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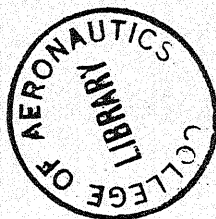
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THE COLLEGE OF AERONAUTICS

CRANFIELD

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An annotated bibliography of presentation
of information in aircraft cockpits

by -

J.G. Fox

I. Ferguson

I.D.C. Andrew

Project Agreement No. PD/28/030
for R.A.E. Farnborough

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INTRODUCTION

In the preparation of this bibliography only data which has been published after 1940 has been considered. The choice of this 'cut-off' point seemed reasonable on two counts: it begins a period when cockpit displays become more varied and steadily become more complex so that the pilot's normal capacities increasingly become a limiting factor in the efficiency of the system; and it was in the early 'forties' that man's capacities first began to be related explicitly to equipment design. It would however have been presumptuous to consider that no work before 1940 had any relevance; that some current principles could not be supported or rejected on the basis of pre-war research or practice. But it is unlikely that the pursuit of earlier work would have added anything to the information given by Nicklas (1958) in A History of Aircraft Cockpit Instrumentation 1903-1946. This admirable review is concerned primarily in showing how each instrument evolved and its purpose, how information was displayed in the cockpit and the mechanical principles employed. But it also considers the empirical solution to implicit ergonomic problems in this area, tracing the manner in which instruments were combined, simplified and arranged for better presentation. In some measure it warns against the presumption of ignoring early data for it points out that the 'recently' evolved principle of grouping instruments in horizontal or vertical arrays to ease the visual task of the pilot was suggested by Doolittle in his 'fog flying' experiments in 1929.

The aims of the bibliography are to present:

1. a comprehensive list of titles relevant to all aspects of presenting information to pilots,
2. a commentary on research publications directly relevant to cockpit instrument design; this is done at two levels:
 - (a) by means of an abstract when only that was available,
 - (b) by a review when the actual publication has been read;
3. a general survey of the direction where future research efforts might be applied.

Compilations of human engineering recommendations (e.g. Grether 1962; Fogel 1963, Chap. 16) and data handbooks (e.g. Baker and Grether 1954) pertinent to cockpit information displays, but dealing specifically with the application of general display characteristics and principles, have been listed in the bibliography. No commentary on them is offered, however, because of their essentially general nature; and because their contents have recently been collated in Human Engineering Guide to Equipment Design (Morgan et al. 1963). This volume, though it may be criticized for its presentation of the material, gives the most up-to-date summary of the data available for the design of the various sub-units of information display in a cockpit. Again this publication is simply noted in the bibliography

for although it would be wrong to suppose that its data is by any means 'established' the text is well referenced and thus the data can best be evaluated by the user according to his needs. The avoidance of giving relatively easily obtainable information on optimum (in terms of the present state of the art) characteristics for hardware has not precluded a consideration of the methodology and criteria of the experimental designs which gave rise to them.

Within the bibliography and the commentary information has been classified where appropriate under six broad headings:

1. General
2. Methodology and criteria
3. Pilot requirements
4. Display presentation
 - (a) digital
 - (b) analogue
 - (i) pictorial and symbolic
 - (ii) scale face design, spatial relationships and warning indicators
 - (c) legibility
 - (d) illumination
 - (e) auditory
5. System presentation
6. Pilot acceptance and training.

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2(a) ABSTRACTS

General

ANON (1959). Human factors quarterly progress report, Army-Navy Instrumentation Program. Bell Helicopter Corporation, Fort Worth, Texas: Contract NONR 1670(00) - June.

This report is the first to be issued quarterly about the work of the Human Factors Group on a research program for instrumentation of the helicopter. The following areas are covered: 1) mission and systems analysis, 2) vertical display, 3) situation display, 4) controls, 5) motion thresholds, 6) Bendix Radar evaluation, 7) Research Helicopter-1 and -2 programs, and 8) obstacle identification and display.

ANON (1960). Human factors quarterly progress report, Army-Navy Instrumentation Program. Bell Helicopter Corporation, Fort Worth, Texas. Contract NONR 1670(00) - March.

This report covers the work of the Human Factors Group on the Army-Navy Instrumentation Program (Helicopters) during the period January 1 through March 31, 1960. It covers progress in the following areas:- (1) vertical display, (2) situation display, (3) auxiliary display, (4) RH-1 programme, (5) RH-2 programme, (6) obstacle identification and display, and (7) dynamic platform.

ANON (1964). Now the pilot sees data at eye level. Engineering, Lond., 197, 286-287.

In modern high speed processes, notably flying, there is no time to spare for referring to conventional instruments. A new technique allows relevant information to be displayed at the controller's eye-level. This display is collimated so that it appears to be suspended in space and superimposed upon the view through the windscreen; it is always in focus to the pilot's eye, at a brilliance that can be varied to suit external conditions. One impressive advantage of this electronic eye-level presentation system is that at the touch of a selector switch, eye-level presentation will give the pilot only the information that he requires for each phase of flight and will give it him in the clearest, most succinct and most easily assimilable form.

BURROWS A.A. and EMERY J.A. (Eds.) (1964). Complex vehicular controls: ONR Symposium (second), May 1962, Royal Air Force Institute of Aviation Medicine, Farnborough. Long Beach, Calif.: Douglas Aircraft Co., AD-604,604.

The fifteen papers and discussions presented cover the subject areas of man-machine systems, display systems, automatic and manual controls, handling qualities, vision problems, human equalisation, environmental effects on operator, tracking and serial choice tasks. Aircraft, helicopters and submarines were the primary vehicles treated.

CHRISTENSEN J.M. (1960). Engineering psychology at the Aerospace Medical Laboratory, Wright Air Development Division. Pap. to Ann. Conf. Ergonomics Research Society, 1960.

The overall systems design and development programme of Wright Air Development Division is considered under the headings:- (1) design of vehicles and stations in space for ease of maintenance; (2) design of visual, auditory and technical displays for ease and accuracy of interpretation; (3) decision making as a function of amount, significance and amount of input; (4) effects of unusual environment on performance; (5) use of servo models in the description of human motor response characteristics; (6) evaluation of the restrictive characteristics of space suits; (7) design problems and the use of models for complex man-machine systems; (8) human performance under weightlessness; (9) human performance as affected by long periods of confinement; and (10) methods and procedures for applying engineering psychology data to actual design problems.

MATHENY W.G. (1959). Consideration of human factors in helicopter design. Human Factors Group, Bell Helicopter Corp., Fort Worth, Tex., Rep. 238. Presented at: Joint Meeting of the Flight Test Panel and Aeronautical Panel, Athens, Greece.

The human factor problems in helicopter design are discussed with primary emphasis on those factors affecting operation and control. There are two main parts of the report, one dealing with the stability of the vehicle and the other with the display of information to the pilot for instrument conditions operation. The latter is part of the research being carried out under the Army-Navy Instrument Program.

SAMPSON P.B. et al. (1961). Literature survey on human factors in visual displays. Medford, Mass.: Tufts Univ., Inst. for Psychol. Res., RADC TR 61-95, Contract AF 30(602)2358, Project 5577, AD-262,533.

The annotations are arranged under four main headings:- (1) information load and speed; (2) display format and content; (3) display integration; and (4) human complex processes as related to displays. Under these headings, reports dealing with a variety of sub-topics such as search and detection of visual targets, recognition and interpretation of display elements, human information processing and channel capacity, signal presentation rate, coding, S-R compatibility, and decision making are to be found. Each of the four parts contain introductory text which analyzes and evaluates the annotations contained in the part.

SECKEL E., TRAYBAR J.J. and MILLER G.E. (1963). An exploratory study of instrument approaches with steep gradient aircraft. Princeton, N.J.: Princetown Univ., Rep. 630, Rep. ATRECOM-TR-63-28, Contract DA-44-177-TC-834, Task ID121401A14203, AD-429,113.

Exploratory flight tests were made to determine the influence of certain parameters and quickened cross-pointer presentations on instrument approaches with steep gradient aircraft. About fifty hooded instrument approaches were flown using a single-rotor helicopter piloted by a highly experienced NASA test pilot. Standard flight instruments were used and tracking presentation for pilot consisted of an ILS type cross-pointer indicators. Parallel beam patterns as well as the standard angular, wedge-shaped ILS beam patterns were simulated by a tracking theodolite system coupled to the aircraft cross-pointer by a radio link. Numerous beam widths, glide slope inclination angles, and quickening inputs were investigated. Maximum glide slope inclination angles studied were in the 8 to 11° range because of operational limitations of aircraft and task (30 knots minimum airspeed and 500 ft/min maximum rate of descent). Parallel beam patterns (constant sensitivity) were preferred to standard angular wedge-shaped beam patterns (sensitivity varying with range from transmitter). No significant improvements were obtained with the quickened presentation in preference to the pure displacement presentation.

SGRO J.A. and DOUGHERTY D.J. (1963). Contact analogue simulator evaluations: hovering and air taxi manoeuvres. Fort Worth, Tex.: Bell Helicopter Co., Rep. TDR-228-421-016, Contract Nonr-1670(00).

In this second of a series of evaluations of the JANAIR vertical display, four basic configurations (basic grid plane, basic grid plane with ground position indicator, basic grid plane with pathway, basic grid plane with pathway plus tar-strips) which could be incorporated into a vertical display

were evaluated. The evaluation was made by four subjects performing the three basic manoeuvres of (1) hovering, (2) takeoff, hover and touchdown, and (3) takeoff, air taxi and touchdown in the Bell Helicopter Co.'s dynamic simulator. For manoeuvres (1) and (3) the configuration of basic grid plane with pathway, and of basic grid plane with pathway plus tarstrips were most effective. For the takeoff, hover and touchdown manoeuvre, the displays differed with respect to the various responses being recorded.

