted to compare and evaluate design features of 3 electronic displays for potential application to V/STOL zero-zero landings, the RAE proposed combined transition display, the Saab perspective display, and the Teldix hover display. Objective measures were obtained of tracking performance, attitude variability, and control activity and were analyzed by an analysis of variance. Pilot opinion was also obtained. It was concluded that (1) the RAE display is less effective than the Saab or Teldix displays for localizer tracking, (2) pilot workload, as indicated by rms variability measures, was lowest with the Saab display and highest with the Teldix display, (3) time to capture was shortest with the Teldix display and longest with the RAE display, (4) extensive central clutter on the Teldix display probably resulted in its being given the lowest pilot opinion rating, and (5) pilot opinion favoring the RAE display over the Saab display was at variance with objective performance measures.

W/L Cat. Code: 1.2, 3.1
Op Behav. Code: 1., 2., 4.

Opinion	Questionnaire	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Murrell, J. F. Pilot's assessment of their cockpit environment. In Problems of the Cockpit Environment, AGARD Conference Proceedings No. 55, March, 1970, 17-1 - 17-6. (AD 705 369).

Assessment by the user pilot is an important source of information as to the efficiency of aircraft display and control systems. Much information can be gained and reduced to quantitative form by use of open-ended questions. In the study reported, 229 civilian airline pilots representing nine different aircraft types, responded to five open ended questions about design and layout of their cockpit. Pilots flying different types of aircraft agreed in the frequency of their comments and criticisms. They most often criticized their radio and navigation aids. Application of these results is discussed.

W/L Cat. Code: 1.2

Op. Behav. Code: 1., 2., 3., 4.

Opinion Questionnaire Experimental Flight test Flight simulator

Flight test

Nagaraja Rao, P. K. and Griffin, M. J. Secondary task performance of helicopter pilots during low-level flight. University of Southampton, Institute of Sound and Vibration Research, Report No. ISVR-TR-54, December, 1971.

An investigation has been made into the changes in performance at a complex reaction time task during helicopter flight. The two-choice reaction time task employed required responses to a continuous tone and a similar tone pulsed with a 6 Hz repetition frequency. Eight pilots flew two-hour flights consisting of 15 minutes at 1000 ft., 90 minutes at 100 ft. and a further 15 minutes at 1000 ft. The task was presented at an average interval of one and a half minutes throughout the two-hour period.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 4.2

Spare m. capacity Subsidiary task Experimental Flight test Flight simulator

Flight test

Nakamura, M., Okaue, M., and Hori, H. The change of heart rate during mental work. Tokyo, Japan: Japan Air Self Defense Force, Aeromedical Laboratory Reports, 1974, 14, 181-190. (In Japanese.)

Experiments were performed to evaluate the change of heart rate during mental work. Two cases of heart rate were tested: one at the time of research presentation; the other of personal behavior under the anxiety states. The following results were obtained: a rapid increase in heart rate was observed when the experiment began, with the rate decreasing immediately after it was finished. When the method of systematic desensitization was administered, the heart rate increment was observed along with muscle tension. The heart rate is affected by emotions, but by training, it is possible that the change of heart rate can be reduced gradually. It is possible that anxiety can be suppressed by controlling one's own heart rate.

W/L Cat. Code: 4.1.9, 4.1.10

Op. Behav. Code: 1., 2.,

Physiological Muscle tension Experimental Laboratory Flight simulator

Heart rate, h.r. var.

NASA-Ames Research Center. Secondary task for full flight simulation incorporating tasks that commonly cause pilot error: Time estimation. Moffett Field, California. NASA-TM-X-74153, October, 1975.

The objective of this joint research program was to provide human factors investigators with an unobtrusive and minimally loading additional task that is sensitive to differences in flying conditions and flight instrumentation associated with the main task of piloting an aircraft simulator. The additional task under investigation was time estimation, an activity occasionally performed by pilots during actual flight. Previous research indicated that the duration and consistency of time estimates is associated with the cognitive, perceptual, and motor loads imposed by concurrent simple tasks. The present research was aimed at clarifying the relationship between the length and variability of time estimates and concurrent task variables under a more complex situation involving simulated flight.

W/L Cat. Code: 2.2.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Time estimation	Experimental	Flight simulator	Flight simulator
				Flight test

Nataupsky, M., Schwank, J. C. H., Griggs, E. B., McKay, K. E., Jr., and Schmidt, S. D. Effect of pretraining criterion on flight simulator and secondary cognitive task performance. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 305-309.

Twenty-eight cadets were trained in a flight simulator under one of four experimental groups. The groups were defined first by having heading information either provided by the normal heading indicator or by peripheral lights and second by their being trained on either a 5° or a 10° heading deviation criterion. All cadets were subjected to four levels of a secondary cognitive task plus a control condition. There were no significant differences for either the main effect of heading indicator type or criterion level of training. The main effect of cognitive task difficulty level was significant for most measures. In addition, the heading indicator type by training criterion level interaction produced significant differences. The study seems to indicate that training criteria are important independent variables in complex psychomotor/cognitive flight simulator tasks.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Navon, D. and Gopher, D. On the economy of the human processing system: A model of multiple capacity. Haifa, Israel: Technion Technical Report AFOSR-77-1, 1977. (AD A059 575).

An approach to human performance which is based on economic concepts is proposed. This approach hinges on the idea that the human processing system has a number of mechanisms each having its own capacity. Those capacities can at any moment be allocated among several processes. Since tasks may differ with respect to the types of mechanisms they call for and the demands they pose for the use of those mechanisms, it is argued that the hope to find single measures for system capacity and mental load may be groundless. Different pairs of time-shared tasks may conflict with each other to a variable degree, which is difficult to predict without knowing the overlap in their demand for various mechanisms. The amount and specific nature of trade-off between time-shared tasks can be displayed by means of performance operating characteristics. The effects of a number of properties of the sytem and of the tasks on the shape and interpretation of performance operating characteristics are discussed. The analysis in this paper also serves to elucidate the notion of resources brought forward by previous authors, to elaborate on the distinction between demand for and supply of resources, to discuss possible interactions between the effects of supply of resources and situation parameters on performance, and to conjecture about the way by which allocation policy depends on the value of outcomes of different allocations. Finally, relevant empirical evidence and implications for further research are discussed.

W/L Cat. Code: 3.3
Op. Behav. Code: 2.0

Primary task	Math.model	Construct	None	Flight simulator
				Flight test

Navon, D. and Gopher, D. Task difficulty resources and dual task performance. Attantion and Performance VIII. Hillsdale, New Jersey: Lawrence Erlbaum and Assoc., 1979. (In press.)

If the processing system is viewed as comprised of a number of mechanisms each having its own capacity, which may be considered as a separate resource, then a difficulty manipulation may affect differentially the use of each of those capacities. If in a dual-task situation a manipulation of the difficulty of one task affects the use of a mechanism which is not required by the other task, processing of the latter may remain intact under some circumstances. To get a complete picture of how difficulty affects dual-task performance, it is proposed to manipulate task preferences as well as difficulty parameters and to present their joint effect by families of POCs. An application of this methodology to the study of pursuit tracking is briefly described and interpreted in terms of multiple resources.

W/L Cat. Code: 2.2.2, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	Laboratory	Background
Primary task	Single measures	Experimental		

Nogoescu, R. Validity and limitations of telemetric evaluations of mental load. Paper presented at the 7th Congress of the International Ergonomics Association, Warsaw, Poland, August 27-31, 1979.

This paper is a personal view of the current status of telemetric measurement of electrophysiological parameters for the ergonomic assessment of perceptual and mental strain. Defining the optimum set of parameters may allow one to establish the relative importance of alternative telemetric methods for some of the more important models of informational workload. To this end we investigated physiological responses in an experimental simulation of: (a) optimum informational load; and (b) sub-optimum load (monotony). Arguments are advanced for the prime importance of heart rate and heart rate variability in optimum load measurement, as well as for the usefulness of plethysmography and electroencephalography in studies of monotonous work.

W/L Cat. Code: 4.1.3, 4.1.5, 4.1.10

Op. Behav. Code: 1., 2.

Physiological	EKG EEG Heart rate, h.r. var.	Experimental	Laboratory	Background

Nicholson, A. N. Aircrew workload during the approach and landing. Aeronautical Journal, 1973, 77, 286-289.

The workload during the approach and landing which is likely to be experienced by any airline pilot operating worldwide routes is analyzed. The operational procedures of the flight deck involved in the study conform to those used by the majority of international carriers. The workload during each letdown was assessed by the pilot. The individual factors which influenced the workload assessment were the technical serviceability of the aircraft and efficiency of the control procedures. It appears that factors amenable to correction are likely to be responsible for much of the high workload situations in civil transport operations.

W/L Cat. Code: 1.2, 2.1.1

Op. Behav. Code: 1., 2., 3.4.

Opinion	Questionnaire	Experimental	Flight test	Flight simulator
Spare m. capacity	Task comp., time assess.			Flight test

Nicholson, A. N., Hill, L. E., Borland, R. G., and Krzanowski, W. J. Influence of workload on the neurological state of a pilot during the approach and landing. Aerospace Medicine, 1973, 44, 146-152.

The workload of a pilot during the let down of a Boeing 707 was modified by coupling the aircraft to the ILS localizer and glide slope path (coupled approach) or by increasing the participation of the co-pilot in the handling of the aircraft (shared approach). The electrocardiogram of the pilot was recorded during the let down and finger tremor was recorded after landing. The operational significance of these studies is discussed.

W/L Cat. Code: 4.1.3, 4.1.9

Op. Behav. Code: 1., 2., 4.

Physiological	EKG	Experimental	Flight test	Flight simulator
	Muscle tension, tremor			Flight test

Noble, M. and Trumbo, D. The organization of skilled response. Organizational Behavior and Human Performance, 1967, 2, 1-25.

A series of experiments concerned with the ways in which responses become organized is discussed. The principle parameter in most studies was stimulus coherence, and tracking tasks were used as a vehicle because graded responses permit detailed and fine-grained analyses. Both spatial and temporal coherence are used in response organization, and type of response strategy varys with degree of stimulus coherence. The effects of secondary tasks, sequence length and task coding were also examined.

W/L Cat. Code: 2.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Laboratory   Background

Noel, C. E. Pupil diameter versus task layout. Master's thesis, Naval Postgraduate School, Monterey, California, September, 1974. (AD 787 375).

Using pupil size as an indirect measure of mental activity, this experiment investigated a spatially compatible and non-compatible forced choice task. It was found subjects could process a higher presentation rate in the compatible layout than in the non-compatible layout without going into an overload condition. Also, when subjects were already in a pupil constricted condition (overloaded) in a non-compatible arrangement, it was found the constriction could be significantly reduced by switching to a compatible arrangement.

W/L Cat. Code: 4.1.8, 3.1

Op. Behav. Code: 1., 2., 4.

Physiological Pupillary dia. Experimental Laboratory Flight simulator
Primary task Single measures

Norman, D. A. and Babrow, D. G. On data-limited and resource limited processes. Cognitive Psychology, 1975, 7, 44-64.

This paper analyzes the effect on performance when several active processes compete for limited processing resources. The principles discussed show that conclusions about the interactions among psychological processes must be made with caution, and some existing assumptions may be unwarranted. When two (or more) processes use the same resources at the same time, they may both interfere with one another, neither may interfere with the other, or one may interfere with a second without any interference from the second process to the first. The important principles are that a process can be limited in tis performance either by limits in the amount of available processing resources (such as memory or processing effort) or by limits in the quality of the data available to it. Competition among processes can affect a resource-limited process, but not a data-limited one. A number of experiments from the psychological literature are examined according to these processing principles, resulting in some new interpretations of interactions among competing psychological processes.

W/L Cat. Code: 2.2, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Review Laboratory Background

Primary task Single measures Construct

North, R.A. Task components and demands as factors in dual-task performance. Savoy, Illinois: University of Illinois at Urbana-Champaign, ARL-77-2/ AFOSR-77-2, January, 1977.

This study explored the effects of interference between tasks as related to their specific functional requirements and under changing priorities. Four tasks were performed singly and in all pairwise combinations to compare their mutual interference levels. The tasks were one-dimensional compensatory tracking, and three self-paced keyboard response tasks, one requiring a transformation by categorizing, one requiring storing and responding with the previous stimulus, and one requiring no intervening activity between stimulus recognition and response. Tracking paired with any of the three keyboard tasks was least interfering, tracking and tracking was moderately interfering, and keyboard/keyboard combinations the most interfering, suggesting that qualitatively dissimilar tasks are performed better than functionally similar tasks. The keyboard task requiring continuous storing and response to the previous stimulus was highly disruptive when paired with other keyboard tasks, and showed little evidence of interweaving with them while the transformation keyboard task was not as disruptive and could be interweaved with itself or the simple keyboard task. The manipulation of dual-task demands produced expected changes in performance in nearly all task combinations, but was strongest in tracking/tracking and certain keyboard/keyboard combinations.

W/L Cat. Code: 2.2.1, 2.2.2

Op. Behav. Code: 1.1, 2.1, 4.2

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

North, R. A. and Gopher, D. Measures of attention as predictors of flight performance. Human Factors, 1976, 18, 1-14.

A new technique for measuring individual differences in basic attention capabilities and the validity of these differences in predicting success in flight training were investigated. The testing system included a digit-processing, reaction-time task and a one-dimensional compensatory tracking task. Comparisons were made between separate and concurrent performances of these tasks, with both equal and shifting task priorities. Adaptive techniques were employed to obtain maximum performance levels for each subject in the single-task condition and to maintain dual-task difficulty within subjects. Consistent individual differences in basic attention capabilities were observed and several dimensions of attention capabilities are suggested. A preliminary validation study compared scores for flight instructors and student pilots. In addition, the student sample was dichotomized based on performance in training. There were reliable differences for both groups on dual-task performance efficiency.

W/L Cat. Code: 2.2.1, 2.2.2, 3.1

Op. Behav. Code: 2.1, 4.2

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures

North, R. A. and Graffunder, K. Evaluation of a pilot workload metric for simulated VTOL landing tasks. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 357-361.

A methodological approach to measuring workload was investigated for evaluation of new concepts in VTOL aircraft displays. Multivariate discriminant functions were formed from conventional flight performance and/or visual response variables to maximize detection of experimental differences. The flight performance variable discriminant showed maximum differentiation between crosswind conditions. The visual response measure discriminant maximized differences between fixed vs. motion base conditions and experimental displays. Physiological variables were used to attempt to predict the discriminant function values for each subject/conditon/trial. The weights of the physiological variables in these equations showed agreement with previous studies. High muscle tension, light but irregular breathing patterns, and higher heart rate with low amplitude all produced higher scores on this scale and thus, represented higher scores on this scale and thus, represented higher workload levels.

W/L Cat. Code: 1.1, 3.2, 4.1.3, 4.1.4, 4.1.7, 4.1.8, 4.1.9, 4.1.10, 4.1.14, 4.2
Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Experimental	Flight simulator
Primary task			Flight simulator
Physiological			Flight test

Noyer, A. Mental fatigue and palmar skin resistance. Travail Humain, 1971, 34, 289-298. (In French).

The palmar skin resistance was measured in eleven subjects during a prolonged period of mental overload (experiment 1), and then during a period of partial mental rest (experiment II). The mean palmar skin resistance at the end of experiment 1 was lower than at the end of experiment II. This difference was found in the majority of subjects--the significance being shown best in subjects where the initial levels were similar for both experiments. The palmar resistance thus seems able to discriminate two mental activities of differing intensities. It is suggested that this method be used in the recognition of mental fatigue. The phenomenon of the individuality of the responses could be confirmed.

W/L Cat. Code: 4.1.2

Op. Behav. Code: 2.1

Physiological GSR Experimental Laboratory Flight simulator

Och, G. Time budget as a criterion for the workload of air traffic controller. Munich, West Germany: Messerschmidt-Boelkov G.m.b.H.

A time optimization method for evaluating the capacity of air traffic controllers is presented. As within a given time interval, only a limited number of minutes can be used for active control, the time consumption for the control of various flight phases was measured and used to calculate the number of flights which could be controlled during this interval. A capacity profile for the entire air space of the Federal Republic of Germany was constituted from characteristic traffic patterns obtained for each control sector.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Field	Flight simulator
Primary task	Single measures	Experimental		

O'Connor, M. F. and Buede, B. M. The application of decision analytic techniques to the test and evaluation phase of the acquisition of a major air system. McLean, Virginia: Decisions and Designs, Technical Report 77-3, April, 1977.

The purpose of this effort has been to explore the feasibility of applying decision analytic techniques to the test and evaluation phase of the acquisition of a major weapons system. The proposed response to this need is a computerized system, implemented on an IBM 5100, which contains the test and evaluation information appropriately prioritized. To achieve this goal, two main tasks must be accomplished. One is the development of a hierarchical evaluation structure which relates all the test and evaluation information to missions of the F18. An initial structure has been developed for the controller of aircraft role for the fighter version of the F18, and this structure has been implemented on the IBM 5100 portable computer. To use such a structure, it is necessary to develop a meaningful rating scale on which to rate the aircraft with respect to these tasks. Two major considerations are involved--pilot workload and system effectiveness.

W/L Cat. Code: 1.1

Op. Behav. Code: 2.1, 2.2

Opinion	Rating scale	Construct	Laboratory	Flight simulator

O'Donnell, R. D. Secondary task assessment of cognitive workload in alternative cockpit configurations. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, AMRL-TR-75-49, 1975. (AGARD-CPP-181).

New developments in cockpit design may introduce significantly greater cognitive demand on the crew member. Yet few measurement techniques exist which are able to provide an objective, reliable estimate of the workload introduced by these new systems. New approaches are therefore required. In a series of pilot studies, traditional secondary-task reserve capacity concepts were modified to be used at sub-maximal levels of workload. A primary flight simulation was performed simultaneously with the item recognition task proposed by Sternberg. This task was chosen because the intercept and slope functions of the memory-load/reaction time function appear to assess independently cognitive and sensory-motor workload. Results indicated the secondary task shows reliable and consistent changes with variations in workload, and appears promising as an objective measure of higher mental functions. Auditory and visual versions have been constructed, and further validation studies are being carried out.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

O'Donnell, R. D. Secondary task assessment of cognitive workload in alternative cockpit configurations. In B.O. Hartman (Ed.) Higher Mental Functioning in Operational Environments, AGARD Conference Proceedings No. 181, April, 1976, C-10. (AD A025 663).

New developments in cockpit design may introduce significantly greater cognitive demand on the crew member. Yet few measurement techniques exist which are able to provide an objective, reliable estimate of the workload introduced by these new systems. New approaches are therefore required. In a series of pilot studies, traditional secondary-task reserve capacity concepts were modified to be used at sub-maximal levels of workload. A primary flight simulation was performed simultaneously with the item recognition task proposed by Sternberg. This task was chosen because the intercept and slope functions of the memory-load/reaction time function appear to assess independently cognitive and sensory-motor workload. Results indicated the secondary task shows reliable and consistent changes with variations in workload, and appears promising as an objective measure of higher mental functions. Auditory and visual versions have been constructed, and further validation studies are being carried out.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

O'Donnell, R.D. and Spicuzza, R.J. Pilot performance assessment in systems using integrated digital avionics. Proceedings of the 46th Annual Meeting of the Aerospace Medical Association, San Francisco, California, 1975.

An attempt has been made to develop new methodological approaches to the assessment of skills which will be required in advanced systems. The overall approach involved development of secondary tasks which the operator was required to perform along with a primary flying task. Well established psychomotor tasks, and tests of cognitive function which have been used in non-applied settings, were explored for their potential value as components of an overall secondary task battery. The simulator chosen for the early phases of this program was driven by the Human Engineering Systems Simulator (IBM 360-40) and used some of the dynamics of the lightweight fighter aircraft. The subject was instructed to fly a particular mission segment lasting from one to five minutes. During that time he was also required to perform one of four secondary tasks. The computer surveyed the status of all systems and determined the degree of error from required flight parameters. These deviations were integrated in a weighted formula to arrive at a single score which summarized the subject's ability to fly that mission for a particular amount of time with a particular secondary task. This evaluation, combined with manipulation of the actual workload, provided a stable base for evaluating the meaning of changes in secondary tasks during performance of particular primary tasks.

W/L Cat. Code: 2.2.1, 2.2.2, 3.2
Op Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Review	Flight simulator	Flight simulator
Primary task	Mult. measures	Experimental		Flight test

Offenloch, K. Neurophysiological assessment of functional states of the brain. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CP-216, April, 1977, A10-1 - A10-4.

Neurophysiological methods are used to assess functional states of the brain with precision that surpasses that of classical psychological methods. Not only neurological syndromes, but also slight changes on the vigilance scale as well as functional changes associated with cognitive and intellectual functions can be correlated with the electrical activity of the brain and hereby be objectively determined.

W/L Cat. Code: 3.1, 4.1.5

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Construct	Laboratory	Background
Physiological	EEG	Experimental		

Ogden, G. D., Levine, J. M., and Eisner, E. J. Measurement of workload by secondary tasks. Human Factors, 1979, 21, 529-548.

The post-1965 literature on the use of secondary tasks in the assessment of operator workload was surveyed. Twelve classes of tasks were identified; the most frequently used were choice reaction time, memory, monitoring, and tracking. The literature review did not suggest a single best task or class of tasks for the measurement of workload. Limitations in using secondary tasks are discussed, and directions for future research are presented.

W/L Cat. Code: 2.2

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Review	None	Flight simulator
				Flight test

Ohhara, S. Changes of tracking performance, respiration, and heart rate during experimentally induced anxiety. Japan Air Self Defense Force, Aeronautical Laboratory Reports, 1970, 11, 198-205. (In Japanese).

Changes caused by unexpected noise stress and anticipated psychic stress on tracking performance, respiration and heart rate were investigated. The main results obtained are: (1) in general, unexpected noise stress affected performance more strongly than anticipated psychic stress; (2) it took 1 sec to recover from the increased heart rate caused by unexpected stimulation; (3) tracking performance was arrested after 0.4 to 0.8 sec following stimulation; and (4) it took 0.8 to 2.4 sec to recover from this block.

W/L Cat. Code: 4.1.10, 4.1.11

Op Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test
	Breathing anal.			

Older, H. J. and Jenney, L. L. Psychological stress measurement through voice output analysis. Alexandria, Virginia: The Planar Corporation, Contract NAS 9-14146, March, 1975.

Audio tape recordings of selected Skylab communications were processed by the Psychological Stress Evaluator (PSE) manufactured by Dektor Counterintelligence and Security, Inc., Springfield, Virginia. Strip-chart tracings were read "blind" and scores were assigned based on characteristics reported by the manufacturer to indicate psychological stress. These scores were analyzed for their empirical relationships with operational variables in Skylab judged to represent varying degrees of situational stress. Although some statistically significant relationships were found, the technique was not judged to be sufficiently predictive to warrant its use in assessing the degree of psychological stress of crew members in future space missions.

W/L Cat. Code: 3.1, 4.3

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Experimental	Flight test	Flight simulator
Physiological	Speech patt. anal.			Flight test

Olson, B. A. Display and control requirements study for a V/STOL tactical aircraft. Wright-Patterson AFB, Ohio: USAF Flight Dynamics Laboratory, AFFDL-TR-66-114, December, 1966.

A study of the display/control requirements for a tactical V/STOL aircraft was conducted using analytical and simulation techniques. Workload levels were calculated by the discontinuous control analysis technique for the V/STOL crews discrete tasks. Pilot workload levels were empirically established for level aerodynamic flight, transition to hover, and landing from hover. Three landing display formats, two manual control modes, three thrust-to-weight ratios and three wind conditions were evaluated. A landing display format was developed that was demonstrated to be feasible for operating a V/STOL IFR with minimum electronic aids on the ground and at less than 100 percent pilot workload.

W/L Cat. Code: 2.1.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Inform. theory	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Onstott, E. D. Task interference in multi-axis aircraft stabilization Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 80-103. (NASA TM X-73,170).

A time domain attention allocating multi-axis pilot model has been used to examine task interference effects in a two-axis attitude stabilization task in turbulence. Configurations from a matrix of uncoupled lateral and longitudinal F-5 dynamics were analyzed to determine the influence of each axis on the control performance of the other. The analysis showed that an inappropriate choice of longitudinal dynamics would deteriorate the roll stabilization with no change in the lateral dynamics or pilot model. Furthermore, the influence of roll versus pitch angle display scalings were analyzed by hypothesizing that the task urgencies used to allocate attention in the pilot model should be weighted by the scaling factors. A fixed base simulation verified the model, the resonant task interference, and the scaling hypothesis; further validation through manned simulation was performed using a complete nonlinear YF-17 aircraft model and the Northrop Large Amplitude Simulator.

W/L Cat. Code: 3.1, 3.3
Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Flight simulator	Flight simulator
	Math. model			Flight test

Onstott, E. D. and Faulkner, W. H. Prediction of pilot reserve attention capacity during air-to-air target tracking. Proceedings of the 13th Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, June, 1977, 136-142.

Reserve attention capacity of a pilot has been calculated using the Northrop pilot model that allocates exclusive model attention according to the ranking of task urgency functions whose variables are tracking error and error rate. The modeled task consisted of tracking a maneuvering target aircraft both vertically and horizontally, and when possible, performing a diverting side task which was simulated by the precise positioning of an electrical stylus and modeled as a task of constant urgency in the attention allocation algorithm. The urgency of the single loop vertical task is simply the magnitude of the vertical tracking error, while the multiloop horizontal task requires a nonlinear urgency measure of error and error rate terms. Comparison of model results with flight simulation data verified the computed model statistics of tracking error of both axes, lateral and longitudinal stick amplitude and rate, and side task episodes. Full data for the simulation tracking statistics as well as the explicit equations and structure of the urgency function multi-axis pilot model are presented.

W/L Cat. Code: 2.2.1, 2.2.2, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	Flight simulator	Flight simulator
Primary task	Math. models	Experimental		Flight test

Opmeer, C. H. J. M. and Krol, J. P. Towards an objective assessment of cockpit workload. I-physiological variables during different flight phases. Aerospace Medicine, 1973, 44, 527-532.

Experiments in a DC-7 simulator and an AT-100 (Beachcraft) simulator, in which an attempt was made to validate heart rate (HR), heart rate irregularity (HI), and respiratory rate (RR) as indicators of mental load are described. As a criterion the following scale was used, from least to most difficult task: rest; level flight; take off; approach. The overall differences proved to be significant at the 0.1% level. The changes in physiological variables from phase to phase showed a correlation of 0.80 with the predicted direction. The highest discriminating power according to the omega squared criterion was shown by RR, followed by HI and HR, in this order. During an experiment with parachute jumpers, in which an anxiety scale was used as a criterion, the reverse order was found.

W/L Cat. Code: 1.1, 4.1.10, 4.1.11

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Physiological	Heart rate, h.r. var. Breathing anal.		Field	Flight test

Opmeer, C. H. J. M. The information content of successive RR-interval times in the ECG. Preliminary results using factor analysis and frequency analysis. Ergonomics, 1973, 16, 105-112.

Factor analysis and frequency analysis were applied to series of interval times between successive heart beats in a preliminary effort to get a maximal amount of information from this kind of data. From a sample, with a mean heart rate ranging from 56·2 to 156·4 per minute, 25 values (partly by using thresholds) were derived and intercorrelated. Scores based on the summation of successive differences and standard-deviation scores showed a mean correlation of 0·96 and were called together a D-complex. Factor analysis revealed 4 interpretable factors, explaining 83% of the total variance. Frequency analysis results were intercorrelated with all other values and showed a high correlation with the D-complex. The use of "scoring" versus "measuring" is discussed.

W/L Cat. Code: 4.1.3, 4.1.10

OP. Behav. Code: 1., 2., 4.

Physiological	EKG	Construct	Laboratory	Background
	Heart rate, h.r. var.	Experimental	Field	

Owens, J. M. and Harris, S. D. On the assessment of processing demands in complex task structures. Pensacola, Florida: Naval Aerospace Medical Research Laboratory, NAMRL-1249, July, 1978. (AD A060 317).

The general applicability of secondary task techniques for assessing processing demands in noncomplex task situations has not been established. Therefore, an investigation involving such tasks was undertaken. A primary task involving successive processing operations upon information including 1) encoding, 2) rehearsal, 3) transformation, and 4) comparison-decision was performed simultaneously with secondary probe tasks requiring simple reaction time (RT) or choice reaction time (RT) responses. Simple RT responses were performed significantly faster than choice RT responses in the secondary task. The increase in reaction time for choice RT responses suggested that subjects used serial processing strategies to avoid capacity overload. Secondary task error rates increased during the comparison-decision interval of the primary task, and primary task reaction times increased when probes occurred during the transformation and comparison-decision intervals. These findings suggest that problems associated with controlling the allocation of processing resources to varying combined-task demands may depreciate the utility of secondary task techniques in complex task situations.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Pardon, N. Methods of evaluation of mental load. Cahiers de Medicine Interprofessionnelle, 1977, No. 65, 19-38. (In French.)

General remarks are presented on work load (different points of view of the work organizer and the ergonomist) and mental load (qualitative and quantative assessment), subjective experience of mental load (individual and collective reactions, fatigue). The article is mainly devoted to a review of objective evaluation criteria (work studies especially on the basis of the bit as unit of information, study of the operator's attitude in mental work situation; productivity studies). The part played by environmental factors, trends in the mental load and ageing is also assessed. An example of a questionnaire design is presented.

