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NASA Technical Memorandum 78512 HUD Report 1

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Project Plan for Joint FAA/NASA Head-Up Display Concept Evaluation

(NASA-TM-78512) PROJECT PLAN FOR JOINT FAA/NASA HEAD-UP DISPLAY CONCEPT EVALUATION (NASA) 16 p HC A02/MF A01 CSCL 05A

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NASA
National Aeronautics and Space Administration

Department of Transportation
United States of America

Project Plan for Joint FAA/NASA Head-Up Display Concept Evaluation

Federal Aviation Administration
Systems Research and Development Service, Washington, D. C., and
Ames Research Center, Moffett Field, California

NASA
National Aeronautics and
Space Administration

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PREFACE

This report contains the official project plan of the joint FAA/NASA Head-Up Display (HUD) Concept Evaluation Project originally approved August 1977 and revised on December 12, 1977. This plan is reproduced in its entirety except for fiscal data and has been reproduced as part of a series of technical reports documenting laboratory and simulator research conducted under this project. It should be understood that this plan is subject to minor changes as new methodological approaches are discovered. However, the basic research issues discussed here form the fundamental core of activities planned.

PROJECT PLAN FOR JOINT FAA/NASA HEAD-UP DISPLAY CONCEPT EVALUATION

Federal Aviation Administration
Systems Research and Development Service

and

Ames Research Center

1.0 INTRODUCTION

This Plan documents the requirements and describes the plan for the evaluation of the Head-Up Display (HUD) concept for large commercial turbojet transports. This project was initiated by letter from the FAA Flight Standards Service Director (AFS-1) dated April 20, 1976, requesting that the FAA Systems Research and Development Service (SRDS) perform a research, development, and evaluation program of the HUD system concept. In a letter dated September 2, 1976, the FAA Administrator requested that the National Aeronautics and Space Administration join FAA in a cooperative effort to investigate the safety potential of HUD. As a result, Task Order DOT-FA77WAI-725 to Inter-Agency Agreement NASA-NMI-1052.151 identifying the extent and the scope of the work to be performed was approved on March 9, 1977.

2.0 OBJECTIVE

The primary objective of the HUD Evaluation Project outlined below is to determine the contribution, if any, of a HUD to aviation safety in the form of improved performance in the operations of large turbojet aircraft during approach and landing. To accomplish this objective, consideration will be given not only to the possible benefits of a HUD but also to the possible limitations that may arise and to any possible detrimental effects or hazards that a HUD may create in the operational environment.

3.0 SCOPE

The performance of the HUD and its effect on the conduct of all-weather flight operations in the approach and landing phase will be examined in critical detail in laboratory, simulation, and flight tests. The primary emphasis of this evaluation will be safety-related and will concentrate on the contribution of the HUD to flight safety in the operation of large turbojet aircraft. Other factors such as installation and maintenance costs, reliability requirements, and cost effectiveness will not be addressed at this time.

Funding and manpower constraints will limit this evaluation to the approach and landing phase only. Further, these constraints will limit the evaluation of the HUD concept to its interrelations with current conventional cockpit instruments only. At some future date, serious consideration must be given to the concept of a totally integrated electronic cockpit display system evaluating the role and concept of the HUD as an integral part of the total all-weather landing system.

4.0 BACKGROUND OF THE APPROACH AND LANDING PROBLEM

Approach and landing accidents continue to occur in air carrier operations in spite of considerable technological improvements in the field of approach guidance systems and in spite of a continuous upgrading of cockpit procedures and crew coordination. Factors such as the increasing number and complexity of cockpit instrument displays, transition to high-performance aircraft, and the lowering of the landing weather minima, have in the past decade increased the demands placed on the flight crew. These factors, combined with the increased volume of air traffic in the terminal areas and increasingly complex air traffic environment, have added significantly to the workload in the cockpit.

