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TECHNICAL EVALUATION REPORT ON 13th SYMPOSIUM OF THE AGARD GUIDANCE AND CONTROL PANEL ON GUIDANCE AND CONTROL DISPLAYS

by

H.B.Lyon, Jr.

This Advisory Report was prepared at the request of the Guidance & Control Panel of AGARD

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GUIDANCE AND CONTROL DISPLAYS

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1. INTRODUCTION

The 13th Symposium of the Guidance and Control Panel was held in Paris, France on 19-21 October 1971. The title of the symposium was "Guidance and Control Displays". The Chairman was Lieutenant Commander H. B. Lyon, U. S. Navy. The program as presented at this symposium is appended to this report. The complete compilation of papers will be published as AGARD CP-96-71.

The problems associated with instrumenting high performance aerospace vehicles are increasing daily. More and more instrumentation requirements are arising for which the time to conduct trade-off studies with todays technology is not adequate. The design criteria which exist today are too general in nature and as such do not provide the specific guidance necessary for optimum system design. This situation led the Guidance and Control Panel, under the Chairmanship of Professor C. T. Leondes, to sponsor their 13th Symposium on developing a Systematic Approach to the proper design of displays for guidance and control. In attempting this approach it was understood that the complexity of this problem is enormous. No single discipline can be overlooked as noncritical, or its investigation deferred for a later phase of a design cycle, without serious implications. Only through a systematic approach can the full set of requirements be established and validated in such a manner as to reduce cost and improve reliability without suffering a performance degradation. This then is the critical issue, "How can we be alert to cost and reliability factors while at the same time achieving optimum performance?" With respect to the scheduling and progression of system development, how can we recognize the implications of our design decisions at an early stage of development while our options for inexpensive corrections are still viable?

The Guidance and Control Panel also sought to determine if the methodology and technology that presently exists has the potential to answer the questions of the preceding paragraph. The symposium was structured in an attempt to identify what additional information is needed to provide this capability. It was felt that this goal would stimulate discussion on pertinent issues and lead to the identification of new materials, criteria, and evaluation techniques. This report represents the best attempt by the symposium chairman to filter the symposia papers and discussion in order to identify the critical issues as well as establish a conference consensus.

2. THE THEME OF THE MEETING

The display of information in present day manned aerospace vehicles has resulted in extremely complex avionics systems. The complexity of these systems has led to severe problems of maintenence and operator training. This statement appears equally valid for tactical and air defense aircraft as well as commercial aircraft and space vehicles. As new systems are defined, even more complex instrumentation systems are demanded. For example, new demands have recently been generated to display information on energy management, decision making, optimal performance, weapons monitoring and weapons delivery. In meeting these demands we can forecast even more severe problems of high cost, maintainability, reliability and training problems in future system development.

The solution to these problems requires the development of a systematic approach to the design of instrumentation. The trade-off between design parameters must be done utilizing some means of mission performance as the index. The resulting system design should be of sufficient capability to insure mission success but no more complex than needed. In this context one could say that we want the "simplest" systems that will accomplish the mission. One of the critical interfaces to be quantified in such a systematic approach is the pilot machine interface. Optimized display control criteria will result from a model of this interface which is a proper mix of information requirements, display technology, pilot performance factors (e.g., workload, visual acuity) and biomedical factors (e.g., physiological stress). The identification and resolution of the critical issues in the pilot machine interface and the definition of possible means of resolution is necessary before optimized aerospace instrumentation design will be feasible.

