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NOISE EFFECTS ON BOAT OPERATOR PERFORMANCE.(U)

JAN 78 C STIEHL, D JOHNSON, L KENDRICK DOT-CG-40672-A

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NOISE EFFECTS ON BOAT OPERATOR PERFORMANCE

FINAL REPORT

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16. Abstract

This document presents the results of the fourth in a series of experiments concerning the effects of the boating environment on a boat operator's ability to respond to a visual target. The experiment was designed to investigate the effects of noise, fatigue, and wind on the operator's response times and error scores on the Visual Alertness Stressor Test (VAST). The results indicated that the test subjects performed much better when the boat's windshield was removed, and that fatigue causes poorer performance in low and medium noise conditions. No overall noise effect was observed in the data. These data are related to the stressor literature at large and to previous VAST studies. Recommendations are made for future applications of the VAST research.

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Indeed, many people were involved in VAST at one time or another, and this report would not have been possible without all of their efforts.

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NOTICE

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
	AREA			
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
	MASS (weight)			
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
	VOLUME			
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
	TEMPERATURE (exact)			
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

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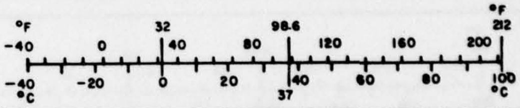
*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
	LENGTH			
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
	AREA			
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
	MASS (weight)			
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
	VOLUME			
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
	TEMPERATURE (exact)			
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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NOISE EFFECTS ON BOAT OPERATOR PERFORMANCE

1.0 INTRODUCTION AND SUMMARY

This document presents the results of the fourth in a series of experiments concerning the effects of the boating environment on a boat operator's ability to respond to a visual target. The experiment was designed to investigate the effects of noise, fatigue, and wind on the operator's response times and error scores on the Visual Alertness Stressor Test (VAST). The results indicated that the test subjects performed much better when the boat's windshield was removed, and that fatigue causes poorer performance in low and medium noise conditions. No overall noise effect was observed in the data. These data are related to the stressor literature at large and to previous VAST studies. Recommendations are made for future applications of the VAST research.

Through detailed studies of boating accident data and in-depth accident investigations, the United States Coast Guard has determined that approximately 90% of the causes of boating collisions are operator related. These cause identification studies have indicated that the boating environment (through stressors such as noise, heat, glare, shock, vibration) may contribute signinificantly to operator-related causes of accidents. The Visual Alertness Stressor Test (VAST) was developed as a means of measuring the effects of stressors on a boat operator's performance.

VAST is a divided attention task. The small boat operator is required to maintain a course and speed dictated by an on board experimenter (primary task), and respond to particular light patterns shown on a semicircular display around the cockpit (secondary task). Basic measures of performance include response times and error scores for the light patterns. This paper presents the results of three years of research in the area of boating stressors and operator performance.

Relevant literature is reviewed in several sections of this report. The experimental design issues are presented in Section 2.1.

The three previous VAST experimenents have shown that environmental stressors have significant effects on boat operator performance. These experiments investigated the effects of fatigue, alcohol, glare, noise, shock, and vibration. For example, it was found that three hours of light exercise in the sun can lead to a doubling of the time required to respond to a visual stimulus on a boat. In one study, the fatigue associated with such exercise was shown to have roughly the equivalent effect on the boat operator as if he had been legally drunk. The experiments are discussed in Section 2.2.

The current effort presented several difficulties in terms of the VAST apparatus and the experimental design. The VAST system was revamped to incorporate two new microprocessors, one to collect the data on board the VAST boat, and one to analyze the data on shore. The VAST noise environment and other design considerations required careful experimental manipulations, and the development of an engine shroud and a windshield for the VAST boat. Details on these topics can be found in Section 3.1 and following pages.

The results of the fourth VAST experiment (see Section 3.2 and following pages) provide data indicating that the subjects performed better when the windshield was removed. This result is discussed in terms of the changes in noise spectra with the removal of the windshield. The data also indicated that fatigue led to performance degradations in low and "normal" noise conditions. No overall noise or fatigue effect was found in the data, although some interactions were significant. Similar studies in automobiles, buses, and trucks failed to produce significant overall noise effects, but they found fatigue effects due to heat. The failure to find an overall fatigue effect in the present study may have been due (at least in part) to the fact that the experiment was run in relatively cool fall weather.

A brief discussion of possible future roles for VAST in Coast Guard programs is presented in Section 4.0. This is followed by four appendices: Appendix A presents a discussion of the statistic d' used in data analyses, Appendix B describes the microprocessors' logic, Appendix C includes most of the data collected to describe the noise environment on the VAST boat, and Appendix D is a glossary of some of the technical terms used in this report from psychology, industrial engineering, and statistics.

The results of all four VAST experiments appear in Table 1. The inescapable conclusion of the three years of VAST studies is that any environmental stressor, in the presence of particular combinations of other factors, can produce operator performance problems. These results were obtained in a real-world program of research, not in a laboratory.

TABLE 1. SUMMARY OF VAST RESULTS

Experiment	Number of Subjects	Approximate Number of Data Points	Approximate VAST Miles*	Significant Results
VAST-1	6	280	600	VAST can measure stressor effects. The combined daytime stressors (fatigue) led to performance degradations.
VAST-2	8	320	450	Alcohol led to performance degradations. Fatigue led to performance degradations of roughly the same magnitude as alcohol.
VAST-3	4	2160	2250	Alcohol, noise, shock, vibration, and glare were all shown to have effects on operator performance. Significant interactions were found between glare and noise, and between fatigue, alcohol and noise. This experiment confirmed that the environmental effects on a boat operator are INTERACTIVE, and depend upon combinations of stressors as well as individual stressors.
VAST-4	6	1440	1500	Removing the windshield resulted in improved performance. Fatigue effects are most pronounced at low and medium noise levels. No overall noise effect was observed.
TOTAL	-	4200	4800	MANY COMBINATIONS OF STRESSORS CAN CAUSE INTERACTIONS THAT PRODUCE POOR OPERATOR PERFORMANCE.

*Miles include checkout, make-up days, and training; data points do not.

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2.0 BACKGROUND

With the conclusion of the present effort, four VAST experiments have been conducted over a period of less than three years. Related research continues to be published in technical journals. This section summarizes the related research reported elsewhere and briefly relates it to the VAST program of research. Previous VAST experiments are also discussed. They provide a framework for incorporating the results of the noise study, and they document the richness of the VAST experimental design.

2.1 Literature Review

Previous reports dealing with VAST have indicated that there is a large number of published reports dealing with stressors and human performance (Reference 1). Much of this work suffers from the fact that it was done in laboratory settings (making real-world applications of the results tenuous at best), and often only one stressor was studied at a time, rather than allowing for the interactions of several stressors. Despite these problems, researchers have provided data that indicate that noise could be a safety and a health problem in boat operation.

National statistics show that total or partial hearing loss is experienced by over 20 million Americans, and is America's major non-fatal health disorder (Reference 2). The source of these data also reports that such problems are a result of exposure to high noise levels off the job and in recreational activities, such as boating.

In addition to the health problems associated with noise, it can cause safety problems. Warner and Heimstra (Reference 3) found that high noise levels (among other stressors) can cause an increase in the times required to detect visual targets. Jerison (Reference 4) and others (Reference 5) have provided evidence of noise effects on human performance in many situations and tasks. In a potential accident situation, the additional loads on human performance created by high noise levels may be enough to prevent accident avoidance. The research indicates the following noise effects:

Noise effects

- cause changes in heart rate and blood flow,

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- cause changes in respiratory patterns,
- cause changes in GSR, galvanic skin response (indicating "stress"),
- can cause dizziness and loss of balance,
- can decrease visual acuity and visual field (peripheral awareness), and
- can cause decrements in mental and psychomotor performance.

With very few exceptions, these studies were performed in laboratory settings and without exposure to stressors other than noise.

