# VISUAL PERFORMANCE MODELING IN THE HUMAN OPERATOR SIMULATOR

Melvin I. Strieb
Analytics
Willow Grove, Pa.

## ABSTRACT

A brief description of the history of the development of the Human Operator Simulator (HOS) model is presented. Features of the HOS micro-models that impact on the obtainment of visual performance data are discussed along with preliminary details on a HOS pilot model designed to predict the results of visual performance workload data obtained through oculometer studies on pilots in real and simulated approaches and landings.

## INTRODUCTION

The HOS model has been under development for approximately 10 years. The concept behind the model was formulated by Wherry (Ref. 1) in 1969. Analytics began the task for formalizing Wherry's ideas and converting them into a functioning model (Ref. 2) in 1971. Development of the basic model was completed in 1976 (Refs. 3, 4, 5, 6, 7, 8) when the model was first applied to a major Naval weapons system (Ref. 9). Since that time, the model has been applied to several other Naval systems (Refs. 10, 11, 12, 13). Each application has resulted in an increasing confidence in the validity and generality of the model and in an expansion of its range of applicability to more and more complex situations.

HOS developed as a result of Wherry's work in the field of crewstation design, test and evaluation. He recognized that the task analyses that were being prepared for the Navy suffered from several major flaws. First, the analyses never adequately expressed what was expected of the operator. Tasks were specified at varying and usually macroscopic levels of detail (e.g., "Pilot acquires and locks on target") and the times assigned to activities were, at best, educated guesses. The analyses would never indicate that the operator was too busy to perform all the assigned functions (though in actual operational situations, the operator might have been) because the analyses were being prepared by equipment manufacturers who had vested interests in making their systems look good. The analyses did not realistically represent either the dynamics of interactions between mission functions or the interactions between the external world and operator activities.

Wherry concluded that, since there were not standards that the Navy could apply to ensure an unbiased and consistent evaluation, the structure of a task analysis, its level of detail, and its insensitivity to variations in crewstation design did not permit the realistic evaluation of design alternatives. Proposed designs could still only be evaluated by building mockups, simulators, and prototypes and running subjects through test scenarios. But such studies, in addition to being costly, time-consuming and confounded by inter-subject variability, could only be performed so late in the design process that the results of the studies could have only minimal impact on the ultimate system design.

Wherry proposed the development of a computer simulation model that would be capable of simulating an operator in a complex crewstation to the level of detail needed for realistic evaluation of alternative designs within the context of simulated missions. The model would be capable of producing the types of data that had been obtainable only from man-in-the-loop experimentation. The characteristics of the crewstation, the performance requirements of the operator and the details of the missions that could be specified to the model were to be completely general. The simulation would become a specific operator with specific tasks to accomplish when the analyst supplied a description of the crewstation, the procedures the operator was to follow to utilize the equipment and a description of the behavior of the external world, just as a human being becomes the operator of a system when placed in a crewstation, told how to use the equipment and given a specific job to do.

To facilitate the process of defining the crewstation, the operator procedures, and the external world, an English/FORTRAN-like language -- the Human Operator Procedures (HOPROC) language -- was developed. HOS translates HOPROC statements describing macro-level operator actions into micro-level activities whose performance times are dependent on basic human performance characteristics and the mission dynamics (Ref. 14).

The HOS approach differs significantly from the approaches used in models like SAINT (Refs. 15, 16, 17, 18), Siegel-Wolf (Refs. 19, 20, 21), TLA (Refs. 22, 23) and the various control theory models (Refs. 24, 25). The essence of HOS is an *explicit model of the operator* and of how the operator translates procedural statements into activities. Underlying the HOS model is the assumption that human performance (in general) and the performance of a well-trained operator (in particular) is *explainable* as the concatenation of micro-activities. The performance time for each micro-activity is *predictable* and expressed functionally by the micro-model for that micro-activity. Since the human performance micro-models are based on experimental data, HOS is not only a means of evaluating complex systems, but also a structure within which experimental models of human performance can be tested and evaluated.

## THE HOS OPERATOR MODELS

There are five major micro-models in HOS -- an anatomy movement model, an information absorption model, a mental computation model, a decision-making model, and a control manipulation model. These models were developed from analyses of both published and unpublished data on human performance.