SHACKEL B. and WHITFIELD D. (1963). Instruments and people.
London: H.M.S.O. D.S.I.R. Ergonomics for Industry, 2.

This booklet considers the design of instruments from the user's point of view. The section headings are:- (1) why 'and people'?, (2) design for use; (3) instrument to user - qualitative displays, quantitative displays, and representational displays; (4) user to instrument - mechanical and visual characteristics of control, distinguishing controls, control to display relationships; (5) panel layout - two principles, general suggestions, planning for emergency; (6) workspace and environment; and (7) making decisions.

Methodology and Criteria

SIEGEL A.I. and MIEHLE W. (1961). Information transfer in display-control systems. I. Survey and variables included in a proposed display evaluative index. Wayne, Penn.: Appl. Psychological Services, Contract DA-039-SC-87230, Proj. 3A99-01-001.

'The logic and basis of an index for evaluating the information transfer characteristics of the displays in a display-human operator-control system are presented. The purpose of the index is to allow comparative, quantitative evaluation of proposed systems while the systems are in the system concept or the early design stages. The index is related to a logic derived from communications theory and includes five bases. The technique for deriving the scores on which the index depends is described by example and proof of the independence of the variables which form the substrate of the index is offered'.

SIEGEL A.I. and WOLF J.J. (1964). A technique for whole aircraft instrument panel evaluation. Wayne, Pa.: Appl. Psychological Services, Psychol. Abs., 38, 349.

The technique involves the determination of a numerical index of merit for each of several instrument panels tested under flight or simulated flight conditions. This approach may prove useful in providing a quantitative and comparative evaluation of new instrument panels used for selected missions.

SIEGEL A.I., MIEHLE W. and FEDERMAN P. (1962). Information transfer in display-control systems. III. Further applications, reliability, and validity of a display evaluative index. Villanova, Pa.: Appl. Psychological Services, Quart. Progr. Rep. 3, Contract DA 36-039-SC-87230, Project 3A99-01-001, AD-275,198.

Work continued on a technique for evaluating the information transfer characteristics of the displays in a display-human operator-control system. The results of applying a quantitative, objective display evaluative technique to two systems are given. Then the inter-user reliability of the technique is presented and held to be adequate. Finally the correlations between the results obtained from applying the technique to several systems and experts' opinions of the display-operator decision-control link in these systems are presented. These validational correlations are interpreted to support a content favouring the use of the technique.

SIEGEL A.I., MIEHLE W. and FEDERMAN P. (1962). Information transfer in display-control systems, IV. Summary review of the DEI technique: Quarterly progress report for 16 March-15 June, 1962. Villanova, Pa.: Appl. Psychological Services, Quart. Progr. Rep. 4, Contract DA 36-039-SC-87230, Project 3A95-20-001, AD-283,247.

A review of the first year of work on the development of a quantitative, objective display evaluative technique is presented. The work suggested that:- (1) the technique possesses adequate sensitivity for achieving its purpose, (2) with trained users, the between user reliability is acceptable, (3) the technique correlated satisfactorily with the outside criterion employed, (4) the technique represents a useful tool for aiding in selection of an equipment design from several alternative early equipment designs.

SIEGEL A.I., MIEHLE W. and FEDERMAN P. (1962). Information transfer in display-control systems, V. Expansion and elaboration of the DEI technique: Quarterly progress report No. 5, 16 June - 15 September 1962. Villanova, Pa.: Appl. Psychological Services Contract DA 36-039,SC-87230, Project 95-02-001, AD-289,368.

Strengthening and elaboration of the display evaluative technique, a method for assessing the ability of the displays in a display operator decision control action loop to transfer information and for the operator to act on this information, are described. Additional concepts now included in the DEI are information precursor, information load, transfer criticality, and utilization efficiency. Application of the expanded technique to eight Signal Corps' systems suggests that the technique possesses sensitivity for achieving its purpose.

SIEGEL A.I., MIEHLE W. and FEDERMAN P. (1963). Information transfer in display-control systems, VII. Short computational methods for and validity of the DEI technique: Quarterly progress report, 16 December 1962 - 15 March 1963. Wayne, Pa.: Appl. Psychological Services, Quart. Progress Rep. 7, Contract DA-36-039-SC-87230, Project 3A95-20-001, AD-404,732.

Several short methods for computing the Display Evaluative Index (DEI) are first described. The first eliminates the requirements for calculating the values for the three factors comprising the DEI; although it does not generally provide an exact value for the DEI, it does provide an approximate value. It is similar to linear extrapolation and is exact to the extent that the fractional changes of the variables are small. A second short computational method is presented which provides exact relative DEIs; it uses fractional increments and is recommended for use in computing DEIs when: (1) only two or three variations of design are involved, and (2) the

increments are known. The third method employs a digital computer for computing DEIs. The DEI was applied to several additional Signal Corps' systems and to hypothetical variations of these systems. The results of these applications again suggested that the technique possesses adequate evaluative sensitivity for distinguishing between various designs of the same system. A final validity study indicated that the DEI possesses adequate empirical validity.

WALKER J.A. (1960). Some concepts of pilot's presentation. Soc. exp. Test Pilots Quart. Rev. IV(2), 90-96.

Discusses the pilot's instrument presentation from the point of view of providing the pilot with a presentation which is coherent and gives him the required information with the least assimilation work-load. Eleven basic criteria for such presentation are indicated. The highlights of the X-15 instrument presentation development program are described and illustrated. The study of four-stage and two-stage boost of vehicles, static and dynamic runs, is described in terms of general instrument requirements.

Pilot Requirements

DENISOV V.G. and LOPATIN R.N. (1962). Flight-navigation instruments: instrument flying (the piloting of a plane by instruments). Wright-Patterson AFB: Air Force Systems Command, Foreign Technology Division, Transl. FTD-TT-63-636, AD-429,102.

Contents: Aircraft Instruments - Measuring instruments, Instruments indicating deviation from fixed parameter values, Combined instruments, Directing (command) devices, Integrated instruments, Indicating devices, Arrangement of instruments and components upon the instrument panel; Instrument Flying - Peculiarities of flight beyond the visibility of the ground and horizon, Takeoff, Level flight, Climb, Flight along a route, Positional air navigation system, Dead reckoning, Inertial navigation systems, Indication of navigation parameters, Descent, Landing; Instrument Flying Under Special Conditions - Low-altitude bombing, Attacking an airborne target, Departure from a complex situation, Flight using support instruments; New Types of Aircraft Instrumentation - Integrated systems of flight-navigation instruments, Visual flight analogues.

DENISOV V.G. and LOPATIN R.N. (1962). Pilot and Aircraft. Wright-Patterson AFB: Air Force Systems Command, Foreign Technology Division, Trans. 1. FTD-TT-63-276, AD-426-827.

Discusses various links between the pilot and the aircraft he is flying, the part played by psycho-physiological factors in human beings when controlling present-day aircraft. Considers the basic properties of an aircraft as a guided object, various instruments and automatic devices as sources of information while flying the aircraft, and deals with technical means of ensuring survival for aircraft crews during high altitudes and high velocity flights as well as during flights through space.

FEARNSIDE K. (1963). Symposium on take-off and landing problems: instrument aids for take-off. J. roy. aero. Soc., 67, 544-551.

The take-off manoeuvre is described and the safety requirements applicable to this phase of flight are briefly reviewed. A detailed inspection of take-off reveals difficulties confronting the pilot and indicates the type of additional information with which he should be provided. This equipment, now being developed, includes: ground run indicator, ground run predictor, pitch rate indicator, and take-off director.

HOLCOMB G.A. (1960). Application of basic human engineering principles to a cockpit design. Aerospace Medicine, 31(8), 674-677.

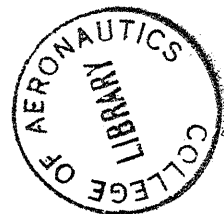
This article points out the need for applying human engineering in the design of cockpits. Outdated specifications and the attempt to pack the maximum number of pieces into the smallest volume has been the governing factor in design. It is recognized now that the cockpit must be treated as a total entity with improved psychological organization, an improved figure-ground relationship between an individual control and its console background, and an increased meaningfulness of switch grouping. An analysis of an operational communications-navigation-identification panel is given with objections presented and possible improvements proposed.

LEONARD J.A. (1963). On the relationship between coding and the ability to see what one is doing in a sensory-motor task. Cambridge: Medical Research Council, Applied Psychological Research Unit. 'Human Performance Reports Lists 9; Work Completed', 39.

In order to examine the possible interaction between different display-control relationships and the ability to look at what one is doing, an experiment was carried out under four conditions: half the subjects were trained with a colour code display, the other half with a positional code; within each group half the subjects were allowed to look at their hands while performing, and the others were not. It was found that the effect of not being allowed to look was larger with the colour code in the initial phase of training, and larger with the positional code in the final phase of training.

OSBORNE J.W. et al. (1959). Human performance in information transmission, III. Flash recognition - scale reading. Urbana: Univ. Illinois, Co-ordinated Science Lab., Rep. R-68, Contract DA 36-039-SC-56695, AD-83,017, PB 160,651.

Sections are devoted to:- evaluation of information transmitted; locating a dot in a square: methods, results, and comment; dial reading: method, results with single dials, multiple dials and pointers; scale reading: method, single scales, two and three scales; multiple scales with variable number of graduations - results; and discussion. 16 refs.



SANDERS A.F. (1963). Some properties of the functional visual field.
Ergonomics, 6, 441-442.

Some experiments on performance as a function of display angle are briefly reviewed. It appears that usually performance declines gradually when the display angle at which the task is viewed increases, but at two critical display angles a rather abrupt drop is found. The areas where the drops appear are between 20° and 40°, and between 80° and 95°. It is shown that in the same area respectively eye and head-movements become necessary to maintain optimal performance. The results are explained in terms of simultaneous versus successive intake of information, the former process allowing a more rapid processing than the latter. One experimental test of this theory is reported in some detail.