With respect to noise levels and pleasure boats, several publications in the past few years have dealt with engine noise measured 50 ft (15.2 m) from the boat. Some states have passed or proposed regulations concerning noise levels measured 50 ft (15.2 m) from the boat. An example is the state law proposed in Illinois in 1977, which would set a limit of 86 dBA at 50 ft (15.2 m) for boats built before 1980, with tougher standards after that. A model act for a state or local government noise control legislation is shown in Figure 1. The standard expressed in Section 1(b)(1) of this model act was used in the experimental design of this VAST study.

Some of the engine manufacturers have invested in studies of "fifty-foot-runby" noise, and they have published pamphlets and movies documenting their case that boat engines are relatively quiet (Reference 6). However, very little attention has been paid to the noise levels within the boat, or to their effects on the operator. One result of the research that has been done is the development of a measurement procedure for exterior sound level for pleasure motorboats (Reference 7). A similar procedure is in the draft proposal stage for interior sound level measurement.

What correspondence is there between the 86 dBA measured 50 ft (15.2 m) from the boat and the noise levels at the operator's ear? To investigate this, one needs to be able to backtrack from the position 50 ft (15.2 m) away from the boat to a position nearer to the source of the noise. Of course, the boat's engine is not the only source of noise as it travels through the water. The wind and water (on the hull) contribute to the overall noise as well. Thus, the intensity of the noise at the operator's ear will be higher than 50 ft (15.2 m) away from the boat's

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MODEL ACT FOR MOTORBOAT NOISE CONTROL

An act to prescribe maximum noise levels for motorboats; to provide testing procedures for determining such levels; to require outboard motor manufacturers and certain boat manufacturers to certify to compliance with such levels; to empower the adoption of regulations governing testing and certification; to preempt motorboat noise control to the State; and to provide a penalty for violation.

The people of the State of _______________ do enact as follows:

Section 1. (a) No person shall operate any motorboat powered by an engine manufactured before January 1, 1975, in or upon the waters of this state in such a manner as to exceed a noise level of 86 dbA measured at a distance of 50 feet from the motorboat.

(b) On or after January 1, 1975, no person shall operate, sell or offer for sale any motorboat for use in or upon the waters of the state in such a manner as to exceed the following noise levels:

(1) For motorboats manufactured on or after January 1, 1975, and before January 1, 1978, a noise level of 86 dbA measured at a distance of 50 feet from the motorboat.

(2) For motorboats manufactured on or after January 1, 1978, and before January 1, 1982, a noise level of 84 dbA measured at a distance of 50 feet from the motorboat.

(3) For motorboats manufactured on or after January 1, 1982, a noise level of 82 dbA measured at a distance of 50 feet from the motorboat.

Section 2. Outboard motors manufactured after January 1, 1976 and offered for sale in this state shall be certified to the Department by the motor manufacturer as having been tested and found not to exceed the noise levels prescribed in Section 1 (b) of this Act. All other marine engines manufactured after January 1, 1976 and offered for sale in this state shall be certified to the Department by the boat manufacturer as having been tested and found not to exceed the noise levels prescribed in Section 1 (b) of this Act. Testing procedures employed to determine such marine engine noise levels shall be in accordance with the Exterior Sound Level Measurement Procedure for Pleasure Motorboats recommended by the Society of Automotive Engineers in its Recommended Practice designated SAEJ34. The Department shall adopt regulations concerning the manner of certification and test procedures, and may amend such regulations as deemed necessary to adjust to advances in technology.

FIGURE 1. A MODEL ACT FOR MOTORBOAT NOISE CONTROL

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Section 3. No person shall remove or alter any part of a marine engine, its propulsion unit, or its enclosure, or modify the mounting of a marine engine in or upon a boat in such a manner as to exceed the noise levels prescribed in Section 1 of this Act.

Section 4. The provisions of this Act shall not apply to motorboats competing under a local public entity or United States Coast Guard permit in a regatta, in a boat race, while on trial runs, or while on official trials for speed records during the time and in the designated area authorized by the permit. In addition, this Act shall not apply to motorboats preparing for a race or regatta if authorized by a permit issued by the local entity having jurisdiction over the area where the preparations will occur.

Section 5. No political subdivision of this state may establish, continue in effect, or enforce any ordinance or regulation which establishes any noise level for motorboats, or which imposes any requirement for the sale or use of marine engines at prescribed noise levels, which is not identical to the provisions of this Act or regulations adopted by the Department pursuant thereto.

Section 6. Any person who violates any provision of this Act or any authorized rule or regulation of the Department adopted pursuant thereto is guilty of a misdemeanor.

FIGURE 1. A MODEL ACT FOR MOTORBOAT NOISE CONTROL (concluded)

engine, and the noise quality (the spectrum of frequencies and their amplitudes) will be different. The noise that the operator hears will include reflections from within the cockpit and boat vibrations through the hull. As an approximation to the overall noise level he is subjected to, one can assume that the noise 50 ft (15.2 m) away is merely a dissipated version of the cockpit noise environment.

Under the assumption that A-weighted sound measurements show the same deterioration characteristics as spherical acoustic waves over distance, one can show that the measured sound level will show approximately a 6 dB decrease with each doubling of the distance from the source of the sound to the measurement device, and that sound levels of well over 100 dBA are possible on board a boat that passes the 86 dBA at 50 ft (15.2 m) standards.

It is known from the physics of sound propagation (Reference 8) that:

$P^2 = A^2/_{r^2}$ were P is the pressure, A is an amplitude constant, and r is the distance from the source. (1)

Dividing both sides of (1) by a reference pressure (P_0^2) we obtain,

$$P^2/_{P_0^2} = A^2/_{P_0^2}\, r^2 \qquad (2)$$

Taking the logarithm of both sides of (2) and multiplying by 10 yields

$$10 \text{ Log } P^2 - 10 \text{ Log } P_0^2 = 10 \text{ Log } A^2 - 10 \text{ Log } P_0^2 - 10 \text{ Log } r^2 \qquad (3)$$

Rearranging produces (SPL = Sound Pressure Level)

$$\text{SPL} = 20 \text{ Log } A/_{P_0} - 20 \text{ Log } r \qquad (4)$$

Since A and P_0 are constants, we have the SPL directly related to the logarithm of the distance from the source. The SPL is seen to be equal to a constant minus a factor related to the distance from the source. When r is doubled, the SPL drops by approximately 6 dB. This is easily shown using equation (4). If $r_2 = 2r_1$, then

$$\text{SPL}_{r_1} = 20\ \text{Log}\ A/P_o - 20\ \text{Log}\ r_1$$

$$\underline{\text{SPL}_{r_2} = 20\ \text{Log}\ A/P_o - 20\ \text{Log}\ r_2}$$

$$\Delta\text{SPL}_{r_1 - r_2} = -20\ \text{Log}\ r_1 + 20\ \text{Log}\ r_2$$

$$= +20\ \text{Log}(r_2/r_1) = +20\ \text{Log}\ 2 = 6.02\ \text{dB}.$$

Using this relationship, we can work backwards from 86 dBA at 50 ft (15.2 m) to find the corresponding noise levels on the boat. This is done in the table below.

TABLE 2. NOISE LEVELS AT DISTANCE r FROM THE SOURCE

SPL	r (DISTANCE)
86.00 dBA	50 ft
92.02 dBA	25 ft
98.04 dBA	12.5 ft
104.06 dBA	6.25 ft
110.08 dBA	3.125 ft
119.98 dBA	1 ft

As can be seen from the table, a boat can satisfy the 50 ft (15.2 m) standard and generate noise levels in excess of 100 dBA on the boat. The value of 119.98 dBA when r=1 can be used in equation (4) to provide an SPL estimate for any r, as shown in equation (5).

$$\text{SPL} = 119.98 - 20\ \text{Log}\ r \tag{5}$$

Thus, for a distance of 5 ft (1.5 m), SPL = 106 dBA. It should be noted that the numbers in Table 2 represent the upper limits of noise levels that could exist on a boat that passes an 86 dBA/50 ft (15.2 m) runby standard. As such they disagree with data from some sources (References 9 and 10) which represent norms, while other sources (Reference 11) report noise levels very comparable to those in the table.

