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Instrument Scan - Is it an Indicator of the Pilot's Workload?

by

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ABSTRACT

This paper describes an investigation of the relationship between an aircraft pilot's visual scanning of instruments and his level of mental activity during a simulated approach and landing. This study is motivated by the increasing concern in several areas of man-machine interaction with the effects of changes in manual control and monitoring procedures on mental workload. This concern is particularly keen with regard to airline pilots, air traffic controllers, power plant operators, and personnel in control of large ocean-going vessels, since the cost of error can be quite high in any of these man-machine systems.

Visual scanning behavior plays an important role in each of these systems, since the operator will typically be required to monitor a number of instruments which display system state variables. In each of the above roles, the human acts as a decision maker, a planner, a manual controller, a monitor, and an event detector. His ability to perform these tasks is generally influenced by their nature, number, and temporal arrangement, by his general physical and psychological state, and by the occurrence of unusual or rare events such as mechanical failures, bad weather conditions, etc.

One may speak of the ability to carry out such tasks in terms of total capacity. Total capacity is a hypothetical limit on tasks which may be performed concurrently and within a certain time period. Under this definition, a person working at 100% of capacity has no resources available to handle additional tasks, while one working at 70% of capaicty could be said to have 30% available capacity which might be applied to additional tasks or held in reserve for use in an emergency.

One must be particularly concerned with periods of extremely high or low utilization of capacity, since experience shows that these tend to be the times at which an operator is most prone to error. In the case of high loading, the error(s) may result from inability to accomplish all required tasks within an allotted time period, or failure to detect some item of critical importance (e.g. aircraft altitude several hundred feet lower than expected during an approach). At periods of low loading, on the other hand, errors may result simply because of a low attention level induced by long periods when little or nothing is happening (e.g. long distance flights over the ocean where the aircraft is controlled by the autopilot and the number of other planes along the airway is low).

Ideally, then, a human operator's job should be designed in such a way as to require an appropriate fraction of the operator's capacity. To accomplish this design objective, however, the designer must have a method at his disposal of estimating the expended capacity under different conditions. While there exists a number of these methods, none is sufficiently benign and non-invasive to be used in the field (for instance, in an airliner's cockpit in flight). Consequently, we have set out to develop an estimator of mental loading based on the operator's visual scan pattern.

In the current work, experiments were conducted in a Terminal Configured Vehicle (TCV) fixed base flight simulator at NASA Langley Research Center. Three NASA test pilots were presented with a piloting task, an arithmetic task designed to vary mental loading, and a side task for calibration of the mental loading task. The pilot lookpoint was obtained by using a highly modified Honeywell oculometer system, and the pilot's eye scan of the instruments was recorded. The piloting task involved flying a curved Microwave Landing System (MLS) approach from a specified waypoint to touchdown. To aid in data analysis, the approach was divided into six segments: downwind, turn to base, base, turn to final, final, and flare. The pilots were aided by a new generation of flight instruments based on CRT displays which were installed in a simulator. These were an Electronic Attitude Direction Indicator (EADI) and an Electronic Horizontal Situation Indicator (EHSI) in place of the conventional flight director and horizontal situation indicator. The EADI provides conventional flight director information such as localizer and glide slope deviations, and pitch and roll attitudes. It also provides additional features including flight path angle, flight path acceleration, radar altitude, and a dynamic perspective drawing of the runway. The EHSI is a moving-map display with ownship at the center. During the MLS approach, the curved MLS glidepath is drawn and the pilot may use various optional features to allow navigation. Features include trend predicor vectors to show aircraft position up to 90 seconds in the future and display of all other aircraft (traffic) in the approach pattern. For further discussion of these displays, see Harris and Mixon (1979).

The mental loading task was chosen so as not to interfere with the visual scanning of the pilot while providing constant loading during the approach. This was accomplished by having the pilots respond verbally to a series of evenly spaced three-number sequences. The pilot was told that he must respond to each three-number sequence by saying either "plus" or "minus" according to the following algorithm: first number largest, second number smallest = "plus"; first number smallest, last number largest = "plus"; otherwise = "minus". The numbers were recorded at twnety second and ten second intervals. These intervals had been determined empirically to vary mental loading under a similar piloting task.

The workload measuring side task employed two lights, one mounted above the other, placed just outside the pilot's peripheral view above the instrument panel. The lights came on at random intervals between one and three seconds and remained on for one second. The pilot was told to turn the lights off by using a three-position rocker switch on the control grip (moving the switch up turned the upper light off, down turned the lower light off). This was done only when the pilot had time left from performing the primary task of flying the airplane. Thus the number of correct responses to the lights gave a measure of the residual capacity of the pilot from which a workload index could be calculated.

The experimental conditions were arranged in a 2 x 2 x 3 factorial design. The conditions were the presence or absence of traffic (other airplanes in the same approach pattern) on the pilot's EHSI display, presence or absence of the side task lights, and mental loading task (no numbers, three number sequences at twenty second or ten second intervals). Two replications were obtained for each pilot. Of the twelve runs per replication, only the six involving no light-cancelling side task were used to study the scanning behavior, since the presence of the side task lights would alter this behavior.

Results of the side task showed a definite increase in workload when the arithmetic task was introduced. The x-y plots of pilot lookpoint for each segment of the approach also show substantial qualitative differences between the different levels of loading. The three instruments used most by the pilot in the scan are the EADI, EHSI and the air-speed indicator. The largest number of transitions were within the EADI, while the next largest were between the EADI and the EHSI, followed by the airspeed and other instruments. The detailed scanning within the EADI is of particular importance. The display is used almost exclusively during final approach and flare, those segments when workload is usually judged subjectively to be the highest.

A computer algorithm has been developed to obtain the first-order, discrete-state, discrete-transition, Markov model for each pilot's scanning pattern. It is assumed that workload is constant within each of the six approach segments since the piloting tasks are essentially constant over each segment. This allows comparison of the instrument transition matrices for each segment with those obtained under different loading conditions. The relationship between visual scanning and workload is given by the change in the elements of these matrices as loading varies. Higher-order Markov models may also be used to provide a more accurate discription of the processes taking place.

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References

Harris, R.L., Sr. and Mixson, R., "Advanced transport operation effects on pilot scan patterns", Proc. Human Factors Society, 23rd. Annual Meeting, Boston, MA, 1979, pp. 347-351.