SWEENEY R. (1959). Crash of Electra may accelerate studies to improve pilot display. Aviation Week, 70(7), 37.

This is a brief note indicating the need for improvement of pilot displays. This interest has been revived as a result of recent indications that the drum pointer altimeter is subject to misreading.

TILLINGHAST N.W and HENDERSON B.E. (1958). A study of cockpit display requirements for VTOL airplanes. Wright-Patterson AFB: U.S.A.F. Flight Control Lab., WADC TR-58-58, Contract AF 33(616)3438, Project 6(1 6190), Task 61908, ONR Rep. ACR-43, IU-180.

To determine the flight instrument display requirements of VTOL (vertical take-off and landing) aircraft, the flight characteristics of the United States Air Force Model X-13 vertical take-off and landing jet airplane were simulated. A functional rotating cockpit, hydraulic system mock-up and analogue computers were utilized. A successive refinement procedure was used in dealing with improvements in instrumentation until display requirements were defined. A display that satisfies the requirements of the VTOL pilot for take-off, transition, low-speed conventional flight, and hovering flight has been built and tested in the simulator.

WILLIAMS A.C. and HOPKINS C.O. (1958). Aspects of pilot decision making. U.S.A.F. Aero Medical Lab., Wright-Patterson AFB, Ohio. Contract AF 33(616)5135, WADC TR 58 522.

This report is concerned with the study of human functions for which displays are required rather than with displays themselves. A diagram of

the sequences of events that might occur during the attack, return to base, and landing phases of a mission is presented.

The authors discuss several decision making theories from the point of view of their applicability to airborne decision-making problems and come to the following conclusions: (1) Theory of riskless choices - not considered applicable; (2) Theory of risky choices - no adequate test of applicability to airborne decision-making; (3) Game Theory - attempt to apply theory not profitable; (4) Decision making theory of detection - developed by Tanner and Swets, may be useful in organising a diverse set of observations at the linguistic level. Authors give general form for application of this model to pilot decision making problems.

WOESSNER B.L., ROSS S. and ANDREWS T.G. (1959). Effects of speed-stress and display-control relationships on response discrimination. J. gen. Psychol., 61, 95-111.

A horizontal display of five lights was presented to the subject singly in a temporally predictable but spatially unpredictable manner. The subject was to respond by pressing an appropriate switch. The signals were presented at three rates and the responses were to conform to three display-control relationships (horizontal, vertical, and M pattern). As the rate of signal presentation and the apparent symmetry between the display and control patterns increased, performance accuracy decreased. Performance accuracy varied significantly with signal position. The most rapid rate of signal presentation was characterized by a steady improvement in performance, but the lesser rates showed a decline on the third trial following improvement on the first two. No change was revealed in the perceptual field with change in display-control relationships, rate of signal presentation, or time on task.

Display Presentation

Digital

INNES L.G. (1962). An evaluation of certain design features of a five digit counter presentation. R.C.A.F. Institute of Aviation Medicine, Toronto, Ontario, Canada. FPME Rep. 62-RD.1.

The effect of variations of digit size and spacing on the readability of five-digit counters and the effect of a cross-hatched flag in the 10,000-ft. window for reading below 10,000 ft. were evaluated. Ss were 16 staff members who read series of 40 numbers, each presented for 1/4 sec. with a 5-sec. interval between numbers. The four series represented different combinations of the variables in question. Digit size was 7/32 in. high and 3/16 in. wide, and 11/32 in. high and 9/32 in. wide; spacing was 3/32, 3/16, and 1/8 in. Presentation conditions simulated an instrument dial. Number of correct readings per series was examined by analysis of variance; differences between all pairs of series were then tested by Fisher's t.

GERMAN G.G. (1963). Digital groundspeed readout CF-104 aircraft. Cold Lake, Alberta: Central Experimental and Proving Establishment, Rep. CEPE - 3230.

A prototype digital groundspeed readout indicator manufactured by Computing Devices Ltd. was tested in a CF-104 aircraft. Flight tests over the instrumented range and a cross-country flight were made. From phototheodolite data obtained during the tests over the instrumented range the true groundspeed was determined for comparison with the indicated value. The average error of the system over the speed range from 350 to 650 kts was -0.3% with a standard deviation of 1.1%. It was thus more accurate than the previously tested analogue range bar system, which had an overall error of 1.7% with a standard deviation of 1.4%.

Analogue: pictorial and symbolic

ANON (1964). Head-up aircraft display. Brit. Communic. Electron.,
11, 340.

High speed flight and the heavy demands on the pilot's concentration require that the need to remove his eyes from the view ahead to look at instruments should be minimized. To meet these demands Spectro Avionics Ltd., of Feltham, Middlesex, has developed a system in which essential information is displayed on to a semi-transparent reflector in front of the windscreen. This enables the pilot to see it with his head up in the normal flying position and his concentration is not interrupted. This new system is more than just a display because it involves the presentation of information in a form which enables a complex and predetermined path to be followed. The display is based on the principle that a displacement or motion in each visual field - the display itself and the background on which it is superimposed - should be in the same or related direction and of the same or related amount. In order to follow a prescribed path, the pilot is required to null the distortions of the analogue display by taking appropriate control actions.

BAINES D.J. and BAXTER J.R. (1960). Link trainer tests on simple modifications to the three pointer altimeter. Melbourne: Dept. of Supply, Aero. Research Labs., Hum. Engng., Note No. 6.

Tests of reading accuracy and reading time were made in a Link trainer on a standard three pointer altimeter and two simple modifications to it, involving replacement of one or more pointers by discs, re-design of the remaining pointers, and provision of coloured sectors on the dial to provide altitude warnings. No significant differences were found among the three altimeters in respect to reading accuracy or reading time, although a trend in error rate was observed. A significant learning effect was established and it seems possible that a more extensive test programme could show up significant differences. By asking the pilots to fly a strenuous flight pattern, involving vertical speeds of up to 20,000 ft/min., reading errors in excess of 1000 feet were produced on about 13% of occasions. This high rate of error and the unknown effects of additional learning provide a strong case for additional tests. 1 ref.

BELDAM E.M. (1959). A study to determine an optimum altimeter presentation. Toronto: R.C.A.F. Institute of Aviation Medicine, LAM 59/2, ONR Rep. ACR-55, IV-133.

To carry out a laboratory evaluation of the IAM (Institute of Aviation Medicine, R.C.A.F. Toronto) experimental altimeter dial, it was compared with the Kollsman Counter-Pointer dial. Twenty-four aircrew Flight Cadets

made forty readings of each dial while carrying on a routine task. The dials were operating during the trials. The criteria were time to read errors (number and magnitude). These data were analysed for differences in performance on the two dials. 4 refs.

CAMERON C. (1962). An airline flight assessment of a servo altimeter presentation. Melbourne: Department of Supply, Aero. Research Labs., Hum. Engng. Note 11.

Pilots flying Electra aircraft on normal route service made comparisons of a servo altimeter providing digital indication of height to the nearest 50 ft. and having a single pointer with the standard three-pointer altimeter. Most of the pilots judged it to be an improvement on the three-pointer instrument; freedom from reading error was said to be its greatest advantage. Disadvantages mentioned included difficulty of reading green digits on a black background. The relatively small advantage in speed of reading which was apparently possessed by the servo altimeter indicates that the method of reading conflicts with established habits of reading the three-pointer altimeter. This is an important consideration in selecting a stand-by altimeter, if the servo altimeter were to go into general service. Eight pilots mentioned the need for further practice in reading the servo altimeter. 8 refs.

DRAZIN D.H. (1959). The 'Hilo' Indicator: An experimental investigation of human factors relevant to the design of a long-range carrier-borne angle of approach indicator. London: Air Ministry, Flying Personnel Research Committee, FPRC Memo. 127.

It is doubtful whether mirror and projector sights now in use will prove adequate for use with carrier-borne aircraft. The split-beam indicator (Hilo) described here would be effective at distances of between 1000 and 4000 yd from the carrier. An experimental investigation into human factors relevant to the detailed design of this indicator was concerned with these questions: Is there any advantage in interposing a band of neutral filter between the red and green segments of the component filter system? What shades of red and green would provide the clearest Hilo indication? Specific recommendations are made for design of the indicator.

FENWICK C.A. (1963). Development of a peripheral command indicator for instrument flight. Hum. Factors, 5, 117-127.

A laboratory experiment was conducted to assess the effects and interactions of seven variables germane to establishing the optimum design of a

peripheral vision display. The display was a simple pattern of black lines and white squares which could move in any direction in the vertical plane faced by a subject. The variables were (1) width of the black lines, (2) black-to-white ratio, (3) display area, (4) display shape, (5) visual fixation point, (6) rate of movement and (7) diagonal vs. horizontal/vertical lines. All variables were involved in significant interaction effects with one four-way interaction being significant. With the best combinations of display variables, direction of motion could be perceived with considerable accuracy when the display was located as far as 35° from the subjects' line of regard.

JOHNSON H.B. and OLIVER F.J.B. (1962). The development and testing of an experimental flight director for helicopters. Farnborough, Royal Aircraft Establishment, Rep. RAE TN IEE 11.

The Flight Director has a four channel system which provides signals for both autostabilisation and flight path control in pitch, roll and yaw, with height control through the collective pitch lever. The flying programme with a Whirlwind Mk V and a number of pilots has covered straight and level flights with preselected turns at constant height and airspeed over a range of speeds. The trials were completed either in actual cloud or under blue/amber safety screens, with a safety pilot. The performance of a pilot using a Flight Director is compared with that using conventional instruments under blind conditions. Statistical analysis shows that the accuracy of flying the helicopter under blind conditions is considerably improved when using a Flight Director, i.e. the manual flight envelope is potentially extended.

