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AN INVESTIGATION OF CORRELATION BETWEEN PILOT SCANNING BEHAVIOR AND WORKLOAD USING STEPWISE REGRESSION ANALYSIS

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SUMMARY

An electro-optical device called an oculometer which tracks a subject's lookpoint as a time function has been used to collect data in a real-time simulation study of instrument landing system (ILS) approaches. The data describing the scanning behavior of a pilot during the instrument approaches have been analyzed by using a stepwise regression analysis technique. A statistically significant correlation between pilot workload, as indicated by pilot ratings, and scanning behavior has been established. In addition, it was demonstrated that parameters derived from the scanning behavior data can be combined in a mathematical equation to provide a good representation of pilot workload.

INTRODUCTION

A program is underway at the NASA Langley Research Center (LRC) to develop a method of measuring pilot workload by use of an objective measure based on pilot scanning behavior. This technique would be particularly applicable to changes in workload induced by display changes or changes in information presented to the pilot. Traditional measures of workload have included subjective ratings such as Cooper-Harper ratings (ref. 1), and the use of sensors attached to the subject's body to make objective measures of heart rate, blood pressure, skin resistance, body temperature, etc. (ref. 2). Also, requiring the subject to perform a secondary task has been used extensively in attempts to measure workload (ref. 2) objectively. Some of these measurements could burden the pilot, possibly interfere psychologically or physiologically with his comfort or performance of the assigned task, and may even themselves add to the workload.

The approach which is presently under investigation at Langley involves measuring the scanning behavior of the subject as a time function by use of an electro-optical device called an oculometer. The primary parameters which the oculometer measures as time functions are the x- and y-coordinates of the subject's lookpoint. These two output signals are used to compute several variables which characterize the scanning behavior of the subject. They will be described in more detail later. An attempt is made to combine some of the derived scanning behavior variables into a linear equation to represent pilot rating, which is assumed to be a measure of workload. Reference 1 discusses the relationship between pilot rating and workload. The process of finding such an equation establishes a correlation between pilot ratings and scanning behavior.

To derive such an equation, a stepwise regression analysis program has been selected. This technique of analysis which will be outlined later in this discussion has at least two advantages. One is that a large number of variables may be considered for inclusion in the final result without forcing the user himself to select a subset. A second advantage is that it facilitates selection of independent variables which correlate to the residual after the effects of already selected variables have been taken into account. These advantages of the stepwise regression process, assuming a model is sought, provide a convenient method for investigating the correlation between workload and scanning behavior.

The present study investigates correlation between pilot ratings and scanning behavior during a simulated instrument approach study conducted on the Langley visual-motion simulator (VMS). The pilot ratings were supplied by a NASA test pilot and are generally representative of ratings given to these tasks by several NASA test pilots. Also reference 1 addresses the general reliability of pilot ratings provided by test pilots experienced in rating with the Cooper-Harper and similar scales. The scope of the work reported here is limited in that only four pilots participated in the tests. In addition, one specific part of the flight regime, an instrument landing system (ILS) approach, was considered; thus, any results may not be generalized over the entire flight regime. Also, task difficulty is varied by manipulating the test setup in only a few of the possible ways. A general discussion of the data used in this study is presented in reference 3.

SYMBOLS AND ABBREVIATIONS

Values are given in both SI and U.S. Customary Units. The measurements and calculations were made in U.S. Customary Units.

a_i ith variable in regression equation

I_X, I_Y, I_Z moments of inertia about X-, Y-, and Z-axis, respectively, kg-m^2 (slug-ft^2)

I_{XZ}, I_{XY}, I_{YZ} products of inertia, kg-m^2 (slug-ft^2)

m,n number of rows and columns, respectively

X	matrix of unknown coefficients
x_i	coefficient of ith scanning behavior variable
Y	response variable or pilot rating
ALT	altimeter
AS	airspeed indicator
CDC	Control Data Corporation
CL	clock
FD	flight director and total counts on flight director
GSI	glide-slope indicator
HSI	horizontal situation indicator
(I,J)	probability of transition from instrument I to instrument J when I and J are replaced by CL, AS, FD, ALT, HSI, and VSI. Also, probability of transition from location I to location J in the flight director; here I and J assume the values 1 to 9.
LTC	lost track count
MDT ( )	mean dwell time on instrument in parentheses, sec
NRP	number of 1/32-sec records processed, run length
R	multiple correlation coefficients
Rg DF	regression degrees of freedom
Rg F	regression F-ratio
Rg MS	regression mean square

Rg SS	regression sum of squares
Rs DF	residual degrees of freedom
Rs MS	residual mean square
Rs SS	residual sum of squares
SDT ( )	standard deviation of dwell time on instrument in parentheses
S E	standard error of regression
TTOI	total time on instrument, 1/32-sec counts
TTT	total tracking time, sec
VSI	vertical speed indicator

SIMULATION HARDWARE

The Langley visual-motion simulator (VMS) was used in the fixed-base mode. A photograph of the interior of the VMS cockpit is presented in figure 1. The cockpit equipment included an instrument panel with instrumentation typical of that found in operational transports. It is, perhaps, of some significance that no engine instruments were visible to the pilot because the mounting of the optical head, as shown in figure 1, blocked their view. However, jet engine noise was simulated and presented to the pilot by speakers located in the rear of the cockpit.