W/L Cat. Code: 1.2, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Questionnaire	Review	None	Background
Primary task	Single measures	Construct		

Parks, D. L. Current workload methods and emerging challenges. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 387-416.

This paper summarizes selected technology methods and needs in system design. Three major subject areas are discussed: (1) Background on methods evolution and effectiveness is summarized to illustrate methods and needs. (2) The applied environment and its demands are described, including the system development process with activities, man-machine interface trade-offs, a workload method that is used, and questions the analyst must resolve on a timely basis. More extensive information on a working approach is presented - including the needs, some of the methods, and some of the constraints for presently developing electronic systems. (3) Near term technology challenges are identified for developing computerized, electronic display and control systems. This latter section emphasizes concern with increasing utility of analytic models to develop or evaluate a proliferation of highly flexible display-control-information processing systems. Overall, selected design methods and questions are presented as a framework to which theorists might relate their current state-of-art and provide techniques for present design use.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp. task assess.	Construct	None	Flight simulator Flight test

Parks, D. L. and Springer, W. E. Human factors engineering analytic process definition and criterion development for Computer Aided Function-allocation Evaluation System (CAFES). Seattle, Washington: Boeing Aerospace Company, D180-18750-1, January, 1976. (AD A040 473).

This report presents results of a study to: (1) develop descriptive information for the Human Factors Engineering process in system development; (2) evaluate the Computer Aided Function-Allocation Evaluation System (CAFES) for ability to support the process and for desirable refinements; and (3) define task and equipment data requirements for CAFES. In the resulting single thread description of an approach to performing HFE activities, requirements, methodology and examples of a manual approach are presented. These are followed by brief descriptions of CAFES models and their capability to support the process. Candidate concepts for further refinement and application of CAFES are included.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator

Pasmooij, C. K. Workload of the radar-air traffic controllers at Schiphol-Amsterdam airport. Leiden, Netherlands: Instituut voor Praeventieve Geneeskunde TNO, Interim Report IR-1, June, 1975. (In Dutch).

The workload at the Amsterdam airport was measured with a view to analyzing mental load factors and to studying the effect of task performance on the air traffic controller. Number and content of the air traffic information strips, radio telephony communication, coordination with other air traffic sectors, and telephone calls with other air traffic control centers were registered for five air traffic controllers during the week of Aug. 6, 1973. The results of the task analysis parameters were evaluated and preliminary conclusions were made.

W/L Cat. Code: 2.1., 3.1, 4.1.10, 4.1.11

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Field	Flight simulator
Primary task	Primary task			
Physiological	Heart rate, h.r. var. Breathing anal.			

Pasmooij, C. K., Opmeer, C. H. J. M., and Hyndman, B. W. Workload in air traffic control. In T. B. Sheridan and G. Johannsen (Eds.) Monitoring behavior and supervisory control. New York: Plenum Press, 1976, 107-117.

The ever-increasing number of flights to be handled during a given time period has made it necessary to increase the capacity of the air traffic control system. Inevitably such increases place extra burdens on air traffic controllers, even as automation has increased. This paper reviews methods for assessing air traffic controller workloads, and indicates which methods have proven successful. Subjective ratings, speech workload, and physiological reaction measures appear most reliable.

W/L Cat. Code: 1., 4.1.3, 4.1.10, 4.3

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Field Flight	Simulator
Physiological	Heart rate, h.r. var. Speech pattern anal.	Review		

Payne, D. R. and Buck, J. R. Synthetic switching time statistics. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 201-204.

A synthetic (predetermined) time system with expected times and time variances appears to have considerable usefulness in the design of panel layouts and the estimation of operator workloads, particularly during early developmental phases of a system. Accordingly, the study was made to see if a synthetic time system could be devised to predict the time statistics for setting and changing various types of switches as a function of several variables. Time data were collected through computerized instrumentation and the root-mean-squares of tracking errors were collected for time intervals between switching task events. Analyses are being made to determine the repeatable predictability of the switching time statistics, the influence of the variables on these statistics, statistical independence of sequential switching times, learning effects on the tracking task, and switching task interferences on the tracking task.

W/L Cat. Code: 2.1.1, 3.1
Op. Behav. Code: 1., 2., 4.1

Spare m. capacity	Task comp., time assess.	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Pettyjohn. F.S., McNeil, R.J., Akers, L.A. and Faber, J.M. Use of inspiratory minute volumes in evaluation of rotary and fixed wing pilot workload. Proceedings of the AGARD Conference on Methods to Assess Workload, ACARD-CPP-216, April, 1977, A9-1 - A9-2.

Nap-of-the-earth (NOE), night nap-of-the-earth (NNOE), and night vision devices (NVD) have added markedly to the workload of the aircrew. During oxygen utilization studies, analysis of Inspriatory Minute Volume (IMV) data indicated significant trends dependent on flight profiles. To further evaluate this method as an indirect and simple modality in the assessment of stress and workload, a study of IMV during varied helicopter and fixed wing aircraft flight profiles was undertaken. Data were obtained from a series of 135 flights of OH-58, UH-1H, and AH-1 helicopters and U-21 and C-2A fixed wing aircraft. Three phases of the flight were evaluated--takeoff (T.O.), cruise (C), and final approach (F.A.). The helicopter flight profile was evaluated under normal flight, NOE, NNOE, and NVD. This paper describes the results of the study.

W/L Cat Code: 4.1.11
Op. Behav. Code: 1., 2., 4.

Physiological	Breathing anal.	Experimental	Flight test	Flight simulator
				Flight test

Pettyjohn, F. S., McNeil, R. J., Akers, L. A. and Faber, J. M. Use of inspiratory minute volumes in evaluation of rotary and fixed wing pilot workload. Fort Rucker, Alabama: US Army Aeromedical Research Laboratory, USAARL Report No. 77-9, April, 1977. (AD 039 854).

Inspiratory minute volume (IMV) measurements by Mueller Respirometer were utilized in the evaluation of US Army aircrew workload and stress in helicopter and fixed wing aircraft. The IMV data obtained demonstrates a significant stress and/or workload level of the aviator in performance of helicopter day nap-of-the-earth (NOE), night nap-of-the-earth (NNOE) and with the use of night vision devices (NVD). IMV of 20.05 to 38.11 liters per minute NTPD were obtained during the performance of these combat operational techniques. IMV determination in-flight is considered a valuable clinical tool in the assessment of aircrew stress and/or workload.

W/L Cat. Code: 4.1.11

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Breathing anal.	Experimental	Flight test	Flight simulator
				Flight test

Pew, R.W. Secondary tasks and workload measurement. In N. Moray (Ed.) <u>Mental workload: its theory and measurement</u>. New York: Plenum Press, 1979, 23-28.

Spare mental capacity concepts of mental workload are discussed and the use of a secondary task is reviewed as a possible measuring procedure. Various considerations and problems of using a secondary task are presented.

W/L Cat. Code: 2.2

Op. Behav. Code: 2.1, 4.1

Spare m. capacity	Subsidiary task	Construct	None	Flight simulator

Pfendler, C. and Johannsen, G. Workload measurement and operator training in simulated STOL approaches. Meckenheim, West Germany: Forshungsinstitut für Anthropotechnik, Report No. 30, October, 1977. (In German).

Manual ILS-approaches were performed by non-pilots in a fixed base STOL-simulator. In addition to performance variables, workload was assessed with a secondary task (tapping) and with a graphic rating scale. Training period data were analyzed to assure that learned performance was stationary. An experienced pilot was also tested. The performance levels of the subjects were comparable to those of the pilot. During the rollowing experiments data were collected to evaluate the suitability of the secondary task and the rating scale as measures of workload for the mentioned guidance and control task. The evaluation techniques used are based on psychological test theory and are suitable for comparing workload measures. The report also contains an overview on selected aspects of sensory-motor learning and on workload measurement techniques.

W/L Cat. Code: 1.1, 2.2.2, 3.1
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental Flight simulator	Flight simulator
Spare m. capacity	Subsidiary task		Flight test
Primary task	Single measures		

Phatak, A. V. Improvement in weapon system effectiveness by application of identification methods for determining human operator performance decrements under stress conditions. Palo Alto, California: Systems Control, December, 1973. (AD 773 856).

This report considers the development of realistic models for weapon system controllers which could be used to predict the effectiveness of manned weapon systems under stress conditions. Two types of models are considered: (1) the input-output stochastic linear state-variable models (equivalent to describing function models when process noise ≡ 0), and (2) the optimal control model developed by Kleinman et al. The maximum likelihood identification technique was used in estimating model parameters from input output data. Results show that the identification algorithm was highly successful in identifying the parameters of the stochastic state variable models. However, difficulties were encountered in applying the technique to identifying parameters of the optimal control model. Both system performance and system difficulty are related in some way to the human operator parameters. Operator workload (and pilot opinion rating) is some linear or non-linear combination of system performance and system difficulty. There is, therefore, a clear need to develop some kind of a metric for system difficulty. This would involve further investigation into the areas of system controllability, observability and identifiability.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 4.

Primary task	Math. model	Construct	Simulator	Flight simulator
				Flight test

Philipp, U., Reiche, D. and Kirchner, J. H. The use of subjective rating. Ergonomics, 1971, 14, 611-616.

To evaluate work load in ATC-tasks the method of subjective rating has been applied in addition to the recording of physiological data and objective work factors. A scoring method and a procedure for observer rating have been used to record variations in the subjective feeling of workload. The results of subjective rating have been related to different measures of information processing. Some problems concerning the influence of individual capacity in the procedure of observer rating for the evaluation of workload and the difficulties in defining "difficulty of the control task" are discussed.

W/L Cat. Code: 1.1

Op. Behav. Code: 2.1, 3.

Opinion	Rating scale	Experimental	Field	Flight simulator
Spare m. capacity	Task comp., time assess.			Flight test
Primary task	Single measures			

Phillips, J. E. The feasibility of short interval time estimation as a methodology to forecast human performance of a specified task. Red River Army Depot, Texarkana, Texas: DARCOM Intern Training Center, DARCOM-ITC-02-08-76-010, April, 1976. (AD A026 727).

This paper proposes and initiates the testing of the hypothesis which states that "An estimate of a short interval of time will indicate one's ability to perform a specified task relative to his ability to perform this same task at other points in time throughout the day." This investigation includes a survey of previous time estimation research and other related chronobiologic studies. This study examines the interval estimation-task performance relationship by correlating two short intervals of time with performance of a letter cancellation task. Although results showed that the hypothesis may be valid for certain individuals, as two of the three tested subjects' performances appeared to be closely related to their estimations of an unrehearsed fifteen second interval, future studies are needed to determine whether any class or classes of tasks produce this interval estimation-task performance relationship in all persons. This paper suggests that all future time estimation research employ unrehearsed intervals for testing.

W/L Cat. Code: 2.2.3

Op. Behav. Code: 1.2, 2., 4.1

Spare m. capacity   Time estimation   Experimental   Laboratory   Background

Posner, M. I. and Boles, S. J. Components of attention. Psychological Review, 1971, 78, 391-408.

The study of human attention may be divided into three components. These are alertness, selectivity, and processing capacity. This paper outlines experimental techniques designed to separate these components and examine their interrelations within comparable tasks. It is shown that a stimulus may be used to increase alertness for processing all external information, to improve selection of particular stimuli, or to do both simultaneously. Development of alertness and selectivity are separable, but they may go on together without interference. Moreover, encoding a stimulus may proceed without producing interference with other signals. Limited capacity results are obtained when mental operations such as response selection or rehearsal must be performed on the encoded information.

W/L Cat. Code: 2.1.1, 2.1.2

Op. Behav. Code: 1., 2.

Spare m. capacity	Task comp., time assess. Inform. theory	Construct	None	Background

Poston, A. M. A survey of existing computer programs for aircrew workload assessment. Aberdeen Proving Ground, Maryland: U.S. Army Human Engineering Laboratory, Technical Memorandum 13-78, May, 1978. (AD A058 518).

Due to increased concerns of crew workload in tactical nap-of-the-earth environments, increased importance has been placed on the need to utilize a computer simulation to serve as a predictor, or estimator, of crew loading. The US Army Human Engineering Laboratory conducted a survey of existing computer programs which can be used for workload assessment. Each program was assessed in terms of input requirements, processing procedures, outputs available, as well as any other pertinent information. Conclusions are drawn and recommendations are made as to how the Army should approach the problem of obtaining a suitable computer program.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Review	None	Flight simulator

Potempa, K.W. A catalog of human-factors techniques for testing new systems. Wright-Patterson AFB, Ohio: USAF Human Resources Laboratory, AFHRL-TR-68-15, February, 1969. (AD 854 482).

The purpose of the described technique is to determine decrement in mission-related performance of system operators as a result of increased workload. The study was performed under dynamic conditions on a Dyna-soar flight simulator. Workload was increased through insertion of external conditions and malfunctions such as shear winds, oxygen pressure losses, etc. Performance decrement was monitored by recording flight control movements and rates and by having pilots report, at regular intervals, the status of 10 mission-relevant items. The pilot's ability to monitor and report the 10 test items was determined through scheduled verbal reports over the simulated radio subsystem. Monitoring and measuring high priority items such as deviations in altitude, air speed, and course heading had been found to show little change affected by workload; therefore, tasks considered to be of secondary, but still mission-essential, importance were used as performance measures in this study. As the workload increased, the verbal reports of the pilots reflected progressive breakdown, first of continuity and then of content also. The interpretation of this was that the pilots were concentrating more on flight-critical tasks and less on nonflight-critical assignments. A similar and concurrent workload-related finding was that small control stick movements dropped in number, while gross control movements increased, indicating a degradation of flying ability.

W/L Cat. Code: 2.2.1, 3.2, 4.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Mult. measure			Flight test
Physiological	Speech patt., anal.			

Price, D. L. The effects of certain gimbal orders on target acquisition and workload. Human Factors, 1975, 17, 571-576.

If air-to-ground imaging sensors are mounted to aircraft by different gimbal order systems, the displayed scene will rotate differently, even though the flight paths are identical. Eighteen experienced pilots were tested to investigate the effects of three gimbal orders (roll-pitch, yaw-pitch, and pitch-yaw) on target detection, recognition, and identification performance, and also on operator workload. The pitch-yaw gimbal order was associated with the greatest range-to-target scores and the lightest workloads. Workload was assessed by means of a digit-reading secondary task.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures		Flight simulator	Flight test

Price, H. E. Development of potential roles of supersonic transport crews. Chatsworth, California: Serendipity Associates, TR 20-66-3, December, 1965.

This report presents a synopsis of the methodological approach and techniques used throughout the entire contract. Much of the method used is explicit in the reports of the study, and this report is intended to synthesize or summarize the method. In addition to presenting the method used for the SST study, an attempt was made to generalize the method so that it might be applied to other studies concerned with the derivation or investigation of crew requirements in other manned systems. This general approach to study of crew requirements evolved during the SST crew requirements study and incorporates methodological improvements resulting from the study. Throughout this report, the general approach to a crew requirements study will be outlined after related aspects of the SST study.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Task comp., time assess. Construct Laboratory Flight simulator

Price, H. E., Honsberger, W. D., and Ereneta, W. J. A study of potential roles of supersonic transport crews and some implications for the flight deck, Volume I: Workload, crew roles, flight deck concepts, and conclusions. Moffett Field, California: National Aeronautics and Space Administration, Ames Research Center, Contractor's Report, NASA CR-561, October, 1966.

The study was conducted largely as a field research and literature survey program to synthesize requirements and constraints relative to potential crew roles and to review technical concepts for implementing SST operational functions with emphasis on potential crew participation. An analysis of the data so developed was conducted to investigate crew workload, distribution of this workload among different numbers of crew members to define potential crew roles, and implications of these potential roles for flight deck design.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Task comp., time assess. Construct Laboratory Flight simulator

Pritsker, A. A. B., Wortman, D. B., Seum, C. S., Chubb, G. P. and Seifert, D. J. SAINT: Volume I. Systems analysis of integrated network of tasks. Wright-Patterson AFB, Ohio: Aerospace Medical Research Laboratory, AMRL-TR-73-126, April, 1974. (AD A014 843).

A simulation approach is used to obtain the performance measures. Human Engineering considerations are included through parameters associated with tasks precedence relations between tasks and factors affecting crew performance. SAINT is both a modeling procedure and an analysis technique. The analysis is performed by a digital computer program which accepts input data concerning tasks and performs two types of analysis. First, SAINT performs benchmark iterations to obtain estimates of the time requirements on the operators performing the mission. Estimates of essential time remaining, nonessential time remaining, and waiting time for various segments of a mission are computed. Second, SAINT obtains mission performance measures which provide estimates of the probability of successfully completing the mission under stress and adverse environmental conditions. This report presents the methods for using SAINT, including the preparation of input data and the interpretation of output reports.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator

Proceedings of the Symposium on Man-System Interface: Advances in Workload Study. Washington, D.C.: Air Line Pilots Association, July 31, August 1, 1978.

This document provides brief summaries of ongoing research in workload estimation techniques for flight-deck applications. Techniques described include human operator models, time-estimation, time-line analysis, performance, and a variety of physiological measures including evoked potentials and pupil dilation. The contributions of twelve researchers are included.

W/L Cat. Code: 2.1.1, 2.2.1, 2.2.3, 3.1, 3.3, 4.1.5, 4.1.6, 4.1.8

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Multiple	Review	Laboratory	Flight simulator
Primary task		Construct		Flight test
Physiological		Experimental		

Rashman, S. M. The function of external respiration in mental activity. Fiziologichnii Zhurnal, 1972, 18, 361-366. (In Ukrainian.)

This paper describes an investigation of the changes affecting the external respiration and cardiovascular systems during intense mental acitivity (namely, problem solution in mathematical analysis). Data are reviewed on: changes in arterial blood saturation by oxygen; respiratory frequency, capacity, and minute volume; oxygen consumption and intake coefficient; ventilation equivalent; and a number of psycho-physiological indices characterizing the state of cortical processes during intense mental activity.

W/L Cat. Code: 4.1.5, 4.1.10, 4.1.11

Op. Behav. Code: 1., 2.

Physiological Multiple Experimental Laboratory Flight simulator

Rasmussen, J. Reflections on the concept of operator workload. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 29-40.

In future complex systems, man is typically allocated functions as a monitor and supervisor. Models of his performance must not only be able to predict his average response in frequent situations, but also his response in unique, infrequent tasks. He is a highly adaptive and goal oriented information processor. Models of his performance in well adapted situations are mainly models of his environment. Models of his performance must also reflect the limiting properties of his internal mechanisms.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 4.

Primary task Math. model Construct None Flight simulator

Rault, A. Pilot workload analysis. In T. B. Sheridan and G. Johannsen (Eds.) Monitoring behavior and supervisory control. New York: Plenum Press, 1976, 139-153.

This paper describes the initial phases of a multidisciplinary study of pilot workload estimation. Both simulated and actual helicopter flight tests are being performed. The goal has been to find a quantitative definition of workload through the use of different approaches. Measures taken included: cardiac rhythm, electromyography of neck muscles, pulmonary ventilation, eye movements, information theoretic formulations, and parameters from dynamic models. Results of these measures are being compared against Cooper scale ratings.

W/L Cat. Code: 1.1, 2.1.2, 3.3, 4.1.3, 4.1.4, 4.1.7, 4.1.9, 4.1.10, 4.1.11

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Construct	Flight simulator	Flight simulator
Spare m. capacity		Experimental	Flight test	Flight test
Primary task				
Physiological				

Rault, A. Measurement of pilot workload. In N. Moray (Ed.) Mental workoad: its theory and measurement. New York: Plenum Press, 1979, 417-422.

Various approaches involving psychological tests, physiological measures (heart rate variability, EMG, and EOG), information theory, and control theory were used in parallel to assess pilot workload. Issues are discussed pertaining to the use of these approaches.

W/L Cat. Code: 1.1, 2.1.2, 3.3, 4.1.4, 4.1.7

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Construct	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Reiche, D., Kirchner, J. H., and Laurig, W. Evaluation of stress factors by analysis of radio-telecommunication in ATC. Ergonomics, 1971, 14, 603-609.

Information content analysis based on information theory can be used to evaluate stress in controllers. The method is applied to the analysis of radiotelecommunication in air traffic control. Message types are defined and their information content is evaluated using the syntactic level of information. Related to time, the measurements of information provide a stress factor. Preliminary results indicate the usefulness of the method.

W/L Cat. Code: 2.1

Op. Behav. Code: 1., 2., 3., 4.1

Spare m. capacity	Task comp., time assess.	Construct	Field	Flight simulator
	Inform. theory	Experimental		Flight test

Reising, J. M. The definition and measurement of pilot workload. Wright-Patterson AFB, Ohio: USAF Flight Dynamics Laboratory, AFFDL-TM-72-4-FGR, February, 1972.

This report is designed as an overview of the state-of-the-art on workload. It is divided into seven sections. Section I provides background information on the relevance of workload to the piloting task. Section II describes the complexity of workload and why there is so much confusion connected with it. Sections III and IV discuss, respectively, the physiological and psychological measures of workload. Section V describes various data analysis techniques used in conjunction with the measurement of workload. Section VI evaluates the current state-of-the-art in workload measurement, and Section VII discusses the implications of workload measurement on the Crew Station Management Program, with emphasis on multidimensional approaches.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Repa, B. S. and Wierwille, W. W. Driver performance in controlling a driving simulator with varying vehicle response characteristics. SAE Paper No. 760779, October, 1976.

This paper describes the effects of variations in vehicle response characteristics on driver-vehicle disturbance responses using a moving base driving simulator. Two exploratory studies are discussed, one dealing with vehicle transient response characteristics and the other with steady state characteristics. Close correspondence with full-scale data reported by others indicates that dynamically realistic simulators can be effective research tools. The flexibility of the simulator has facilitated the collection of other preliminary data which extend the full-scale findings. Considerably more effort will be needed, however, before strong arguments either for or against specific parameter boundaries can be made.

W/L Cat. Code: 1.1, 3.2

Op. Behav. Code: 1., 2., 4.

Opinion	Ratings	Experimental	Simulator	Flight simulator
Primary task	Mult. measures			Flight test

Repko, J.D., Loeb, M. and Brown, B.R. Behavioral effects of prolonged exposure to continuous and intermittent noise. Louisville, Kentucky: University of Louisville, Performance Research Laboratory, ITR-74-29, June, 1974.

The puspose of this investigation was to assess man's performance in a work situation wherein 90 dB continuous and periodic 96 dB intermittent noise were separately presented as environmental stressors. The present study employed a synthetic-work approach in which several tasks were combined into a multiple-task performance battery (MTPB). An index of general performance was employed to assess the over-all work behavior of the Ss. The results showed that the mean percentage of baseline performance was enhanced by a periodic 96 dB intermittent noise. On the other hand, since continuous noise may be considered as containing fewer stimulus elements than intermittent noise, it was expected that general performance during continuous noise would be less than during intermittent noise. The nature of the results obtained with the 90 dB continuous noise indicated that the condition neither enhanced nor degraded performance.

W/L Cat. Code: 3.2
Op. Behav. Code: 1., 2., 4.

Primary task	Mult. measures	Experimental	Laboratory	Flight simulator
				Flight test

Replogle, C. R., Holden, F. M., Gold, R. E., Kulak, L. L., Jonas, F. and Potor, G., Jr. Human operator performance in hypoxic stress. Wright-Patterson AFB, Ohio: USAF Aerospace Medical Research Laboratory, AMRL-TR-71-29, Paper No. 31, December, 1971. (AD 740 468).

This experiment was designed to assess the value of several different tracking tasks in quantitatively measuring the effects of hypoxia on human operator performance. Each subject was required to perform three tracking tasks. One was an adaptive first order unstable task. The second represented stable third order longitudinal airframe dynamics. The last was a two axis combination of the first two, with the stable task represented by the vertical display axis and the unstable task on the horizontal axis. Hypoxic stress was simulated by breathing O_2, N_2 mixtures representing sea level, 12,000 ft and 22,000 ft altitude. The studies employed six well trained subjects breathing the appropriate gas mixtures for two minutes. The experimental factors were randomly ordered with two replications per set of factors. A two by two analysis of variance was employed to provide estimates of the reliability of the measurements. The results indicate that the adaptive unstable task is significantly sensitive to hypoxic stress, whereas to identify similar changes in the stable task requires frequency domain analysis. There is some indication that the unstable task may be sensitive to 12,000 ft simulated hypoxia after only 2 minutes of exposure.

W/L Cat. Code: 3.1
Op. Behav. Code: 1., 2., 4.

Primary task   Single measures   Experimental   Laboratory   Flight test
Physiological

Ringland, R. F., and Craig, S. J. A survey of piloting factors in fixed-wing V/STOL aircraft. In Atmospheric Flight Mechanics Conference, Technical Papers. Hollywood, Florida, August 8-10, 1977, American Institute of Aeronautics and Astronautics, 1977, 239-246.

This paper summarizes the key results of a recently completed review of the available literature pertaining to piloting factors in fixed-wing V/STOL aircraft design. It emphasizes mission- and vehicle-related factors which are peculiar to the V/STOL concept and which determine the control/display system requirements. The review shows excessive pilot workload originating primarily in the control aspects of the aircraft to be the central problem in past designs. These aspects include management of the propulsion/lift systems during conversion, stabilization of vehicle attitude, and the stabilization and control of the aircraft's speed and path angle responses. Results show display technology improvements alone cannot solve these piloting problems without control augmentation because the pilot's capability remains overtaxed.

W/L Cat. Code: 2.1.1, 3.3
Op. Behav. Code: 1., 2., 4.2

Spare m. capacity   Task comp., time assess.   Review   None   Flight simulator
Primary task   Math. model   Construct

Roedinger, H. L., III, Knight, J. L., Jr., and Kantowitz, B. H. Inferring decay in short-term memory: the issue of capacity. Memory and Cognition, 1977, 5, 167-176.

Experiments examining the issue of decay in short-term memory have assumed a single undifferentiated source of processing capacity which cannot be devoted to rehearsal when consumed in the processing of a nonverbal interpolated task. Three experiments reported here call this logic into question, since variations in difficulty in the nonverbal interpolated task failed to affect recall. Slight forgetting produced by a nonverbal interpolated task, relative to a no interpolated task control, was attributed to qualitative differences from performing two tasks simultaneously rather than only one. Results from the third experiment indicated that retrieval after a period of nonverbal interpolated activity is from primary rather than secondary memory.

W/L Cat. Code: 2.2, 3.1

Op. Behav. Code: 1., 2., 4.1

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Rohmert, W. An international symposium on objective assessment of workload in air traffic control tasks: Held at the Institute of Arbeitswissenschaft, The University of Technology, Darmstadt, German Federal Republic. Ergonomics, 1971, 14, 545-547.

The first International Symposium on Objective Assessment of Work Load in Air Traffic Control Tasks, arranged by the 'Stress in Air Traffic Control Research Association--SATCRA' in June 1971 at Darmstadt, is introduced. A distinction is made between objective methods and results of the determination of stress of work tasks and subjective strain on the controllers due to these stressing factors. Certain stressors cause different strain in different controllers because of their different individual capacities and abilities. Methods and equipment for determining individual capacities and approaches for correlating stress and strain are described.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Rohmert, W. Determination of stress and strain of air traffic control officers. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A6-1 - A6-8.

At Frankfurt airport several field studies were carried out over a period of roughly four years including research on about 115 air-traffic control-officers. Methods were developed for assessment of stress and strain. Stress is defined as all factors of work which result in reactions of the controller's receptory and effectory system. Strain in human beings is not only dependent on stress but also on distinguishing individual characteristics. An overview of all methods and techniques used for assessment of stress and strain is presented. Based on the concept of the man-at-work system and the description of strain-related work contents, a new Ergonomic Job Description Questionnaire has been developed, the results of which allow a deeper look into methods and techniques needed in designing future air-traffic control-systems. Results of some of the field studies in air-traffic control research are illustrated.

W/L Cat. Code: 1.2, 2.1.1, 4.1.3, 4.1.5, 4.1.10
Op. Behav. Code: 1.1, 2.1

Opinion	Multiple	Review	Field	Flight simulator
Spare m. capacity				Flight test
Physiological				

Rohmert, W. Determination of stress and strain at real work places: methods and results of field studies with air traffic control officers. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 423-443.

This paper begins with a description of the air traffic controller's tasks, including the demands, behaviors, and capacities. Subsequently, techniques for measuring stress and strain are described: motion analysis, information content analysis, time-budget study, physiological study, psychological study, and work medicine. The results obtained using each of these techniques are presented.

W/L Cat. Code: 2.1, 3.1, 4.1.3, 4.1.4, 4.1.9, 4.1.10, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Multiple	Experimental	Field	Flight simulator
Primary task				
Physiological				

Rohmert, W., Laurig, W., Philipp, U. and Luczak, H. Heart rate variability and work-load measurement. Ergonomics, 1973, 16, 33-44.

Heart rate variability is a result of the superimposition of different sources of variation which are systemized. Three parameters are used to describe the phenomenon of heart rate variation. The range of variation of these parameters is discussed using examples from both laboratory and field investigations. Analyses demonstrate a correlation between heart rates and their variability. Discussion of the variation of the chosen parameters suggests that, when heart rate variability is used as a measure of strain in field research, strain might be under-assessed.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2.