KEARNS J.H. and WARREN E. (1962). Vertical Instruments. Paris: North Atlantic Treaty Organisation, Advisory Group for Aeronautical Research and Development, AGARD Rep. 404.

A discussion of Vertical Scale Instruments covering the historical facts which lead to their design through to their application. The point is made that Vertical Instruments represent the foundation of a new approach to the creation, design and development of displays. 58 refs.

MAHR V.M. (1962). Operational test and evaluation of AQU-4/A horizontal situation indicator. Randolph AFB: Air Force Instrument Pilot Instructor School, Train. Res. and Dev. Rep. 62-5, Project NR-62-5, AD-288,670.

The improved Horizontal Situation Indicator (AQU-4/A) incorporates several proposed changes designed to improve the display and reliability

of the production model (AQU-2/A). The results of this OT and E indicate that these changes, with one exception noted in the report, have brought about a more usable display to the pilot. It is recommended that the AQU-4/A display, changed as indicated in this report, be incorporated into future production.

MENGELKOCH R.F. and HOUSTON R.C. (1958). Investigations of vertical displays of altitude information, I. Comparison of a moving-tape and standard altimeter on a simulated flight task. U.S.A.F. WADC Tech. Rep. 57-384.

Twenty experienced instrument rated pilots flew a standard programme of manoeuvres in a modified C-8 Link-type trainer. Each pilot flew once using a standard altimeter with index marks placed for every 20 feet and once using a vertical reading altimeter having a moving tape with index marks placed for every 100 feet. Subjects were scored every 5 in. for accuracy in maintaining the designated altitude. Under these conditions performance was superior using the standard altimeter.

MENGELKOCH R.F. and HOUSTON R.C. (1958). Investigations of vertical displays of altitude information simulated flight task using a moving-tape altimeter. U.S.A.F. WADC Tech. Rep. 57-385.

It was thought that the experienced pilots used as subjects in Part I of this study might be performing simulated manoeuvres in a modified C-8 Link-type trainer more accurately when using a standard altimeter than when using a vertical reading altimeter because they were experienced with the standard altimeter. Therefore, 14 of the 20 experienced pilots used in Part I were given two more sessions. The first, a practice session, consisted of another trial on the flight task and 30 minutes of supervised practice using only the vertical display altimeter. The second session consisted of repeating the same manoeuvres used in Part I but reversing the order of using the vertical and standard altimeters. Probably due to familiarity with the trainer, there was improvement in accuracy of maintaining the designated altitude for both types of altimeters, but the differences were now even more in favour of the standard altimeter.

MENGELKOCH R.F. and HOUSTON R.C. (1958). Investigation of vertical displays of altitude information. III. The effect of an expanded scale on performance of a simulated flight task using a moving-tape altimeter. U.S.A.F. WADC Tech. Rep. 57-549.

Ten of the pilots used as subjects for Parts I and II of this study and

twelve Air Force pilots attending the University of Illinois performed the same standard programme of manoeuvres in a modified C-8 Link-type trainer that were used for the first two parts of this study. This time, however, the scale on the moving-tape vertical altimeter was increased from 1.5 in. to 2.375 in. per 100 ft. Under these conditions the new subjects performed as accurately using the vertical altimeter as when using the standard altimeter. The ten 'experienced' subjects seemed to perform better on the standard altimeter, but when one subject who misunderstood the altitude assigned and his running mate were eliminated, the difference disappeared.

SPERLING H.G., McLANE R.C. and ANDERSON D.A. (1964). Peripheral augmentation of range perception in pictorial displays. Pap. 55.4 to International Convention of the Inst. of Elect. and Electronics Engrs., N.Y. 23-26 March 1964; abstr. in IEEE Spectrum, March 1964, 1, 104.

Primarily concerned with manual controllability of a six-degree-of-freedom vehicle in which separate control of each degree of freedom is provided. One of the specific goals was to quantify information presented by a pictorial display and to seek out methods of providing equal accuracy of control in all axes. A peripheral display was found to be necessary to augment fore-aft range perception. A control station mock-up, including a six-degree-of-freedom input control and a vertical pictorial or contact-analogue type display with an integrated quickened tracking symbol, was combined with a real-time simulation of vehicle characteristics for controllability performance tests.

TRIGGS T.J. (1961). A comparison of four altimeter presentations of the three pointer instrument type. Melbourne: Dept. of Supply, Aeronautical Res. Labs. Hum. Engng. Note 10.

A comparative evaluation was made of the Standard Three Pointer altimeter and three modified presentations suggested by airline operators. Thirty two pilots participated in a two-part experiment. First, static presentations were read using subject-controlled exposures. This was followed by reading of the altimeter under dynamic conditions in the Link Trainer. Reading accuracy and reading times were recorded. Then, to find subjective preferences, a paired comparison of the altimeters was run, together with an interview. Some significant differences between the instruments were established:- (1) all three modifications were superior to the Standard Three Pointer; (2) two of the modifications were superior to the third; (3) on pilot preference scores, one of these two modifications, the 'Yellow Line' was significantly superior to the other three altimeters. It is recommended that the 'Yellow Line' altimeter, which is equipped with a follow-up line to the 10,000 ft. index, be adopted as a suitable interim altimeter presentation. The Link Trainer technique used in this experiment proved to be too insensitive to indicate differences between the modified presentations.

WETMORE J.W. (1958). Considerations on take-off monitors. Washington:
NASA, Nov.

Take-off monitors are relatively new aircraft instruments or systems whose function is to assure the pilot that take-off is progressing satisfactorily or providing a warning if it is not. Some of the factors involved in take-off monitoring are pointed out, some of the possible take-off monitor arrangements are discussed, without reference to actual hardware, and the types of indication that might be expected in certain take-off situations are illustrated for three types of monitor.

Analogue: scale face design

ANON (1963). Designing instruments and control panels. Instrum. Contr. Engineering, Aug., 22-25.

Present trends towards continuous or semi-continuous processing often demand a multiplicity of instruments. Overall supervision is still carried out by human operators in case quick decisions or rapid corrective action should be required. In the design of instrument and control panels the aim is to present the operator with full information on plant conditions and, by correctly located control knobs, hand wheels and levers enable him to apply the necessary corrections in the least possible time. The fewer the instruments the operator has to watch the easier will be his task, hence the essential instruments must be well placed. Sometimes, space can be saved on panels by replacing instruments by coloured lights to show safe and dangerous conditions. The size and shape of various panels are discussed. Natural and artificial lighting and the viewing angle are considered. Graphical panels, plate panels, the position of instruments on the front and rear panels, the panel materials and finish are also investigated.

ANON (1963). Designing easy-to-read scales. Instrum. Contr. Engng., June, 20-23.

Although many industrial processes are controlled automatically, overall supervision still has to be performed by a human operator. For information on plant conditions he relies on the measurement of process variables indicated by instruments, which, in some cases, may number hundreds. The speed with which an operator can read instruments depends largely on the clarity with which the information is presented to him by the indicator, and so ultimately on the basic design of the scale and everything associated with it. Visual indicating instruments used in industrial processes can be divided into three main types: (1) quantitative such as watches or clocks, pressure gauges or temperature indicators, (2) qualitative such as car brake lights, traffic lights, etc. and (3) representational indicators as artificial horizons on aircraft, lift indicators, etc. Of the three types, the quantitative type is the most widely used.

ELAM C.B., EMERY J. and MATHENY W.G. (1962). Tracking performance as affected by the position of the attitude display. Fort Worth, Tex.: Bell Helicopter Corporation, REP. D228-421-010, Contract NONR-1670 00, AD-273,967.

A study was conducted to determine if the position of an attitude display

with reference to the orientation of the subject and the position of the subject and the position of the control stick affected performance. Performance was adversely affected when the display was rotationally offset 45° from a line passing through the subject's body and the control stick, as compared to the condition where the display was directly in front of the subject.

GRETHER W.F. (1948). Design of instrument dials for ease of reading. S.A.E. Quart. Trans., 2(4) 539-545.

A survey of some of the psychological research aimed toward improvement in ease of reading of aircraft and other instrument dials is presented. The need for such studies is illustrated through a discussion of pilot errors in instrument reading followed by sections on how instruments are read, studies of check reading, studies of qualitative reading and studies of quantitative reading. Future needs are indicated.

WILKERSON L.E., FOX G.A. and MATHENY W.G. (1959). The effect of scale form on the speed and accuracy of scale reading. Fort Worth, Tex.: Bell Helicopter Corp., Rep. D228-420-003, Contract Nonr-1670(00).

To evaluate three types of displays - circular-moving pointer, linear-moving pointer, thirty six subjects were given ten presentations of each display and required to record the reading following a one-half second exposure. The size of numbers, graduation mark separation, interval values, and pointer width were the same for all three scales. Frequency of errors in reading each of the scales as well as for segments of the scales were examined. Magnitude of errors was also analysed. The results were discussed relative to the number of fixations possible with the exposure time used.

System Presentation

ANON (1958). Optimum panel arrangement of flight instruments for army fixed-wing aircraft. Report of project NR-AVN 1557.5. Fort Rucker, Ala., U.S. Army Aviation Board, Rep. ATDEV 6 452/4, Project NR AVN 155, ONR Rep. ACR-55, IV-136.

To determine for Army fixed-wing aircraft optimum panel arrangements for (1) basic flight instruments, (2) instruments currently in use, and (3) integrated instrument systems, an analytical study of the factors underlying the problem was made. After arriving at an arrangement of the basic instruments which satisfied all the factors, optimum arrangements for (2) and (3) were determined during flight tests under actual and simulated conditions. Optimum arrangements are recommended.

