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THESIS

A MODEL THAT USES PSYCHOMOTOR TESTING TO
PREDICT NAVAL AVIATOR PRIMARY FLIGHT GRADES

by

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September 1988

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With the costs of pilot training escalating, it is becoming increasingly important to make as few mistakes as possible in the selection of potential aviators. In the early days of aviation the use of psychomotor testing played a big role in this selection process, but the physical complexities of the system caused its discontinuance. More recently, researchers at the Naval Aerospace Medical Research Laboratory, using micro-computers, have developed two new series of psychomotor tests. This thesis uses stepwise and multiple regression techniques to confirm the viability of using such a series of psychomotor tests to predict the flight grades of student aviators in primary flight school. The fitted regression model accounted for 77% of the variance in the primary flight grade data examined and appeared to be approximately 4.5 times better than the model currently used.

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A Model That Uses Psychomotor Testing To Predict Naval Aviator Primary Flight Grades

by

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ABSTRACT

With the costs of pilot training escalating, it is becoming increasingly important to make as few mistakes as possible in the selection of potential aviators. In the early days of aviation the use of psychomotor testing played a big role in this selection process, but the physical complexities of the system caused its discontinuance. More recently, researchers at the Naval Aerospace Medical Research Laboratory, using micro-computers, have developed two new series of psychomotor tests. This thesis uses stepwise and multiple regression techniques to confirm the viability of using such a series of psychomotor tests to predict the flight grades of student aviators in primary flight school. The fitted regression model accounted for 77% of the variance in the primary flight grade data examined and appeared to be approximately 4.5 times better than the model currently used.

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I. INTRODUCTION

A. INTRODUCTION

Since the middle of World War I there has been a concerted effort to predict the physical skills and mental facilities necessary to ensure completion of the rigorous, and often dangerous, pilot training syllabus. Batteries of tests, mostly of the "paper-and-pencil" type (such as the Navy's Flight Aptitude Rating(FAR) and the Academic Qualifying Test(AQT) which are currently used), have been developed and used exclusively since World War II, with limited success. With the costs of pilot training escalating to phenomenal levels ($804,793 for the jet aircraft training pipeline) it has become increasingly more important to improve the predictive validity of the aircrew selection process. [Ref. 1]

To this end, the Naval Aerospace Medical Research Lab located at the Naval Air Station in Pensacola, Florida has developed and administered a number of computer-assisted divided-attention and undivided-attention psychomotor tests to volunteer Student Naval Aviators (SNA) and Student Naval Flight Officers (SNFO), prior to their entry into formal flight training. The results of these tests have been compiled with individual results from primary flight school, SNA/SNFO demographic information (degree major, age, sex, etc.), and FAR/AQT scores.

The purpose of this thesis is twofold:

1) to produce a model which will indicate the value of reinstituting psychomotor testing using current computer technology; and,

2) to analyze the validity of psychomotor testing as a predictor of flight grades during the primary flight training syllabus.

B. BACKGROUND

Just two years prior to the United States' entry into World War I, the Aviation Service had but 52 fliers on its roster. By April of 1919 the number had grown dramatically to approximately 19,000 [Ref. 2:p. 103]. With this growth was a growing concern for the methodology in selecting the "right person" for the demanding, stressful, and often hazardous training.

Early procedures, more esoteric than scientific, required only that the future aviator be "of good education and high character, men who were in every way qualified and fitted to become officers of the U. S. Army." [Ref. 2:p. 103] These selection criteria, which were the same for the cavalry, were completely arbitrary and non-quantitative, leading to inconsistency in aviator selection. The high accident rate during flight school made it apparent that these qualitative procedures were adequate for "ground positions", but did nothing to predict the behavior or abilities of these men once they entered the cockpit. The need for a well organized predictive series of examinations began to emerge.

The first series of examinations that were developed were utilized until the end of the 1940's, and were moderately successful, involving the use of tests for mental stability and psychomotor skills. The psychomotor tests, however, were awkward and difficult to carry to each entry station. The Mashburn Automatic Serial Action Apparatus, as depicted in Figure 1, consisted of a frame 60 inches long, 29 inches wide, and 18 inches high, in which were mounted an adjustable seat and airplane controls (i.e., stick and rudder). In front of the controls was an upright section 64 inches high and 36 inches wide [Ref. 3]. In addition, this equipment required special training for assembly and for accurate collection of performance data. By 1951, the many administrative, reliability, and quality control problems forced this type of testing to be discontinued by all services [Ref. 4].

Attempts to reinstate psychomotor testing have failed over the past nearly 40 years. Written tests designed to "imitate" psychomotor tests proved inadequate, measuring only the most basic of dexterity and coordination skills. In its place appeared the "perceptual/cognitive tests", such as the Spatial Apperception Test, which have changed little in spite of the vast advances in technology.

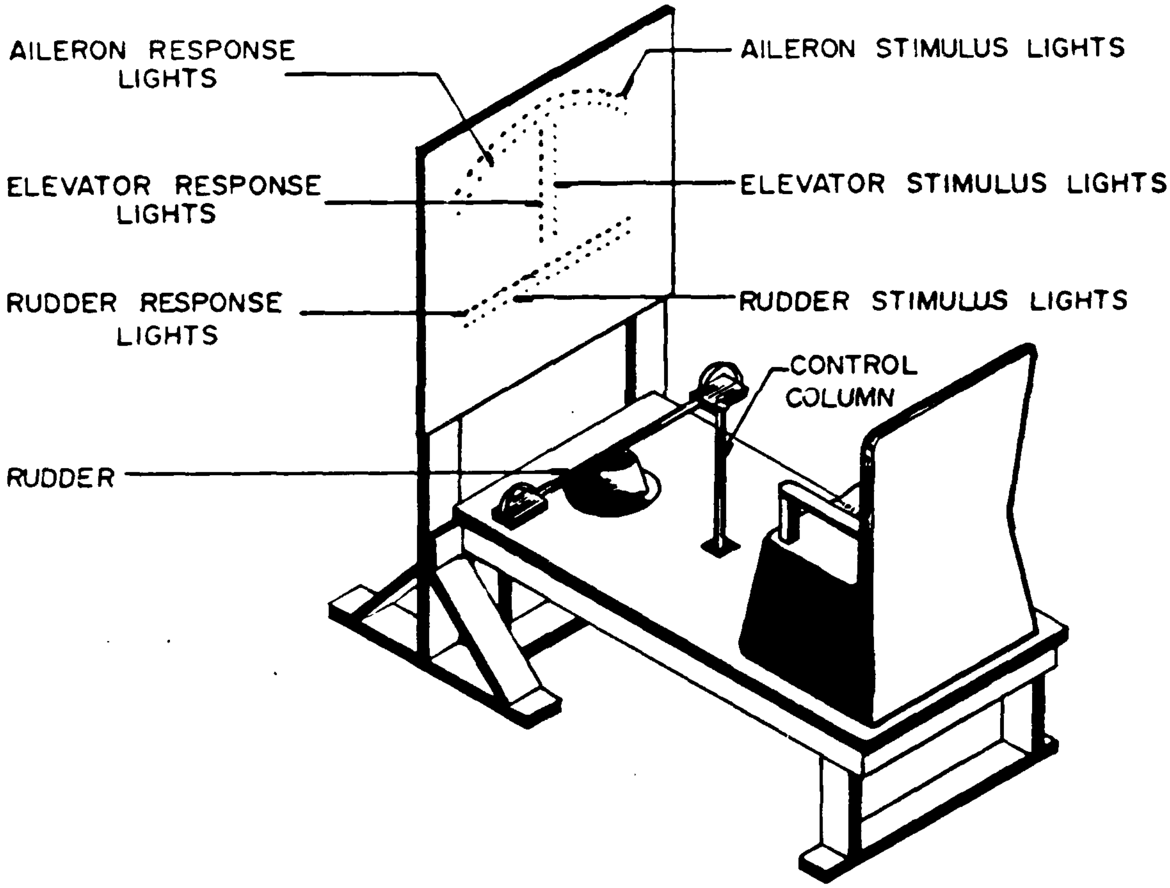


Figure 1. Mashburn Automatic Serial Action Apparatus

C. PRESENT DAY TESTING

Current testing of potential aviators begins and ends at the Naval Recruiting District, where the battery of officer selection tests is administered. This sequence of tests consists of three timed and one untimed examinations.

The timed tests last no longer than 110 minutes and test for general intelligence, general mechanical aptitude, and ability to orient in space. The remaining "test" is untimed and aimed at the evaluation of specific elements of personal history, interest, and general knowledge of aerospace. These tests (the Academic Qualification Test, the Mechanical Comprehension Test, the Spatial Apperception Test, and the Background Inventory) are described in more detail in Chapter Two of this paper. Sample questions for each of these tests are found in Appendix D.

Once the tests have been completed or the time limit for each has expired, they are hand graded, twice, by recruiting personnel. Within five days the tests are forwarded to Naval Aerospace Medical Institute (NAMI) in Pensacola, Florida for further validation.

Test scores are combined into two ratings which are used as two of the criteria for the selection of potential officer candidates. The raw scores of the Academic Qualification Test and the Mechanical Test are added to yield the Officer Aptitude rating (OAR). Using Table I this score is converted into the final OAR. The Flight Aptitude Rating (FAR) is calculated by adding the converted scores of the Mechanical Comprehension Test, the Spatial Apperception Test, and the Biographical Inventory (Tables II, III, and IV.) This score is further converted using Table V generating the final FAR score.

Minimum acceptable scores for acceptance into flight training are: (read: Pipeline/GPA/AQT/FAR/OAR)

Pilot/2.0/3/5/40

Other Aviation(NFO,etc.)/2.0/3/3/40

The ease associated with the administration of written tests is offset by inherent drawbacks. Since these tests are "graded" at the Recruiting District, the test keys are susceptible to compromise. Additionally, study books, such as the ARCO "Officer Candidate Tests" Study Book, may prepare potential aviators for the examination, but may not improve their skills in the air.

Computer-assisted psychomotor testing, on the other hand, tests the potential aviator's innate ability to handle minute changes in direction, speed, and altitude. Should computer programs which emulate Navy testing be sold commercially to "tutor" prospective aviators, the result could produce potentially better fliers, a most desirable effect.

TABLE I. OFFICER APTITUDE RATING SCORE CONVERSION

Raw	Converted	Raw	Converted
164/above	80	116-117	49
163	78	115	48
162	76	113-114	47
161	74	112	46
159-160	73	110-111	45
158	72	108-109	44
157	70	105-107	43
156	69	104	42
155	67	102-103	41
153-154	66	99-101	40
151-152	65	97-98	39
148-150	64	96	38
147	63	93-95	37
144-146	62	91-92	36
141-143	61	89-90	35
139-140	60	87-88	34
138	59	85-86	33
136-137	58	83-84	32
134-135	57	82	31
131-133	56	80-81	30
128-130	55	77-79	28
126-127	54	75-76	27
124-125	53	74	26
122-123	52	73	24
120-121	51	72	21
118-119	50	71/below	20

TABLE II. MECHANICAL COMPREHENSION TEST SCORE CONVERSION

Raw	Converted	Raw	Converted
70/above	19	43-45	9
67-69	18	40-42	8
65-66	17	38-39	7
63-64	16	35-37	6
61-62	15	33-34	5
59-60	14	31-32	4
57-58	13	27-30	3
53-56	12	24-26	2
59-52	11	23/Below	1
46-48	10		

TABLE III. SPATIAL APPERCEPTION TEST SCORE CONVERSION

Raw	Converted	Raw	Converted
29-30	19	16-17	9
28	18	14-15	8
27	16	12-13	7
26	15	10-11	6
25	14	8-9	5
23-24	13	7	4
22	12	5-6	3
20-21	11	4	2
18-19	10	3/Below	1

TABLE IV. BIOGRAPHICAL INVENTORY SCORE CONVERSION

Raw	Converted	Raw	Converted
59/above	19	28-30	9
55-58	18	26-27	8
52-54	17	24-25	7
50-51	16	21-23	6
46-49	15	19-20	5
43-45	14	17-18	4
40-42	13	15-16	3
37-39	12	13-14	2
34-36	11	12/Below	1
31-33	10		

TABLE V. FLIGHT APTITUDE RATING SCORE CONVERSION

Raw	Converted
42/above	9
39-41	8
36-38	7
32-35	6
29-31	5
25-28	4
22-24	3
19-21	2
18/Below	1

II. THE TESTS

The data used in this study were taken from the series of pen-and-paper and psychomotor tests discussed below. These data were later analyzed for inclusion in a regression model used to exam the validity of psychomotor testing as a tool in predicting the flight grades achieved by student aviators during primary flight training. The exact regression model is discussed in greater detail in Chapter IV of this study.

A. THE SUBJECTS

All subjects were volunteers awaiting assignment to one of three flight training squadrons (VT-2, VT-3, or VT-6) at Whiting Field, Milton, Florida. Of the 111 original participants, 55 were chosen at random as the basis of this study. The remaining 56 were used for cross-validation of the model. The selection was performed using the random number generator in STSC, Incorporated's APL*PLUS APL language package. A random seed of 1,153,851,501 was used. Of the 55 chosen Student Naval Aviators, 52 were male and three were female, with ages ranging from 21 to 28 years (Median = 23 years, Mean = 23.27, SD = 1.15). The majority, 47 , had no previous logged flight time (Minimum = 0 hours, Maximum = 90 hours, Median = 0 hours, Mean = 6.05 hours, SD = 19.31 hours).

All subjects had obtained at least a baccalaureate degree, with the majority having a degree in mathematics-specific programs, as indicated by Figure 2. All were commissioned officers, the majority of whom received their commission through Aviation Officer Candidate School (Figure 3).

Each of the participants had completed either Aviation Officer Candidate School (AOCS) or Aviation Indoctrination classes. These schools offer only technical aviation instruction, such as Air Navigation Theory, Basic Aerodynamics, and Aircraft Engineering, and do not involve actual "in-flight" aviation training.

Engineering/Math	xxxxxxxxxxxxxxxxxxxxxx (22)
General Science (Biology, etc.)	xxxxxxxx (8)
Business	xxxxxxxxxxxxx (13)
Social Science	xxxxxxxxxxx (11)
Physical Education	x (1)

Figure 2. Degree Majors Of Participants; (Parenthesis indicate number of Participants with Degree in that field)

After the experimental tests, all volunteers went to Whiting Field for primary flight training. The distribution of the subjects across training squadrons is represented in Figure 4.

Aviation Officer Candidate School	xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx (31)
United States Naval Academy	xxxxxxxxxx (10)
Reserve Officer Training Corps	xxxxxxxxxxx (11)
Other (Direct commission, etc.)	xxx (3)

Figure 3. Source Of Commission
(Parenthesis indicate number of Participants with Degree in that field)

VT-2	xxxxxxxxxxxxxxxxxxxxxxxxxxx (27)
VT-3	xxxxxxxxxxxxxx (14)
VT-6	xxxxxxxxxxxxxx (14)

Figure 4. Distribution Of Subjects Across Training Squadrons
(Parenthesis indicate number of Participants with Degree in that field)

B. APPARATUS AND TESTS

The tests and their associated apparatuses can be divided into three distinct categories: Pen-and-Paper Tests, Gibb-Damos Computer-Based Tests, and the Griffin-Mosko Computer-Based Tests.