Physiological	Heart rate, h.r. var.	Experimental	Laboratory	Flight simulator
			Field	Flight test

Rolfe, J. M. Multiple task performance: Operator overload. Occupational Psychology, 1971, 45, 125-132.

This paper considers some of the problems arising from the changing content of human work, for example increased vehicle performance and the reduction in crew complement which often accompanies it. Some of the psychological factors which influence human response in such situations are discussed.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	None	Flight simulator
				Flight test

Rolfe, J. M. Whither workload. Applied Ergonomics, 1973, 4, 8-10.

Although the demands placed on flight deck personnel are not continuously excessive, the short periods of high load combine to produce a cumulative effect at the end of an operation. At the RAF Institute of Aviation Medicine, aircrew are examined on their in-flight workload by a questionnaire method and this is compared with other methods including physiological measurement. The effects of work away from the flight deck, and of factors peripheral to the job situation, are considered, and it is suggested that care must be taken to avoid eliminating job satisfaction with reduction in workload.

W/L Cat. Code: 1.2, 4.2

Op. Behav. Code: 2.1, 4.2

Opinion	Questionnaire	Review	Flight simulator	Flight simulator
Physiological	Mult. measures		Flight test	Flight test

Rolfe, J. M. The secondary task as a measure of mental load. In W. T. Singleton, J. G. Fox, and D. Whitfield (Eds.) Measurement of Man at Work. London: Taylor and Francis, 1973, 135-148.

The human operator can be viewed as a single channel data processing system, having its limitations in the central decision mechanism which must be allowed a finite time to process one stimulus-response before a second can be accepted. Evidence for this view has come from the study of the phenomenon known at the psychological refractory period. This paper reviews the ramifications of the single channel hypothesis and the use of secondary tasks to measure mental workload. The effects of learning, experimental shortcomings, range of applications, interference, and validation are discussed.

W/L Cat. Code: 2.2.

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Review	None	Flight simulator
				Flight test

Rolfe, J. M. The measurement of human response in man-vehicle control situations. In T. B. Sheridan and G. Johannsen (Eds.) Monitoring behavior and supervisory control. New York: Plenum Press, 1976, 125-137.

This paper reviews the measurement of human response in vehicular control situations, and describes the relationship between such measurements and vehicle design. A number of specific categories of response assessment are identified, including performance requirement, response levels, effectiveness, environmental impairment, and comparisons among operators. In addition, supplementary measures are identified, including observational analysis, subjective assessment, loading tasks, and physiological measures.

W/L Cat. Code: 1., 2.2, 3.1, 4.1

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Construct	None	Background
Spare m. capacity				
Primary task				
Physiological				

Rolfe, J.M., Chappelow, J.W., Evans, R.L., Lindsay, S.J.E. and Browning, A.C. Evaluating measures of workload using a flight simulator. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD-CP-146, April, 1974, A4-1 - A4-13.

The paper describes an experiment in which a flight instrument trainer, resembling a twin jet communications aircraft, was used to evaluate questionnaire, performance and activity analysis measures of pilot workload. Attempts were made to distinguish between the physical, perceptual and mental components of workload. For this purpose three flight plans were devised, of approximately equal duration, differing markedly with respect to the three above components. Six professional pilots flew each flight plan and after landing completed questionnaires to assess the workload levels and the task content. During the flights video recordings were made of the pilot's manual and communication activity. Performance during ILS approaches immediately before and after the experimental flight plans was also measured. From these measures it was possible to obtain significantly different results relating to the different flight plans.

W/L Cat. Code: 1., 3.2
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Questionnaire			Flight test
	Mult. measures			

Rolfe, J. M. and Lindsay, S. J. E. Flight deck environment and pilot workload: Biological measures of workload. Applied Ergonomics, 1973, 4, 199-206.

The object of this paper is to examine some of the techniques that are being used to study the demands of the work situation upon the individual. While the emphasis throughout the paper is on studies of aircrew workload, the findings have a general applicability to applied ergonomics.

W/L Cat. Code: 1., 2.2, 3.1, 3.3, 4.1

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Roscoe, A. H. Heart rate monitoring of pilots during steep-gradient approaches. Aviation, Space, and Environmental Medicine, 1975, 46, 1410-1413.

As part of a large scale investigation into noise abatement landing approaches, one trial involved the flight evaluation of steep-gradient and two-segment approaches; these were 3°, 6°, 7.5°, and 9° single-segment, and 7.5°/3° two-segment approaches. To augment the subjective opinions of the test pilots, their heart rates were monitored during all the experimental runs. The resulting heart rate values for the different approaches correlated reasonably well with the subjective ratings of the relative workload levels. There is some evidence that the pilot workload level for the 7.5°/3° approaches is of the same order as the level for the conventional 3° gradient.

W/L Cat. Code: 1.1, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Roscoe, A. H. Pilot workload during steep gradient approaches. Farnborough, England: Royal Aircraft Establishment, Flight Systems Department, Technical Memorandum No. TM FS 78, 1976.

A flight trial to evaluate different approach profiles and techniques using a BAC VC-10 is described. Pilot's heart rates were measured which, together with subjective opinions, were used to assess levels of workload. Most of the experimental approaches and landings were flown by two test pilots, though other pilots participated briefly in the trial. The types of approach investigated included single segment with gradients up to and including 6 1/2°, 5°/3° two segment with an intersection height of 500 ft, 5°/3° two stage flares, and low drag approaches. Evidence is presented to show that 5°/3° two segment approaches do not cause significantly higher heart rates than do conventional 3° approaches. In general, heart rate levels and subjective estimations showed good agreement, this was especially so when comparing workload levels generated by the different profiles and techniques. Results seem to support the contention that the introduction of noise abatement approaches and landings need not necessarily cause an increase in pilot workload.

W/L Cat. Code: 1.1, 4.1.10

Op. Behav. Code: 1., 2., 4.

Opinion	Ratings	Experimental	Flight test	Flight test
Physiological	Heart rate, h.r. var.			Flight simulator

Roscoe, A. H. Use of pilot heart rate measurement in flight evaluation. Aviation, Space and Environmental Medicine, 1976, 47, 86-90.

Experimental test pilots involved in the flight evaluation of handling qualities and systems were monitored for heart rate during an investigation to assess the possible use of this measure to augment their subjective opinions. Reference is made to examples from several different flight trials using a variety of aircraft types. It is concluded that pilot heart rate measurement is a worthwhile technique and can play a useful part in flight evaluation provided that certain limitations are recognized.

W/L Cat. Code: 1.1, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Roscoe, A.H. (Ed.) Assessing pilot workload. AGARD-AG-233, February, 1978. (AD A051 587).

This AGARDograph, written primarily for flight test engineers and pilots, is intended as a guide to the different methods available for estimating workload and in particular to those techniques suitable for use in aircraft. An introductory chapter reviews the various concepts and classifications of workload; the former tend to fall into two main areas, those related to workload as task-demands and those to workload as pilot-effort. In Chapter 2, subjective assessment is discussed from the viewpoint of the test pilot. Physiological methods in general are reviewed in Chapter 3 with those techniques available for use in flight being discussed in more detail. Chapter 4 describes various objective methods and presents examples of their practical application. Whereas the methods in Chapters 2 and 3 are appropriate only to workload as effort, objective methods contain techniques appropriate to workload as task-demands as well as to effort. The former techniques are particularly valuable for providing data which can be used to construct models and to predict levels of workload.

W/L Cat. Code: 1., 2., 3., 4.
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Roscoe, A.H. Physiological methods. In A.H. Roscoe (Ed.) Assessing pilot workload. AGARD-AG-233, February, 1978, 23-51. (AD A051 587).

The rationale of recording physiological activity to assess levels of pilot workload depends on two assumptions: (a) that an acceptable concept of workload is the physical and mental effort required to satisfy the demands of the flight task, and (b) that the level of arousal, as measured by physiological indices, is related in some way to the amount of effort. Of the various physiological indices heart rate has been shown to be generally reliable for realistically demanding flight tasks and it is reasonably easy to record and to analyze. An added advantage of this measure is that when displayed in beat-to-beat form, heart rate variability is available (as a bonus) for use as a sensitive indicator of changes in mental load. Because of the limitations inherent in using physiological measures to assess pilot workload there are several pitfalls for the unwary. Physiological measures alone can be used to estimate levels of workload and especially to identify peaks and troughs in the workload patterns. However, they are of more value when used to augment pilot opinion and, therefore, should be used in conjunction with some form of subjective measure.

W/L Cat. Code: 4.
Op. Behav. Code: 1., 2., 3., 4.

Physiological	Multiple	Review	None	Flight simulator
				Flight test

Roscoe, A. H. Stress and workload in pilots. Aviation, Space and Environmental Medicine, 1978, 49, 630-636.

Several studies have highlighted the increase in physiological activity which occurs in pilots during flight and especially during takeoffs and landings. For example, it has been clearly demonstrated that pilots' heart rates increase during the landing approach to reach a peak at or just before touchdown. These changes have been attributed to workload and to psychological or emotional stress. This paper examines a number of test pilots' heart rate responses recorded during various flight trials involving different types of aircraft. It is concluded that heart rate responses in experienced pilots are influenced almost entirely by workload-related factors and not by emotional stressors, such as risk and anxiety. Because of the emotional overtones of the word 'stress', it is suggested that the term workload should be used when referring to the reason for increased cardiovascular activity in pilots.

W/L Cat. Code: 3.1, 4.1.3, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Experimental	Flight test	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Roscoe, A. H. Handling qualities, workoad, and heart rate. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 83-91.

Workload levels for a given piloting task are related to the aircraft's handling characteristics, but a valid rating for the latter may no always give a reliable estimate of workload. Experienced test pilots may be quite adept at using opinion rating scales, but occasionally, it seems difficult to separate assessments of workload from those of handling qualities, leading to anomalies and ambiguities. Westbrook and his colleagues commented that: "If a reliable method were available to obtain a measure of workload or stress, it is undeniably true that many of the anomalies in handling qualities data could be explained." Several investigators have recorded physiological variables from pilots in real and simulated flights as a means of estimating levels of stress and workload. This paper, by describing two current flight trials and by referring briefly to previous studies, examines the relationship between pilot's heart rate and subjective assessment of handling qualities and workload.

W/L Cat. Code: 3.1, 4.1.3, 4.1.10
Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Flight test	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Roscoe, A. H. and Goodman, E. A. An investigation of heart rate changes during a flight simulator approach and landing task. Farnborough, Hants, England: Royal Aircraft Establishment, RAE-TM-Avionics-155, 1973.

A blind landing simulator was used in the fixed-base mode to examine changes in heart rate as a function of simulator effectiveness and differences in the various approach conditions. Seventy-five pilots did over 800 runs to give them experience of approaches and landings in low visibility conditions. It was found that significant changes in heart rate occurred due to simulator effectiveness only.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Experimental	Flight simulator	Flight simulator

Roscoe, S. N. Assessment of pilotage error in airborne area navigation procedures. Human Factors, 1974, 16, 223-228.

In 1969, by specifically including "pilotage error" in the error budget for area navigation system certification, the Federal Aviation Administration legally attached economic premiums and penalties to human, as well as equipment, performance in man-machine system design. To establish the accuracy of use and freedom from pilot blunders associated with systems employing various configurations of displays and controls requires both simulator and flight experimentation. An automatically adaptive cockpit side task provides a saturating level of pilot workload and allows the sensitive, orderly, and statistically reliable measurement of a pilot's residual attention as a common metric for area navigation system assessment.

W/L Cat. Code: 2.2.4, 3.1

Op. Behav. Code: 2.1, 4.2

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test

Rosenbrock, F. Hardware problems in ergonomics measurements. Ergonomics, 1971, 14, 617-623.

The most difficult problem in analyzing man-machine systems is the assessment of the operator's workload. The methodological difficulties are evident because of the human complexity and the necessity of avoiding any interference in the work situation. These problems, especially the great number of data needed, necessitate new concepts in ergonomics measurements. By using an actual problem, the analysis of the task and workload of radar controllers the application of multichannel automatic data acquisition and processing is demonstrated. For assessing strain, advantage is taken of the physiological variables: electro-cardiogram (ECG), electro-oculogram (EOC) in both directions, electro-myogram (EMG) of a back muscle and respiration. To correlate these variables with factors of stress and strain a coding is described, which renders the evaluation of a multi-dimensional work process study automatically and synchronously with the physiological data.

W/L Cat. Code: 4.1.3, 4.1.4, 4.1.5, 4.1.11

Op. Behav. Code: 1., 2., 3., 4.

Physiological	EKG EMG EEG Breathing anal.	Construct	None	Flight simulator Flight test

Rotondo, G. Workload and operational fatigue in helicopter pilots. Aviation, Space, and Environmental Medicine, 1978, 49, 430-436.

A brief review is presented concerning possible causes of operational fatigue to which flying personnel in general are exposed in the exercise of flying activity. The paper then describes and analyses the meaning and importance of the various stressing factors that constitute the physical and psychic workload to which the helicopter pilot is subjected in performing his professional activities. Also analyzed are the influences exercised, both separately and jointly, on the genesis of flight fatigue in helicopter pilots by stressing and fatiguing effects of vibrations, noise and psycho-emotional and psycho-senorial factors related to the variety and danger of utilization of this modern aircraft. Such an analytical investigation indicates that helicopter piloting involves a psycho-physical workload certainly no less than that required by more powerful and faster aircraft.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Review	None	Background

Rouse, W. B. Human-computer interaction in multitask situations. IEEE Transactions on Systems, Man, and Cybernetics, 1977, SMC-7, 384-392.

Human-computer interaction in multitask decisionmaking situations is considered, and it is proposed that humans and computers have overlapping responsibilities. Queueing theory is employed to model this dynamic approach to the allocation of responsibility between human and computer. Results of simulation experiments are used to illustrate the effects of several system variables including number of tasks, mean time between arrivals of action-evoking events, human-computer speed mismatch, probability of computer error, probability of human error, and the level of feedback between human and computer. Current experimental efforts are discussed and the practical issues involved in designing human-computer systems for multitask situations are considered.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 4.

Primary task   Math model   Construct   Laboratory   Flight simulator

Experimental

Rouse, W.B. Approaches to mental workload. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press. 1979, 255-262.

This paper addresses the issues involved in defining, predicting, and measuring mental workload. It has been argued that fraction of attention and intensity of effort are the essential components of mental workload. An approach utilizing queueing models and utility functions has been suggested. The difficult issues considered include measurement of intensity of effort as well as inter-task and inter-individual comparisons. Also, it is noted that development of other than an ordinal scale of mental workload may prove difficult.

W/L Cat. Code: 1.1, 3.1, 3.3, 4.1
Op. Behav. Code: 1., 2., 3., 4.

Opinion   Multiple   Construct   None   Flight simulator
Primary task
Physiological

Sanders, A.F. Some remarks on mental load. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 41-77.

This paper presents an analysis of the concept of mental load from the point of view of human performance theory. In the first section the theoretical status of the concept of mental load is considered. It is concluded that it is based upon common sense, which cannot be empirically founded in a simple way. Then an outline is given of the main procedures of measurement. The next section describes a number of theoretical bases which are all related to some kind of limited capacity notion. It is concluded that the original idea of channel capacity in terms of information theory fails to provide a sound theoretical framework. Other capacity concepts in terms of limited capacity processors and in terms of effort are described. Three types of processors are distinguished, which have different consequences for the measurement of mental load. The fourth section describes experimental trends. It is concluded that a multichannel type of processor, composed of a network of internal mechanisms is most favored by the data.

W/L Cat. Code: 1., 2., 3., 4.
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity		Construct		
Primary task				
Physiological				

Sanders, M.G., Burden, R. T., Jr., Simmons, R. R., Lees, M. A., and Kimball, K. A. An evaluation of perceptual-motor workload during a helicopter hover maneuver. Ft. Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, 78-14, May, 1978.

The current research project examines a method of aiding the MEDEVAC pilot in performing a hover maneuver while perhaps reducing workload. A modular, four-axis stability augmentation system (Ministab) with integrated rate attitude and heading retention was installed on the USAARL JUH-1H helicopter. Participating personnel for the project were nine US Army aviators with a total average of 1172 flight hours. The aviators hovered at 30 feet above ground level for five minutes under each of the three following flight control conditions: (1) Unaided--"normal" hover with visual flight rules conditions, (2) using Force Trim, and (3) using the Ministab. Continuous information from twenty pilot and aircraft monitoring points was recorded on an incremental digital recorder for all flights. Multivariate analyses were performed on both aircraft status variables and control input workload/activity measures. Under the conditions tested, the stability augmentation system evaluated did not provide a clear-cut improvement in flight performance and workload across all flight parameters.

W/L Cat. Code: 1.1, 3.2
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Multiple measures			Flight test

Sanders, M. G., Simmons, R. R., and Hofmann, M. A. Visual workload of the copilot/navigator during terrain flight. Human Factors, 1979, 21, 369-383.

The visual workload of the navigator/copilot during terrain flight in a UH-1H helicopter is investigated. Oculomotor performance during nap of the earth, contour and low level flight was recorded by a modified NAC Eye Mark Recorder in conjunction with a 16 mm high speed motion picture camera. Data indicate little variation between time spent at each visual area for different flight tasks. Visual cues needed for navigation were primarily obtained from terrain viewed from the copilot's windscreen, with frequent reference to the handheld map. It is found that the duty of navigating required 92.2% of the copilot's visual time, while the engine and flight instruments were utilized only 4.0% of the time; a visual free time task was utilized only 3% of the time, mostly during hover periods.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2.

Physiological   Eye movement   Experimental   Flight test   Flight simulator

Flight test

Sanders, M. G., Simmons, R. R., Hofmann, M. A. and DeBonis, J. N. Visual workload of the copilot/navigator during terrain flight. Proceedings of the Human Factors Twenty-First Annual Meeting. San Francisco, Calif.: Human Factors Society, October 1977, 262-266.

The emphasis on aviator workload has been of primary concern to the US Army aviation community since the incorporation of low altitude terrain flight techniques into the helicopter tactics repertory. Since aviation has been a particularly acute problem at low altitudes, this project examined the visual workload of the navigator/copilot during terrain flight (nap-of-the-earth, contour and low level) in a UH-1H helicopter. Visual performance was measured via a modified NAC Eye Mark Recorder used in conjunction with a LO-CAM high speed camera. This technique provided the means to objectively record and analyze the navigator's visual performance through the examination of: (1) visual time inside the cockpit of flight and engine instruments, (2) time inside the cockpit on the map or other navigation aids, and (3) time outside the cockpit in various windscreen sectors.

W/L Cat. Code: 2.2.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Subsidiary task   Experimental   Flight test   Flight simulator

Physiological   Eye movement   Flight test

Sanders, M. S., Jankovich, J. J. and Goodpaster, P. R. Task analysis for the jobs of train conductor and brakeman. Crane, Indiana: Naval Ammunition Depot, RDTR-No. 263, July, 1974.

This report identifies and describes the principal tasks performed by conductors, rear brakemen, and head brakemen during over-the-road freight operations utilizing diesel-electric locomotive equipment. Forty-four tasks and subtasks were analyzed and grouped into six categories: basic handling tasks, pre-run preparation and starting off tasks, over the road tasks, terminating tasks, operating emergency and malfunction tasks, and auxiliary equipment operating tasks. Each task or subtask is described from a system's perspective. The descriptions depict the tasks' initiating stimuli, the information processing and decision making, the response made by the operator and the feedback received. The tasks are also analyzed to determine task difficulty, potential hazards and the criticality of each task. The task descriptions are translated into operational sequence diagrams with additional information given concerning the decisions depicted on each operational sequence diagram.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator

Savage, R. E., Wierwille, W. W. and Cordes, R. E. Evaluating the sensitivity of various measures of operator workload using random digits as a secondary task. Human Factors, 1978, 20, 649-654.

Problems have been encountered in previous research in developing a secondary task measure of mental workload that is both sensitive and stable. Ordinarily a single measure of secondary task is analyzed as an indicator of difference in workload. The purpose of the experiment reported here was to determine whether alternate measures taken from a single secondary task might prove more sensitive. Twelve subjects participated in the experiment involving a primary task (meter pointer nulling) and a secondary task (reading random digits aloud). The independent variable (primary task difficulty level) was adjusted by changing the number of meters that had to be monitored (two, three, or four meters). Dependent measures were taken on the (1) number of random digits spoken (usual workload formula), (2) longest interval between spoken responses, (3) longest consecutive string of spoken digits, and (4) the number of "triplets" spoken. Results show that the dependent measures (1), (3), and (4) were significant with (1) being the most sensitive.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator Flight test

Sayers, B. M. Analysis of heart rate variability. Ergonomics, 1973, 16, 17-32.

Spontaneous variability of heart-rate has been related to three major physiological originating factors: quasi-oscillatory fluctuations thought to arise in blood-pressure control, variable frequency oscillations due to thermal regulation, and respiration; frequency selective analysis of cardiac interbeat interval sequences allows the separate contributions to be isolated. Using this method, a laboratory and field study of the effects of mental work load on the cardiac interval sequence has been carried out. Results suggest that mean heart rate and variance are unreliable measures, but that consistent changes in interval spectrum occur; these have been traced to alterations mainly in the 0.1 Hz region, perhaps originating with changes in the patterns of respiration which interact with the 0.1 Hz vasomotor activity.

W/L Cat. Code: 4.1.10, 4.1.11

Op. Behav. Code: 2.

Physiological	Heart rate, h.r. var.	Review	Laboratory	Flight simulator
	Breathing anal.	Construct	Field	Flight test
		Experimental		

Schick, F. V. On the practical utility of critical flicker fusion frequency measurements to the assessment of mental workload. Braunsweig, West Germany: Institute für Flugfuhrung, Report DLF-FB 76-67, 1976. (In German). (Available in English as European Space Agency translation ESA-TT-398-Revised, November, 1977.)

Two experiments were conducted to evaluate the utility of an advanced measuring device, coupled with a practicable measurement procedure, with respect to reliable and valid assessment of mental workload by measuring critical flicker fusion frequency (CFF). In the first experiment, basic variability of CFF scores, obtained under nonworkload conditions, was studied. Error of measurement as well as physical and physical interference variables were discussed to be sources of the large oscillations actually observed from data. It was found necessary to modify the measurement procedure. In the second experiment CFF thresholds were examined. Statistical analysis revealed generally low reliability coefficients. Also thresholds failed to discriminate between low workload and high workload treatments.

W/L Cat. Code: 5.1, 4.1.1
Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Background
Physiological	FFF			

Schiffler, R. J., Geiselhart, R., and Griffin, J. C. A study of crew task loading on the C-141 aircraft. Wright-Patterson Air Force Base, Ohio: Air Force Systems Command, ASD-TR-78-3, April, 1978. (AD A057 346).

At the request of the Military Airlift Command, human factors engineers participated in a C-141 crew composition and task load analysis. The objective of the study was to determine the feasibility of a four-man crew consisting of two pilots, a flight engineer and a flight system operator, to fly C-141 missions. The test results indicated that the air/land mission can be accomplished with a four-man crew. Presently for a combat airlift mission (airdrop) the most optimal crew composition would be two pilots, navigator and flight engineer. With additional training, it might be feasible to substitute a flight system operator for navigator in the combat airlift mission.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Flight test	Flight simulator
Primary task	Single measures			Flight test

Schiffler, R. J., Geiselhart, R. and Ivey, L. Crew composition study for an Advanced Tanker/Cargo Aircraft (ATCA). Wright-Patterson, AFB, Ohio: USAF Aeronautical Systems Division, ASD-TR-76-20, October, 1976.

To determine the minimum crew complement required for an Advanced Tanker/Cargo Aircraft a series of contractor and AF task analyses were reviewed and evaluated. Coupled with these analyses were a series of flight tests which verified some of the task times and procedures required for Advanced Tanker/Cargo Aircraft. It was concluded that a three man crew (P, CP, Boom Operator) had crew work overloads during several flight segments and this crew size would be unacceptable in a Emergency War Order (EWO) environment. A four man crew (P, CP, N/FE and Boom Operator) was the most advantageous and could handle most tasks below a 100% task loading.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator
Primary task	Single measures	Experimental	Flight test	

Schiflett, S.G. Operator workload: An annotated bibliography. Patuxent River, Maryland: US Naval Air Test Center, SY-257R-76, December, 1976.

The importance of maintaining optimal aircrew workload levels has long been recognized as a significant factor that contributes to the overall success or failure of a mission. Workload as traditionally defined in the context of crew work-rest schedules or time-and-motion studies are typically measured by "amount of expended physical effort" or "time analysis of activities." However, these types of approaches have the same methodological problems as some of the more modern techniques of measuring workload, e.g., man-simulation models, because they were not developed for the test and evaluation environment and, consequently, were derived from an inadequate and inappropriate data base. The purpose of this study was to compile an annotative bibliography of methodologies that measure operator workload in aircrew systems. This compilation is necessary to meet the need for a continuing review of test and evaluation methodology.

W/L Cat. Code: 1., 2., 3., 4
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Schiflett, S. G. Voice stress analysis as a measure of operator workload. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 573.

A need exists for a general stress measure which is nonobtrusive and can be applied in actual operational circumstances without interfering with operator performance. Previous research in the field of voice analysis has indicated that the psychophysiological stress-state of the speaker may manifest itself in the acoustic domain by changes in the frequency modulation (8 to 12 Hz) of the fundamental frequency (50 to 250 Hz) of the voice. This study attempted to determine if such frequency modulation changes can be used to detect the amount of situational stress in the voice while subjects performed a four-choice information processing task at different presentation rates. A Response Analysis Tester (RATER) presented a four-choice discrimination task in which each subject was required to match a response key to each of four stimuli (numbers -one, two, three, and four) appearing in a display window. The voice was analyzed by a device manufactured by Dektor, Incorporated, called a Psychological Stress Evaluator (PSE), developed specifically as a deception-detection instrument. Preliminary voice stress analyses for 15 subjects show correlations between performance scores and stress ratings. The results are discussed as to the potential application for a nonobtrusive measure of stress in vocal communication systems that require operator workload assessments.

W/L Cat. Code: 4.3
Op. Behav. Code: 1., 2., 3., 4.1

Physiological	Speech pat. anal.	Experimental	Laboratory	Flight simulator
				Flight test

Schiflett, S. G. Evaluation of a pilot workload assessment device to test alternate display formats and control stability variations. Patuxent River, Maryland: Naval Air Test Center, SY-33R-80, February 1980.

This inflight research project evaluated the utility of a Workload Assessment Device (WAD) to measure pilot workload for approach and landing tasks under simulated instrument meterological conditions, alternate Head-up Display (HUD) formats, and control stability variations. The flight tests were conducted in an NT-33A research aircraft, extensively modified for the Air Force and Navy by the Display Evaluation Flight Test Program. The hardware, software, and test procedures associated with the WAD functioned efficiently with only minor discrepancies and minimum pilot distraction. The project established the feasibility of using an item recognition task as a measure of sensory-response loading and reserve information processing capacity while flying precision approaches. The results indicate an appreciable increase in reaction time and errors on the secondary task flown with degraded handling qualities as compared to ground baseline measures and good handling qualities. The pilots showed more mental reserve capacity when flying pictorial/symbolic HUD configurations as compared to conventional HUD formats with standard scales and alphanumerics. It is recommended that further evaluations be conducted to establish the efficacy of utilizing the WAD to measure mental workload in a wide variety of aircrew tasks.

W/L Cat. Code: 1.1, 2.2.1
Op. Behav. Code: 1., 2., 4.

Opinion	Rating scales	Experimental	Flight test	Flight simulator
Spare M. capacity	Secondary task			Flight test

Schiflett, S. G. and Loikith, G. J. Voice stress as a measure of operator workload. Patuxent River, Maryland: Naval Air Test Center, Technical Memorandum TM79-3 SY, December 31, 1979.

This paper documents a study that attempted to determine if the PSE could be used to detect the amount of situational stress in the voice while subjects performed a four-choice information processing task at different presentation rates. The purpose was to evaluate the relationship between performance scores, self-rated stress, and measured vocal stress due to increases in presentation rates. Voice stress analysis showed significant correlations with performance scores and stress ratings of a selected pool of subjects (N=12). The results are discussed as to the potential application of an objective, reliable, and nonobstrusive measure of stress in vocal communication systems that require operator workload assessments.

W/L Cat. Code: 1.1, 3.1, 4.3
Op. Behav. Code: 1., 2., 3., 4.1

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test
Physiological	Speech patt. anal.			

Schmidt, D. K. On modeling ATC work load and sector capacity. Journal of Aircraft, 1976, 13, 531-537.

This paper describes a semi-empirical, deterministic work load model and a procedure intended to aid in the design and evaluation of those units of airspace (sectors) under the jurisdiction of a team of air traffic controllers. The technique relates the traffic variables, route and sector geometry, and control procedures to an index that quantifies the work load required on the part of the air traffic control (ATC) team. Work load is considered to constitute the required sector evaluation criterion when maximum overall ATC facility capacity and manning efficiency are desired. With proper calibration, the model may be used to assess the impact on work load and sector capacity of future automation features. An example evaluation of an actual high altitude, enroute sector is included.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Math. model	Construct	None	Flight simulator

Schmidt, D. K. A Queueing analysis of the air traffic controller's work load. IEEE Transactions on Systems, Man and Cybernetics, 1978, SMC-8, 492-498.