A recent National Transportation Safety Board (NTSB) survey of low-visibility approach and landing accidents and incidents from 1968 through 1972 revealed that 47% of the air carrier landing accidents occured during precision Instrument Landing System (ILS) approaches. More recently, a survey of 17 ILS approach accidents and incidents during the years 1970 through 1975 disclosed that almost every mishap occured after the flight crew had seen the ground, approach lights, or runway scene. In several cases, this study disclosed that the pilot(s) had trouble in visually judging the flightpath or the descent angle, particularly in low or obscured visibility. While there is an urgent need to explore those factors affecting the aircraft and its crew performance, considerable controversy still exists as to which factors are primarily responsible for these approach and landing accidents. This National Transportation Safety Board accident survey cites human error as the primary cause for most approach and landing accidents. However, in rebuttal, pilot organizations, while admitting some partial pilot factors, claim that the real culprit is poor cockpit instrument format and location. In the landing task, where there is little margin for error, the crew may not have sufficient time to adequately evaluate both instrument and visual cues at the decision height when using today's conventional aircraft instruments and when following currently established flightcrew procedures. They also cite shortcomings in the design of conventional cockpit instruments contending that they do not provide adequate cues for rapid detection of glidepath dispersions. The difficulty that pilots have in rapidly detecting and correcting dispersions caused by wind shear or turbulence when using conventional displays, the presence of visual cue illusions, and the lack of vertical guidance cues when reverting to head-up viewing (particularly at night), are also cited as major problem areas. Inadequate time for the pilot to assess the outside visual cues from decision height (DH) to touchdown in low visibility is often cited as one of the more significant problem areas in the see-to-land concept. Some studies have concluded that 4 or 5 sec may be required for the pilot to refocus his eyes and transfer his attention from head-down instrument guidance to the head-up position before he can accurately assess the visual scene.

This suggests that the aircraft may possibly descend below the DH for as long as 4 or 5 sec before the decision to land or go around is made. If so, the margin of error is further degraded. However, this assumption may or may not be valid, because the decision-making process is an accumulative one, continuing throughout the approach for some time prior to arrival at the decision height. The need for one crewmember to monitor the flight instruments throughout the approach is well recognized as a desirable safety procedure; however, there is evidence that this procedure is not always being followed, particularly after the first visual cues appear during the approach. A recent USAF study concluded that once the ground or runway appears there is some reluctance to return to the cockpit instruments, even when encountering marginal visibility later in the approach.

Research must continue into means of optimizing crew procedures and refinement of present day instruments in the hope of determining more efficient and safe means of operating with today's conventional electro-mechanical instrument systems. In the meantime, serious consideration must be given to the more flexible advanced electronic display systems which may offer the crew a more precise and efficient means of performing the landing task.

A proposed alternative to conventional cockpit instruments is the HUD, an electro/optical system which displays instrument guidance information on a semitransparent glass combiner plate located above the instrument panel in a direct line with the pilot's view of the outside world. Proponents claim that the HUD provides total and simultaneous access to both outside visual reference and to instrument guidance information displayed on the unit's combiner plate. Two of the most important advantages often claimed are:

1. The HUD provides the pilot an easy transfer from instrument flight to visual flight because the instrument guidance information is displayed within the pilot's viewing area of the outside world. It eliminates the 4- or 5- sec head-down to head-up transition period, therefore providing valuable additional time for assessment of the visual scene.

2. The HUD provides the pilot with a more accurate means of obtaining relevant information concerning vertical flightpath guidance on a one-to-one real-world scale. Sighting angles of 1° or 2° are readily discernible on the one-to-one scale of a HUD but cannot necessarily be detected readily on panel instruments. This allows better detection of vertical flightpath deviations, thus decreasing the probability of undershooting and overshooting the runway.

The HUD concept is not without its critics who point out that today's approved approach and landing operations are more than adequate for conducting safe transport category all-weather operations and have been so proven over the years. To date, there have been no recorded accidents in certified Category II operations. The present concept for Category IIIA calls for a fully automatic approach and landing, which could well reduce the role of a HUD system to that of a monitor.

There are other critics who question the reliance upon external visual cues in low visibility because of the deceptiveness and the difficulty in interpretation of cues. The HUD's combiner glass has no unique way of increasing visual acuity in a degraded scene, other than by the addition of a contact analog runway scenario. The question may be raised "Does the HUD really improve the pilot's performance in the see-to-land concept, assuming that a few seconds may be saved in the assessment time, if the outside scene is degraded by the reduced transmissivity of the optics that are used?" There is some evidence that the added symbology on the HUD combined with the outside scene may distract, distort, or otherwise divide the pilot's attention to a point where he may lose the ability to detect important changes in both instrument and/or outside visual cues. There may be other arguments, both pro and con, that must be addressed prior to the acceptance of an airborne display system as sophisticated and costly as the HUD. All of these factors, suppositions, claims, and counterclaims must be thoroughly investigated because of the impact which the HUD concept may have on future airline operations.

It is unfortunate that in the past and indeed, today, the HUD concept has been judged to a great extent by intuitive feelings and highly emotional views by both sides. To date, however, very little quantitative data have been gathered, particularly in the human factors field and relatively little airline operational experience exists. Although the military has accumulated more than 10 years of HUD operational experience, the particular problems to be addressed in this evaluation do not relate to the military mission oriented HUD design.