3. THE PURPOSE AND SCOPE

The purpose of this meeting was to bring together the principle disciplines involved in the designing of displays for guidance and control. The sessions were structured around the logical and traditional evolution of the design process. Discussion sessions were held after all the papers of a particular session were presented. It was hoped that in this way discussion would not be limited by the short (10-15 minutes) periods available after each paper nor to the details of one paper. Rather, it was hoped that the total effect of all the papers would yield discussion leading to an identification of critical issues. The session Chairmen were provided with a few questions and proposed statements of critical issues to ensure that discussion was forthcoming and productive. These had to be used rarely, since more than adequate response was observed. There are, however, traditional discussions in this area that have been published and argued for years. This evaluation will attempt to go beyond this level and to identify new thoughts and possible new approaches or new emphasis which resulted from papers and the discussion periods. This evaluation will discuss the conference from three viewpoints in an attempt to provide a better understanding of the total conference. These will be:

(a) General Criteria
(b) Criteria for Specific Applications
(c) New Technology

4.1 GENERAL CRITERIA FOR GUIDANCE AND CONTROL DISPLAYS

There are certain physiological and psychological factors that are general to all man/machine investigations. Certain of these factors are closely linked to the problems of Guidance and Control Displays. These general criteria provide the basic data for specific display applications. The conference papers, in part, focused upon two factors especially critical to guidance and control. The first area was the problem of vision, i.e., the ability to see a display adequately under all anticipated projected environments. The second was the index of workload, i.e., the ability of the human operator to adequately perform all assigned functions.

4.1.1 Vision

There has been a lack of quantitative data from which to define the minimum acceptable performance required from a display over the entire range of ambient conditions. These conditions extend from the dark adapted, night cockpit to the high ambient high altitude flight regime. One set of instrumentation must satisfy the entire range of conditions. This fact many times leads to the over or under specification of equipment parameters. This leads to excessive initial acquisition costs in the former and unexpected engineering changes in the latter. One goal of a systematic approach to the design of guidance and control displays must be the proper definition of design criteria. A significant advance in this direction was provided by papers 1, 7, and 23. However, the analysis of the old data and the gathering of the required data must still be completed. These papers provide a new start in this effort and provide a new point of departure for any future effort.

The parameters which must be defined in a display are confounded by the use of color. Monochromatic techniques for coding information can, with effort, be quantified while the use of color is presently difficult to quantify. Data on the measure of perception is confounded by cognitive processes in the test subject. The literature does not contain the necessary information which can be analyzed by compact mathematical techniques. Yet, the use of color is proposed and subjectively considered as an improvement. Papers 2, 3 and 16 discussed the use of color in displays. The data available establishes an estimate of the trade-off point at which the use of color becomes more effective than monochromatic techniques. The question remains to be answered if the increased complexity, due to the use of color, is justified. One, two or three resolvable colors can be presented using penetration tubes with little increase in complexity or cost. Full color or displays of many colors are costly in initial purchase and upkeep.

Insufficient data exists to establish the merits of the use of color. There is a difference between what the pilot thinks he wants in a color display and whether his performance will improve. There are also additional problems of the visibility of a colored display under different brightness ambients, and of different colored ambients. The present state of affairs is that color will be used, leading to increased system cost and complexity, while the necessity of such expenditure cannot be justified objectively. To make the best use of available technology, a better understanding of the factors, such as the use of color, must be developed.

4.1.2 Workload

The complexity of modelling the human operator presently leads to confounded results and long lists of study constraints. Despite these objections, effort is continuing on model development. The necessity for developing such models and techniques is obvious when one views the design of a system. Certain decisions must be made at specific points in the design cycle. The implications of these decisions presently cannot be evaluated until much later in the cycle. The problem lies in developing techniques that will allow for the extrapolation of results from one environment into another, i.e., from the laboratory to the aircraft and which will give answers when required.

Workload measurement techniques have been developed and were reported on in this conference in papers 4, 5, 6, 8 and 10. These techniques all utilize an index of performance known as workload to define the optimum display configuration. "Display configuration" used in this context refers to the amount of augmentation in the display presentation, the amount of augmentation of controls, or the sequencing of tasks in the cockpit. Each paper presented reported on a methodology which had been utilized to define a display configuration in a system application. A maturity in the use of these techniques was evident in these presentations. The papers presented in the symposium are representative of a much larger number of techniques.

