THE USE OF A VISUAL TESTING APPARATUS FOR SPACE APPLICATION

FINAL REPORT

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CHAPTER I
INTRODUCTION

This report is a description of the support services provided by Serendipity Associates to the NASA Ames Research Center, for the calibration and development of optimum utilization plans for a Visual Parameter Tester. The report is in compliance with Article IV of the negotiated contract NAS2-3725.

Manned spaceflight imposes rigorous requirements for a high degree of visual skills. Such skills can for the most part be made part of the selection program for astronauts and astronauts/scientists. However, the influence of the space environment on vision has received relatively slight study in the previous years of spaceflight experimentation. Most visual testing techniques focus entirely on visual acuity. Yet, this is only one of several potential parameters of visual skills that may be influenced by and, in turn, have great influence on spaceflight. The Visual Parameter Tester (VPT) developed by Douglas Aircraft Corporation for NASA was designed to provide a testing environment not only for visual acuity but several other key vision parameters. These parameters include absolute and relative brightness and flicker fusion.

A complete description of the Visual Parameter Tester is provided by Douglas[1]. However, since some understanding of the nature of the VPT is essential to the comprehension and use of this report, the instrument is briefly described below.

The Visual Parameter Tester is a 6 inch x 6-3/4 inch x 12-1/2 inch unit completely self-contained except for a hand-held response button and an interface simulator unit that provides test control. Subject stimuli are presented in a 1.5 inch-diameter opaque glass screen at the front of the VPT. Four visual tests are included:

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[1] Moss, E.G.: Final Report on the Development and Delivery of An Apparatus for Measuring Human Vision (Visual Parameter Tester). Douglas Report SM-52034, April 1966.

1. Absolute Brightness. A disk of light, .75 inches in diameter, is presented to the subject in the center of the viewing screen against a nonilluminated background. This disk of light gradually increases or decreases in brightness during the course of a trial. The subject depresses the response button when he no longer perceives the light or if it is on an increasing brightness cycle when he just perceives it.

2. Relative Brightness. In all ways similar to the above test except that the stimulus light is presented against a background illumination of 30, 3.0, 0.3, or 0.03 ft.-lamberts.

3. Visual Acuity. A set of Ronchi grids are positioned over the viewing screen in such a way as to generate moire patterns appearing to the subject as black strips on a transparent background. Rotation of one grid gives the effect of these lines either getting thinner and closer together or thicker and farther apart. The subject responds when he can no longer distinguish the lines or when he can just perceive them. The same four background illuminations, mentioned in test 2 above, are used here.

4. Flicker Frequency. The viewing screen is illuminated by any one of the four light levels (30, 3, .3, and .03 ft.-lamberts). The light beam is interrupted by a butterfly wheel, either increasing or decreasing in RPM, and causing the screen illumination to flicker. The subject responds by indicating when the flicker is no longer visible or when he just begins to see it.

The VPT, therefore, permits assessment of limenal subject responses by the psychophysical method of limits[1]. Test and illumination level selection may be made in any order by the controls on the interface simulator.

The method of limits is one of several psychophysical research models for determining an individual's threshold for a variety of stimuli. As might be expected, this method is only a general model; specific procedures are contingent

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[1] Cf. Guilford, J.P.: Psychometric Methods. McGraw-Hill, N.Y., 1954.

on particular application. Therefore, a brief description of the procedure used with the VPT may be in order. For purposes of explanation the following description exemplifies a hypothetical subject taking one of the acuity tests.

The subject is told that he will see two series of stimuli; in one series the dark lines will appear to get smaller and smaller until he can no longer distinguish them. He is told to indicate that point at which he can no longer see the individual lines. The second series will start with the lines too small to be distinguished. These lines will appear to get larger and larger and he will indicate when he first can distinguish them as separate lines. These series will alternate for a fixed number of trials—say ten. The subject's responses might appear as in figure 1.

In this figure the response indicates a change in perception. Consequently, prior to this change point the subject is implicitly responding that he either sees the lines or doesn't (depending on whether it is an ascending or descending series).

The threshold value (limen) may be defined as that point on the stimulus continuum at which the subject perceives the stimulus 50 percent of the time. It may be estimated, in this method, not by any given response point, but rather the mean of the response points of all the ascending and descending trials. In this example the limenal (mean) value is 0. 113 mm. It may be seen that a subject could respond earlier on both ascending and descending series and still have the same limenal value. The VPT continues a series for a random period of time after a response (from one to five seconds); therefore, the start point for the next series will also vary—as a function of shaft position and delay duration.

As delivered to the NASA (Ames Research Center), the VPT was essentially complete, but it had not been validated in use with subjects, nor had testing protocols been established and tested. The goal of the program described in the following chapters was primarily to compile the necessary data to support VPT use as a potential candidate device for testing visual skills in a space environment. More specifically, the scope of this program embraced the areas of:

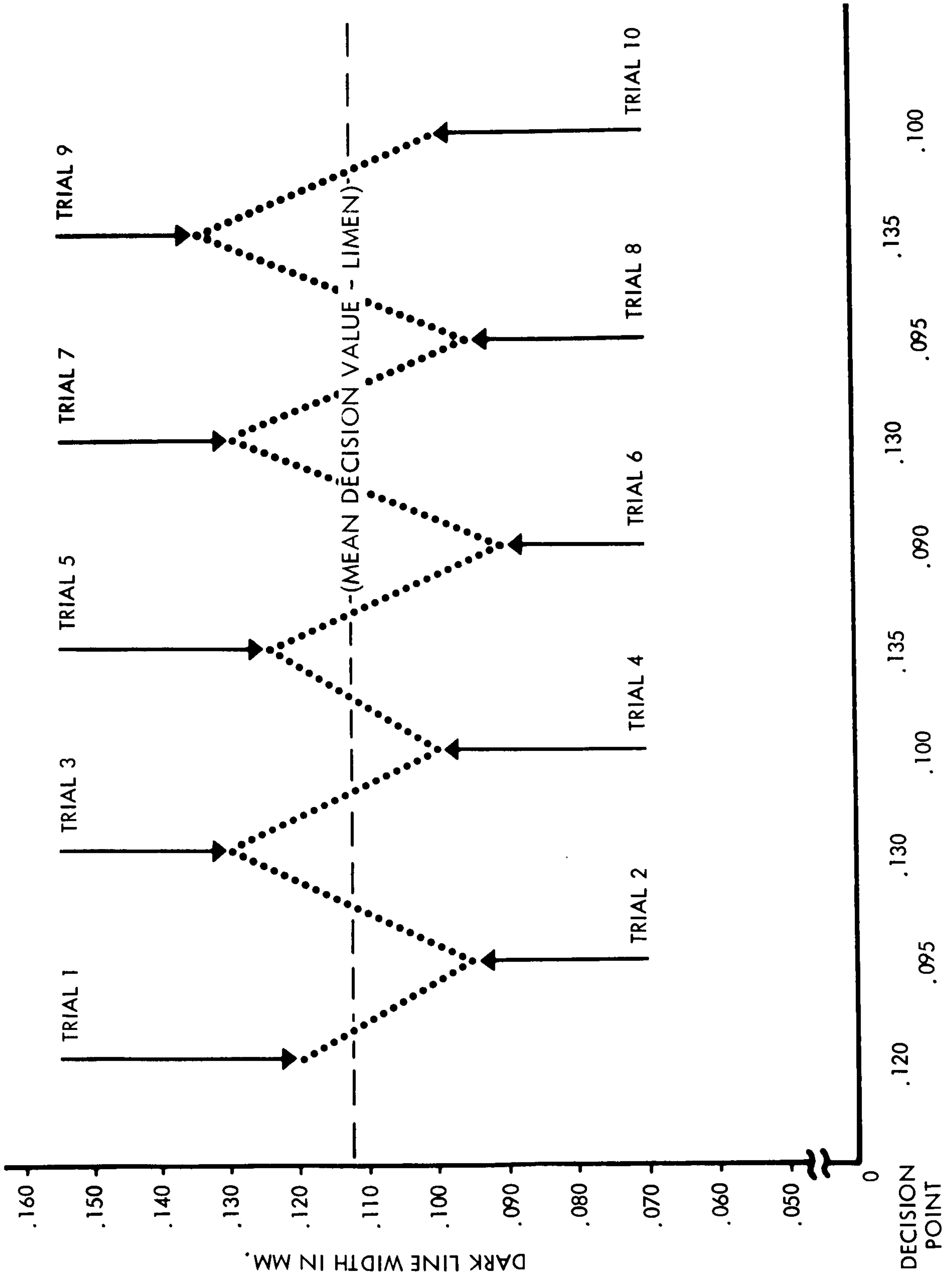

FIGURE 1. AN EXAMPLE OF THE METHOD OF LIMITS

1. Calibration of the device; that is, relating machine shaft positions with precise measurement of visual angles, brightness levels and flicker frequencies.

2. Comparison of the visual acuity measures of the VPT with those obtained using standard acuity tests.

3. Development and testing of experimental protocols for using the VPT in a spaceflight environment.

4. Review and analysis of potential future VPT utilization.

The following sections detail the procedures and results of Serendipity Associates' investigation of the above areas. Chapter headings are self-explanatory and will not be elaborated on here. When the nature of results require complex and/or lengthy tabular presentation, as in the case of calibration data, they will be found in the appendix. This approach was taken to maintain both completeness and readability.

CHAPTER II
CALIBRATION

In use, the visual parameter values produced by the VPT are varied about their value ranges as a function of the rotation of a central geared encoder shaft. This shaft rotates through an arc of approximately 216 discrete steps, dwelling at each step about .25 second. A subject response is sensed within the VPT as a particular shaft position, converted to a binary-type code (Gray Code) and can be output as a visual light sequence or as input to a variety of print out devices. Conversion tables for relating this binary code to decimal values were provided by Douglas (op. cit.). These tables have since been programmed for a NASA (Ames) computer.

The major purpose of the calibration effort was to determine the relation of the encoder shaft position to the various visual parameters involved in the four VPT tests. For absolute brightness and the four brightness difference tests, this variable was the intensity (in foot-lamberts) of the center spot illumination. For visual acuity, the variable was visual angle or absolute size of the stimulus lines. The variable for flicker fusion was cycles per second of flicker.

The nature of the VPT is such that the amount of illumination is, for the most part, a function of the light source (a small projection bulb) and the voltage applied to that light source. These components are also discussed in this chapter.

Calibration Procedures

All measures of illumination were taken with a Pritchard photometer (Spectra). Prior to each series of readings, the photometer was calibrated to a standard light source of 9 foot-lamberts. Measures were made in a darkened room with a photometric angle and photometer to VPT distance, such that the photometer measured approximately two-thirds of the VPT viewing screen. The coverage was selected after a series of small angle spot measures indicated a 15 to 20 percent variation of illumination over the surface of the viewing screen. Each measure series was repeated at least twice: resultant data represent an arithmetic average.

Visual acuity angles were measured with a Wald theodolite. Theodolite to VPT distance was adjusted during the calibration series to provide the most accurate measurement. All measures were converted to visual angles of subject viewing distance and width, in millimeters, of the grid components.

The frequency of flicker at each shaft position was measured by a stroboscope. These measures were made for only one level of background luminance since the flicker is independent of the screen luminance.

All calibrations of variables dependent on encoder shaft position were made with the shaft uncoupled from the drive mechanism and rotated by hand. Some portion of each parameter-shaft position relation was linear. For that portion, shaft position measures were made at about three shaft position intervals.

Field Brightness

Subsequent to the initial calibration, the light source of the Visual Parameter Tester was replaced with a new light bulb. The voltage was manipulated until a maximum field illumination of 30 foot-lamberts was obtained. The VPT was then calibrated according to the recommended Douglas procedure. During the course of machine usage in the following weeks, periodic photometric measures were made of field illumination. These data are summarized in table 1. After 50 hours of use, field illumination has remained approximately constant (within measurement error of the photometer).

Brightness Tests

The relation of the center spot brightness to encoder shaft position was measured at the four levels of brightness background (30, 3, 0.3, and 0.03 foot-lamberts), as well as with zero background illumination and zero background illumination with a log three neutral density filter in front of the visual display. The results of these measurements are presented in Appendix A. The

TABLE 1
PHOTOMETRIC MEASURES OF VPT: FIELD LUMINANCE

	FIELD BRIGHTNESS (IN FT.-LAMBERTS)			
DAY	HI	HI-	LO+	LO
1	31.0	3.4	.32	.036
2	30.5	3.2	.288	.0335
3	29.8	3.19	.291	.0345
11	29.6	3.24	.305	.0335
20	33.0	3.30	.29	.040

log three neutral density filter was included because early tests of the VPT revealed that for a large percentage of subjects the center spot, in the absolute brightness test, always seemed to be present. This condition made the Absolute Brightness test unusable. The neutral density filter reduced the illumination significantly and remedied the situation.

Flicker Fusion

The relation of flicker fusion (CPS) to encoder shaft position was performed at only one brightness level. Changes in brightness intensity do not result in changes in cycles per second-encoder position relationship. The result of this measurement is presented in Appendix B.

Visual Acuity

In the test for visual acuity, four levels of illumination are provided. These four levels are constant during the test run. The rotation of the main shaft in this test does not change the amount of illumination but rather rotates the Ronchi gratings that provide the target for visual acuity. As this grating is rotated, the apparent size of the grating increases or decreases. The task of this calibration effort was to relate the change in grid size and corresponding visual acuity measures to the appropriate shaft position.

Visual acuity may be defined in a variety of ways. For the development of the VPT, acuity may best be defined in terms of resolution. Douglas Aircraft has, for all practical purposes, defined acuity in terms of the resolution of line pairs per millimeter. That is, the measured difference between the midpoint of one black line to the midpoint of an adjacent black line. It would appear that at least two other measures could be taken which might have utility in the future for defining acuity in this context: width in millimeters of each stimulus line, and the ratio of black line to total space between lines. All three measures were taken during the course of this calibration. The relation of line pair to encoder shaft position is shown graphically in Appendix C, as are the other measures. These curves are free-hand drawn to the raw data points.

Light Source Stability

The light source for all visual tests performed by the device is a commercially available, standard, six-volt, fixed-focus exciter lamp. Illumination from this light source reaches the viewing screen in an optically uncomplicated manner. The main light, used to illuminate the outer perimeter of the viewing screen in the brightness tests and the entire screen for flicker fusion and visual acuity, is directed to the viewing screen via a series of circular apertures cut in the metal supporting members of the device itself. Illumination of the center circle, necessary for both absolute and relative brightness tests, is provided by the same light source and directed, by a series of mirrors in a U-shaped path, to eventually reach the center section of the viewing screen.

It may be seen from this brief description of the device's optical system that the amount of illumination reaching the screen is contingent primarily on the illumination provided by the 6-volt bulb. The bulb illumination is, in turn, contingent on the amount of voltage received by the bulb as well as well as the bulb age and condition of the clear glass surrounding the filament. In the latter case, this may be dependent not only on how clean the glass is in terms of dust and fingerprints on the outside of the glass, but also on minute deposits of metal resulting from the deterioration of the tungsten filament—the metal dust is deposited on the inner surface of the glass as the bulb is used.

Because the luminance of the bulb depends heavily on the voltage supplied to it, the VPT has a voltage regulator for the bulb. This regulator permits a maximum of 6.3 volts supplied to the bulb. However, in order to use such a regulating device in maintaining a constant illumination, the device must be partially dismantled in order to get at the voltage regulator. In addition, and more critical, is the fact that the regulation cannot be made with respect to luminance unless a photometer is available. Since the requirement for onboard photometric measures would impose an additional system, as well as an increased task load for any space application of the VPT, the degree to which the illumination system degrades from a standard illumination over time is quite critical to its potential application. For this reason, special attention was directed toward determining the amount and nature of this degradation.

As has been mentioned, the bulb used is standard and is available from both General Electric Company and Sylvania. According to the General Electric data handbook, the life span of this type of bulb is approximately 100 hours. This means, 50 percent of the sample bulbs tested had failed. Apparently, the failure curve for this type of bulb is a standard one. For the convenience of the reader, such a curve is illustrated in figure 2. The nature of the curve is such that there is little question of the bulb's utility for an up to 30-day space mission application. However, this comment is with respect to the bulb's functioning versus nonfunctioning; it is not directed toward the stability of illumination by the bulb over such a 30-day period.

Five bulbs were life tested in simulated visual parameter testers. Two were permitted to remain on until they failed. The others were subjected to intermittent use: one was turned on and off with the experimental VPT, the remaining units were used eight hours per day. All bulbs lasted over three hundred hours of use. For the first 25 hours, they showed a rapid degradation of luminance of about 12 percent. Their decay then leveled off until approximately the 250th hour of use when the decay curve again became steep. One may conclude that the bulbs should be first "aged"; that is, used for about 25 hours before they are placed in the VPT. They may then be adjusted for correct level of luminance and used in testing for at least 100 hours without significant change in luminance.

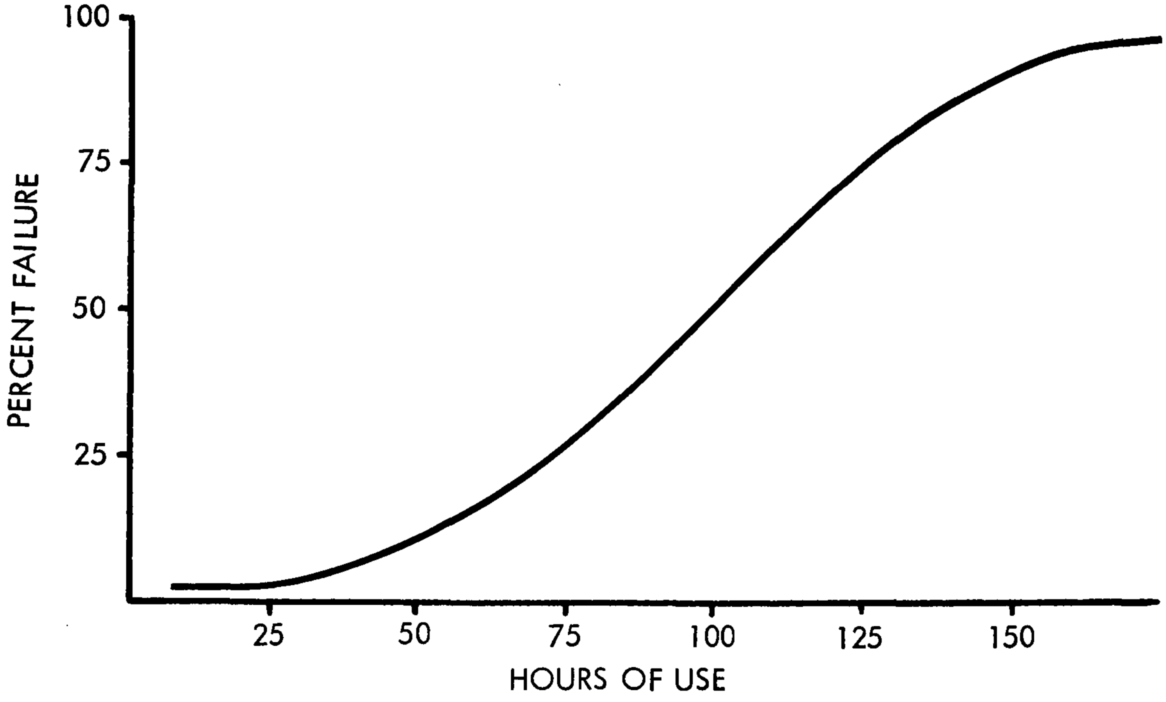

FIGURE 2. TYPICAL LIGHT BULB FAILURE CURVE.