1. Pen-and Paper Tests

These tests are currently used for the selection of Aviation Officer Candidates and Naval Flight Officer Candidates. They are, generally, administered at the Naval Recruiting Center located in the region of recruitment.

a. Academic Qualifying Test (AQT)

The AQT is a test of general intelligence, measuring verbal aptitude (i.e.,Vocabulary) and quantitative aptitude (i.e., arithmetic reasoning). Scores are discrete measures, ranging from a low of 1 to a high of 9. This test is administered at the Naval Recruiting Center.

b. Mechanical Comprehension Test (MCT)

Administered at the Naval Recruiting Center, this test measures the subject's ability to understand physical relationships and the principles involved in the operation of mechanical devices (i.e., basic physics). Scores range from a low of 1 to a high of 19.

c. Biographical Inventory (BI)

This test is presented in questionnaire format and has no time limit. Emphasis is placed on: basic knowledge of aerospace history, technology, and terminology; personal opinions; areas of interest and attitudes. No single item is heavily scored or significant in itself. Administered with the MCT, scores range from a low of 1 to a high of 19.

d. Spatial Apperception Test (SAT)

Administered along with the MCT and BI, this tests the candidate's ability to orient in space or, specifically, to visualize the spatial relationship between the attitude of a plane and the territory over which it flies. Scores range from a low of 1 to a high of 19.

2. Gibb-Damos Computer-Based Tests

a. Apparatus

This battery of tests was conducted on a Apple IIe micro-computer connected to Amdek Color I Plus monitor and Apple IIe numeric keyboard. The control stick, used to emulate an aircraft control stick, was a Measurement Systems Incorporated 542 cursor control unit mounted on a chair and located between the legs of the subject.

b. Tasks

There are two basic tasks involved in this series of tests: One-dimensional Compensatory tracking and Absolute Difference. These two tasks are performed independently and then concurrently in a dual-task format. For the Absolute Difference tests, the number of correct and incorrect responses, as well as the associated response times, was recorded. There were no timed responses for the compensatory tracking tasks.

(1) Absolute Difference Tasks. Randomly selected digits ranging in value from 1 to 9 were displayed at the center-top of the monitor. The subject mentally calculated the absolute difference between the digit displayed and the immediately preceding digit and entered this value on the numeric keypad. The only valid responses were the integers 1 through 4. Each session had a duration of 2 minutes with a 15-second rest between sessions. Each subject completed 10 such sessions.

(2) One-dimensional Compensatory Tracking. This task description is quoted from Gibb-Damos [Ref. 6:p. 5]:

> The subject was required to keep a 0.6-centimeter square centered in a 9.75-centimeter by 1.25-centimeter rectangle by making appropriate left-right movements of a control stick. The cursor was driven by a forcing function consisting of equal amplitude broadband noise.... This task was controlled by the subject's left hand. The subject received five 2-min trials. Each trial was separated by a 30-s rest. The dependent measure was RMS error. With the control stick displaced as far as possible to one side throughout the trial, the average RMS error was 125. With no control inputs, the average RMS error score was 78.

(3) Dual-task Tracking-Absolute Difference. During the dual task trials, the absolute difference numbers were displayed at the center-top above the tracking task. The subject was informed to place equal emphasis on each of

the the tasks. The same measures as the single-tasks versions were used. There were a total of five 2-minute sessions with approximately 30 seconds between each trial.

3. Griffin-Mosko Computer-Based Tests

a. Apparatus

Test equipment for this series of tests was similar to that of the Gibb-Damos tests. The major differences were in the additional axes for the rudder simulation and throttle simulation. The Dichotic Listening Tests were performed with the aid of a dual-channel tape recorder and binaural headphones (Figure 5).

b. Tasks

For this battery of tests there are, again, only two basic parts: The Dichotic Listening Tests and the Multidimensional compensatory tracking tasks. As in the Gibb-Damos series, these two tasks were performed singly and then as a dual-task. At the beginning of this battery of tests the subject was presented with an example of each of the tasks, and was afforded the opportunity to contact the test administrator should any question or problem arise prior to the start of the tests.

This task, representing the communications and attention management component of the simulated flight task, consisted of two separate sets of letter-digit strings read simultaneously over the binaural headsets, one string heard in the left ear and one string heard in the right ear. The subject was presented with 24 trials during the single task session and was instructed to respond only to the digits heard in the designated ear, while ignoring the letters and digits heard in the "non-designated" ear. A sample of the DLT letter-digit string is presented in Figure 6 [Ref. 7:p. 3]. The number of correct responses was recorded as the measure of performance.

(1) Multidimensional Compensatory Tracking. In this tracking task, the subject views a video screen displaying a "cross-hair" pattern. A cursor was forced vertically and horizontally from the center of the cross-hair pattern. The subject was required to keep the cursor in the center position using a control "joy-stick" whose movements are opposite of the anticipatory movement of the cursor. For instance, when the joy-stick was moved to the right, the cursor moved to the left.

Figure 5. Griffin-Mosko Experimental Apparatus

```
Part I
     (Left Ear)  R 8 N S M Y 2 G B 7 F L 6 R L S
"RIGHT" (Vocal Channel "attend" Command)
     (Right Ear) Y L 3 S R 4 F Z 9 X F 0 F N 1 L
---------------------------------------------------
Part II
     (Left Ear)  B F 4 3 7 9
"LEFT" (Vocal Channel "attend" Command)
     (Right Ear) G L 1 5 6 2
---------------------------------------------------
Correct Responses
     3 4 9 0 1  4 3 7 9
---------------------------------------------------
```

Figure 6. DLT Example

(2) Dichotic Listening Task (DLT). A second cursor, simulating rudder movement, was positioned at the bottom of the screen and moved only along the horizontal axis. It was controlled by rudder-like pedals which, again, moved the cursor in the opposite direction from that anticipated. The last cursor moved vertically along the y-axis and was controlled by a joy-stick whose movements are normal with respect to the cursor (move the joy-stick forward, the cursor goes down.) The first test involved only the horizontal/vertical (X and Y) axes, and simulated aircraft control stick movement, solely. There were a total of two sessions lasting 3 minutes each. The second single task test was a simulation of aircraft stick and rudder (X, Y, and Z axes), with three sessions lasting 3 minutes each. The last single task simulated aircraft stick, rudder, and

throttle movement and control (X, Y, Z, and T axes). There were two 3-minute task sessions. The error score was derived automatically from .01 inch deviations from the "target" position on all axes. Average error for each minute of each session was recorded. Cumulative error for each axis during the session was recorded at the termination of each session.

(3) Dual-task Tracking-DLT. Subjects performed the DLT simultaneously with all the tracking combinations mentioned above, except the stick, rudder, and throttle (X, Y,Z, and T axes). The number of DLT trials was held to 12, as compared to the original 24 for the multi-task sessions. The presentation of the DLT letter-digit strings began 30 seconds after the beginning of the tracking tasks, and ended 1.5 seconds before the end of the tracking tasks. The performance measures for both remained the same.

III. DISCUSSION OF THE DATA AND EXPLORATORY ANALYSIS

The initial exploratory analysis of the data was done using the capabilities of the APL-PLUS and STATGRAPHICS personal computer software packages. After the preparation of the data, which is described in detail in this chapter, each variable was evaluated against the dependent variable "Primary Flight Grades." Unless otherwise noted all results are quoted at the .05 significance level.

A. DATA PREPARATION

The data was provided in a matrix consisting of 111 observations each containing 172 variables. Most of the variables were multiple observations of tracking data with the X-axis, Y-axis, and Z-axis each represented by a different variable.

The first transformation of the data was performed on the tracking data. Using the simple Pythagorean equation, presented below, the X, Y, and Z coordinates were translated into a Euclidean distance.

$$\text{Tracking Error} = \sqrt{X^2 + Y^2 + Z^2}$$

where: X = the X axis coordinate

Y = the Y axis coordinate

Z = the Z axis coordinate (when available)

This distance summarizes the tracking error for that task from the origin, measured in computer graphics "pixels". After the distance was computed, each of the trials was averaged to yield a single performance summary for that specific tracking task.

Other multiple observations, such as the Dual Task Dichotic Listening Test and the Single Digit Absolute Difference Test, were averaged to obtain a single representative number or summary.

The transformations and groupings resulted in the reduction of the number of variables from 172 to 41. The final list of variables and the original list are both presented in the appendix. Note that there are 42 variables listed vice 41 variables, the first of which is the subject number. All variable numbers listed throughout the analysis portions of this study may be cross-referenced with the list in Appendix B.

The last variable, VAR42, was the tracking error utilizing the throttle dimension (X/Y/Z/T axis tracking.) Since there were not enough observations with this variable to produce a model and perform cross validation it was deleted from this study. This in no way reflects negatively on this variable, which may prove to be a valuable input to later models.

B. EXPLORATORY ANALYSIS

During this phase of the analysis it was thought prudent to see if there was an "obvious" relationship between any of the myriad variables available and the primary flight grades of the subjects. The initial analysis follows.

1. Primary Flight Grades vs. AQT(VAR8) and FAR(VAR9) Scores

As seen in Figure 7 there appears to be little predictive nature to the AQT scores. At first there appears to be a small curvature (e.g. quadratic) effect, but this is not borne out in later analysis. Since those subjects whose AQT scores were at level 4 performed approximately as well as those whose score was the highest value of 9, this variable was not considered to have a significant effect on the flight scores.

In case of the FAR scores depicted in Figure 8, however, there appears to be a slight trend as the score increases. Those with scores in the 7-9 region appeared to score higher in flight school.

2. Primary Flight Scores vs. Tracking Error

In all cases the tracking error scatter plots were not helpful in establishing a perceivable trend. Figure 9 provides a representative plot. In this plot the Primary Flight Scores are plotted against the one dimensional compensatory tracking error (VAR21). Notice that there

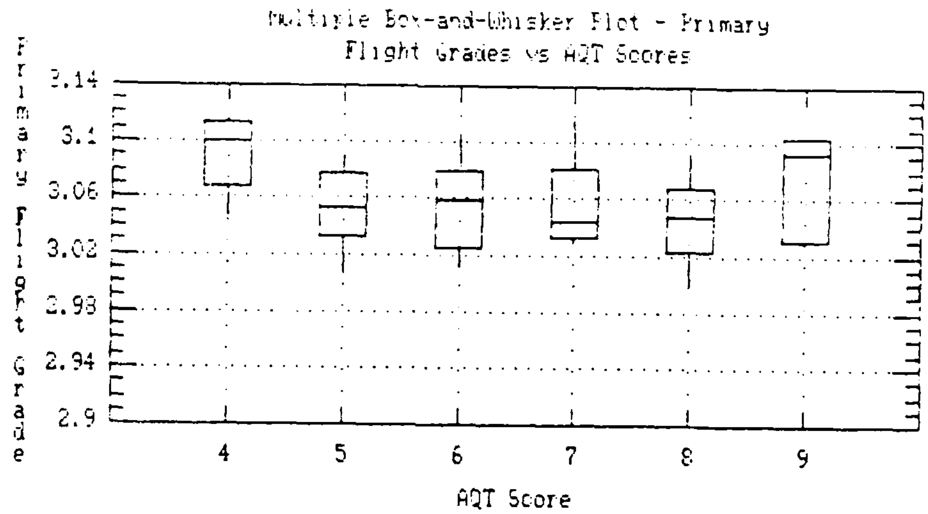


Figure 7. Multiple Box Plot Of Primary Flight Scores vs. AQT (VAR8) Scores

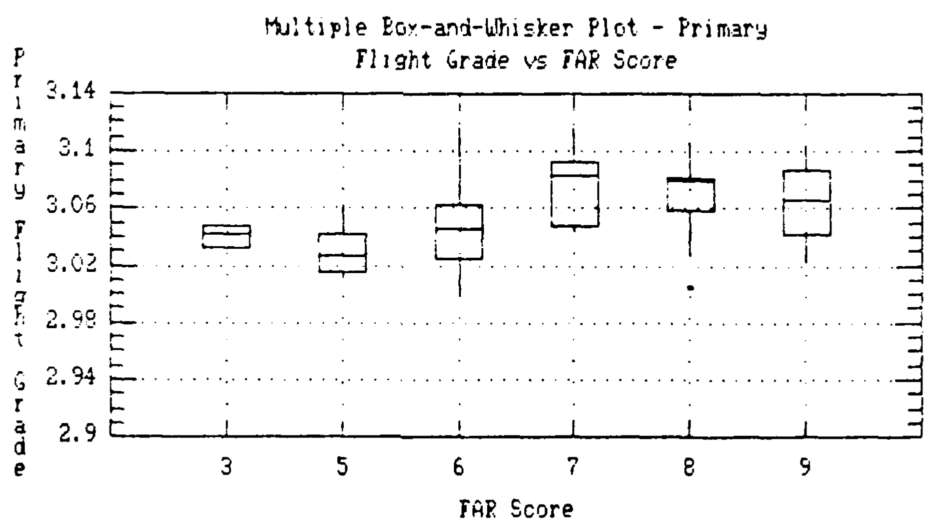


Figure 8. Multiple Box Plot Of Primary Flight Scores vs. FAR (VAR9) Scores

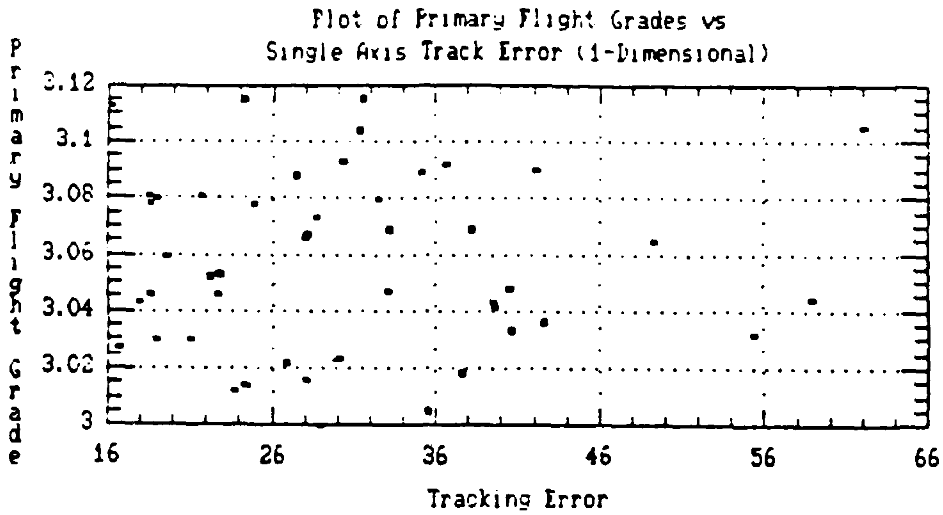


Figure 9. Scatter Plot Of Primary Flight Grades vs. Tracking Error

appears to be no discernible pattern or trend to the data. The remainder of the tracking error scatter plots exhibited similar behavior. These plots can be found in Appendix C.

3. Primary Flight Grades vs. Remaining Variables

These plots, like those of the tracking error, displayed little, if any, pattern indicating some relationship between the variable and primary flight grades. In Figure 10 the number of incorrect responses obtained during the single task absolute difference (VAR25) test are plotted against flight grades.