Two difficult decisions were approached by the contributions to this conference. The first was the task of defining the levels of automation in a flight control task. These techniques utilize the reduction of workload with increasing augmentation as a guide to establish the proper level of automation. The other techniques involved methodologies where all of the various tasks which must be accomplished by the pilot can be totalled up and a gross estimate of workload assigned. As mentioned before, the results of these efforts are difficult to interpret and can be severely limited in application by the necessary study constraints. However, these techniques can give a good first approximation, early in the cycle and may provide sufficient information at the time critical decisions must be made.

There are a significant number of reservations which are expressed by the community in accepting the results of these studies. On the other hand, these studies can be extremely valuable in evaluating the optimum decision alternatives in the conceptual stages of a design. However, it will be necessary to improve, refine and validate these models and procedures in order to improve our ability to predict the effects of variations in design configurations upon system performance.

4.2 CRITERIA FOR SPECIFIC APPLICATION OF GUIDANCE AND CONTROL DISPLAYS

The general criteria which were discussed in Section 4.1 are applicable to all display investigations. These techniques could ultimately be applied to certain special applications and project the optimum design criteria. There is effort spent on special types of displays for guidance and control. These will be discussed in this evaluation as: (1) types of displays; such as head-up displays (HUD), multi-format displays and map displays, and (2) mission specific displays; such as vertical take-off and landing and high performance vehicle landing displays.

4.2.1 Head-Up Displays

The head-up display (HUD) is a "see through" display in which symbology can be projected against the real world background. Papers number 14 and 18 discussed this technology. The present state of affairs in HUD displays is well reviewed in the conference proceedings. These devices are projected to be an integral part of all strike aircraft in the foreseeable future. The critical issues are well-defined in the conference proceedings. Any attempt to increase the accuracy of weapon delivery in the near time frame will ultimately hinge around the accuracy of the head-up display.

Proposed in the conference was a means of overcoming the 15 degrees field of view restriction which presently exists as well as providing the capability of a 3D presentation usable for landings. The present situation in HUD is that displays are technology limited. Improved performance will result from advances of the type proposed.

Effort is still required to define the proper allocation of functions to the HUD as opposed to the Head-Down or Vertical Situation Display. Questions are still unanswered concerning the allocation of computer capacity to the display, i.e., should each display have its own computer? These and other questions reinforce the objective of a systematic approach to design.

4.2.2 Multi-Format Displays

The integration of information presented on many display faces is required by space constraints in the modern day cockpit. This is presently possible through the use of electronic multi-function displays. Papers numbered 15 and 16 gave a review of the status of these display criteria. It is proposed that electro-mechanical displays will soon be replaced by all electronic multi-functional displays. The trade-off between computer and display and the relationships between other computers and displays must be defined by a systematic approach. Significant deficiencies presently exist in defining the criteria for this type of display. Technological advances in materials and methodologies must be encouraged to insure that these displays will be effective.

4.2.3 Map Displays

The necessity for an attack pilot to maintain his geographic orientation in nap of earth flight is obvious. Map displays are the means by which this is accomplished in modern attack systems. Papers 12 and 13 give a very thorough review of this type of display. An objection on the lack of design criteria for map displays would be valid; however, it is encouraging to note that analysis and experiment are presently in progress to properly define map displays. The papers presented in this conference identify the capability and limitations of this particular type of display and are a valuable reference for anyone attempting to establish state-of-the-art in map displays.

4.2.4 VTOL Displays

Significant among all application areas was the interest in VTOL displays. There are a significant number of problems in instrumenting a VTOL vehicle. The principle problem is lack of experience in VTOL transitions in any but visual conditions. The display problem in VTOL is compounded by the requirement for the vehicle to transition from a conventional (aerodynamic) mode of flight to a vectored thrust (hovering) mode of flight in instrument conditions. The ability to conduct such transitions is a requirement for all-weather operations. The capability to perform such a transition is tied to the display/control augmentation trade-off. The transition must also be conducted in an optimum manner due to the high consumption of fuel utilized in the transition and hover. All of these requirements must be merged to result in proper display design criteria. The papers (9, 10, 11) in this conference outline critical issues and propose alternative solutions to the problem. No validated flight test data exists, however, a significant number of simulation results are available to propose that IFR flights are possible within 2 to 3 years.