Because of these findings, no recommendations for inflight calibration are necessary. As has been discussed, the VPT, as it is currently configured, would be difficult to adjust in other than a laboratory setting.

CHAPTER III
PROTOCOLS

A great deal of information about the procedures, test order, ambient conditions, etc., was necessary before the VPT could be used in any kind of space environment research. The principal purpose of the study effort described here was to develop such information. In addition, this information was essential to the design and conduct of experimentation, to relate performance on the VPT with standard tests of visual acuity.

The first step toward developing a standard protocol was the identification of potential critical variables. These were obtained through an extensive review of historical and current vision research (a summary of the review is presented in the appendix). The variables thus identified were used to design a pilot study in which the variables were subject to empirical investigation.

Pilot Study

The purpose of the pilot study was to determine appropriate paradigms to be used for full-scale investigatory effort. Of particular concern were the effects on subject performance of the following variables:

> Presentation Order.—There are four major test parameters and, within three of these, four orders of brightness. Although the combinations and permutations of presentation order for these various tests and subtests is quite complex, at least major orders necessitated study—previous visual experimentation indicate some performance/ order interaction.
>
> Darkness Adaptation.—The degree to which the subject is permitted time for complete adaptation to the ambient darkness in which the test is to be conducted, has a great bearing, particularly on brightness tests. The method and duration of adaptation means therefore required study.

Response Ranges. —This refers to both inter- and intrasubject ranges of scores on the various tests. Such data is important not only in determining subject reliability but also in assessing and predicting total durations of test administration and, indirectly, assessing the adequacy of stimulus ranges as provided by the VPT.

Ambient Conditions. —Of concern here are the attendant conditions to the experimental setting such as general background illumination level, noise level, and seating positions.

Data Reduction Needs. —Because the VPT produces encoder shaft positions in Gray code, some means must be provided for translating these positions to decimal figures and ultimately to parameter scale positions.

Control Conditions. —This refers to those variables directly related to the man-machine interface. Included here are subject instructions, the manner in which visual display and subject distances are maintained, the general presentation format and instructions relating to subject response indications.

Method

Ten subjects were provided from the general subject pool available to the Human Performance Laboratroy at Ames. These subjects for the most part were college students available on a part-time basis to serve as subjects for a variety of experiments being performed at this research center. While no attempt was made to control the age of the subject, their ages were typical of the young college population. All subjects had participated in assessment of visual acuity on one or more of several acuity tests (e.g., Snellen eye charts, Landolt ring eye chart, and/or Orthorater). To a large degree subjects were screened for normal vision in terms of acuity. Most of the subjects had 20-20 vision. The subjects might be classed as sophisticated because they had participated in one or more additional experiments being conducted by the Human Performance Laboratory. In some cases their participation in other experimentation alternated with their use on this project.

Subjects were tested, one at a time, over a period of a week and a half. Prior to the experimentation the subject was requested to put on a pair of red dark-adaptation goggles and to sit in subdued lighting for a period of ten minutes. In previous experimentation, both at Ames and at other vision laboratories, a ten minute dark-adaptation period has been found to be adequate. During the latter part of the ten minute adaptation time, subjects were seated at the experimental apparatus and given initial instructions as to the use of the Visual Parameter Tester. Specifically, this meant learning how to use the response mechanism and the appropriate placement of their head within the chin and forehead rest provided as a distance-limiting tool. For all subjects the eye-to-visual-display distance was 28 inches.

During the ten minute adaptation period the display was not visible to the subject because of a sliding partition between the subject and the VPT. At the end of the ten minute period, room illumination was turned off, Ss removed their goggles, and the sliding partition opened to reveal the visual display. The subject was again instructed specifically on his required responses for the first test and permitted several trial responses. When, in the judgment of the experimenter, the subject had understood the instructions and was responding correctly, he was told to continue his responses until he received further instructions.

At the end of a complete test administration, the subject was requested to again put on the dark-adaptation goggles and was given a ten-minute rest period. After the ten-minute rest period he was given a second administration of the entire test package. In general, total administration time, including dark adaption and rest periods averaged about one-and-a-half to two hours per subject.

Subjects were seated directly in front of the VPT, in an enclosed area of the laboratory. All walls were draped in black and the rug was black. The VPT support equipment and the experimenters were in another portion of the laboratory separated by a thick curtain. This arrangement permitted verbal contact between subject and experimenter as well as allowing the support equipment to be illuminated without changing the experimental ambient illumination (which was virtually absolute darkness).

As mentioned earlier there are a variety of combinations and permutations of test and subtest order that could be investigated. However, it was decided that since brightness thresholds are the most sensitive to the degree of subject dark adaptation, it would be best to start with those tests of brightness. Within the brightness threshold tests the same reasoning resulted in a selection of the first test for all subjects to be absolute brightness judgment. This was immediately followed by the brightness difference tests starting with low background illumination and working up to the 30 foot-lambert illumination. Because of the similarity among these tests, they were run sequentially with only a minute between each subtest. After the high-brightness background test, subjects were given a two-minute rest period during which they were instructed as to their responses for the following test. The following tests, either visual acuity or flicker fusion, were represented in four classes of presentation order. These classes are illustrated in table 2. It may be seen from this table that flicker can precede or follow acuity, and that the tests might start with low brightness and proceed to high, or start with high brightness and proceed to low. Since each subject was to receive two administrations of the test, each received two orders. Orders were assigned randomly for each subject and for each administration with the restraint that no subject would on two administrations receive the same order.

Data collected from the subjects was card punched and fed into a computer for which a program had been developed to translate Gray code into encoder shaft positions. Each subject was permitted between 16 and 21 trials per subtest. Because of the nature of data acquisition on the VPT—following a method of limits technique—these trials were averaged to give a subject-subtest threshold value. Intra- and intersubject means and standard deviations were computed for each subtest.

Results

Prior to the initial pilot testing, a number of variables had been isolated as potentially relevant to final protocol recommendation. In some cases the nature of these variables was such as to make including them, as independent variables to be tested during the pilot study, unwarranted and costly in terms

TABLE 2

TYPES OF TEST ORDER

A	B	C	D
Absolute Brightness	Same as A	Same as A	Same as A
Diff. Brightness (Low)			
Diff. Brightness (Low+)			
Diff. Brightness (Hi-)			
Diff. Brightness (Hi)			
Acuity (Low)	Flicker (Lo)	Flicker (Hi)	Acuity (Hi)
Acuity (Low+)	Flicker (Lo+)	Flicker (Hi-)	Acutiy (Hi-)
Acuity (Hi-)	Flicker (Hi-)	Flicker (Lo+)	Acuity (Lo+)
Acuity (Hi)	Flicker (Hi)	Flicker (Lo-)	Acuity (Lo)
Flicker (Low)	Acuity (Lo)	Acuity (Hi)	Flicker (Hi)
Flicker (Low+)	Acuity Lo+)	Acuity (Hi-)	Flicker (Hi-)
Flicker (Hi-)	Acuity (Hi-)	Acuity (Lo+)	Flicker (Lo+)
Flicker (Hi)	Acuity (Hi)	Acuity (Lo)	Flicker (Lo)

of effort and time. Consequently, these variables were tested only in the sense of requiring demonstration of adequacy without having to evidence statistical supremacy over different variable values. An example of this is darkness adaptation. No attempt was made to study various durations of adaptation. We accepted ten minutes as a reasonable time period and then used it during the pilot testing. In the course of the pilot testing there was no reason to suspect that ten minutes was an inadequate or inappropriate time period. Similarly, no attempt was made to vary the general man-machine interface nor the physical experimental conditions. These, too, proved to be satisfactory.

Within ambient and control conditions, however, several inadequacies were revealed. While the subject-to-visual-display distance could be accurately maintained by the chin rest and forehead bar that was used during the course of the experimentation, subjects had a tendency to lean back from the chin rest thus changing the critical distance. The chin rest apparatus was also found to be uncomfortable for many of the subjects. Consequently, a bite bar was used for further experimentation.

Through interviews with subjects subsequent to their experimental runs it was found that some subjects could distinguish whether the VPT was on an up or down cycle because of the change in sound generated by the rotation of the encoder shaft. Because such sound distinctions may be used as response cues it was decided to provide future subjects with ear phones and prerecorded white noise to mask any potential sounds from the VPT.

Also noted during this pilot study was that although some subjects responded consistently throughout the absolute brightness test they later mentioned that, in a sense, their responses were not valid because the center spot never seemed to disappear for them. This phenomenon was also noted by the experimenter and is a function of the limits of minimum illuminance of the VPT as well as the brightness sensitivity of many subjects using peripheral retina vision. Since it is practically impossible to limit the small eye muscle movements that result in the availability of peripheral retina vision, the total illumination range was reduced by insertion of a number three neutral-density filter over the viewing screen for that one test. This modification proved satisfactory in later experimentation.

The techniques employed for reducing the data proved to be inadequate for a number of reasons. First, data collection sheets must be reformatted to appropriate data tallies so that they may be card punched, a time-consuming and redundant effort. Second, the process of reformatting the data provides opportunity for matter error. Because data at this stage are all in Gray code, the inadvertent change of one figure from zero to one, or one to zero, can substantially change the translated shaft position. Consequently, the output mechanism of the Visual Parameter Tester has been changed to permit the use of a computer tape punch device. Thus scores are directly printed on appropriate computer software.

Of major importance in the ultimate utility of the VPT are the effects of presentation and learning. These two variables were studied in depth and were the only variables to which statistical analysis was applied.

The first area of concern is that of the effects of learning. Since each subject was given two administrations of all tests, one way of assessing the effects of learning would be to compare performance on the two administrations. The result of such an analysis are presented in figure 3 . (N. B. On this and subsequent pilot study results the "scores" used are encoder shaft positions. These shaft positions are related curvilinearly to the various visual parameters tested. Therefore, one cannot conclude an interval scale relationship among the encoder shaft positions.) From this figure it may be seen that while in most cases performance as measured by encoder shaft position did increase slightly, the increase was not statistically significant.

The principal way in which presentation order varied was with respect to whether the tests of visual acuity preceded or succeeded flicker fusion, and whether the subtests would start from the low or high levels of brightness. Several graphic analyses were made to investigate this area. The general results with respect to performance on the flicker fusion tests are summarized in figure 4. Distinctions presented in this figure are of whether acuity (Ac) preceded flicker (F1) as the first test given, and whether high (Hi) or low (Lo) brightness initiated this test sequence. It may be seen that for all practical purposes there is no distinction to be drawn in performance on flicker-fusion tests by the presentation order.

The effect of presentation order on flicker-fusion performance may also be seen in second-order interaction graphs. These are presented in figures 5 and 6. In these figures, a comparison is made between whether acuity precedes or succeeds flicker and between starting with low or high brightness; the degree to which the lines within subsets are not parallel is the degree to which there are some second-order interactions. It may be seen, therefore, that presentation order does change flicker-fusion performance, but not to a large degree. Statistical analysis of these data using both the Mann-Whitney U test and the sign test[1] support the conclusion of no difference: that is, they are not statistically significant.

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[1] Siegel, S.: Non-Parametric Statistics for the Behavioral Sciences. McGraw-Hill, 1956.