Magrab (Reference 12) and others (Reference 1) have measured noise levels on outboard boats in excess of 90 dBA at full throttle at various distances from the engine. These levels are well beyond the range of loud conversation (60-70 dBA), and prolonged exposure to these high noise levels could cause hearing damage.

Research at the University of Windsor (Reference 13) has indicated that wind noise alone (measured at the human ear) can reach 100 dBA. The noise equations indicate that a boat passing a 86 dBA/50 ft (15.2 m) runby standard can generate over 100 dBA on board. Add to that the wind noise (not measured by 50 ft (15.2 m) runby measurements), and consider the noise contributions due to the water on the hull (some of which are measured in the 50 ft (15.2 m) runby standards). Those standards permit noise levels on boats which: 1) mask speech communication, 2) can cause temporary threshold shifts, 3) can contribute to permanent hearing damage, 4) may cause other physiological (heart rate, respiratory rate, etc.) or psychological (GSR, etc.) problems, and 5) may cause operator performance degradations.

The use of VAST in the analysis of noise problems on small boats is primarily an attempt to measure the fifth effect in the preceding paragraph, the effect on operator performance. This effect may be particularly important in collisions. When Wyle studied a sample of over 150 boats involved in collisions as part of Phase II of Collision Research, the researchers agreed that noise problems existed in over 68% of the cases where enough information was available to make an evaluation. Finally, it will be shown below (from the third VAST experiment) that the boaters performed better when wearing ear protectors, despite their complaints that the devices were annoying and uncomfortable.

2.2 Previous VAST Experiments

Coast Guard sponsored research has been investigating the causes of collisions for several years. Detailed studies of the accident data and in-depth investigations of accidents showed that approximately 90% of the causes of boating collisions were related to operator errors. One of the major contributors to operator errors was found to be the effects of the boating environment on the operator's abilities to respond to visual stimuli and control his boat (References 14, 15, and 16).

The Visual Alertness Stressor Test (VAST) was developed as a means of measuring the effects of different components of the boating environment on the operator's performance. VAST is a divided attention task. The small boat operator is required to maintain a course and speed dictated by an on board experimenter (primary task), and respond to particular light patterns shown on a semi-circular display around the cockpit (secondary task). Basic measures of performance include response times and error scores for the light patterns.

The use of a secondary task to measure degradations in performance (while a required level of skill is maintained on a primary task) is an approach that is well-documented in the human performance literature. For example, Moskowitz (Reference 17) has shown the divided attention task to be of benefit in alcohol research, and Neisser (Reference 18) discussed the use of similar methods to measure the effects of stressors on information processing and the interactions of sensory modalities. VAST requires the subject to maintain a boat on a course and speed specified by an on board experimenter (primary task). At the same time, the subject is required to respond to particular patterns of lights displayed in a semi-circle around the cockpit of the boat (secondary task). The basic measures of performance are: 1) the number of times the experimenter alerted the subject to the fact that he was off course or speed, 2) the response times to the light patterns that should be responded to, and 3) the frequencies of errors (failures to respond, and "false alarms").

The VAST apparatus consists of a 17 ft (5.2 m) runabout equipped with a 190° light display (driven by a micro-computer) mounted in front of the subject (see Figure 2). The light display contains 39 automobile taillights recessed in a flat black covered ring just below the operator's line of sight over the bow (one light for every 5° of arc)(see Figure 3). The light display is mounted approximately three feet (0.9 m) from the operator. A tachometer, compass, and power trim switch are mounted on the control panel in front of the operator (see Figure 4). The experimenter dictates course and speed (rpm setting) for the subject to follow as his primary task. Whenever a subject is off course or speed by a specified amount, the experimenter activates a boat horn directed at the cockpit which causes the subject to take corrective action. A response switch is mounted on the throttle for the subject to use when he detects a light display that he should respond to (see Figure 5). The light displays are controlled by the micro-computer, and occur at various times throughout a half hour test session. Lights may appear to be "moving" left to right or right to left, or they may be stationary. Any non-moving light should be responded to. These may (or may not) occur at the end or beginning of a "moving" sequence, or independently.

FIGURE 2. VAST-4 UNDERWAY

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FIGURE 3. VAST COCKPIT

FIGURE 4. CONTROL STATION AREA

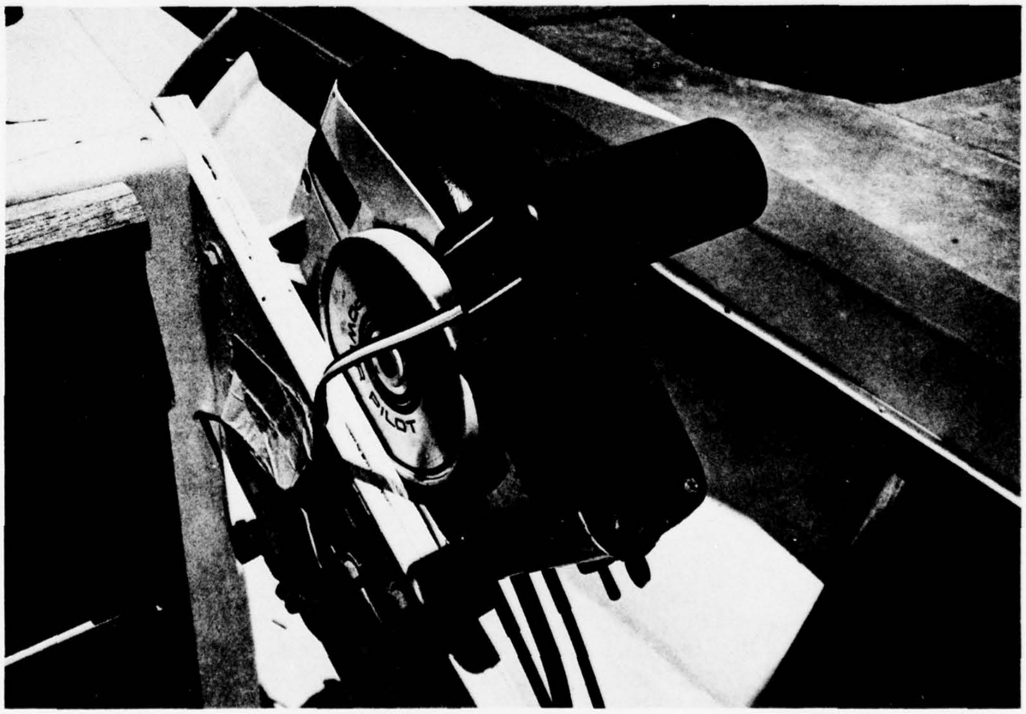

FIGURE 5. THROTTLE AND RESPONSE BUTTON

N-4 Furnished

Complete patterns could include lights of several types (moving either direction, stationary, etc.), with some occurring simultaneously. Patterns could occur at any time and could be separated by from one second to eight minutes. The light sequences could originate and terminate at any location in the display.

2.2.1 VAST-1

In the first VAST experiment, the Coast Guard was interested in determining: 1) if the combination of typical environmental stressors found in daytime boating leads to significant decrements in operator performance, and 2) if the VAST apparatus and experimental paradigm were sensitive to stressor-induced operator performance degradations. The experimental evidence in VAST-1 indicated that stressors were important and their effects could be measured using VAST.

In VAST-1, 2 x 2 factorial design was used where the factors were the type of fatigue (exposure to environmental influences representative of a fisherman's outing, as opposed to those of a family outing) and amount of fatigue (subjects were tested in a "rested" state and a "fatigued" state -- after three hours of exposure). Each subject served as his own control. An individual subject took his first VAST run in a rested condition. Then he underwent a scenario of activities representative of one of the two types of fatigue. Finally, he executed his second VAST run (fatigued). For the fisherman scenario, subjects spent three hours alternately drifting and motoring in a small boat. These subjects were exposed to sun, heat, glare, vibration, etc. The family scenario consisted of three hours of exposure to similar environmental variables while exercising lightly (walking, picking up shells, playing catch, etc.). Six male USCG personnel were used as subjects, but the data for two were discarded because they failed to master the task. The results confirmed that the overall effect of "typical" exposure to the environmental stressors of boating was a significant degradation in the operator's performance in response times and error scores. The main effect of type of fatigue (fisherman versus family) and the interaction of level of fatigue with type of fatigue were not significant.