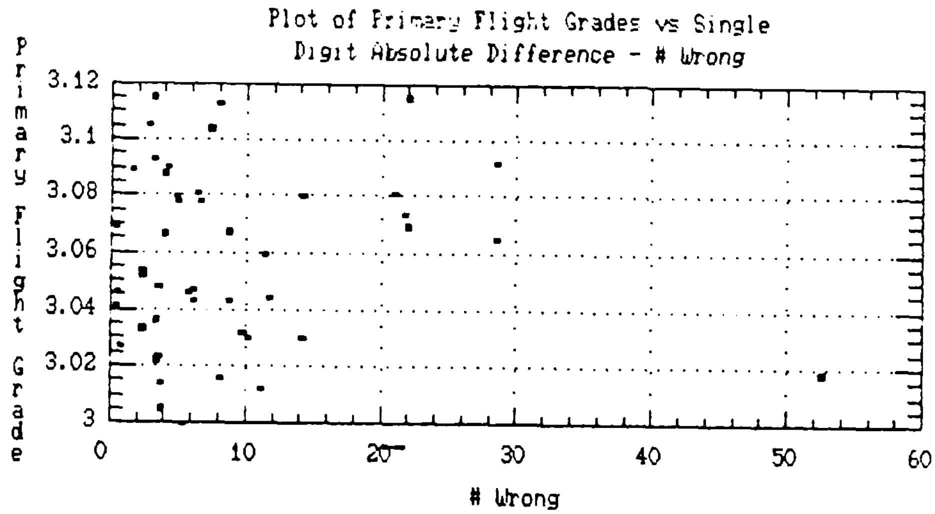


Figure 10. Scatter Plot Of Primary Flight Grades vs. Number Wrong On Absolute Difference Test (VAR25)

4. <u>Distribution of Primary Flight Grades</u>

During the initial analysis of the flight grades, using the box plot function of the STATGRAPHICS package, the data distribution appeared similar to the Normal distribution (Figure 11.) The Normal hypothesis was tested using the Chi-Square Goodness-of-Fit test and the Kolmogorov-Smirnov (K-S) test statistic, both found within the STATGRAPHICS library. A histogram of the data was plotted and appears in Figure 12.

The Chi-Square test proved to be significant at the 0.873 level and the K-S test had an approximate significance level of 0.99999. Table VI is the complete results of the

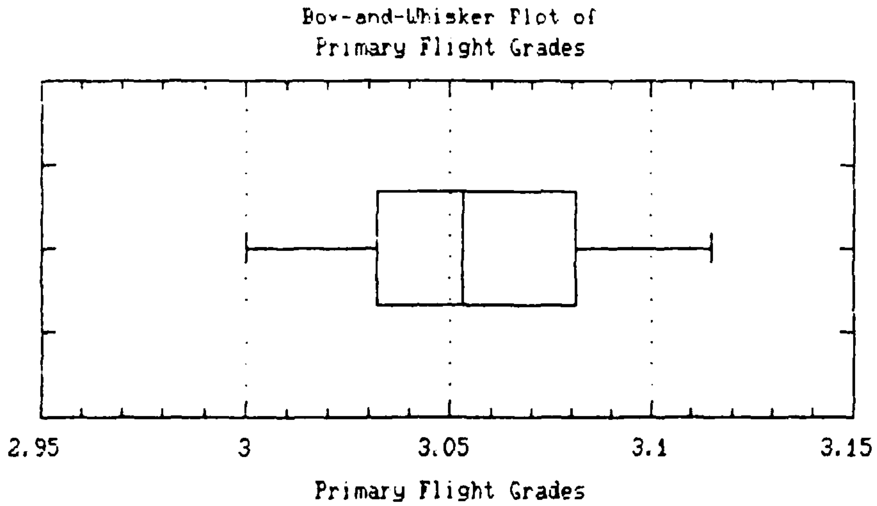


Figure 11. Box Plot Of Primary Flight Grades

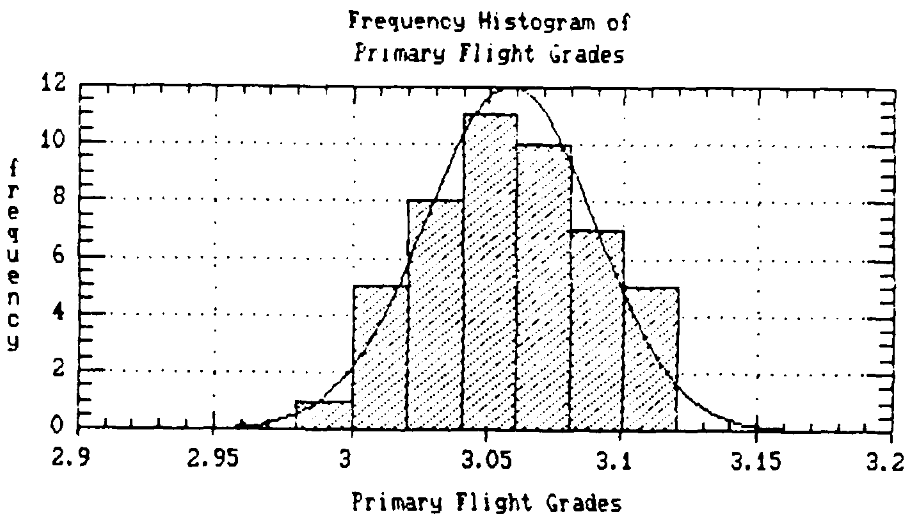


Figure 12. Histogram Of Primary Flight Grades With Normal Distribution Curve Overlay

TABLE VI. CHI-SQUARE TEST RESULTS OF PRIMARY FLIGHT GRADES

Chisquare Test

	Lower Limit	Upper Limit	Observed Frequency	Expected Frequency	Chisquare
at or below		3.02	6	5	.090331
	3.02	3.04	8	8	.000871
	3.04	3.06	11	12	.022213
	3.06	3.08	10	11	.088258
above	3.08		12	11	.069912

Chisquare = 0.271585 with 2 d.f. Sig. level = 0.873024

Chi-Square test and Table VII is the outcome of the K-S test. Both test indicate that the primary flight grades are distributed approximately according to a Normal distribution. However, the data may well be described by other distributional families.

Initial analysis of the selected 55 observations revealed two passing grades which were below the 3.0 passing flight grade minimum, observation numbers 6 and 27. Contact with both NAMRL and the appropriate flight training squadrons did not resolve this inconsistency. Therefore, these points were considered entered in error and deleted from the study.

Since only those subjects who pass are given a flight grade there is an distinct truncation of grades at the 3.0 level. Table VIII provides the sample statistics for this variable.

Estimated KOLMOGOROV statistic DPLUS = 0.0902373
Estimated KOLMOGOROV statistic DMINUS = 0.083588
Estimated overall statistic DN = 0.0902373
Approximate significance level = 0.99999

TABLE VII. KOLMOGOROV-SMIRNOV TEST RESULTS OF PRIMARY FLIGHT_GRADES

Sample size	47
Average	3.05768
Median	3.053
Mode	3.069
Geometric mean	3.05753
Variance	9.67961E-4
Standard deviation	0.0311121
Standard error	4.53816E-3
Minimum	3
Maximum	3.115
Range	0.115
Lower quartile	3.032
Upper quartile	3.081
Interquartile range	0.049
Skewness	0.0975125
Standardized skewness	0.272919
Kurtosis	-0.915932
Standardized kurtosis	-1.28176

TABLE VIII. DESCRIPTIVE STATISTICS FOR PRIMARY FLIGHT GRADES

IV. REGRESSION ANALYSIS AND RESULTS

This chapter discusses the regression model used for the final stage of the analysis and the method used to deal with missing values in the dependent variable.

A. MULTIPLE LINEAR REGRESSION MODEL

The linear regression model used for this study was of the form:

$$Y = \beta X + \varepsilon$$

where, Y is a vector of response (dependent) variables

β is a vector of coefficients or weights

X is a matrix of explanatory (independent) variables

ε is an error term

In using this model certain assumptions were made concerning the error term [Ref. 8]: .LS1

1) they were assumed to be independent random variables;
2) they were assumed to have mean zero with constant variance σ^2; and,
3) they were assumed to be Normally distributed.

Unfortunately, not all of these assumptions can be easily checked.

Avoiding an over-determined model was the first concern in the regression analysis. To reduce the large number of variables available, the step-wise regression routine was used. This routine selected the "most significant" variables based on the impact each had on the model. In this case 11 of the variables (VAR9, VAR21, VAR24, VAR25, VAR26, VAR27, VAR33, VAR34, VAR36, VAR39, AND VAR40) were designated as the most significant. Since the U. S. Navy is not likely to delete the AQT test from its inventory, it was included with little impact on the overall effectiveness of the model.

The results of the initial regression are displayed in Table IX. This regression omitted any observations that were missing the primary flight grade. This effectively eliminated any failed scores from entering the regression, which can introduce biases. The overall R-Square was 0.618882. When adjusted for the number of degrees of freedom the R-Square, commonly referred to as the adjusted R-Square, dropped to 0.4844. The adjusted R-square is defined as [Ref. 9:pp. 177-178]:

$$\text{R-Square(adj.)} = 1 - \frac{(e'e) \,/\, (n-k)}{(y-ybar)'(y-ybar) \,/\, (n-1)}$$

where, y is a vector of the observed dependent variables

ybar is the scalar representing the mean of the observed y

e is the residual of the observed values of y minus the predicted values values of y n is the number of observations

k is the number of variables entered into the model

' symbolizes matrix transpose.

TABLE IX. REGRESSION WITH CENSORED FLIGHT GRADES

Independent variable	coefficient	std. error	t-value	sig.level
Constant	2.883279	0.050654	56.9215	0.0000
VAR8	-0.001384	0.002987	-0.4632	0.6462
VAR9	0.00717	0.0025	2.8685	0.0070
VAR21	0.00105	0.000372	2.8218	0.0079
VAR24	-0.029158	0.016293	-1.7896	0.0824
VAR25	0.001106	0.000564	1.9622	0.0[illegible]
VAR26	0.012698	0.008096	1.5684	0.1260
VAR27	-0.007158	0.010119	-0.7074	0.4841
VAR33	0.013533	0.008828	1.5329	0.1346
VAR34	-0.009264	0.008585	-1.0791	0.2882
VAR36	0.001028	0.00034	3.0194	0.0048
VAR39	-4.512378E-6	6.418263E-6	-0.7031	0.4868
VAR40	-6.69913E-6	3.020554E-6	-2.2178	0.0333

R-SQ. (ADJ.) = 0.4844 SE= 0.022341 MAE= 0.014695 DurbWat= 2.119

Previously: 0.0000 0.000000 0.000000 0.000

47 observations fitted, forecast(s) computed for 6 missing val. of dep. var.

For cross-validation, the coefficients of this regression were used with the variables from the remaining 56 observations. The results of the plot of the observed primary flight grades versus the predicted primary flight grades can be seen in Figure 13. While this does not indicate "perfect" predictability, there is still an evident relationship.

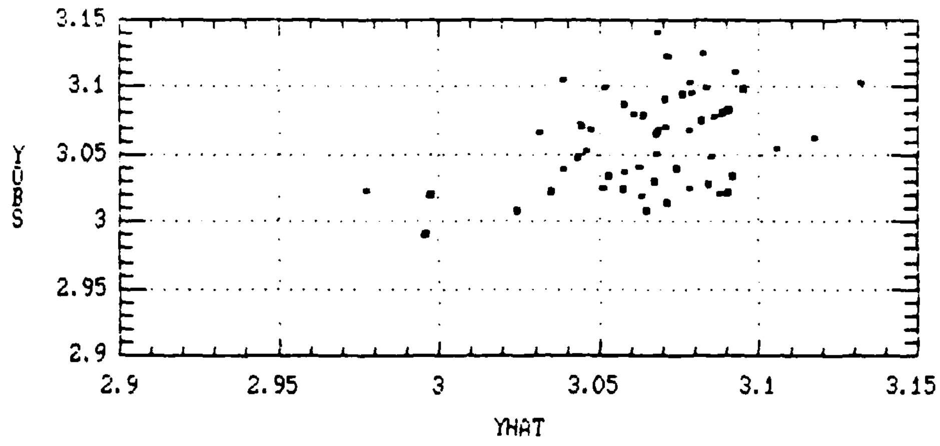


Figure 13. YHAT vs. YOBS

In an effort to show how representative the predicted y values were, the correlation coefficient was calculated using [Ref. 10:p. 213]:

$$r(yobs, yhat) = \frac{Covariance(yobs,\ yhat)}{\sigma(yobs)\ \sigma(yhat)}$$

For this regression the correlation was .4216, indicating moderate correlation between the predicted values and the observed.

For comparison a regression was performed using only the AQT (VAR8) and FAR (VAR9) tests scores, which are the only tests currently administered for aviation selection.

This regression, appearing in Table X, shows an R-Square of 0.1764 and an adjusted R-Square of only 0.1389, considerably lower than the previous regression.

TABLE X. REGRESSION OF CURRENT TEST

Independent variable	coefficient	std. error	t-value	sig.level
Constant	3.026862	0.023888	126.7095	0.0000
VAR8	-0.003617	0.00312	-1.1594	0.2526
VAR9	0.007795	0.002595	3.0037	0.0044

R-SQ. (ADJ.) = 0.1389 SE= 0.028870 MAE= 0.022699 DurbWat= 1.961
Previously: 0.0000 0.000000 0.000000 0.000
47 observations fitted, forecast(s) computed for 6 missing val. of dep. var.

Cross-validation fared no better with the coefficients from this limited testing. Figure 14 displays a total lack of predictive quality in this model. The correlation coefficient for this model was 0.0762, indicating little, if any, correlation between the predicted values and the observed values.

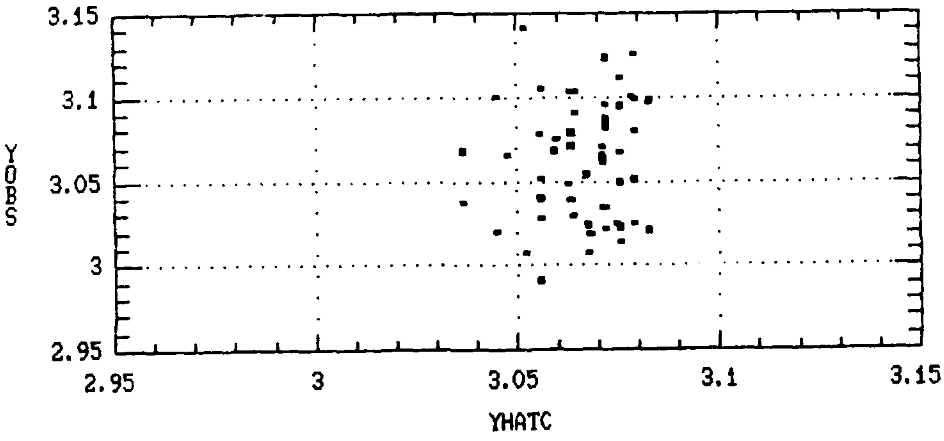


Figure 14. YHAT vs. YOBS

B. MISSING VALUES

Of the 53 observations, six involved subjects who did not complete flight training, and, therefore, did not have associated primary flight grades. These missing values, thus deleted observations, could hold valuable input to model and warranted further study.

The first attempt to estimate these missing values relied on the primary flight grade distribution's similarity to the Normal distribution. If, indeed, the failures could be attributed to low flying grades (those below 3.0), then using the sample's mean and variance an expected value for the Normal tail area below the 3.0 level could be computed.