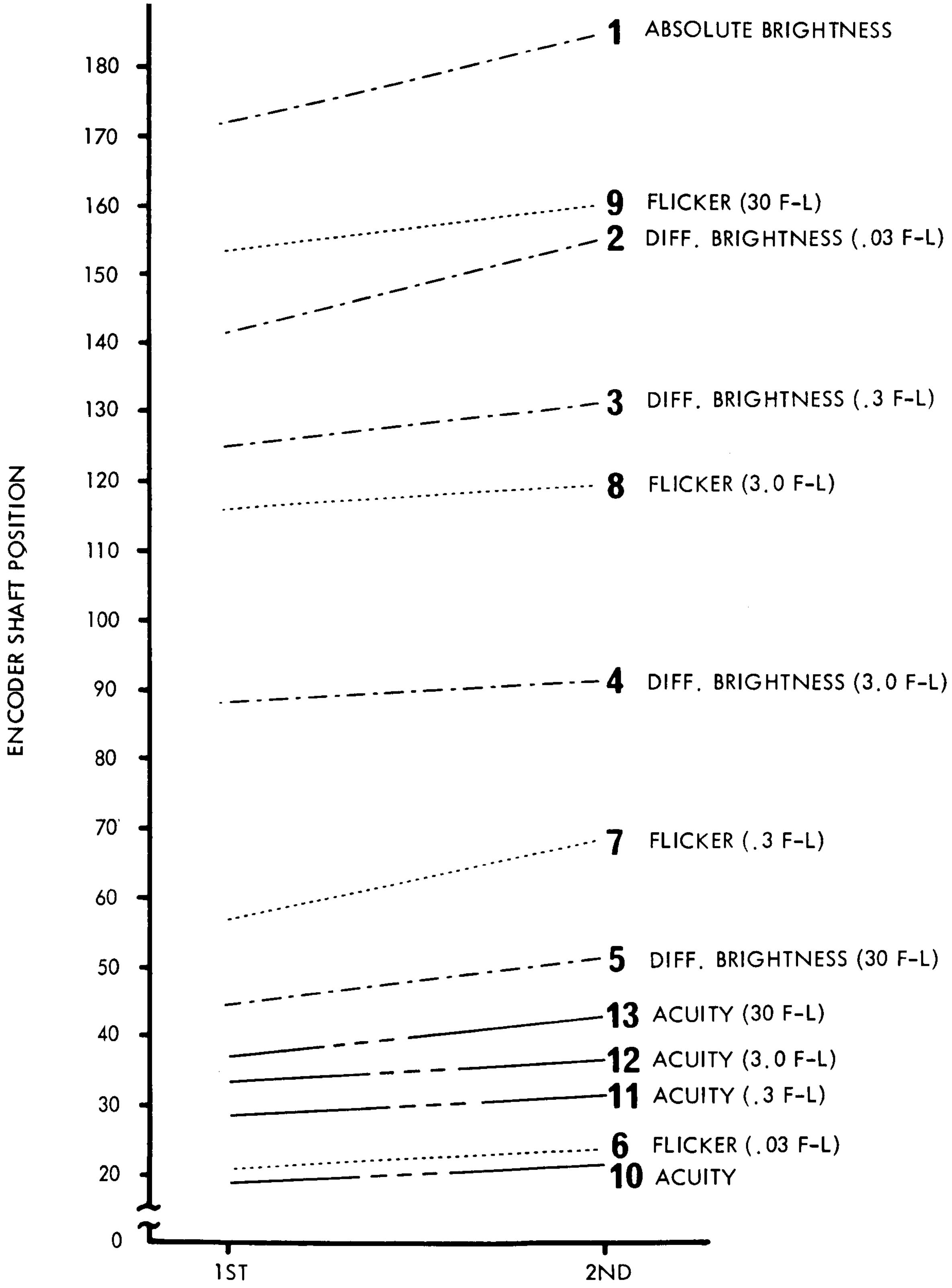


FIGURE 3. ADMINISTRATIVE ORDER FOR ALL TESTS

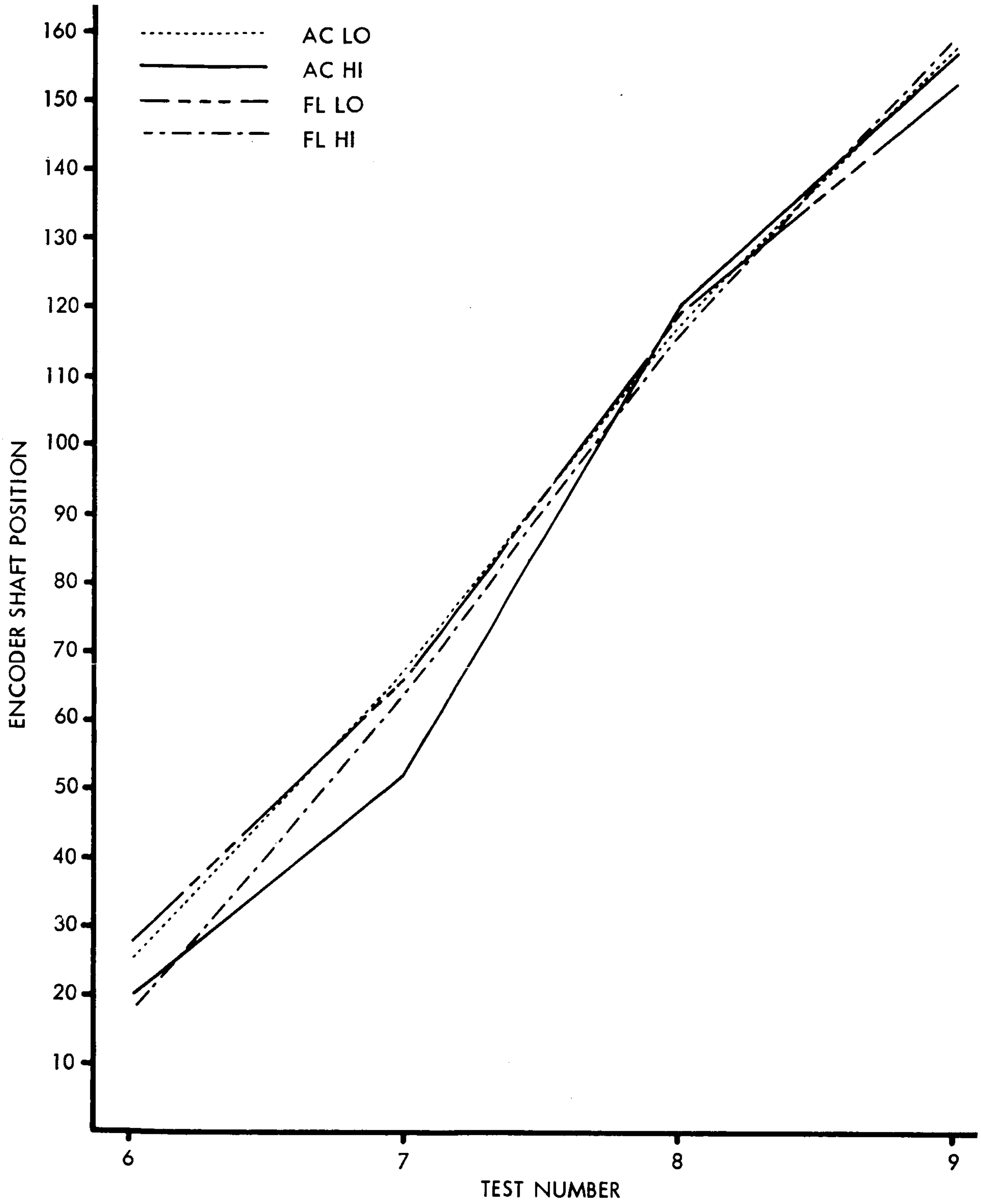


FIGURE 4. FLICKER PERFORMANCE

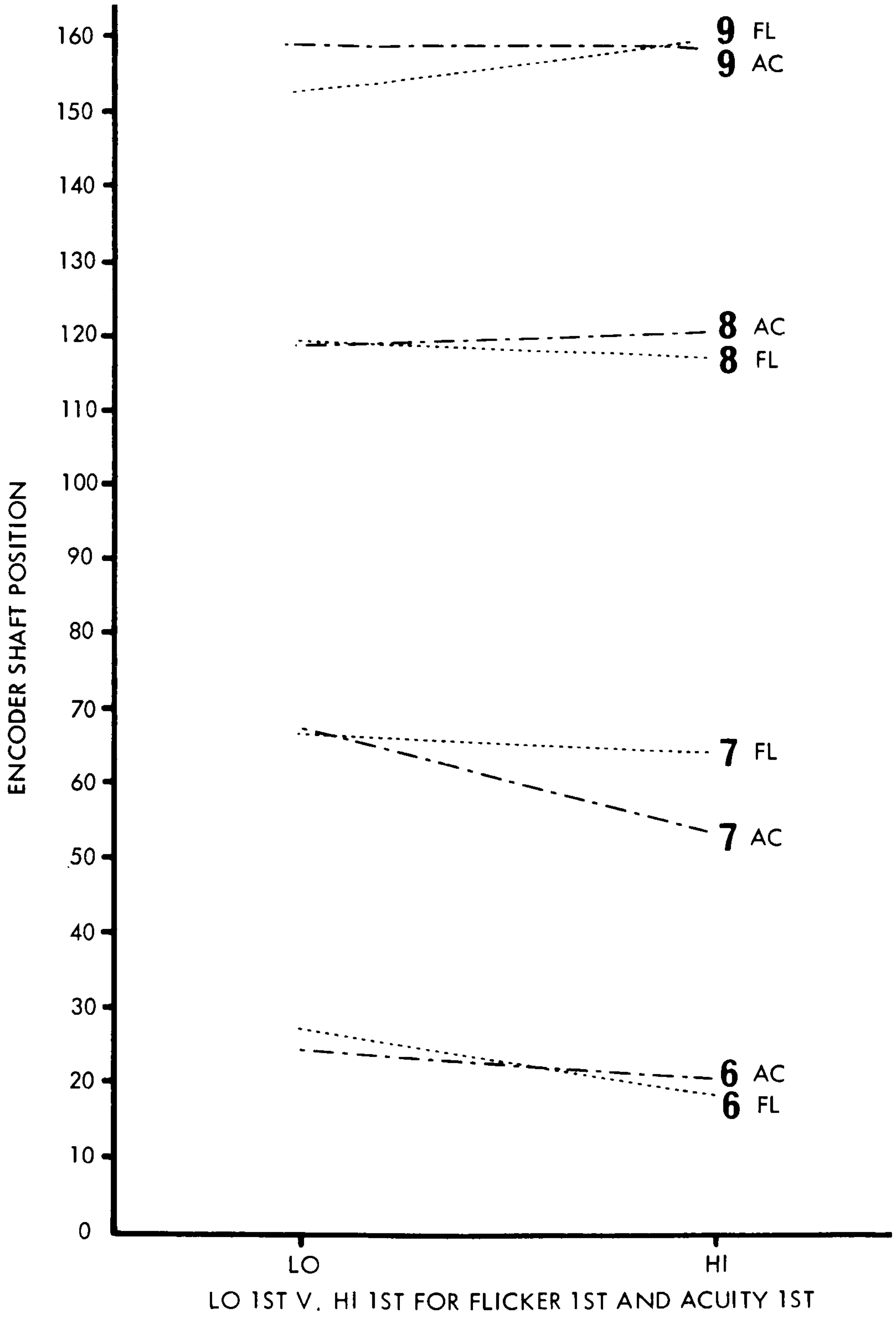
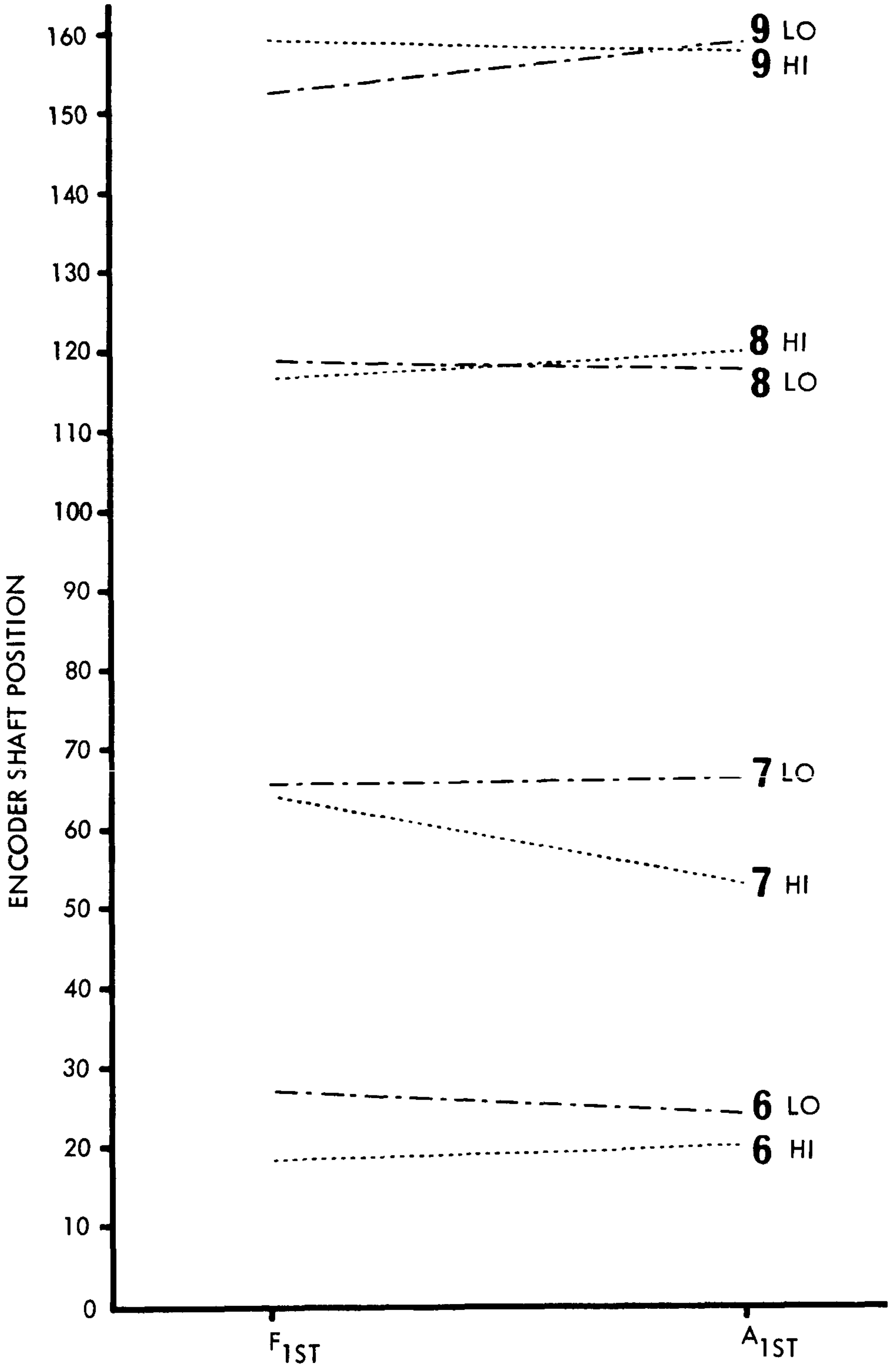


FIGURE 5. FLICKER PERFORMANCE



ACUITY 1ST V. FLICKER 1ST FOR LO 1ST AND HI 1ST

FIGURE 6. FLICKER PERFORMANCE

Focusing on the effects of presentation order on visual acuity performance resulted in a similar set of results. These are presented in figures 7, 8 and 9. While these data were not found to be statistically significant, it would appear that when acuity precedes flicker tests and when it is begun with the high intensity brightness, substantially different performance results than under presentation orders. This is certainly true with respect to performance on brightness levels of 30 and 3 foot-lamberts, although this difference disappears at lower brightness levels. There is insufficient data to warrant the generation of any hypothesis to explain this phenomenon. However, the order difference seen here might hold true for lower brightness levels if the score range were as broad as in higher brightness levels.

Full-Scale Study

The results of the pilot study were incorporated into the design of the full-scale study. All conditions proved adequate. The conclusions drawn from this study, with respect to experimental protocol, are summarized below.

1. For the lowest within test and light-adaptation interactions, the sequence of tests should be:
   - (A) Absolute Brightness;
   - (B) Relative Brightness, starting from the lowest background brightness level and proceeding sequentially to the highest;
   - (C) Visual Acuity, from highest background illumination to lowest;
   - (D) Flicker Frequency, from lowest to highest background illumination.
2. Under normal circumstances, a ten minute dark-adaptation period, with red goggles, is adequate.
3. Some means of masking the shaft rotation noise is necessary. White noise at 70db is sufficient.

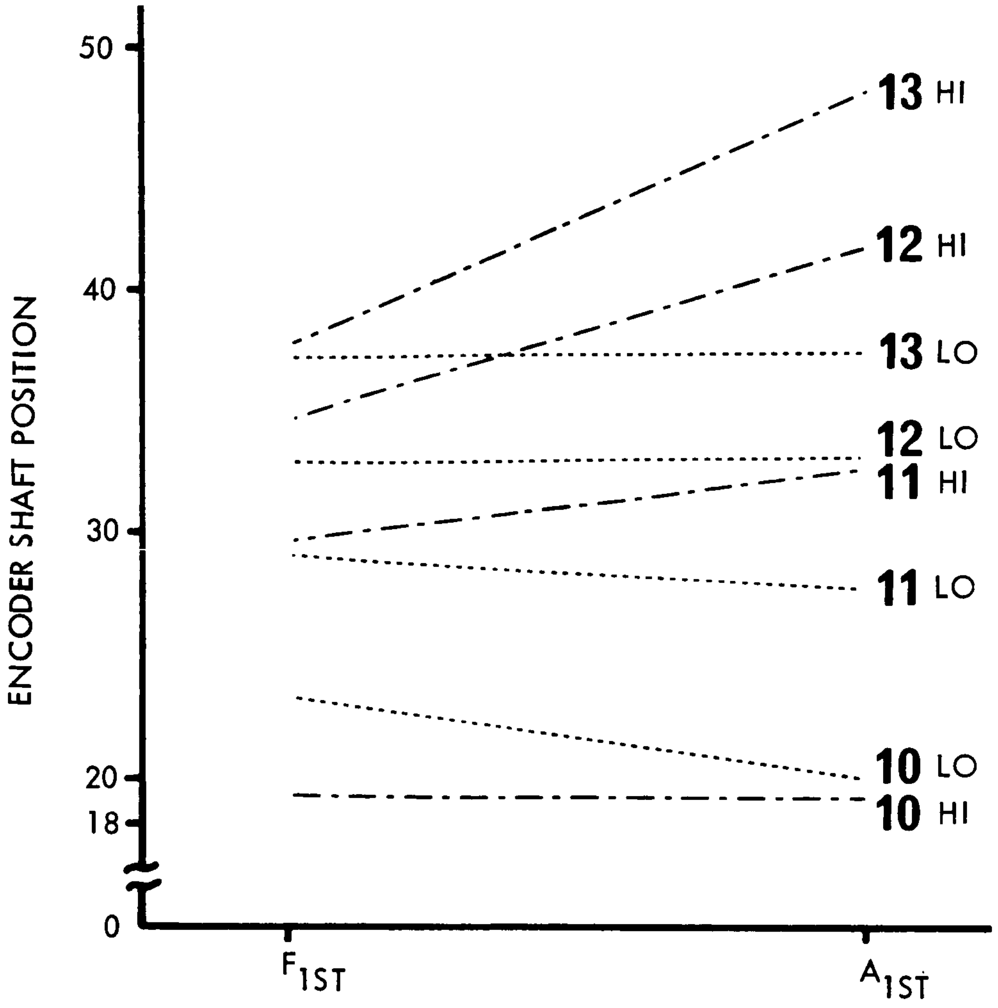


FIGURE 7. ACUITY PERFORMANCE: FLICKER 1ST VS. ACUITY 1ST

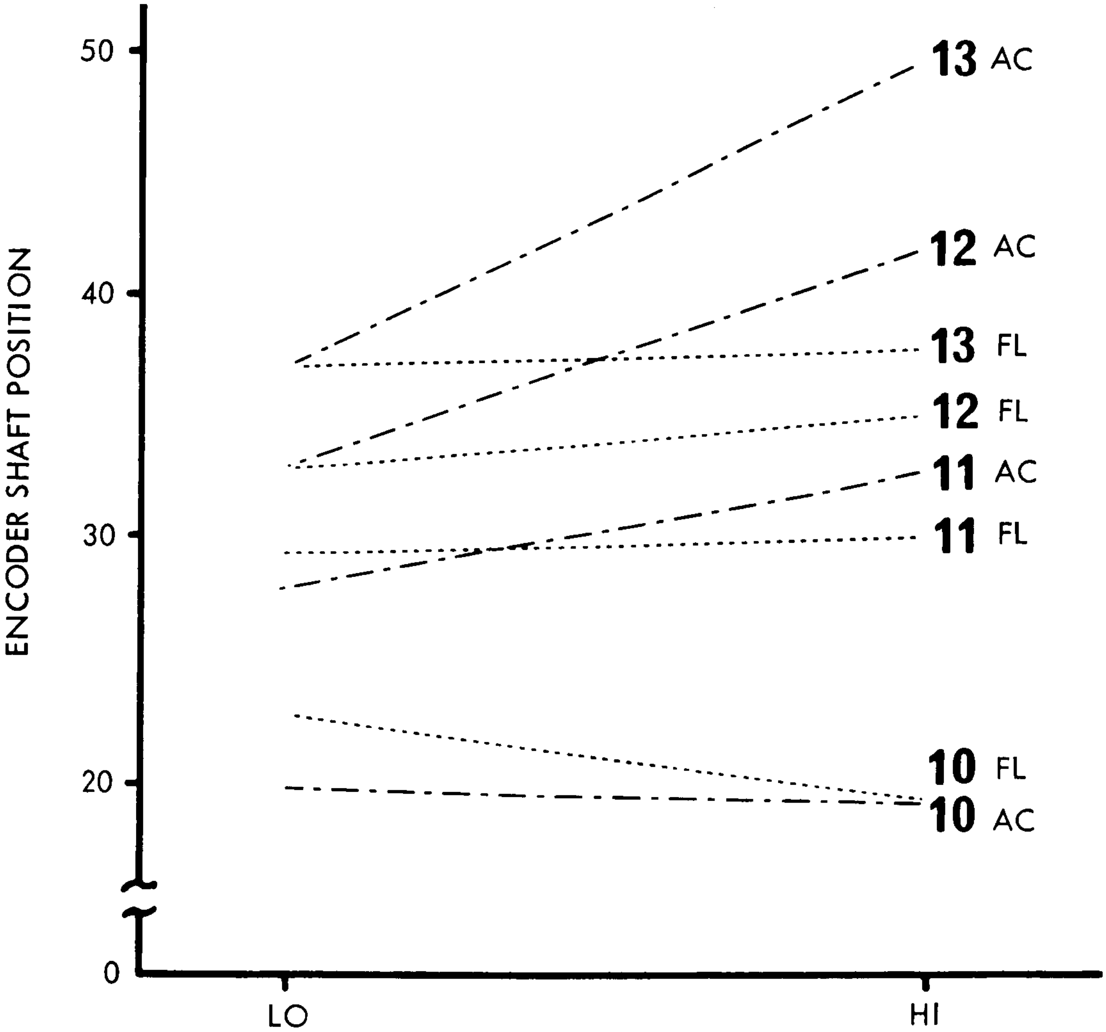


FIGURE 8. ACUITY PERFORMANCE: LO VS. HI

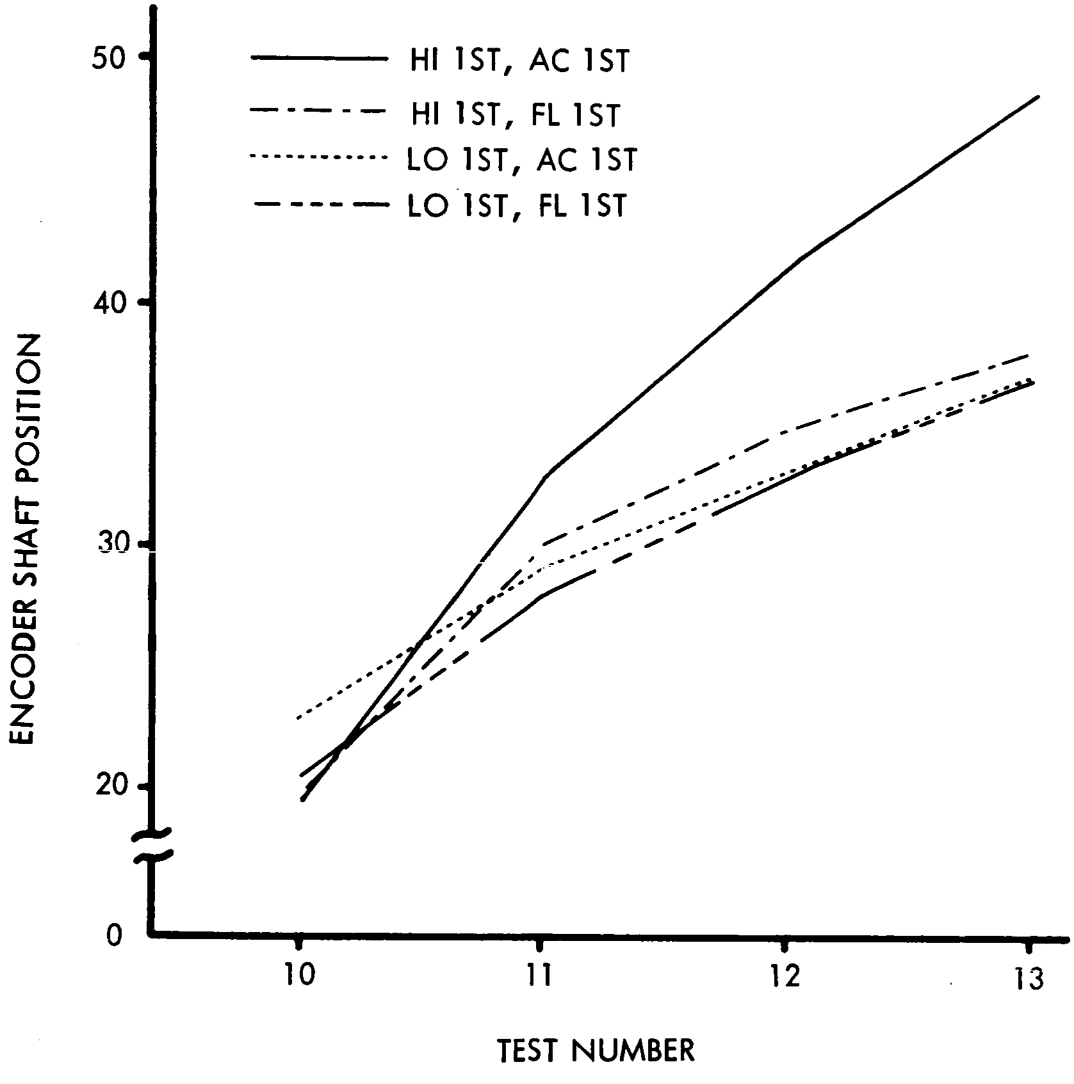


FIGURE 9. ACUITY PERFORMANCE

4. The absolute brightness test should be conducted within a lower brightness range. A number three neutral-density filter over the viewing screen was completely satisfactory.