The first VAST experiment showed that the combined daytime environmental stressors in boating (heat, noise, glare, etc.) did affect operator performance ($F=28.1$, $p<0.01$ for missed signals, $F=19.5$, $p<0.025$ for response times), and the VAST

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apparatus and experimental paradigm were sensitive to these effects. The mean effect of fatigue over four subjects was an increase in response time of 1900 milliseconds. At 30 mph (48.3 kph), this corresponds to the operator travelling an additional 84 ft (25.6 m) before responding when fatigued. How many collisions would have been prevented if the operator had responded 84 ft (25.6 m) sooner? Of perhaps greater significance was the result that when fatigued, the subjects missed many more signals than when rested. This situation might correspond to "missing" (failing to detect) another boat when fatigued. One of the dangerous aspects of a stressor such as fatigue (as defined above) is that the subjects are often unaware of its effects. One subject in this experiment said that he had performed much better <u>after</u> the fatigue scenario than before, although his data showed degraded performance when fatigued.

2.2.2 VAST-2

The accident data analyses reported earlier (Reference 1, and others) have indicated that alcohol was frequently a factor in collisions and other types of boating accidents. The second VAST experiment was designed to provide performance data concerning alcohol as a stressor in boating, and to compare its effects with those of general fatigue.

The second VAST study was a 2 x 2 factorial design: two levels of fatigue (rested and fatigued) and two levels of alcohol (0.00% BAC and 0.10% BAC). The latter <u>B</u>lood <u>A</u>lcohol <u>C</u>oncentration (BAC) corresponds to the definition of "legally drunk" in most states.

The experimental paradigm and apparatus were the same as those used in the first VAST experiment, using only the family type of fatigue scenario (light physical activity on the shoreline). The alcohol levels that were actually attained varied around 0.10% BAC, with a mean of about 0.102% BAC and a standard deviation of approximately 0.06% BAC. The results (in terms of response times) indicated that fatigue and alcohol individually led to significant decrements in performance that were of approximately the same magnitude. The interaction of fatigue and alcohol did not lead to a significant decrement in performance, although some mitigating circumstances may have influenced this result. The second VAST experiment included eight subjects. The mean size of the alcohol effect

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(t=3.69, p<0.001) in response times was an increase of 285 milliseconds, while the mean effect of fatigue (t=6.14, p<0.001) was an increase in response times of 191 milliseconds. Two other data points were acquired: one for a subject at 0.075% BAC and one at 0.014% BAC. These data indicated that the alcohol effects in VAST may vary continuously with BAC level. The subjects and location for testing were different for VAST-2 from what they had been in VAST-1. It is not known how much this contributed to the change in the magnitude of the observed effects (from ~2000 milliseconds to ~200 milliseconds).

2.2.3 VAST-3

With the qualified successes of the first and second VAST studies, the objective of the VAST program became clear: use VAST to analyze the effects of the major stressors in the boating environment. The third VAST experiment was designed to investigate the main effects and interactions of fatigue (two levels), alcohol (three levels), noise/shock/vibration (three levels), and glare (two levels). Several experimental design criteria limited the third VAST study to a five factor, 3 x 3 x 3 x 2 x 2, factorial design. There were three subjects. The three alcohol levels were 0.00% BAC, 0.05% BAC, and 0.10% BAC. Noise, shock, and vibration were manipulated using 10-20 dB attenuating earmuffs and a shock absorbing pedestal seat (which could be locked in a firm position). Noise, shock, and vibration were treated as a single variable with three levels: 1) low noise, low shock/vibration, 2) high noise, low shock/vibration, and 3) high noise, high shock/vibration. To have done otherwise would have violated the experimental design criteria (see Reference 1). Fatigue was manipulated as it has been previously. Glare was manipulated by having the subjects wear or not wear polarized sunglasses.

It should be noted that the glare and noise manipulations involved on-boat glare and noise during test runs, and not the cumulative effects of glare and noise throughout the day. No one wore sunglasses other than during specified testing sequences. The experimental design required ten days of testing for ten hours per day. Some difficulties were encountered in keeping the on board microprocessor running after continuous exposure to shock, vibration, and salt water.

Response times, error scores (using the measure d' - the reader who is unfamiliar with this measure is referred to Appendix A), and speed/accuracy trade-offs were analyzed, as well as the spatial distribution of slow responses. In this study, as before, some subjects believed that they were performing better under the influence of some stressors when they actually were not performing well. The main effect of alcohol was statistically significant (F=10.95, p<0.025) with the legally drunk condition (BAC=0.10%) leading to the poorest performance. The main effects of glare (sunglasses) and noise-shock/vibration were marginally significant (0.05<p<0.10). Greater exposure to noise, shock, and vibration generally led to longer response times. In the case of glare, wearing sunglasses resulted in somewhat longer response times, on the average, than not wearing them. This may have been due to salt spray on the lenses, reduction of peripheral field due to the frames, or other factors.

Two-way interactions between fatigue and alcohol (F=30.7, p<0.005), and between glare and noise/shock/vibration (F=7.8, p<0.05) were significant in the error data. All two-way interactions involving glare, noise/shock/vibration, and fatigue were marginally significant in response times (F=5.0, 0.05<p<0.10). The fatigue by alcohol interaction in error scores was due primarily to a large increase in errors when the subjects were both fatigued and drunk. No similar effect was found in the response time data. The glare by noise/shock/vibration interaction was complicated, and not easily interpreted. The three marginally significant interactions in the response time data were also difficult to interpret, although there was a trend toward non-additive degradations in performance under the greatest exposures; i.e., the effect of high exposure to two stressors tended to be greater than the sum of the effects of the individual stressors. No higher order interactions were significant.

In the third VAST experiment, all main effects except fatigue were found to be at least marginally significant. Reasons can be proposed for the lack of a fatigue effect and the observed glare effect, although these arguments may not account for all of the observed data. Glare was treated as an instantaneous variable, and not as a cumulative one. Noise was not measured directly. Rather, the noise level was reduced for the operator from "normal" to a subdued level using ear protectors. It should be noted that the response time data showed a systematic improvement in performance when wearing the ear protectors despite complaints by the subjects that they were uncomfortable.

2.2.4 Discussion

From VAST-3 it is clear that any or all of the stressors under study are important to one degree or another depending upon the circumstances. This result was not unexpected, due to the complicated nature of stressors, and the interdependence of stressor effects. Some of the results might appear to be confusing. For example, why should glare interact with noise? Perhaps the best way to answer questions of this type would be return to some of the basic hypotheses of this research. Stressors are complicated and interactive. The psychological and safety literature indicates that the major effects of stressors may be on the central processing capabilities of man. Thus, the fact that different stressors may affect man through different sense modalities does not preclude their interacting within the central nervous system.

It must be remembered that VAST is not a precise simulation of boating activity. It is a visual alertness task performed on a boat in real-world conditions. The results from VAST are indicative of the kinds of effects attributable to stressors that might be present in the boating population. The response time degradations measured in VAST underestimate the true magnitudes of these effects. In VAST the subject need only detect a signal and depress a button. In the real boating environment, the subject must detect and identify another vessel (more eye movement), try to figure out what that other boat is going to do, plan a course of action (or select a set of alternatives), and execute that course of action.

The VAST studies have been designed to measure stressor effects in the detection and identification phases of boating. The nature of the detection and identification task depends to a large extent upon factors such as the boating traffic, the weather, the time of day, and the boater's activity. For the VAST studies, the subjects were operating in areas where the traffic varied from light (very few other boats) to moderate (the operator must pay attention to the other traffic). Thus, the VAST studies relate to other research on detection and identification problems (Reference 19, for example), but only insofar as the applications are similar to boating. Eye movement research is abundant in automobiles and aircraft, but not boating.