ANON (1959). Study, design, and development of navigation display for helicopters: final report. Boston: Laboratory for Electronics Inc., Contract AF 33(600)34034.

The study, design, and development programme summarized in this report had as its prime purpose the overall improvement in helicopter instrument flight. Three aspects of the programme were described:- (1) investigation of kind and type of instruments required and wanted by experienced helicopter pilots and of the way in which the instruments should be grouped, (2) investigation of the advantages to be gained by incorporating Doppler radar to improve the guidance displays for the pilot of a manually controlled aircraft and (3) investigation of a Doppler-controlled automatic-stabilization system using the auto-pilot.

ANON (1962). Cockpit displays for all-weather landings: Final report. Wright-Patterson AFB, Aeronautical Div., Flight Control Lab. Rep. FAA/BRD 114-15-2D.

Three instrument display systems, designed to augment all-weather landing capabilities of aircraft, were evaluated in a flight simulator test programme. The display instruments were of two basic types, a conventional round dial and fixed scale with a moving pointer, and two vertical scales with moving tape instruments. These instruments are designed to display two new flight parameters, absolute altitude below approximately 300 ft. and instantaneous vertical velocity of the aircraft. These parameters are presented to help the pilot maintain positive position control during the critical approach and landing phase of flight.

ANAST J. (1959). Advanced cockpit instrumentation. Paris: N.A.T.O. Advisory Group for Aeronautical Research and Development, Report No. 235.

This report described development work by the U.S. Government and Lear Inc. on an integrated cockpit instrumentation system to meet the changing requirements of high-altitude, high-speed flight. The primary effort had been in the development of all-attitude instrumentation systems to meet the demands of all-weather flight. The Standard and Phase II GI (Vertical Gyro Indicator) Systems were discussed and their limitations indicated. Other indicators (Three-Axis, Two-Axis Flight-Director, and Three-Axis Flight-Director) were described. Application of the integrated display to helicopters, command and remote standby instrumentation, and verticality errors were discussed.

BESCO R.O., McELWAIN C.S. and BAUERSCHMIDT D.K. (1963). Studies of manual attitude control: Control-device/display content comparisons. I.E.E.E. Trans. Hum. Factors Electron., HFE-4, 17-24.

Experimental simulation studies were conducted to determine the effects of displayed information content and hand control device configuration on the ability of pilots to stabilize the attitude of a tumbling space vehicle and to maintain a fixed attitude while external torques were being applied. Four pilot-engineers performed both tasks in a fixed-base manned space vehicle simulator which was mechanized to provide three degrees of angular freedom. Four types of hand control devices and two display content conditions were investigated. Results indicated that the amount of displayed information was a powerful variable for both tasks. A strategy or technique for accomplishing the stabilization manoeuvre was evolved which approached an optimum solution in terms of energy expenditure or fuel consumption.

BROWN I.D., HOLMQUIST S.D. and WOODHOUSE M.C. (1961). A laboratory comparison of tracking with four flight-director displays. Ergonomics, 4, 229-257.

The following flight-director displays were compared in the laboratory on a simple aircraft simulator under controlled conditions of noise and ambient illumination:- (a) Streaming Lights which presented errors in the flight of the 'aircraft' by the direction and rate of apparent movement of streaming lights; (b) 'Barber's Poles' which presented errors by the direction and rate of translational movement of a white helical strip along a black, rotating pole; (c) Flashing Lights attached to the simulator, or to a helmet worn by the subject, which presented errors in each dimension by the position and rate of flash of a single flashing light; and (d) I.L.S. Meter which was intended to represent a Zero-Reader display and present errors by the

position of two pointers, mounted at right angles to each other. All these displays were designed to present navigational information to a pilot while he was scanning the outside world, and all except the last presented the information in peripheral vision. Three experiments are described:- (1) continuous tracking; (2) getting back on to course; and (3) getting back on to course with combined flight-director displays. The results are discussed under the headings:- (1) attention to the flight-director upset the control task; (2) flashing lights on the helmet were the best display for monitoring; (3) head rotation hardly affected performance with peripheral displays; (4) combined responses were made to displays in two dimensions; (5) two altitude displays introduced conflicting control-display relationships; and (6) why controlling in altitude was sometimes harder than controlling in bearing.

BROWN T.M. (1961). A survey of vertical display contact analog systems. Bell Helicopter Co. Rep. D228-201-001, Contract NONR-16-7000, AD-266,807.

Vertical display systems which utilize a contact analogue ground plane presentation, a pathway or other form of director, and various special symbols are discussed. The objective is the uniform presentation of data to all personnel in the field of information presentation. Information is presented in chart form for the vertical display systems used in the Bell RH-2 research helicopter, the Grumman A2F attack aircraft, the Douglas Aircraft simulator, and the SUBIC submarine programmes. There is also a description of work being performed at Johnsville, AIL, with part of the Grumman system installed in an R4Y aircraft. The results, including descriptions of sensors and computers used to drive the vertical display systems, should provide convenient reference.

BRADLEY W.A. (1959). Experimental design for human engineering evaluation of DV-10/A2F displays. Johnsville, Pa.: Naval Air Development Centre, Aeronautical Instruments Lab., Rep. NADC-AI-5958, Project TED.ADC AV-73011, PB 149,526.

The purpose of this experiment is to determine the optimum scale factors of certain variables in an electronic contact analogue display on the basis of minimum errors obtained in this experiment. These optimum scale factors will then be utilized in the experimental cockpit of the R4Y in real flight and the results compared with those obtained in the simulator.

BUYAN J.R. (1964). Manned military spacecraft displays. Los Angeles: Aerospace Corp. Rep. TDR-269-4540-30-1, SSD-TDR-63-303, Contract AF04-695-269, AD-430,563.

The state-of-the-art of manned spacecraft display systems is discussed with emphasis on how future display developments will effect spaceborne computer requirements. Considerable differences of opinion exist on how spacecraft display subsystem should be evolved. Essential points of difference are whether time shared general purpose displays should replace the traditional maze of individual instruments and how and when man should enter into the control loop of the functions being displayed. The potential of both electroluminescent panels and cathode ray tubes as general purpose displays are discussed. Now and in the near future only cathode ray tubes are capable of satisfying spaceborne general purpose display requirements. Three-dimensional displays, predictor instruments, and contact analogue are evaluated as potential spaceborne displays. Display capabilities and philosophies of several companies are presented and some of their significant display projects are described.

CONNELLY R.E. (1958). Evaluation of MA-1 Integrated Electronic and Control System Instruments. Wright-Patterson AFB: USAF Directorate of Flight and All-Weather Testing, WADC TN NR 5835, Task 61979(1), ONR Rep. ACR-43, IV-177.

This report presents the results of the flight test evaluation of the 'MA-1 Integrated Electronic and Control System Instruments' (cockpit 'A'). The cockpit 'A' instrument panel embodies the 'outside-in' display concept where aircraft performance is displayed by moving aircraft symbols against stationary scales or background. Test results were based on pilot opinion obtained in flight by use of wire recorder and after flight debriefings and questionnaires. Four pilots performed a varied series of flight profiles. Analysis was made in terms of (1) specific instruments, (2) the integrated panel, and project use of horizontal Situation Indicator.

CLARKE D.G. (1959). Optimum instrument presentation and panel arrangement for Army rotary-wing aircraft: Report of project NR AVN 457.8/59. Fort Rucker, Ala.: U.S. Army Aviation Board, ONR Rep. ACR-55, IV-209.

To determine the optimum panel arrangement for the 'basic six' flight instruments in Army rotary-wing aircraft, aviators with varying amounts of experience flew helicopters under actual and simulated instrument conditions using various panel arrangements. Further testing and study were conducted to determine an optimum presentation for helicopter integrated instrument displays. Instrument flight was attempted from the copilot's seat, utilizing the pilot's instruments in order to determine whether a copilot's panel is required. Recommendations are included.

FEDDERSON W.E. (1962). Simulation evaluation of a head mounted orientation display. Fort Worth, Tex.: Bell Helicopter Co., Tech. Data Rep. D-228-421-012, Contract NONR 1670/00/, Project ANIP, AD-295,169.

Results of a study designed to determine the effect upon hovering performance of angular differences between head position and field of view as presented by a helmet-mounted contact analogue display are presented. The results, as presented in terms of integrated absolute ground position error scores, indicated that pre-test performance on a panel-mounted contact analogue display was superior to that exhibited by the subjects on the helmet-mounted display. Such was to be expected since the former system was near optimum in terms of resolution, clarity, comfort and subject experience. When performing with the helmet-mounted display the subjects' performance deteriorated but the deterioration was distributed across all conditions of head position and field of view and was not restricted to any particular head orientation. As determined by a standard non-parametric test of significance none of the performance differences between left and right hand position were significant when compared with the condition in which the forward looking display view coincided with the orientation of the head.

GAINER C.A. (1963). Air Force flight control and flight display integration program: final summary report, 1 March 1962 - 28 Feb. 1963. Baltimore: Martin Marietta Corp., Rep. ER12905, Contract AF 33(657)8600, AD-104,850.

The Martin Company provided human engineering support to a number of Air Force programmes being conducted under Project 6190. The extent of task activities was broad in scope and diverse in subject matter. Members of the group were involved in research projects, consulting activities, reviews of literature and methodological development. Each of these kinds of tasks is briefly reviewed and the topics investigated are discussed. The subject matter of these tasks in part consisted of controller studies, display evaluations, display development, performance and opinion measurement, and programme planning.

GORDON H.C. and SCHWEDES J.C. (1960). Vertical flight instrument presentation test F-106A/B category II. Edwards AFB: U.S.A.F. Flight Test Centre, AFFTC TR 59 26, Addendum I.