5. The subject-to-viewing-screen distance is critical and must be maintained as a constant over all tests. A bite bar proved effective and easy to use.

6. For reliability of measures over the effective illumination range of the VPT, tests should be conducted in absolute darkness.

7. For all tests except the modified (cf. 4 above) Absolute Brightness test, the field illumination is sufficient to permit the subject a constant focusing point. The Absolute Brightness test requires some type of fixation point. Florescent points about the viewing screen and illuminated by ultraviolet light provided adequate targets for fixation.

VPT Test Protocol For Apollo

The development of the following protocol for employing the VPT in orbital testing makes several important assumptions concerning the reliability and utility of the device which are not supported by the results. Specific problems associated with the VPT which might compromise test validity or obfuscate interpretation of results are discussed in this critique.

Test application. —As presently designed, the VPT must be used for individual testing. Three astronauts or astronaut/scientists would probably be tested sequentially on a single piece of apparatus while in orbit.

The time required to complete the entire VPT series is about 40 minutes, excluding ten minutes for dark adaptation. Table 3 below shows the average time required to complete subtests. A one-minute delay is necessary between subtests to allow the machine to hit the stop and change background brightness. In the present study, two minutes were allowed between the different tests (acuity, flicker, etc.) to permit the subject to rest his eyes.

TABLE 3
VPT TEST TIME (MINUTES)

VISUAL PARAMETER	BRIGHTNESS	TEST TIME	WAIT TIME
Absolute Brightness	lo	2	2
Differential Brightness	lo	2	
	lo-	2	1
	hi-	2	1
	hi	2	1
Visual Acuity	hi	2	2
	hi-	2	1
	lo-	2	1
	lo	2	1
Flicker Fusion	lo	2	2
	lo-	2	1
	hi-	2	1
	hi	2	1
	SUBTOTAL	26	15
	Total Elapsed Time: 41 Minutes		

In administering the test to astronauts for the first time, the instructions, presented in the appendix, should be read aloud by the test administrator. In subsequent tests utilizing an automatic program, subjects should be able to proceed through the entire test series without instructions.

In the pilot study, some improvement was noted in the scores of subjects tested for the second time. However, several subjects used in the pilot study were also tested in the full-scale experiment and no further improvement was observed. In fact, they appeared to score slightly lower. However slight, the learning effect should be considered in designing the protocol for VPT utilization.

The learning effect may operate differently for each subject. That is, the slope of the learning curve may vary among subjects. If subjects were tested in space prior to experiencing the maximum learning effect, an improvement in visual performance might still be attributable to learning. And if visual performance were degraded by orbital flight, the effect might be counteracted or disguised by the learning effect.

General experimental design. —The implication for protocol design is that individual subjects should be tested with the VPT until no significant improvement in performance is noted. Such procedure is consistent with establishing a baseline for a pretest versus post-test experimental design with the subject acting as his own control.

The pretest phase would consist of sufficient trials to minimize improvement due to learning and to establish a normal range of response values for each subject. Thus a measure of variability would be derived for each subject for each VPT subtest. The subject's scores, expressed statistically, could be used to establish confidence intervals about his mean performance on each test.

Scores achieved on the VPT while in orbit could be evaluated in terms of significant deviation from mean performance on the pretest. If in-orbit vision tests were repeated periodically throughout the mission, the resulting plot of scores could be analyzed for deviation outside the confidence intervals (e.g., .05 or .01 probability) and for possible trend effects.

To adapt the VPT for use in space vehicles, some equipment modifications would be necessary. A means for maintaining a constant viewing distance and dark ambient environment must be provided. A hood could be constructed which protrudes from the VPT and terminates with a chin and forehead rest 28 inches from the display; a large lightproof bag with a drawstring button might be fitted over the end of the hood. The astronaut would slip the bag over his head and tighten the drawstring so as not to admit light during the tests.

Test procedures. —The test procedures followed during orbit should be identical to those used in prelaunch tests. If there are procedural constraints peculiar to testing aboard the Apollo capsule, they should be incorporated into the pretest situation to insure that conditions are essentially identical. The procedures described below are therefore applicable to pretests and orbital testing.

Prior to test administration, the astronaut subject should become dark adapted. This is accomplished by wearing a pair of tight-fitting goggles equipped with red lenses for ten minutes. Normally, ten minutes of darkness (or wearing red goggles) is sufficient to produce dark adaptation. However, exposure to very high brightness levels, as in direct viewing of the sun, can significantly affect the dark-adaptation process for several days.

The subject should remove the goggles after securing the light-tight VPT hood over his head. He then assumes the proper viewing position (chin and forehead against the rests) and initiates the test sequence.

At the end of each series of 15 responses, the astronaut should be so advised and stop responding until the brightness level changes. Two-minute rest periods should be allowed between the parameter tests.

Data handling and reduction. —It may be important for ground controllers to monitor for changes in visual ability of orbiting astronauts. If so, test results, whether in raw or processed form, would have to be relayed to the ground station. The analysis of VPT scores consists of a comparison of subtest means with the score distribution obtained prior to launch. Each subtest mean is based upon 15 scores. The required computation could be accomplished in a variety of ways, depending upon system capability. That is, the 195 scores could be transmitted to the ground station and processed there, or computation could be accomplished via an on-board computer and only subtest means transmitted.

On the other hand, if there were no requirement to monitor for changes in visual ability during flight, the data could be collected and stored aboard the space capsule and processed after recovery.

CHAPTER IV
VISUAL ACUITY COMPARISONS

Of the four parameters measured by the VPT, the test most apparently relevant to potential visual changes in a spaceflight environment is the visual acuity measure. As mentioned previously, this test is one of detecting apparent lines of a Ronchi grating. Project effort was directed to two questions: Does this test significantly distinguish levels of visual acuity, and what is the relationship of this type of measure with the more standard tests of acuity? The method of investigating these questions and the results of the investigation are discussed below.

Procedure

The most direct way of relating visual acuity as measured by the VPT and standard tests would be to test a large number of subjects on both kinds of acuity measures. Such an investigation plan was implemented. For this study, 38 male subjects were obtained from the general subject population at the Ames Research Center, local colleges, and fire departments. Within this subject population, visual acuity, as measured by the Snellen Test, ranged from 20/10 to 20/120. While several of the subjects wore glasses which corrected their vision to 20/20, all subjects were tested without corrective lenses being used. Several attempts were made to obtain subjects with greater acuity deficiency than 20/100—principally through local optometrists—however no subjects were obtained.

The experimental conditions of this study were in keeping with the protocol recommendations made in the preceding chapter. During the conduct of the experimentation, the subject was isolated in a small soundproof room with the VPT. Test sequences, scoring, and instructions were conducted by the experimenter in a remote location. The purpose of the VPT isolation was incidental to the conduct of the experimentation and is explained fully in the critique section of this report.

Each subject was tested at each level of brightness on each test. Fifteen responses per brightness-parameter configuration were obtained for each subject. The interface simulator was connected to a computer tape punch machine so that subject responses could be computer analyzed without necessitating card punching.

All subjects participating in this study were tested for visual acuity on the Snellen, Landolt, and Orthorater tests. The latter instrument provided measures of acuity for both far and near point vision. Results were analysed by a Pearson Product-Moment correlation computer program which resulted in a complete table of intercorrelation. In this table all variables were analysed for correlation with all other variables, including visual acuity as measured by the Snellen and Landolt eye charts and the Orthorater measures of acuity (far vision, both eyes; far vision, best eye; near vision, both eyes; and near vision, best eye). The dependent variables on which the intercorrelation table was based, were parameter values equivalent to shaft positions: that is brightness levels in foot-lamberts; flicker frequency in cycles per second; or, in the case of visual acuity test, line pair width, width of black line, and black line/ space between line ratios.

Results

The major question—the relation of VPT acuity measures with standard acuity tests—is, in a sense, answered by the correlations of these two sets of variables. These correlations, for the tested subjects, are presented in table 4.

As may be seen in this table, the correlations, in general, are low. They are statistically significant, at the .01 level, only for the two lowest brightness levels, .3 and .03 foot-lamberts. In order to interpret these correlations it is helpful to also see the relations among the standard tests themselves. These data are presented in table 5. Tests of far vision, the Snellen, Landolt and Orthorater-far, are highly intercorrelated as would be expected. The relation between far and near acuity, however, is relatively low, and is also to be expected (cf. Bausch and Lamb Orthorater Instruction Manual). Consequently, the VPT, with its subject-to-viewing-screen distance of 28 inches, provides a measure of near point acuity and would not necessarily relate to far distance measures.

TABLE 4

CORRELATIONS OF STANDARD AND VPT MEASURES OF VISUAL ACUITY

BACKGROUND ILLUMINATION LEVEL	DEPENDENT VARIABLE	SNELLEN	LANDOLT	ORTHORATER			
				FAR VISION BOTH EYES	FAR VISION BEST EYE	NEAR VISION BOTH EYES	NEAR VISION BEST EYE
30 ft-L	Pair Spacing	.038	.056	.052	.014	.133	.122
	Ratio	-.015	-.037	-.023	.007	-.124	-.112
	Line Width	.075	.101	.084	.056	.161	.158
3 ft-L	Pair Spacing	.117	.146	.010	-.019	.384	.402
	Ratio	-.122	-.152	-.023	.003	-.346	-.380
	Line Width	.123	.156	.028	.002	.344	.378
0.3 ft-L	Pair Spacing	.301	.354	.066	.021	.613*	.596*
	Ratio	-.275	-.323	-.110	.054	-.524*	-.537*
	Line Width	.318	.371	.078	.030	.615*	.603*
0.03 ft-L	Pair Spacing	.597*	.638*	.405	.349	.658*	.719*
	Ratio	-.554*	-.589*	-.420	-.362	-.573*	-.658*
	Line Width	.588*	.633*	.426*	.372	.619*	.695*

* = Significant at the .01 Level

TABLE 5
INTERCORRELATIONS AMONG THE STANDARD TESTS OF ACUITY

	SNELLEN	LANDOLT	ORTHO FAR BOTH EYES	ORTHO FAR BEST EYE	ORTHO NEAR BOTH EYES	ORTHO NEAR BEST EYE
S.	1.00000	0.97874	0.87011	0.87054	0.27849	0.50014
L.	0.97874	1.00000	0.83414	0.83414	0.32650	0.51136
O.F. Both	0.87011		1.00000	0.91985	0.07732	0.30304
O.F. Best	0.87054			1.00000	0.06959	0.36327
O.N. Both	0.27849				1.00000	0.85554
O.N. Best	0.50014					1.00000

This observation is supported by the data only for the brightness level of .3 foot-lamberts, although for all brightness levels the correlations are numerically higher with near than with far visual acuity. It also appears that there is no significant difference among the three dependent variables: Line pair spacing, line/space ratio, and line width.

Although the background illumination is designed to vary by several orders of magnitude, the stimulus (the lines of the Ronchi grating) does not. At any given encoder shaft position the size of each line of the Ronchi grid is constant, independent of the background illumination. Changes in visual performance, then, are a function of the stimulus-illumination interaction. The relation between these parameters, averaged for all subjects, is shown in table 6. These data are in keeping with a variety of previous investigations which showed that the minimum line width perceivable by a subject is a function of background brightness.

Thus far the results presented are concerned with the validity of the VPT as a test of visual acuity. A second important consideration is the reliability of measures obtained with the device. With this in mind, eight subjects were retested on the VPT with a two-month interval between tests. Their performance on the visual acuity tests was compared with Spearman Rank Order

TABLE 6

RELATION OF BACKGROUND ILLUMINATION AND STIMULUS (LINE) SIZE

(Line Size in Millimeters)

BRIGHTNESS LEVEL	MEAN THRESHOLD LINE WIDTH (all subjects)
30 foot-lamberts	.158
3.0 foot-lamberts	.180
0.3 foot-lamberts	.209
0.03 foot-lamberts	.275

correlations. The resultant coefficients are presented in table 7. From these data it appears that the lowest level of background brightness has the highest reliability as well as the highest validity measures.

TABLE 7

TEST RETEST CORRELATION COEFFICIENTS

Background Illumination	r_s
30 foot-lamberts	.667
3.0 foot-lamberts	.738
0.3 foot-lamberts	.738
0.03 foot-lamberts	.952*

*Significant at the 0.01 Level

A useful means of summarizing the relationships investigated here would be through construction of a nomograph. However, the magnitude of the relations do not warrant, nor effectively permit, the development of such a device. It is felt that, at this time, a more meaningful presentation of the data could be made in a tabular, subject by variable, format. These data are so presented in tables 8, 9, 10, and 11.

TABLE 8

SHAFT POSITION - ACUITY STANDARDS EQUIVALENTS .03 FOOT-LAMBERTS

SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"	SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"
53	10	10	12	40	20	30	12
51	13	15	12	39	15	17.5	11
48	13	15	12	39	20	25	9
47	10	15	12	38	13	15	12
47	13	25	12	38	30	45	12
46	13	12.5	11	37	20	25	11
46	13	17.5	12	37	10	17.5	12
45	13	17.5	12	36	13	12.5	12
45	10	15	12	35	13	15	12
44	25	50	12	35	15	25	12
43	10	12.5	12	33	13	20	11
43	13	15	12	32	13	15	12
42	13	15	11	32	13	17.5	12
42	13	15	12	32	70	85	9
42	13	20	12	27	13	15	11
41	10	12.5	12	24	20	40	11
41	40	45	12	23	100	125	11
40	20	25	12	20	25	35	8
40	25	30	12	18	70	100	8

TABLE 9

SHAFT POSITION - ACUITY STANDARDS EQUIVALENTS

.3 FOOT-LAMBERTS

SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"	SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"
71	10	10	12	52	13	15	12
68	13	15	12	51	20	25	9
65	13	17.5	12	50	13	20	12
64	13	15	12	49	10	17.5	12
62	40	45	12	48	13	15	11
61	10	15	12	48	13	15	12
61	10	12.5	12	48	10	15	12
61	13	17.5	12	48	100	125	11
60	13	12.5	11	47	70	85	9
59	10	12.5	12	44	13	15	12
58	20	25	11	43	13	15	12
58	13	25	12	42	15	25	12
57	20	30	12	42	20	40	11
56	30	45	12	42	13	12.5	12
56	25	50	12	41	13	15	12
56	13	15	11	36	13	17.5	12
55	25	30	12	34	20	25	11
54	20	25	12	34	25	35	8
53	15	17.5	11	27	70	100	8

TABLE 10

SHAFT POSITION - ACUITY STANDARDS EQUIVALENTS

3 FOOT-LAMBERTS

SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"	SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"
82	10	10	12	63	15	25	12
82	13	15	12	62	13	25	12
82	13	17.5	12	62	100	125	11
76	13	15	12	62	30	45	12
75	13	15	11	61	13	15	12
74	40	45	12	58	10	15	12
74	10	12.5	12	55	13	20	12
70	10	12.5	12	53	20	40	11
70	25	50	12	52	70	85	9
69	20	25	9	52	13	15	11
68	10	15	12	51	13	15	12
68	13	15	12	51	13	15	12
67	20	25	11	46	10	17.5	12
67	25	30	12	45	13	12.5	12
67	13	12.5	11	44	20	25	11
66	15	17.5	11	44	70	100	8
66	20	30	12	43	13	15	12
65	13	17.5	12	42	13	17.5	12
64	20	25	12	40	25	35	8

TABLE 11

SHAFT POSITION - ACUITY STANDARDS EQUIVALENTS

30 FOOT-LAMBERTS

SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"	SHAFT POSITION	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR "BEST"
108	13	17.5	12	68	13	15	12
90	10	15	12	67	25	30	12
90	10	10	12	67	20	40	11
89	40	45	12	65	13	15	12
89	10	12.5	10	65	70	85	9
88	13	15	12	65	30	45	12
86	20	25	11	64	100	125	11
85	15	17.5	11	63	70	100	8
84	13	15	12	63	20	30	12
83	13	15	12	62	13	25	12
78	13	12.5	11	60	13	20	12
78	13	15	11	59	13	15	12
78	13	17.5	12	59	13	15	11
78	100	12.5	12	55	10	17.5	12
75	15	25	12	54	25	35	8
71	25	50	12	52	20	25	11
70	10	15	12	46	13	12.5	12
70	20	25	9	46	13	15	12
69	20	25	12	45	13	17.5	12

Brightness tests. —There is one test of absolute and four tests of relative brightness currently measured by the VPT. Subject responses to these tests were analysed in the same manner as were the acuity measures. The correlations of these tests with standard measures of acuity are shown in table 12. To the degree that these tests are valid measures of brightness discrimination, performance on them would seem to be unaffected, in general, by acuity.