Figure 6 shows the probability of an error or long response (response time greater than 3500 milliseconds) plotted against the location of the light that signalled the response (Light 39 was on the subject's right on the boat, and Light 1 was on his left). It is not surprising that the highest probabilities of errors and long response times occur with the peripheral lights, particularly since the primary task in VAST focuses the subject's attention on the compass and traffic (straight ahead). Recent research on eye movements in boating (Reference 20) has shown differences in scanning and eye fixation patterns which may be attributable to changes in the boating task. Therefore, any pattern such as the one in Figure 6 might be changed by altering the boater's task.

2.2.5 Summary of Previous VAST Research

Environmental stressors have been shown to have significant effects on boat operator performance. Individual stressors such as fatigue, alcohol, glare, noise, and shock/vibration have been found to be important contributors to performance degradations under specific circumstances. The performance degradations have been measured in a visual alertness task (VAST). The complicated and interactive nature of stressors has been explored. One of the most dangerous aspects of stressors has been the fact that the subjects have often not noticed the effects. Subjects have expressed the belief that they performed well, when the data indicated significant performance degradations. In one study, the effect of three hours of light exercise was found to be roughly equivalent to the degradation performance due to attaining a legally drunk state. In another, the effect of fatigue (light exercise) was found to be roughly equivalent to doubling the time required for a subject to respond to a signal. With respect to noise, the subjects performed better when wearing noise-attenuating earmuffs, despite the subjective discomfort associated with the ear protectors.

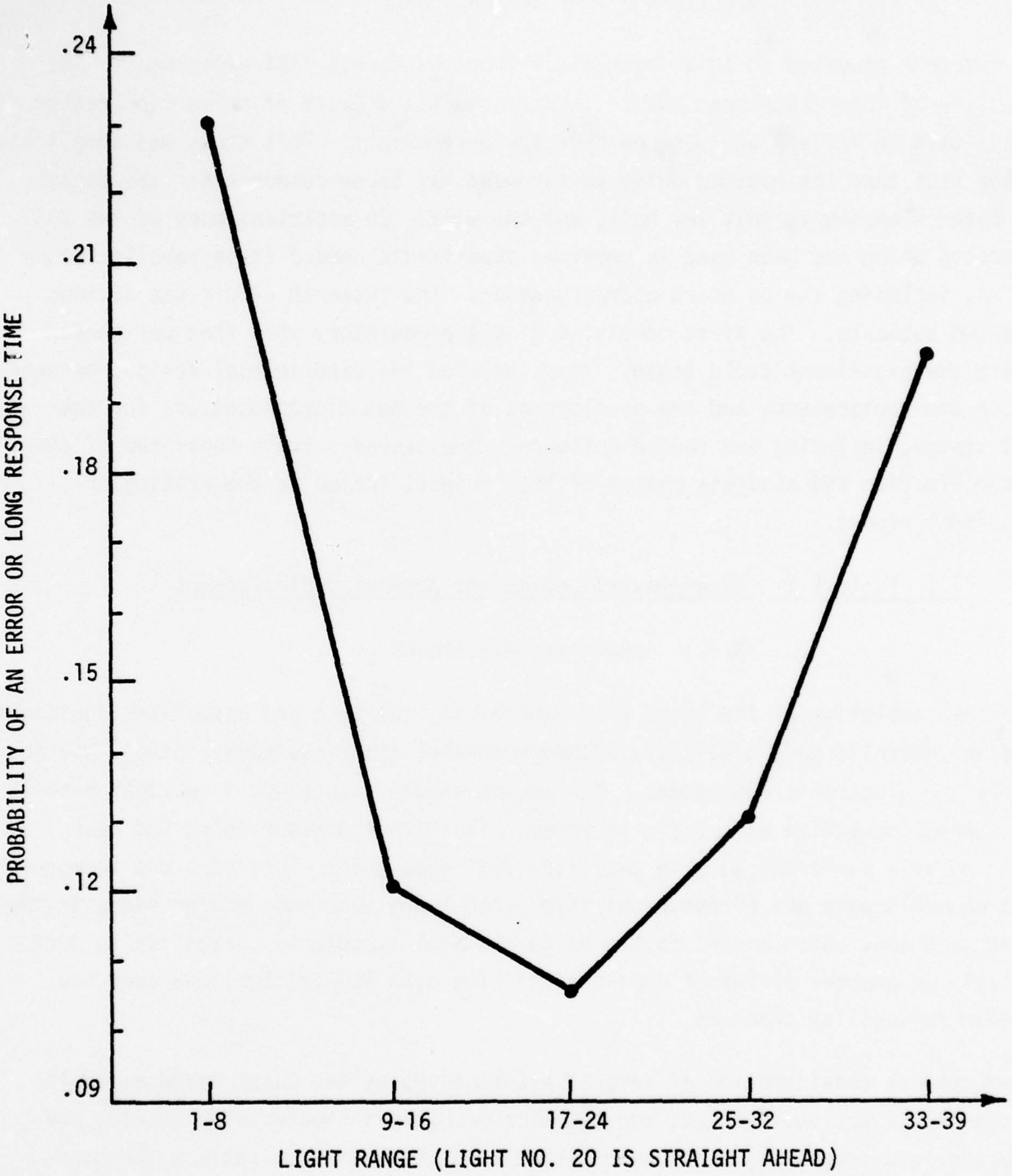

FIGURE 6. ERRORS AND LONG RESPONSE TIMES BY STIMULUS LOCATION IN VAST-3

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3.0 1976 - 1977 VAST RESEARCH

The research reported in this document is from the fourth VAST experiment. The objective of this experiment was to investigate the effects of noise (in greater detail than in VAST-3) and wind on operator performance. This study was complicated by the fact that the boating noise environment has three components: the engine, the water slapping against the hull, and the wind. In addition, much of the VAST apparatus which had been used in previous experiments needed to be rebuilt before VAST-4, including the on board microprocessor. The research effort was divided into two subtasks. The first consisted of all preparatory work that was needed before the experiment could begin. This included the experimental design, hardware repair and replacement, and the development of the new microprocessors for the VAST system, including the needed software. The second subtask consisted of the data collection and analysis phases of the project, including the writing of this final report.

3.1 Subtask 1: Experimental Design and Apparatus Development

3.1.1 Apparatus Development

Upon the completion of the third VAST experiment, the boat and associated equipment were in generally good condition, although several items needed attention, particularly the electronic components. The engine needed a tune-up. The light banks and connecting cables were badly corroded. The microprocessor which had been built by Wyle performed well in the third VAST experiment. However, the independent channels were out of synchronization, and there were some malfunctions in the light programs, which caused doubts as to the mini-computer's capability to perform reliably in another series of experiments. The data acquisition tape deck had similar reliability problems.

After careful consideration of several alternatives by the Coast Guard and Wyle personnel, it was decided that two new microprocessors should be purchased, constructed, and programmed. A ruggedized unit was purchased to replace the hand-wired mini-computer used previously. The years of use and exposure to salt water (during testing at Sanibel, Florida) had corroded most of the electrical components of the old system, making it unserviceable. A second microprocessor was purchased to be used on shore at the test site. This microprocessor was used to analyze data and compute results within minutes of the completion of a test run. This system was designed to save several weeks of data analysis time over previous VAST experiments, and it did.

The engine was tuned. With a new set of spark plugs and a rebuilt carburetor, the engine performed up to its power ratings. The light display was completely reworked, rewired, and strengthened. Supports were added to improve longitudinal strength and stability. The light display was dismantled, repainted, and reassembled with new "marinized" lamp sockets and lamps. The terminals were replaced as well as the wiring. These changes were made in order to improve the circuit paths for the new microprocessing unit. The interfacing of the light hardware and the microprocessor was "weatherized" as a system. Bendix-type connectors were installed facing the light display with the driver portion of the microprocessor, as well as a test unit, to insure compatability. This type of connector is environmentally protected. New tape decks were purchased to complement the new duplicate microprocessors. The reliability of the data acquisition system was improved by providing on-site replacement equipment and rapid evaluation of system performance during testing.