During the simulation only the six instruments in the basic T-arrangement presented in the photograph of figure 2 were used by the pilot. These instruments are the clock, the airspeed indicator, the flight director or attitude direction indicator (depending on the configuration of the instrument), the altimeter, the horizontal situation indicator, and the vertical speed indicator. The flight director used in this study is depicted in figure 3. The command bars of the flight director were programed according to specifications initially supplied by the Boeing Company for a terminal configured vehicle simulation program. Comments from the pilots indicated that this flight director system had some deficiencies under the heavy turbulence condition studied. Such conditions, however, were probably pushing the use of the system beyond its design criterion. Also, the flight director contained a speed command indicator (speed bug). This indicator with graduations at 5- and 10-knot increments indicated deviation from the nominal 120-knot airspeed.

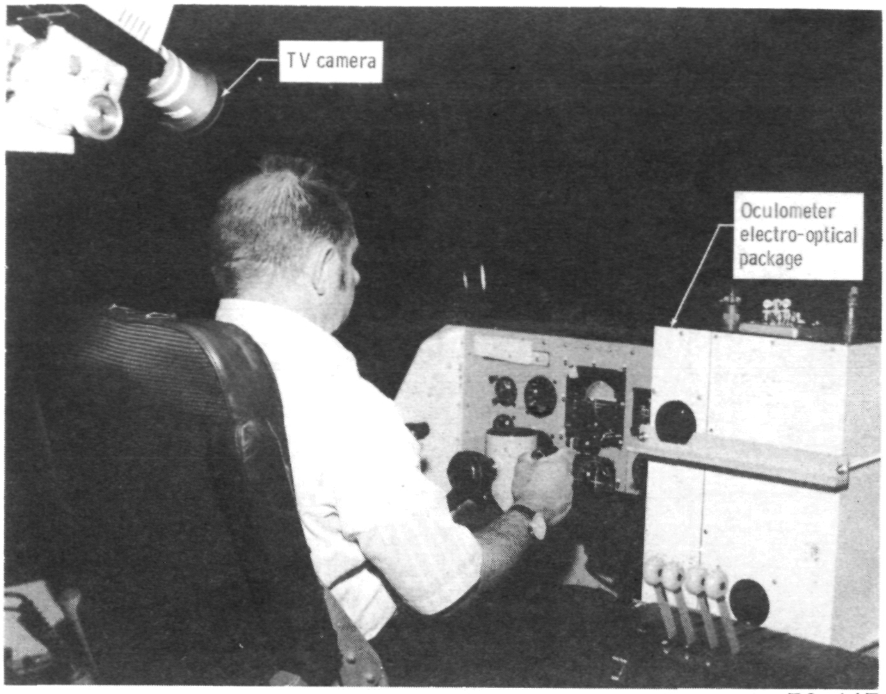

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Figure 1.- The oculometer installed in VMS simulator cockpit.