Some of the basic problem areas that must be addressed during the project are as follows:

1. What are the operational problems that a HUD will solve?

2. What and how much does a HUD contribute to aviation safety?

3. Will the use of a HUD create some new problem area(s) not previously encountered, and what will the human reaction be to these conflicts?

4. In what role(s) will a HUD enhance operational performance, and how effective is it?

This evaluation project must, by necessity, be heavily oriented toward gaining a better understanding of the various human factor relationships which exist between the crew and the HUD system. It will explore some of the more familiar human factors concepts such as crew workload, cockpit coordination procedures, visual illusory effects, and system-induced problem areas. As stated before, time and manpower constraints will limit the evaluation to the approach and landing phases of flight only. The goal of this project is not to develop HUD hardware or system design criteria but to evaluate the HUD concept, as to its influence on human performance in the cockpit and its contribution to aviation safety.

5.0 PROJECT DESCRIPTION

The specific HUD evaluation project which is outlined in the following section will investigate the advantages and disadvantages of the HUD concept in operations of large turbojet aircraft during approach and landing. Factors such as easing the transition from IFR to VFR conditions, reducing touchdown dispersions on short runways, stabilization of the flightpath on precision and nonprecision approaches, and detecting and coping with wind shear will be addressed. The project will yield sound objective data relating HUD optical, perceptual, and human factors characteristics to aircraft control under operational conditions. These data will be of benefit to both the FAA and the civil and military aviation community.

The following paragraphs will describe three parts of the project consisting of a background review, basic laboratory and simulation experiments, and a full crew operational simulation evaluation.

Part I: A comprehensive background review and documentation will be conducted jointly by FAA and NASA. This review will provide the experimenters with the latest information on the state of the art of both military and civil HUD hardware and will provide the rationale for determining the selection and priority of the specific items to be addressed during parts II and III that follow. It will also serve as a current status document of past HUD research efforts and will prevent needless duplication. The FAA will be responsible for preparation of the review report.

Part II: This part will comprise the basis laboratory and simulator tests on HUD concepts and will be conducted by NASA-Ames Research Center. It includes questions which have not yet been addressed by others or which require further investigation as indicated by the review. These initial studies will provide data for the selection of the most potentially adequate candidate HUD. A candidate HUD is defined as an optical device whose display characteristics have been shown to contribute to the most efficient all-around pilot control of his aircraft during approach and landing under operational conditions.

Part III: This part will consist of a full crew operational simulation evaluation of the candidate HUD under conditions as close to the operational environment as possible, comparing pilot performance both with and without the use of the HUD. Accomplishment of this part of the effort will be the responsibility of NASA-Ames Research Center.

5.1 PART I. HUD BACKGROUND REVIEW

1. A comprehensive literature search will be conducted including domestic and foreign literature in order to determine the state of the art related to HUD concepts, symbology, hardware, and prior experiments and analysis. This will be a joint FAA/NASA effort in which close collaboration will be maintained in order to minimize duplication of effort and proper documentation.

2. HUDs now in service will be reviewed both through on-site visits to HUD manufacturers and users (military and civilian) and/or visits by HUD manufacturers and users to NASA facilities, as appropriate. These visits will be made by either FAA and/or NASA personnel as necessary for the adequate performance of this project.

3. Persons knowledgeable in HUD research studies, simulation, flight tests, and operational use will be appropriately surveyed with regard to such HUD factors as symbology/format, information content, mission-related effectiveness, etc. In addition, the findings of previous HUD surveys will be reviewed and analyzed.

4. Based upon the findings of the above activities, a determination will be made of the potential advantages and disadvantages of the HUD concept. This will be done to insure that these factors will be adequately evaluated in the research to follow. Information will be collected concerning what kinds of information pilots require for acceptable aircraft control during approach and landing. This will be related to current flight deck task analyses, taxonomies, display symbologies, and display techniques.

5.2 PART II. LABORATORY AND SIMULATOR TESTS TO SELECT CANDIDATE HUD

Each experimental research area to be addressed will include the following steps: (1) establish the research objectives (based upon the findings of Part I); (2) design the experiments with the primary emphasis upon HUD safety-related functions, outline the relevant test parameters, performance measurement techniques, analysis requirements, and data base; (3) establish the requirements for the testing environment (simulator, laboratory, other); (4) define the number, type, and qualifications of test subjects, (5) develop appropriate means of assessing the test participants' prior attitudes and opinions regarding the HUD concept, and (6) prepare the test facilities (hardware, data collection/analysis systems, etc.).