The operator's station was modified to accommodate the experimental design relative to noise (see Section 3.1.3). A noise attenuating engine shroud and amplification system was constructed. This shroud and speaker/tape system (see Figure 7) was designed and constructed according to the specifications of a Wyle acoustical engineer. The shroud was made of 3/4" (1.9 cm) plywood with all seams sealed by glue and screws. Acoustic foam material was appended to the inner surfaces of the shroud to further dampen engine noise. This material was covered by a layer of plastic for protection. The amplification system provided continuously variable reproduction of VAST engine noise beyond 105 dBA at the operator's ear.

A removable windshield was mounted above the light display to allow for wind manipulations. A screen was mounted directly in front of the operator between two of the light display supports. These changes resulted in the elimination of much of the apparent wind reaching the operator's head.

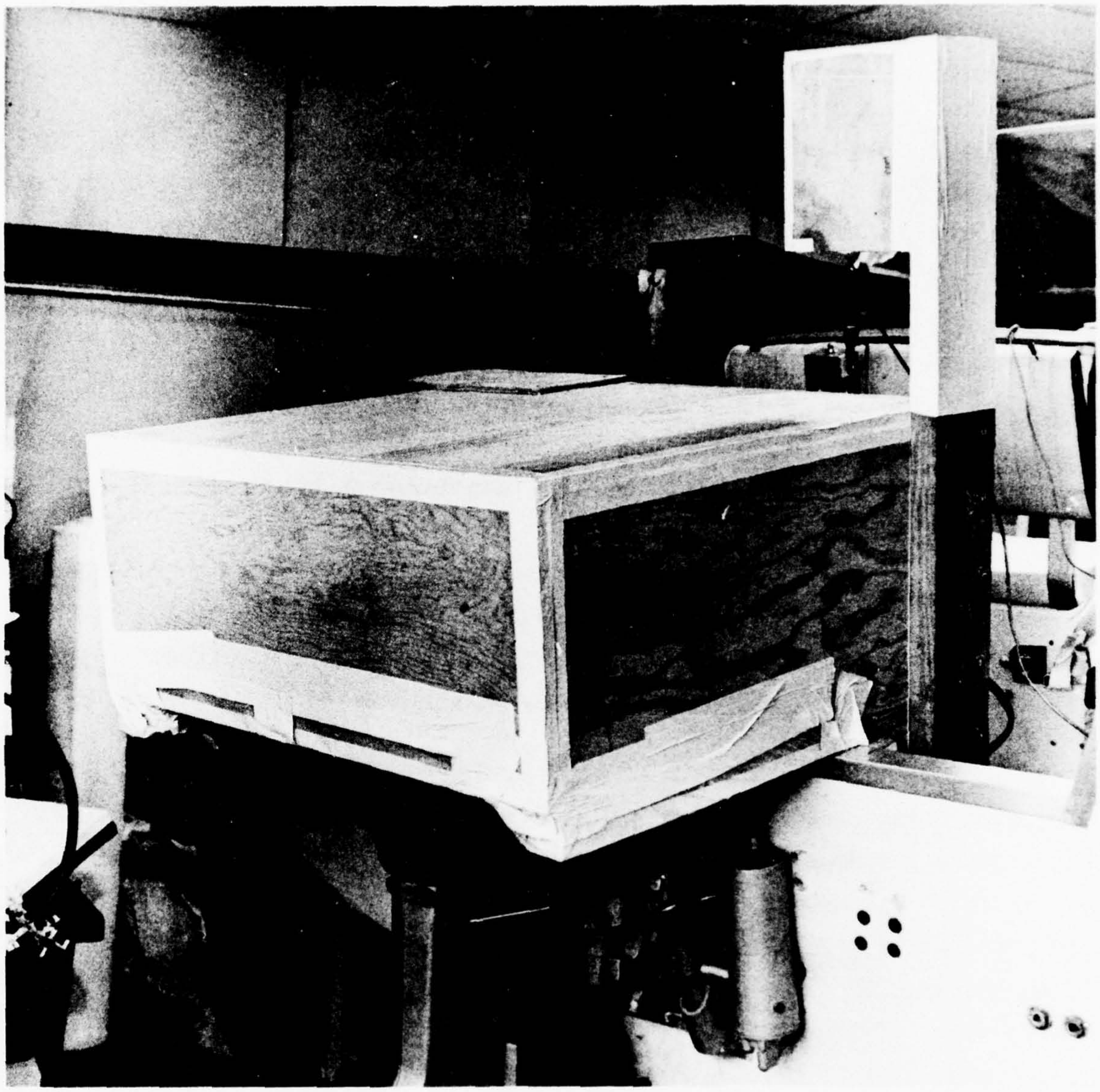


FIGURE 7. ENGINE SHROUD

With the completion of the maintenance and modification indicated above, the VAST system was redesigned to allow for changes in wind and noise levels. The remaining apparatus development problems concerned the two new microprocessors and related software and hardware components.

Two mini-computers were used in the 1977 VAST experiments. One was on board the VAST boat, driving the light display and collecting data. The other was on shore and was used to analyze and interpret data. These two microprocessors made up the bulk of the data acquisition/control system. They were responsible for:

- the control of the lights during the tests
- the monitoring and recording of operator responses during the tests
- outputting the (analyzed) response information in a convenient format after the tests.

A brief discussion of the architecture and software for the VAST microprocessor system can be found in Appendix B.

With the new microprocessor system, data reduction was accomplished on site and within minutes of the completion of each test run. When the boat arrived at the completion of a test run, gas tanks were switched (a full one was loaded), the data were extracted from the previous test, and a program for the next subject was loaded into the mini computer. Meanwhile, the extracted data were analyzed by the shore-based microprocessor. Figure 8 provides a time line description of this process, counting from the time that the boat arrives after a test. Figure 9 is an advertising picture of the shore-based microprocessor. Figure 10 is a pair of photographs of the VAST on board microprocessor. When the VAST boat arrived at the end of a test run, one of the experimenters would read the just acquired data onto the blank tape cartridge, and deliver the cartridge to the data analyst. The new light program for the next subject would then be read into the on-board microprocessor. Meanwhile, the data analyst would turn on the AC generator and printer for the on shore microprocessor. The data tape would then be rewound, read and analyzed. The results were printed out as response times, error signals, missed signals, and course corrections. An HP-97 programmable calculator was used to convert some of these data. The time line shown in Figure 8 is conservative; i.e., the process often required only 4-5 minutes.