According to current studies dealing with this phenomena (e.g., Little and Rubin, 1983; Wachter and Trussel, 1982), using the mean and variance from the truncated sample may bias the estimation of the the missing values. Little and Rubin recommend using [Ref. 11:pp. 218-220]:

$$\hat{\mu} = X_{bar}$$

$$\hat{\sigma}^2 = S^2(n/N)$$

where, n represents the number of uncensored observations

N is the total number of observations

X_{bar} is the sample average

S^2 is the sample variance

The assumption for this estimation is that the values are missing at random.

With this randomness restriction and the data's approximation to the Normal distribution in mind, the missing data were evaluated along the same lines as recommended above. Since all the data were missing from the tail, i.e., grades below 3.0, the conditional expected value of the missing points could be estimated by taking the expected value of any point in the area below the 3.0 cut-off, given that the point actually appeared below that cut-off, or, mathematically:

$$\hat{Y}_{miss} = \frac{\int_{-\infty}^{G_p} X \; 1/\sqrt{2\pi}\sigma \; e^{-\frac{1}{2}((X-\mu)/\sigma)^2} \, dX}{\int_{-\infty}^{G_p} 1/\sqrt{2\pi}\sigma \; e^{-\frac{1}{2}((X-\mu)/\sigma)^2} \, dX}$$

where, G_p is the minimum grade required to pass primary flight school.

This yielded a value of 2.989 to be used in place of the missing values during the regression analysis. The results of this regression appear in Table XI.

Notice the smaller R-squared term, 0.3988, in this model as compared to the previous model when the missing values were simply omitted.

Of note, however, is that during the cross validation procedures the correlation between the observed responses, YOBS, and the predicted responses, YHAT, was higher using these values than any other values. Unfortunately, the value, 0.4246, still represented a relatively low number. Figure 15 shows the linear relationship between the predicted values and the observed values.

TABLE XI. REGRESSION USING MISSING VALUE ESTIMATES CALCULATED FROM NORMAL DISTRIBUTION

Independent variable	coefficient	std. error	t-value	sig.level
Constant	2.875482	0.044126	65.1654	0.0000
VAR8	-0.000739	0.0025	-0.2956	0.7690
VAR9	0.006458	0.002264	2.8520	0.0068
VAR21	0.001102	0.000333	3.3114	0.0020
VAR24	-0.025995	0.014895	-1.7451	0.0886
VAR25	0.001438	0.000208	6.9016	0.0000
VAR26	0.01397	0.006142	2.2745	0.0284
VAR27	-0.010557	0.00757	-1.3946	0.1708
VAR33	0.015411	0.007704	2.0005	0.0523
VAR34	-0.011056	0.007297	-1.5151	0.1376
VAR36	0.001034	0.000317	3.2637	0.0023
VAR39	-5.692148E-6	5.636992E-6	-1.0098	0.3187
VAR40	-6.558864E-6	2.630838E-6	-2.4931	0.0169

R-SQ. (ADJ.) = 0.6949 SE= 0.021067 MAE= 0.014470 DurbWat= 2.059
Previously: 0.4844 0.022341 0.014695 2.119
53 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

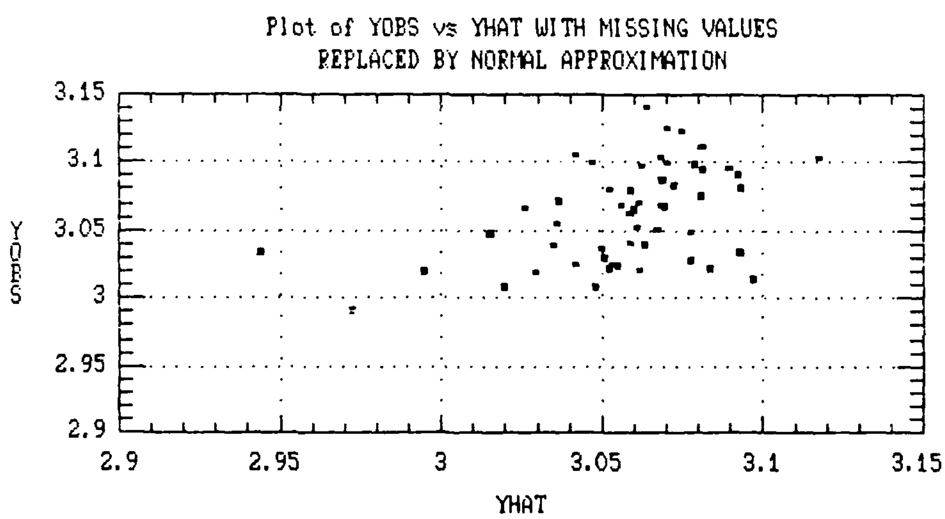


Figure 15. YHAT vs. YOBS

This method relies heavily on the assumption that all of the missing values lie below the minimum passing flight grade of 3.0. This assumption is weakened by the fact that poor flight performance is not the only motivating factor in dropping a student from the flight program. In fact in many cases those students who are dismissed from flight training are performing well in the cockpit of an aircraft, but lack the motivation or aggressiveness needed to be a Naval pilot or simply do not meet the academic standards required in Naval aviation. In these cases it is reasonable to assume that the test results for such an individual could indicate a propensity to do well in flight training, but nonetheless be listed as a failure in the data set. This indicated that another method for replacing missing values had to be evaluated.

This second, and last, method used for estimating the value of the missing flight grades is taken from Yates. During this procedure coefficients of all available variables were calculated using the multiple regression formula [Ref. 12:pp. 41-56]:

$$Y = \beta^* X + \varepsilon$$

where, Y is a vector of the flight grades with missing values not represented by estimation

β^* is a vector of coefficients or weights

X is a matrix of explanatory variables

ε is an error term.

These β^* coefficients are then used to predict the value of those data points that are missing. The new, and complete, set of flight grades, Y*, are then entered into a separate regression resulting in a new vector of β weights.

$$Y^* = \beta X + \varepsilon$$

where, Y* is the vector of flight grades which contains the estimated missing values. All other symbology remains unchanged in translation.

What made these missing value estimations unique was that unlike the other method for estimating these values, they were not below the failing grade of 3.0. This method might help compensate for those individuals who either voluntarily withdrew or were involuntarily withdrawn for other than poor flight performance. Reasons for the "fail" indication did not accompany the data, making verification of these high-mark missing values impossible.

Using this method, Table XII, the R-square reached its highest value, 0.76531, with an adjusted R-square of 0.69490. With nearly 77% of the variance in the model explained, these coefficients were used in cross validation with surprising results.

Although the plot of the data, Figure 16, appears to show some strong predictability, the correlation of the YHAT and YOBS was lower, 0.3910, than that of either the model without estimation or the model using the Normal tail approximation.

TABLE XII. REGRESSION USING MISSING VALUE ESTIMATES CALCULATED USING THE YATES APPROACH

Independent variable	coefficient	std. error	t-value	sig.level
Constant	2.93446	0.067756	43.3093	0.0000
VAR8	0.003707	0.003839	0.9657	0.3400
VAR9	0.005548	0.003477	1.5958	0.1184
VAR21	0.000788	0.000511	1.5407	0.1313
VAR24	-0.0488	0.022872	-2.1336	0.0391
VAR25	-0.000328	0.00032	-1.0244	0.3118
VAR26	0.011323	0.009431	1.2006	0.2370
VAR27	-0.00494	0.011624	-0.4250	0.6731
VAR33	-0.000258	0.011829	-0.0218	0.9827
VAR34	0.011545	0.011204	1.0304	0.3090
VAR36	0.0007	0.000486	1.4404	0.1575
VAR39	-7.228588E-6	8.655663E-6	-0.8351	0.4086
VAR40	-5.496087E-6	4.03968E-6	-1.3605	0.1813

R-SQ. (ADJ.) = 0.2185 SE= 0.032349 MAE= 0.021708 DurbWat= 1.752
Previously: 0.0000 0.000000 0.000000 0.000
53 observations fitted, forecast(s) computed for 0 missing val. of dep. var.

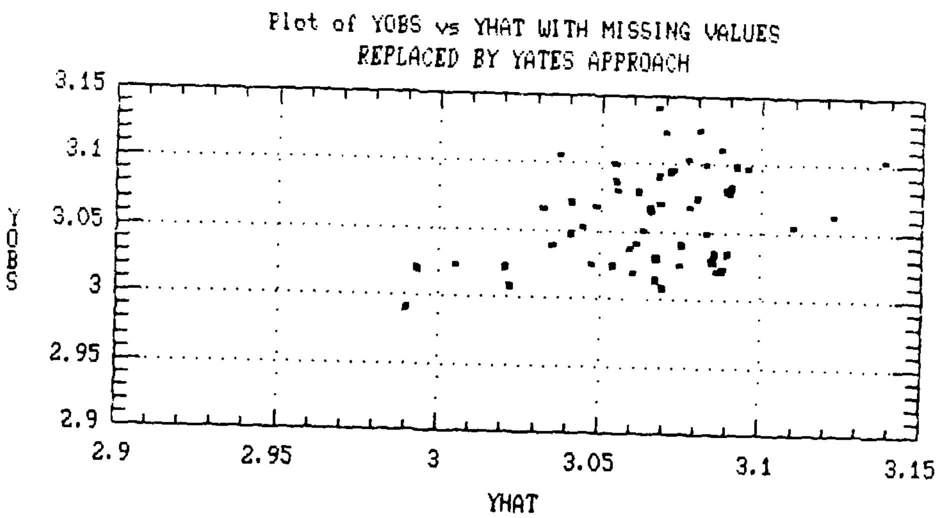


Figure 16. Yhat vs. Yobs

C. HYPOTHESIS OF CORRELATIONS

The correlation coefficients of the three methods were subjected to a test to determine if they were from the same population.

H_o: $rho_1 = rho_2 = rho_3$

H_1: Not H_o

The initial calculation, taken from Snedecor and Cochran, involves the transformation of the correlation coefficient, r, to a quantity designated z, given by [Ref. 13:pp. 185-187]:

$$z = \tfrac{1}{2} \{\ln (1 + r) - \ln (1 - r)\}$$

The test statistic, U, is distributed as a Chi-Square with (k-1) degrees of freedom, where k is the number of correlations to be tested. The statistic is given by:

$$U = \sum_{i=1}^{k} w_i \ z_i^2 - \left(\sum_{i=1}^{k} w_i \ z_i \right)^2 / \sum_{i=1}^{k} w_i$$

where, w_i is $n_i - 3$

n_i is the number of observations

k is the number of correlations to be tested

z is the z value given by the equation listed above.

The computations for this study appear in Table XIII. As presented, there is not sufficient evidence to reject the null hypothesis that the correlations are drawn from a common population correlation.

TABLE XIII. TEST OF HYPOTHESIS OF COMMON POPULATION CORRELATION

Sample	n	n-3	r	z	(n-3)z	(n-3)z^2
Censored	53	50	.4216	.4496	22.4800	10.107
Normal Approx	55	52	.4246	.4533	23.5716	10.685
Yates	55	52	.3910	.4115	21.3960	8.8053
Total	163	154			67.4476	29.5973

X^2(Calculated) = 0.0572
X^2(.95;2 d.f.) = 0.1026

Table XIV is a summary table showing the coefficients and related R-Square/adjusted R-Square for each of the methods used in this analysis. In any case there is ample evidence that methods in dealing with missing values should be investigated any time studies of this type are undertaken.

TABLE XIV. SUMMARY OF REGRESSIONS

	CURRENT	VALUE MISSING	NORMAL APPROX	YATES
Coefficients				
Constant	3.0268	2.8833	2.9345	2.8755
VAR8	-3.62E-3	-1.38E-3	3.707E-3	-7.39E-4
VAR9	7.80E-3	7.17E-3	5.548E-3	6.46E-3
VAR21		1.05E-3	7.880E-3	1.10E-3
VAR24		-0.02916	-0.048800	-0.25995
VAR25		1.11E-3	-3.280E-4	1.44E-3
VAR26		0.01269	0.011323	0.01397
VAR27		-7.16E-3	-4.940E-3	-0.01056
VAR33		0.01353	-2.580E-4	0.01541
VAR34		-9.26E-3	0.011545	-0.01106
VAR36		1.03E-3	7.000E-4	1.03E-3
VAR39		-4.51E-6	-7.229E-6	-5.69E-6
VAR40		-6.70E-6	-5.496E-6	-6.56E-6
R-SQUARE	0.17635	0.61888	0.398815	0.76531
R-SQUARE (ADJ)	0.13890	0.48440	0.218460	0.69490
CORR (YHAT,YOBS)	0.07620	0.42160	0.424600	0.39100

V. CONCLUSIONS

Psychomotor testing is not new, and had not fallen in disfavor for lack of predictive validity when it was dropped from the selection process. The decision to eliminate this test was based mostly on its size and the difficulty encountered in calibrating the equipment. Such is not the case with today's computer-assisted tests. The equipment is easily transported and maintained.

In this study, certain aspects of the psychomotor test as a predictor became clear. First, the replacement of missing dependent values, at least in this study, had little impact on the overall success of the model, if success is measured by the amount of correlation alone. If, however, the measure of success is the amount of variation explained by the model, then the impact was significant. Second, specific elements of each of the two series of tests made statistically significant contributions to the selected criterion, Primary Flight Grades. Third, The Academic Qualification Test did little to predict the scores of the student aviators in primary flight training. Fourth, and most importantly, psychomotor testing, in general, dramatically increased the predictability of primary flight grades over the limited system of pen-and-paper tests currently in use by the U. S. Navy.

The replacement of missing data points presented an interesting paradox. In this sample the replacement had no significant bearing on the predictability of the model, but did indicate a dramatic increase in the R-Square term.

While the Snedecor/Cochran method showed that the correlation coefficient of each model was from the same population correlation, there were considerable differences in the R-Square term associated with each approach. For instance, if it is assumed, as indicated, that the correlations are from the same population, then using the model which explains the most variance would be the logical choice (the Yates method). If, however, these correlations are not assumed from the same population then high R-Square of the yates approach and the high correlation coefficient of the Normal approximation method may be overshadowed by the consistency displayed in the model using the censored flight grades. In this model the R-Square is still relatively high, 0.62, and the correlation coefficient, 0.4216, is only slightly lower than the highest, 0.4246. These results may well be indicative solely of this data and bears close scrutiny in future studies in this arena.

Most of the variables chosen through the stepwise regression were intuitively appealing. It seems rational to believe that one's ability to perform well in the air can be linked to one's ability to perform well on a tracking task when one's attention is focused elsewhere (Multi-dimensional dual task Compensatory Tracking.) Others, however, were not as intuitive, e.g., the standard deviation of the time to answer the absolute difference test numbers correctly.

Notice that the variables included in the regression models were divided between the two series of tests, Gibb/Damos and Griffin/Mosko. While it appears that the Gibb series contributed the greatest number, it is worth remembering that only 3 of the 7 variables are from different tests, e.g., the VAR24, VAR25, VAR26 and VAR27 are part of the Single Task Absolute Difference test. It is difficult to ascertain the effect of deleting any one portion of either of these series of tests, even though the variable does not enter the model. It is recommended, therefore, that both series be administered in their entirety.