5.2.1 Research Area 1. Title: "Perceptual Evaluations of Existing HUDs" (Experiments 1A, 2A, 2B, 3A, 3B, 4A, 4B)

Objectives and Approach: To critically and systematically evaluate the most important human perceptual response capabilities, using several existing operational HUD systems which have undergone optical evaluations. A question of major interest is what the HUD can contribute in the critical IFR to VFR transition phase of the approach in terms of providing necessary and sufficient vertical quidance information within a relatively short period of time. Some of the perceptual characteristics of the pilots which will be quantified include: capability of rapidly and accurately obtaining relevant flight information from different HUD symbologies versus standard cockpit instruments versus outside scene (simulated); time required, accuracy, and procedures involved in assessing available information which is of a discrepant nature (e.g., a conformal HUD display of a runway trapezoid which is out of registration with the runway seen out of the window); and the relative dependence of the pilot upon HUD-provided information versus out-the-window information in conditions in which the atmospheric visibility is intermittent.

The question "Can pilots become 'transfixed' or 'fascinated' by the collimated HUD image(s) and what is the resultant implication(s) for HUD symbology format/luminance/etc., design characteristics?" will be addressed.

5.2.2 RESEARCH AREA 2. Title: "Symbology Evaluations of Existing HUDs" (Experiments 1A, 1A[1])

Objectives and Approach: To critically and systematically determine the pilot's ability to detect, recognize, and use HUD information during the approach and landing phase of flight-given various display symbologies. Initial studies will focus upon such display characteristics as scale factor, legibility, and layout format. Later studies will concentrate upon optimizing information transfer related to vertical guidance information in low-visibility conditions. In support of the above experiments, it will be necessary to evaluate the perceptual fidelity of the outside scene generator's dynamics and related visual characteristics. It is planned that the current low-visibility scene generators used on NASA-Ames' simulators will be empirically validated and upgraded, if necessary, so as to more nearly correspond with real-world visibility. In this way, the simulator evaluations of the candidate HUD, derived from other parts of this project, will be made more valid.

In order to select the candidate HUD for use in the full-crew operational simulation evaluation program, it will be necessary to critically and comprehensively evaluate all prior experimental data obtained. These data will be compared to previously obtained data from other HUD programs (where possible) in order to help insure that all key display factors have been taken into account. This evaluation effort will provide data for selection of a candidate HUD that will be used in the full-crew simulation to follow. It is hoped that the present state of the art is such that an existing HUD may only require minor modifications, if any.

5.2.3 Research Area 3. Title: "Initial Piloted Simulation Tests of Selected Existing HUD Concepts" (Experiments 1B, 1B[1], 8)

Objectives and Approach: To make a preliminary assessment of several HUD symbology formats, to develop evaluation techniques, and to carry out preliminary tests of these techniques. A series of integrated, moving-base simulation studies will measure such parameters as glide-path tracking accuracy, air-speed control, opinion ratings of pilot users of the HUD(s), etc. The possibility exists for monitoring pilot eye movement as well. These tests will be conducted in the Ames' Flight Simulator for Advanced Aircraft (FSAA), and other facilities using medium jet transport dynamics, collimated Redifon display, and computer-generated HUD. Of particular concern will be the determination of what role HUD plays in providing necessary and sufficient vertical guidance cues in reduced visibility conditions.

5.2.4 Research Area 4. Title: "Optical Evaluations of Existing HUDs"

Primary Objective and Approach: To obtain quantitative and qualitative data on several existing operational HUD systems which will allow for a systematic, critical comparison between their optical characteristics and their perceptual, human factors, and other features to be determined in later experiments. These empirical tests will measure and evaluate such parameters as collimation accuracy, exit pupil dimensions (related to pilot head movement tolerances), combiner plate transmissions, etc. Since the basic optical characteristics of a HUD play a vital role in determining its eventual perceptual adequacy, it is essential to understand the relationship between these two factors before attempting to discover the (potential) causes of more subtle sources of difficulty in the information transfer process.

5.3 PART III. FULL CREW OPERATIONAL SIMULATION USING CANDIDATE HUD

This phase of the HUD evaluation project will be conducted by NASA with FAA assistance. Once the candidate HUD has been selected and made operational for simulator tests, it will be installed and checked out in an appropriate simulator facility. The final choice of the type of aircraft simulator to be used will primarily depend upon the research findings of the test planning phase outlined above in Part II and upon the availability of facilities.

Questions such as "How should a HUD be operationally integrated into the cockpit?", "Will the use of a HUD increase stabilization of the flightpath in nonprecision approaches or reduce touchdown and/or glidepath dispersions in low and/or intermittent visibility conditions?" will be addressed in this part of the project. The incorporation of the candidate HUD into the cockpit, which also involves full-crew coordination, may also potentially identify further advantages and disadvantages of the HUD concept. Changes in current crew procedures resulting from the use of the HUD may also become apparent.