The degree to which the brightness tests are intrarelated is also of interest and is presented in table 13. As may be seen, there are several high correlations but in general each test appears relatively independent.

There is no direct method of validating these tests as measures of brightness discrimination. Results, in terms of absolute numbers cannot readily be compared with other investigations because the nature of tests varies widely from experimenter to experimenter. However, one can determine how well the data collected here fits with accepted constructs. One such construct is that the magnitude of the relation between the brightness of an object and its surrounding field, for the object to be just perceived, will vary inversely to the surrounding field brightness. That is, the brighter the background, the smaller the brightness difference between an object and that background. The VPT situation parallels the requirements of this construct and the predicted relation should obtain.

TABLE 12

CORRELATIONS BETWEEN BRIGHTNESS TESTS AND STANDARD MEASURES OF VISUAL ACUITY

			ORTHORATER			
	SNELLEN	LANDOLT	Far (Both Eyes)	Far (Best)	Near (Both)	Near (Best)
Absolute Brightness	-.139	-.137	-.108	-.161	.035	.073
Relative Brightness (30 ft-L)	.003	-.018	.013	-.003	.119	-.017
Relative Brightness (3.0 ft-L)	.375	.388	.419	.371	.313	.419
Relative Brightness (0.3 ft-L)	.156	.153	.156	.132	.425	.348
Rleative Brightness (0.03 ft-L)	.371	.383	.339	.266	.494	.518

TABLE 13
BRIGHTNESS INTERCORRELATIONS

	ABSOLUTE BRIGHTNESS	RELATIVE BRIGHTNESS 0.03 ft-L	RELATIVE BRIGHTNESS 0.3 ft-L	RELATIVE BRIGHTNESS 3.0 ft-L	RELATIVE BRIGHTNESS 30 ft-L
A.B.	1.00000	-0.07811	0.29205	0.11351	0.27383
R.B. 0.03	-0.07811	1.00000	0.01692	0.80383*	0.01040
R.B. 0.3	0.29205		1.00000	0.53231	0.86944*
R.B. 3.0	0.11351			1.00000	0.55135
R.B. 30	0.27383				1.00000

*Significant at the .01 Level

Such a test was made and is presented in table 14. The data are in support of this construct. There are several ways of quantifying the object-background relation. One is by use of the brightness contrast; that is:

$$\text{Contrast} = \frac{B_1 - B_2}{B_1} \times 100$$

where

B_1 = brighter of two contrasting areas

B_2 = darker of two contrasting areas

A second method is by expressing the brightness ratio as the ratio of an object's brightness to the area surrounding the object. In this table both expressions are given, as is the mean center spot brightness.

The reliability of these tests was assessed with the same method as that used for acuity: test-retest correlations. The resultant correlation coefficients, based on Spearman's r_s, is shown in table 15.

TABLE 14
CENTER SPOT TO BACKGROUND RELATION

BACKGROUND BRIGHTNESS	CENTER SPOT BRIGHTNESS IN FOOT-LAMBERTS	BRIGHTNESS CONTRAST	BRIGHTNESS RATIO
Absolute	.051		
0.03 ft-L	.071	.57	2.3:1
0.3 ft-L	.492	.38	1.63:1
3.0 ft-L	4.02	.25	1.34:1
30.0 ft-L	38.49	.22	1.27:1

TABLE 15
TEST RETEST CORRELATION COEFFICIENTS
(BRIGHTNESS TESTS)

BACKGROUND BRIGHTNESS	SPEARMAN'S r_s
Absolute	.476
0.03 ft-L	.738
0.3 ft-L	.833*
3.0 ft-L	.899*
30.0 ft-L	.833*

*Significant at the 0.01 Level

Flicker frequency. —Performance on the flicker tests does not relate significantly on any other tests, or to the standard visual acuity tests. Within the flicker subtests there is a degree of significant correlation: table 16 presents these data.

TABLE 16

FLICKER SUBTEST INTERCORRELATIONS

BRIGHTNESS LEVEL	0.03	0.3	3.0	30.0
0.03 ft-L	1.00	.492	.416	.242
0.3 ft-L		1.00	.788	.595
3.0 ft-L			1.00	.813
30.0 ft-L				1.00

Averaged for all subjects, limenal flicker frequencies increase as a function of background brightness. This relation is shown in table 17. This finding is supported by the extant literature. Reliability of this test, as determined in the way described for previous tests, is presented in table 18.

TABLE 17

RELATIONS OF FLICKER FREQUENCY LIMENS AND BACKGROUND BRIGHTNESS

BRIGHTNESS (In Foot Lamberts)	FLICKER LIMEN (In Cycles Per Second)
0.03	17.3
0.3	23.4
3.0	33.8
30.0	41.9

TABLE 18
TEST RETEST CORRELATION COEFFICIENTS
(FLICKER TESTS)

BACKGROUND BRIGHTNESS (In Foot-Lamberts)	SPEARMAN'S r_s
0.03	.243
0.30	.692
3.00	.932*
30.00	.814*

*Significant at the 0.01 level.

Conclusions

On the basis of the analysis described above it would appear that the visual acuity tests of the VPT do not reliably measure the same parameter as the standard acuity tests. Possible exceptions to this are the acuity tests at the .03 and .3 foot-lambert background brightnesses, particularly the former. However, even in these two conditions the correlations with standard tests are not high enough to permit any direct translation from one type of "score" to another. In the face of the proven reliability and utility of the standard tests, it is doubtful whether there is need for an idiosyncratic acuity parameter such as the VPT might define. Certainly it would take considerable time and effort to validate and standardize the VPT as a unique test of acuity.

There is little evidence to support a choice average line-pair spacing, line width, and line background ratio as the variable from which acuity may be measured. For this reason, decimal equivalent encoder shaft position might be used instead, thus saving a lengthy computer conversion.

The brightness and flicker tests seem to measure with a relatively high reliability. The lack of intercorrelations among subtests may only indicate that at different brightness levels different visual skills are required, or that there is intrasubject variability among the brightness levels. The nature of the analysis, designed to quantify the relations among visual acuity measures, was not as appropriate to the analysis of main and interaction effects as would be, say, a factorial design.

It would be in order to assess the degree to which subject's mean score reflects a consistent estimate of his true threshold. However, the nature of the psychophysical method of limits employed by the VPT precludes meaningful use of the more usual measures of variability. The issue here is not the variability of subject choices on each trial—rather, it is the likelihood that subsequent trials with the VPT will result in similar threshold scores (mean trial scores). A descriptive statistic suitable for this kind of issue is the standard error of the mean.[1] The standard error of the mean (S.E.$_{\overline{m}}$) was computed for each subject on each test. The mean of each test's distribution of S.E.$_{\overline{m}}$ was computed and is presented in table 19. To preserve the context for interpolation of the statistic, the mean threshold scores for each test are also presented in this table.

In general, the table may be read and used as follows: If the same subjects were retested, one may expect that subsequent threshold values would fall within the range from the mean indicated by the S.E.$_{\overline{m}}$ about two thirds of the time (i.e., $p = .68$).

Further conclusions and recommendations go beyond the scope of the experimental data per se and as such will not be presented here. The final chapter of this report is a critique of this first experimental use of the VPT in which broader conclusions are discussed.

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[1] Cf. J.P. Guilford: Fundamental Statistics in Psychology and Education. McGraw-Hill, New York 1956.

TABLE 19
MEASUREMENT OF SUBJECT VARIABILITY

TEST	MEAN S.M.$_{\overline{m}}$	MEAN THRESHOLD VALUE
1	.0077	.0514 ft-L
2	.0215	.0718 ft-L
3	.0044	.4920 ft-L
4	.0222	4.0276 ft-L
5	.2038	38.494 ft-L
6	.0068	.1580 mm Line Width
7	.0061	.1805 mm Line Width
8	.0081	.2089 mm Line Width
9	.0127	.2753 mm Line Width
10	.7888	17.35 cps
11	.4468	23.47 cps
12	.5777	33.84 cps
13	.8483	41.98 cps

CHAPTER V
CRITICAL REVIEW OF VPT UTILIZATION

The study reported in these pages represents the first active use of the visual parameter tester. It is nonetheless not too soon to ask what role the VPT may have in future spaceflight, nor, certainly, what research must be undertaken to insure the greatest utilization of that role. It is to these issues that this chapter is addressed. However, before such a discussion is initiated, it will be beneficial to review the utilization of the VPT in the course of this current project.

In discussing the use of a testing apparatus as the VPT, one may distinguish two utilization categories: mechanical and substantive. The former category refers to the manner in which the instrument is constructed, whether it can be conveniently used, its reliability, portability, etc. The latter refers to such questions as: does the instrument test what it purports to test, and is what it purports to test important? Both these categories had reason to be considered in the course of this investigation.

Mechanical

It was not the responsibility of this study to evaluate the mechanical aspects of the VPT except to the degree that modifications or maintenance were required for the conduct of investigation. In the course of this study, several modifications were required. Changes in the way in which the Ronchi grid was articulated with the central shaft were necessary to insure that the machine would conform more nearly to its specifications with respect to encoder shaft position-acuity relation. The center spot, in the absolute brightness test, was found to be too bright even at its dimmest position to be used for testing lower limits of absolute brightness discrimination. This was modified by the insertion of a number three neutral-density filter over the viewing screen which resulted in a lower range of brightnesses for this test. A third and major modification was required because the Ronchi grids produced a relatively narrow band of useful acuity stimuli. This was modified by the substitution of a more appropriate set of Ronchi grids. The time required to make these modifications, plus downtime due to required maintenance, resulted in several months' delay in project activities.

The aforementioned problems were, in time, remedied and should not have been unanticipated in the development of any new testing apparatus. However, prior to the initiation of this program's full-scale experimentation effort, a problem arose which has serious ramifications to any immediate utilization of the VPT. Subsequent to the connection to the VPT of a computer tape printout, the VPT became extremely sensitive to vibration and electrical disturbances. Any of a wide variety of phenomena would result in the machine changing brightness levels, tests, or both. Remedial methods taken for this problem resulted in all interconnections being made with shielded cables and the VPT itself being placed in a shielded, isolated room for use during experimentation. Under these conditions, the machine functioned adequately. However, these conditions imposed to ameliorate the malfunctions result in conditions that severely delimit the environments in which the VPT may be used for future experimentation.

Substantive

The VPT, as it currently stands, purports to provide stimuli to measure four visual parameters. Currently there is little support in the literature, with the exception perhaps of anecdotal reports, to suggest that these parameters are critical or essential to man's safety and effectiveness in a space environment and are subject to change during that environment. Conversely, there is no evidence to suggest that these parameters are not potentially important to spaceflight, nor is it essential to have research literature support in order to initiate investigation of these kinds of parameters. Nonetheless, these issues should be resolved before costly and time-consuming research be conducted. Certainly man's visual skills, particularly with respect to acuity, are critical to his many roles in space. In this spirit, acuity is an important parameter provided by the VPT and evaluation of it played a prominent role in this current investigation.

As mentioned in the previous chapter, few of the acuity subtests seemed to measure the same parameters measured by standard visual acuity tests.

If one may conclude that the VPT provides an independent, but equally valid measure of acuity from the standard acuity tests, such measures would have to be standardized over the population to which it would be addressed: the astronaut/scientist population. On the measures taken, the VPT did not provide a highly reliable acuity measure. However, a more comprehensive test of reliability may provide higher correlation coefficients. For example, if a few subjects were run on the VPT on a daily basis for a long period of time, say a month, their acuity scores may stabilize to such a point as to permit the establishment of some kind of baseline score for each individual. This, associated with a confidence, could be used to detect future changes in acuity performance on the VPT. Changes of either increased or decreased performance would, themselves, have to be maintained over time for this type of technique to be used.

In summary, the VPT is not currently in a form to permit or warrant extensive further use in visual skills research. The only environment in which the machine performs adequately, in terms of mechanical reliability, is one of electrical and vibration isolation. The tests themselves must be developed further before they may be taken as valid and reliable instruments for measuring the stated parameters. A six-month to one-year program would be necessary to standardize performance sufficiently on the VPT parameters.

Further Research Utilization

Given the current state of VPT development, three types of potential further research areas warrant attention. These are:

1. Complete VPT development cycle. —That is, what are the development and research tasks necessary to provide a visual parameter tester that would effectively measure absolute and relative brightness, visual acuity, and flicker frequencies? The end result of such development work would be a validated testing instrument meeting, in general, the specifications already set down for the VPT. To a large degree, this topic has already been covered in the report.

2. VPT standard utilization.—If item 1 above could be satisfactorily concluded, this utilization area would be concerned with the kinds of research for which such a device might be used.

3. VPT modifications.—Viewing the VPT only as a vehicle in which a variety of visual skill parameters could be measured, what other visual skills could be measured and what kinds of modifications would be required of the VPT in order to facilitate further parameter investigations?

If the VPT functioned as it was designed to, and if the four parameters were appropriately validated and reliable, several "next step" programs could be defined. For example, the machine could be installed in the setting of a human centrifuge. Very little is known about the effect of forces on the variety of visual skills that could be measured by the VPT. The protocol and analysis of such VPT data would not differ substantially from the recommendations made in prior sections of this report. A second application of the VPT would be its use as a visual skill testing device in long-duration missions in slow-rotation devices. Such missions incorporate both the effects of confinement and g loadings on human subjects—either or both of which may affect near point visual acuity and brightness discriminations to a significant degree. The VPT could also be used as a visual skill testing instrument in simulated long-duration spaceflight missions, as, for example, MORL or AAP-type missions. In all these cases, subjects with visual skills paralleling the astronaut/scientist popluation, should be used. Because of the nature of measurement provided by the VPT, parallel skill performance should be interpreted as subject mean scores and variability. This latter characteristic is critical to the use of the VPT in establishing baseline skill data against which condition specific data may be compared.

Assuming the VPT may be used as a vehicle for presenting and testing other parameters, several potentially important visual skills may be assessed. While there is no evidence to suggest that visual acuity degrades in a zero g space environment, what little research has been undertaken has been directed toward acuity measures of panchromatic stimuli. No attempt has been made, either in a space environment or in space effect simulation studies, to investigate possible changes in monochromatic acuities. That is, the space environment (zero g, vibration, confinement, reduced far vision targets, etc.) may have an effect on acuity and brightness detection skills, but only with respect to specific bands in the visual spectrum. To the degree that the astronaut is used as an observer and as an essential part of in-space experimentation, changes in visual skills of this nature could be critical. The VPT could readily be modified to measure these phenomena by the insertion of colored filters in the light paths prior to the viewing screen. The filter should be effective because the nature of illumination provided by the standard exciter light bulb has been measured to be essentially rectangular in frequency distribution across the visual spectrum.

Confinement studies have produced data which suggest that long-duration confinement in relatively small capsules with reduced far-vision stimulation, results in a degradation of far-vision performance. The VPT, as it stands, cannot be used to investigate this phenomenon readily. Its visual target is established only for near point vision. However, collimating lenses between the subject and the VPT viewing screen could permit the device to be used with a subject's eyes focused at infinity. This would permit the device to be used as a measure of far point visual acuity, as well as being used as a training and visual skill maintenance instrument during long periods of limited visual fields.

In the above discussion, no attempt has been made to completely detail the nature and conduct of potential research. The primary reason for this is that the current state of the VPT does not permit any further use of the device as an investigative tool. If the end products of the above research are assessed as important to utilization of man in a space environment, and if the VPT may be evaluated as an appropriate means for conducting such investigations, the first order of business would be a program to develop and standardize the parameters and measures provided by the VPT. The components of such a program have already been discussed.

APPENDIX A

CENTER SPOT BRIGHTNESS CALIBRATIONS[1]

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[1] These have been programmed for the NASA (Ames) computer.