Of equal interest is the exclusion of the AQT scores. In each of the models the AQT had the lowest significance level. In fact, when it was removed from the model the correlation coefficients of the three models did not change significantly. This would seem to indicate that the AQT does not do well in predicting flight grades. This in no way reflects unfavorably on the test, which may do well in predicting a strict pass/fail in the flight training, or in general, in predicting an individuals acceptability as a Naval Officer.

While the inclusion of these variables are as interesting as they are puzzling, the real interest lies in the model's increased predictability over the current procedures. As seen above, the current tests, the AQT and the FAR, have low correlation with the flight grades of the subjects. It is recognized, however, that these pen-and-paper tests are extremely portable and convenient for administering to potential aviators at college campuses, career fairs, etc. The inclusion of computer-generated tests may cause logistical problems in the transportation of the testing equipment.

This difficulty can be circumvented easily by administering the pen-and-paper tests at remote sites. This may require lowering the minimum AQT/FAR scores to avoid filtering out those individuals who would have otherwise done well on the psychomotor tests and, presumably, in flight training. Those individuals who meet these revised standards for aviation would then be eligible to take the computer-assisted test administered at the Naval Recruiting District.

Psychomotor tests show great potential in predicting the degree of success in the flight syllabus. It is in this later role that these tests may eventually prove their worth. Such early selection would help eliminate manpower shortages in the various pipelines by matching the aviator's ability to the type of aircraft. "A 200 knot mind does not belong in a Mach 2 aircraft.", is a quote from an unidentified aviation instructor. What is missing, however, is that that "200 knot mind" may do extremely well at the controls of a rotary wing aircraft. Psychomotor testing may help to predict this man/machine match.

VI. RECOMMENDATION FOR FURTHER STUDY

This study barely scratches the surface of the pilot selection issue. The data for these tests are still being collected and subjects who took these tests originally are still being tracked.

An excellent follow on study to this would be examining the pass/fail variable using the logistic regression model defined as [Ref. 14:pp. 1110-1117]:

$$Pr(T=t) = \frac{c\ e^{\beta X}}{\sum_{i=1}^{n} \{1 + e^{\beta X i}\}}$$

where, c is the number of distinct binary vectors (in this case c = 1)

X is a matrix of variables

β is a vector of beta weights obtained through maximum likelihood estimation

This model would produce a probability of pass/fail for each of the subjects, and could be used as a strong supplement to the current FAR/AQT testing.

These tests offer a myriad opportunities for further studies. The information available from the Naval Aerospace Medical Research Laboratory is theoretically limitless. This data alone could have been studied in numerous different ways, e.g., the effect of implementing the throttle portion of the tracking test and evaluating its impact on the predictive model. Decision analysis techniques could be employed to determine the costs of selecting a failure.

Additional studies should be conducted as each of the subjects in this study complete additional flight training. Of importance will be the failure rate of the tested subjects at advanced flight schools, e.g., advanced jet aircraft training.

This will add validity to the utilization of psychomotor testing as a tool for pipeline selection.

APPENDIX A

ORIGINAL VARIABLE LISTING

VAR #	VARIABLE NAME
1	SUBJ NUMBER
2	DESIGNATOR 1 = SNA 2 = SNFO
3	AGE
4	SEX 1 = MALE 2 = FEMALE
5	ACCESSION 1 = AOC/OCS 2 = USNA 3 = NAVCAD 4 = USMC 5 = ROTC 6 = OTHER
6	EDUCATION 1 = ENGINEERING/MATH 2 = GEN SCIENCE/BIOLOGY, GEOLOGY, ETC 3 = BUSINESS 4 = SOCIAL SCIENCE 5 = PHYSICAL EDUCATION
7	PRIOR FLIGHT HOURS
8	AQT
9	FAR
10	SAT
11	MCT
12	BI {NOTE 10, 11, 12 ARE INDIVIDUAL SECTIONS OF FAR}
13	OAR

14	PRIMARY COMPOSITE GRADE
15	AVIATION INDOC GRADE
16	PRIMARY ACADEMIC GRADE
17	PRIMARY FLIGHT GRADE
18	PASS/FAIL 1 = PASS 2 = FAIL
19	PIPELINE 1 = JET 2 = HELO 3 = PROP 4 = E2C2
20	PRIMARY TRAINING SQUADRON 2 = VT-2 3 = VT-3 6 = VT-6
21	SINGLE AXIS TRACK ERROR TASK 1
22	SINGLE AXIS TRACK ERROR TASK 2
23	SINGLE AXIS TRACK ERROR TASK 3
24	SINGLE DIGIT ABSOLUTE DIFFERENCE (SDAD) TASK 1 # CORRECT
25	SDAD TASK 1 MEAN # CORRECT
26	SDAD TASK 1 STANDARD DEVIATION OF # CORRECT
27	SDAD TASK 1 # WRONG
28	SDAD TASK 1 MEAN # WRONG
29	SDAD TASK 1 STANDARD DEV OF # WRONG
30	SDAD TASK 2 # CORRECT
31	SDAD TASK 2 MEAN # CORRECT
32	SDAD TASK 2 STANDARD DEV OF # CORRECT
33	SDAD TASK 2 # WRONG

34	SDAD TASK 2 MEAN # WRONG
35	SDAD TASK 2 STANDARD DEV OF # WRONG
36	SDAD TASK 3 # CORRECT
37	SDAD TASK 3 MEAN # CORRECT
38	SDAD TASK 3 STANDARD DEV OF # CORRECT
39	SDAD TASK 3 # WRONG
40	SDAD TASK 3 MEAN # WRONG
41	SDAD TASK 3 STANDARD DEV OF # WRONG
42	SDAD TASK 4 # CORRECT
43	SDAD TASK 4 MEAN # CORRECT
44	SDAD TASK 4 STANDARD DEV OF # CORRECT
45	SDAD TASK 4 # WRONG
46	SDAD TASK 4 MEAN # WRONG
47	SDAD TASK 4 STANDARD DEV OF # WRONG
48	SDAD TASK 5 # CORRECT
49	SDAD TASK 5 MEAN # CORRECT
50	SDAD TASK 5 STANDARD DEV OF # CORRECT
51	SDAD TASK 5 # WRONG
52	SDAD TASK 5 MEAN # WRONG
53	SDAD TASK 5 STANDARD DEV OF # WRONG
54	DUAL SINGLE AXIS TRACK ERROR TASK 1
55	DUAL SDAD TASK 1 # CORRECT
56	DUAL SDAD TASK 1 MEAN # CORRECT
57	DUAL SDAD TASK 1 STANDARD DEV OF # CORRECT
58	DUAL SDAD TASK 1 # WRONG

59	DUAL SDAD TASK 1 MEAN # WRONG
60	DUAL SDAD TASK 1 STANDARD DEV OF # WRONG
61	DUAL SINGLE AXIS TRACK ERROR TASK 2
62	DUAL SDAD TASK 2 # CORRECT
63	DUAL SDAD TASK 2 MEAN # CORRECT
64	DUAL SDAD TASK 2 STANDARD DEV OF # CORRECT
65	DUAL SDAD TASK 2 # WRONG
66	DUAL SDAD TASK 2 MEAN # WRONG
67	DUAL SDAD TASK 2 STANDARD DEV OF # WRONG
68	DUAL SINGLE AXIS TRACK ERROR TASK 3
69	DUAL SDAD TASK 3 # CORRECT
70	DUAL SDAD TASK 3 MEAN # CORRECT
71	DUAL SDAD TASK 3 STANDARD DEV OF # CORRECT
72	DUAL SDAD TASK 3 # WRONG
73	DUAL SDAD TASK 3 MEAN # WRONG
74	DUAL SDAD TASK 3 STANDARD DEV OF # WRONG
75	DLT SINGLE # CORRECT
76	FIRST DLT DUAL # CORRECT
77	SECOND DLT DUAL # CORRECT
78	THIRD DLT DUAL # CORRECT
79	SINGLE STICK 1ST SESSION MINUTE 1 X-AXIS
80	SINGLE STICK 1ST SESSION MINUTE 1 Y-AXIS
81	SINGLE STICK 1ST SESSION MINUTE 2 X-AXIS
82	SINGLE STICK 1ST SESSION MINUTE 2 Y-AXIS
83	SINGLE STICK 1ST SESSION MINUTE 3 X-AXIS

84	SINGLE STICK 1ST SESSION MINUTE 3 Y-AXIS
85	SINGLE STICK 2ND SESSION MINUTE 1 X-AXIS
86	SINGLE STICK 2ND SESSION MINUTE 1 Y-AXIS
87	SINGLE STICK 2ND SESSION MINUTE 2 X-AXIS
88	SINGLE STICK 2ND SESSION MINUTE 2 Y-AXIS
89	SINGLE STICK 2ND SESSION MINUTE 3 X-AXIS
90	SINGLE STICK 2ND SESSION MINUTE 3 Y-AXIS
91	DUAL STICK MINUTE 1 X-AXIS
92	DUAL STICK MINUTE 1 Y-AXIS
93	DUAL STICK MINUTE 2 X-AXIS
94	DUAL STICK MINUTE 2 Y-AXIS
95	DUAL STICK MINUTE 3 X-AXIS
96	DUAL STICK MINUTE 3 Y-AXIS
97	DUAL STICK MINUTE 4 X-AXIS
98	DUAL STICK MINUTE 4 Y-AXIS
99	SINGLE STICK/RUDDER 1ST SESSION MINUTE 1 X-AXIS
100	SINGLE STICK/RUDDER 1ST SESSION MINUTE 1 Y-AXIS
101	SINGLE STICK/RUDDER 1ST SESSION MINUTE 1 Z-AXIS
102	SINGLE STICK/RUDDER 1ST SESSION MINUTE 2 X-AXIS
103	SINGLE STICK/RUDDER 1ST SESSION MINUTE 2 Y-AXIS
104	SINGLE STICK/RUDDER 1ST SESSION MINUTE 2 Z-AXIS
105	SINGLE STICK/RUDDER 1ST SESSION MINUTE 3 X-AXIS

106	SINGLE STICK/RUDDER 1ST SESSION MINUTE 3 Y-AXIS
107	SINGLE STICK/RUDDER 1ST SESSION MINUTE 3 Z-AXIS
108	SINGLE STICK/RUDDER 2ND SESSION MINUTE 1 X-AXIS
109	SINGLE STICK/RUDDER 2ND SESSION MINUTE 1 Y-AXIS
110	SINGLE STICK/RUDDER 2ND SESSION MINUTE 1 Z-AXIS
111	SINGLE STICK/RUDDER 2ND SESSION MINUTE 2 X-AXIS
112	SINGLE STICK/RUDDER 2ND SESSION MINUTE 2 Y-AXIS
113	SINGLE STICK/RUDDER 2ND SESSION MINUTE 2 Z-AXIS
114	SINGLE STICK/RUDDER 2ND SESSION MINUTE 3 X-AXIS
115	SINGLE STICK/RUDDER 2ND SESSION MINUTE 3 Y-AXIS
116	SINGLE STICK/RUDDER 2ND SESSION MINUTE 3 Z-AXIS
117	SINGLE STICK/RUDDER 3RD SESSION MINUTE 1 X-AXIS
118	SINGLE STICK/RUDDER 3RD SESSION MINUTE 1 Y-AXIS
119	SINGLE STICK/RUDDER 3RD SESSION MINUTE 1 Z-AXIS
120	SINGLE STICK/RUDDER 3RD SESSION MINUTE 2 X-AXIS
121	SINGLE STICK/RUDDER 3RD SESSION MINUTE 2 Y-AXIS
122	SINGLE STICK/RUDDER 3RD SESSION MINUTE 2 Z-AXIS

123	SINGLE STICK/RUDDER 3RD SESSION MINUTE 3 X-AXIS
124	SINGLE STICK/RUDDER 3RD SESSION MINUTE 3 Y-AXIS
125	SINGLE STICK/RUDDER 3RD SESSION MINUTE 3 Z-AXIS
126	DUAL STICK/RUDDER 1ST SESSION MINUTE 1 X-AXIS
127	DUAL STICK/RUDDER 1ST SESSION MINUTE 1 Y-AXIS
128	DUAL STICK/RUDDER 1ST SESSION MINUTE 1 Z-AXIS
129	DUAL STICK/RUDDER 1ST SESSION MINUTE 2 X-AXIS
130	DUAL STICK/RUDDER 1ST SESSION MINUTE 2 Y-AXIS
131	DUAL STICK/RUDDER 1ST SESSION MINUTE 2 Z-AXIS
132	DUAL STICK/RUDDER 1ST SESSION MINUTE 3 X-AXIS
133	DUAL STICK/RUDDER 1ST SESSION MINUTE 3 Y-AXIS
134	DUAL STICK/RUDDER 1ST SESSION MINUTE 3 Z-AXIS
135	DUAL STICK/RUDDER 1ST SESSION MINUTE 4 X-AXIS
136	DUAL STICK/RUDDER 1ST SESSION MINUTE 4 Y-AXIS
137	DUAL STICK/RUDDER 1ST SESSION MINUTE 4 Z-AXIS
138	DUAL STICK/RUDDER 2ND SESSION MINUTE 1 X-AXIS
139	DUAL STICK/RUDDER 2ND SESSION MINUTE 1 Y-AXIS

140	DUAL STICK/RUDDER 2ND SESSION MINUTE 1 Z-AXIS
141	DUAL STICK/RUDDER 2ND SESSION MINUTE 2 X-AXIS
142	DUAL STICK/RUDDER 2ND SESSION MINUTE 2 Y-AXIS
143	DUAL STICK/RUDDER 2ND SESSION MINUTE 2 Z-AXIS
144	DUAL STICK/RUDDER 2ND SESSION MINUTE 3 X-AXIS
145	DUAL STICK/RUDDER 2ND SESSION MINUTE 3 Y-AXIS
146	DUAL STICK/RUDDER 2ND SESSION MINUTE 3 Z-AXIS
147	DUAL STICK/RUDDER 2ND SESSION MINUTE 4 X-AXIS
148	DUAL STICK/RUDDER 2ND SESSION MINUTE 4 Y-AXIS
149	DUAL STICK/RUDDER 2ND SESSION MINUTE 4 Z-AXIS
150	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 1 X-AXIS
151	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 1 Y-AXIS
152	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 1 Z-AXIS
153	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 1 T-AXIS
154	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 2 X-AXIS
155	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 2 Y-AXIS
156	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 2 Z-AXIS

157	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 2 T-AXIS
158	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 3 X-AXIS
159	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 3 Y-AXIS
160	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 3 Z-AXIS
161	STICK/RUDDER/THROTTLE 1ST SESSION MINUTE 3 T-AXIS
162	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 1 X-AXIS
163	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 1 Y-AXIS
164	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 1 Z-AXIS
165	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 1 T-AXIS
166	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 2 X-AXIS
167	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 2 Y-AXIS
168	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 2 Z-AXIS
169	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 2 T-AXIS
170	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 3 X-AXIS
171	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 3 Y-AXIS
172	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 3 Z-AXIS
173	STICK/RUDDER/THROTTLE 2ND SESSION MINUTE 3 T-AXIS