Where no data or models were found to exist, "common-sense" models were developed. These models can be modified either as new data becomes available or as specific applications indicate the need for model improvements. The models and the sources from which they were derived are discussed in detail elsewhere (Ref. 14). However, for the purposes of understanding visual performance as modeled in HOS, it is necessary to briefly review the eye movement features of the anatomy movement micro-model and the information absorption micro-model and the HOS models of operator variability and error.

## Eye Movement

When a HOPROC instruction (e.g., READ THE ALTIMETER) requires the operator to move his eyes to a specific device, the eye movement micro-model is accessed. This model computes a movement time based on location of the current eye fixation point and the new fixation point. The equations used in this micro-model are based on published experimental data on lateral eye movements (Ref. 26) and data from an unpublished experiment by Wherry and Bittner involving both lateral and convergence movements. Figure 1 indicates the range of eye movement times for situations involving only lateral movements between two fixation points on a plane 71 cm (28 in.) from the operator.

## Information Absorption

The HOS information absorption micro-model is dependent on a *hab strength* parameter, derived from Hull's learning theory habit strength concept. Information is absorbed in discrete chunks (*micro-absorptions*). Each micro-absorption increases the operator's confidence (hab strength) until the operator is sufficiently confident in his knowledge of the value of the device, at which time the absorption process is terminated.

Each micro-absorption results in the addition of a *micro-absorption time charge* whose value is dependent on input quantities supplied by the analyst in combination with characteristics of the device (e.g., whether the device is discrete or continuous, how many settings it has, etc.). Figure 2 indicates how hab strength varies as a function of time for four different devices.

## Operator Performance Variability

The HOS model views operator performance variability as the result of differences in the performance capabilities of different subjects coupled with differences in operator strategies. Differences in performance capabilities are represented by parametric differences in the functional relationships in the micro-models. Differences in operator strategies are representable as either different decision rules in the operator procedures or as differing prioritizations of the operator procedures. By parametrically varying these quantities, HOS can be used to evaluate both the operator performance required by a system and alternative operator strategies and prioritization schemes. The first type of evaluation (operator performance capabilities) can be useful in the process of screening candidate operators. The latter evaluation (strategies and prioritization schemes) can help to develop training procedures that will ensure that operators are trained to optimally utilize the system's capabilities. Although both of these possible uses of HOS have yet to be explored, they were anticipated in Wherry's original conceptualization of HOS. The former was implied by the "o-state" (operator state) concept that allows variations in the operator performance equations throughout the mission; the latter in the criticality values assigned to different operator procedures that can be (and are) dynamically modified throughout the simulation[1] and in the English-like syntax of the HOPROC language that enables the HOS procedures to be used directly as training materials.

## Operator Error

One of the most controversial issues associated with HOS is its model of operator error. To understand this model, it is important to remember that the primary objective for which HOS was developed was the evaluation of the nominal performance of a system by a *well-trained, average* operator. By definition, a well-trained operator is one who carries out instructions "by the book," without omitting a step, making an incorrect decision (based on the decision rules specified in the instruction set), or incorrectly carrying out an instruction. However, this definition does not preclude all sources of operator error. For HOS, the significant sources of operator error are:

(1) Requiring the operator to perform more activities in a given period of time than possible (because of human and/or equipment limitations), thereby causing the operator to "fall behind" in the mission.

(2) Giving the operator an incorrect set of decision rules and/or operating instructions, thereby causing tactical and/or operational errors.

(3) Giving the operator poor displays and/or controls that do not permit information to be read or controlled with sufficient accuracy to permit proper operation of the system, causing errors to occur in carrying out subsequent (or concurrent) operations and/or requiring the operator to invest more time, once again causing the operator to fall behind in the mission.

These types of errors *result* in operator performance errors, but are really failures in the design of the system -- flaws which the human factors engineer must address in proposing design modifications. They are problems created when system designers fail to take into account human performance limitations. Clearly, they are not errors of the same sort as when an operator inadvertently pushes a wrong button -- such errors are either random and of low frequency (in which case it is unfair to use them to evaluate the nominal performance of the system) or caused by working the operator beyond capacity. They are, however, the types of errors that must be engineered out of the system.