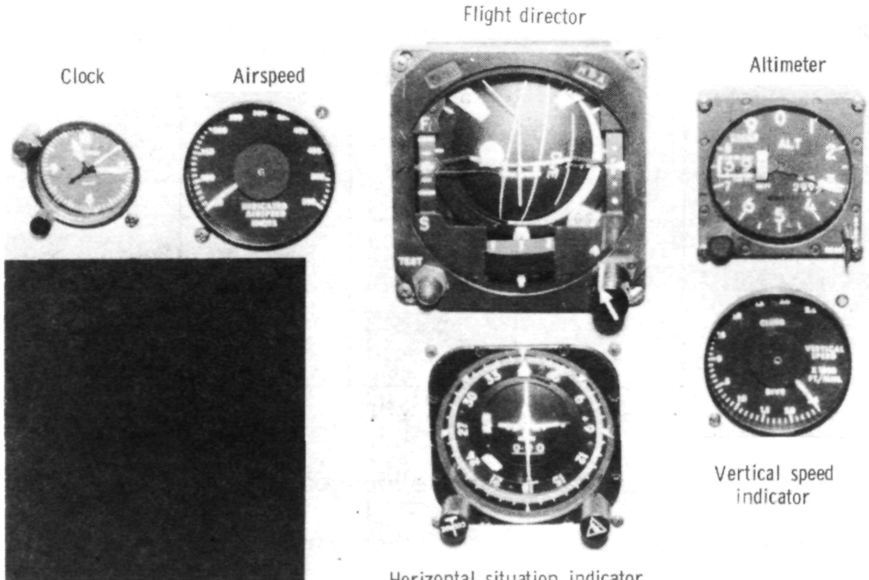

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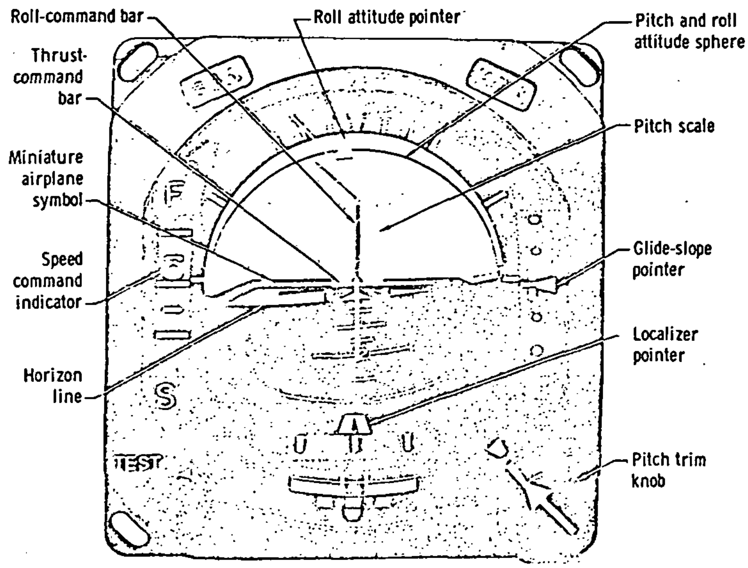
Figure 2.- Basic T-arrangement of the six instruments.



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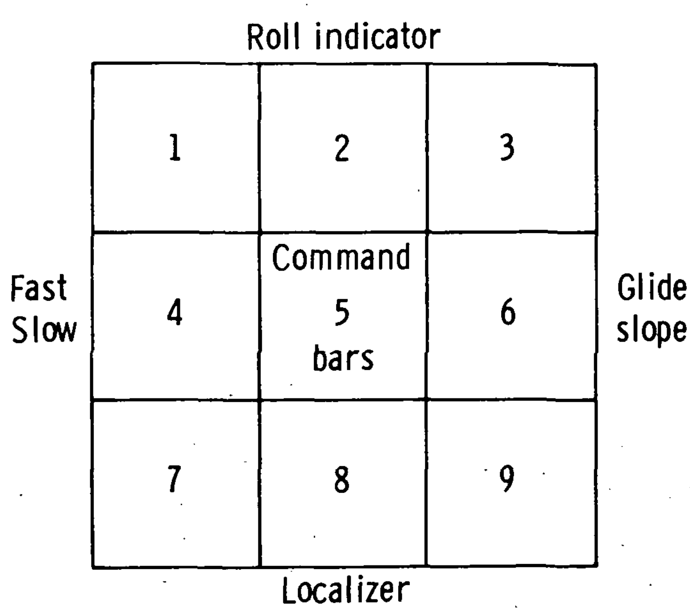
(a) Photograph of flight director.



(b) Gridding used to describe lookpoint in flight director.

Figure 3.- Flight director.

The speed command is not universally available in airline and military flight director instruments. Pilot comments, in addition to those about the flight director, indicated that the airspeed indicator was not very satisfactory because it could not be read as fast as they would have liked on account of the size of the numbering on its face.

The simulator cockpit was also equipped with a control column and wheel, a thumb-activated pitch and roll trim switch, rudder pedals, and a right-hand-operated engine throttle control. No out-of-the-window visual scene was presented.

The simulator was controlled from the Langley real-time digital computer system (CDC 6600) in which the equations of motion, aircraft dynamics and control system, display instrument dynamics, and routines for recording data on magnetic tape were all programed. The computing cycle was 1/32 of a second and data were recorded on the magnetic tape during each cycle.

DESCRIPTION OF OCULOMETER

The oculometer is an electro-optical device built by the Honeywell Radiation Corporation (NASA contracts NASw-1159 and NAS12-531). The basic principle of operation involves illuminating the subject's eye with infrared radiation and monitoring the reflected radiation with an infrared-sensitive television (TV) camera and using an associated mini-computer for processing the signal. More detailed discussions of the operating principle of the oculometer are available in references 3 and 4. The tracking accuracy of the oculometer is 0.5° radius and head movement in a cubic foot volume is allowed.

The electro-optical package of the oculometer is the only part of the system which has to be located in the cockpit. Its location for the present study can be seen in figure 1. It must be mounted so that its beam can be directed at the subject's eye (one eye is tracked). This is the primary restriction in using the oculometer in the simulator environment. It is a remote tracking system and thus requires no attachments to the subject and hence should not impact the performance of the subject.

In addition to recording the lookpoint data on magnetic tape, a TV camera was mounted in the cockpit to view the instrument panel over the right shoulder of the subject. This video image of instruments with a moving dot (generated by the associated electronics of the oculometer) superimposed to represent the subject's lookpoint is recorded on video tape. The video tape data were used in analyzing the results to provide confirmation of the trends pointed out by the regression analysis technique.