APPENDIX B

MODIFIED VARIABLE LISTING

VAR #	VARIABLE NAME
1	SUBJ NUMBER
2	DESIGNATOR 1 = SNA 2 = SNFO
3	AGE
4	SEX 1 = MALE 2 = FEMALE
5	ACCESSION 1 = AOC/OCS 2 = USNA 3 = NAVCAD 4 = USMC 5 = ROTC 6 = OTHER
6	EDUCATION 1 = ENGINEERING/MATH 2 = GEN SCIENCE/BIOLOGY, GEOLOGY, ETC. 3 = BUSINESS 4 = SOCIAL SCIENCE 5 = PHYSICAL EDUCATION
7	PRIOR FLIGHT HOURS
8	AQT
9	FAR
10	SAT
11	MCT
12	BI (NOTE 10, 11, 12 ARE INDIVIDUAL SECTIONS OF FAR)
13	OAR

14	PRIMARY COMPOSITE GRADE
15	AVIATION INDOC GRADE
16	PRIMARY ACADEMIC GRADE
17	PRIMARY FLIGHT GRADE
18	PASS/FAIL 1 = PASS 2 = FAIL
19	PIPELINE 1 = JET 2 = HELO 3 = PROP 4 = E2C2
20	PRIMARY TRAINING SQUADRON 2 = VT-2 3 = VT-3 6 = VT-6
21	SINGLE AXIS TRACK ERROR (Average of 3 Tasks)
22	SINGLE DIGIT ABSOLUTE DIFFERENCE (SDAD) # CORRECT (Average of 5 Tasks)
23	SDAD MEAN TIME TO MAKE CORRECT ANSWER (SDADCM) (Average of 5 Tasks)
24	SDAD STANDARD DEVIATION OF TIME TO MAKE CORRECT ANSWER (SDADCSD) (Average of 5 Tasks)
25	SDAD # WRONG (SDADW) (Average of 5 Tasks)
26	SDAD MEAN TIME TO MAKE WRONG ANSWER (SDADWM) (Average of 5 Tasks)
27	SDAD STANDARD DEV OF TIME TO MAKE WRONG ANSWER (SDADWSD) (Average of 5 Tasks)
28	DUAL TASK SINGLE AXIS TRACK ERROR (Average of 3 Tasks)
29	DUAL TASK ABSOLUTE DIFFERENCE # CORRECT (DDADC) (Average of 3 Tasks)
30	DUAL TASK MEAN TIME TO MAKE CORRECT ANSWER (DDADCM) (Average of 3 Tasks)

31 DUAL TASK STD DEV TIME TO MAKE CORRECT ANSWER (DDADCSD) (Average of 3 Tasks)

32 DUAL TASK ABSOLUTE DIFFERENCE # WRONG (DDADW) (Average of 3 Tasks)

33 DUAL TASK MEAN TIME TO MAKE WRONG ANSWER (DDADWM) (Average of 3 Tasks)

34 DUAL TASK STD DEV OF TIME TO MAKE WRONG ANSWER (DDADWSD) (Average of 3 Tasks)

35 DLT SINGLE # CORRECT (DLTS)

36 DLT DUAL X/Y AXIS # CORRECT (SXYDLT)

37 DLT DUAL X/Y/Z AXIS # CORRECT (DXYZDLT) (Average of 2 Tasks)

38 SINGLE TASK X/Y-AXIS TRACK ERROR (SXYTE) (avg 2 Sessions, 3 minutes each)

39 DUAL TASK X/Y-AXIS TRACK ERROR (DXYTE) (Avg 1 Session, 4 Minutes)

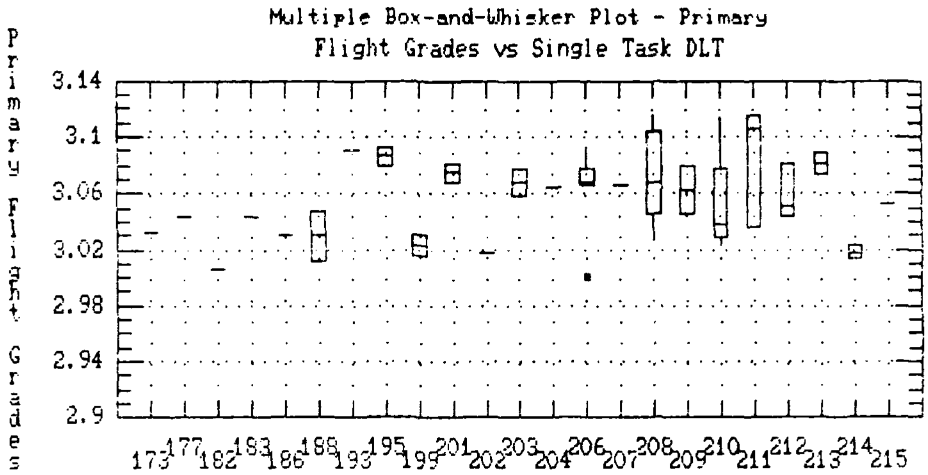
40 SINGLE TASK X/Y/Z-AXIS TRACK ERROR (SXYZTE) (Avg 3 Sessions, 3 Minutes each)

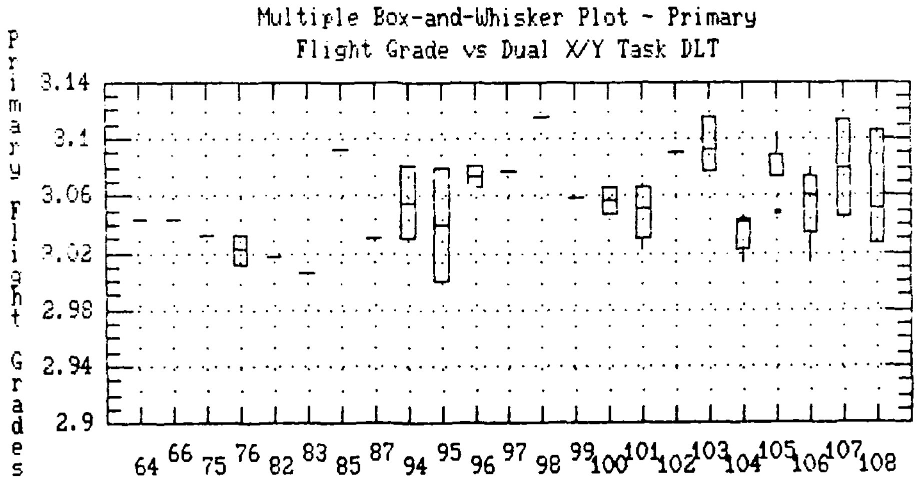
41 DUAL TASK X/Y/Z-AXIS TRACK ERROR (DXYZTE) (Avg 2 Sessions, 4 Minutes each)

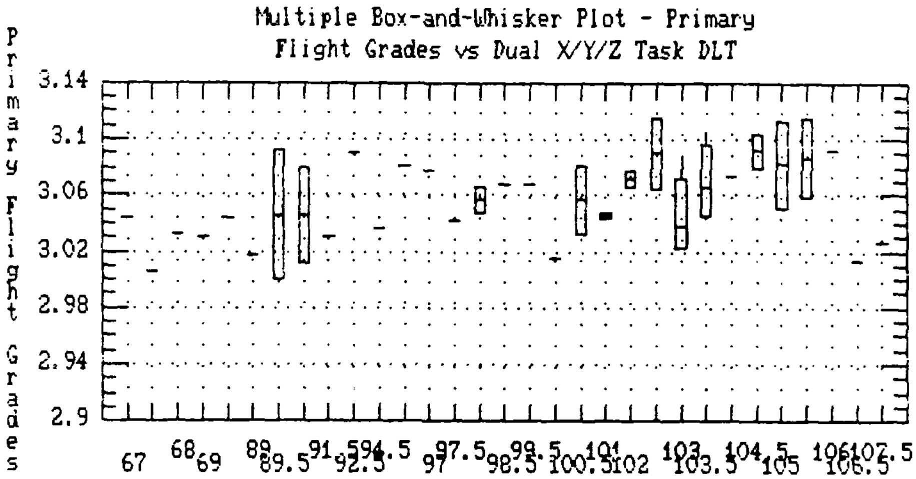
42 SINGLE TASK X/Y/Z/T-AXIS TRACK ERROR (SXYZTTE) (Avg 2 Sessions, 3 Minutes each)

APPENDIX C

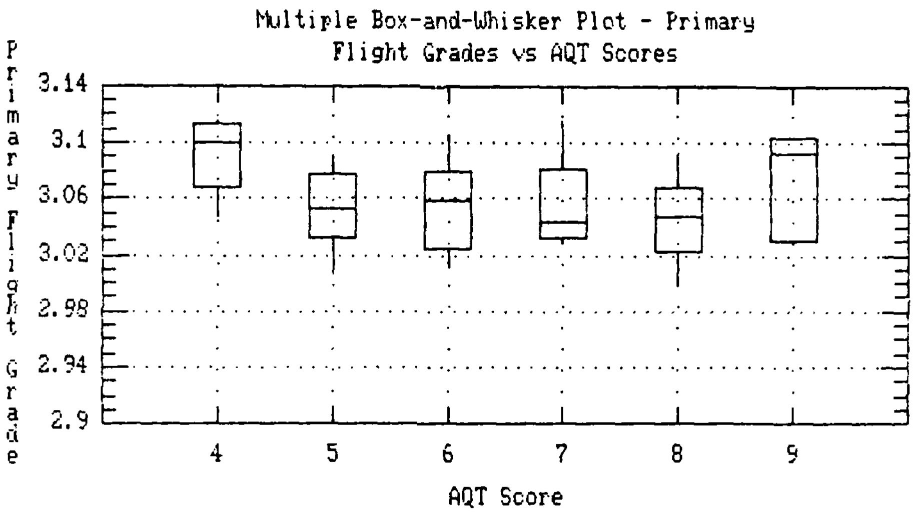
PLOTS OF VARIABLES

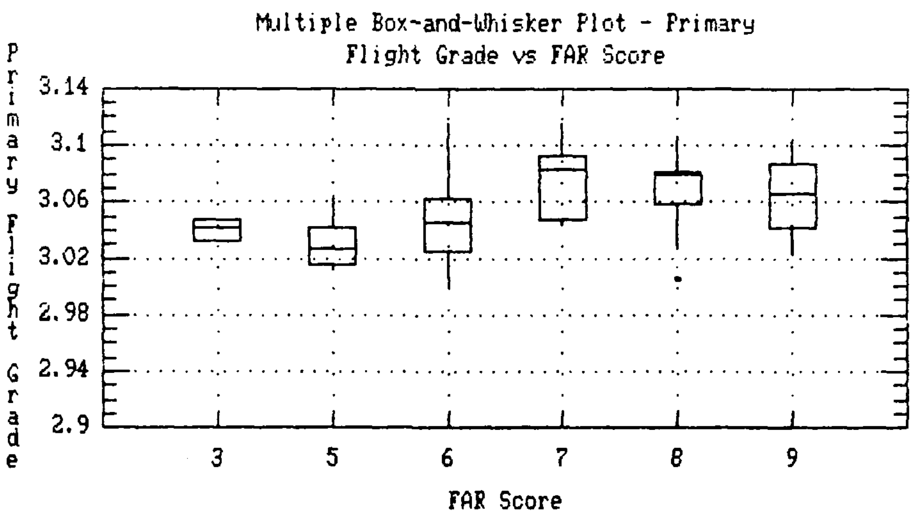


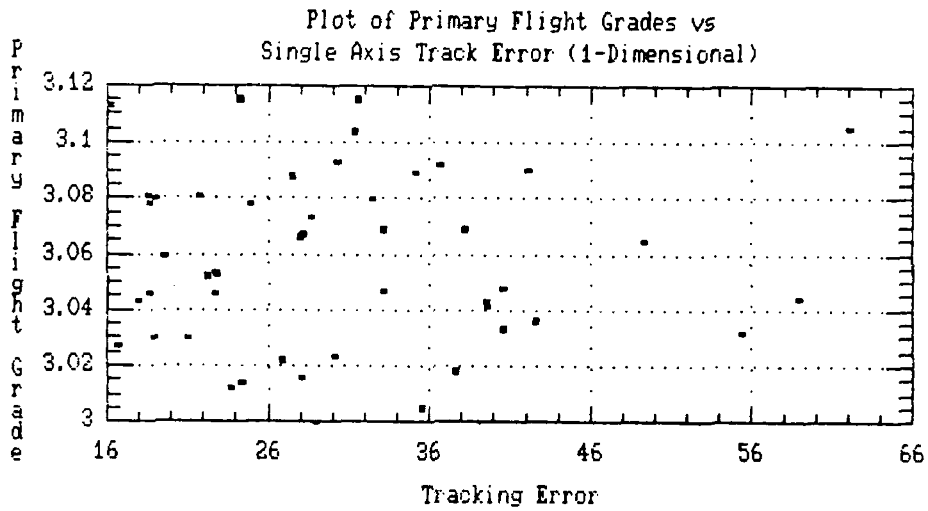


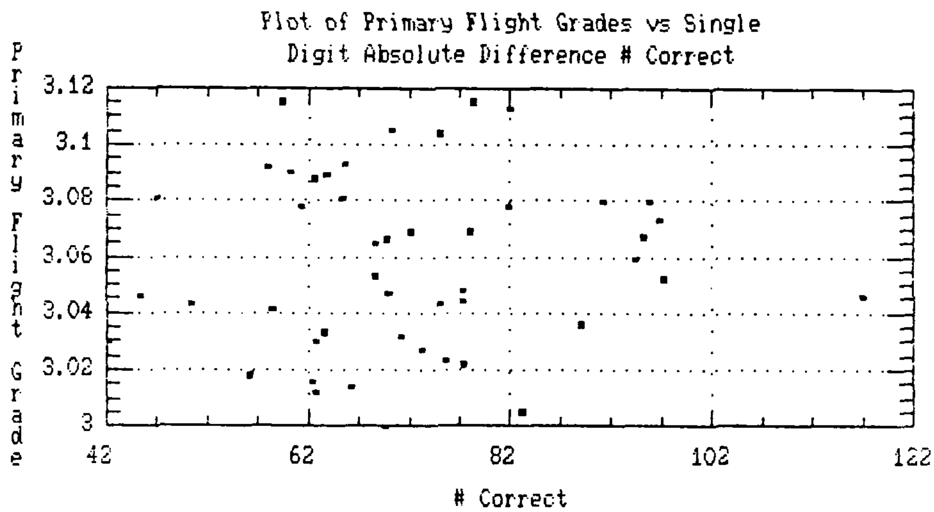


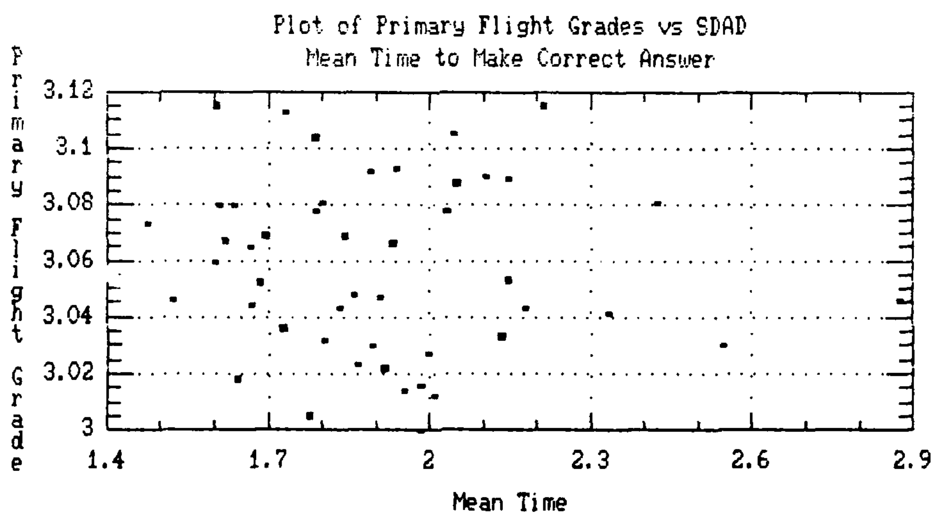
Dual Task X/Y/Z DLT



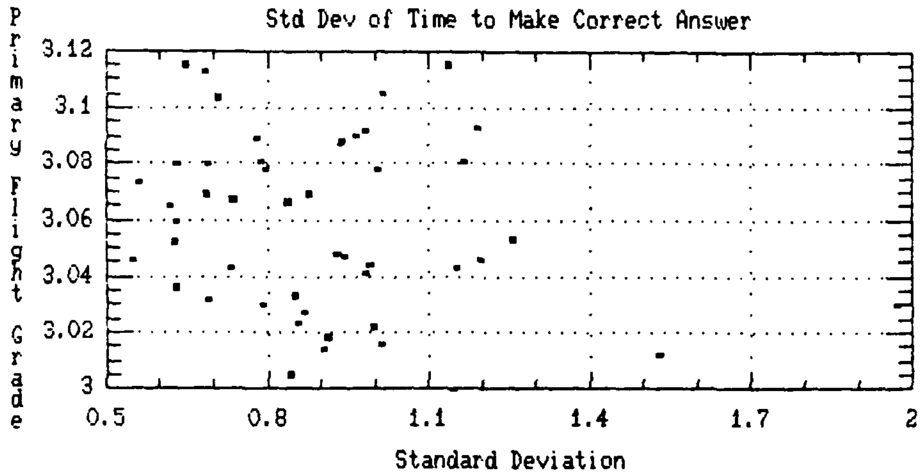



Plot of Primary Flight Grades vs
Single Axis Track Error (1-Dimensional)
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
16
26
36
46
56
66
Tracking Error