4.2.5 High Performance Landing Displays

The successful landing of high performance vehicles in blind conditions was discussed at this conference. This is a significant guidance and control problem due to the shrinking of safe envelopes of operation and increasing approach speeds. The aircraft dynamic response and the display dynamics are confounded in the analysis of landing displays. However, the proper mix of display augmentation for a given aircraft application can be estimated from simulation. The concepts presented in this conference (21, 22) did consider displays for automatic landings and it was concluded that the primary display requirements for an automatic system are the same as for a manual system. In both of the papers it was indicated that with proper displays, pilots can perform the landing task adequately either manually or automatically.

4.3 NEW DISPLAY MATERIALS

New solid state display technologies were reviewed in papers numbered 17 and 20. Recent advances in solid state technology and space flight instrumentation make the use of luminescent display materials appear feasible. Life times and brightness are acceptable. The cost of such displays and spectrum (color) still appear to be problems. A new concept of a three dimensional volume display was presented. This is a research item which may have broad application. The paper (19) dealt with concepts only and had little or no feasibility of application in the near future, but does offer a new approach to the display of information in future cockpits. There are a significant number of other new concepts in aerospace electronic and optical materials which were not covered in this conference, most noteworthy of which are plasma display panels, liquid crystal displays, and fiber optic data transmission techniques.

5. CONCLUSIONS

One of the most difficult aspects of establishing a set of conclusions is to base these conclusions, solely, on results of the conference. In a conference of this type, with the large number of representative disciplines, it is difficult to maintain the necessary objectivity. The twelve conclusions which follow represent the best summation possible by the author but do contain an awareness of other issues that may or may not be gleaned from the conference proceedings.

5.1 It is possible to structure each AGARD conference differently to stimulate the maximum exchange of information from all participants. This, however, will require a knowledge of the technologies, the critical issues, the present design limitations, and the proclivities of the participants.

5.2 A systematic approach to the proper design of displays for guidance and control is necessary if not critical to achieving design objectives. This approach does not exist today.

5.3 A maturity in methodologies for achieving the proper design criteria is greater than thought by many program managers. Early utilization of these techniques would answer some, but not all, of the critical questions at the required time in the cycle.

5.4 Much of the basic psychological and physiological data is not in a form usable for direct application to defining display criteria. Therefore, it is not possible even to identify the missing data.

5.5 Many established positions or ways to approach the problem of identifying a systematic approach exist today. One must keep in mind the assumptions (i.e., study constraints) which are implied in these techniques. With this in mind, many techniques are available for use at the present time.

5.6 Visual data on the use of color must be carefully analyzed. It is possible that the proposed use of color in an aircraft display may confound the situation rather than enhance performance.

5.7 Workload as a performance index can be a valuable tool. However, one must mix in a significant amount of operational experience in validating the criteria resulting from each investigation.

5.8 The allocation of computer augmentation into the many possible sub-systems (i.e., controls, displays) must be resolved through the use of a systematic approach. The proliferation of dedicated computers which is existent in many present day systems leads to intolerable costs and the unnecessary complexity mentioned earlier.

5.9 The display design criteria for Head-Up Displays or Map Displays will soon, if not now, be in an acceptable form. The criteria for multi-sensor, multi-format displays are in need of more quantitative data.

5.10 Vertical take-off and landing displays are critical to the all-weather operation of these systems. The simulation phases of potential formats have proposed that all-weather IFR transitions will be successful. Flight test should confirm or deny these conclusions within 2 or 3 years.

5.11 Landing displays have been evaluated for the high performance blind landings. Simulator results and flight tests demonstrate that techniques are available which could be used for manual, as well as automatic systems.