THE SIMULATED AIRCRAFT

The aircraft simulated in this study is a large transport. Some of the relevant characteristics of the aircraft are

Weight, N (lb) 40 003.4 (90 000)
Mass, kg (slugs) 40 823.3 (2797.28)
Moments of inertia, kg-m^2 (slug-ft^2):
I_X . . . . 5.08×10^5 (3.75×10^5)
I_Y . . . . 11.86×10^5 (8.75×10^5)
I_Z . . . . 16.27×10^5 (12.0×10^5)
Products of inertia, kg-m^2 (slug-ft^2):
I_{XZ} . . . . 6.51×10^4 (4.80×10^6)
I_{XY} 0.0 (0.0)
I_{YZ} 0.0 (0.0)
Wing span, m (ft) 28.35 (93)
Mean aerodynamic chord, m (ft) 3.41 (11.20)
Wing area, m^2 (ft^2) 91.05 (980.00)

Control surface deflection limits are

Rudder deflection, deg . . . . ±24
Elevator deflection, deg . . . . ±21
Aileron deflection, deg . . . . ±20

SIMULATION TEST CONDITIONS

The test design used in the present study consisted of instrument approaches made in the six conditions listed in table I. Changes in turbulence level and display modifications were used to vary workload. The display changes consisted of conditions with and without the flight director glide slope and localizer command bars. Also the speed command was covered in one test condition.

TABLE I.- TEST CONDITIONS

Condition	Initial offset (horizontal)		Display	Cross wind, deg	Turbulence	Pilot rating
	m	ft				
I	0	0	No speed command	0	None	3.0
II	0	0	Normal	0	None	2.5
III	152.4	500	No command bars	0	None	4.0
IV	152.4	500	Normal	45	Moderate	3.5
V	152.4	500	No command bars	45	Heavy	7.0
VI	152.4	500	Normal	45	Heavy	5.0

Condition II is considered the nominal condition. The speed command on the flight director was covered in condition I to allow assessment of the effects of the speed command on the pilot's scanning behavior. In conditions III and V, the pitch and roll command bars in the flight director were inoperative. These conditions allowed evaluation of scanning behavior and performance when basic instruments, without command information available, were used. Also conditions IV, V, and VI have turbulence and a 15-knot (7.72-m/s) cross wind added to allow the effects of these disturbances to be determined.

The instrument approaches were started 10 058 m (33 000 ft) from the runway threshold at an altitude of 487.68 m (1600 ft). Nominal airspeed for the approach was 222.2 km/hr (120 knots). The cross wind entered the simulation at 6705.6 m (22 000 ft) from the runway threshold. The turbulence was simulated by the Dryden turbulence model presented in reference 5. The flight was along a 3° glide path and required about $2\frac{1}{2}$ minutes for completion.

Four pilots were used as subjects in the tests. Three of these were U.S. Air Force pilots current in a large transport (C-130) and one was a NASA test pilot current in the Boeing 737 as well as a wide variety of other aircraft.

STEPWISE REGRESSION ANALYSIS

Regression analysis is a method of identifying the parameters of an overdetermined system of equations. In general, the term will include such techniques as least squares, maximum likelihood, minimum variance, and several other classical means of estimating the parameters of such a system. The particular estimation technique used in the present study is least squares. A complete discussion of this process can be found in many textbooks on the subject of regression analysis. Reference 6 is a good example, and the reader is referred there for a detailed discussion of the least-squares process and regression analysis.

As a brief overview of the subject, however, assume that one wishes to solve a system of overdetermined linear equations represented in matrix notation by

$$Y = AX + \epsilon$$

where Y is an m by 1 column vector, A is an m by n matrix, X is an n by 1 vector, and ϵ is an m by 1 vector of experimental errors. The simple least-squares solution for X which minimizes the sum of the squares of the experimental error ϵ, when appropriate assumptions (ref. 6) are used, is

$$X = \left(A^T A\right)^{-1} A^T Y \tag{1}$$

where A^T is the transpose matrix.

In application then, when given m measurements of Y, the response, and corresponding observations of the n elements in the rows of the A matrix, $m > n$, equation (1) will provide the simple least-squares solution to the overdetermined system. With no rigor intended in the discussion, this solution guarantees that the sum of the squares of the residuals or errors is minimized.

It was assumed in the previous discussion of regression analysis that a linear equation with unknown coefficients had been selected to represent the response Y in terms of the independent variables of the A array before starting the process. In the subject application, however, choosing a set of independent variables is a part of the problem and is accomplished by the stepwise regression process. Stepwise regression analysis begins with no model; thus, it is assumed that the model developed will be a linear combination of some subset of the independent variables considered, and a set of m observations of the response and the independent variables. It proceeds to find the best (in some sense such as least squares) set of variables to include in the linear model. This process is applicable when several independent variables have been measured because they are thought to be correlated to the response and yet the researcher does not know whether all should be included in the model or some subset.

The stepwise regression analysis proceeds by entering into the model first the independent variable which is most highly correlated to the response. It enters next the independent variable which is most highly correlated to the response when given the effects of the previously included variable. This is the same as choosing next the variable most highly correlated with the residual. A second criterion in addition to correlation of a variable to the response is imposed. The significance of the variable under consideration is tested against the F-distribution; therefore, its F-ratio must exceed a designated critical value. Also each time a new variable is entered into the model, the variables already in the model are each checked to ascertain that their F-ratios still exceed a designated critical value. If this is not the case for any variable, it is removed from the regression equation. Imposing this second criterion insures statistical significance of the result. The process is terminated when no additional independent variables can be added to the model. The output from the stepwise regression is then a set of independent variables which can be combined in a linear model to represent the response. Also, the coefficients (X vector of eq. (1)) are computed. Statistics to allow an analysis of variance or to evaluate goodness of fit of the resulting equation are included in the output of the particular computer program used. (See ref. 7.)