The following basic steps will be followed in the conduct of Part III: (1) establish the research objectives (based upon the findings of Part I and II), (2) design the evaluation experiments, (3) obtain and install the necessary data collection/recording/management systems in the simulator, (4) develop all required test procedures, pilot questionnaire, and schedules, and (5) select and train subject pilots for the simulation exercise(s). The full-crew operational simulation evaluations of the candidate HUD will follow.

Since the many complex and interacting factors which are involved in the development of the candidate HUD will have been (primarily) determined during the end of Part II of this project, it is anticipated that only minor modifications in HUD symbology/format will be required during Part III. Consequently, it will be possible to concentrate upon those questions which are more related to operational issues, cockpit procedures, and overall engineering design factors. Close communication between the cognizant FAA program manager, experimenters, and potential HUD users will be maintained during this part of the project.

6.0 REVIEW AND ANALYSIS OF THE LABORATORY AND SIMULATOR DATA

An in-depth review of the data obtained from the entire project will be performed. In addition, a concurrent flight-test program will be conducted at the National Aviation Facilities Experimental Center (NAFEC) in Atlantic City by the FAA. Relevant data concerning the candidate HUD display found during this review phase will be directly applicable to the development of the test plan for flight tests. The NASA will assist the FAA in the flight-test program planning. A flight-test program plan will be produced as a separate document and will be inserted as an addendum to this plan.

7.0 PROJECT DOCUMENTATION

In order to make the results of this evaluation project available to the FAA in a convenient and timely manner, the interim findings from the NASA portions of the project will be sent to the cognizant FAA program manager as they become available. It is anticipated that each NASA experimenter will prepare reports on his part of the project and will decide the most appropriate form of publication. Nevertheless, it is necessary that the cognizant FAA program manager has the opportunity to read and comment on prepublication drafts of these reports. This will not only insure the timely transmission of information during the on-going project to the FAA but will also help facilitate the inclusion in these reports of the FAA's point of view and related findings.

At the conclusion of Part II, the NASA project manager will prepare a report for the FAA, documenting the background, methods, results, and preliminary conclusions/recommendations derived up to that point. It is anticipated that these recommendations will address the implications of the various results obtained by NASA for the planning of Part III. Of particular concern will be the documentation of the optical, perceptual, and human factors findings obtained during Part II of this project. This effort will constitute a separate technical report(s), if necessary (depending upon the progress and success of Part II of the project).

A final report will be prepared at the conclusion of Part III of this evaluation project and will fully document the results of the full-crew operational simulation evaluation of the candidate HUD portion of the project. It will include sections dealing with the advantages and disadvantages of the use of HUD in the operational environments which were studied and those clearly defined implications for redefinition of crew roles (where called for). It will also provide the test data in a form which will be of most use to the FAA in making the subsequent decisions regarding HUD implementation and certification criteria, if proposed.

8.0 MANAGEMENT RESPONSIBILITIES

Overall program management and responsibility for coordination with the major participating organizations including NASA, FAA, DOD, airlines, and manufacturers will be maintained by the FAA Airborne Systems Branch, ARD-730. Management of the various program elements will be the responsibility of the organization having the primary role in each task. Responsibility for day-to-day coordination may be delegated to on-site personnel and will be documented by the respective program manager.

Program managers for each program phase are as follows:

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Phase IV Mr. Robert H. Pursel National Aviation Facilities Experimental Center (ANA-310) Atlantic City, New Jersey 08405	________________

Each program manager is responsible for the planning, directing, and monitoring of progress of all related efforts falling within the area of his responsibility. Because of the wide interest that is likely to be shown in the development of the HUD concept, it will be necessary to maintain a very close coordination of efforts between the principal organizations of the program. This will necessitate almost daily contact by phone, in addition to quarterly progress reports, planning conferences, and frequent project meetings.

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15. Supplementary Notes

16. Abstract

This report documents the requirements and describes the plan for the evaluation of the Head-Up Display (HUD) concept for large commercial turbojet transport aircraft. The primary objective of the project is to determine the contribution, if any, of a HUD to aviation safety in the form of improved performance in the operation of large turbojet aircraft during the approach and landing phase of flight. Each of the five project phases is described in some detail, as are the basic research areas to be addressed. These areas represent fundamental questions that are still unresolved and which are considered important to the effective use of the HUD by pilots. Project documentation and management responsibilities are outlined.

17. Key Words (Suggested by Author(s))

Head-up display
Flight guidance information display
Computer-generated display
Technical program plan

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