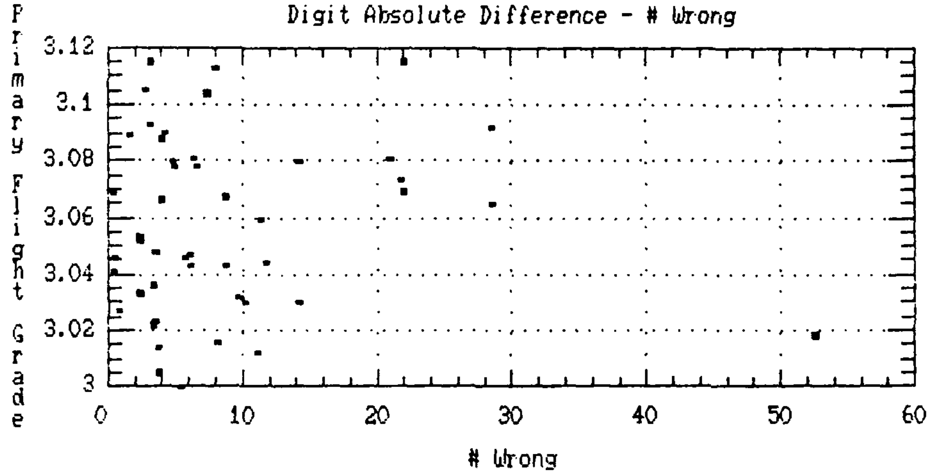

Plot of Primary Flight Grades vs Single
Digit Absolute Difference # Correct
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
42
62
82
102
122
Correct


Plot of Primary Flight Grades vs SDAD
Mean Time to Make Correct Answer
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
1.4
1.7
2
2.3
2.6
2.9
Mean Time

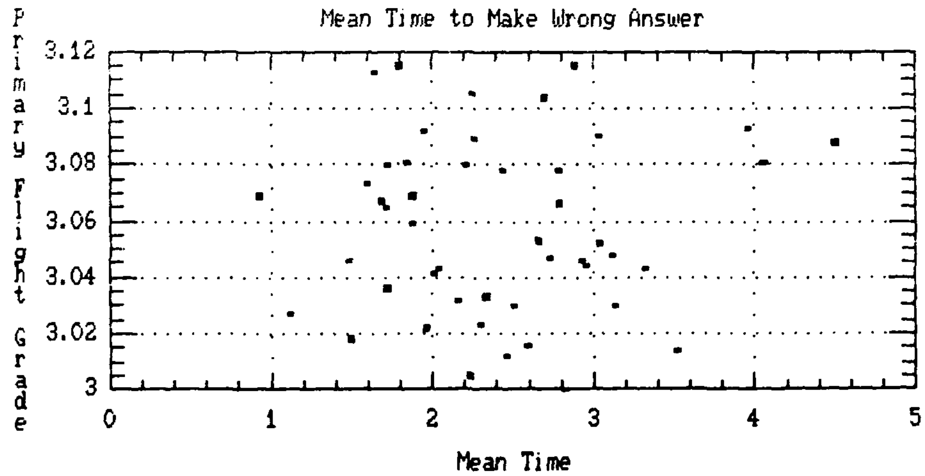
Plot of Primary Flight Grades vs SDAD
Std Dev of Time to Make Correct Answer

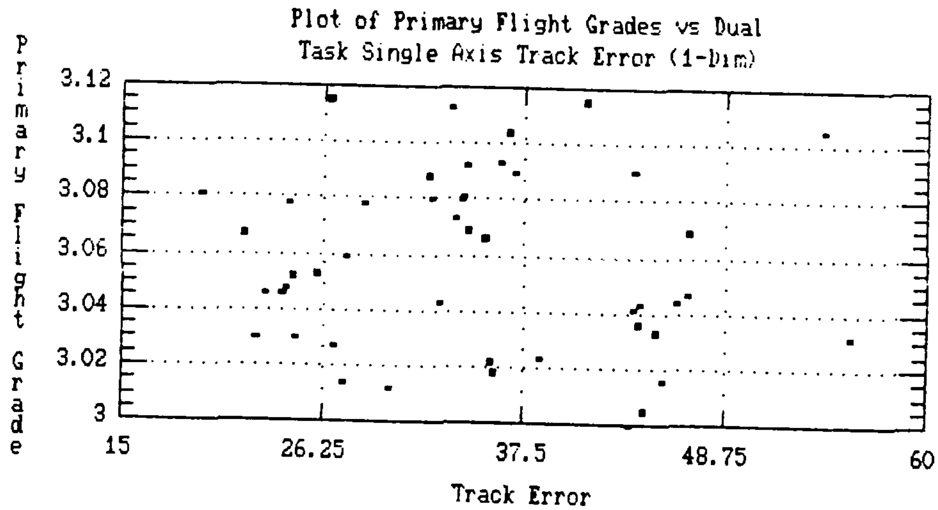


Plot of Primary Flight Grades vs Single
Digit Absolute Difference - # Wrong

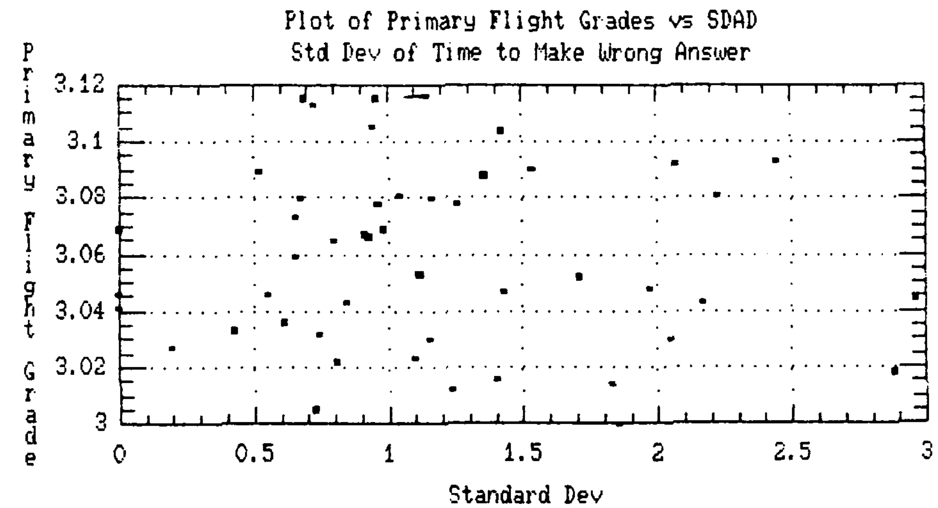


Plot of Primary Flight Grades vs SDAD
Mean Time to Make Wrong Answer

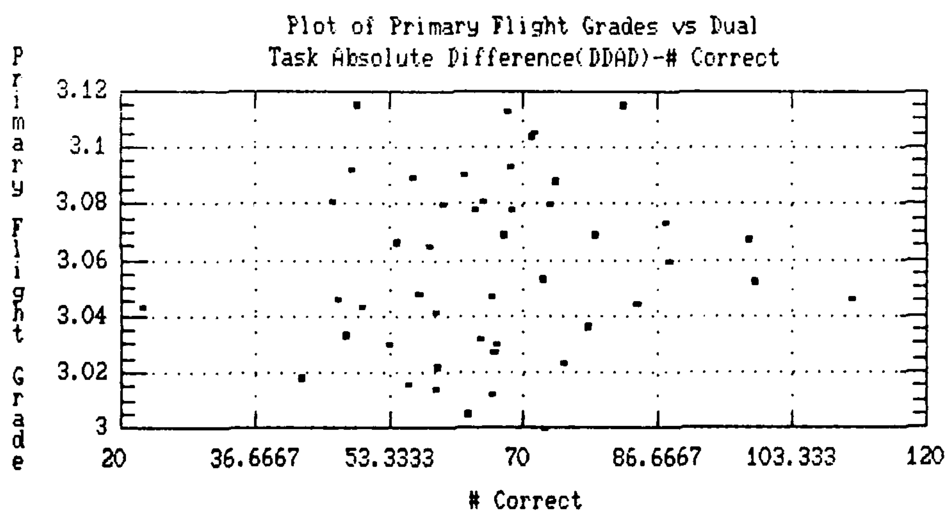




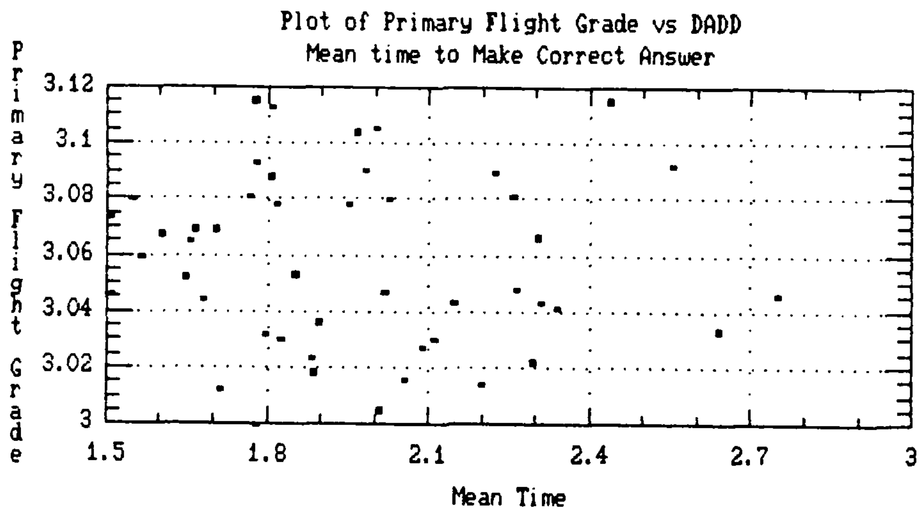
Plot of Primary Flight Grades vs Dual
Task Single Axis Track Error (1-Dim)
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
15
26.25
37.5
48.75
60
Track Error

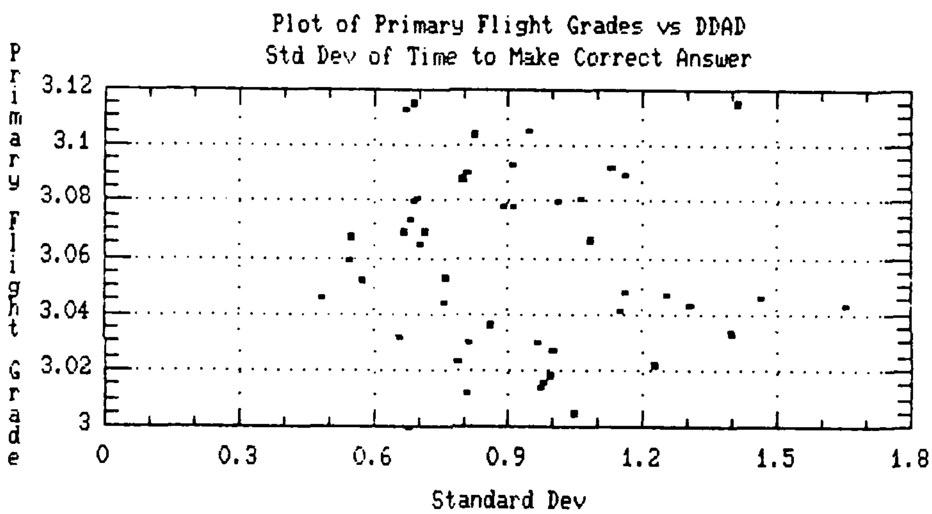


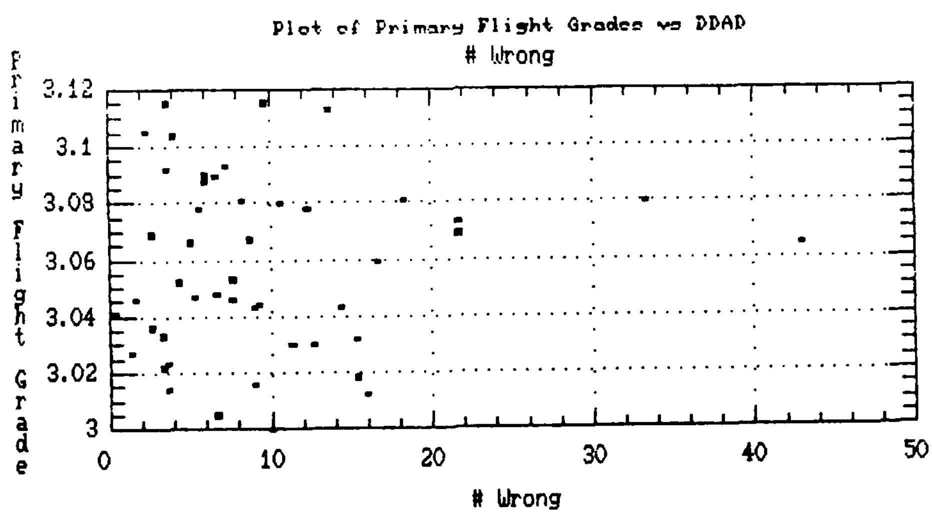
Plot of Primary Flight Grades vs SDAD
Std Dev of Time to Make Wrong Answer
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
0
0.5
1
1.5
2
2.5
3
Standard Dev