APPLICATION OF STEPWISE REGRESSION ANALYSIS TO APPROXIMATE WORKLOAD

The data from the oculometer were reduced first to an instrument-to-instrument transitions probability matrix. This matrix was computed by counting the number of 1/32-second intervals the pilot was found looking at each instrument location. A diagonal term of this matrix is incremented each interval that the subject is found looking at the same instrument as during the previous interval. An appropriate off-diagonal term is incremented when the subject is found to have changed instruments. The counts in this matrix are normalized to give probabilities by dividing each element by the total number of time intervals that the oculometer tracked the subject. Table II presents an example of such a 6 by 6 transition probability matrix for the six instruments (fig. 2) included in the data analysis of this study. The elements of this matrix are among the independent variables considered in the stepwise regression and are represented by terms such as (HSI, FD) to designate the probability of transition from the horizontal situation indicator (HSI) to the flight director (FD).

TABLE II.- EXAMPLE OF A TRANSITION PROBABILITY MATRIX

FROM	TO					
	CL	AS	FD	ALT	HSI	VSI
CL	0.0001	0.0000	0.0000	0.0000	0.0000	0.0000
AS	.0000	.0053	.0003	.0000	.0000	.0000
FD	.0000	.0003	.9020	.0013	.0009	.0014
ALT	.0000	.0000	.0012	.0133	.0000	.0000
HSI	.0000	.0000	.0008	.0000	.0108	.0001
VSI	.0000	.0000	.0016	.0000	.0000	.0203

In a similar analysis a transition probability matrix for the scanning behavior of the subject within the flight director was derived. The flight director instrument is divided into a 3 by 3 array of rectangles as illustrated in figure 3(b). These rectangles are numbered one (1) to nine (9) as indicated in the figure. To derive a transition probability matrix for the flight director, the entries in the transition matrix derived by following this scheme are divided by the total number of counts the subject looked at the flight director. The elements of the matrix are also included in the stepwise regression process and are represented in the discussion of the results by symbols such as (1,2) to mean number of transitions from the square numbered 1 to that numbered 2 (fig. 3), etc.

The other variables which were considered as candidate independent variables in the stepwise regression analysis included mean and standard deviation of the dwell time (or duration of fixations) on each of the six instruments and on each of the nine squares dividing the flight director. Also, variables which were tallies on number of records processed, total time the oculometer tracked, etc., were included.

In addition to each variable mentioned, its square was also included. However, no product or interaction terms were considered. Measurements of these variables made up the A matrix in equation (1). The response variable Y was the pilot rating for each of the six conditions. These were the Cooper-Harper ratings assigned to each of the six test conditions by a NASA test pilot. Table I which lists the test conditions also includes the pilot rating given to each condition.

The results of the stepwise regression analysis will be an equation of the form

$$Y = \sum a_i x_i + x_o$$

where the a_i's are the scanning behavior variables included in the equation after the stepwise regression analysis process has been completed. The x_i's are the corresponding coefficients and x_o is a constant.

The application of stepwise regression analysis in the present study included an algorithm which was constructed to overcome difficulties associated with sorting a large number of candidate independent variables. Two hundred and ten data runs were available for analysis. One hundred and fifty candidate independent variables plus the square of each were selected for the stepwise regression analysis process. Analysis of the programing requirements to handle this amount of data indicated that a large amount of computer memory is necessary to execute stepwise regression analysis directly. The assumption is made that the process would stop before the number of variables included in the equation approached the number of measurements. An alternate processing procedure was sought. The variables were randomly divided into eight groups. The stepwise regression process was performed on each group separately. Since it was possible that some variables could be zero all or most of the time, it was arbitrarily decided to eliminate from the analysis any variable which was found to be zero in 95 percent of the runs. Therefore, group size varied in the analysis. The variables entering the equation resulting from the processing of each of the eight groups were next combined in a final stepwise regression process.

An algorithm such as the one discussed requires an investigation of the stability or repeatability of the results. This is true partly because of the existence of correlation between the candidate variables. Such correlation could make variable grouping an important factor influencing the results. It could mean that there is more than one set of variables which could form an equation representing the response variable equally well.

RESULTS AND DISCUSSION

A typical example of the results of the stepwise regression program follows. The purpose for presenting the example is to provide the reader with enough of the details of one attempt at a solution to the problem to see how the stepwise analysis program functioned.

The variables entering the program were first randomly subdivided into eight (8) groups. When a variable was assigned to a group, its squared value was also assigned to the same group. Table III lists the variables entering each group in a separate column.