The qualitative relations between workload measures (or stressors), strain, fatigue, and the performance of the man in the air traffic control (ATC) system are reviewed. A number of stressors, including the workload magnitude (i.e., minimum utilization time per unit time), delay in ATC task execution due to excessive activity, and mental image updating requirements are identified and discussed. With the various ATC tasks competing for the man's information-processing activity, a queuing model is presented. Calibrated with field data, a computer simulation of the model was used to obtain trends in the above stressors versus traffic demand for two enroute sectors. Preliminary estimates of maximum allowable thresholds for these stressors are used to infer the controller's traffic-handling capacities.

W/L Cat. Code: 2.1.1, 3.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Field	Flight simulator
Primary task	Math. model	Experimental		

Schori, T. R. A comparison of visual, auditory, and cutaneous tracking displays when divided attention is required to a cross-adaptive loading task. Ergonomics, 1973, 16, 153-158.

The present investigation was designed to order the relative difficulty of tracking with a visual, an auditory and a cutaneous display. Utilizing one of the three displays, subjects were required to track while simultaneously performing a visual loading task. Tracking performance did not differ as a function of the type of tracking display utilized. However, performance on the loading task accompanying visual and auditory tracking was superior to that accompanying cutaneous tracking. From these findings it was concluded that visual and auditory tracking are less difficult than cutaneous tracking in that both the former leave the operator with more "spare attention" for carrying additional tasks.

W/L Cat. Code: 2.2.4, 2.2.5, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures Flight test

Schori, T. R. and Jones, B. W. Smoking and work load. Journal of Motor Behavior, 1975, 7, 113-120.

Smokers, smokers deprived, and nonsmokers performed a compensatory tracking task while simultaneously performing a cross-adaptive loading task. By means of the cross-adaptive technique, the size of the subject's total work load (tracking and loading tasks combined) was individually tailored to utilize each subject's entire attentional capacity. No differences were detected as a function of smoking condition either in tracking or loading task performance, and it was concluded that smoking condition did not affect the size of the workload which could be handled. Performance generally improved with trials, however, none of the smoking condition x trials interactions was significant, indicating that performance changes with practice did not differ among the various smoking conditions.

W/L Cat. Code: 2.2.4, 2.2.5

Op. Behav. Code: 1., 2., 3., 4

Spare m. capacity Subsidiary task Experimental Laboratory Background

Schouten, J.F., Kalsbeek, J.W.H., and Leopold, F.F. On the evaluation of perceptual and mental load. Ergonomics, 1962, 5, 251-260.

Human labor may roughly be divided into three different categories: physical, perceptual and mental. Physical labor can be measured in terms of physical units of consumption and production of energy. Physical labor is the only kind, as yet, which can be expressed in adequate units of labor. Perceptual labor and load seem to lay themselves open to interpretation in terms of such concepts as information and manipulation similar to those used in communication theory. This, however, could at best apply to relatively simple patterns of stimuli and reactions. Although, in a general way, the manifold perceptual faculties are limited in speed, accuracy, extension and complexity, it is not known whether these faculties lend themselves to being expressed in terms of a universal unit, permitting of the relative calibration of the load of a perceptual task. Mental labor and load might be rubricated in terms of such concepts as attention, vigilance, motivation, responsibility, perseverance, stress, strategy, tactics, etc.

W/L Cat. Code: 1., 2., 3., 4
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				
Primary task				
Physiological				

Schultz, W. C., Newell, F. D. and Whitbeck, R. F. A study of relationships between aircraft system performance and pilot ratings. Proceedings of the 6th Annual NASA-University Conference on Manual Control, Wright-Patterson AFB, Ohio, April 7-9, 1970, 339-340.

This study examines the relationship between man-machine system performance and pilot evaluation data. The intent of the experiment described herein is to add to the library of knowledge concerning quantitative analytical measures of pilot-aircraft performance for complex piloting tasks including use of glideslope and localizer for ILS tasks. The Cooper-Harper rating scale was used.

W/L Cat. Code: 1.1, 3.3

Op. Behav. Code: 1.1, 1.2, 4.2

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Math. model			Flight test

Schvaneveldt, R. W. Effects of complexity in simultaneous reaction time tasks. Journal of Experimental Psychology, 1969, 81, 289-296.

Two experiments investigated the effects of information load (number of alternatives) and S-R code in each of two simultaneously performed reaction time (RT) tasks. The subjects were required to make both a verbal and a manual response on each trial in the simultaneous-performance conditions. Each task was also performed alone for comparison. The results were: (a) In simultaneous performance, RT in each task was greater with more alternatives or an indirect S-R code in either task; (b) the complexity of the verbal task had a smaller effect on verbal RT when the complexity of the manual task was increased; and (c) details of the data argued against a response-grouping interpretation. The evidence for overlap between the two tasks has important implications for the single-channel hypothesis.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Schwarz, J. J. and Ekkers, C. L. Estimation of task loading by observing and regulating complex technical systems. Mens en Onderneming, 1976, 76, 85-108. (In Dutch).

The increasing use of complex automated technical systems leads to higher risks for people in and outside these systems. Of crucial importance in this respect is the control task of the human operator. It is proposed that task performance will diminish when the task load for the operator is too heavy. The aim of this study is to estimate the task load of the operator by systematic observation of his behavior and physiological measurements (ECG). An observational system has been developed which can be used in different control tasks. In this study the observational system has been tested with three different control tasks. The results were that the observational system differentiates between different levels of task load and the frequency of the ECG is higher with higher levels of task load. Further investigations are being prepared in which data concerning task load will be correlated with criteria of health and well-being over longer periods of time.

W/L Cat. Code: 2.1.1, 4.1., 3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Task comp., time assess. Experimental Laboratory Flight simulator

Physiological EKG

Sebej, F. and Biro, V. Effect of psychic load on the course of respiration. Studia Psychologica, 1978, 20, 67-71.

An attempt was made to analyze the relationship between respiratory parameters and psychic load. The latter was made to simulate the following elements: time pressure, feedback information on perception of subject's own performance, sensorimotor coordination, speed and precision of perception. The results imply that 1. the respiratory system is a sensitive indicator of psychic load, 2. awareness of one's own performance exerts an activating influence on some measures of function of the respiratory system, 3. the selected measures proved appropriate in following up respiratory changes under conditions of psychic load.

W/L Cat. Code: 3.1, 4.1.11

Op. Behav. Code: 1., 2., 4.

Primary task   Single measures   Experimental   Laboratory   Flight simulator

Physiological   Breathing anal.

Seibel, R., Christ, R. E. and Teichner, W. H. Perception and short term memory under workload stress. Port Washington, New York: U.S. Naval Training Device Center, NAVTRADEVCEN 1303-2, June, 1964. (AD 604 866).

This report is one of three evaluations of differently proposed methods for increasing the ability of individuals to report the contents of briefly exposed alphabetic displays. In this case, increasing the number of consecutive displays, the number of displays per unit time, and the number of letters per display all lead to an increase, or at least no decrease, in the total number of letters correctly reported when the individual was asked to report all that he had seen. These forms and levels of input stress did not lead to breakdown in performance. If individuals were called on to report only certain parts of what they had seen, however, then the increases in input stress lead to decreases in total number of correctly reported letters. The results suggest that individuals protect themselves from high input rates by filtering out what they cannot handle, and only if they must process the information are high input rates likely to lead to performance breakdown. The military implications of the results are discussed.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.1

Primary task   Single measures   Experimental   Laboratory   Background

Seifert, R., Daniels, A. F. and Schmidt, K. A method of man-display/control system evaluation. Proceedings of the AGARD Conference on Guidance and Control Displays, AGARD-CP-96, 8-1 - 8-8. (AD 739 779).

The paper describes a method for evaluating the design and assessing the layout of an aircraft cockpit. This method can also be readily applied to the evaluation of other display/control systems. The objectives of the study and their timing in relation to the overall development process are discussed. Factors significantly affecting the design, such as scenario, and operational and equipment requirements are introduced and a description of the rig facility provided. The use of the Cooper-Harper rating system, Semantic Differentials and Guided Interviews in the analysis of subject performance and opinion is described. Finally the paper concludes that complex man-display/control systems can only be optimized by the adoption of a comprehensive approach to experimental studies of the kind described in the paper.

W/L Cat. Code: 1.

Op. Behav. Code: 1., 2., 4.

Opinion   Rating scale   Construct   Laboratory   Background

Questionnaire   Experimental

Sekiguchi, C., Handa, Y., Gotoh, M., Kurihara, Y., Nagasawa, A., and Kuroda, I. Evaluation method of mental workload under flight conditions-relationship to heart rate variability. Aviation, Space, and Environmental Medicine, 1978, 49, 920-925.

To analyze the relationship between heart rate variability (HRV) and the flight tasks of pilots, HRV of various mental and physical work stressors were investigated. For the physical stress on the treadmill, S.D. of heart rate sequence showed a minimum value at medium stresses and remained there until the maximum stress. However, the centrifuge acceleration test presupposed special physical stresses, and S.D. was almost same as the resting findings. In the tracking tasks, which presupposed maximum interpretative actions, the increase in the mean heart rate (MHR) was small with the S.D. increased a greater amount than for resting results. Consequently, preflight checks and level flight phases presupposed medium interpretative actions and mental stress with reserve capacity. Takeoff and landing phases were considered as both high interpretative action and high emotional stress situations. Acrobatic and gunnery training flight phases were considered physical load, strong interpretative actions, and emotional stress tasks.

W/L Cat. Code: 4.1.3, 4.1 10

Op. Behav. Code: 1., 2., 4.

Physiological   Heart rate, h.r. var.   Experimental   Laboratory   Flight simulator

Simulator   Flight test

Sem-Jacobsen, C. W. ECG monitoring of heart failure and pilot load/overload by the Vesla seat pad. Aviation, Space, and Environmental Medicine, 1976, 47, 441-444.

Heart failure has caused sudden incapacitation of pilots in command of commercial airliners. These fatal episodes have occurred in connection with takeoffs and landings, and have resulted in incidents as well as major accidents. Sudden cardiac arrest or serious episodes, such as ventricular tachycardia, usually cannot be detected at autopsy. A number of accidents due to unknown reasons or to "pilot error" can be due to, and some probably are, cardiac breakdown. The Vesla Seat Pad is a device for biomedical monitoring of ECG signals from human subjects without attachment to the subjects of any leads or sensor devices. It is capable of obtaining appropriate ECG signals, transmitted to the pad through the medium of the subject's perspiration, for monitoring the subject's heart action. ECG signals, together with other data, can be electronically processed and used to warn the co-pilot and tower of impending hazard. The "dead man's button" with an overload warning system could greatly, when taken into use, improve flying safety.

W/L Cat. Code: 4.1.3, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Physiological	EKG	Construct	Laboratory	Flight simulator
	Heart rate, h.r. var.	Experimental		Flight test

Senders, J. Axiomatic models of workload. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 263-267.

This paper provides definitions, axiomatic statements, and hypotheses concerning workload. Several classes of workload are presented, including study-state workload, non-study-state workload, internal switching load, time cost of switching, and motivation and effort.

W/L Cat. Code: 2.1, 3.3

Op. Behav. Code: 1., 2.

Spare m. capacity	Task analytic	Construct	None	Background
Primary task	Math. modeling			

Senders, J.W. The human operator as a monitor and controller of multidegree of freedom systems. IEEE Transactions on Human Factors in Electronics, 1964, HFE-5, 2-5.

Although most research and theory building on human operator performance has considered the operator to be a continuous single-channel controller, straightforward examination of real situations and real behavior shows him to be a sampled-data, commutated single-channel controller. This arises from the fact that the human operator must distribute his attention sequentially over many information sources. Both monitoring and controlling behavior are subject to the constraint that the operator's eyes can fixate on only one place at a time. This report sets forth a model which attempts to predict the relation between the kind and rate of information displayed on any display and the frequency and duration of samples made of that display. The approach utilizes the notion that it is possible to quantify the attentional demand placed on the controller by each source of information in a complex man-machine system. The attentional demand can be calculated on the basis of the bandwidth and required precision of readout of the signal presented by an information source.

W/L Cat. Code: 2.1.2
Op. Behav. Code: 1., 2.

Spare m. capacity	Inform. theory	Construct Experimental	Laboratory	Flight simulator

Senders, J.W. The estimation of operator workload in complex systems. In K.B. DeGreene (Ed.) Systems Psychology. New York: McGraw-Hill, 1970, 207-216.

Eye movements and visual scanning processes, considered the major indicator of operator workload, are emphasized in this discussion. Human monitors of systems sample instruments at different rates and for different durations in a consistent way which appears to be almost completely a function of the nature of the signal presented. Shannon (1948) and Shannon and Weaver (1949) showed that the information in bits per second generated by a continuous time function (subject to certain limitations regarding the shape of the spectrum) was directly proportional to the bandwidth of the signal in cycles per second, and to the logarithm of the ratio of the signal power to the permissible mean square error power in the readout. An extended theory based on the notion of a "queue" of instruments waiting for attention provides a means of generating probability distributions of demand and a consequent estimation of the reliability of the operator as a system constituent.

W/L Cat. Code: 2.1.2, 3.3
Op. Behav. Code: 1., 2., 4.

Spare m. capacity Primary task	Inform. theory Math. model	Construct	Flight simulator	Flight simulator

Senders, J.W., Kristofferson, A.B., Levison, W.H., Dietrich, C.W. and Ward, J.L. The attentional demand of automobile driving. Highway Research Record, 1967, No. 195, 15-33.

A theoretical analysis and an experimental investigation of certain aspects of automobile driver information processing were undertaken. The theoretical analysis was the result of an effort to avoid difficulties associated with a servomechanistic approach to the automobile driving problem. The analysis is predicted on the assumption that a driver's attention is, in general, not continuously but only intermittently directed to the road. A simple threshold model appears to be a useful analog of the driving process. The analysis makes specific predictions about the form of the functional relationship between intervals between observations and vehicle speed. The experimental program had two goals. One was the empirical investigation of the relation between amount of interruption of vision and driving speed. The other was the determination of the parameters in the mathematical model. This report presents the results of the theoretical and experimental investigation.

W/L Cat. Code: 2.1.2, 2.3
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Inform. theory	Construct	Field	Flight simulator
	Occlusion	Experimental		

Senders, J. W. and Posner M. J. M. A queueing model of monitoring and supervisory behavior. In T. B. Sheridan and G. Johannsen (Eds.) Monitoring behavior and supervisory control. New York: Plenum Press, 1976, 245-259.

In the design of workplaces for monitoring and supervisory activity, economic and physical space requirements play an important role. These requirements as well as human factors engineering requirements must be met. This paper describes mathematical models for assessing human operator behavior in such systems. The models are based on information theoretic concepts combined with queueing models of instrument servicing. The concept of avoiding system failure by maintaining manageable task demands is presented.

W/L Cat. Code: 2.1.2, 3.3

Op. Behav. Code: 1., 2.

Spare m. capacity Information theoretic Construct None Flight simulator

Primary task Math. modeling

Sheridan, T.B. and Stassen, H.G. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 219-233.

Alternative definitions of workload are presented in a control paradigm, and various trade-offs between workload factors are considered. Descriptions of workload in terms of stress and strain, capacity, and attention allocation are briefly reviewed. The utility of applying formal models of workload is described in terms of candidate models which include the optimal control model, decision models, information channel models, and activation/uncertainty models.

W/L Cat. Code: 2.1.2, 3.3
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Inform. theory	Construct	None	Flight simulator
Primary task	Math. model			

Sherman, M. R. The relationship of eye behavior, cardiac activity and electromyographic responses to subjective reports of mental fatigue and performance on a Doppler identification task. Master's thesis, Naval Postgraduate School, Monterey, California, September, 1973. (AD 769 754).

This research investigated relationships between subjective fatigue, performance, and four physiological parameters: sinus arrhythmia, pupil behavior, blink rate, and tension of the neck muscles. Fatigue was induced by a doppler recognition task and rigid body posture. Performance was measured as the proportion of correct doppler identifications. There was no detection of a performance change during the two and one half-hour experimental sessions. Sinus arrythmia and eyelid blink rate were also found to remain unchanged. An alteration was found in the measures of neck muscle tension levels, subjective fatigue, and the average pupil diameter. Subjective ratings of fatigue were found to be highly correlated with time-on-task and the electromyographic response of certain neck muscles. Polynomial regression indicated a significant linear relationship between the subjective ratings and the tension measured.

W/L Cat. Code: 1.2, 3.1, 4.1.4, 4.1.7, 4.1.8, 4.1.9, 4.1.10

Op. Behav. Code: 2., 3., 4.

Opinion	Multiple	Experimental	Laboratory	Flight simulator
Primary task				Flight test
Physiological				

Shiffrin, R. M. and Gardner, G. T. Visual processing capacity and attention control. Journal of Experimental Psychology, 1972, 93, 72-82.

Three experiments tested whether visual processing operates under attentional control, and with temporal-spatial capacity limitations. The Ss identified which of two key letters was present in briefly presented four-letter displays. Models postulating attentional control and limited capacity would predict an advantage for the sequential condition since in this case processing capacity need not be simultaneously shared among four letters. The results demonstrated simultaneous and sequential conditions to be equal. It was concluded that the initial stages of visual processing, up to at least the level of letter recognition, take place without capacity limitation and without attentional control.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2.

Primary task   Single measures   Experimental   Laboratory   Background

Shulman, H.G. and Briggs, G.E. Studies of performance in complex aircrew tasks. Columbus, Ohio: The Ohio State University, Research Foundation, RF Project 2718, Final Report, December, 1971. (AD 753 762).

The basic objective of the research described in this report was the investigation of human performance under conditions of divided attention. This research has focused on performance in two types of divided attention paradigms referred to as the sequential and simultaneous demand paradigms. Research on the simultaneous demand situation centered on performance when a memory task was time-shared with a pursuit tracking task similar in principle to a vehicular control task. These experiments showed a) that decrements occur in both tracking and retention performance, b) that these increments increase with signal complexity on the tracking task and acoustic similarity on the memory task, and c) that practice reduces these decrements by an amount proportional to the size of the initial decrement. Experiments on sequential demand time-sharing focused on two basic situations. First were situations characterized by heavy memory loads and interstimulus intervals between 1 and 8 seconds. Second were situations involving low memory loads and interstimulus intervals between .1 and 1.0 seconds. In both situations, a time-sharing decrement occurs and is proportional to the interstimulus interval.

W/L Cat. Code: 2.2.1, 2.2.2 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures		Flight simulator	Flight test

Siegel, A. I., Lanterman, R. S., Platzer, H. L. and Wolf, J. J. Techniques for evaluating operator loading in man-machine systems: Development of a method for real time assessment of operator overloading. Wayne, Pennsylvania: Applied Psychological Services, January, 1976. (AD 479 045).

The logic involved in deriving certain constants, thought important for describing the human transfer function, is presented. Then an experiment investigating the effects of varying operator alertness level (sleep deprivation) on two of the constants is described and the results presented. In the experiment, subjects performed compensatory tracking and a series of cognitive and perceptual motor tasks at intervals over a 27 hour period of sleep deprivation. The results were not in accordance with the preexperimental hypothesis, which stated that the two constants derived should decrease as the alertness level decreased (increasing period of sleep deprivation). On the other hand, some relationship was found between one of the transfer function constants and the scores of the subjects on the accessory intellectual and cognitive tasks. Several possible explanations for the findings are presented.

W/L Cat. Code: 2.2.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Math. model			Flight test

Siegel, A. I. and Williams, A. R., Jr. Identification and measurement of intellective load carrying thresholds. Wayne, Pennsylvania: Applied Psychological Services, AFOSR-TR-75-0593, December, 1974. (AD A009 159).

The conjecture was investigated that the intellective load carrying capability for selected intellective functions is identifiable and measurable. Intellective load carrying failure was defined as the point at which a change in transfer function components occurs as a tracking and a scaled intellective function were concomitantly performed. The scaled intellective functions were drawn from the Guilford Structure-of-Intellect model. The transfer function components included amplitude ratio and phase lag as defined by the frequency-response analytic method. Anticipated between individual and between intellective function differences were found. The ability to isolate the intellective load carrying threshold for individual subjects and for individual intellective functions was demonstrated.

W/L Cat. Code: 3.1, 3.3

Op. Behav. Code: 1., 2., 4.2

Primary task	Single measures	Construct	Laboratory	Flight simulator
	Math. model	Experimental		

Siegel, A.I. and Wolf, J.J. <u>Man-machine simulation models: Psychosocial and performance interaction</u>. New York: Wiley, 1969.

Techniques for including characteristics of both individuals and groups into the logic of digital simulation are discussed. Two well defined models in which effects of such variables as stress, operator proficiency, morale, and group psychosocial efficiency are simulated as part of an operational task. Methods for system optimization early in the development stage and a basis for estimating manpower and skill requirements within a system are described. A discussion of general simulation methods involved, the costs, advantages and disadvantages, and the types of results which can be expected from digital computer simulation are included. Techniques for considering the handling of emergencies, sick personnel, work crew formations, equipment failure, group selection, and interopreator communication in timeline modeling are also presented.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Simulator	Flight simulator
				Flight test

Siegel, A. I., Wolf, J. J., Fischl, M. A., Miehle, W. and Chubb, G. P. Modification of the Siegel-Wolf operator simulation model for on-line experimentation. Wright-Patterson AFB, Ohio: USAF Aerospace Medical Research Laboratory, AMRL-TR-71-60, June, 1971.

The primary effort in this study was to modify the existing Siegel-Wolf operator simulation model to allow dynamic interaction with an experimental subject performing on-line in some sort of pseudo real time environment. The Siegel-Wolf model is capable of simulating task performance by a one or two-man crew to determine the impact human factors have on systems effectiveness and mission success. The BUIC III active tracking task was used in this work as a representative environment. The other three phases of the effort dealt with the conceptual aspects of the model. Variables known to contribute to performance, but which were not incorporated into the model, were considered to determine their possible contribution to enhancing the model's predictive validity. Four of these variables were identified as the more promising candidates: graded task essentiality, information load, goal proximity or goal gradient effects, and decision making. Flow charts were prepared to illustrate how these variables could be incorporated into the model, but no computer programming was attempted. The third phase of the effort involved the definition of an alternate method for predicting operator/system performance. The last phase of the effort entailed the examination of additional areas where the model could be expanded.

W/L Cat. Code: 2.1.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct Experimental	Laboratory	Flight simulator

Siegel, A.I., Wolf, J.J. and Sorenson, R.T. Techniques for evaluating operator loading in man-machine systems: Evaluation of a one or a two-operator system evaluation model through a controlled laboratory test. Wayne, Pennsylvania: Applied Psychological Services, Contract Nonr 2-492(00), July, 1962. (AD 284 182).

A stochastic, digital computer simulation model was previously derived for and applied to the problem of simulating one or two-operator man-machine systems. Further test of the validity of the model through comparisons of the model's predictions of team performance with the actual performance of trained teams on a man-machine task is described. A complex two-operator man-machine equipment task involving team and individual branching, operator stress buildup, looping, cooperative work, communication, waiting, etc., was developed. This same task was inserted into the high speed computer programmed in accordance with the model. On the basis of non-statistically significant differences, in nine of ten possible comparisons, it was concluded that support is gained for a contention favoring the validity of the model.

W/L Cat. Code: 2.1.1, 3.1
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Simmons, R. R. Methodological considerations of visual workloads of helicopter pilots. Human Factors, 1979, 21, 353-367.

Modifications to and applications of the Eye Mark Recorder corneal reflection apparatus for the assessment of the visual performance and workload of pilots during helicopter operations are presented. Modifications accomplished to ensure compatibility with the helicopter flight environment include adjustments to the face mask for comfort and stability, a variable power supply, a special mount for the recording camera inside the helicopter and the addition of a blue template to the instrument panel to allow for proper image contrast inside and outside the aircraft. Test and data reduction procedures for use with the apparatus are outlined.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2., 4.1

Physiological	Eye movement	Experimental	Flight simulator	Flight simulator
			Flight test	Flight test

Simmons, R.R. and Kimball, K.A. Methodological considerations of visual workloads of helicopter pilots. Proceedings of the AGARD Conference on Methods to Assess Workload ACARD-CPP-216, April, 1977, A2-1.

A methodology is described for assessing inflight oculomotor and perceptual motor performance, a methodology which is instrumental in collecting baseline data of pilot workload during various helicopter operations to include instrument flight, visual flight, or terrain flight. Visual performance was assessed via a modified NAC Eye Mark Recorder in conjunction with a 16 mm motion picture camera with time code capability. A reticle is superimposed on a primary image of the pilot's field of view and recorded on 16 mm film. Modifications were accomplished to allow inflight stability to the system for accuracy and to allow freedom of head movement for the pilot. Inflight performance measures were also obtained. The system measures pilot's cyclic, collective and pedal inputs, and simultaneously records the aircraft's response to include position, acceleration, and rate changes.

W/L Cat. Code: 3.2, 4.1.7
Op. Behav. Code: 1., 2., 4.

Primary task	Mult. measures	Experimental	Flight test	Flight simulator
Physiological	Eye movement			Flight test

Simmons, R. R. and Kimball, K. A. Operator visual workload shifts as a function of vehicle stability. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 352-356.

This research was initiated to compare the visual performance/workload of pilots during fixed wing and rotary wing flights. The corneal reflection technique was used to obtain the visual data. The results demonstrate that visual performance/workload of the pilots was different for each aircraft. Because the major difference between the aircraft was the aerodynamic stability, it was assumed that the visual workload was in fact a function of aircraft stability. The overall purpose of such research has been to provide information concerning pilots' visual requirements for safe mission accomplishment.

W/L Cat. Code: 2.1.1, 4.1.7

Op. Behav. Code: 1., 2.

Spare m. capacity	Task comp., time assess.	Experimental	Flight test	Flight simulator
Physiological	Eye movement			Flight test

Simmons, R. R., Kimball, K. A. and Diaz, J. J. Measurement of aviator visual performance and workload during helicopter operations. Ft. Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, 77-4, December, 1976.

This report was initiated to review the techniques and modifications developed by the U.S. Army Aeromedical Research Laboratory for assessing visual performance/workload of pilots during helicopter operations. Although the corneal reflection technique for gathering eye movement data is not new, innovative modifications had to be developed to permit accurate data collection in this flight environment. This study reports on these techniques, modifications, and applications.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2., 4.

Physiological	Eye movement	Review	Flight simulator	Flight simulator
			Flight test	Flight test

Simmons, R. R., Lees, M. A., and Kimball, K. A. Visual performance/workload of helicopter pilots during instrument flight. Ft. Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, 78-6, January, 1978.

Flight under instrument flight rules (IFR) is reported to be one of the most important factors contributing to aviator fatigue during helicopter operations. This study was initiated to collect visual and psychomotor performance data in an attempt to investigate and study the general visual performance of aviators during IFR conditions. Two groups of aviators, with varied experience levels, were the subjects. A NAC Eye Mark Recorder and the Helicopter In-Flight Monitoring System were utilized to collect the required data. The results indicated, among other findings, that pilot subjective opinion does not agree with objective data. Additionally, the attitude indicator and radio compass comprised over 60% of the pilots' total visual workload, while the aircraft's status gauges were monitored less than 10% of the total time. These data should provide invaluable information concerning the visual requirements of pilots for safe helicopter operations.

W/L Cat. Code: 1.1, 3.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Single measures			Flight test
Physiological	Eye movement			

Simmons, R. R., Lees, M. A., and Kimball, K. A. Aviator visual performance: a comparative study of a helicopter simulator and the UH-1 helicopter. In AGARD Operational Helicopter Aviation Medicine, AGARD-CP-255, May, 1978, 52-1 - 52-13.

This research project was initiated to compare the visual performance/workload of pilots during helicopter and simulated helicopter instrument flights (IFR). The corneal reflection technique was utilized to obtain the visual data. Although pilot performance in the Army's UH-1FS simulator and the UH-1H helicopter were similar, several differences were noted. Additionally, the zone/cost factor theory from previous studies was expanded. The overall purpose of such research has been to provide information concerning pilots' visual requirements for safe mission accomplishment.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2., 4.

Physiological	Eye movement	Experimental	Flight simulator	Flight simulator
			Flight test	Flight test

Simmons, R., Sanders, M., and Kimball, K. Visual performance: a method to assess workload in the flight environment. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 73-81

This paper addresses the assessment of workload of the visual information input channel. A cost factor (CF) theory is presented which provides a more concise picture of visual workload than the classical methods. The applications section suggest that the CF theory is a valuable tool in testing and determining what the visual workload should be for combat proficient pilots, how long pilots with varying degrees of proficiency could be expected to fly in combat, and aircraft design requirements to reduce onset of fatigue-induced errors. CF theory can also be used to test and determine varying mission-related workload.

W/L Cat. Code: 3.1, 4.1.7

Op. Behav. Code: 1., 2.

Primary task	Single measures	Construct	Flight simulator	Flight simulator
Physiological	Eye movement	Experimental	Flight test	Flight test

Simonov, P. V. and Frolov, M. V. Analysis of the human voice as a method of controlling emotional state: Achievements and goals. Aviation, Space, and Environmental Medicine, 1977, 48, 23-25.