## VALIDATION

Validation of any complex model (and particularly a Monte Carlo simulation model like HOS) is fraught with difficulties. One can argue that such models can *never* be fully validated -- the best one can hope for is that in specific situations, given well-defined sets of inputs, the model can be shown to produce the outputs that match expectations, experience and available data. The problem is even more complex with a model like HOS because, unlike simulation systems that manipulate the user's model of a situation (i.e., the inputs) according to incontrovertible mathematical formulae, in HOS there is both the HOS model of the operator *and* the user's model of how the system functions and how the operator will utilize it. Both models must be valid for the results of any particular simulation to be valid. But since human behavior is so complex, one can never be sure that all possible circumstances have been fully described and all possible alternatives foreseen. It is therefore almost impossible to validate any specific model.

Notwithstanding these difficulties, efforts have been made to ensure both the validity of the HOS operator model and the reasonableness of the outputs obtained from specific user models. Tests of the validity of the HOS model have involved simulations of specific experiments drawn from the human factors and experimental psychological literature (Refs. 8, 10, 11). User model validations have included simulations of specific Navy crewstations (Refs. 9, 12, 13). Both types of simulations have confirmed the general validity of HOS.

Although comparing model results with experimental data has generally been straightforward, validation of the model in complex military situations has been problematical because of the difficulties associated with attempting to capture all the potentially significant variables in the simulation. The converse of this problem is also true -- one can establish a scenario that can be run through HOS, but it is difficult (if not impossible) to set up real-world situations (e.g., at-sea exercises) that will conform to the hypothetical situations modeled in the simulations. Further confirmation of the HOS model is expected as the result of a series of HOS simulations coupled with laboratory experiments that are currently in the planning stages. These simulations will attempt to ensure the validity of the model (and will determine the values of certain input data quantities needed by the model) for a range of situations of varying complexity commonly experienced in Naval weapons systems. In addition, an effort is currently underway with NASA Langley that will test a HOS pilot model through its conformance with visual performance data collected by Spady and Kurbjun (Ref. 27). Preliminary details on this model are presented below.

An operator can be modeled as timesharing his attention among a set of monitoring procedures designed to keep specific displayed items of information at their nominal values. For example, in the approach phase of an IFR landing, a pilot timeshares his attention among at least eight different instruments simultaneously -- the ADF, the radar altimeter, the horizontal and vertical situation indicators, the barometric altimeter, the airspeed indicator, the clock, and the flight director. HOS enables the analyst to describe the pilot's monitoring behavior by a set of *monitor* procedures. Each instrument has its own monitor procedure, e.g.:

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DEFINE THE PROCEDURE TO MONITOR THE ALTIMETER.
  IF THE ESTIMATED VALUE OF THE ALTIMETER IS WITHIN LIMITS
  THEN WAIT.[2]
        .
        .
        .
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Such procedures define the actions that the operator is to perform in order to keep the specified instrument within a predefined (and dynamically modifiable) set of limits. These limits, which are defined around a *desired value* (also dynamically modifiable) can be set to a value of zero, in which case the pilot will act like an optimal controller by continuously taking actions to minimize the error. Alternatively, the limits can be set to some non-zero value, in which case the pilot will only take corrective action when the displayed item exceeds its allowable range of variability.

Monitor procedures are executed periodically with a frequency dependent upon a set of decision rules that are part of the HOS decision-making micromodel. These rules use values of how long it has been since the procedure was last executed, how close the device being monitored is to its desired value and the criticality of the device to determine which procedure to work on next. Thus, if all devices are of equal criticality and at their nominal values, each monitor procedure would be executed once before any procedure was executed a second time. By assigning appropriate criticalities to the devices (or to the monitor procedures, themselves), the analyst can control the frequency with which the procedures are executed. When the value of the device differs from the nominal, the HOS decision-making algorithms will perturb the a priori criticalities (and hence the nominal monitoring frequencies) by an amount dependent on the deviation of each device from its nominal value. These changes in the monitoring frequencies correspond to the effects that one sees in a pilot's performance when certain devices become more critical during certain mission phases or when the pilot dedicates more time to maintaining control over certain items because they are harder to control.