To evaluate the vertical instrument equipped aircraft (F-106) for the safety of flight deficiencies and instrument system accuracy, reliability, and maintainability, one F-106A was flown on fifty two test missions for 70.15 h and one F-106B was flown on thirty missions for 40.05 h. The F-106

Vertical Flight Instrument Panel consists of nine instruments: Mach-air speed-angle of attack indicator, standby air speed indicator, attitude director indicator, horizontal situation indicator, altimeter-vertical speed indicator, standby altimeter, display mode selector, heading select switch, and bearing selector. The performance of each is discussed.

KELLY C.R. (1958). The predictor instrument. In Smith B.J. (ed.) Human Control Dynamics in Air and Space Craft. Flight Safety Foundation, Inc. 468 Fourth Avenue, N.Y.

The paper discusses the predictor instrument. This instrument gives the operator information about the future of the system he is operating by means of a computer which uses the dynamic equations of the system and present state information to predict future states or projected paths. It allows the operator to make corrections on the basis of whether or not the system is going to do what he wants it to do. Predicted errors may be corrected before they occur.

The predictor display is essentially a status indicator and as such differs from quickened indicators which are basically command displays and do not show the current status to the operator.

It was concluded that if one wants the operator to have a stabilized gain and bandwidth one should use a quickened display. If, however, one wants maximum flexibility for the operator, the predictor display is better.

It was also concluded that use of the predictor display minimizes training time because the operator does not have to learn the 'dynamics' of the system he is controlling. Instead, they are displayed for him.

LEFLER J.H. (1958). Fixed-wing instrument presentation: final report of Test Project NR AVN 1557. Fort Rucker, Ala.: U.S. Army Aviation Board, Project 1557, ONR Rep. ACR-55. IV-218.

To determine the optimum attitude and navigation instrument and/or instrument system presentation for use in Army fixed-wing aircraft, instrument-qualified aviators, with more than average amounts of instrument experience, flew under instrument conditions, using various panel arrangements. Existing attitude and navigation instruments as well as integrated instrument systems (Collins Integrated Flight Systems FD-103C and FD-105, and Sperry Integrated Instrument System) were evaluated. An optimum panel arrangement of flight instruments is recommended for standard Army airplanes.

McINERNEY J.E., HAAG J.I. and STARKE R.T. (1964). Operational test and evaluation of the Decca roller map: final report. Langley AFB, Va.: Tactical Air Command, Rep. TAC-TR-62-60, AD-429-817.

This test evaluated the Mark II Roller Map which uses inputs from the AH/APN-131 Doppler Navigation System to display aircraft present position directly on a flight chart. The Roller Map significantly improves the operational capability of the F-105D on low-level weapons delivery missions and offers a solution to safety problems associated with cockpit map handling at low altitude. Several modifications are required to improve the operational capability of the equipment in an all-weather tactical strike fighter. These modifications are described together with recommendations for the desired configuration of the Moving Map Display in future tactical fighter aircraft.

McINERNEY J. (1962). Study programme for all-weather instrument landing system: final report, phase 1. Teterboro, N.J.: Bendix Corp., Eclipse Pioneer Division, Contract FAA/ARDS 572, Project 114.15, AD-407,564.

This report specifies recommended system concepts for integration of an Instrument Panel best suited for monitoring an Automatic All-Weather Landing or conducting a manual landing in low-visibility, low-ceiling conditions. The instrument panel displays recommended fulfill the requirements of presenting all the presently available navigation and landing air parameters required for this programme. The detailed panel layouts, block diagrams depicting the system interconnections, price, delivery, and other pertinent information have been included to aid in the choice of the most economical and technically feasible system.

MARTIN C.L., BYRD W.H. and WILLIAMS R.R. (1958). Fixed wing instrument presentation: evaluation of the Collins Integrated Flight System. Fort Monroe, Va.: U.S. Army Continental Army Command, ATDEV 6 452/18, Project NR AVN 1557.1, ONR Rep. ACR-43, IV-222.

As part of a programme to determine the optimum altitude and navigation instrument, and/or instrument system, for use in fixed-wing aircraft, this study evaluates the Collins Integrated Flight System (CIFS). The CIFS was flown approximately 500 hours over a period of 12 months. Results and recommendations are indicated.

MARTIN C.L. (1960). Fixed-wing instrument presentation evaluation of the Sperry Integrated Instrument System. Fort Rucker, Ala.: U.S. Army Aviation Board, Project NR AVN 1557 2, ONR Rep. ACR-55, IV-251.

The system was installed in an Army aircraft (L-23B, No. 53-6164) and was flown 150 hours. All types of approved instrument approaches and instrument training manoeuvres were performed. Aviators with varying degrees of instrument experience were given instruction in the use of this equipment, and transition or training time was recorded. Comparisons of performance with SIIS were made with that possible from present standard displays. Recommendations are included.

NAISH J.M. (1961). A system for presenting steering information during visual flight (the head-up display). Part I: The effect of location of the instrument display on combined instrument and visual flying. R.A.E. Farnborough, Tech. Note IAP 1132.

Modes of flight are defined in which manual control is effected by means of information originating in discrete fields, the external (E) field and the instrument (I) field. It is shown that these modes cannot always be separated and that it is desirable for the pilot to be able to attend concurrently to information in both fields to carry out his dual and visually-mediated task. The effect of altering the location of the I-field on performance of the dual task is examined by considering three possible alternatives to the conventional location. It is shown in the laboratory that, for simple tasks, the best dual task capability obtains when the two fields are brought into the closest possible proximity, i.e. the I-field is presented centrally within the E-field by collimation. This method also permits natural ocular usage and provides the best information capacity. It is shown with developed tasks that the collimated method is superior to the conventional because interaction between tasks is then negligible. The dual task capability is examined in real flight, with satisfactory results, but with some interaction. An additional laboratory experiment is used to show that concurrent critical interpretation may be exercised in respect of information in both E and I fields. The overall effect of I-field location is to affect significantly performance of the visually-mediated dual task, without serious penalty to the discrete task components.

OBERMAYER R.W. (1961). Air force flight control and flight display integration programme. Baltimore: Martin Co., Engng. Rep. 12190, Contract AF 33(616)7752, AD-273,446.

Briefly summarizes work on projects including:- procedures for in-flight instrument evaluation; eye movement study; operator controls research; display assessment; approach and landing control-display problems; simulator test of three different altimeters; development of an advanced aerospace vehicle control-display system; design of digits and coding for flight displays; three dimension, volumetric display investigation; transition from IFR to VFR during the approach for landing. A list of reports and articles written under the contract is included.

RITCHIE M.L. and BAMFORD H.E. (1958). Investigations in instrument integration. In symposium on USAF flight control display integration programme. WADC, Wright-Patterson AFB, Ohio.

The authors viewpoint is that what the operator needs to know about a vehicle in order to control it can best be described in terms of the equations of motion for the vehicle. The discussion covers many points on how such information should be supplied.

With regard to display integration the authors assert that one can not design complex displays by simply putting simple ones together, and suggest two integration principles. The first is illustrated by the check reading experiments where groups of instruments have their 'normal' reading in the same position. If any instrument departs from normal, the pattern is altered and easily detectable. The second called 'pointer matching', displays a parameter and its rate of change side-by-side. Keeping the pointers matched results in an asymptotic approach to the desired value. In each case the increased utility of these grouped indications arises from the availability of an extra quantity or variable present as a consequence of the grouping.

RONCO P.G., CHANDLEE J. and SAMPSON P.B. (1958). Human factors in helicopter instrumentation: an evaluation of two navigation displays. Boston, Mass.: Lab. for Electronics Inc., Interim Rep. 2, Contract AF 33(600)34034, Subcontract 484 76004.

As part of an investigation on the design of an optimal integrated instrument display for an all weather helicopter, this report compares the efficiency of a Rho-Theta and a Course Indicator display as navigation aids. The actions of these two instruments were reproduced photographically during simulated flights of 18 minutes duration. The subjects, twelve inexperienced

and six experienced pilots or navigators, were shown their point of departure and destination on a map and, after watching displays for a portion of the flight, asked to mark their locations on the map. Differences between true and estimated locations were analysed for differences due to instruments, type of course, and experience.

SCHREIBER A.L. (1961). Measuring the relevance of an item of information to the command of a complex man-machine system. Arlington Va.: Sciences Res. Inc., Rep. 10, HSR-TN-61/1-sm, Contract Nonr-252500, AD-257,607.

A mathematical approach is presented on one of the most critical problems in development of command consoles and displays, i.e. the evaluation of the relevance of potential information inputs. It may be applied to any kind of proposed system to determine command information requirements when current methods may not be adequate to the task.

SEMINARA J.L. and PARSON S.O. (1963). Display systems design. Design, Lond., 35, 165-176.

In the usual man/machine relationship, the machine communicates with the man through various displays and indicators - in terms either quantitative, qualitative, or both. Such information serves as the basis for decision making and control action by the operator. If the communication link between user and equipment is efficient, the machine indicates clearly, simply, and directly. Any change in a display attracts the operator's attention promptly - particularly when immediate corrective action is necessary. If communications are garbled - because the machine warning system is ambiguous, it doesn't say enough, or overloads the operator's sensory capabilities a serious degradation in system performance can be anticipated. Overcoming such design faults may demand, at the very least, an extensive and costly operator training programme. Obviously, the task of the equipment designer is to forestall the need for such improvisation. In this brief outline the author suggests that when a rapid assessment of a large number of functions must be made, a series of colour-coded qualitative displays is far superior to an equal number of meters in speed and accuracy of evaluation. However, when a malfunction does arise, and the test engineer must rapidly determine its severity, a quantitative display is necessary. Examples are shown of colour displays, coded for fast identification of size, shape, orientation, of positive and negative readouts, electroluminescent displays, the green board as used in submarines, the pictorial board and the summary board.