Background factors and those of formant structure, spectral and spectro-temporal characteristics of rapid and slow speech components, temporal peculiarities, and intensity of speech turned out to be informative indices of the human emotional state. Application of mathematical methods, in particular methods of recognition theory, to these factors helped to assess the degree and the psychological sign of emotion, to diagnose the status of attention and fatigue, and to differentiate emotional and physical stress. The paper outlines the results obtained in model experiments on cosmonaut A. Leonov at different flight stages, including EVA, on Voskhod-2.

W/L Cat. Code: 4.3

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Speech patt. anal.	Experimental	Flight test	Flight simulator
				Flight test

Simonov, P. V., Frolov, M. V., and Sviridov, E. P. Characteristics of the electrocardiogram under physical and emotional stress in man. Aviation, Space, and Environmental Medicine, 1975, 46, 141-143.

The changes in the length of R-R interval and heart rate are widely used for estimation of man's physical state. However, this ECG index has several drawbacks including a relatively low sensitivity and non-specificity, indirection of changes under different states: attention and fatigue, physical and emotional stress, etc. Moreover, one and the same factor, e.g. emotional stress, can lead both to a decrease and an increase in the heart rate. Hence, it is necessary to find other more adequate ECG parameters, which would enhance the reliability and accuracy of assessment of man's state. The analysis of data found in the literature and the results of our preliminary experiments have shown that the amplitude of the T-peak and duration of the R-T interval of ECG can be used as such parameters.

W/L Cat. Code: 4.1.3, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Physiological	EKG	Experimental	Laboratory	Background
	Heart rate, h.r. var.			

Simpson, C.A. and Hart, S.G. Required attention for synthesized speech perception for two levels of linguistic redundancy. Paper presented at the 93rd meeting of the Acoustical Society of America, State College, Pennsylvania, June 7-10, 1977.

It was hypothesized that additional contextual linguistic redundancy in the wording of synthesized speech cockpit warnings would result in less required attention. Twelve pilots were repeatedly presented unfamiliar warnings in two wording formats, key word and sentences. Then they heard the same warnings embedded in weather broadcast at a warning-to-weather sound pressure level ratio of +3 dB. For both listening conditions the task was to read back the message and estimate the passage of time during message comprehension or recognition. As expected in the present study, intelligibility was higher and response time shorter for the sentence format than for the key word format. For unfamiliar messages, the tendency to underestimate the passage of time was greater for the two word format than for the sentence format. For familiar messages there was no significant difference in performance on the time estimation task for the two levels of linguistic redundancy.

W/L Cat. Code: 2.2.3
Op. Behav. Code: 2., 3.

Spare m. capacity Time estimation Experimental Laboratory Flight simulator

Simpson, C. G. Improved displays and stabilization in general aviation aircraft. Moffett Field, California: National Aeronautical and Space Administration, N69-24238, November, 1968. (AGARD Symposium paper).

A project is described which examined the use of improved displays and automatic flight control as methods of easing the cockpit workload of a single pilot flying on instruments. The data indicate an appreciable pilot workload reduction when a pictorial navigation display is employed in conjunction with normal instruments for flight under instrument conditions, and an almost equal additional amount of workload reduction if the aircraft is stabilized and controlled by means of an autopilot. Such an improved cockpit environment also appears to facilitate instrument training.

W/L Cat. Code: 2.1, 4.2

Op. Behav. Code: 1., 2., 4.

Primary task Single measures Experimental Flight simulator Flight simulator

Flight test

Sinaiko, H.W. Third international congress on argonomics. London, England: Office of Naval Research, ONRL-C-19-67, November, 1967.

This report summarizes twelve invited papers and comments on some additional contributed papers. The appendix contains list of the latter. Principal sessions included: measurement of workload in mental tasks. product design, checklists, relevance of laboratory studies, office design, and future needs in ergonomics. In regard to mental workload, techniques of secondary task, pupillary diameter, and adaptive tracking are reviewed and critiqued.

W/L Cat. Code: 2.2., 4.1.8

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Review	None	Flight simulator
Physiological	Pupillary dia.			

Smit, J. Pilot workload analysis based upon in-flight physiological measurements and task analysis methods. In T. B. Sheridan and G. Johannsen (Eds.) Monitoring behavior and supervisory control. New York: Plenum, 1976, 119-124.

During the last several decades much effort has been directed at reducing pilot workload. According to Jahns, the ultimate objective of workload research is to develop reliable predictions of human effort to meet predetermined input loads. This paper describes the initiation of a program designed to determine which of the many workload estimation techniques are most applicable to specific pilot workload problems. The program will include subjective, physiological, and performance measurement and will attempt to correlate them with relevant personality traits.

W/L Cat. Code: 1., 3.1, 4.1

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Construct	None	Background
Primary task				
Physiological				

Smit, J. and Wewerinke, P. H. An analysis of helicopter pilot control behavior and workload during instrument flying tasks. In ACARD Operational Helicopter Aviation Medicine. AGARD-CP-255, May, 1978, 30-1 - 30-11.

During helicopter instrument hover and navigation (tracking) tasks a number of flight data, physiological measures and subjective ratings were collected. Mathematical model were used to describe and analyze the pilot's control behavior and attention workload. The optimal control model seems to offer a suitable framework for the description of control tasks complex as helicopter instrument flying. A control effort model, which was formulated in terms of the optimal control model, describes the relationship between performance and attention paid to the task. The physiological variables and subjective ratings in general reflected the variations in control effort connected with the various tasks.

W/L Cat. Code: 1.1, 3.3, 4.1

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Construct	Flight test	Flight simulator
Primary task		Experimental		Flight test
Physiological				

Smith, H. P. R. A simulator study of the interaction of pilot workload with errors, vigilance, and decisions. Moffett Field, California: National Aeronautics and Space Administration (Ames Research Center), NASA-TM-78482, January, 1979.

A full mission simulation of a civil air transport scenario that had two levels of workload was used to observe the actions of the crews and the basic aircraft parameters and to record heart rates. The results showed that the number of errors was very variable among crews but the mean increased in the higher workload case. The increase in errors was not related to rise in heart rate but was associated with vigilance times as well as the days since the last flight. The recorded data also made it possible to investigate decision time and decision order. These also varied among crews and seemed related to the ability of captains to manage the resources available to them on the flight deck.

W/L Cat. Code: 3.1, 4.10

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Flight simulator	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Smith, W. S., Jr. Effects of neuromuscular tension in the use of an isometric hand controller. Monterey, California: U.S. Naval Postgraduate School, Master's thesis, December, 1972. (AD 757 252).

The effects of operator workload on average grip pressure and of neuromuscular tension on tracking performance were the objects of this research. In one experiment, a "sub-critical" tracking task was performed by the operator while measurements of grip pressure were taken.. In a second experiment, the operator was required to maintain average grip pressure at specified levels during 100-second tracking tasks while his RMS tracking error was measured. The results clearly indicate that average grip pressure increases as the workload increases and that higher average grip pressures result in higher RMS tracking error values.

W/L Cat. Code: 3.1, 4.1.9

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Muscle tension			Flight test

Soede, M. Reduced mental capacity and behavior of a rider of a bicycle simulator under alcohol stress or under dual task load. Proceedings of the 13th Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, June 15-17, 1977, 143-151.

Experiments were carried out in a bicycle simulator with either alcohol administration or a binary choice task in separate sessions, intending to reduce the subject's mental capacity. Before and after such sessions a visual evoked response measurement was done. The subject's performance was analyzed with describing function techniques. The results indicate that alcohol affects the course following task as well as the balancing task: i.e. a general effect. The binary choice task is more specifically influencing the course following task. The dual task shows a more pronounced effect on the recovery of the evoked response. The alcohol delays the recovery curve of the evoked response. A tentative explanation can be given which agrees with the performance data.

W/L Cat. Code: 2.2.1, 3.1, 4.1.3, 4.1.6, 4.1.10
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Simulator	Flight simulator
Primary task	Single measures			Flight test
Physiological	ECP			
	Heart rate, h.r. var.			

Soede, M. On mental load and reduced mental capacity; some considerations concerning laboratory and field investigations. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 445-467.

This paper presents some reflections about the problem of mental load and the measurement of the level of mental load. A general model of the relation between mental control effort and performance is given. Some connotations are made regarding the notion of mental capacity. The model proposed is suggested to be applicable in the particular man-machine situation of an arm amputeed patient using a prosthesis. Pilot experiments with the aim to develop methods to measure the control effort in using a prosthesis is given as an example of the application of mental load measures. At the end of this paper some questions are raised as to the factors which may restrain progress in mental load research.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	Laboratory	Flight simulator
Spare m. capacity		Construct	Field	
Primary task				
Physiological				

Soliday, S. M. Effects of task loading on pilot performance during simulated low-altitude high-speed flight. Fort Eustis, Virginia: U.S. Army Transportation Research Center, USATRECOM 64-69, February, 1965. (AD 614 243).

The effects of task loading on pilot performance during simulated low-altitude, high-speed flight were studied. Approximately 210 hours of flight were made by experienced pilots in a moving-base simulator that had a total vertical travel of 12 feet and an acceleration capability of ± 6G. The flights were made over several types of terrain at several airspeeds under different conditions of navigation task and emergency task loading. Medium-heavy turbulence was simulated for all flights. Data were analyzed in terms of human performance aspects of the missions.

W/L Cat. Code: 1.2, 3.2

Op. Behav. Code: 1., 2., 4.

Opinion	Interview	Experimental	Flight simulator	Flight simulator
Primary task	Mult. measures			Flight test

Soliday, S. M. and Schohan, B. Task loading of pilots in simulated low-altitude high-speed flight. Human Factors, 1965, 7, 45-53.

Pilots were task-loaded to various degrees in simulated low-altitude, high-speed flight. Approximately 210 hours of flight were made in a moving-base simulator that had a total vertical travel of 12 feet and an acceleration capability of ±6G. A jet aircraft in the light fighter or attack category was mechanized on the simulator's analog computer. Flights were made over several types of terrain at several airspeeds under different conditions of navigation task and emergency task loading. Medium-heavy turbulence was simulated for the flights, each of which lasted one hour. Performance deteriorated markedly as terrain slopes increased in steepness and as airspeed increased from .4 Mach and .7 Mach to .9 Mach. Navigation and emergency task performance did not vary with any of the experimental conditions, and did not affect the pilots' ability to maintain a 500 foot terrain clearance. There was no evidence of fatigue during the flights.

W/L Cat. Code: 1.2, 3.2

Op. Behav. Code: 1., 2., 4.

Opinion	Interview	Experimental	Flight simulator	Flight simulator
Primary task	Mult. measures			Flight test

Soultages, D. Questionnaire theory: modelling of the pilot's mental load. Paris, France: Office National d'Etudis et de Recherches Aerospatiales, ONERA-NT-230, 1974. (In French.)

The task carried out by a human operator is modelled, in the form of a robot (in the sense of heuristic programming), and the concept of operator's workload is associated to that of information processed by the robot who makes decisions. The purpose of questionnaire theory is to formalize the concept of information processed. The main definition of this theory is presented, preceded by a brief survey of information and graph theory concepts necessary to understand them. The connection between heuristic programming and the manner in which questionnaire theory permits the formalization of the informative cost of decisions is also established.

W/L Cat. Code: 1.1, 1.2, 2.1.2, 3.3

Op. Behav. Code: 1., 2.,

Opinion	Rati[illegible] scale	Construct	None	Flight simulator
Spare m. capacity	[illegible]naire			
Primary task	[illegible]n. theory			
	Math. model			

Soutendam, J. Instruments and methodology for the assessment of physiological cost of performance in stressful continuous operations - the air traffic services tower environment. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CPP-216, April, 1977, A7-1 - A7-32.

The study was designed to test methods and instruments of potential use in the determination of the physiological cost of work performance in stressful environments. A second goal of the study was a preliminary test of the hypothesis that air traffic services traditionally considered stressful, was significantly different from general forms of employment traditionally considered less stressful. To test this hypothesis people employed as air traffic control tower personnel were slated as the experimental group and subjects employed in an operationally oriented research facility served as the control group. Within the parameters of this research design, consistent statistical significance was established when the entire sample was recategorized on the basis of subjective sleep adequacy assessment rather than by job describption.

W/L Cat. Code: 1.2, 4.1.3, 4.1.6, 4.1.12
Op. Behav. Code: 2.

Opinion	Questionnaire	Experimental	Laboratory	Flight simulator
Physiological	ECP			
	EKG			
	Body fluid anal.			

Spady, A. A., Jr. Airline pilot scanning behavior during approaches and landing in a Boeing 737 simulator. Paper presented at the AGARD 25th Guidance and Control Panel Meeting/Symposium on Guidance and Control Design Configurations for Low Altitude and Terminal Area Flight, Dayton, Ohio, October 17-20, 1977.

A series of approaches using airline pilots in an FAA qualified simulator has been conducted. The test matrices include both manual and coupled approaches for VFR, Category I and Category II conditions. A nonintrusive oculometer system was used to track the pilot's eye-point-of-regard throughout the approach. The results indicate that, in general, the pilots use a different scan technique for the manual and coupled (auto pilot with manual throttle) conditions. For the manual approach 73 percent of the time was spent on the flight director and 13 percent on airspeed as opposed to 50 percent on flight direction and 23 percent on airspeed for the coupled approaches. For the visual portion of approach from less than 100m (300 ft) to touchdown or when the touchdown point came into view, the pilots tend to fixate on their aim or touchdown area until the flare initiation, at which time they let their eye-point-of-regard move up the runway to use the centerline lights.

W/L Cat. Code: 4.1.7

Op. Behav. Code: 1., 2., 4.

Physiological	Eye movement	Experimental	Flight simulator	Flight simulator
				Flight test

Spady, A. A., Jr. Airline pilot scan patterns during simulated ILS approaches. Hampton, Virginia: National Aeronautics and Space Administration, Langley Research Center, NASA-TP-1250, October, 1978.

A series of instrument system approaches have been conducted using seven airline pilots in a Federal Aviation Administration qualified simulator. The test matrix included both manual and coupled approaches with and without atmospheric turbulence in Category II visibility conditions. The results indicate that, in general, the pilots use different scan techniques for the manual and coupled conditions. A comparison between objective measures of the instrument scan (oculometer data) and subjective pilot opinion, ranking their use of each instrument, has been included. The pilots consistently ranked the instruments in terms of most used to least used. The ranking obtained from the oculometer data agrees with the pilot ranking for the flight director and airspeed, the most important instruments. However, the pilots apparently ranked the other instruments in terms of their concern for information rather than according to their actual scanning behavior.

W/L Cat. Code: 1.1, 3.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test
Physiological	Eye movement			

Sperandio, J. C. Variation of operator's strategies and regulating effects on workload. Ergonomics, 1971, 14, 571-577.

In a real work situation the operative strategy choosen by subjects depends on three variables, the characteristics of the operator (training, motivation, age, health, etc.); the characteristics of the task, i.e., the level of task requirements; and the level of workload, which itself results from the operator strategy. Ergonomists try often to measure the workload, but do not pay enough attention to the regulating effects exerted by the workload, through feed-back, on the strategy used by operators. This paper summarizes an experimental study carried out in a ATCC, showing how air traffic controllers modify their operative methods when workload increases.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 3., 4.1

Primary task	Single measures	Experimental	Field	Flight simulator
				Flight test

Sperandio, J. The regulation of working methods as a function of work-load among air traffic controllers. Ergonomics, 1978, 21, 195-202.

A series of field studies among air traffic controllers is reviewed. It largely concentrated on regulatory aspects of operational behavior, using a model based on the concept of 'economy' in the individual's selection of operating procedures. Attention is directed at processes involving reasoning, the receipt and transmission of information, and the division of tasks between controllers at the same station. The basic hypothesis, which is supported by numerous data, is that for a given task and a given controller certain operating procedures are less costly than others; that is, they generate lower levels of load. These procedures will therefore be more and more employed as work demand increases, together with the relaxation of certain, self-imposed, qualitative criteria. This regulatory feedback between workload and operating methods is used by the controller to avoid the abrupt onset of overload conditions and to delay satiation. For the investigator, these progressive changes in operating procedure can provide indirect indices of load. Several ergonomic consequences of this approach for system design are discussed.

W/L Cat. Code: 1.2, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion	Questionnaire	Review	Field	Flight simulator
Primary task	Single measures			

Spicuzza, R. J., Pinkus, A. R. and O'Donnell, R. D. Development of performance assessment methodology for the digital avionics information system. Dayton, Ohio: Systems Research Laboratories, Final Report, 1 December 1973 - 30 June 1974, August, 1974.

The purpose of this overall effort is to develop, instrument, and test a flexible series of human performance assessment measures which will be used as standard evaluation tools in future advanced digital avionics information systems. In order to meet these requirements a primary flying task was simulated on an IBM 360-40 computer. The dynamics of this simulator resembled those of a lightweight fighter, and allowed the subject to control all relevant flight parameters. Seven subjects were used to test the validity of four secondary tasks. These are (1) the Jex tracking task, (2) the Sternberg technique for assessing memory/processing, (3) an eye movement methodology, and (4) the auditory shadowing technique. Analyses were designed primarily to provide information on the feasibility of using these tasks as secondary workloads, and on the best methods of presenting them in future closed loop protocol studies of DAIS--like systems. Results indicate that all of the methodologies tested are feasible and should have operational validity in performance assessment.

W/L Cat. Code: 2.2.1, 2.2.5, 4.1.7

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Flight simulator	Flight simulator
Primary task	Single measures			Flight test
Physiological	Eye movement			

Spyker, D.A., Stackhouse, S.P., Khalafalla, A.S. and McLane, R.C. Development of techniques for measuring pilot workload. Washington, D.C.: National Aeronautics and Space Administration, Contractors' Report NASA CR-1888, November, 1971.

The goal of this study was to provide an objective method of assessing information workload based on physiological measurements. Information workload or reserve capacity, was measured using a visual discrimination secondary task and subjective rating of task difficulty. The primary task was two axis tracking, and the independent variables in this study were aircraft pitch dynamics and wind gust disturbances. A measured workload index (MWI) and physiological workload index (PWI) were extracted. An important measure of the success of this study was the degree to which the MWI and PWI agreed across the 243, four-minute trials. The electrophysiological data collected included vectorcardiogram, respiration, electromyogram, skin impedance, and electroencephalogram. A "best" subset of 10 features was chosen to predict the three measures of reserve capacity. The cannonical correlation coefficient was .754 with a chi squared value of 91.3 which allows rejection of the null hypothesis with $p > .995$.

W/L Cat. Code: 1.1, 2.2.1, 3.1, 4.1.2 4.1.3, 4.1.4, 4.1.5, 4.1.7, 4.1.10, 4.1.11
Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Experimental	Laboratory	Flight simulator
Spare m. capacity				Flight test
Primary task				
Physiological				

Stackhouse, S. Workload evaluation of LLNO display. Minneapolis, Minnesota: Honeywell, 7201-3408, October, 1973.

The objective of this study was to evaluate concepts which were represented by particular parameters and formats, as well as two display devices, panel CRT displays and a helmet mounted display. Both simulator and inflight helicopter evaluations were made. The variables used in making the evaluation were chosen from the following classes of data: aircraft state variables, secondary task scores, subjective pilot opinions, and physiological features derived from the electrocardiogram, electromyogram, respiration, and phonocardiogram. A performance measure was calculated based on the discriminating variables related to performance. This performance estimate of how well the subject-system performed was then related to how hard the subjects worked to process the information which yielded their measured performance. This latter estimate was based on the predictive features which were extracted from the physiological measures.

W/L Cat. Code: 1.1, 2.2.1, 3., 4.1.3, 4.1.10
Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Experimental	Flight simulator	Flight simulator
Spare m. capacity			Flight test	Flight test
Primary task				
Physiological				

Stackhouse, S. P. The measurement of pilot workload in manual control system. Minneapolis, Minnesota: Honeywell, Inc. F0398 FR1, January, 1976.

This study had two objectives: 1) to derive and validate a physiological workload metric using an adaptive performance measure as a basis, and 2) to evaluate tasks of differing difficulty in two experiments - precision hover and approach to landing. Both objectives were satisfied. In the precision hover experiment, both physiological measures and performance measures were acquired. The physiological measures were features extracted from the ECG, two EMG channels (forehead and forearm), and breathing. The performance measures were rms position error scores and a time delay measure (Δt) used in an adaptive paradigm. The physiological features and their multiple regression coefficients which best predicted the performance measures were determined. The coefficients were then applied to the physiological features obtained from the approach to landing experiment.

W/L Cat. Code: 2.2.4, 2.2.5, 3.2, 4.1.3, 4.1.4, 4.1.11

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Multiple	Experimental	Flight simulator	Flight simulator
Primary task				Flight test
Physiological				

Stackhouse, S. P. Measurement of aircrew information processing workload. Minneapolis, Minnesota: Honeywell, Unpublished manuscript, 1978.

Physiological measures can be used as an adjunct to performance measures showing not only how well the man-system performed, but how difficult it was for the man to perform that well. Physiological measures are especially sensitive to the task difficulty levels usually found in flight tests. If task difficulty induced changes in physiological measures generalize (are not specific to type of information processing task) then a broadly applicable, quantitative, and objective systems evaluation method will be available.

W/L Cat. Code: 4.1, 4.2

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Multiple	Review	None	Flight simulator
		Construct		Flight test

Stager, P. and Muter, P. Instructions and information processing in a complex task. Journal of Experimental Psychology, 1971, 87, 291-294.

Two experiments involved a decision task with a static display analogue of a radar display similar to that used in air traffic control. The Ss were required to detect potential collision situations in a sequence of independent displays. Following an earlier study, Ss in both experiments either (a) were trained entirely with pictorial displays and provided with assumptions involved in constructing the air traffic situations, or (b) were initially trained with displays containing verbal descriptions of possible situations and not given underlying assumptions. In Exp. I, a secondary loading task was performed concurrently with the decision task. In Exp. II, Ss were required to analyze both redundant and nonredundant displays. Results indicated that the procedures acquired by pictorially trained Ss were less susceptible to processing overload and that an additional performance advantage derived from their use of redundancy in the displays.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Stager, P. and Zufelt, K. Dual-task method in determining load differences. Journal of Experimental Psychology, 1972, 94, 113-115.

In two previous studies, differences in information processing in a complex decision task have been reported to depend on the training instructions. Group differences in the susceptibility to processing overload and the use of task redundancy have been specified. The present study attempted to evaluate the observed differences in a dual-task situation. The Ss were required to perform the complex decision task and a keeping-track task concurrently. It was hypothesized that performance on the subsidiary keeping-track task would be an inverse function of the instructions-induced load of the decision task. Significant differences between groups were obtained on the decision task, but there were no differences in subsidiary task performance. The discussion concerned the limited capacity model and the value of assessing apparent differences in processing or task load by means of a dual-task situation.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Flight test

Stamford, B. A. Validity and reliability of subjective ratings of perceived exertion during work. Ergonomics, 1976, 19, 53-60.

The purpose of the present investigation was to determine the reliability of the Borg (RPE) Scale under a variety of experimental conditions. Fourteen sedentary female subjects performed six repeated work tasks (12 in all) distributed over four experimental testing sessions and presented in a randomized order. Work tasks involved treadmill walking and jogging, cycling, and stool stepping. Workloads were presented in progressive (step-wise), oscillating, or single load submaximal intensities. During work, heart rate (HR) was recorded at regular intervals and ratings of perceived exertion (RPE) were elicited either at regular intervals (interval) or only during the final minute of work (terminal). RPE responses were found to be highly reproducible whether interval or terminal. High correlations were also found between interval and terminal RPE responses. RPE demonstrated a strong relationship with HR and work intensity. It was concluded that category ratings of perceived exertion according to the Borg (RPE) Scale offer a sensitive and reliable measure of stress encountered during work.

W/L Cat. Code: 1.1

Op. Behav. Code: 4.1

Opinion	Rating scale	Experimental	Laboratory	Flight simulator
				Flight test

Steininger, K. Subjective ratings of flying qualities and pilot workload in the operation of a short haul jet transport aircraft. Proceedings of AGARD Conference on Studies on Pilot Workload, AGARD-CPP-217, April, 1977, B11-1.

A representative sample of pilots employed by an airline operating a short haul jet transport aircraft assessed the acceptability of the cockpit layout and instrumentation, the handling quality, and the feasibility of the system operation in regard to the pilots workload. The assessment consisted of two parts: 1) a questionnaire of 82 fixed items, answered on a 7 step rating scale. 2) a semi-structured interview concerning 19 items. Critical points and favorable capabilities of the man-machine-system can be evaluated economically and objectively if the following conditions are met: carefully chosen questionnaire and interview strategy, a well established rating scale, and a sufficient sample of subjects for statistical reliability of the data.

W/L Cat. Code: 1.1, 1.2

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
	Questionnaire			Flight test

Steininger, K. and Wistuba, C. Minimum flight crew of transport aircraft. Methods for measuring workload of flight crews. Hamburg, West Germany: Deutsche Forschungs-und Versuchsanstatt fuer Luft-und Raunfahrt, Report No. DLR-IB-355-74/3, 1974. (In German).

Objective quantitative estimation of pilots' workload considering the present state of measurement and knowledge is discussed. Pilot workload is an essential criterion for defining minimum flight crew in civil transport aviation. Best provad methods are selected, including time and motion studies, flight performance and psychological measurements, and measurement of reserve capacity. It is expected that such studies will improve human engineering and operational organization.

W/L Cat. Code: 2.1.1, 2.2.1, 3.1

Op. Behav. Code: 4.2

Spare m. capacity	Subsidiary task	Review	Flight test	Flight test
Primary task	Single measures			Flight simulator

Stephens, B.W. and Michaels, R.M. Timesharing between two driving tasks: Simulated steering and recognition of road signs. Paper presented at the 43rd Annual Meeting of the Highway Research Board, Washington, D.C., January, 1964.

This study was designed to determine general driver ability to steer a vehicle while simultaneously searching for a specific sign and to measure the timesharing basis used in performing the two tasks. Analyses were conducted to determine: (1) the influence of constituents of the tracking task upon performance of the search-and-recognition task, and (2) the influence of components of the search-and-recognition task upon tracking performance. Integrated tracking error variances were analyzed, as were the recognition time variances for each of the conditions associated with the dynamic recognition task. In the second kind of analysis, basic to the inquiry was a test of a generalized timesharing hypothesis, which states that there is a trade-off between the two tasks. The erroneous recognition of signs presented was examined in the third kind of analysis. The fourth kind of analysis was made of control tests that were conducted to: (1) ascertain the possible effects of learning occurring throughout the experiments, and (2) make a comparison of experimental and baseline test conditions in which the tracking tasks and search-and-recognition tasks were presented singly. In all comparisons of the independent tasks and their timeshared counterparts, the performance of test operators deteriorated when the tasks were shared.

W/L Cat. Code:	2.2.1, 2.2.2			
Op. Behav. Code:	1., 2., 4.			
Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

Sternberg, S. High-speed scanning in human memory. Science, 1966, 153, 652-654. (See also P. N. Haber (Ed.) Visual perception, New York: Holt, Rinehart and Winston, 1969, 226-230.)

When subjects judge whether a test symbol is contained in a short memorized sequence of symbols, their mean reaction-time increases linearly with the length of the sequence. The linearity and slope of the function imply the existence of an internal serial-comparison process whose average rate is between 25 and 30 symbols per second.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Construct	Laboratory	Background
Primary task	Single measures	Experimental		

Stone, L. W., Sanders, M. G., Glick, D. D., Wiley, R., and Kimball, K. A. A human performance/workload evaluation of the AN/PVS-5 bifocal night vision goggles. Fort Rucker, Alabama: U.S. Army Aeromedical Research Laboratory, USAARL Report No. 79-11, July, 1979.

Eight experienced US Army aviators performed various maneuvers in an instrumented helicopter to test the relative usability of two bifocally configured night vision goggles. Both configurations were statistically better than the unmodified arrangement when looking at a pilot's ability to hold a precise altitude at night. The subjective data, supported by flight performance observed between the two bifocals, further suggested that a 24% bifocal version was more desirable than a 14% configuration. The inference is that the reduced inside field-of-view presented by the 14% bifocal interfers with a pilot's ability to rapidly locate instruments once he has directed his attention inside the cockpit.

W/L Cat. Code: 1.1, 1.2, 3.1

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Questionnaire			Flight test
	Single measures			

Storm, W. F. and Hapenney, J. D. Mission-crew fatigue during rivet joint operations. Brooks AFB, Texas: USAF School of Aerospace Medicine, SAM-TR-76-36, September, 1976.

Subjective fatigue and sleep data were collected from a USAF Security Service airborne mission team before and during an airborne mission. The primary purpose of the test was to refine the procedures and analytical techniques in preparation for an upcoming demonstration/evaluation of a new and modernized system. Results indicated that only minor changes in procedures and techniques were necessary. The data also provide unique baseline information for future comparison and evaluation of similar data from the modernized system.

W/L Cat. Code: 1.1, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Physiological	Body fluid anal.			Flight test

Storm, W. F., Hartman, B. O., Intano, G. P. and Peters, G. L. Endocrine-metabolic effects in short-duration high-workload missions: Feasibility study. Brooks AFB, Texas: USAF School of Aerospace Medicine, SAM-TR-76-30, August, 1976.