Spady and Kurbjun collected (Ref. 27) oculometer data on pilot eye movements during both actual and simulated approaches and landings. Their data functionally describes the variation in the pilot's perceived criticality under varying circumstances. The data on coupled (i.e., autopilot engaged) approaches, for example, (Figure 3), is indicative of operator monitoring frequencies when the operator has a minimum number of functions to perform, i.e., when all devices remain within their limits and no corrective actions are required by the operator.[3] Their data for uncoupled (autopilot disengaged) approaches (Figure 4) indicates how these frequencies change when additional pilot control functions are added. In HOS, this corresponds to increasing the pilot's hab strength thresholds when the pilot is performing the control functions and to the addition of the control activities defined by succeeding statements in the monitor procedures.

It is expected that the HOS micro-models will produce eye movement data directly comparable to the data obtained by Spady and Kurbjun (Figures 3 through 5).

## SUMMARY AND IMPLEMENTATION CONSIDERATIONS

This paper has discussed those aspects of the HOS model pertaining to the modeling of visual performance data and the efforts that are currently underway to confirm the validity of those models.

CDR Norman Lane, Naval Air Development Center, Warminster, Pa., directs the Navy's HOS modeling efforts. The Navy is anxious to encourage others to use the model and will provide access to the model for those wishing to.

HOS consists of three major programs which are in FORTRAN, but use some CDC-specific features. The programs would therefore require some (relatively minor) conversion before they could be used on another computer system. The program is large (it can use $200K_8$ words or more of storage for complex simulations[4]) and, for complex problems, can be expensive to run. However, it offers the potential for substantial savings when used as a substitute for real-time simulations and as a means for obtaining types of data that might be virtually impossible to obtain by any other means. HOS should also be considered as an integral part of the system design process, enabling the human factors engineer to propose, test, and either justify or reject proposed system designs based upon a clear and consistent model of human performance.

## FOOTNOTES

[1]Criticalities can be explicitly modified by procedural statements and are implicitly modified by the model's decision-making micro-model.

[2]This statement can also be written as either

IF THE ALTIMETER IS WITHIN LIMITS THEN WAIT.

or

IF ALTIMETER IS OK THEN WAIT.

or in any one of a number of other semantically equivalent forms. The HOPROC syntactical analyzer program translates them all into a standard form for use by the simulator.

[3]These data are only *indicative* of the monitoring frequencies because the Piedmont 737's flown were not equipped with an auto throttle; therefore, the pilot was required to control the airspeed with the throttle.

[4]A version of HOS that uses the CDC Extended Core Storage facility is also available.

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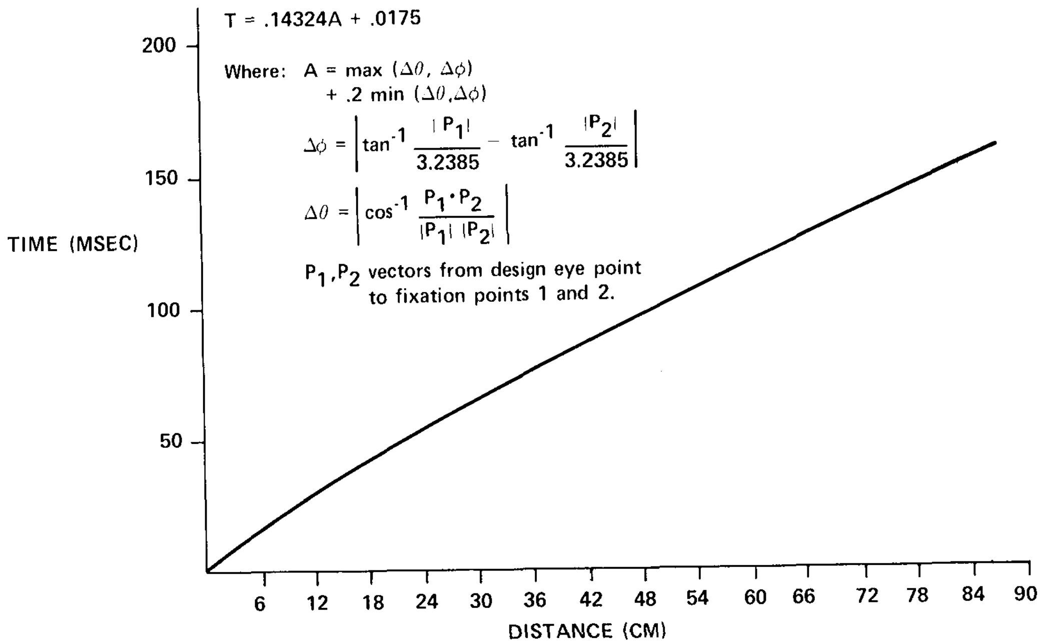