5.12 New technology in display media will enhance performance. With the exception of matrix displays, new technology will most probably enhance such parameters as weight, space, flexibility, cost, reliability, etc. while maintaining the presently established levels of intensity, resolution, etc.

6. RECOMMENDATIONS

(a) A guide to possible formats for AGARD symposia should be developed for program committees. This guide should present the many possible formats and approaches which exist for achieving desired conference objectives. The program committee of each conference should utilize such a guide in structuring the symposia after the responses to the Call for Papers are received.

(b) The utilization of design methodologies (i.e., systematic approaches) to generate criteria for aerospace development programs should be encouraged and the necessary research supported.

(c) The definition of specific quantitative design criteria for displays controls and computers should be encouraged and supported.

(d) The Guidance and Control Panel should continue in its effort to identify the critical issues through interdisciplinary conferences sponsored and supported by other AGARD panels.

REFERENCES

Papers contained in AGARD Conference Proceedings No. 96
"Guidance and Control Displays"

		TOPIC I - VISUAL CRITERIA FOR G&C DISPLAYS
1.	CAPT K. T. Burnette	The Status of Human Perceptual Characteristic Data for Electronic Flight Display Design
2.	Ralf Beyer	A Limited Study of the Trade-Off Between Luminance and Color Coding in Electronic Aircraft Displays
3.	John A. Barnes	What Color Display Element
		TOPIC II - WORKLOAD CRITERIA FOR G&C DISPLAYS
4.	Dr. J. V. Murphy B. S. Gurman	The Integrated Cockpit Procedure for Identifying Control and Display Requirements of Aircraft in Advanced Time Periods
5.	O. H. Lindquist	Design Implications of a Better View of the Multi-Channel Capacity of a Pilot
6.	W. F. Clement D. T. McRuer H. R. Jex D. Graham	Systematic Manual Control Display Design
		TOPIC III - VALIDATION OF DESIGN CRITERIA FOR G&C DISPLAYS
7.	Dr. K. F. Kraiss	A Symbol Generator for the Human Engineering Evaluation of Integrated Displays
8.	Dr. F. Seifert	A Method of Man-Display/Control System Evaluation
		TOPIC IV - DISPLAYS FOR G&C OF VTOL AIRCRAFT
9.	Professor L. Young	Integrated Display Principles and Some Applications to VTOL Aircraft
10.	H. J. Kornstadt J. Pfenningstorf	Evaluation of an Integrated Flight Display for the Manual IFR-Landing of VTOL Aircraft
11.	D. J. Walters Ralf Beyer	V/STOL Displays for Approach and Landing
12.	T. S. Briggs	A Navigation Computer and Display Unit for Harrier
		TOPIC V - DISPLAYS FOR SPECIFIC APPLICATIONS
13.	Dr. J. J. McGrath	Contemporary Map Displays
14.	J. H. Smith	The Impact of Advancing Technology on the Evolution of Electronic Head-Up Display System
15.	P. A. Learne D. W. Hussey	Operational and Engineering Aspects of Multi-Function Displays
16.	M. J. Jullien	Systeme Integre de Controle et de Commande des Avions
		TOPIC VI - NEW TECHNOLOGY FOR G&C DISPLAYS
17.	Dr. P. M. Hemenger	Materials and Technology for New Information Displays
18.	J. A. La Russa	Multi-Purpose Wide Field, Three Dimensional Head-Up Display for Aircraft
19.	Dr. J. D. Lewis G. P. Walling	A Flat 2-D or True 3-D Display
20.	J. Koprowski	Space Technology Applications to G&C Displays

TOPIC VII - TESTING AND EVALUATION OF G&C DISPLAYS

21. Dr. K. D. Cross F. R. Cavallero	Utility of the Vertical Contact Analog Display for Carrier Landings - A Diagnostic Evaluation
22. E. M. Bobbett K. Woodruff	Rate of Closure as a Performance Monitoring Parameter
23. LT D. L. Turney	The Electroluminescent Panel Lighting Research Program

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