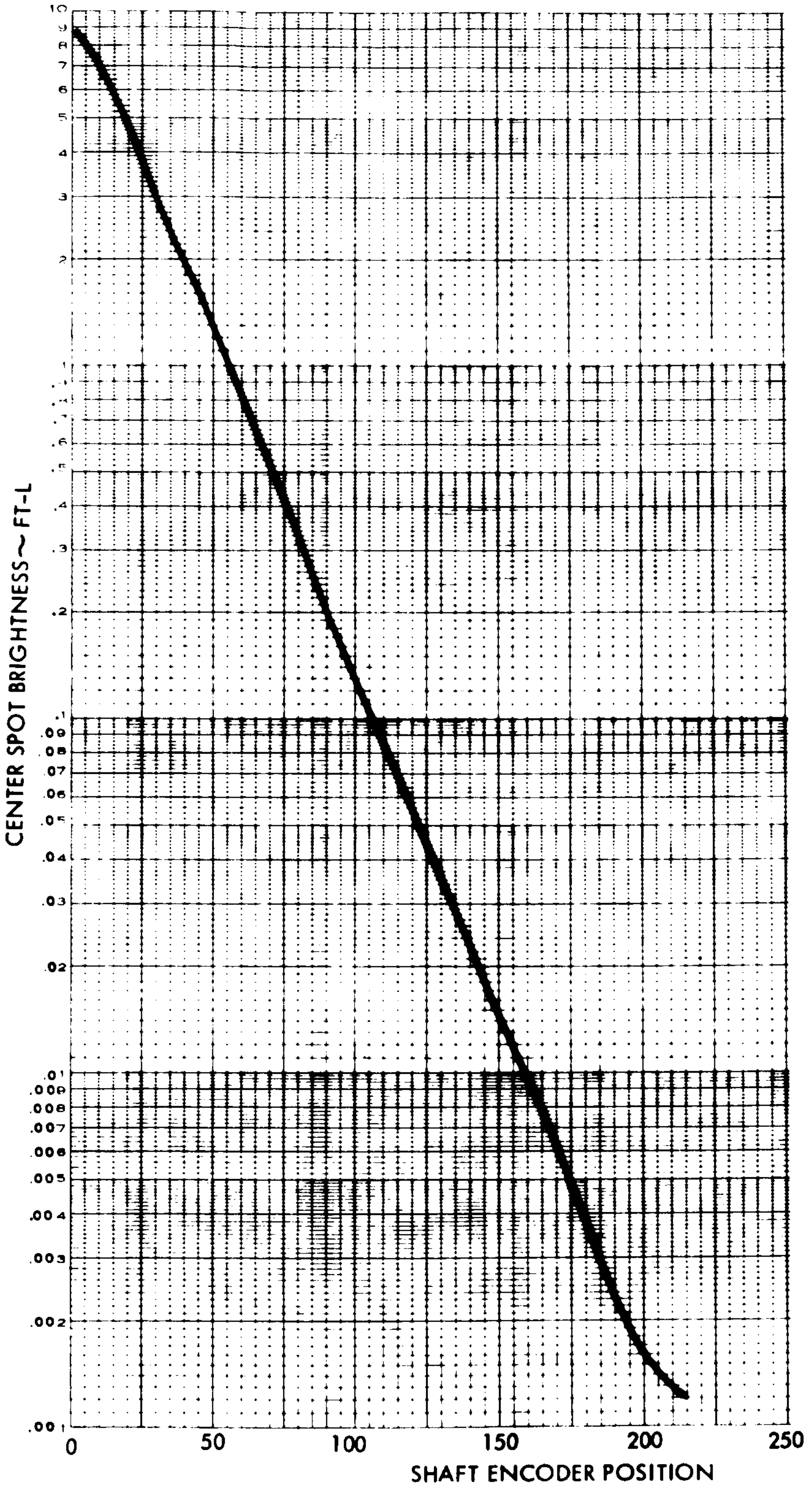

FIGURE A-1. CENTER SPOT BRIGHTNESS (NO FIELD ILLUMINATION)