A study was conducted at the USAF Instrument Flight Center to test an augmented assembly of measures for assessing the relative merits of various flight instrumentation systems. The USAF School of Aerospace Medicine (SAM) stress battery was included. Although the study was not designed so as to permit an optimized evaluation of the SAM stress battery, the following results were noted: anticipatory stress, mild flight stress, and no habituation across missions. The SAM battery appears to be a useful addition to the flight instrumentation research program.

W/L Cat. Code: 1.1, 2.2.1, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Spare m. capacity	Subsidiary task			Flight test
Physiological	Body fluid anal.			

Strasser, H. Work-physiological investigations for the objectivization of the tracking behavior, the mental load, and its psychopharmacological modulability. Doctoral dissertation, Muenchen (Munich) Technische Universitaet, 1972. (In German.)

Problems connected with the integration of man in the technological environment are examined, giving attention to dangers connected with the monotony and the mental stress. A theoretical analysis of test-connected relations is conducted, taking into account a cybernetic analysis of the factor 'man.' an analysis of technical factors involved in control and guidance activities, aspect of psychophysical performance and mental load. Approaches and equipment needed for the experimental investigations are discussed together with model concepts concerning physiological changes under mental stress, the effect of stimulants on performance, effects produced by tranquilizers, the influence of alcohol on tracking performance, and tests involving psychopharmacological agents.

W/L Cat. Code: 3.3

Op. Behav. Code: 1., 2., 4.

Primary task	Math. model	Construct	None	Background

Strasser, H. Heart rate and sinusoidal arrhythmia measurement in view of objectivating concentration and stress in control tasks. In DGLR New or Newly Tested Methods for the Assessment of Pilot's Workload, 1974. (Munich, West German, In Germe .)

Mental effort during control tasks such as pursuit tracking tests was correlated with heart rate, low frequency arrhythmia, and high frequency sinus arrhythmia profiles monitored for several hours. Results show that pulse frequency and sinusoidal arrhythmia appear in a somewhat reciprocal relation. Sinus arrhythmia, though varying greatly among individuals, is a reliable parameter which provides supplementary information when test linked factors cease to show up in pulse frequency.

W/L Cat. Code: 3.1, 4.1.10

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Heart rate, h.r. var.			

Strasser, H. Physiological measures of workloads: correlations between physiological parameters and operational performance. Proceedings of the AGARD Conference on Methods to Assess Workload, AGARD-CP-216, April, 1977, A8-1 - A8-8.

The influence of different hypoxic gas mixtures on pursuit tracking and on physiological parameters was studied. The following conclusions are drawn. Already, in relatively mild hypoxia, physiological changes are present, but normally were concealed by reactions due to prolonged test time. In spite of statistically significant physiological effects, no noticeable deterioration of performance in tracking was measured in hypoxia down to a hypoxic gas mixture of only 13% O2 in inspired air. Not until before 11% O2 significance and mentionable impairments of tracking performance were found. The same, shown for hypoxia, is true of noise. Decreased performance in noise was not found, but an increased level of heart rate indicated the stress. Physiological indicators definitely react in a low workload situation to bring in action reserves of energy.

W/L Cat. Code: 3.1, 4.1.10

Op. Behav. Code: 1., 2., 4.

Primary task Single measures Experimental Laboratory Flight simulator

Physiological Heart rate,
h.r. var.

Strasser, H. Measurement of mental workload. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 345-348.

This paper provides a brief summary of applications problems not currently receiving attention by workload researchers. Some of the problems described are: underloading, reliability and validity of workload measures, extrapolation of laboratory studies to field applications, and adaptation effects on workload measurement.

W/L Cat. Code: 3.3, 4.1

Op. Behav. Code: 1., 2., 3., 4.

Primary task Math. modeling Critique None Background

Physiological Single measures

Strasser, H., Brilling, G., Klinger, K. P., and Mueller-Limmroth, W. Physiological and operational state of a group of aeroplane pilots under the conditions of stressing tracking tasks. Aerospace Medicine, 1973, 44, 1040-1047.

A test set-up is described with which a picture of the operational and physiological state of a group of pilots during a period of about 2 hours was obtained. The results recorded for tracking performance with both fixed and adaptive self-adjusting degrees of difficulty, together with the simultaneous recording of the heart rate, sinus arrhythmia, and acoustically evoked potentials, were compared with the figures obtained from a control group. Through the combination of the parameters measured it could be demonstrated that the group of pilots had an above-average level of performance in the tracking tests, as well as a high capacity for prolonged mental concentration. A relatively small acute alcohol effect, which cannot be separated from the natural effects of training by means of the operational data, is clearly shown in the parameter of evoked potentials that describes information processing by the central nervous system.

W/L Cat. Code: 3.1, 4.1.6, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	ECP			
	Heart rate, h.r. var.			

Street, R. L., Singh, H. and Hale, P. N., Jr. The evaluation of mental stress through the analysis of parotid fluid. Human Factors, 1970, 12, 453-455.

This study investigates the utilization of the 17-hydroxycorticosteriod (17-OHCS) level in the parotid fluid as a measure of mental or emotional stress. Twelve graduate students were subjected to three levels of mental stress, and the results of the chemical analysis of the parotid fluid indicate that there is a definite relationship between mental or emotional stress and the 17-OHCS level.

W/L Cat. Code: 4.1.12

Op. Behav. Code: 1., 2., 4.

Physiological	Body fluid anal.	Experimental	Laboratory	Flight simulator
				Flight test

Stress in Air Traffic Control Research Association, International Symposium on Objective Assessment of Work Load in Air Traffic Control Tasks, Technische Universitaet Darmstadt, Darmstadt, West Germany, June 1971, Proceedings. Ergonomics, 1971, 14.

Objective research methods and results are described relative to the determination of the stress of work tasks performed by air traffic controllers. Procedures and equipment for determing individual capacities are explained, together with approaches for correlating stress and strain. Topics examined include criteria for evaluating ATC systems, analysis of mental processes in ATC, variation of operator strategies, ergonomics measurements, hardware and software problems in workload analysis, use of subjective ratings, attitudes of operators to work and working conditions, and the use of simulators in testing both individual capacity and system models.

W/L Cat. Code: 1.1, 2.1, 3., 4.1

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	Laboratory	Flight simulator
Spare m. capacity		Construct	Field	Flight test
Primary task		Experimental		
Physiological				

Strieb, M. I. The human operator simulator, volume I: Introduction and overview. Willow Grove, Pennsylvania: Analytics, August, 1975.

The Human Operator Simulator (HOS) is a computer simulation of a human being in a goal-oriented task processing environment. To facilitate the entry of the task and environment descriptions into HOS, the Human Operator Procedures Language (HOPROC), an English-like meta-language was developed. HAL, the HOPROC Assembler/Loader, processes HOPROC statements and compiles them into a series of pseudo-machine instructions for use by HOS. During the execution of HOS, each of the HOPROC macro-level instructions are translated into micro-level actions which are interpretable by the Human Operator Data Analyzer/Collator (HODAC) into body motion statistics, information absorption statistics, etc. This volume presents an overview and rationale for HOS, and is the first of a series providing complete documentation. Volume II is a user's guide for HOS, including the HOPROC language. Volumes III, IV and V contain programmer's guides for HAL, HOS, and HODAC respectively. This volume makes obsolete Analytics' Technical Report 1046-K.

W/L Cat. Code: 2.1.1, 2.2.1, 2.2.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess. Subsidiary task	Experimental	Laboratory	Flight simulator

Strieb, M. I., Glenn, F. A., Fisher, C. and Fitts, L. B. Chapter VII from the human operator simulator, volume VII: LAMPS air tactical officer simulation. Willow Grove, Pennsylvania: Analytics, November, 1976.

The HOS display and control taxonomy and task taxonomy are models that influence and must be evaluated separately from the dynamic performance models for which they structure the inputs and outputs. The procedure multiplexing model is the protocol by which the simulated operator schedules the execution of his various tasks. These models and how they evolved are described herein. The anatomy movement models describe the functional assignments of body parts and the dynamic response characteristics for each body part. These are also presented. Finally, a detailed description of the structure of the perception, memory, and mental computation models is presented. These are the models of the operator's cognitive processes as represented in HOS. They describe how the operator functions as an information processor.

W/L Cat. Code: 2.1.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator
Primary task	Math. model			

Strieb, M. I. and Harris, R. Sensitivity analyses for cost effectiveness of P-3C SS-3 operator station: the human operator simulator, vol. X-part 2. Willow Grove, Pennsylvania: Analytics, Technical report 1330, October 26, 1978.

This report documents a series of sensitivity analyses that have been performed on the data generated from a simulation of the functions of the Sensor Station 3 (SS-3) operator onboard the Navy's P-3C Orion anti-submarine warfare (ASW) patrol aircraft. The sensitivity analyses are an outgrowth of an intial study that examined the SS-3 operator's performance in three alternative crewstation configurations on the P-3C and under a degraded mode of operation. The study used the Human Operator Simulator (HOS) to simulate the functions of the SS-3 operator in several different crewstation configurations. Measures of overall system performance were then applied to the simulation results to determine the relative effectiveness of each configuration. The data were then used to determine the cost effectiveness of each configuration.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Laboratory	Flight simulator
Primary task	Math. model			

Strieb, M. I., Preston, J. F., III, Harris, R., and Fisher, C. Weapon system economic analysis-the human operator simulator, volume VIII. Willow Grove, Pennsylvania: Analytics, TR 1289, March 27, 1978.

The Human Operator Simulator (HOS) is a digital computer simulation of the performance of an operator in a goal-oriented, task-processing environment. This report describes a study whose purpose was to determine the feasibility of using HOS to assess the impact of alternative crewstation designs on total system performance and hence the cost-effectiveness of alternative crewstation configurations. The P-3C Sensor Station 3 (non-acoustic) operator station was used as the testbed for this study. The simulations modeled the SS-3 operator's performance during a reconnaissance mission similar to those currently flown in the Mediterranean. This volume is the eighth in a series providing complete documentation on HOS.

W/L Cat. Code: 1.2, 2.1.1, 3.3

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Questionnaire	Construct	Simulator	Flight simulator
Spare m. capacity	Task comp., time assess.	Experimental		
Primary task	Math. model			

Strother, D. D. Visual activities of the helicopter pilot during low-altitude, VFR flight. Aircrew performance in army aviation. Proceedings of a conference, 27-29 November, 1973. U.S. Army Aviation Center, Fort Rucker, Alabama, 1974, 188-192.

This paper addresses a vital problem of very low altitude flight missions. The problem involves the visual capabilities of the helicopter pilot during low altitude, VFR flight. It may be defined as establishment of the pilot's visual workload. The urgency of this problem stems from the trend to add to the pilot's existing tasks. He is now asked, in fighter and scout helicopters, to perform two new tasks: (1) to increase his surveillance activities in the target area since the gunner is becoming a head-down crew member during attack and search mission phases, and (2) to act as a substitute gunner by using a helmet mounted sight and a headtracker. These tasks must be performed in addition to nap-of-the-earth flight. Continuing studies must define the time required of these additional tasks so that the time required can be matched with the time available. Any overburdening of the pilot must be addressed by tactical and operational planners.

W/L Cat. Code: 3.1, 4.1.7
Op. Behav. Code: 1., 2., 3., 4.

Primary task	Single measures	Construct	Flight test	Flight simulator
Physiological	Eye movement	Experimental		Flight test

Strother, D. D. Visual and manual workload of the helicopter pilot. Paper presented at the Annual National Forum of the American Helicopter Society, Washington, D.C., May, 1974. (Preprint No. 321).

The total workload of the helicopter pilot includes many forms of human activity: manipulation, vision, audition, cognition. The summation of the activity in each of these may be considered the total pilot workload. Two facets of the total pilot workload are discussed in this paper. The first addresses manipulative workload during single-pilot actual instrument flight in a high density zone. Data indicate the helicopter pilot has ample time to perform his required manipulative tasks. The second discusses visual workload and an experimental technique for measuring this load. Data are presented which indicate an interaction of visual workload with altitude. Human Factors Engineering depends on an ability to predict pilot performance in order to design optimal cockpits. Indices of the pilot workloads discussed are critical during the iterative process of design.

W/L Cat. Code: 2.1.1, 2.2.1, 3.1, 4.1.7

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Construct	Flight test	Flight simulator
Primary task	Subsidiary task	Experimental		Flight test
Physiological	Single measure			
	Eye movement			

Sun, P.B., Keane, W.P. and Stackhouse, S.P. The measurement of pilot workload in manual control systems. Proceedings of Aviation Electronics Symposium, Fort Monmouth, New Jersey, April, 1976.

The objective of this study was to measure both performance workload and physiological workload in a hover simulation and to apply the derived weighting coefficients for some of the physiological variables to those same physiological measures made in a simulated decelerating landing experiment. The primary objective was methodological. That is, could physiological variables be used to measure workload during transient maneuvers when the weighting coefficients for these variables were derived from their relationship to an adaptive performance measure obtained during a steady state maneuver such as precision hover? A further objective of this study was to evaluate three combinations of control system feedback with three quantities to compare workload during a decelerating approach to landing.

W/L Cat. Code: 2.2.4, 2.2.5, 3.2, 4.1.3, 4.1.4, 4.1.11
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Multiple	Experimental	Flight simulator	Flight simulator
Primary task				Flight test
Physiological				

Sundermeyer, P. and Alles, W. The influence of the amount of automation in a flight path guidance system on flight path deviation and pilot work load. Paper presented at Symposium ueber Fliegen im Flughafen-Nahbereich, Hamburg, West Germany, April, 1979. (In German.)

Attention is given to simulations carried out to investigate the delegation of duties between the pilot and autopilot by determining the effect of the amount of automation on flight path accuracy and pilot work load. Three steps of automation are studied: (1) flight path guidance with autopilot control, (2) flight path quidance with information relay to the control elements, and (3) fully automatic flight path guidance. It was found that flight path accuracy improved through a vertical speed error reduction of 20% for step 2, and 25% for step 3. In addition, course errors were reduced 10 and 25%, respectively.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.

Primary task Single measures Experimental Flight simulator Flight simulator

Flight test

Sverko, B. Individual differences in time sharing performance. Urbana-Champaign, Illinois: Aviation Research Laboratory, Technical Report, ARL-77-4/AFOSR-77-4, January, 1977. (AD A043 525).

Experiments in time-sharing ability were performed. Four tasks were used: (1) The rotary pursuit task; (2) The digit processing task; (3) The mental arithmetic task; and (4) The auditory discrimination task. Sixty subjects performed the tasks several times singly, one by one, as well as concurrently, in all possible two-task combinations. Sixteen scores were obtained for every subject: performance on each task when performed singly, as well as when performed concurrently with each of three other tasks. These 16 variables were intercorrelated and the resulting matrix of intercorrelations was submitted to a factor analysis. Only task-specific factors were identified. No evidence for a time-sharing factor, which would account for concurrent task performances, was found. Thus, the notion of "time-sharing ability" was not supported.

W/L Cat. Code: 2.2, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Szekely, J. Evaluation of mental load in the study and design of work conditions--theory, measurement, application. Institute National de Recherche et de Securite, Paris, Notes Scientifiques et Techniques de l'INRS, No. 4, January, 1975. (In French.)

This report examines developments in the assessment of mental load in the industrial context. The literature is reviewed and an attempt is made to clarify the concept of mental load in ergonomic terms. The chief methods of measuring mental load are reviewed, and the practical possibilities of applying these methods are examined.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion Multiple Review None Background

Spare m. capacity

Primary task

Physiological

Teichgraber, W. M. The effects of signal quantization on compensatory tracking performance. Unpublished master's thesis, Naval Postgraduate School, December, 1972. (AD 758 680).

The effects of quantizing the displayed error were investigated in both single- and dual-axis critical compensatory tracking tasks and in cross-adaptive tracking tasks. Both first order and second order controlled elements were used, as well as an intermediate "1.5" order element. Quantization intervals investigated ran from 0 to 1.69 cm on a 10 cm by 10 cm display. A digital computer program was written for use with a hybrid computer in order to mechanize the various types of tracking tasks used in this research and for future use at this facility. Results of the critical tracking task runs indicate that the operator's performance deteriorates almost linearly as the quantization interval is increased. Cross-adaptive tracking task results indicate a pronounced increase in operator workload when quantization is used.

W/L Cat. Code: 2.2.5, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Teiger, C. Regulation of activity: an analytical tool for studying work-load in perceptual motor tasks. Ergonomics, 1978, 21, 203-213.

Work-load imposed on the operator performing perceptual-motor tasks subject to rigid time-constraints may be analysed by investigating methods of regulation between various psychophysiological functions. This is particularly true for the study of relationships between operating methods and postural activity, and also by the change in these relationships over time. Thus we appear to have a method for analysis of external and internal constraints on the operator, additional to the tool for evaluating the physiological cost entailed in meeting work demand, provided by the E.M.G. Results are presented from industrial studies of electronic component assembly and contrasted with laboratory findings. Combination of the two types of study is seen to be necessary and important for analysis of workload.

W/L Cat. Code: 2., 4.

Op. Behav. Code: 4.1.4

Physiological	EMG	Review	Field	Flight simulator
				Flight test

Teper, G. L., Hon, R. H., and Smyth, R. K. Preliminary candidate advanced avionics system (PCAAS) - reduction in single pilot workload during instrument flight rules flight. Hawthorne, California: Systems Technology, Inc. TR-1084-1 (NASA-CR-152026), September, 1977.

Specifications which define the system functional requirements, the subsystem and interface needs, and other requirements such as maintainability, modularity, and reliability are summarized. A design definition of all required avionics functions and a system risk analysis are presented.

W/L Cat. Code: 2.1.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	Laboratory	Flight simulator
Primary task	Math. model	Experimental	Flight simulator	

TerBraak, F. High workload tasks of aircrew in the tactical strike, attack, and reconnaissance roles. In AGARD simulation and study of high workload operations, AGARD-CP-146, October, 1974, A17-1 - 17-3.

High workload tasks are outlined for aircrew performing three distinct tactical roles, namely the strike, the attack and the reconnaissance roles. The total mission is covered, which is from the time the pilot receives his orders until the debriefing following the flight has been completed. At the same time differences between each role, as related to workload, are printed out so that a fairly realistic comparison can be made as to the workload of each category.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1.1, 1.2, 2.1, 4.2

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator
				Flight test

Thackray, R. I., Jones, K. N., and Touchstone, R. M. The color-word interference test and its relation to performance impairment under auditory distraction. Oklahoma City, Oklahoma: Civil Aeromedical Institute, FAA-AM-72-14, March, 1973.

An examination was made of the relationship between performance on the Stroop color-word interference test (a suggested measure of distraction susceptibility) and impairment under auditory distraction on a task requiring the subject to generate random sequences of letters. Although there was a significant decrease in randomness as a result of auditory distraction, the correlation between change in randomness and amount of color-word interference was nonsignificant. These findings suggest that the Stroop test may measure a rather restricted type of perceptual interference essentially unrelated to a possibly more general ability to maintain concentration in the presence of competing (distracting) stimuli.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Background
Primary task	Single measures			

Thorne, R. G. Pilot workload: A conceptual model. AGARD Conference Proceedings No. 119 on Stability and Control, Braunschweig, Germany, April 10-13, 1972, 21-1-21-6. (AGARD-CP-119). (AD 754 524).

A conceptual model is described for the situation when, some of the crew, some of the time, are unable to complete satisfactorily, some of their tasks. The model relates task difficulty to operator capacity as a means of defining areas of overload. A case is made for more realistic simulations of the more difficult tasks.

W/L Cat. Code: 2.1.1, 2.1.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Math. model Construct None Background

Torashevskaya, L. I. The reaction of the cardio-vascular and sympathico-adrenal systems to intellectual activity with emotional stress--human operator performance. Ocherki Psykhologii Truda Operatora. Moscow: Nauka Press, 1974, 275-290. (In Russian.) (English translation appears in Essays on the Psychology of Operator Labor. NASA-TT-F-16020, January, 1975, 335-351.)

The effect of emotiogenic factors on an operator's intellectual activity were studied for differing working regimes on an experimental control panel that provided for light, sonic, and electrocutaneous stimuli. The latter stimulus was activated automatically if the subject gave an incorrect response. It was shown that the working capacity of the operator under stress depends to a great extent on the effect of the emotiogenic factors on the individual functioning characteristics of the cardiovascular and sympathetic-adrenal systems. Moral, intellectual, willpower, emotional, and other personality traits are decisive factors of operator function.

W/L Cat. Code: 3.1, 4.1.10, 4.1.12

Op. Behav. Code: 1., 2., 3., 4.

Primary task Single measures Experimental Laboratory Background

Physiological Heart rate, h.r. var. Body fluid anal.

Triggs, T.J. Aspects of mental workload. Proceedings of the IERE-GMMS ERS International Symposium on Man-Machine Systems, Cambridge, England, September, 1969.

During task performance, the nature of the information processing demands at any point in time obviously determines to a large extent the operator's mental workload. However, the human in operational circumstances must be regarded as more than a passive single-channel processor of information. In situations of any complexity, there may be time-sharing demands on the human, or he may be required to respond to a rapid sequence of signals. There is good evidence in such situations that the nature of the task which the operator may be called on to perform at short notice can influence the current workload and degrade present performance. These aspects of task loading will be considered in terms of a central capacity-sharing model, where the preparatory processes required for task elements immediately in the future are assumed to require information-processing capacity. Experimental data from a serial reaction-time task will be presented in support of the model. The results indicate that the preparatory state for a future reaction can be developing prior to emission of the preceding response, and that processing capacity is allocated between the components of the serial task to allow this active process of preparation.

W/L Cat. Code: 2.2.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Trumbo, D. and Noble, M. Response uncertainty in dual-task performance. Organizational Behavior and Human Performance, 1972, 7, 203-215.

In three experiments, Ss performed under one of several secondary task conditions while engaged in pursuit tracking as a primary task. Secondary tasks were of the information creation (1:many) type with from one to five alternative response buttons to be used randomly in response to a tone cue. The results generally support the prediction that interference in the primary task increases as a function of the response uncertainty in the secondary task. These results provide further evidence that information processing capacity may be relatively limited at the response selection stage.

W/L Cat. Code: 2.2.1, 2.2.2

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Trumbo, ", Noble, M. and Swink, J. Secondary task interference in the performance of tracking tasks. Journal of Experimental Psychology, 1967, 73, 232-240.

The effects of secondary verbal tasks on tracking performance were examined. In Experiment I, redundancy was varied in both primary and secondary tasks, with the latter introduced at a retention session. The secondary task resulted in marked interference, independent of either primary to secondary task redundancy, primarily in the timing aspect of tracking. In Experiment II, stimulus and response components of the secondary task were presented separately. The response component produced as much interference as the cognitively more difficult secondary task. Experiment III showed that secondary task effects occur independent of a retention interval.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Ursin, H. and Ursin, R. Physiological indicators of mental load. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 349-365.

This paper discusses the available methods of measuring mental load by physiological methods. Specifically, five physiological aspects are reviewed: activity of the central nervous system; specific activation; energy requirements; wear and tear, stress, strain, and health; and restoration processes. The position taken is that it is fairly easy to measure and therefore exclude the physical workload, and measure psychological activation. However, there are serious difficulties if one desires to discriminate between emotional factors and information workload. If this is not done, measuring "mental workload" does not involve anything but conventional evaluation of "activation", on which there is a considerable bulk of information.

W/L Cat. Code: 4.

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Multiple	Review	None	Flight simulator
		Construct		

van Gigch, J.P. A model for measuring the information processing rates and mental load of complex activities. Canadian Operational Research Society Journal, 1970, 8, 116-128.

When industrial operatives perform complex activities during their work the correspondence between stimuli and responses becomes difficult to establsih. In such cases, existing models which require that the marginal probabilities of inputs and outputs be known cannot be used to measure the amount of information transmitted. A model is presented here which allows quantification of the levels of integrative behavior on the basis of the determination of the total entropy transmitted in the performance of information processes of various degrees of complexity. Mental therbligs are used to describe the activities of the human communication channel. This leads to the calculation of the total amount of information transmitted from input stimuli to output responses, and to the determination of an information processing rate which characterizes the mental content of the work performed.

W/L Cat. Code: 2.1.2
Op Behav. Code: 2.1

Spare m. capacity Inform. theory Construct Field Flight test

van Gigch, J.P. Applications of a model used in calculating the mental load of workers in industry. Canadian Operational Research Society Journal, 1970, 8, 176-184.

This paper describes the field work and results obtained in the application of a model of integrative behavior which is used to measure the mental load of various industrial tasks. The model identifies information processes which take place while the operator is performing his work. The amount of information, in the information theory sense, which is transmitted while the human communication system accomplishes mental therbligs is calculated. The application of this model is made to sets of jobs found at two or more distinct levels of technology. The mental contribution of industrial workers is analyzed to determine the impact of technology on the mental content of work. The information processing rates are broken into their two components--entropy per cycle and repetition cycle rate--to evaluate the potential for further mechanization and automation. The effects of increasing work complexity on the operators' speeds of response are studied.

W/L Cat. Code: 2.1.2
Op. Behav. Code: 2.1

Spare m. capacity Inform. theory Construct Field Flight simulator
Flight test

Verplank, W. L. Is there an optimum work-load in manual control? Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 72-79. (NASA TM X-73, 170).

Experiments on a closed-circuit-television driving simulator were designed to answer the question: is there an optimum work-load that (a) sustains performance in long-term driving and (b) facilitates transitions to new tasks or emergencies? The results affirm (a) with reservations but not (b). A second experiment is planned and a new measure for work-load proposed.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.2

Primary task   Single measures   Experimental   Simulator   Background

Verplank, W. L. The facilitating effects of uncertainty in long-term manual control. Proceedings of the 13th Annual Conference on Manual Control, Massachusetts Institute of Technology, 1977, 101-117.

A tracking task with different disturbance inputs was used to look for the effects of reduced task demands on long term manual control. The expected facilitating effects of task difficulty are hard to find. The decrements in performance over the run are no greater for the easier tasks. The detrimental effects of lower demand appear to be increased relative variability in performance, and possibly reduced performance on transition to unexpected, more difficult tasks. An information measure, including the effects of 'self-induced' uncertainty is developed as a work-load measure. There is a positive correlation between this 'self-induced workload' and performance decrement for the easiest task, just the opposite of what the facilitation hypothesis would predict.

W/L Cat. Code: 2.1.2, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity   Inform. theory   Construct   Laboratory   Flight simulator

Primary task   Math. model   Experimental

Vettes, B. Evaluating the workload of helicopter pilots. In-flight recordings of heart rate and cardiac arrhythmia. In AGARD Studies on Pilot Workload, AGARD-CP-217, November, 1977, (In French.)

In-flight recordings were made of the heart rate and cardiac arrhythmia in four helicopter test pilots during increasingly difficult ILS approaches. Five types of tasks were identified, each task being repealed five times during the same flight. An analyses of concommitant rhythm variations, especially if the subject had a greater number of variations when at rest. This increase of cardiac rhythm is exacerbated by the addition of external function factors (turbulence). The influence of apprehension is evidenced by a detectable decrease in heart rate during successive repetitions of the same task. The inclusion of subjective criteria can provide some useful information. A study of arrhythmia appears to be a better measure than the instantaneous heart rate; however, an exact relationship between these parameters and the aviator's workload can not yet be affirmed.

W/L Cat. Code: 1.2, 4.1.10

Op. Behav. Code: 1., 2., 4.

Opinion	Questionnaire	Experimental	Flight test	Flight simulator
Physiological	Heart rate, h.r. var.			Flight test

Volle, M. A. Work, fatigue, and frequency of critical flicker fusion. Ergonomics, 1978, 21, 551-558. (In French.)

Fatigue due to a physical or a mental workload is here considered as a dynamic phenomenon dependent upon the type of work performed. Acute or chronic fatigue, as measured by CFF, has often led to contradictory interpretations among research workers. Data presented come from five groups of subjects submitted to different mental or physical workloads and to CFF measurements before, during and after the task. In general, with initiation of work, an increase in CFF is observed which probably corresponds to a CNS excitation induced by the workload. However, it appears that only some definite work situations could induce a CFF decrease as it is generally accepted for chronic or acute fatigue. In some tasks, the CFF continued to increase after work; in others, it showed no variation or decreased below the basal level observed at rest.

W/L Cat. Code: 4.1.1

Op. Behav. Code: 1., 2., 3., 4.

Physiological	FFF	Experimental	Laboratory	Background

Waller, M. C. An investigation of correlation between pilot scanning behavior and workload using stepwise regression analysis. Hampton, Virginia: NASA Langley Research Center, NASA TM X-3344, March, 1976.

An electro-optical device called an oculometer which tracks a subject's look-point as a time function has been used to collect data in a real-time simulation study of instrument landing system (ILS) approaches. The data describing the scanning behavior of a pilot during the instrument approaches have been analyzed by use of a stepwise regression analysis technique. A statistically significant correlation between pilot workload, as indicated by pilot ratings, and scanning behavior has been established. In addition, it was demonstrated that parameters derived from the scanning behavior data can be combined in a mathematical equation to provide a good representation of pilot workload.

W/L Cat. Code: 1.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight simulator	Flight simulator
Physiological	Eye movement			Flight test

Waller, M. C., Harris, R. L., Sr., and Salmirs, S. A study of parameters affecting a display for aircraft instrument landing. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 345-346.