TABLE III.- AN EXAMPLE OF RESULTS OF STEPWISE REGRESSION PROCESS USED

Statistical measures	Group								FINAL
	1	2	3	4	5	6	7	8	
	(HSI,VSI)	SDT (2)	SDT (6)	(9,8)	LTC	SDT (9)	(5,9)	TTT	
	[a](6,2)	[a](ALT,HSI)	(2,3)	(5,3)	(6,6)	(ALT,ALT)	[a](8,7)	(7,4)	
	[b]MDT (VSI)	(4,5)	(5,6)	[a](7,8)	[b]FD	[b](4,2)	(1,4)	(7,7)	(FD,HSI)
	(2,8)	[c](1,2)	(FD,ALT)	(8,6)	(9,5)	(6,5)	[b](2,4)	[a](8,8)	$(TTOI)^2$
	[a]MDT (HSI)	[a](ALT,FD)	(9,7)	[a](2,5)	NRP	(9,9)	SDT (1)	(6,9)	$(5,2)^2$
	MDT (6)	SDT (4)	(4,7)	[c](VSI,VSI)	[a]SDT (VSI)	[c](HSI,HSI)	(2,1)	(4,4)	$(3,2)^2$
	(5,4)	[c]MDT (FD)	[a](5,8)	[a](VSI,ALT)	MDT (ALT)	(6,3)	[a](AS,AS)	[b](3,6)	(4,8)
	(HSI,ALT)	MDT (3)	(9,6)	MDT (4)	(VSI,HSI)	(8,9)	SDT (9)	(7,5)	(6,2)
	[a](FD,AS)	MDT (5)	[a](1,1)	(6,8)	[b]MDT (9)	(ALT,VSI)	[b](FD,FD)	[a](4,8)	(5,1)
	[c]SDT (8)	SDT (ALT)	[a](FD,HSI)	(5,5)	[a](HSI,FD)	[b]TTOI	MDT (1)	(3,5)	
	[c](8,5)		[a]MDT (7)	(4,1)	(2,6)	(3,3)	[b](5,2)	[a](AS, FD)	
	(7,9)		(2,2)	MDT (AS)	[b]SDT (AS)	[a]SDT (3)	(FD,VSI)	[a](5,1)	
	(VSI,FD)			MDT (2)	MDT (2)		[a]SDT (5)	(8,4)	
				(1,5)	[b](3,2)		SDT (FD)	(5,7)	
Rs DF	192	194	196	195	194	195	194	195	193
Rs SS	240	307	213	314	168	172	190	298	120
Rs MS	1.25	1.58	1.08	1.61	0.86	0.88	0.98	1.53	0.62
Rg DF	9	7	5	6	7	6	7	6	8
Rg SS	3885	3818	3912	3810	3957	3953	3934	3827	4005
Rg MS	431	545	782	635	565	658	562	638	500
Rg F	343	344	717	393	651	743	571	416	804
S E	1.18	1.25	1.04	1.27	0.93	0.94	0.99	1.24	0.78
R	0.97	0.96	0.97	0.96	0.97	0.97	0.97	0.96	0.99

[a]Variable placed in equation.

[b]Square placed in equation.

[c]Both variable and square included.

The column headed "FINAL" lists the variables entering the regression equation when the stepwise regression process is carried out on the combined results from the eight preliminary groups. Although not listed in the table, a constant is included in each group. Also the following statistics about the results of each regression step are listed in each column:

Rs DF	residual degrees of freedom, number of observations minus Rg DF
Rs SS	residual sum of squares, sum of squared values of differences between rating provided by test pilot and that predicted by model
Rs MS	residual mean square, Rs SS/Rs DF
Rg DF	regression degrees of freedom, number of independent variables included in predicting equations
Rg SS	regression sum of squares, sum of squared values of predicted response variable
Rg MS	regression mean square, Rg SS/Rg DF
Rg F	regression F-ratio, Rg MS/Rs MS
S E	standard error of regression, $\sqrt{\text{Rg MS}}$
R	multiple correlation coefficient of regression, $\sqrt{\dfrac{\text{Rg SS}}{\text{Rs SS} + \text{Rg SS}}}$

The program also computes the correlation coefficients of the variables a_i considered in a particular group. These are available for printing.

These statistical measures are discussed in detail in most texts on regression analysis. (See, for example, ref. 6.) For a good estimating equation one would, in general, want the following (least-squares case):

Rs SS	minimum
Rs Ms	minimum
Rg SS	maximum
Rg MS	maximum
Rg F	maximum
S E	minimum
R	maximum, approaching 1.0

These statistics are interrelated and forcing one to approach the desired value usually causes the others to be incremented in the desired direction. Again, these comments are not meant to be a rigorous discussion but are intended to present an overall view of the analysis pursued here. The parameters also allow analysis of variance tests on the statistical significance of various estimating equations.

The final estimating equation which resulted for this particular example is

$$Y = 5.771 - \left(1.384 \times 10^{-7}\right)(TTOI)^2 + 229.2(FD,HSI) + 669.2(5,2)^2$$
$$- 39\,880.0(3,2)^2 + 490.8(4,8) + 637.0(6,2) + 509.6(5,1)$$

Figure 4 presents a plot of the average and standard deviation of the pilot rating estimated by the preceding equation compared with the actual pilot rating supplied by the NASA test pilot.