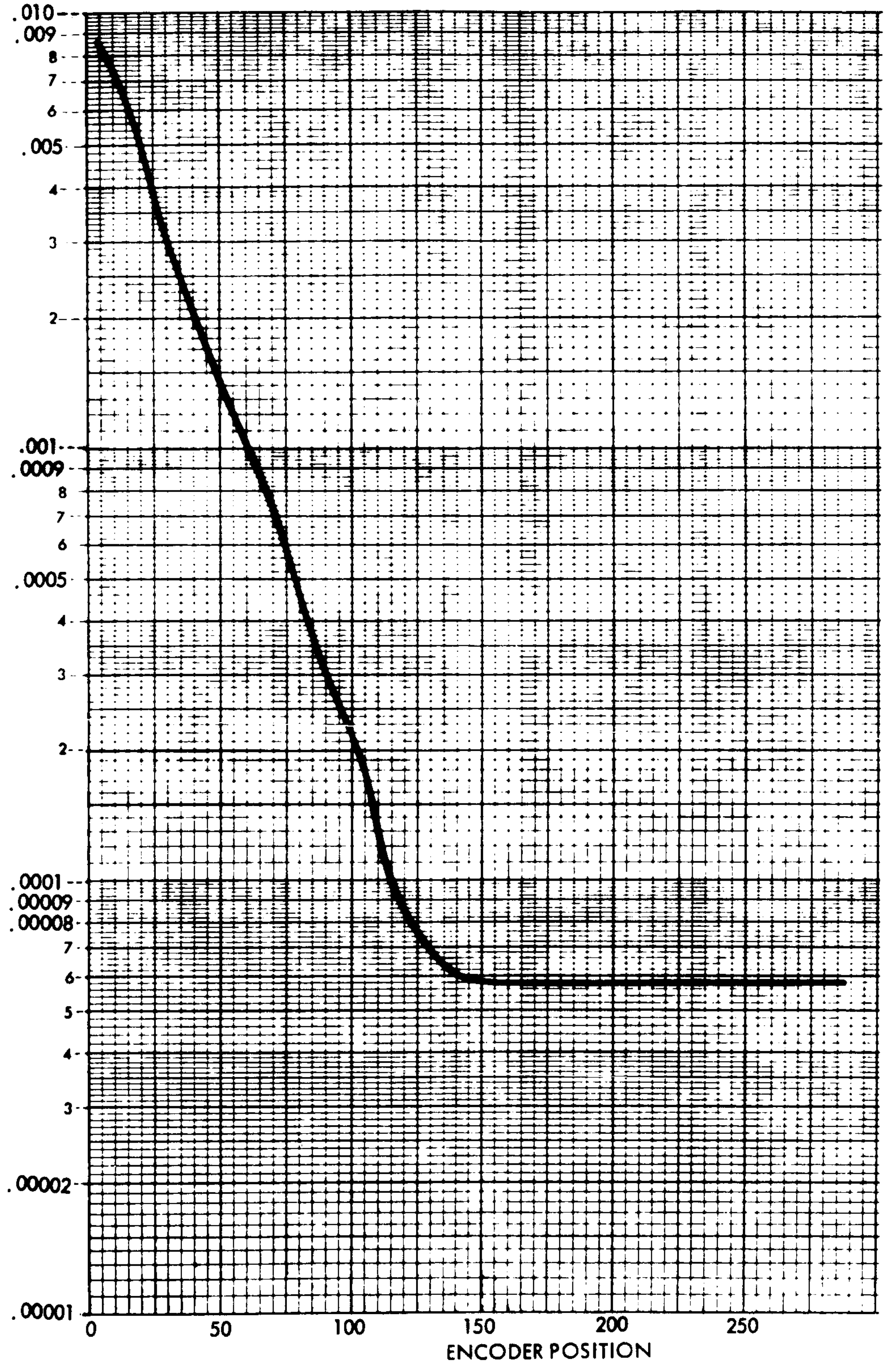

FIGURE A-2. CENTER SPOT BRIGHTNESS WITH N.D. FILTER 3

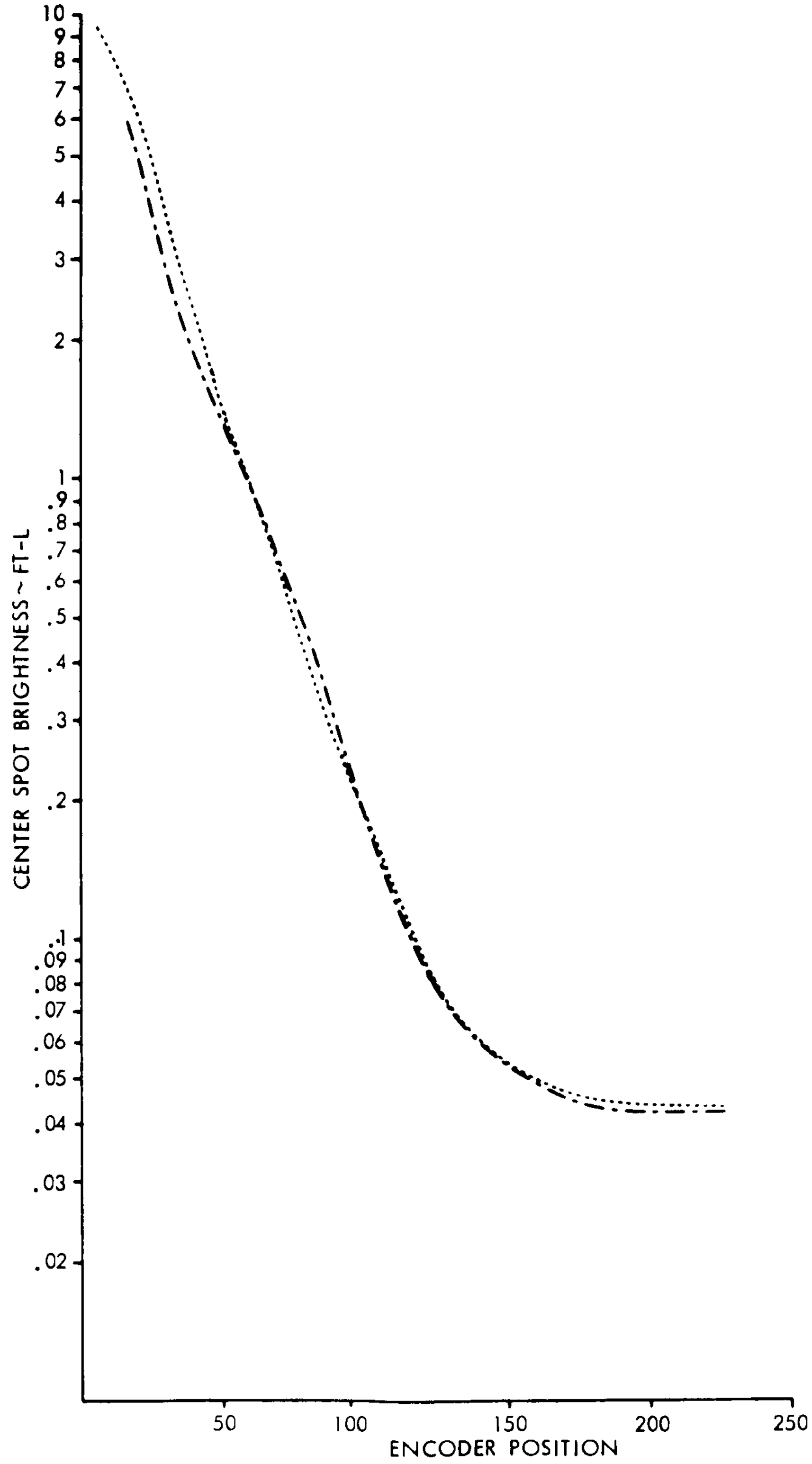

FIGURE A-3. CENTER SPOT BRIGHTNESS
AND ENCODER POSITION WITH .03 FT-L FIELD BRIGHTNESS

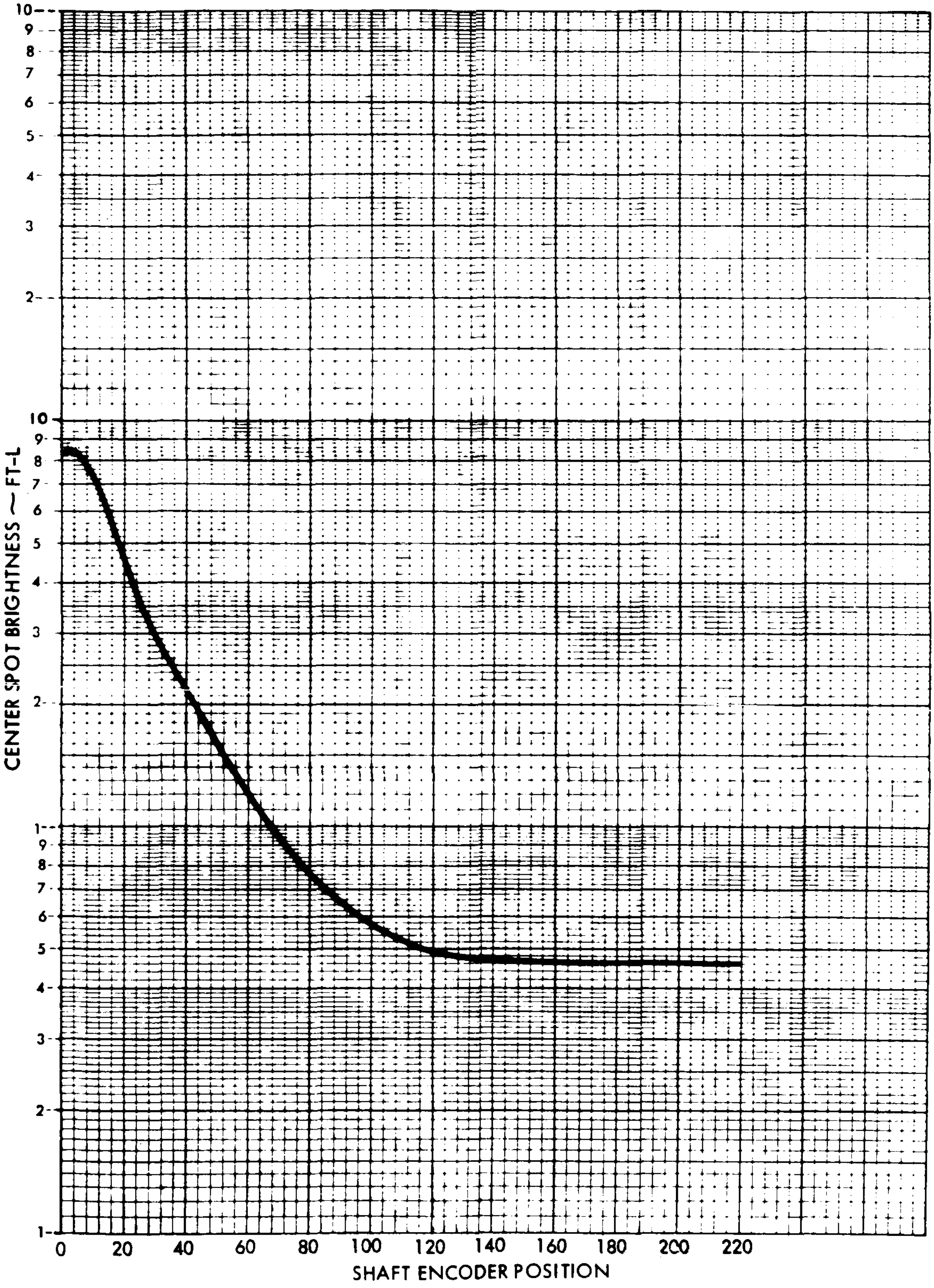

FIGURE A-4. CENTER SPOT BRIGHTNESS AND ENCODER POSITION WITH 0.30 FT-L FIELD BRIGHTNESS

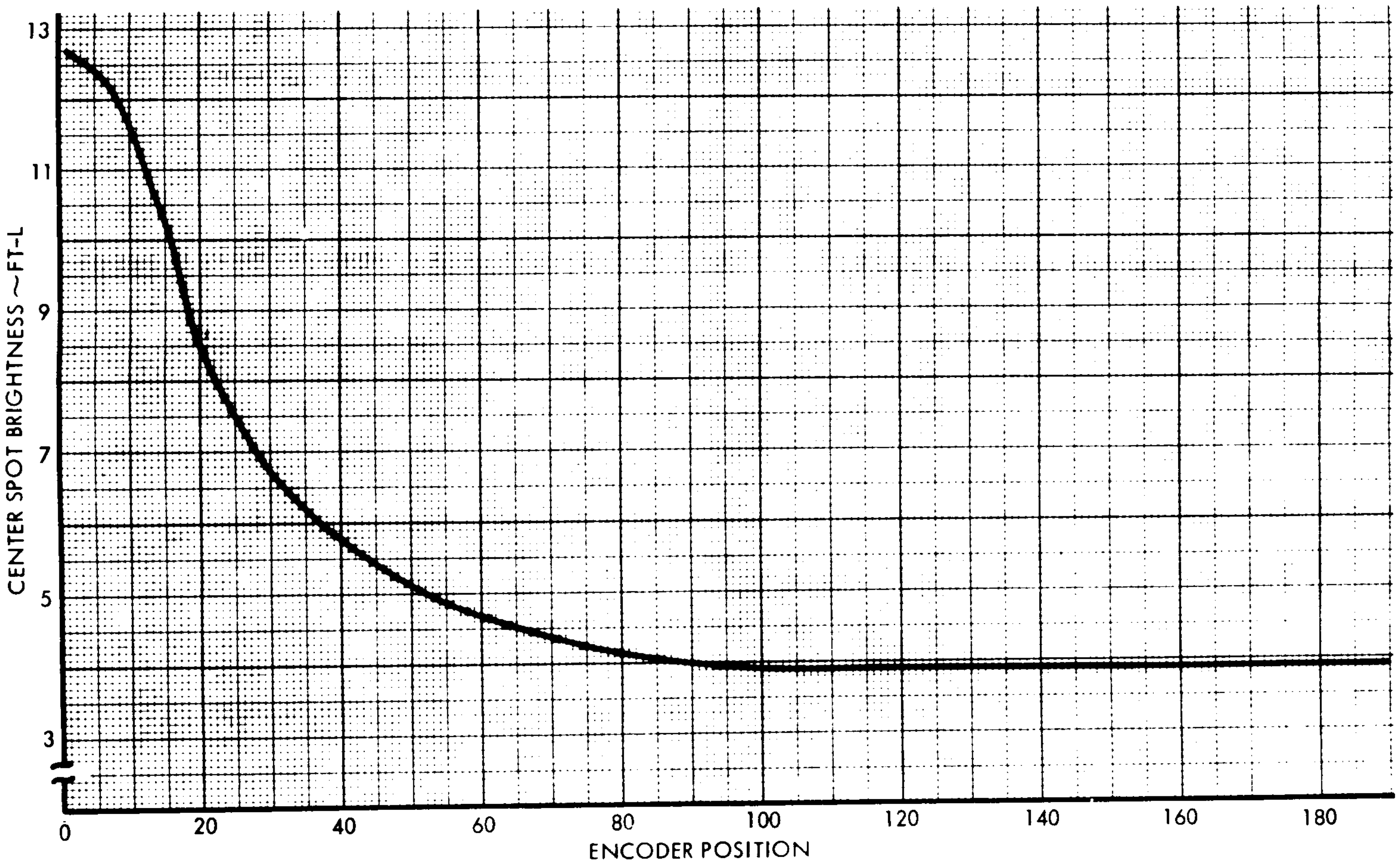

FIGURE A-5. CENTER SPOT BRIGHTNESS AND ENCODER POSITION WITH 3.0 FT-L FIELD BRIGHTNESS

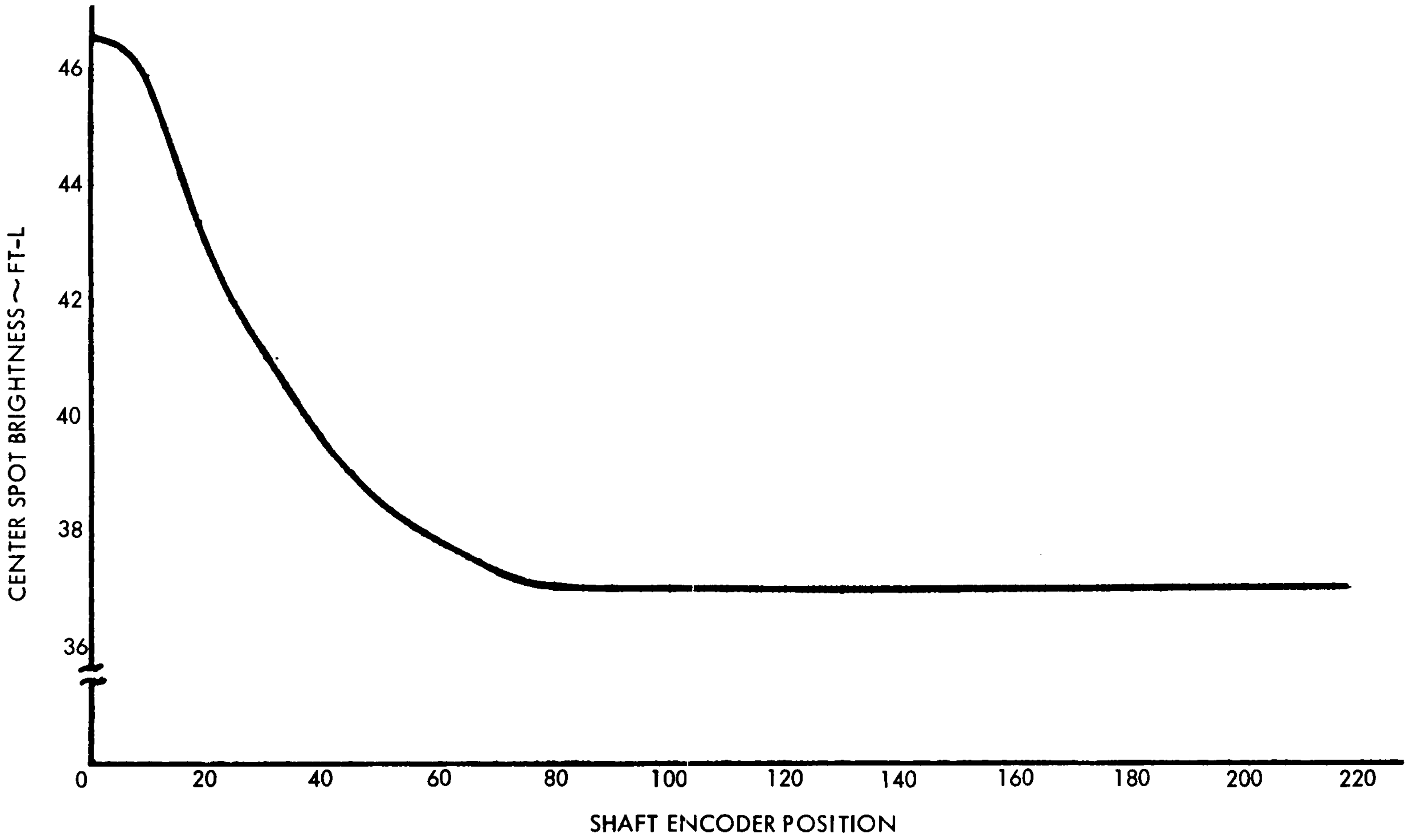

FIGURE A-6. CENTER SPOT BRIGHTNESS WITH 30 FT-L FIELD BRIGHTNESS

APPENDIX B
FLICKER CALIBRATIONS[1]

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[1] These have been programmed for the NASA (Ames) computer.

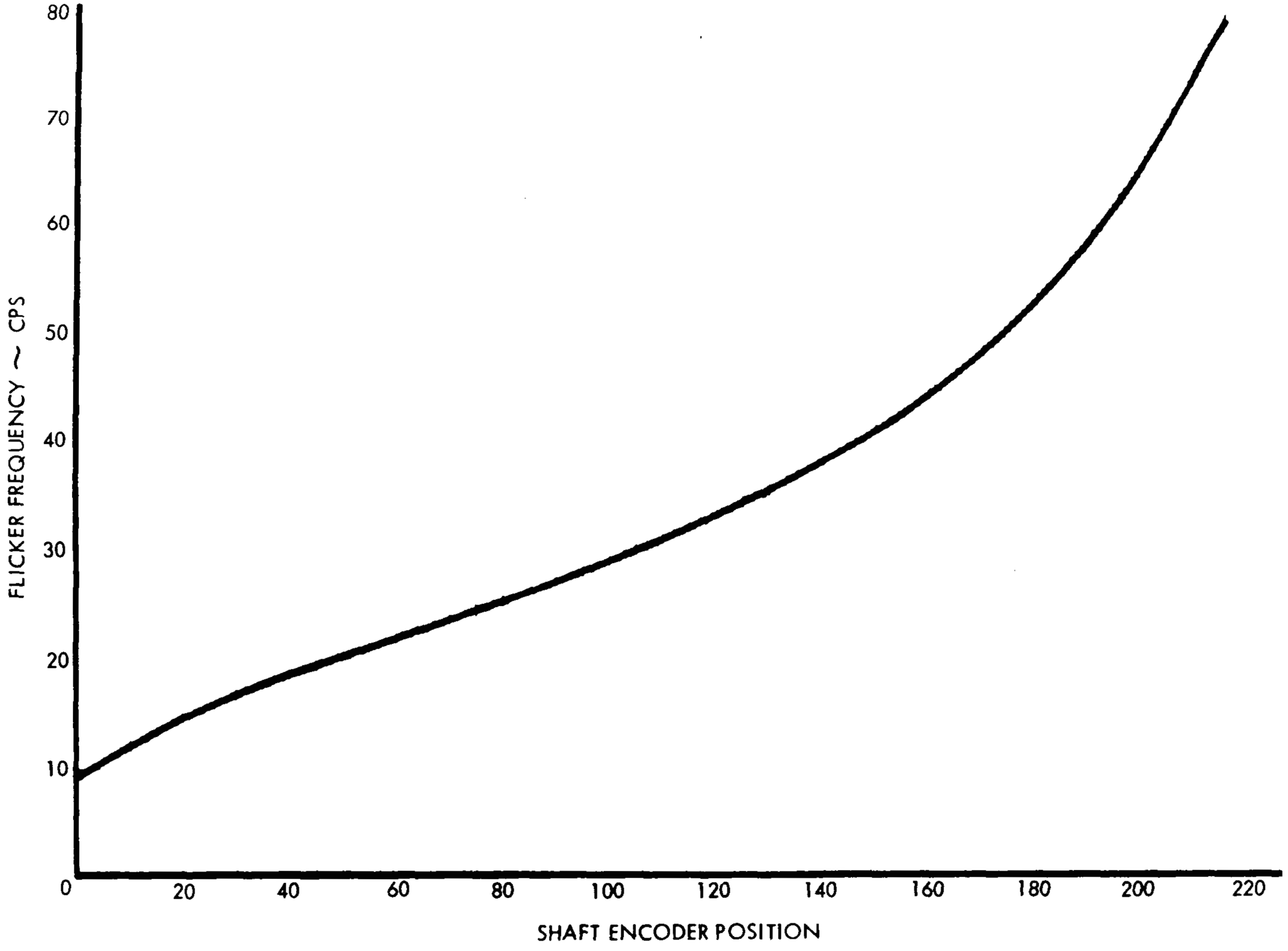

FIGURE B-1. RATE OF FLICKER AS A FUNCTION OF SHAFT ENCODER POSITION

APPENDIX C

ACUITY CALIBRATIONS[1]

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[1] These have been programmed for the NASA (Ames) computer.

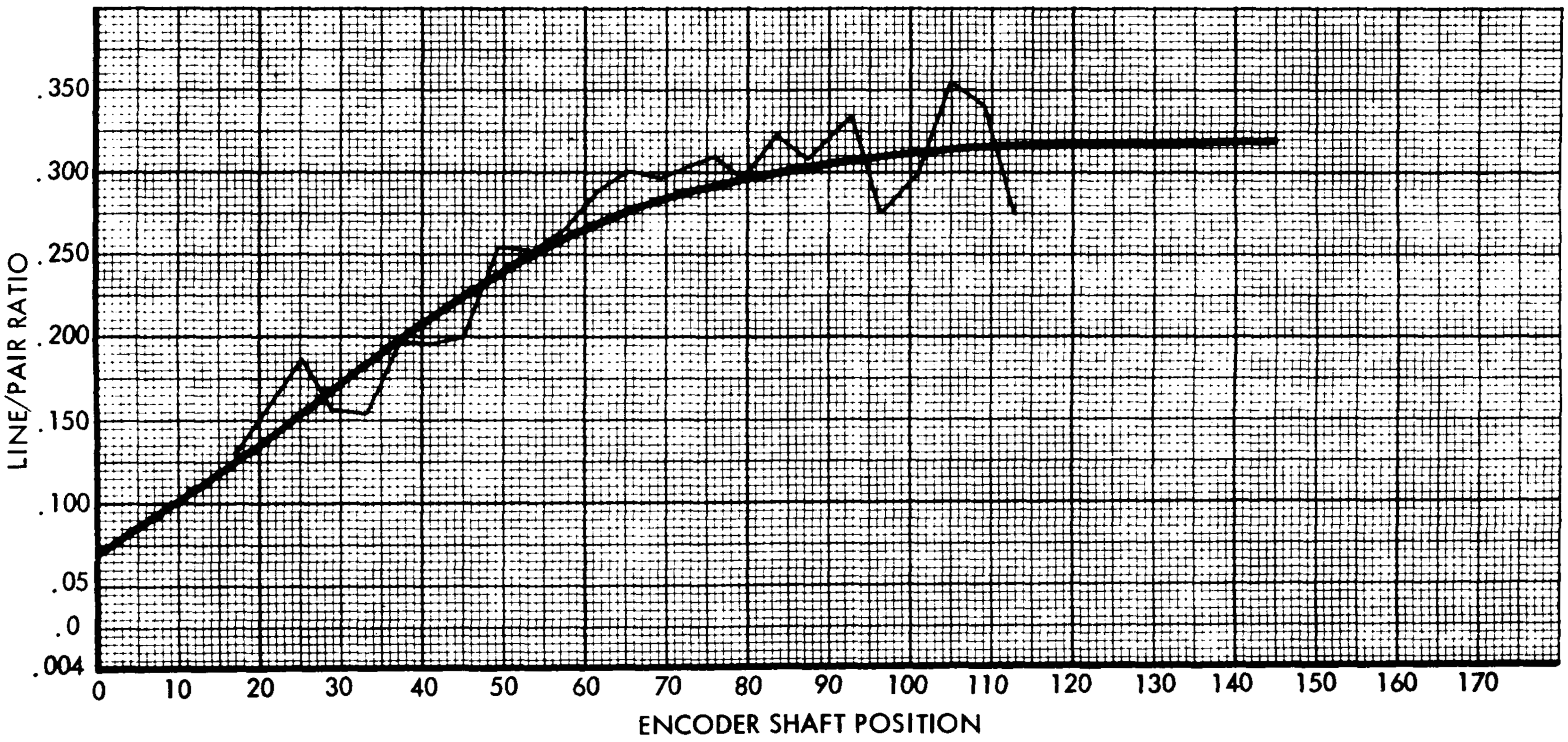

FIGURE C-1. RELATION OF LINE/PAIR RATIO AND ENCODER SHAFT POSITION

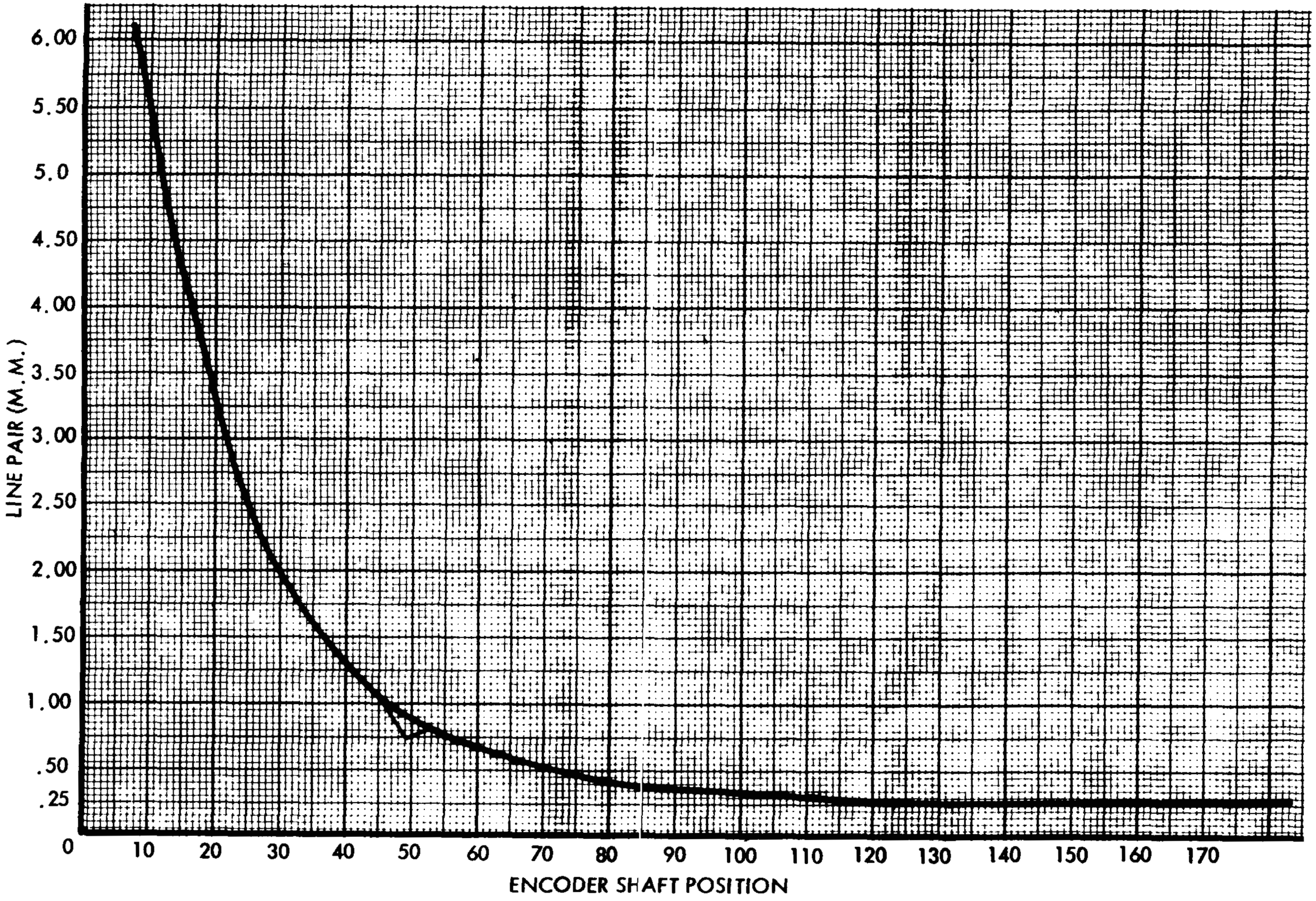

FIGURE C-2. RELATION OF LINE/PAIR (MM) AND ENCODER SHAFT POSITION

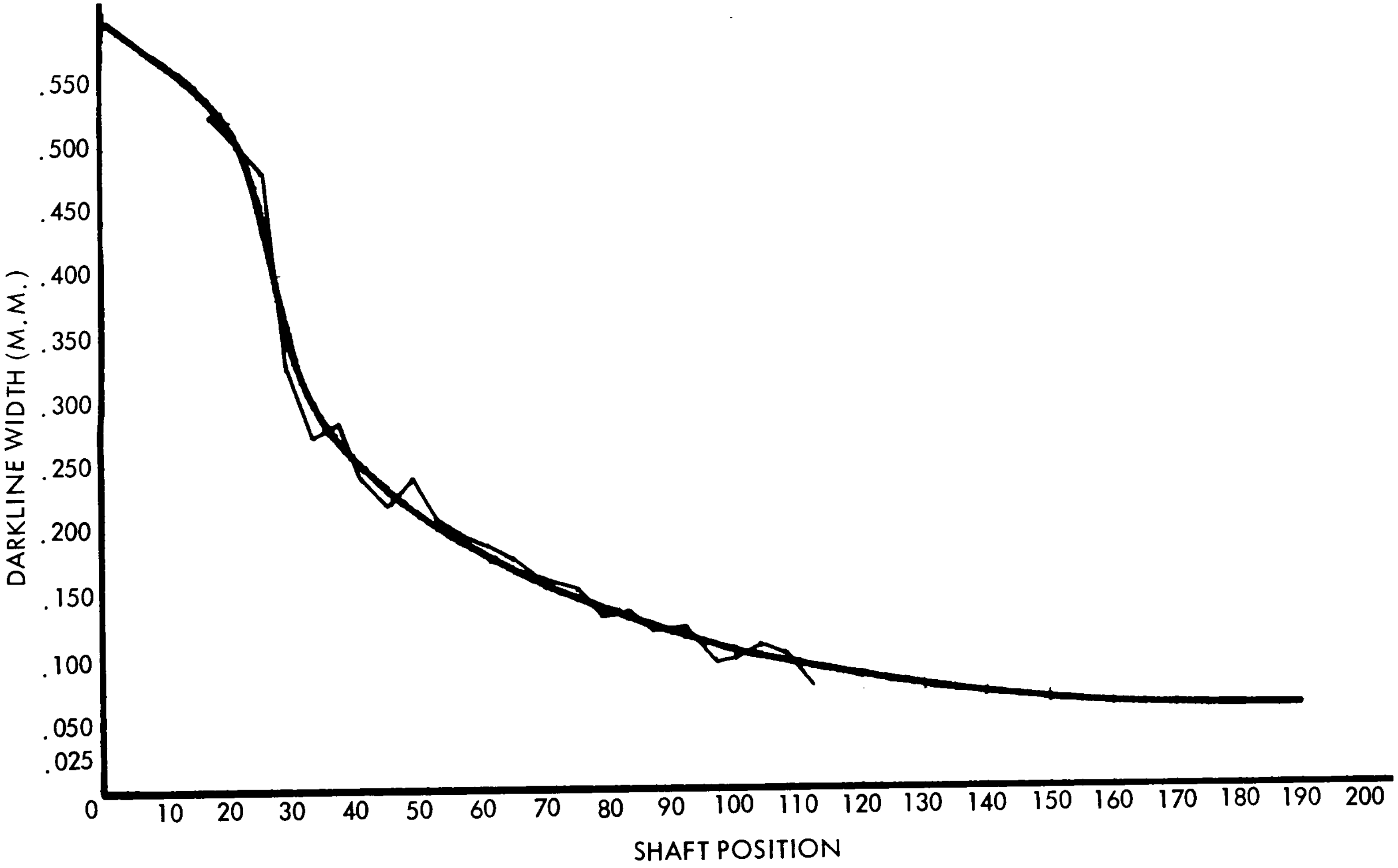

FIGURE C-3. RELATION OF DARK LINE WIDTH (MM) AND ENCODER SHAFT POSITION

APPENDIX D
SUBJECT INSTRUCTIONS

Each S was dark adapted for ten minutes. During this time, he was given a brief description of the VPT and the procedure to be followed during testing.