Figure 1.- Time for lateral eye movements as a function of distance between two targets.

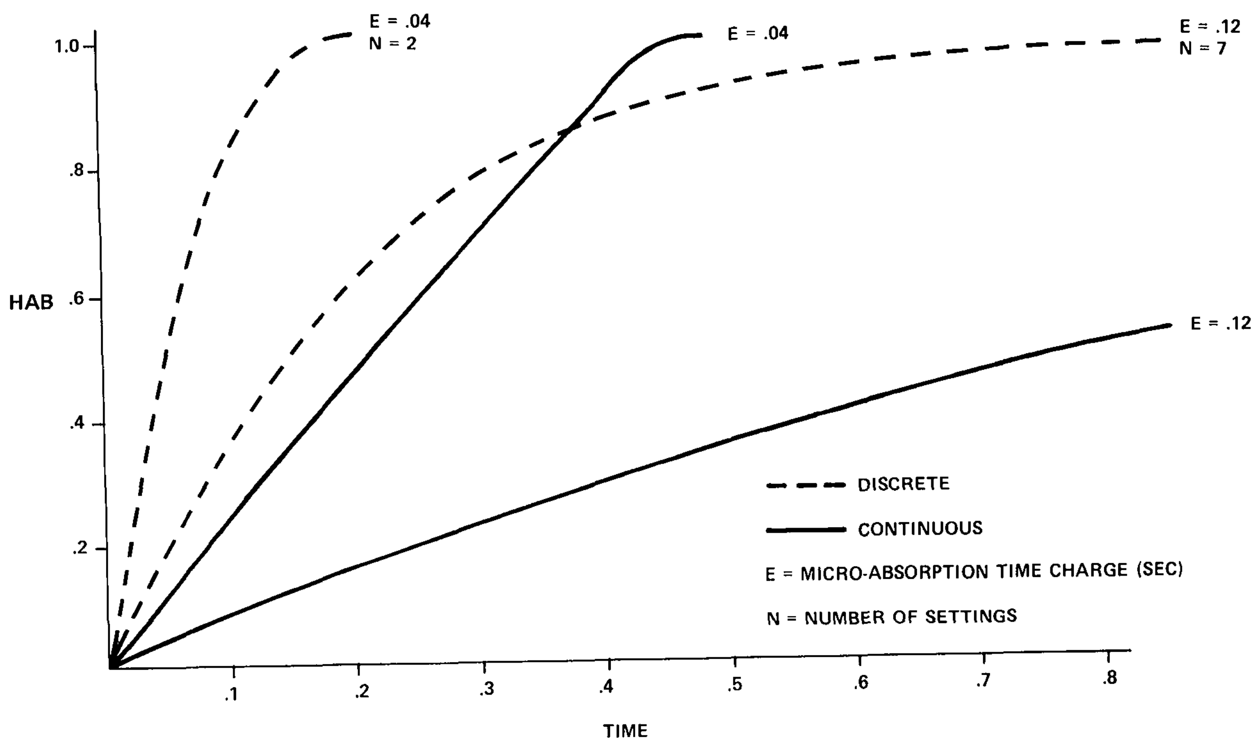


Figure 2.- Hab strength as a function of absorption time.