This paper presents the results of a series of tests conducted in a fixed base simulator to evaluate the effects of varying parameters of a vertical situation display for landing a transport aircraft. The results of the test were evaluated in terms of touchdown performance, pilot control activity, and scanning behavior. The results indicate that size of the display, location of the display, and amount of information provided, all play a role in touchdown performance. It is also concluded that the presence of a perspective runway improves pilot acceptance of the display for landing.

W/L Cat. Code: 3.1, 4.1.7

Op. Behav. Code: 1., 2., 4.

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	Eye movements			

Wanner, J. C. The multiloop concept of pilot workload as a basis of future experiments and studies. Chatillon-sous-Bagneux, Hauts-de-Seine, France: ONERA, TP No. 1978-10, 1978. (In French.)

The perceptual and behavioral components of a pilot's performance are examined, a multiloop mathematical model of pilot behavior is presented, an approach to analyzing flight conditions and pilot tasks is indicated, and differences in feedback and loop characteristics for servomechanisms and for human pilots are noted. A multiloop workload is more than the sum of the component loops (involving control of or response to a single parameter or variable) since the multiloop workload includes the switching task, which is the transition from one loop to another. Short-term safety loops, immediate safety loops, and control forces are distinguished, and accidents are analyzed with relation to the workload.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	None	Background
Primary task	Single measures			

Watson, B. L. The effect of secondary tasks on pilot describing functions in a compensatory tracking task. Toronto, Canada: University of Toronto, Institute for Aerospace Studies, UTIAS Technical Note No. 178, June, 1972.

This report explores the effect certain secondary tasks have on human pilot describing functions. The describing functions were generated from a compensatory tracking task with rate-control dynamics. The experiment involved six well-trained subjects in a multi-task situation where the primary control task was tracking. The results are presented as amplitude and phase plots of measured describing functions, which are fitted by an eight-parameter theoretical pilot model. The effects are described in terms of both raw data and model parameters.

W/L Cat. Code: 2.2.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Math. model			Flight test

Waugh, J. D. Pilot performance in helicopter simulator. Aberdeen Proving Ground, Maryland: U.S. Army Engineering Laboratory, Technical Memorandum 23-75, September, 1975. (AD A017 441).

Six Army helicopter pilots, instrument rated, flew a difficult precision instrument flight pattern in this laboratory's GAT-2H helicopter simulator. For each flight, each subject was given a different combination of thrust to weight, cyclic control sensitivity and cyclic spring centering force gradient condition making up an incomplete, balanced block-type experimental design. Several error measurements were recorded during the trials; however, none could be satisfactorily utilized to predict either accuracy of performance, or be an indicator of relative workload. An unanticipated large variation of measures taken is thought to be the cause. Additional approaches and further study of the problem is recommended.

W/L Cat. Code: 3.2

Op. Behav. Code: 1., 2., 4.

Primary task	Mult. measures	Experimental	Flight simulator	Flight simulator
				Flight test

Way, T. C. Verification of workload-a job for simulation-pilot performance. In Flight Technologies Conference, Arlington, Texas, September, 1978, 99-104. (American Institute of Aeronautics and Astronautics, New York.)

The challenge to designers of flight decks and avionics suites, is to configure the crew station in such a way that required tasks can be accomplished by the allotted crew complement while holding crew workload within reasonable limits. An outline is presented of an approach involving the use of piloted simulation as an aid in meeting this challenge. The advantages of simulation over flight test for workload studies include cost, safety, efficiency, and timeliness. It is found that the state-of-the-art in fine-grain workload assessment is not particularly satisfying. However, it is possible to take the broader approach of designing and integrating a flight deck to minimize workload based on prior experience, industry standards, and good human engineering practice.

W/L Cat. Code: 2.1, 3.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task analytic	Construct	None	Background
Primary task	Math. model			

Weir, D. H. and Klein, R. H. Measurement and analysis of pilot scanning behavior during simulated instrument approaches. Proceedings of the 6th Annual NASA-University Conference on Manual Control, Wright-Patterson AFB, April, 1970, 83-108.

Experimental measurements of pilot scanning and control response in a simulated instrument approach are reported. Airline pilot subjects flew ILS approaches in a six degree of freedom fixed-base DC-8 Simulator at the NASA Ames Research Center. A conventional instrument panel and controls were used, with simulated vertical gust and glide slope beam bend forcing functions. Pilot eye fixations and scan traffic on the panel were measured using a recently developed eye-point-of-regard system. Simultaneous recordings were made of displayed signals, pilot response, and vehicle motions. The data were reduced for 31 approaches with a cross section of subjects to obtain dwell times, look rates, scan rates, and fractional scanning workload. Flight director approaches as well as standard localizer/glide slope approaches were made. The scanning results showed the attitude and glide slope/localizer instruments to be primary in a manual ILS approach. Differences in dwell time between pilots occurred mainly on the attitude instrument. With the flight director, glide path deviation errors were reduced and the flight director instrument dominated pilot attention. There were no apparent circulatory scanning patterns in any of the apporaches.

W/L Cat. Code: 4.1.7
Op. Behav. Code: 1., 2., 4.

Physiological	Eye movement	Experimental	Flight simulator	Flight simulator Flight test

Welford, A. T. Stress and performance-behavioral and ergonomics aspects. Ergonomics, 1973, 16, 567-580.

The effects on performance are discussed of various types of stress deriving from imbalance between capacity on the one hand and, on the other, the demands of tasks, environmental conditions and social situations which either overload or underload the individual. Common cybernetic principles seem to apply over an area which includes not only stress, but also motivation and arousal. A model is proposed which ties together three previously existing models current in this field: The Inverted-U Hypothesis, Signal Detection Theory and the Yerkes-Dodson Law. The model is examined further in relation to individual differences.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2.

Spare m. capacity	Task comp., time assess.	Construct	None	Background
Primary task	Math. model			

Welford, A. T. Mental work-load as a function of demand, capacity, strategy and skill. Ergonomics, 1978, 21, 151-167.

An attempt is made to outline a conceptual framework in which to view the problems of defining and measuring mental work-load. This is treated in terms of the demands made by tasks, the capacities the subject brings to meet these demands, and the strategies he uses to relate the first to the second. Two types of demand are distinguished: the amount of data to be handled at a particular moment, and the amount to be dealt with during a particular period of time. Each type is considered in relation to the main central functions of perception, decision and choice, phasing and coordination of action, memory, and motivation. Capacity, and the effects of various factors upon it, are considered in relation to concepts of signal-to-noise ratio in the central nervous system. Two basic approaches to the measurement of work-load are compared: the synthetic, in which the load imposed by the task as a whole is calculated from the loads imposed by its components; and the analytic, in which the task is studied as a whole, and components are analyzed from the whole performance.

W/L Cat. Code: 2.11, 3.1
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Task comp., time assess.	Construct	None	Flight simulator
Primary task	Single measures			Flight test

Wempe, T. E. and Baty, D. L. Human information processing rates during certain multiaxis tracking tasks with a concurrent auditory task. IEEE Transactions on Man-Machine Systems, 1968, MMS-9, 129-138.

A series of experiments was conducted to determine the information processing rates of several subjects performing one- and two-axis compensatory tracking tasks with a secondary auditory task. The experimental variables were the order of controlled element dynamics, the forcing function, and the addition of a secondary task. Human information processing rates decreased slightly on each tracking channel with the addition of the second tracking channel or the secondary auditory task. Other than this effect, the information processing rates were additive until a limit in the total information processing rate was reached. This limit was related to the order of the controlled element.

W/L Cat. Code: 2.1.2, 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Inform. theory	Experimental	Laboratory	Flight simulator
Primary task	Subsidiary task			Flight test
	Single measures			

Westbrook, C. B., Anderson, R. O. and Pietrzak, P. E. Handling qualities and pilot workload. Wright-Patterson AFB, Ohio: AF Flight Dynamics Laboratory, AFFDL-FDCC-TM-66-5, September, 1966. (AD 655 340).

This paper has the objective of defining the relationship between handling qualities and pilot stress and workload. The reasons underlying the importance of pilot workload measurement are discussed and ways to analyze or treat pilot vehicle systems are reviewed. The various measures of pilot workload that have been used or considered are discussed and some new data on the possible use of pupil dilation as a measure of stress are presented.

W/L Cat. Code: 2.2.5, 3.3, 4.1.2, 4.1.4, 4.1.8

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Review	Laboratory	Flight simulator
Primary task	Math. model	Experimental		Flight test
Physiological	Pupilary dia.			

Weverinke, P. H. Human control and monitoring-models and experiments. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 14-38. (NASA TMX-73, 170).

This paper deals with the results of a theoretical and experimental program concerning human monitoring behavior. Apart from monitoring an automatic approach, combined monitoring and manual flight director control was studied to determine the interference between subtasks. Also simultaneous monitoring and auditory tracking was included. The results demonstrate that the multivariable monitor model adequately describes human behavior in the aforementioned tasks. Furthermore, a multivariable workload model is developed. Computed workload is shown to agree excellently with subjective ratings.

W/L Cat. Code: 1.1, 2.2.1, 2.2.2, 3.3

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Rating scale	Construct	Laboratory	Flight simulator
Spare m. capacity	Subsidiary task	Experimental		Flight test
Primary task	Math. model			

Wewerinke, P. H. Performance and workload analysis of in-flight helicopter tasks. Proceedings of the 13th Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, June 15-17, 1977, 105-117.

The study described in this paper was aimed at assessing the potentials of the optimal control model structure to predict the important characteristics of realistic operational helicopter missions. The theoretical and experimental results indicate that the optimal control model successfully predicts the best attainable (rather than the average) inflight performance of a group of well-trained, highly motivated subjects. Furthermore, the model allows a description of inter-subject variability. The control effort model predictions have been supported by subjective ratings. The model seems to provide a meaningful representation of pilot workload involved in complex control tasks.

W/L Cat. Code: 1.1, 3.3

Op. Behav. Code: 1., 2., 4.

Opinion	Rating scale	Experimental	Flight test	Flight simulator
Primary task	Math. model			Flight test

Wewerinke, P. H. and Smit, J. A simulator study to investigate human operator workload. Proceedings of the AGARD Conference on Simulation and Study of High Workload Operations, AGARD-CP-146, April, 1974, A2-1 - A2-6.

This paper presents the results of an exploratory experiment which was conducted to investigate human response characteristics in control situations of widely varying difficulty. The experiment was aimed at a better understanding of the human operator limitations in terms of control effort as included in the optimal control model. Based on the experimental results a control effort index is presented. The "predicted" control effort correlates well with subjective ratings and seems to possess generality.

W/L Cat. Code: 1.1, 3.3

Op. Behav. Code: 4.2

Opinion	Rating scale	Construct	Flight simulator	Flight simulator
Primary task	Math. model	Experimental		Flight test

Whitaker, L. A., Dual-task interference as a function of cognitive load processing. Acta Psychologica, 1979, 43, 71-84.

Sixteen subjects participated in a dual-task study designed to measure processing requirements of a choice reaction time (RT) task. Two levels of choice RT stimulus-response (S-R) compatibility were tested with each of two tracking tasks to provide different levels of dual-task loading. In one tracking task, the target's temporal-spatial pattern was fixed; in the other, the target's path was a function of the subject's performance. Choice RT results indicated that compatibility and set size interacted; the increase in response latency as a function of set size was much greater when compatibility was low. An increase in choice RT response latency occurred when the secondary tracking task was added. Within a given compatibility level, this dual-task decrement was constant for all levels of set size; however, the magnitude of dual-task decrement varied as a function of S-R compatibility, being greater when compatibility was low than when it was high.

W/L Cat. Code: 2.2., 2.2.5, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			

White, R. T. Task analysis methods: Review and development of techniques for analyzing mental workload in multiple-task situations. St. Louis, Missouri: McDonnell Douglas Corporation, MDC J 5291, September, 1971.

Representative task analysis formats were reviewed and a large number of task classification schemes or taxonomies were analyzed. The historical development of these techniques was reviewed to identify weaknesses and sources of error. Various attempts to quantify workload also were reviewed and the desirable characteristics of an improved approach to task analysis were identified. With this as background, an approach to task analysis was developed that concentrates on the interactions between tasks and the time-sharing or scheduling demands that are imposed on operators. Cognitive or mental workload is stressed rather than sensory or motor aspects of tasks. This approach analyzes broad operator functions or tasks in relation to the task characteristics or demands that determine workload and is suitable for use during early design phases when detailed task information is not available. An example is given to illustrate its use in analyzing a complex, multiple-task situation.

W/L Cat. Code: 2.1.1, 2.1.2

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Review	None	Flight simulator
	Inform. theory			Flight test

White, R. T. Mental workload assessment, I. Laboratory investigation of decision-making and short-term memory in a multiple-task situation. St. Louis, Missouri: McDonnell Douglas, MDC J6662/01, December, 1975.

This report describes the results of a preliminary investigation of two types of mental workload (MWL): Time-sharing decisions and short-term memory (STM). Subjects were tested in a multiple-task situation that required them to monitor either four or six single-digit light-emitting diode (LED) counters to prevent errors (counts above nine indicated by a displayed decimal point) by reset actions taken in a keyboard. The results of this study suggest the complexity of time-sharing or self-scheduling decisions may be quantified by the number of alternatives or channels being monitored, and the amount of processing may be quantified in terms of the frequency of the decisions. Short-term memory demands may be quantified in terms of the number of separate items or groups (chunks) of elements to be stored in memory and the duration of the storage interval.

W/L Cat. Code: 2.2.1

Op. Behav. Code: 1., 2., 4.1

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

White, R. T. and Gaume, J. . Mental workload assessment, III. Laboratory evaluation of one subjective and two physiological measures of mental workload. St. Louis, Missouri: McDonnell Douglas Corporation, Report MDC J7024/01, December, 1975.

A laboratory evaluation was conducted on two physiological measures and one subjective technique for the assessment of mental workload (MWL). Twelve Ss were tested in a multiple-task situation in which they monitored four single-digit, light emitting diode (LED) counters to prevent errors (i.e., counts above 9, indicated by displayed decimal points). MWL in terms of decisions per minute was varied by changing the rates at which individual LEDs increased their counts. Subjects also performed a secondary task which required them to monitor and report the degree of stress they were experiencing. Physiological measures recorded throughout the test included integrated pulse volume (IPV), integrated respiration volume (IRV), GSR, EKG, and pulse and respiration waveforms. These results support the use of IPV and IRV in MWL assessment but further tests are needed to determine their sensitivity and range of application. Subjective estimates of stress levels did not appear to degrade performance and are potentially valid and reliable indications of MWL levels.

W/L Cat. Code: 1.1, 2.2.1, 4.1.2, 4.1.3, 4.1.10, 4.1.11
Op Behav. Code: 1., 2., 4.1

Opinion Multiple Experimental Laboratory Flight simulator
Spare m. capacity
Physiological

White, R. T. and Ware, C. T. Prediction of human operator performance in the design of command and control systems. Paper presented at the Annual Meeting of the Western Psychological Association, Vancouver, British Columbia, June 21, 1969. (Douglas Paper 5539).

Military command and control operations of manned interceptors were analysed to define typical tactical and air defense missions and the task loading on human operators who control these missions. Man-machine functions were analyzed in systems where information is computer-based to describe the control, display, and communication requirements for the study. Volunteer military subjects were trained to perform the required tasks, and their performance under gradually increasing load (information handling and processing) conditions was measured in terms of time and correctness of voice messages transmitted and manual switch actions completed. The operator performance data obtained in this study have been interpreted for use in the following areas of design applicability: Operator Task Performance Times; Performance Decrement; and Number of Operators Required.

W/L Cat. Code: 2.1.1, 3.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Simulator	Flight simulator
Primary task	Single measures			

Wickens, C. D. The effect of time sharing on the performance of information processing tasks: A feedback control analysis. Ann Arbor, Michigan: The University of Michigan, Human Performance Center, Technical Report No. 51, August, 1974. (AD A012 023).

Usually the effects of diverted attention on task performance is assessed either by very global measures or by the highly specific measure of an increase in processing time. There is evidence, however, that other effects of diverted attention, such as an increase in internal processing noise, or a cognitive change in processing strategy, exist, but may only be revealed by a more detailed analysis of task performance. The purpose of the current research was to examine these time-sharing effects in a manual tracking paradigm, employing the fine-grained analysis provided by the techniques of feedback control theory. Subjects each performed three information-processing tasks under seven time-sharing conditions. Each task was performed singly, and in combination with one and with both of the other two tasks. The results indicated that all tasks showed both performance decrements and processing-noise increases under some time-sharing conditions. Time-sharing interference, however, was most evident between the response aspects of the tasks, and the noise-level increase in the tracking task was concluded to result from motor, rather than perceptual, processing interference.

W/L Cat. Code: 2.2.1, 2.2.2, 3.3
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Math. model	Review		Flight test

Wickens, C. D. The effects of divided attention on information processing in manual tracking. Journal of Experimental Psychology, 1976, 2, 1-13.

Six subjects performed a manual tracking task concurrently with each of two secondary tasks: an input task (auditory signal detection) and an output task (application of a constant force). A feedback-control analysis of tracking performance was utilized to analyze the time-sharing decrements observed in mean squared error, in terms of components due to processing delay, addition of internal processing noise, and change in response bias (tracking gain). The results indicated that only the parameters measuring noise and gain were sensitive to time-sharing conditions, and these only to concurrent performance of the force application task. It was concluded that limits of attention in dual-task performance are more severe in output than in input stages of processing, but that these limits are not necessarily those of a single-channel bottleneck. Instead, a broader conception of attention is proposed: one that includes changes in processing noise and shifts in response bias, as attention-related phenomena.

W/L Cat. Code: 2.2.1, 2.2.2

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Construct	Laboratory	Flight simulator
Primary task	Single measures	Experimental		Flight test

Wickens, C.D. Measures of workload, stress and secondary tasks. In N. Moray (Ed.) Mental workload: its theory and measurement. New York: Plenum Press, 1979, 79-99.

The concept of operator workload is defined in terms of the human's limited processing resources. Operator workload scales monotonically with the extent to which the tasks performed by the operator utilize these limited resources. It is asserted that: (1) processing resources are demanded by a task to the extent that the performance of a second, independent task performed concurrently deteriorates from its single task level. (2) Changes in the objective characteristics of a task will vary the processing resources demanded by its performance at a constant level, to the extent that secondary task performance varies concomitantly. In either instance, therefore, the manipulation of adding the primary task or of changing its characteristics will be described as increasing operator workload to the extent that secondary task performance deteriorates. This paper reviews the advantages and disadvantages of a wide variety of workload estimation techniques.

W/L Cat. Code: 2.2, 3., 4.0
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Multiple	Review	None	Flight simulator
Primary task				Flight test
Physiological				

Wickens, C. D. The structure of attentional resources. In R. Nickerson (Ed.) Attention and Performance VIII. Hillsdale, New Jersey: Lawrence Erlbaum and Assoc., 1979. (In press.)

Structural and capacity theories of dual task performance are contrasted and a hybrid conception of structure-specific capacity is proposed in which processing resource reservoirs are defined by processing structures. A review of the literature identifies candidates for structural resource reservoirs, defined by input and output modalities, stages of processing, and hemispheres of processing. An experiment is reported in which encoding and response modalities of a digit processing task are varied, as it is time-shared with a tracking task, whose difficulty is manipulated. The results are interpreted in terms of the concepts of capacity, structure, and resource pools.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Review	Laboratory	Background
Primary task	Single measures	Experimental		

Wickens, C. D. and Gopher, D. Control theory measures of tracking as indices of attention allocation strategies. Human Factors, 1977, 19, 349-365.

In an intelligent man-machine control system, control theory measures describing the operator's tracking performance can provide useful information concerning an operator's attentional state. This information may be used to implement adaptive aiding procedures. Research is reviewed that relates attentional manipulations to variation in control theory parameters, and an experiment is then described in which 29 subjects performed a tracking task alone, and concurrently with a serial reaction-time task. Within the time-sharing condition, relative priorities between the two tasks were manipulated. The results are interpreted in terms of the separate effects of time-sharing and of priority manipulations upon measures of tracking gain, remmant, time-delay and response "holds," and the feasibility of on-line measurement of those variables.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Construct	Laboratory	Flight simulator
Primary task	Single measures	Experimental		Flight test

Wickens, C. D., Isreal, J. and Donchin, E. The event related cortical potential as an index of task workload. Proceedings of the 21st Annual Meeting of the Human Factors Society, San Francisco, California, 1977, 282-286.

This paper describes an investigation which assessed the feasibility of the event related brain potential (ERP) to provide an index of operator workload in adaptive man-machine systems. The characteristics and requirements of such systems are described and some limitations of secondary task workload measures enumerated. The results of an experiment are then presented in which ERPs were recorded from 10 subjects, while the difficulty of a concurrent tracking task was varied. Subjects performed either a one or a two dimensional compensatory tracking task, while ERP's were elicited by presenting discrete auditory stimuli. The amplitude of the P300 complex, a component of the ERP, elicited by the stimuli, decreased from the control condition (no tracking) to the tracking conditions. An ERP based measure of sequential processing of the stimuli was further affected as tracking difficulty was increased from 1 to 2 dimensions. An algorithm for obtaining an on-line ERP based measure of workload is then described.

W/L Cat. Code: 3.1, 4.1.6

Op. Behav. Code: 1., 2., 3., 4

Primary task	Single measures	Experimental	Laboratory	Flight simulator
Physiological	ECP			Flight test

Wickens, C., Isreal, J., McCarthy, G., Gopher, D. and Donchin, E. The use of event-related potentials in the enhancement of system performance. Proceedings of the 12th Annual NASA-University Conference on Manual Control, University of Illinois, May, 1976, 124-134. (NASA TM X-73, 170).

Advancing computer technology has facilitated the implementation of on-line adaptive man-machine systems. In these systems, computer decisions based on information concerning the state of the operator can affect the nature of the man-machine interaction. Some limitations of performance measures as sources to provide information to the computer are presented. It is suggested that psychophysiological measures such as the event related cortical potential (ERP) may be utilized to bypass these limitations. The characteristics of the ERP and experimental demonstrations of its sensitivity to attentional manipulations are described and a program of relevant research is then outlined.

W/L Cat. Code: 2.2.2, 4.1.6
Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Physiological	ECP			Flight test

SY-27R-80

Wickens, C. D. and Kessel, C. The effects of participatory mode and task workload on the detection of dynamic system failures. Proceedings of the 13th Annual NASA-University Conference on Manual Control, Massachusetts Institute of Technology, June 15-17, 1977, 126-135.

The ability of operators to detect step changes in the dynamics of control systems is investigated as a joint function of, (a) participatory mode: whether subjects are actively controlling those dynamics or are monitoring an autopilot controlling them, and (b) concurrent task workload. A theoretical analysis of detection in the two modes identifies factors that will favor detection in either mode. Three subjects detected system failures in either an autopilot or manual controlling mode, under single-task conditions and concurrently with a "subcritical" tracking task. Latency and accuracy of detection were assessed and related through a speed-accuracy tradeoff representation. It was concluded that failure detection performance was better during manual control than during autopilot control, and that the extent of this superiority was enhanced as dual-task load increased. Ensemble averaging and multiple regression techniques were then employed to investigate the cues utilized by the subjects in making their detection decisions.

W/L Cat. Code: 2.2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures Flight test

Wickens, C. D., and Kessel, C. The effects of participatory mode and track workload on the detection of dynamic system failures. IEEE Transactions on Systems, Man, and Cybernetics, 1979, SMC-9, 24-34.

The ability of operators to detect step changes in the order of control dynamics is investigated as a joint function of a) participatory mode, whether subjects are actively controlling those dynamics or are monitoring an autopilot controlling them, and b) concurrent task workload. Five subjects either tracked or monitored the system dynamics on a two-dimensional pursuit display under single task conditions and concurrently with a "subcritical" tracking task at two difficulty levels. Detection performance was faster and only slightly less accurate in the manual as opposed to the autopilot mode. Performance in each mode was derogated by the concurrent tracking requirement, but not by increases in loading task difficulty. Further analysis indicated that manual superiority was attributable to the additional proprioceptive information resulting from operator-control adaptation to the system change.

W/L Cat. Code: 2.1.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures

Wickens, C. D. and Pierce, B. Attentional resource allocation in a variable difficulty dual task paradigm. Urbana-Champaign, Illinois: Engineering Psychology Laboratory, University of Illinois, Technical Report AFOSR-78-1/EPL-78-1, February, 1977. (AD A059 463).

A model of the attention allocation process in a dynamic environment with changing task demands is presented. Eight subjects then time-shared two compensatory tracking tasks under conditions of constant task difficulty, and under conditions when the difficulty of one task was varied over the course of the trial. Subjects were instructed to maintain constant performance on the variable difficulty task, and augmented performance feedback was presented on half of the trials. The data were evaluated in terms of the model, and coherence and error analysis revealed that allocation was far from optimal. The failure of augmented feedback to improve the optimality of allocation suggested that the limitation lay within the allocation, rather than the demand evaluation process. Some reasons are proposed for these limitations, and for the contrast of the current results with optimum allocation observed in constant difficulty dual task studies.

W/L Cat. Code: 2.2, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Background

Primary task Single measures

Wickens, C. D. and Tsang, P. Attention allocation in dynamic environments. University of Illinois (Urbana-Champaign) Engineering Psychology Research Laboratory, Technical Report EPL-79-3/AFOSR-79-3, June, 1979.

Three policies of attention resource allocation between tasks of dynamically varying difficulty are described. These policies optimal allocation, optimal resource expansion, and non-optimal allocation are distinguished analytically by the gain of the transfer function between task difficulty and primary and secondary task performance. Eight subjects time-shared two compensatory tracking tasks in which the control dynamics of the primary task fluctuated continuously between first and second order. The difficulty and filtered RMS error performance measures indicated that subjects were initially non-optimal in their allocation policy, failing to guard the primary task in the face of fluctuations in its difficulty. With practice, a trend toward more optimal performance was observed. Close analysis and comparison of the variable difficulty data with performance in constant difficulty dual task conditions indicated a persisting limitation in subjects' ability to reallocate resources from the secondary task when required by demand changes of the primary. The source of this limitation was postulated to reside in the difficulties operators encounter when maintaining two concurrent and dissimilar describing functions.

W/L Cat. Code: 2.2.2, 2.2.5, 3.1, 3.3
Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator
Primary task Single measures
Math. model

Wickens, C. D., Tsang, P. S., and Benel, R. A. The allocation of attentional resources in a dynamic environment. Proceedings of the 23rd Annual Meeting of the Human Factors Society, Boston, Massachusetts, October 29-November 1, 1979, 527-531.

Three experiments are reported in which subjects performed a primary task, whose difficulty varied quasi-randomly over time, concurrently with a secondary task, whose difficulty remained constant. Three models of resource allocation were described which varied in the degree of optimality with which operators can mobilize resources in response to the demand changes. These are quantified by linear time-series analysis. In experiment 1 employing two tracking tasks, allocation behavior was non-optimal, but indicated a trend toward optimality with practice. In experiment 2 when tracking difficulty was varied concurrently with a dynamic system monitoring task, behavior was somewhat optimal. In experiment 3 which again paired tracking and monitoring, but varied monitoring task demand, resource allocation was extremely non-optimal. Some reasons for this departure from optimality are considered.

W/L Cat. Code: 2.2.2, 2.2.5, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity Subsidiary task Experimental Laboratory Flight simulator

Primary task Single measures

Wiener, E. L. Controlled flight into terrain accidents: system induced errors. Human Factors, 1977, 19, 171-181.

Controlled flight into terrain accidents are those in which an aircraft, under the control of the crew, is flown into terrain (or water) with no prior awareness on the part of the crew of the impending disaster. This paper examines recent experience with these accidents, seeing them as the result of errors generated by a complex air traffic control system with ample opportunities for system-induced errors. Such problem areas as pilot-controller communication, flightdeck workload, noise-abatement procedures, government regulation, visual illusions, and cockpit- and ground-radar warning devices are discussed, with numerous examples of recent accident cases. The failure of the human factors profession to play a more significant role in the air traffic complex is also considered.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 3., 4.

Primary task Single measures Review None Background

Wierwille, W. W. Physiological measures of aircrew mental workload. Human Factors, 1979, 21, 575-593.

Physiological measures of aircrew mental workload were divided into fourteen specific classes. Each class was then summarized in terms of background, applications, and implications for research and implementation. It is concluded that several physiological measures appear promising, but that more research is needed to provide convincing evidence of viability. Physiological techniques can, however, be combined with other workload assessment techniques to provide a more complete understanding of the workload associated with given aircrew tasks.

W/L Cat. Code: 4.

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Multiple	Review	None	Flight simulator
				Flight test

Wierwille, W. W. and Gutmann, J. C. Comparison of primary and secondary task measures as a function of simulated vehicle dynamics and driving conditions. Human Factors, 1978, 20, 233-244.

In a previously reported experiment involving a moving base driving simulator with computer-generated display, secondary task measures of workload showed significant increases as a function of large changes in vehicle dynamics and disturbance levels. Because the secondary task measures appeared less sensitive than desired, driving performance measures recorded furing the same experiment were later analyzed. Particular emphasis in examining the driving performance data was placed on (1) determining the degree of intrusion of the secondary task on the driving task as a function of the independent variables, and (2) on comparing the sensitivity of the primary and secondary task measures. The results showed the secondary task does intrude significantly upon the driving task performance at low workload levels, but that it does not significantly intrude at high workload levels. Also, when the four primary task measures were analyzed for sensitivity to the independent variables, new information was obtained indicating greater sensitivity than is obtained with the single secondary task measure.