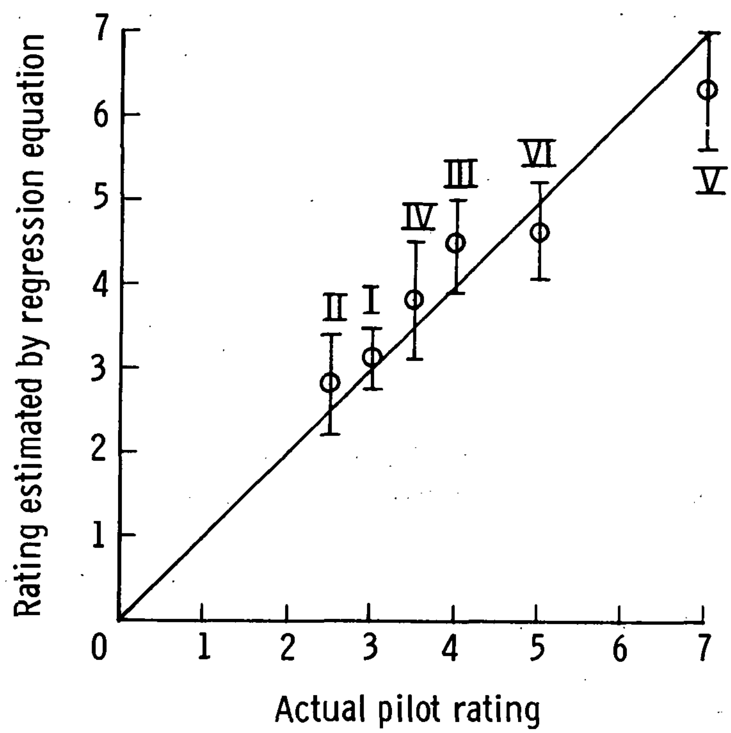


Figure 4.- Example of regression results.
Standard error, 0.8.

Table IV presents the average value over all data runs used in this example for the variables which entered the resulting equation for estimating pilot rating. This might offer some clues as to the role of each variable in the resulting equation.

TABLE IV.- VARIABLES REMAINING IN REGRESSION

[Entries in tables are average data values]

Variable	Condition					
	I	II	III	IV	V	VI
Pilot rating (dependent variable, Y) . . .	3.0	2.5	4.0	3.5	7.0	5.0
Constant	--------	--------	--------	--------	--------	--------
Square of number of counts on instruments	$(4578)^2$	$(4783)^2$	$(4291)^2$	$(4297)^2$	$(3798)^2$	$(4987)^2$
Transition probability from FD to HSI	0.0007	0.0009	0.0055	0.0015	0.0074	0.0037
Transition probability from block 5 to 1	0.0000	0.0000	0.0000	0.0002	0.0003	0.0001
Transition probability from block 6 to 2	0.0000	0.0000	0.0002	0.0000	0.0003	0.0000
Transition probability from block 4 to 8	0.0000	0.0000	0.0002	0.0000	0.0005	0.0003
Square of transition probability from block 5 to 2 . . .	$(0.0027)^2$	$(0.0056)^2$	$(0.0070)^2$	$(0.0073)^2$	$(0.0130)^2$	$(0.0044)^2$
Square of transition probability from block 3 to 2 . . .	$(0.0003)^2$	$(0.0008)^2$	$(0.0015)^2$	$(0.0004)^2$	$(0.0006)^2$	$(0.0001)^2$

One apparent advantage in using stepwise regression analysis is that it can point out subtle correlations which might not have been considered in more conventional type analyses. In the example considered here the constant term entered the estimating equation first. Then a correction term involving the total time spent on instruments and one involving the number of transitions to the HSI were entered. These might have been an obvious inclusion to an equation by considering the correlation matrix or just looking at the data. Some of the other terms which describe specifically how the subject used the flight director from condition to condition might well have easily been overlooked in a more conventional approach, particularly since these are the lower magnitude parameters in the flight director transition probability matrix.

Although looking at the average data presented in table IV does confirm that there is correlation between the test conditions and variation of all the parameters included in the resulting equation, the reason for this correlation in some cases might be a subject of speculation. The inclusion of frequency of transition to roll information from the flight director center $(5,2)^2$ is not surprising. Transitions from the speed command to the localizer information (4,8) seem correlated to both the format of the flight director (absence of command bars) and the presence of a high turbulence level. The reason for its correlation with the latter is not clear. The reason for correlation of pilot rating and transitions from block 3 to roll information is not obvious. This transition in lookpoint is present in each condition tested to some degree. Reviewing several video tapes indicates that this behavior might be associated with the return path from the altimeter to the roll pointer on the flight director during the final phase of each run. Transitions from the glide-slope indicator (GSI) to the roll pointer (6,2) show up significantly only when the command bars or the flight director are not active. The reason for the presence of transitions from center of the flight director to block 1 (5,1) is not obvious. It appears from looking at video tapes that this scanning behavior is associated with the amount of sequential and vigilant monitoring of the roll pointer and speed command. It appears that block 1 might be used as a good location for the pilot to see simultaneously the speed command and the roll pointer and return easily to the information in the center of the flight director. It is emphasized that these explanations of the reasons for the measured correlation are to a large degree educated guesses and may prove erroneous as the phenomena involved become better understood.