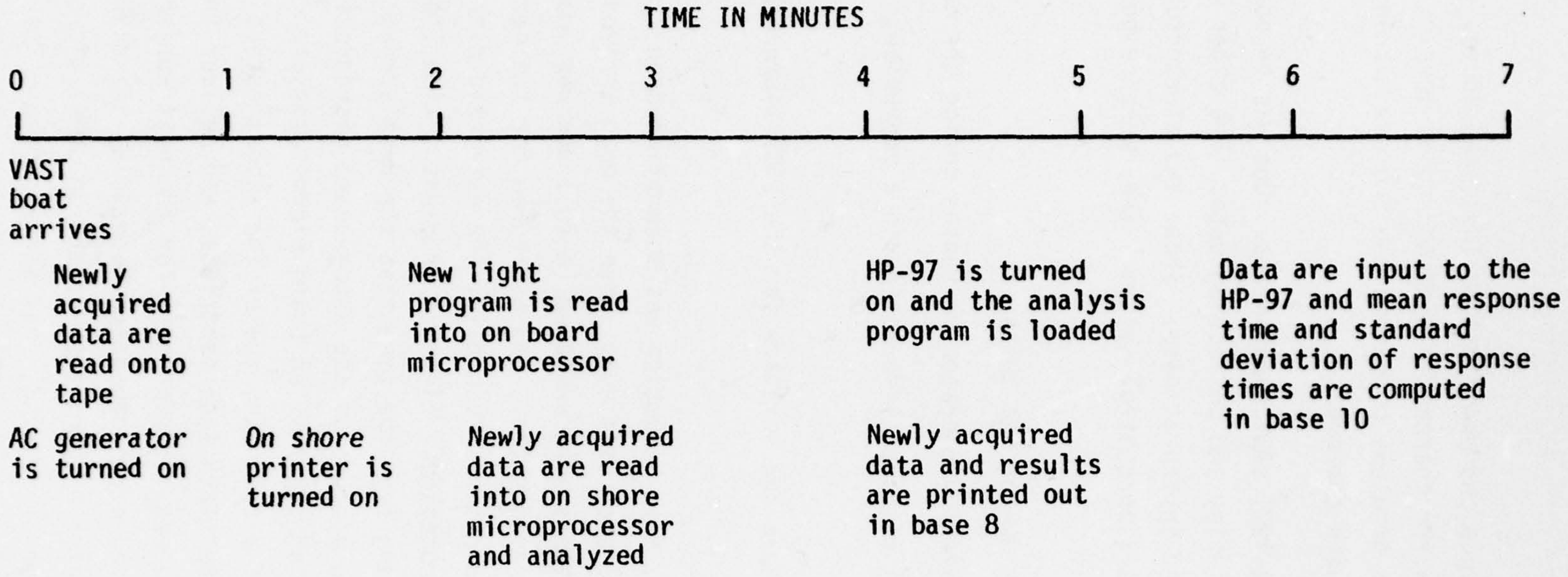


FIGURE 8. VAST DATA ANALYSIS TIME LINE

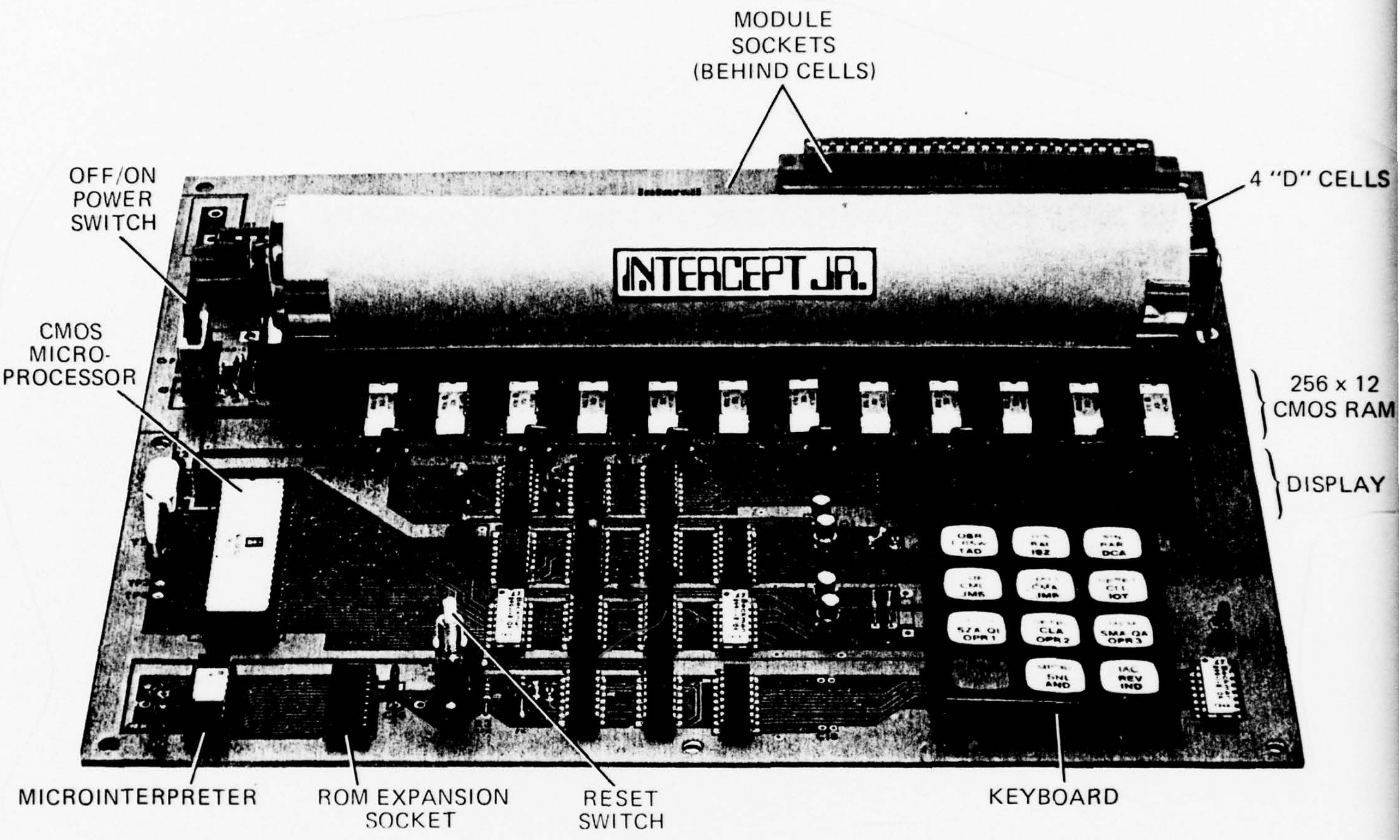


FIGURE 9. ADVERTISING PICTURE OF SHORE-BASED MICROPROCESSOR

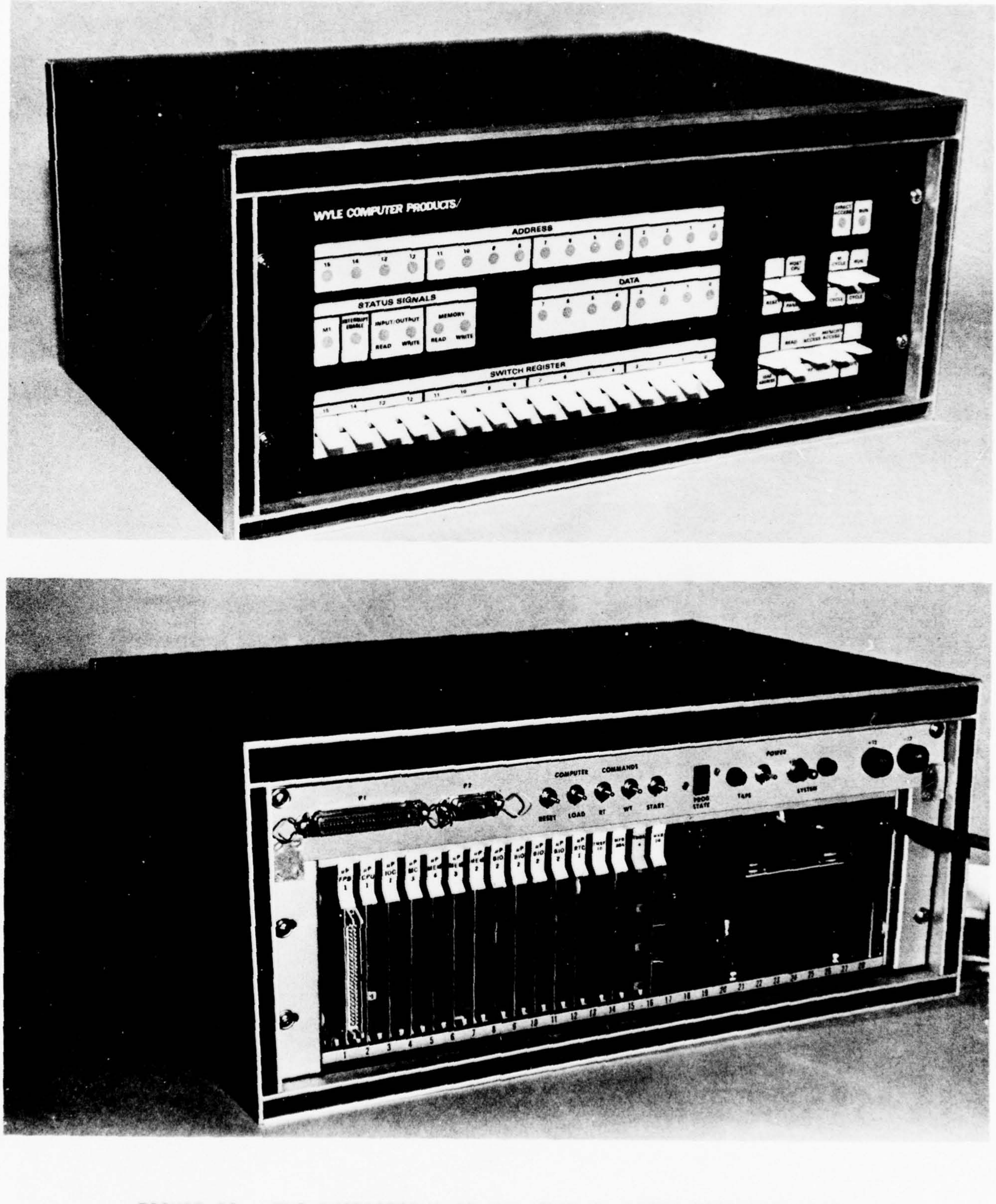


FIGURE 10. TWO PHOTOGRAPHS OF THE VAST ON-BOARD MICROPROCESSOR

3.1.2 Experimental Design Problems

Since one of the main objectives of this project was to measure the effects of noise on operator performance on VAST, the noise environment on the VAST boat had to be defined for each of the proposed test conditions. The noise on board the VAST boat was measured as part of Subtask 1.

Wyle originally proposed to use three levels of noise in this study: below normal, normal, and high. The normal noise, as generated by the VAST boat, was recorded on tape. This tape was used to generate "normal" noise and amplified noise on board during the actual testing. By using the tape, the engine shroud did not have to be removed to generate the normal noise, and the only difference in the amplified and normal conditions was the volume (amplitude). The amplified noise was the same as the normal noise in terms of the frequency spectra. Also, the major components of repeated normal and amplified noise were the same, trial by trial, since only one tape was used. This reduced the chances for spurious noise.

Noise measurements were obtained on the VAST boat under several circumstances. The three intended noise levels were: 1) 90 dBA (subdued engine noise achieved by the shroud without amplifier system) 2) 97 dBA (the approximate "normal" for the VAST boat, achieved by the shroud plus the tape/amplifier system) and 3) 105 dBA (loud engine noise, shroud plus amplifier). The noise level of 105 dBA still measures less than 86 dBA at 50 ft (15.2 m).

The objective in collecting the data shown in Table 3 was to document the noise levels that might be observed during testing. Weather conditions during testing varied from partly cloudy to sunny with 0-6" (0-12.5cm) chop and 0-15 mph (0-24.1 kph) winds. Of course, the ideal situation would have been to have the same weather every day. The limits outlined above were chosen to allow for some variation in conditions without conceding too much control of the data in the experiment to natural causes. This is a necessary tradeoff in real-world experimentation.

TABLE 3. VAST NOISE DATA

OCTAVE BAND AND OASPL MEASUREMENT RECORDED AT VARIOUS CONDITIONS USING VAST BOAT WITH 135 HP OMC OUTBOARD.

RUN #	OCTAVE BAND CONTROL FREQUENCY											OVERALL SPL dBA			COMMENTS
	31.5	63	125	250	500	1000	2000	4000	8000	16,000	31,500	MEASURED	INTENDED	COMPUTED	
	dB(A) CORRECTION														
	-40	-26	-16	-9	-3	0	+1	+1	-1	-10	-16				
1	94* 54**	92 66	90 74	93 84	87 84	84 84	77 78	74 75	69 68	63 53	47 31	91	90	90	Low noise with windshield/ wind 10-12 knots.
2	91 51	92 66	90 74	92 83	87 84	91 91	90 91	71 72	61 60	52 52	45 29	97	97	95	Medium noise with windshield/ wind 10-12 knots.