At the beginning of each test, S was asked if he saw the center spot (lines, flicker). After a "yes" response, he was then instructed to respond, by depressing the button, the first time the center spot (lines, flicker) disappeared and again when it reappeared, and to continue responding at each appearance and disappearance until instructed to "stop." He was then told that the background brightness would change, and after the change he was to begin responding again the first time the center spot (lines, flicker) disappeared and to continue as before.

Instructions

Absolute brightness.—When I turn on the vision display, you will see an illuminated circle in the center of the viewing screen. This center spot will become progressively dimmer until you can no longer distinguish it. When the point is reached at which you can no longer see the center circle, you are to push the response button in your hand. Within a few seconds after this response, the center spot will start to get brighter again. When you can again distinguish the center spot, you are to depress the response button again. Continue to depress the response button each time the center circle appears, and again when it disappears until I say "stop."

Do you have any questions?

(MACHINE ON). . .

All right. When the circle disappears, press the button.

Differential brightness.—The next four displays will be essentially the same as the last one except that the outer circle will also be illuminated. Again you are to depress the response button each time the center circle appears and when it is no longer distinguishable. Continue to respond at these points until I say "stop." Shortly after you have stopped responding, the background illumination will change to a different level. When it has changed, I will say "begin" and you are to respond in the same manner as before with the new background illumination.

Flicker fusion.—At the beginning of the next display, you will see that the entire screen is illuminated and appears to be flickering. You are to depress the response button when the light no longer appears to flicker and again when it starts to flicker once more, and continue these alternate responses until I say "stop." After you have stopped, the screen will change to a different brightness, and when I say "begin" please press the button when the flicker starts or stops. Continue until you are told to stop.

Acuity.—You will now see some fairly distinct parallel lines on the viewing screen. The lines will become narrower and closer together. Please depress the response button when you can no longer distinguish the individual lines, and again when you can see them once more. You are to continue to respond until I say "stop." There will be several brightnesses. I will tell you when to begin and stop for each one.

APPENDIX E
LITERATURE REVIEW SUMMARY
VISUAL TEST AREA REVIEW

To understand the quantitative aspects of vision and visual perception, it is first necessary to become familiar with the terms and methods of measurement employed and their relationships to one another. This presents more of a problem in vision testing than in many other areas of investigation because, although methods and areas of investigation have been fairly constant for at least 30 years, the quantitative terms used are almost as numerous as the investigators themselves. An attempt is made, therefore, to identify and interrelate some of the more common terms used, and is presented in table E-1.

TABLE E-1
COMMON QUANTITATIVE TERMS

TERM	SYMBOL	EQUIVALENT UNITS
luminous flux	F	= lumen (lu)
luminance (photometric brightness)	L	= candle/meter^2 (c/m^2), = 0.3142 millilambert (mL), = 0.2919 foot-Lambert (ft-L), = (trolands/pupil diam^2) (1.273)*, = 0.2019 lu/ft^2
illuminance	E	= lumens/meter^2 (lu/m^2), = meter-candle (m-c), = 0.0929 ft-candle (ft-c)
retinal luminance	L · S	= troland = luminance of 1 c/m^2 on surface viewed through artificial pupil of area S=1 mm^2, = c/mm^2 (pupil diam^2) (7.854 x 10^{-1}), = ft-L (pupil diam^2) (2.691)*

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* pupil diameter in mm.

Another variable frequency encountered in vision testing is the visual angle, which refers to the arc subtended at the eye by a critical dimension (width, spacing, etc.) of the test object. If the angle is small, as in most vision testing applications, it can easily be calculated by use of the equation:

$$\beta = 3450\ W/D$$

where β is the visual angle in minutes of arc, W is the critical dimension and D is the distance from the eye to the test object. Both W and D must be in the same units. The reciprocal of this angle ($1/\beta$) is defined as visual acuity, v, and may be expressed by:

$$v = 1/\beta = 0.00029\ D/W$$

For the visual areas of interest in this investigation (acuity, critical flicker fusion and brightness) the only meaningful human response parameter is that of threshold (e.g., "yes, I see it" or "no, I don't see it"). The threshold is influenced by a number of independent variables such as size of stimulus field, dimensions and shape of test object, luminance, time of exposure, rate of exposure and visual angle, to name but a few. The thresholds are not usually linearly related to the units of the variables. For this reason most results are reported in terms of log units, which tend to produce a more linear relationship throughout the range. It is the first derivative (slope) of the equation for this line which results in the numerical value of Weber's Law (ratio) for the particular variables involved (e.g., $\frac{\Delta L}{L}$, in the case where luminance differences are being investigated).

Flicker

Flicker (or pulsed light) is produced by an intermittent (or interrupted) light. Interrupted light may be obtained either through changes in the amount of current to the light or by occluding the light by some means. The most common method of producing a pulsed light is to rotate a disk, divided into solid and open sectors, in front of the light source. When the disk is rotated at low speed the individual sectors are easily discernible. As the speed of rotation is increased, the perception of the individual sectors decreases until all that can be detected is an apparent flickering of the light. The flicker phenomonon extends over a relatively wide range of frequencies (2-50 cps) until a critical point is reached, at which the flicker disappears and the light appears fused. This threshold point between flicker and fusion, the critical flicker frequency (CFF), may be measured using any device with a controlled variation in flicker in conjunction with a psychophysical method of limits.

The CFF has been found to be very stable for a given subject (S) within a single testing session. There is some disagreement as to the relative constancy of threshold for a given S over a period of time, but one of the more recent and extensive studies of this aspect (Murawski, 1960) indicates that individual thresholds are relatively constant over time. In this study, using male college seniors, Ss were tested one to three times per week for five weeks. Means for the five weeks for the individuals were approximately 32-47 cps, with individual variation ranging from 2-19 percent (majority, 3-5 percent). The differences between Ss were significant at the 0.05 level. There was a slow, gradual increase in the overall daily means, but this was caused by a very few individuals rather than being indicative of the group as a whole. Included in the sample of 26 Ss were four pairs of monozygotic twins. They showed a close correspondence in threshold, with differences ranging from 0.8 to 7.9 cps.

A relatively wide variability of threshold for a single S is not a random occurrence, but rather it has been found to correlate significantly with changes in the mental or physical state of the organism and, for this reason, is beginning to be used as a diagnostic tool for identification of mental or physical abnormalities. However, it is not the intent of this review to cover that more clinical aspect of CFF.

A number of variables have been found to affect the CFF. The most important of these are: (1) intensity of the light stimulation, (2) size of the stimulus field, and (3) light-dark ratio.

The effective intensity of flicker follows Talbot's Law which states that with intermittent stimulation the perceived brightness of a steady light produced is as bright as it would be if the same total stimulation were distributed evenly throughout the cycle. In other words, with a light-dark ratio of 1:1, where the on-time of the light equals the off-time, the effective intensity is one-half that of the steady light without any off periods. With respect to intensity, the general result is that as intensity increases, CFF increases ("better" performance). Granit and Harper (1930), with small circular test targets (0.98-5.0° diameter), found a linear relationship between log luminance and CFF. Hecht and Smith (1936) found the same type of relationship with an even wider range of visual angles (0.3-19°) and observed that at a retinal illuminance of about 4 log trolands the CFF reaches a maximum (at about 45 cps at 2°) and then begins to decrease. Sen and Morobray (1963) in a more recent investigation, which involved frequency matching at different luminance levels (2.5, 4.0, 100, and 400 mL) found that at the two low levels of luminance the point of minimum sensitivity occurred at 15 cps, and at the higher levels minimum sensitivity occurred at 22.5 cps. From these low-sensitive points, sensitivity increased to the respective CFF values of 38-41 cps for low luminance and 50-55 cps for higher luminances, again indicating a decided increase in CFF with increase in intensity. Another result of this study was that changes in background luminance with respect to the test target had little if any effect on CFF.

Dillon (1963) varied wave length and area as well as intensity with results indicating that as the frequency of the intermittent light increased, the threshold CFF could be obtained only with an increase in luminance and/or area of the stimulus. Foley (1960) investigated the interrelationships of background area (A_B), target area (A_T), background luminance (B_B), and target luminance (B_T), using three target sizes, four background areas and three stimulus luminance values. CFF was found to increase linearly with log A_B, log A_T, and log B_T, with background area having much less effect than target area or target luminance. The results can be described generally by an equation of the form $N_C = k \log A_B + k$, where N_C = CFF. It was observed that the relationship between background and target luminance is such that maximum values of the equation and its derivative occur when $B_B = B_T$. The slope of the background area function is independent of the target area and target luminance so that, in general, the effect of increasing background area may be thought of as increasing the level of performance, without in any way affecting the kind of performance.

Another of the main variables affecting CFF is the light-dark ratio (LDR). There has been some confusion in the past about this term and its use, with some investigators interpreting it as the ratio of light to the total cycle (light/light + dark) and others as the ratio of light to dark (light/dark). The former interpretation, for better understanding, should be referred to as the proportion of light to total cycle (P_L) and this can be converted to the conventional LDR with the equation LDR = $P_L/1 - P_L$.

With intensity held constant, comparisons of CFF against P_L have consistently shown an inverted U-shaped curve with a maximum CFF at $P_L = 0.5$ (LDR = 1:1) for low luminance levels ($\text{Log } I \leq 4$), while at high luminances ($\text{Log } I > 4$) the maximum CFF is at a low P_L (Bartley and Nelson, 1961; Lloyd and Landis, 1960).

Domey (1964), using ten different LDRs (from $P_L = 0.02$ to 0.98), found fairly consistent CFFs (41.12 - 47.25) for all subjects (whose age ranged from 13 to 49) up to $P_L = 0.50$. Beyond $P_L = 0.50$ there was a sharp decline in CFF, until at $P_L = 0.98$ the values of CFF were 9.88 - 10.67.

Visual parameter tester. — The VPT, when used for testing CFF, uses four brightness levels (approximately 0.03, 0.3, 3.0 and 30.0 ft-L) of the illuminating beam, which illuminates the entire 1-1/2 inch diameter test screen. The light is interrupted by a rotating butterfly shutter which is reported (Moss, 1966) to provide 100 percent square wave modulation, the frequency of which is continuously variable between 10 and 75 cps. The visual angle subtended by the test field at a viewing distance of 28 inches is approximately 3°, which is about midpoint in the range of angles used by most investigators. At the luminance levels used, and with a LDR of 1:1 it is expected that all Ss with normal vision will have fusion thresholds between about 35 to 45 cps, which is well within the limits of the device.

Acuity

Visual acuity is the ability to discriminate points in the field of view. It is usually measured in terms of (1) the width of the object itself if the distance from the object is constant, or (2) the visual angle subtended by the object or objects being discriminated.

In clinical practice, a series of test objects is used in which some critical aspect of each test object subtends an angle of one minute of arc for "normal" visual acuity at a standard viewing distance, usually 20 feet. Larger test objects are provided which subtend one minute of arc at progressively greater viewing distances. A determination is made of the smallest test object that can be correctly identified by any given subject, and the S's visual acuity $\underline{v}$ is given by the relation: $\underline{v} = \frac{D'}{D}$ where D' is the standard viewing distance and D is that distance at which this minimum test object subtends an angle of one minute of arc. Thus the S is said to have 20/30 vision if, at a viewing distance of 20 feet, he can just respond correctly to a test object which subtends an angle of one minute at a distance of 30 feet. Values of $\underline{v}$ so determined are the equivalent of values specified as the reciprocal of the just discriminable visual angle in minutes of arc (Riggs, 1965).

Under optimal light and contrast conditions it has been found that Ss with normal vision can discriminate even better than 60 seconds of arc. For the Landolt ring, most workers report acuity values on the order of 30 seconds. Keesey (1960) found the critical detail (CD), the dimension which is to be discriminated, at the threshold for a dark grating to be about 50 seconds, and also noted that for a grating test object, horizontal or vertical test orientation yields better acuity than do oblique positions. Ogilvie and Taylor (1959), using lines and squares, found threshold values of 0. 5 seconds of arc for long lines and 10 to 20 seconds for squares, and also found that for the majority of their Ss, vertically oriented lines were more visible than those obliquely oriented. In another study involving orientation, Beck (1965) found that visual acuity was better for vertical lines than for horizontal at a distance of 10 feet with lines of dimensions 14. 4 x 0. 25 cm, but, using lines of equivalent visual angle of 20 feet and at one foot, found no differences in acuity related to orientation.

A grating or grid (a set of parallel light and dark stripes) has been used extensively in determining visual acuity. Shlaer (1937) reports acuities of 35 seconds of arc at high luminance values using a grating test, but most investigators seem to agree that the minimum width of a stripe for resolution is about one minute of arc. Senders (1948) lists among others the values of Lister, 64 seconds; Hirschmann, 50 seconds; Bergmann, 52 seconds; Helmholtz, 64 seconds; and Cobb, 64 seconds.

Luminance has a decided effect on acuity, as was evidenced nearly 30 years ago in the work of Hecht and Mintz (1939). They used single dark lines against a background luminance which ranged from -5 to 1.5 log mL. The resulting acuity values in minutes of arc subtended at threshold ranged from about 16 minutes at the lowest luminance to about 30 seconds at a luminance of 30.2 mL.

Visual parameter tester. — Visual acuity on the VPT is measured with a dual Ronchi grating device which is positioned over the 1-1/2 inch screen. The rotation of one grating with respect to the other produces a moire pattern of parallel lines which vary in number and width in a nonlinear relationship to the angle formed by the two sets of parallel lines. The rotation is reported (Moss, 1966) to change the number of lines crossing the field from near zero to 240 lines/inch. The minimum distance between lines subtends a visual angle of one-half minute at a test distance of 28 inches (equivalent to Snellen targets for 20/10 acuity). Four background luminance levels may be used: 30.0, 3.0, 0.3, and 0.03 ft-L.

Brightness Discrimination

Absolute and differential brightness thresholds are considered under the same heading because the absolute threshold is simply a special case of the differential threshold. Differential threshold is the value of a stimulus required for a figure to emerge upon a ground having an intensity value greater than zero, while absolute threshold is the value of the stimulus required for emergence of the visible feature on a totally dark background. These thresholds vary with duration of exposure, test field area, and background luminance.

Brown and Mueller (1965) report that in 1911 Lasareff showed that increases in field diameter (d) yield lower threshold ΔL values. Heinz and Lippay (1927) are reported to have obtained the same type of results using stimulus sizes ranging from 11.6 to 183 minutes of arc in diameter. When the threshold points are plotted as log d versus log ΔL, a linear relationship is obtained at least within the range covered by this study. More recent studies by Steinhardt (1936) and Blackwell (1946) have shown similar results. Steinhardt used circular targets with diameters of 9.1 to 250 minutes and a three-second exposure time. Blackwell (1946) used diameters of 3.6 to 121 minutes with a range of luminances of about eight log units and an exposure time of six seconds (which is considered a long exposure duration by many investigators). Again the results show a progressive shift of the detectable contrast curves to higher and higher values for smaller and smaller areas. For example, a target of 20 minutes diameter with a retinal luminance of three log trolands requires a difference ratio of log $\Delta L/L = 1.5$, while a target of 6.6 minutes diameter at the same retinal luminance requires a log $\Delta L/L$ value of -0.35 for detection. The relationship of area and luminance to threshold (C) has been expressed in two equations (for different size areas). For areas whose diameter is less than 10 minutes the equation $L \times A = C$ (Ricco's Law) holds, and for larger areas (diameter $2\text{-}7^{\circ}$) Piper's Law, $L \times \sqrt{A} = C$ is the appropriate equation. In other words, for smaller areas, the product of area and added luminance is approximately a constant. As the area is increased, the dependence of the threshold luminance on the area of the test stimulus becomes less pronounced, therefore the use of $\sqrt{A}$ in the equation for the larger angles.

More recently, Diamond (1962) explored the test field luminance required to match the brightness of a constant match-field luminance at test field areas of 2.69 feet to 26.86 feet and luminances ranging from threshold (log C = −1.317 mL) to 2.56 log mL. The results showed that only at threshold were there systematic differences in test luminance as a function of test area. Threshold luminance decreased as area increased. At suprathreshold test luminances, differences that did occur were not systematic.

The typical brightness threshold study employs a variable intensity test field of about one minute to one degree diameter with a larger surround area which can be held at a number of constant intensities. Typically, the S is dark-adapted ten to fifteen minutes and is then light-adapted to the background luminance for one to five minutes while maintaining a more or less steady fixation point by using a bite-board or head rest. The duration of the test stimulus is usually relatively short (0.05 - 6.0 seconds).

Under ordinary conditions, both the brightness (psychological, rather than photometric variable) and increment threshold of a test stimulus vary directly with its luminance. However, when the surround has a greater intensity than the test field, the brightness of the test field decreases while its luminance remains unchanged. To determine whether it is brightness or luminance which affects the increment threshold, Cornsweet and Teller (1965) varied both parameters and found the increment threshold under all conditions to be independent of brightness and dependent only on the retinal illuminance of the region to which the test flash was added.

Visual parameter tester. — The VPT has two tests related to this area, absolute brightness and differential brightness. For the determination of absolute brightness threshold, only the center spot (of diameter ≈ 3/4 inch) is illuminated. The luminance is continuously varied in a form of the method of limits, with S responding at the appearance of the spot and again at the disappearance. The same method is used in the differential brightness threshold but with the addition of a background luminance of 0.03, 0.3, 3.0 or 30.0 ft-L.

APPENDIX F
SUBJECT BASELINE DATA

SUBJECT	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR-BEST EYE	SUBJECT	SNELLEN 20/—	LANDOLT 20/—	ORTHORATER NEAR-BEST EYE
1	10	15	12	20	13	15	12
2	10	10	12	21	13	12.5	11
3	10	15	12	22	13	15	11
4	13	25	12	23	13	17.5	12
5	30	45	12	24	13	15	12
6	20	30	12	25	20	40	11
7	10	12.5	12	26	13	15	12
8	25	30	12	27	25	50	12
9	20	25	12	28	15	17.5	11
10	25	35	8	29	13	17.5	12
11	10	12.5	12	30	13	15	12
12	100	12.5	11	31	10	17.5	12
13	13	15	12	32	40	45	12
14	70	85	9	33	13	20	12
15	13	12.5	12	34	20	25	11
16	13	15	12	35	70	100	8
17	20	25	11	36	15	25	12
18	13	15	11	37	20	25	9
19	13	15	12	38	13	17.5	12

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