W/L Cat. Code: 2.2.1, 3.2
Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Simulator	Flight simulator
Primary task	Mult. measures			Flight test

Wierwille, W. W., Gutmann, J.C., Hicks, T. G., and Muto, W. H. Secondary task measurement of workload as a function of simulated vehicle dynamics and driving conditions. Human Factors, 1977, 19, 557-565.

A driving simulator with a computer-generated display and a four degree of freedom physical motion system was used to determine the sensitivity of a secondary task to vehicle handling parameters and various driving conditions. Six subjects drove a simulated vehicle with normal automobile handling and another six drove with degraded handling. Steering ratio and disturbance level were adjusted within each set of subjects. A secondary task consisting of reading random digits aloud from a single-digit dashboard display was used to assess workload. It was found that workload increased significantly as disturbance level increased. Furthermore, workload increased significantly with degraded vehicle handling. In contrast, increasing steering ratio did not produce a significant change in workload. These results indicate that the secondary task method can be used to assess the major effects of simulated vehicle handling on driver workload. Problems remain, however, in designing more sensitive secondary-task measures.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Simulator	Flight simulator
Primary task	Single measures			

Wierwille, W. W. and Williges, B. C. Survey and analysis of operator workload assessment techniques. Blacksburg, Virginia: Systemetrics, Inc. Report no. S-78-101, September, 1978.

Over 600 references relating to operator mental workload were selected and classified according to a two-dimensional scheme including workload methodology and universal operator behavior. Twenty-eight specific techniques of assessing workload by means of subjective opinions, spare mental capacity, primary task, and physiological measures were cataloged. This catalog summarizes critical criteria that need to be considered in the flight test and evaluation environment and describes each technique in terms of theory and background, description of necessary method/apparatus, area of application and example, limitations, and suggested RDT&E follow-ups.

W/L Cat. Code: 1., 2., 3., 4.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity		Construct		Flight test
Primary task				
Physiological				

Wierwille, W. W., Williges, R. C., and Schiflett, S. G. Aircrew workload assessment techniques. In B. O. Hartman and R. E. McKenzie (Eds.) Survey of methods to assess workload. AGARD-AG-246, August, 1979, 19-53.

A classification scheme is presented which summarizes a survey and analysis of aircrew workload assessment techniques relevant to inflight test and evaluation considerations. Two dimensions consisting of universal operator behaviors and workload assessment methodologies were used in the classification scheme. The universal operator behaviors were classified according to the Berliner, Angell, and Shearer (1964) categories including perceptual, mediational, communication, and motor processes; whereas the workload assessment methodologies were cataloged into 28 procedures under the general categories of subjective opinion, spare mental capacity, primary task, and physiological measures. An applicability matrix based on this classification scheme is presented which summarizes existing research on workload assessment methodologies, and a bibliography of over 400 relevant references is provided as an appendix to this paper. Procedures are described whereby this matrix can be used as a guide for selecting candidate aircrew workload assessment measures for inflight evaluation.

W/L Cat. Code: 1., 2., 3., 4.
Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity		Construct		Flight test
Primary task				
Physiological				

Wildervanck, C., Mulder, G. and Michon, J. A. Mapping mental load in car driving. Ergonomics, 1978, 21, 225-229.

A system is being developed which permits the identification of traffic locations which impose a heavy mental load on the car driver. The method employs a car equipped with a video-recorder, of which the camera is mounted behind the windscreen, continuously recording the independent variable of traffic load. Dependent variables are physiological indices and performance on a secondary task. This working report is a review of the factors taken into consideration in the preparatory phase of the experiments.

W/L Cat. Code: 2.1.2, 2.2.2, 3.2, 4.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Multiple	Review	Field	Flight simulator
Primary task				Flight test
Physiological				

Williams, C. E. and Stevens, K. N. Emotions and speech: some acoustical correlates. Journal of the Acoustical Society of America, 1972, 52, 1238-1250.

This paper describes some further attempts to identify and measure those parameters in the speech signal that reflect the emotional state of a speaker. High-quality recordings were obtained of professional "method" actors reading the dialogue of a short scenario specifically written to contain various emotional situations. Excerpted portions of the recordings were subjected to both quantitative and qualitative analyses. A comparison was also made of recordings from a real-life situation, in which the emotions of a speaker were clearly defined, with recordings from an actor who simulated the same situation. Anger, fear, and sorrow situations tended to produce characteristic differences in contour of fundamental frequency, average speech spectrum, temporal characteristics, precision of articulation, and waveform regularity of successive glottal pulses. Attributes for a given emotional situation were not always consistent from one speaker to another.

W/L Cat. Code: 4.3
Op. Behav. Code: 1., 2., 3.

Physiological | Speech patt. anal. | Experimental | Laboratory | Background

Williams, L. W. Feasibility of saliva analysis for measuring mental stress in man. Master's thesis, Texas A & M University, College Station, Texas, 1971 (AD 747 671).

The purpose of the investigation was to determine the usefulness of the parotid fluid analysis technique in measuring mental stress. Ten subjects were used in the experimental portion of this work. Three levels of stress were used. A low stress level was taken with the subjects at rest. The medium and high stress levels were set up using 30 and 60 revolutions per minute respectively on a rotary pursuit tracking task. Parotid fluid was collected for a 30 minute period at each of the three stress levels for each subject. The chemical analysis of the parotid fluid was carried out to determine the concentrations of corticosteroids (17-OHCS) in the parotid fluid samples. Mathematical analysis of the data indicated that there was no change in the 17-OHCS level as a result of increased stress levels. The results were attributed to using a tracking task lacking sufficient difficulty to produce mental stress.

W/L Cat Code: 4.1.12
Op. Behav. Code: 1., 2., 4.

Physiological | Body fluid anal. | Experimental | Laboratory | Flight simulator

Williges, R. C. and Wierwille, W. W. Behavioral measures of aircrew mental workload. Human Factors, 1979, 21, 549-574.

Behavioral research literature pertaining to the measurement of aircrew workload was classified into general categories of subjective opinion, spare mental capacity, and primary task metrics. Fourteen specific classes of workload measures related to these general categories were reviewed specifically in regard to aircrew workload assessment in the flight test and evaluation. Each class of measures was summarized in terms of background, applications, and implications for research and implementation. It was concluded that no one, single measure can be recommended as the definitive behavioral measure of mental workload. Due to the multidimensionality of workload, it appears that the most promising assessment procedure should include multiple measures of subjective opinions, spare mental capacity, and primary task measures as well as physiological correlates.

W/L Cat. Code: 1., 2., 3.

Op. Behav. Code: 1., 2., 3., 4.

Opinion	Multiple	Review	None	Flight simulator
Spare m. capacity				Flight test
Primary task				

Wingert, J. W. Function interlace modifications to analytic workload prediction. In K. D. Cross and J. J. McGrath (Eds.) Crew System Design. Santa Barbara, California: Anacapa Sciences, July, 1973.

Analytic prediction of operator workload has been used to evaluate the result of allocating functions to human operators for a specific system concept. A common workload definition used is the ratio of time needed to perform all required tasks to the time available. This technique has proved useful in that system concepts which impose excessive workload demands on the operator can be abandoned early in the development cycle. The usual techniques involve task analysis, with performance time prediction based on eye-movement data, information processing time data and time and motion data. The human is typically modeled as a single-channel device. The results are quite conservative if complex well-practiced tasks are involved. Function interlace provides a model which permits time-sharing of [illegible] capacity to yield workload predictions more closely in agreement with simulation workload data. The theory is not as yet substantially developed, although some validating laboratory measurements have been made.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3.

Spare m. capacity	Task comp., time assess.	Construct	Flight simulator	Flight simulator
				Flight test

Wisner, A. Electrophysiological measures for tasks of low energy expenditure. In W. T. Singleton, J. G. Fox, and D. Whitfield (Eds.) Measurement of man at work. London: Taylor and Francis, 1973, 61-73.

Having no good measure of the energy aspect of brain activity, researchers have recorded and evaluated the electrical activity of the brain and some physiological functions which are more or less faithful images of central activity. In early studies technical difficulties restricted interest to certain variables and experimental conditions, and the resulting interpretations are not of little importance. Many people now prefer to measure both in laboratory experiments and in the field and the classification of work situations in terms of a single scale of arousal is no longer accepted. As well as estimating the cost of high or low extremes of activation, we must also determine the orientation of attention towards different aspects of the work situation. Only thus can physiological measures be of any use in the study of man-machine systems.

W/L Cat. Code: 4.1.3, 4.1.4, 4.1.5, 4.1.6, 4.1.7, 4.1.10
Op. Behav. Code: 1., 2., 4.

Physiological	Multiple	Review	Laboratory	Flight simulator

Wolf, J. D. Workload evaluation of control-display configurations for approach to landing. Minneapolis, Minnesota: Honeywell, SRC Report F0548-IR, August, 1977.

The program objective is to develop a quantitative measure of information processing workload for evaluation of alternative flight control and display configurations. Simulator tests described below are designed to support this objective by providing operator response data and analysis results:

- To show that physiological and performance measures can be combined to predict information processing task difficulty.
- To show the relative predictive merits of different combinations of measures.
- To show the generality of physiological measures in predicting information processing workload.
- To compare the relative sensitivities of different methods of evaluating cockpit systems.

W/L Cat. Code: 4.1.3, 4.1.4, 4.1.7, 4.1.11

Op. Behav. Code: 1.1, 2.2.1, 3.2, 4.

Opinion Spare m. capacity Primary task Physiological	Multiple	Experimental	Flight simulator	Flight simulator Flight test

Wolfe, J. D. Crew workload assessment-development of a measure of operator workload. Wright-Patterson Air Force Base, Ohio: Flight Dynamics Laboratory, Final Technical Report, AFFDL-TR-78-165, December, 1978.

The study objective was to develop a quantitative measure of workload useful in crewstation evaluation. Flight tasks of varying difficulty were simulated, and 35 pilot response variables analyzed. Selected physiological and visual response variables were applied in a stepwise regression procedure to the prediction of a composite performance/opinion measure, which reflected differing levels of task difficulty. The resulting linear equation was reformulated as a preliminary operationally-defined measure of information-processing workload.

W/L Cat. Code: 1.1, 2.2.1, 3.2, 4.1.3, 4.1.4, 4.1.7, 4.1.8, 4.1.10, 4.1.11, 4.2

Op. Behav. Code: 1., 2., 4.

Opinion	Multiple	Experimental	Flight simulator	Flight simulator
Spare m. capacity				
Primary task				
Physiological				

Wong, P. J., Couluris, G. J., and Schmidt, D. K. Aggregate flow model for evaluating ATC planning strategies. Journal of Aircraft, 1977, 14, 527-532.

An aggregate traffic flow model is developed and used to evaluate the potential benefits of automated, facility-level, on-line air traffic flow control. The model monitors and dynamically adjusts traffic flow rates and traffic densities on the routes in the ATC network. The route flow adjustments are based on controller workload criteria, with the intent of eliminating traffic surges and the associated periods of excessive workload. The model is used to evaluate two flow control strategies with respect to aircraft delay, controller workload, and staffing considerations.

W/L Cat. Code: 2.1.1, 3.3

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity	Task comp., time assess.	Experimental	Field	Background
Primary task	Math. model			

Yoshitake, H. Three characteristic patterns of subjective fatigue symptoms. Ergonomics, 1978, 21, 231-233.

An extensive field survey of subjective symptoms of fatigue revealed three characteristic patterns. One, in which 'drowsiness and dullness' predominated, was frequent both among those who reported many symptoms and those who reported few and was not characteristic of any particular type of work. A second, in which "inability to concentrate" was prominent, was more frequent among those who reported many symptoms and was characteristic of mental workers, especially after night work. A third pattern, in which awareness of physical discomfort was characteristic, was found mainly among those who reported few symptoms and were engaged in physical work.

W/L Cat. Code: 1.2

Op. Behav. Code: 2., 3., 4.

Opinion Interview Experimental Field Flight simulator

Zaitzeff, L. P. Aircrew task loading in the Boeing multimission simulator. Proceedings of the 56th AGARD Conference on Measurement of Aircrew Performance. Brooks Air Force Base, Texas, May,1969, pp. 8-1 to 8-3.

The Boeing Company's new multimission simulator, combining a 160° "real-world" visual display in high-resolution color, together with a completely functional and correlated cockpit, is described. The simulator permits aircrews to train in proposed aircraft and avionics systems and fly real-time missions over a specially designated area of the United States. The simulator was designed to evaluate aircrew performance using state-of-the-art concepts, controls, and displays incorporated in the cockpit of an advanced fighter/attack aircraft. Visual target acquisition performance was used as a measure of task loading in tests of one- and two-man crews flying both realistically task-loaded missions and sequences requiring visual target acquistion only. Visual target acquisition performance of two-man crews was significantly better than that of one-man crews in both types of flights.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.2

Spare m. capacity Subsidiary task Experimental Flight simulator Flight simulator

Primary task Single measures

Zeier, H. Concurrent physiological activity of driver and passenger when driving with and without automatic transmission in heavy city traffic. Ergonomics, 1979, 22, 799-810.

Twelve subjects were selected for a comparison of driver and passenger reactions in vehicles with automatic transmission and with manual transmission. Each subject underwent four test runs, as a driver and as a passenger with each transmission. During the tests, skin conductance (SCL and SCR), EMG from the frontalis muscle and ECG were recorded from both the driver and the passenger. Urine samples were taken to measure catecholamine excretion. The test driving-circuit was about 14 km in length and each test run consisted of four complete circuits. In drivers, significant differences were only found between driving with automatic and manual transmission. When driving with manual transmission, rate of adrenaline excretion, skin conductance activity (SCR), heart rate and heart rate variability were significantly higher than when driving with automatic transmission or when riding as a passenger. Between the latter two conditions there were no significant differences with respect to these variables.

W/L Cat. Code: 4.1.2, 4.1.3, 4.1.4, 4.1.9, 4.1.10

Op. Behav. Code: 1., 2., 3., 4.

Physiological	Multiple	Experimental	Field	Flight simulator
				Flight test

Zeitlin, L. R. and Finkelman, J. M. A "random digit" generation subsidiary task measure of operator perceptual-motor loading. Experimental Publication System, August, 1969, 1, MS. No. 035-B.

"Spare capacity" measures, while indirect, offer a means of comparing control-display configurations in the less extreme range of operating conditions, before overt errors occur, and as such can be useful in field research in automotive and aircraft safety where extreme operating conditions may be dangerous. Spare capacity is, in most instances, determined by noting the degradation of performance on a secondary task while the operator holds primary task performance constant. Because of the field conditions in which most of the studies in this area were performed, primary task analysis and subsidiary task standardization were often sacrificed to expediency. Random digit generation was utilized in this study as a subsidiary task measure of the load imposed by a simple perceptual motor tracking function. As expected, primary task performance increased with practice and was not degraded by the introduction of the subsidiary task. Scores on the subsidiary task distinguished between primary task load and no load, and also indicated a drop in information processing load as primary task performance approached an asymptote after extensive practice. Although the present subsidiary task may be somewhat insensitive to small changes in loading, upon refinement, it should prove a valuable research tool in the development of man-machine systems and in the assessment of operator information processing requirements.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 3., 4.

Spare m capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Zeitlin, L. R. and Finkelman, J. M. Measurement of operator loading in pursuit rotor tracking by a "random digit" generation subsidiary task. Hoboken, New Jersey: Stevens Institute of Technology, Davidson Laboratory, Technical Report R-1401, August, 1969.

Random digit generation was used in this study as a subsidiary-task measure of the load imposed by a simple perceptual-motor tracking function. As expected, primary-task performance increased with practice and was not degraded by the introduction of the subsidiary task. Scores on the subsidiary task distinguished between primary-task load and no load, and also indicated a drop in information-processing load as primary-task performance approached an asymptote after extensive practice. Although the present subsidiary task may be somewhat insensitive to small changes in loading, it should, upon refinement, prove a valuable research tool in the development of man-machine systems and in the assessment of operator information-processing requirements.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Zeitlin, L. R. and Finkelman, J. M. A subsidiary task evaluation of the information processing load in a vehicular control simulation. Washington, D.C.: American Psychological Association, Experimental Publication System, Issue 3, Manuscript No. 106B, December, 1969.

The information processing load imposed upon an operator by compensatory tracking in a basic vehicular control simulation was measured by means of a "random digit" generation subsidiary task. The actual degree of loading was varied through manipulation of the frequency of the tracking forcing function and the order of the control. Performance was inversely related to both tracking frequency and control order. A significant interaction was found between the tracking frequency and the control order. The subsidiary task clearly distinguished load conditions from the no-load condition.

W/L Cat. Code: 2.2.1, 3.1, 3.3

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test
	Math. model			

Zeitlin, L.R. and Finkelman, J.M. Comparison of "random digit generation" and "delayed digit recall" as subsidiary task measures of operator loading in man-machine systems. Experimental Publication Systems, June, 1971, 12, MS. No. 458-12

"Spare capacity" measures, while indirect, offer a means of evaluating operator loading in man-machine systems in the less extreme range of operating conditions, before overt errors occur. As such, they can be useful in field research in automotive and aircraft safety where extreme operating conditions may be dangerous. Spare capacity is, in most instances, determined by noting the degradation of performance on a subsidiary task, while the operator attempts to hold primary task performance constant. Because of the field conditions in which most of the studies in this area were performed, primary task analysis and subsidiary task standardization were often sacrificed to expendiency, making the comparison of results between research studies and across systems difficult. Prior to choosing a standard spare capacity measure for use in a large scale automotive stability and handling project, a variety of subsidiary tasks utilizing an oral response mode were screened. These included digit span, mental arithmetic, self paced generation of random digits, and delayed recall of random digits. These measures were paired with the primary sensorimotor task of vehicle steering simulation. They were evaluated in terms of their: interference with the primary task; sensitivity to primary task loading; and convenience and ease of interpretation.

W/L Cat. Code: 2.2.1, 3.1
Op. Behav. Code: 1., 3., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Zeitlin, L. R. and Finkelman, J. M. Subsidiary task techniques of digit generation and digit recall as indirect measures of operator loading. Human Factors, 1975, 17, 218-220.

As part of an ongoing experimental program, two subsidiary tasks using an oral response mode were screened. They were self-paced generation of random digits and delayed recall of random digits. These measures were paired with the primary sensorimotor task of "vehicle steering" simulation. They were evaluated in terms of their interference with the primary task, sensitivity to primary task loading, and convenience and ease of interpretation. Although both subsidiary tasks satisfied the fundamental requirement that they not interfere with performance on the primary task, the differed markedly in their sensitivity to the primary task loading. The delayed digit recall subsidiary task was sensitive, whereas the random digit generation subsidiary task was not.

W/L Cat. Code: 2.2.1, 3.1

Op. Behav. Code: 1., 2., 4.

Spare m. capacity	Subsidiary task	Experimental	Laboratory	Flight simulator
Primary task	Single measures			Flight test

Ziegler, P. N. Single and dual axis tracking as a function of system dynamics. Human Factors, 1968, 10, 273-276.

Single axis manual tracking was compared to dual axis tracking for zero, first, second and third order dynamics. Tracking error on the original axis was significantly degraded for first, second and third order dynamics with no difference occurring for zero order. The results seem to indicate that the operator's information handling capacity becomes overloaded as the system order increases resulting in a decrement of performance.

W/L Cat. Code: 3.1

Op. Behav. Code: 1., 2., 4.2

Primary task Single measures Experimental Laboratory Flight simulator

Flight test

Zipoy, D. R., Premselaar, S. J., Gargett, R. E., Belyea, I. L., and Hall, H. J., Jr. Integrated information presentation and control system study. Volume I system development concepts. Wright-Patterson AFB, Ohio: Air Force Flight Dynamics Laboratory, Technical Report AFFDL-TR-70-79, August, 1970. (AD 876 624).

A cockpit concept for a tactical fighter aircraft of the 1975-1980 time period was developed to significantly reduce pilot workload. Within the context of this study, a composite mission profile and scenario are presented to define the operational requirements for the system concept. Airplane configuration and performance are described, and the characteristics and capabilities of the on-board avionics are summarized. A full-sized, single-place cockpit mockup and three interior configurations have been fabricated to reflect study results and to serve as evaluation tools.

W/L Cat. Code: 2.1.1

Op. Behav. Code: 1., 2., 3., 4.

Spare m. capacity Task comp., time assess. Experimental Flight simulator Flight simulator

Zolina, Z. M. Physiological criteria for, and definition of, physical and mental stress at work. Proceedings of a Symposium on Ergonomics in Machine Design, Prague, Czechoslovakia and Geneva, Switzerland, 1969, 223-228. (In Russian).

This paper gives a physiological definition of the concept of heavy work and occupational stress. The characteristics of these factors are evaluated objectively both at the start of work, during the steady-state phase and following reduction of physical function capacity during the day or week. The steady-state phase is accompanied by higher-nervous center stimulation and is related to individual 'dominance'. The author proposes that the criteria for workload and work stress should be based on A. A. Ukhtomsky's 'principle of dominance' (1950). The phase at the start of work, which precedes the development of dominance over the work, is a period of adaptation to work tempo. This was observed during the author's studies of work carried out at a constant temp on a conveyor belt. The rapid increase in fatigue is manifested by a fall-off in dominance and pronounced changes in physiological function.

W/L Cat. Code: 4.1.[illegible]

Op. Behav. Code: 4.1, 4.[illegible]

Physiological	Muscle tension, tremor	Construct	None	Flight simulator
				Flight test

Zwaga, H. J. G. Psychophysiological reactions to mental tasks: Effort or stress? Ergonomics, 1973, 16, 61-67.

The implications of the mental load model, used implicity or explicitly by many investigators, appear to be inconsistent with many experimental results. It is demonstrated that a clearer picture emerges if the concept of arousal is taken into consideration.

W/L Cat. Code: 4.1.10

Op. Behav. Code: 1., 2., 4.

Physiological	Heart rate, h.r. var.	Construct	Laboratory	Flight simulator
		Experimental		Flight test

LISTING OF INCOMPLETE CITATIONS

The documents listed below did not have complete citations or had not been received at the time of publication of this bibliography. They are listed in an attempt to provide the reader with the maximum information.

Bartell, A. and Kantowitz, B. H., Tradeoffs in Dual-Task Performance Induced by Emphasis of which Task was Primary. Paper Presented at the 50th Annual Meeting of the Midwestern Psychological Association, Chicago, Illinois, May, 1978.

Baschera, P. and Grandjean, E., Effects of Repetitive Tasks with Different Degrees of Complexities on Critical Flicker Frequency and Subjective State. Paper Presented at the Ergonomics Society Annual Conference, 1977.

Billings, C. E. and Lauber, J. K., Short-Term Workload in Airline Operations. Paper Presented at the IATA Conference on Safety in Flight Operations, Istanbul, Turkey, 1975.

Boelhouwer, A. J., et. al., Blink Reflexes and the State of Arousal. Journal of Neurology, Neurosurgery, and Psychiatry, 1977, 40, 58-63.

Brabec, V. and Popelova, J., Investigations of Mental Load Imposed on Drivers of Hydraulic Excavators and Loaders. Paper Presented at the 7th Congress of the International Ergonomics Association, Warsaw, Poland, August 27-31, 1979. (In German.)

Childs, J. M., et. al., Identification and Measurement of Critical IERW Performance Variables. Fort Rucker, Alabama: Canyon Research Group, Research Memorandum, March, 1979.

Childs, J. M., et. al., Development of Procedures and Techniques for In-Flight Performance Assessment. Ft. Rucker, Alabama: Canyon Research Group, Research Memorandum, April, 1979.

Curry, G. A., Hiett, D. J., and Welder, G. J. S., Task Load in the Motor Vehicle: A Comparative Study of Assessment Procedures. Ottawa, Ontario, Canada: Ministry of Transport, Road and Motor Vehicle Traffic Safety Branch Report, 1975.

Donchin, E., Event-Related Brain Potentials: A Tool in the Study of Human Information Processing. (Unpublished Manuscript, University of Illinois, Cognitive Psychophysiology Laboratory.)

Hartman, B. O. and Ellis, J. P., Arousal and Sleep Disturbance: Biochemical Considerations. Presentation in AGARD Lecture Series No. 105, Headquarters, AGARD, Paris, France, October, 1979.

Isreal, J. B., Chesney, G. L., Wickens, C. D., and Donchin, E., On the Constancy of P300 Amplitude in Concurrence with Continuous Variations in Tracking Difficulty. (Unpublished Manuscript, University of Illinois, Cognitive Psychophysiology Laboratory.)

Isreal, J. B., Wickens, C. D., and Donchin, E., The Dynamics of P300 during Dual-Task Performance. Proceedings of the 5th International Symposium on Electrical Potentials Related to Motor and Sensory Processes of the Brain, Amsterdam, Netherlands, 1980.

Kantowitz, B. H., Channels and Stages in Human Information Processing: A Limited Review. (Unpublished Manuscript, University of Trondheim-The Norwegian Institute of Technology, 1979.)

Kutayev-smyk, L. A., Neumyvakin, I. P., and Ponomarenko, V. A., Contribution to the Question of the Methods of Evaluating the Psychophysiological State of the Pilot in an Emergency Situation during Flight. Problems of Engineering Psychology, NASA TT (Technical Translation) F-312, May, 1965.

Macdonald, W. A. and Hoffmann, E. R., A Secondary Task Measure of Driving Demands: Test Track Evaluation. Australian Road Research Board, Research Report AAR No. 70, 1977.

Macdonald, W. A. and Hoffmann, E. R., A Secondary Task Measure of Driving Demands: Pilot Field Study. Australian Road Research Board, Internal Report AIR No. 247-2, 1978.

Roscoe, A. H., Psychological Stress and Heart Rate Response in Test Pilots. Paper Presented at the Ergonomics Society Annual Conference, 1977.

Scientific and Technical Aerospace Abstracts, The Influence of Environmental Factors on Task Load and Driving Behavior, Report No. IZF-1976-7; TDCK-67928. (In Dutch.)

Senders, J. F., The Measurement of Workload in Mental Tasks. Ergonomics, 1967, 10, 539. (Title Only.)

Shiraishi, N., Estimation of Mental Work Capacity with Special Reference to Controlled Work Capacity and Information Processing Capability. Japan Journal of Hygiene, 1975, 30, 276.

Walker, N. K., Dual-Task (ZITA/ADT) Performance Tests on Student Pilots in Fighter Lead-In. Rockville, Maryland: Norman K. Walker Associates, Report No. 90, September, 1979.

Walker, N. K. and Walker, M. M., A Comparison of a Particular Dual Task Performance (ZITA/ADT) System with Other Means of Assessing Pilot Workload and Combat Performances. Rockville, Maryland: Norman K. Walker Associates, Report No. 88, July, 1979.

WORKLOAD TECHNIQUE AND EXPERIMENTAL FACILITY INDEXES

In this section two indexing schemes are presented, one which groups the documents by workload technique and one which groups them by experimental facility used.

The workload technique index corresponds exactly to the "W/L Cat. Code" numerical categories appearing in each citation. In abstracting the documents, the most general numerical rating was used. For example, if a document contained information on a Task Component-Time Summation technique and an Information-Theoretic technique, the category code would be 2.1 instead of 2.1.1 and 2.1.2.* Therefore, in using this index, if a reader were interested in information-theoretic estimation techniques, the reader should look under 2.1.2 Information-Theoretic, 2.1 Task Analytic, and 2. Spare Mental Capacity.

The experimental facility index corresponds to the fourth column of the word descriptors on each abstract. The groupings used are Laboratory, Field, Simulator, Flight simulator, and Flight test. If no experimental facility was used, the document is not cited in this section.

The groupings appear by author or authors and date. If more than one citation has the same authorship and date, lower case letters in alphabetical order follow the dates. These letters correspond to the order in which the citations appear in the annotated bibliography.

*Note that 2.1.1 and 2.1.2 are the only subdivisions under 2.1.

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ATTENTIONAL DEMAND	SECONDARY TASK	
MENTAL LOAD	SPARE MENTAL CAPACITY	
MENTAL WORKLOAD	SUBSIDIARY TASK	
OPERATOR LOADING	WORKLOAD	

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An annotated bibliography on operator mental workload is presented with supporting information. This bibliography is based upon two literature searches, one performed in 1977 in support of a survey and analysis catalog (AD A059-501) and one performed in 1979 as an update.

Each literature citation presented contains reference information, an abstract, a numerical workload technique category classification, a numerical operator behavior

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classification, and a group of word descriptors. Workload methods are divided into 28 specific techniques in four major categories: opinion, spare mental capacity, primary task, and physiological. Applicable operator behaviors are similarly divided into categories.

The descriptors associated with each citation designate the general workload classification, the specific workload classification, the type of presentation, the type of facilities used, and the potential aircrew application. Over 600 citations are presented. Two indexes are also provided. The first is a workload technique index, and the second is an experimental facility index. It is concluded that periodic updating of the bibliography will be required and that attention should be directed toward computerizing future workload bibliographies.

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