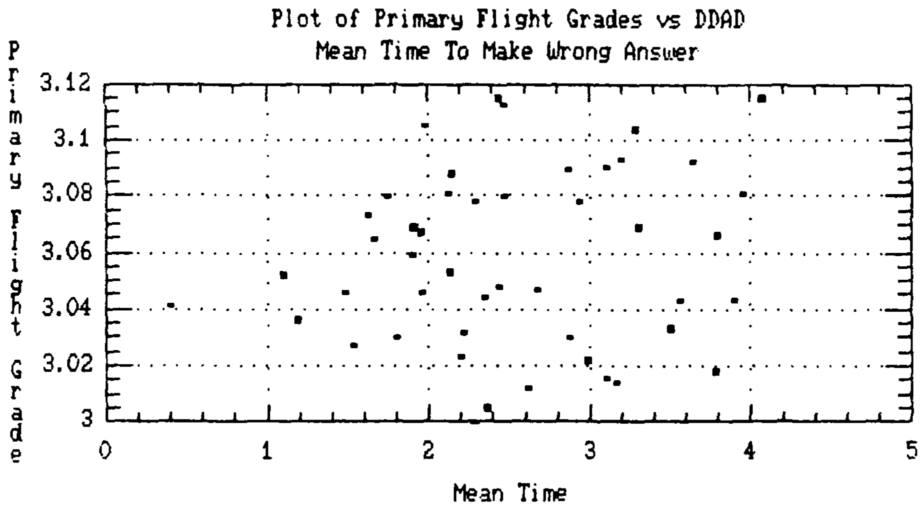


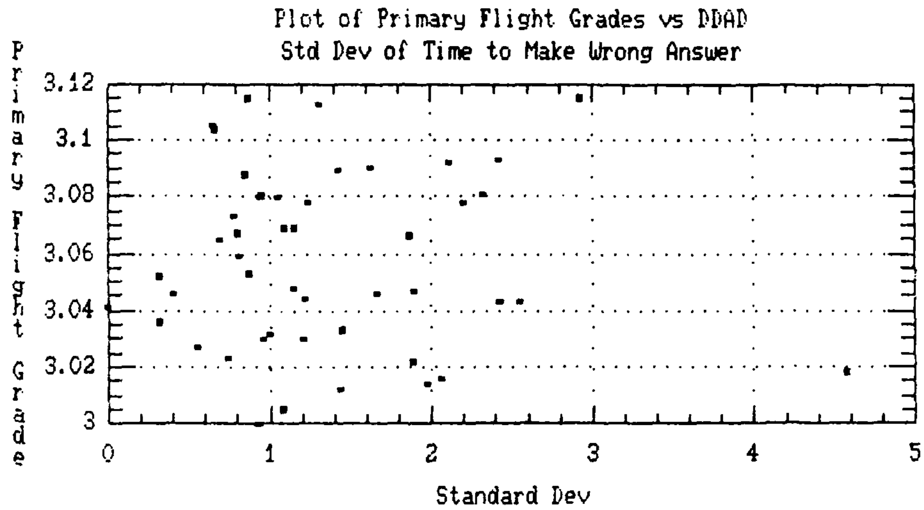
Plot of Primary Flight Grades vs Dual
Task Absolute Difference(DDAD)-# Correct
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
20
36.6667
53.3333
70
86.6667
103.333
120
Correct

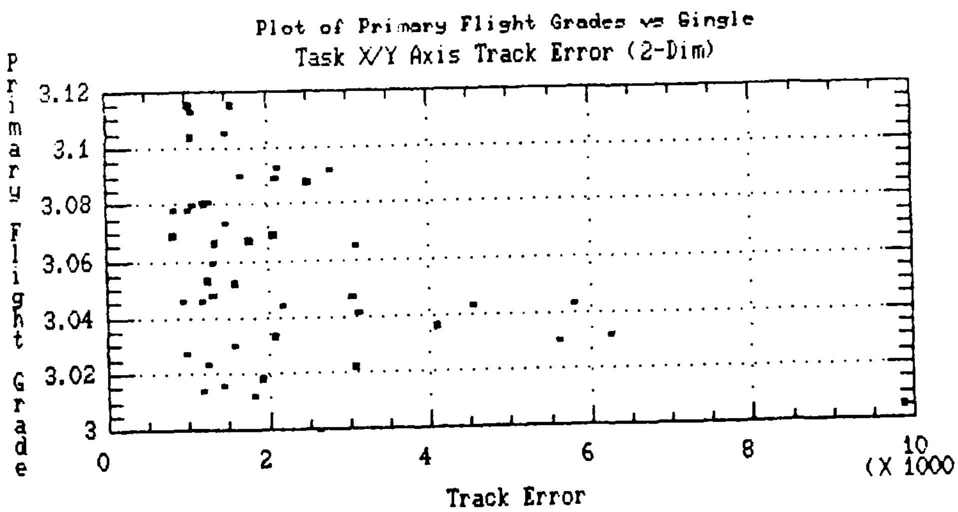

Plot of Primary Flight Grade vs DADD
Mean time to Make Correct Answer
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
1.5
1.8
2.1
2.4
2.7
3
Mean Time


Plot of Primary Flight Grades vs DDAD
Std Dev of Time to Make Correct Answer
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
0
0.3
0.6
0.9
1.2
1.5
1.8
Standard Dev

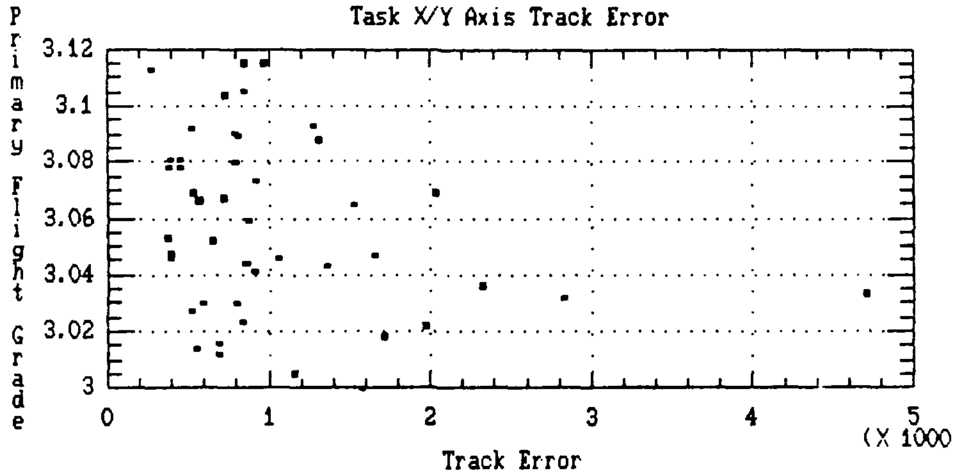

Plot of Primary Flight Grades vs DDAD
Wrong
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
0
10
20
30
40
50
Wrong


Plot of Primary Flight Grades vs DDAD
Mean Time To Make Wrong Answer
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
0
1
2
3
4
5
Mean Time

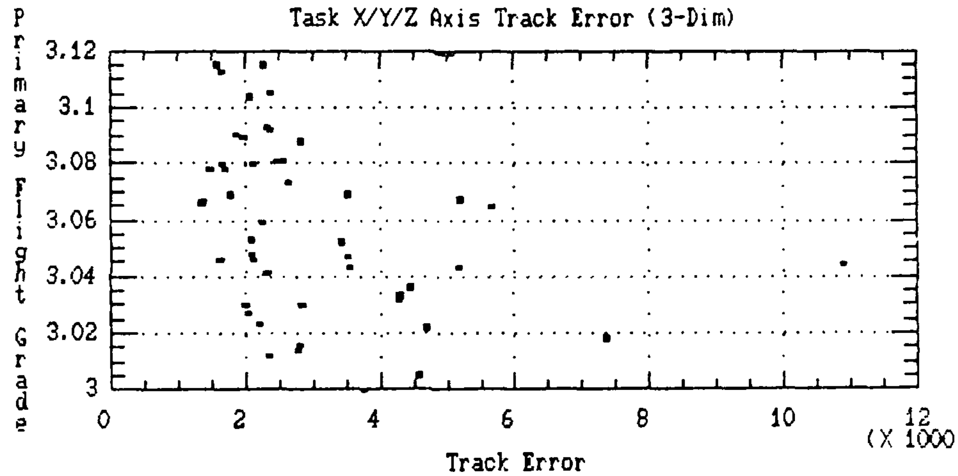

Plot of Primary Flight Grades vs DDAD
Std Dev of Time to Make Wrong Answer
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
0
1
2
3
4
5
Standard Dev


Plot of Primary Flight Grades vs Single
Task X/Y Axis Track Error (2-Dim)
Primary Flight Grade
3.12
3.1
3.08
3.06
3.04
3.02
3
0
2
4
6
8
10
(X 1000
Track Error

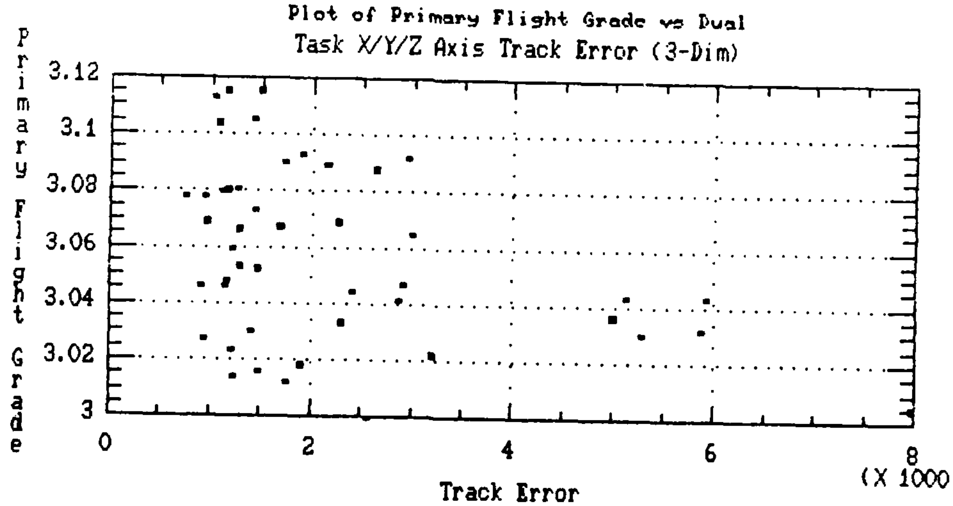
Plot of Primary Flight Grades vs Dual
Task X/Y Axis Track Error

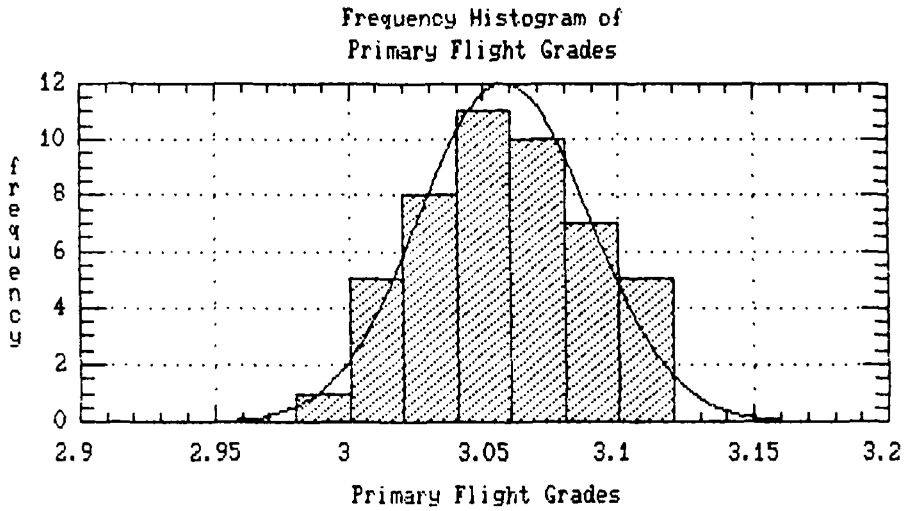


Plot of Primary Flight Grade vs Single
Task X/Y/Z Axis Track Error (3-Dim)



Plot of Primary Flight Grade vs Dual
Task X/Y/Z Axis Track Error (3-Dim)




Frequency Histogram of
Primary Flight Grades
frequency
12
10
8
6
4
2
0
2.9
2.95
3
3.05
3.1
3.15
3.2
Primary Flight Grades

APPENDIX D

SAMPLE AQT/FAR QUESTIONS

ACADEMIC QUALIFICATIONS TEST (AQT)

Verbal Analogy:

ZINC : SULFURIC ACID ::

(A) atom : molecule
(B) copper : brass
(C) element : compound (correct ans)
(D) metal : salt
(E) molecule : mixture

MECHANICAL COMPREHENSION TEST (MCT)

Mechanical Principles:

What is the ideal mechanical advantage of an incline that rises 3 feet for each 12 feet of length?

(A) 3
(B) 4 (correct ans)
(C) 5
(D) Not enough information to answer question

BIOGRAPHICAL INVENTORY (BI)

Personal Interest:

1. Which of the following interest you **least**:

(A) Football
(B) Water Sports
(C) Badminton
(D) Tennis

2. Do you enjoy team sports more than individual (one-on-one) sports?

(A) Yes
(B) No

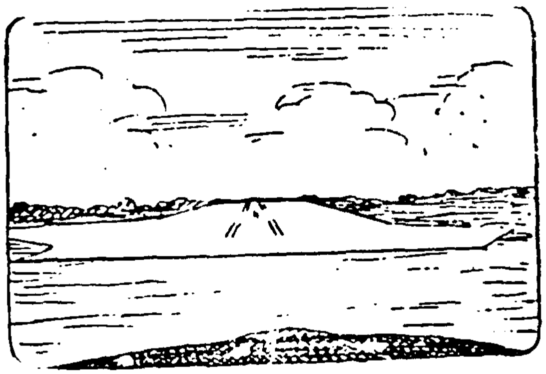
Aviation Information:

Lowering the flaps

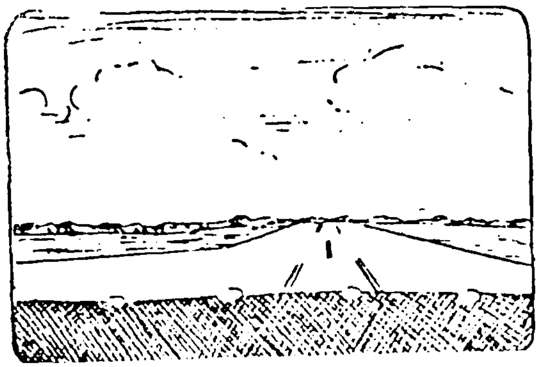
(A) increases wing lift (Correct Ans)
(B) turns the aircraft
(C) Prepares the aircraft for fast flight
(D) decreases wing surface area.

SPATIAL APPERCEPTION

If view A indicates that the aircraft is higher than in view B, mark A, otherwise mark B.



A



B

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2. Henmon, V.A.C., "Air Service Tests for Aptitude for Flying", Journal of Applied Psychology, v. 3, June 1919.

3. Mashburn, Neely C., "Mashburn Automatic Serial Action Apparatus for Detecting Flying Aptitude", Journal of Aviation Medicine, v. 3, December 1934.

4. Naval Aerospace Medical Research Laboratory Special Report 77-2, Aviation Selection 1919-1977, by Robert A. North and Glenn R. Griffin.

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