SVIMONOFF C. (1958). The air force integrated flight instrument panel
U.S.A.F. WADC Tech. Rep. 58-431.

Since the conventional flight instrument panel limited the full tactical realization of the aircraft combat potential, an integrated flight instrument panel has been developed and tested. The purpose was to display all information so that the pilot can obtain what he needs quickly and accurately. It not only tells him what he is doing, but gives 'command information' as to what he should be doing. By using the system engineering approach, the optimal panel layout was found to have the attitude of plane information in the centre above the heading, navigation and tactical information. The altitude and rate of climb information in vertical moving tape form is placed to the right and the airspeed and Mach information in vertical tape form is placed to the left. This centralization achieved functional objectives with a minimum utilization of space, weight and power. The attitude director and horizontal situation indicator incorporated in the display were considered as major break-throughs in the field of flight instruments. A 'moving horizon-fixed aircraft' attitude presentation and white numerals on black tapes were adopted. The use of central air data computers for giving command information on the panel instruments was entirely new.

2(b) A REVIEW OF PAPERS READ

Methodology and Criteria

In a survey of the literature on dials and instrument displays Senders and Cohen (1953) give particular emphasis to the underlying methodology and philosophy in this area. They considered 64 studies (Summarized in Table I) and found that characteristically experiments present tachistoscopic exposures of single instruments, record oral responses, and measure performance in terms of exposure time and errors. More than ten years later it seems that their principle comments are still true: firstly, that our thinking about problems and methods in this area is too limited and insufficient consideration has been given to the fundamental processes which determine how men use instruments: secondly, that too often there is little validity in the experimental results, correlation between experimental and performance measures being poor. This latter shortcoming they attribute to poor criteria of efficiency. Thus they derived nineteen criteria of 'good' instruments and panels. Most of these seem to have found their way into various 'cook books' on the subject.

One aspect of this question of validity is using slides or photographs of displays as opposed to presenting actual hardware in the experimental situation. This is one of the criticisms Rolfe (1964) makes of Grether's (1947) experiments. However Churchill (1956) compared the two forms of display - real and photographed - and he found only a slight but insignificant advantage in favour of panel presentation. His results, he felt, justified applying slide projection data directly to actual displays which slides are intended to represent.

Methods of simplifying the pilots task have on occasion been related to 'quickenings' the display. Taylor and Birmingham (1956) suggested this and Fogel and Dwonczyk (1958) carried out some preliminary work in this area limited to altitude response. Instrumentation which would be necessary in developing such 'anticipatory' displays has been described by Loewe, Sisson and Horwitz (1960) and Fenimore (1963).

TABLE I Summary of Methodology

TABLE I Summary of Methodology				METHOD	RESPONSE	INDEP. VAR.	DEP. VAR.	READING	DIALS	INSTR.	SUBJECTS																									
Biblio. No.	EXPERIMENTER	DATE	PROBLEM	ICM EXP	D-PAID EXP	TRAINING EXP	FLYING	OTHER	WRITTEN	SWITCH	FILING	TALKING	OTHER	DIR OR DISPLAY CHAR.	ILLUM MOTION REL.	MANEUVER CHAR.	TRACKING	OTHER	TIME ON TARGET	OTHER ERROR	QUANTITATIVE	CLOCK	TRACKING	SETTING	MULTI-DIAL PANEL	DUAL DIAL PANEL	SCALE DIAL (GALS)	ACCURACY	BOTH	TRAINING	NO REPORT	COLLEGE STUDENTS	NAVAL STUDENTS	TRAINED PERSONNEL	UNTRAINED PERSONNEL	WHEELER GROUP
1	Barber & Garner	1951	Effect of numbering system	X																																
2	Broadbent	1950	Standardize apparatus																																	
3	Broadbent	1951	Effect of noise on vigilance																																	
4	Browne	1945	Comparison of attitude indicators																																	
5	Chalmers, Kappauf, Goldstein	1950	Effect of illumination intensity	K																																
7	Christensen	1948	Staircase scale	X	X																															
8	Christensen	1952	Effect of exposure time, moving scale vs. moving pointer	X																																
9	Cohen & Senders	1952	Effect of coding dial panel	X																																
10	Cohen, Vanderplas, White	1952	Effect of viewing angle, parallax																																	
11	Connell	1950	Most desirable type of instrument for check reading	X																																
12	Conrad	1949	Effect of pointer speed on continuous performance																																	
14	Fitts, Jones, Milton	1950	Pilot eye-movements																																	
15	Fitts & Simon	1949	Arrangement of instruments																																	
16	Gardner	1950	Movement relationship, cross-pointer																																	
17	Graham	1952	Scale shape and tracking																																	
18	Graham, Baxter, Brown	1951	Effect of dial shape on tracking																																	
19	Grether	1946	Design of 24-hour clock dial																																	
20	Grether	1947	Design of altimeter																																	
21	Grether	1947	Movement relationship																																	
22	Grether & Connell	1948	Desirable type of instrument for check reading	X																																
23	Grether & Williams	1947	Dial diam. and spacing of scale divisions																																	
24	Hake & Garner	1951	Effect of discrete scale steps on information	X																																
25	Jones, Milton, Fitts	1949	Pilot eye-movements (transmitted)																																	
26	Jones, Milton, Fitts	1950	Pilot eye-movements																																	
27	Kappauf	1947	Develop methodology	K																																
28	Kappauf	1951	Effect of origin and number location	K																																
30	Kappauf	1951	Effect of interpolation		X																															
31	Kappauf & Smith	1948	Dial size and graduation	K																																
32	Kappauf & Smith	1950	Errors in different parts of dial	K																																
33	Kappauf & Smith	1950	Scale range, graduation size	K																																
34	Laurie, McCarthy, Murrell	1951	Dial size and distance	K																																
35	Long	1949	Design of airspeed indicator																																	
36-37	Loucks	1944	Influence of numbering system	X																																
38	Loucks	1944	Design of climb indicator																																	
39	Loucks	1944	Design of manifold pressure gauge																																	
40	Loucks	1945	Movement relationship																																	
41	Loucks	1947	Development of trainer																																	
42	Loucks	1949	Effect of instructions																																	
43	Loucks	1949	Movement relationship, cross-pointer																																	
44	Loucks	1950	Moving scale vs. moving pointer, azimuth indicator																																	
45	Loucks	1950	Design of azimuth indicator																																	
46	Milton, Jones, Fitts	1949	Pilot eye-movements																																	
47	Milton, Jones, Fitts	1950	Pilot eye-movements																																	
48	Milton, McIntosh, Cole	1951	Pilot eye-movements																																	
49	Milton, McIntosh, Cole	1952	Pilot eye-movements																																	
50	Milton & Wolfe	1952	Pilot eye-movements																																	
51	Morley & Suffield	1951	Position of pointer alignment																																	

LEGEND:
Numbers in "Other" columns
under first four headings
explained below.

METHOD

1. Continuous vigilance
2. Setting
3. Respond to rapidly moving pointers

RESPONSE

1. Check - controlling
2. Setting

INDEP. VAR.

1. Fixation and exposure time
2. Pointer speed
3. Interpolation
4. Instructions
5. G-forces
6. Number of pointer positions

DEP. VAR.

1. "Hits, wides, misses."
2. Number of fixations, duration of fixation, link values
3. Preferred direction of motion

Totals

Pilot Requirements

If task-analyses have been carried out to determine what information the pilot needs and its relative value in conducting a particular phase of the flying task then it would seem to have been only rarely reported in the literature. Fearnside (1963) in considering instrument aids for take-off revealed in a detailed description of this manoeuvre some of the difficulties which confronted the pilot and indicated the type of additional information with which he should be provided. He considered how such information might be provided by means of (i) a ground run indicator, (ii) a ground run predictor, (iii) a pitch rate indicator, and (iv) a take-off director. He further developed the theme by giving thought to the problem of incorporating the additional information into existing flight systems.

Another investigation of this phase of the flying task has been carried out by Roscoe (1948) who looked at the effects of eliminating binocular and peripheral monocular visual cues upon pilot performance when landing. Under these conditions the effort of successively reducing visual cues on the criteria of the error in landing distance was demonstrated.

Emerson (1955) too has discussed the problems of distance reduction when landing and the importance of angular velocity of ground objects as a cue for distance; especially when information is provided by a periscope arrangement.

Zeller et al. (1961) discussed very fully with reference to aircraft accident statistics, the requirements of an information display to provide a basis for decision making. They analysed crashes in the U.S.A.F. for 1957-1958 and gave a table of factors considered to be the primary cause of the accidents. Many examples were given of inadequate instruments leading to accidents and three cases were defined in which the information supplied to the pilot was inadequate.



Display Presentation

Digital displays

The information available to date regarding the displaying of digital information has recently been examined by Rolfe (1964). He noted the lack of work in certain areas of the field and the shortcomings of some of the work which has been performed. He made the very important criticism that while there have been recent proposals to use purely digital displays for aircraft displays, very little is known from an applied psychological point of view as to the information transmission characteristics of digital displays in the dynamic situation. As he said 'reference to the available literature' shows 'in the main recommendations regarding the use of digital displays have been made of the basis of pitifully few experimental investigations and very much anecdotal speculation'. The author outlined a programme which he intended to pursue for the dynamic evaluations of digital displays in dynamic situation.

An investigation by the Royal Canadian Air Force (Rp. N 62-RD-1, 1962) would appear to suffer from the defects alleged by Rolfe: in addition to that of using non-pilots to evaluate a type of display largely designed for trained pilots. It evaluated the readability of five-digit counters which had:

1. equal size digits and equal spacing between them;
2. equal size digits and wide spacing separating the thousands from the hundreds digits;
3. two sizes of digits and equal spacing, i.e. tens and units digits were smaller;
4. two sizes of digits, wide spacing separating thousands and hundreds, tens and units digits were smaller.