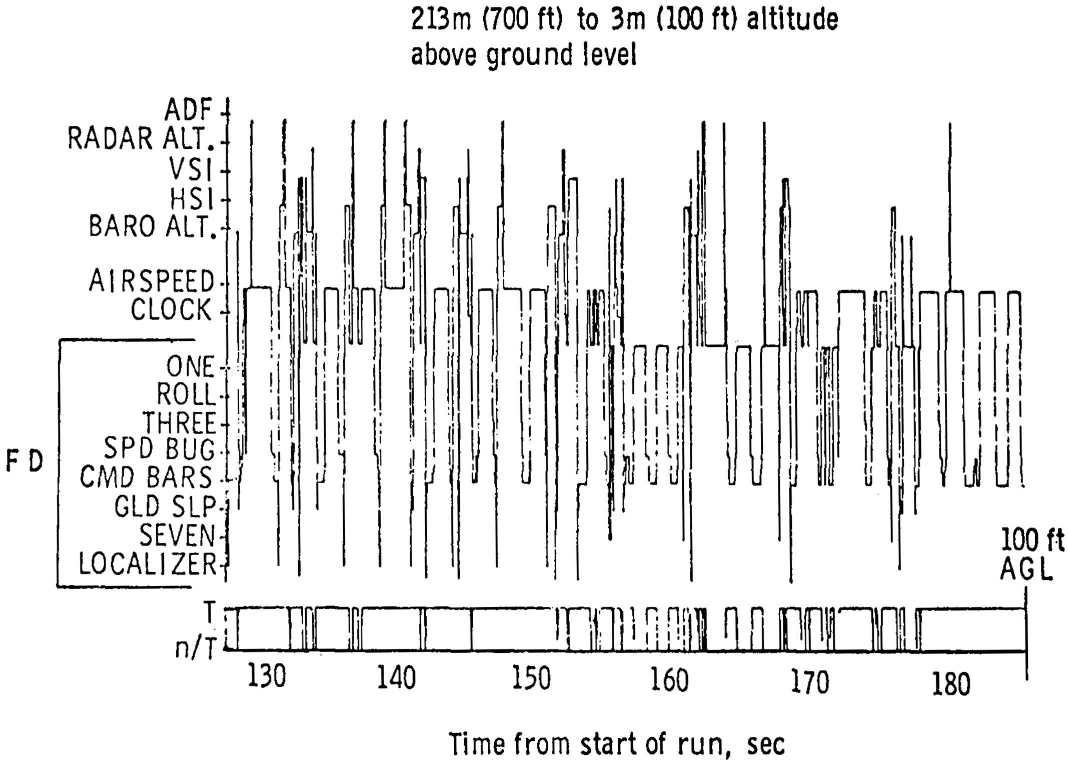


Figure 3.- Time history of one pilot's scan during coupled approach.