To investigate the stability or repeatability of the results of the processing used here, a routine was added to the computer program which grouped the variables entering the process randomly each time the program was run. Over several computer runs, the variables remaining in the regression were compared.

It was observed that the results varied considerably from run to run. Table V presents the results from executing the program several times. It was found, however, that several of the variables (or their squares) that are free to enter the results did so almost invariably: (1) a constant, (2) total time spent on the instruments, (3) number of transitions from the flight director to the HSI, (4) number of transition from the glide-slope indicator to the roll information in the flight director (6,2), and (5) number of transitions from the center of the flight director to location 1 in the flight director (5,1).

TABLE V.- RESULTS OF 10 EXECUTIONS OF STEPWISE REGRESSION ANALYSIS PROGRAM WITH VARIABLES RANDOMLY GROUPED

Parameter	a1	a2	3	a4	a5	6	7	8	9	10	Total
Constant	✓	✓	✓	✓			✓	✓	✓	✓	10
TTOI	✓	✓		✓							3
(FD,HSI)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	10
$(6,2)^2$	✓			✓	✓		✓	✓			6
(4,8)	✓	✓	✓	✓	✓			✓		✓	7
(1,2)	✓										1
SDT (3)	✓	✓		✓							3
$(2,5)^2$		✓									1
(5,1)		✓	✓	✓	✓	✓	✓	✓		✓	8
$(1,5)^2$		✓				✓					2
$(5,1)^2$		✓				✓	✓				3
$(\mathrm{TTOI})^2$			✓			✓	✓		✓	✓	5
$(5,2)^2$			✓		✓					✓	3
(2,3)			✓								1
(6,2)			✓						✓	✓	3
$(3,5)^2$				✓							1
$(2,3)^2$					✓			✓	✓		3
$(\mathrm{FD})^2$					✓			✓			2
MDT $(\mathrm{VSI})^2$					✓			✓			2
MDT (3)					✓						1
(AS,AS)					✓			✓			2
SDT (HSI)					✓			✓			2
(2,2)					✓						1
$(3,2)^2$							✓		✓	✓	3
$(5,3)^2$						✓					1
MDT $(4)^2$							✓		✓		2
$(7,7)^2$							✓				1
$(4,7)^2$									✓		1
(8,6)									✓		1
(FD)									✓		1
$(6,3)^2$									✓		1
(3,3)									✓		1
(FD,AS)									✓		1
SDT $(8)^2$									✓		1
(5,8)									✓		1
Rs DF	194	192	193	193	189	194	192	191	186	193	
Rs SS	127	125	123	121	122	130	114	123	103	120	
Rs MS	0.65	0.65	0.64	0.62	0.64	0.67	0.59	0.64	0.57	0.62	
Rg DF	6	8	8	7	11	6	9	10	15	8	
Rg SS	356	358	4001	362	361	353	4011	4001	4022	4005	
Rg MS	59	44	500	51	32	58	445	400	268	500	
Rg F	90	68	780	82	50	87	746	617	481	804	
S E	0.81	0.8	0.80	0.79	0.80	0.82	0.77	0.80	0.74	0.79	
R	0.85	0.86	0.98	0.86	0.86	0.85	0.92	0.98	0.98	0.99	
Intercept	9.0	8.6	5.95	8.6	6.09	6.08	6.01	5.9	6.62	5.77	

[a]Intercept (Constant) is forced into the regression results. Statistics account for role of the free variables only.

CONCLUDING REMARKS

Stepwise regression analysis has been used in the present study to investigate the hypothesis that there is a correlation between workload measured in terms of a Cooper-Harper rating and pilot scanning behavior. This study has demonstrated that such a correlation does exist and that, in fact, scanning behavior parameters measured by an oculometer can be used to predict the pilot rating with standard error of 0.8 unit on the Cooper-Harper scale which ranges from 1 to 10.

It was found that five parameters free to enter the regression results (or their squared value) did so almost invariably regardless of the manner in which the terms were grouped in the analysis. These parameters are

(1) a constant,

(2) total time spent on the instruments,

(3) number of transitions from the flight director to the horizontal situation indicator (HSI),

(4) number of transitions from the glide-slope indicator to the roll information in the flight director, and

(5) number of transitions from the center of the flight director to location 1 in the flight director.

One specific goal of the research conducted in this area is to establish a model for computing a pilot rating from oculometer measurements. The present study has demonstrated the feasibility of this goal by deriving example equations which can be used to compute pilot ratings for the six conditions of the present study. However, those example equations found here are not necessarily descriptive of the underlying principles involved in assigning pilot ratings to the tasks. They are models only in the sense that they can be used to represent the response as a mathematical function of the oculometer variables. Also, no claim is made of validity of these equations for predicting pilot rating under conditions different from the ones investigated in the present study. Nevertheless, this study has demonstrated the feasibility of approaching the more general problem.

It is also pointed out that for purposes of the present study, consideration was not given to including in the analysis all oculometer variables which might correlate to workload. This was not felt to be particularly necessary to establish whether a correlation exists between scanning behavior and workload measured in terms of pilot rating. It is believed, however, that developing a more general model should include such a step.

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