In addition it tested the effect on accuracy of reading of having a cross hatched flag instead of a blank preceding a four digit presentation.

The only conclusive results were that two sizes of digits reduced the accuracy of reading five-digit numbers to a large degree.

That there seems little advantage in using different sized digits is surprising. At high altitudes pilots presumably only use altitude correct to 100 ft: at lower altitudes they may require more accurate information and that the final two digits were separated spatially and by size would have been thought to be a help. It may be a matter of training that the normal grouping of digits was superior.

Much of the work done on analogue presentation of data to pilots has concerned itself with aircraft attitude indicators: comparison being made between the 'earth reference' type where the moving element represent the

horizon and the 'aircraft reference' type where the moving element represents the aircraft. In spite of the volume of work (e.g. Gardner (1954); Baker and Grether (1954); Simon et al. (1956); Angrist (1957) the problem of which is superior remains unresolved.

In this area however a most interesting alternative comes from Fogel (1959, 1963). Recognising the conflict the pilot encounters when he is faced with the problem of resolving the difference between the information he receives from the visual displays and that which he receives directly within his body, Fogel describes a technique which may be used to resolve this sensory conflict. The forces acting on the operator's kinaesthetic senses are related to the attitudes of the aircraft and to the earth's surface and presented visually so that the aircraft's instruments behave as a kinaesthetic analogue of the human body. By means of line drawings 'earth' and 'aircraft reference' instruments are compared with kinaesthetic altitude indicators at various stages during particular aircraft manoeuvres. The report proposes individual cockpit instruments, integrated pictorial displays and an optical projection system for the presentation of kinaesthetic analogue information. However no evidence has come to light indicating that the concept has been developed or that there has been any attempt to evaluate it experimentally.

Innes (1962) compared a linear and a non-linear scale as a gross analogue indication of attitude in terms of accuracy of determining the distance and direction from a command altitude. The results suggested the superiority of the non-linear scale.

In another study (Innes and Beldam (1962)) a comparative evaluation was made of the Kollsman Three Pointer, the Smith's Counter Pointer and the Bendix Counter Analogue Altimeter presentation. The last named instrument was clearly the most effective in reducing reading errors with the experimental task, levelling off accurately at a command altitude. It may well be however that the result was influenced by the experimental design: all the subjects (not all flyers) were tested with first the three pointer instrument, second with the counter pointer; and third the counter analogue. This was also the order of efficiency rating for the instruments suggested by the results.

System Presentation

Important as the correct design of the component units of cockpit displays are, a real solution to the problem posed by the complexity of cockpit instrumentation can only come from a consideration of the total system and its compatibility with the task requirements. Beals (1952) protested against the increased complexity of information presented by instruments in aircraft. He suggested that conventional military aircraft instrumentation provided (1) more information than necessary, (2) raw information requiring complex pilot computation before it was meaningful and (3) information displays that isolated or failed to match normal patterns of comprehension. He suggested an integrated instrumentation system based on six functional elements which was to be developed to match task requirements with the whole system: over-emphasis of a particular element would lead to redundancy of information and hence decrease the efficiency of the overall system; similarly under-emphasis of an element could cause a functional weakness in the system.

Fragola and Hecker (1956) have also pursued this line commenting on the need for integrated instruments of the flight director type.

A report of the objectives of the Army - Navy Instrument Programme (Anon 1960) suggested that a number of individual systems are being developed including analogue displays. Kearns (1957) and Roscoe (1957) respectively indicated that similar work was being done by the WADC and the Hughes Aircraft Co. Sweeny (1962) described a combined-function flight group instrument panel system which met the needs of commercial aviation in terms of bulk, weight, power required, capabilities, and initial price and maintainability. The elements of the system were: the pilot display panel, an air data computer, steering computer, ARINC - output vertical gyro, a 'slaved' gyrosyn compass unit, plus appropriate radio and ARINC - output. The technical characteristics of the system were outlined as were the basic functions available to the pilot. The components of the display panel, i.e. attitude indicator, compass card ring, bank command indicator, glide slope indicator were described and diagramed.

Steps towards reducing the pilot's load by presenting the required information within a single system have been taken by studies of grouping related display elements within a sub-system (perhaps a single instrument). Payne (1952) described an investigation in which 32 military or ex-military pilots worked navigation problems of a close-in nature, as might be required in an air traffic control situation, using a functional model of an aircraft movement pictorial display and a functional model of a map movement pictorial display. Variables tested in addition to the display movement principle were: heading shown or not shown on the symbol for the pilot's aircraft; map detail or no map detail shown; a portion of the ground track to be flown drawn or not drawn in on the map; and the aircraft symbol heading up or heading down on the aircraft movement display.

The conclusions of this study suggested that the best pictorial air navigation display would be of the aircraft movement principle with the heading shown on the aircraft symbol: that the fixed map should show at least a portion of the path to be flown: and that the entire display should be manually rotatable; using this feature, the pilot could rotate the display, wherever necessary, so that the aircraft symbol could be made to fly on an 'up' heading.

De Pasqua (1963) dealing with the development of a simplified version of an Engine Performance Indicator described a three module, screw driven indicator which displayed information relative to engine speed, exhaust gas temperature and fuel flow utilizing a vertical tape readout. The report was largely concerned with the system hardware with no human factors discussed but it is interesting in so far as it shows an integrated instrument.

A report by the Bell Helicopter Company (Rpt. No. D288-201-001, 1961) gave details of four vertical display systems which were designed for the 'Bell RH-2' helicopter, the Grumman A2F attack aircraft, the Douglas simulator, and the SUBIC submarine programme. It gave a description of these four systems detailing the type of symbols used to represent the system variables, the sources of information and computation required to drive the equipment, and the then current state of development of the equipment (the times to various stages of testing and completion).

3. SUGGESTIONS FOR FUTURE WORK

In the preparation of this bibliography it has become evident that, though there is an abundance of literature on displays in general, and no small amount on aircraft displays in particular, the designer would have difficulty in creating a cockpit display control system which could be clearly shown to be compatible with the pilot's normal operating characteristics. In spite of a mass of data his troubles would stem from:

1. a lack of any apparent attempt to carry out a thorough analysis of the pilot - airplane system;
2. a lack of data on the information handling characteristics of the pilot in relation to the various phases of flight;
3. a fragmentary approach to research on individual instruments which has resulted in little data which is truly established;
4. the inadequate attempts to investigate the suitability of particular instruments on criteria that are based on a fundamental understanding of the information handling capacities of the human operator;
5. the questionable validity of some of the research;
6. problems of pilot acceptance and training.

To fly efficiently the pilot must gather the information on which to base his judgements from many sources in a display. Though there has been some mention in the literature of 'integrated displays' and 'integrated systems' there is little evidence that there has been a fundamental analysis of the pilot-airplane system; or that there has been any attempt to produce a task analysis in terms of the system's objective. Without this first step it has been impossible to allocate functions to the man or a mechanical system on the basis of human characteristics. Similarly no data seems to be available on the information handling characteristics of the pilot in relation to the various phases of flight. As a consequence the pilot's requirements of the display have never been truly determined. It is self-evident that without an accurate specification an efficient display cannot be designed.

Clearly there is a need for an exhaustive systems analysis. To be exhaustive there must be as many analyses as there are phases of flight and types of aircraft with different objectives. This would be a not inconsiderable task and not inexpensive as it is envisaged that the evaluation and development of such task analyses and studies of pilot information handling characteristics would be achieved by means of simulators. Such simulators would be in a sense self correcting in that information derived from them would allow modifications to the allocation of functions and hence to the display in order to progressively reduce noise in the system. Only by such an approach, it is felt, will it be possible to derive a means of measuring work load and performance in flight operations which is essential

before the present design method of single or multiple crew opinion is superceded.

Crew opinion leads to another possible area which requires elucidation: that of pilot acceptance and training. It has been found in communicating with the various sources for the bibliographic material, research workers, system's engineers and the like, that very rarely is there any relation between the abstract appraisal of a display and the pilot's subjective opinion. Thus no matter how carefully it is experimentally proved that the the display has 'optimum' characteristics, its operational utility is almost certain to be less than hoped for. The poor correlation between objective and subjective opinions of a display it is felt stems from the pilot's basic training situation. It may be that there has been insufficient analysis of training requirements in relation to operational needs. Certainly the subjective opinion of research workers is that aircrew build up their concepts of their requirements of a display during their basic training and though in their later flying certain aspects of the display become redundant in some operational roles they feel distressed at their absence; and in addition are remarkably disinterested in new aspects of the display which within the new conditions are highly important. The problem of innovation within a population with a very special 'image' seems worthy of further consideration if real benefits are to accrue from applied research.

Similarly for effective research on the suitability of particular instruments there must be a return to fundamental considerations. Questions of methodology, criteria and general validity of experiments within the cockpit display context have to be faced before adequate consideration can be given to hardware. Research into display designs, and it typifies human factor research in its enthusiastic infancy, pursued many avenues of interest. Now it seems necessary to utilize its findings to build a genuine philosophy for itself before it can proceed fruitfully.

Most valuable contributions can be made by competent excursions into the field to remedy the present shortcomings; and, its ordinary conventions accepted, 'competent' implies 'systematic' and 'on the grand scale'. Real success will not come cheaply: it can only come from a long term programme by a large multidisciplined group working in concert on the various inter-related facets of the problem using much expensive equipment. It is not improbable that to ensure moderate success with a relevant programme the cost must be measured in hundreds of thousands of pounds. To conceive the programme in lesser terms may be simply to add to the accumulating mass of data whose value so often can bear little scrutiny.