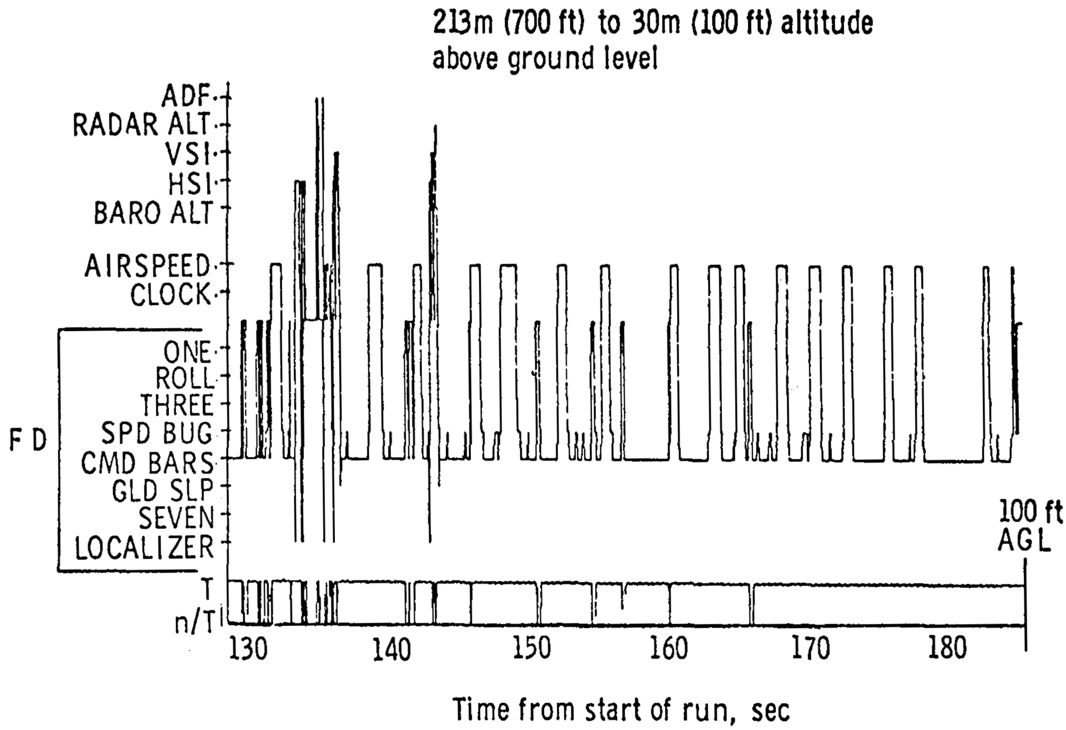


Figure 4.- Time histories of one pilot's scan during manual approach.

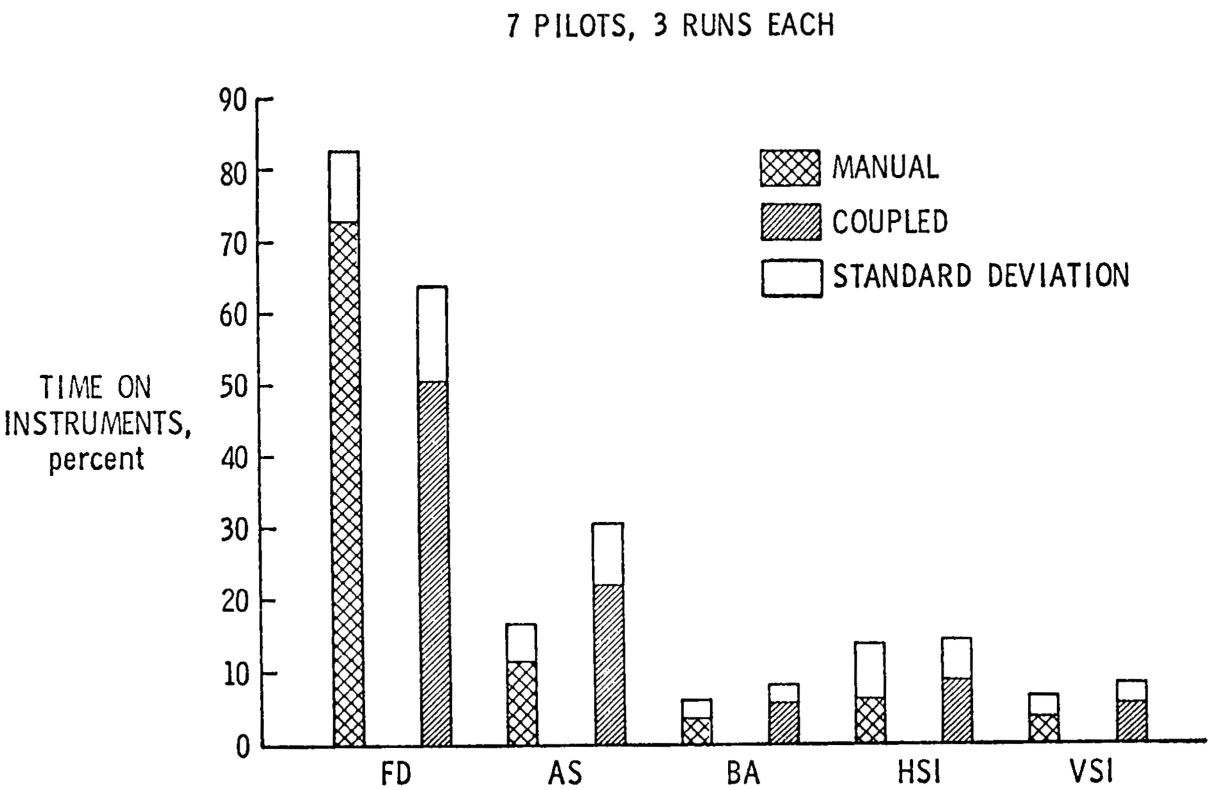


Figure 5.- Percent time on instruments for manual and coupled approaches.