3	94 54	92 66	90 74	98 89	95 92	102 102	101 102	92 93	75 74	60 50	42 26	105	105	106	High noise with windshield/ wind 10-12 knots.
4	88 48	91 65	86 70	82 73	81 78	78 78	76 77	74 75	66 65	58 48	43 27	85		84	Tow test with windshield/ wind 12 knots/4" chop/motor idling.
5	86 46	88 62	86 70	82 73	82 79	80 80	77 78	76 77	68 67	61 51	46 30	85		86	Tow test with windshield rerun/ wind 12 knots/4" chop/motor off.
6	80 40	85 59	84 68	80 71	81 78	79 79	75 76	71 72	67 66	63 53	44 28	84		84	Low noise tow test with windshield/ no wind/calm water/motor off.
7	100 60	102 76	98 82	95 86	89 86	82 82	77 78	72 73	64 63	55 45	43 27	91		91	Low noise tow test without windshield/calm water/motor off.
8	107 67	104 78	101 85	99 90	96 93	97 97	97 98	88 89	74 73	61 51	52 36	104	105	102	High noise powered without windshield/calm wind and water.
9	101 61	102 76	99 83	96 87	92 89	90 90	86 87	84 85	65 64	58 58	45 29	97	97	96	Medium noise powered without windshield/calm wind and water.
10	104 64	102 76	101 85	102 93	97 94	90 90	85 86	74 75	67 66	58 48	46 30	94	90	98	Low noise without windshield/ calm wind and water.
11	109 69	108 82	106 90	104 95	98 95	94 94	92 93	77 78	66 65	61 51	48 32	100	90	102	Low noise into wind without windshield/wind 15 mph/4-6" chop.
12	94 54	97 71	93 77	92 83	86 83	83 83	78 79	72 73	65 64	56 46	45 29	89	90	90	Same as above except with the wind.
13	108 68	107 81	105 89	97 88	97 94	93 93	91 92	84 85	70 69	58 48	46 30	99	97	100	Medium noise into wind without windshield/wind 15 mph/4-6" chop.
14	100 60	99 73	94 78	93 84	87 84	85 85	84 85	74 75	64 63	56 46	44 28	94	97	92	Same as above except with the wind.
15	112 72	105 79	107 91	106 97	100 97	97 97	97 98	87 88	72 71	61 51	50 34	104	105	103	High noise into wind without windshield/wind 12 mph/4" chop.
16	97 57	98 72	94 78	98 89	92 89	93 93	96 97	88 89	71 70	60 50	46 30	100	105	100	Same as above except with the wind.
17	90 50	93 67	89 73	89 80	82 79	81 81	76 77	68 69	62 61	55 45	40 24	90		90	Low noise with windshield/ calm wind and water.
18	102 62	98 72	90 74	91 82	88 85	92 92	89 90	75 76	64 63	58 48	44 28	96		95	Medium noise with windshield/ calm wind and water.
19	100 60	96 70	90 74	92 83	88 85	92 92	85 86	70 71	63 62	56 46	41 25	97		94	Medium noise with windshield/ calm wind and water.
20	95 55	98 72	90 74	99 90	93 90	100 100	95 96	83 84	66 65	58 48	42 26	103		102	High noise with windshield/ calm wind and water.
21	100 60	98 72	94 78	104 95	97 94	103 103	105 106	87 88	77 76	68 58	48 32	105		108	High noise with windshield/ calm wind and water.

* Octave band SPL dB (linear)
** Octave band SPL (dBA)(corrected)

Notes:
- Calm wind and water with motor at idle = 75 dBA SPL
- Low noise is without amplifier; medium noise is with low amplifier; high noise with with high amplifier
- All tests made at 3700 rpm - 26 mph - 135 HP OMC outboard
- All except calm wind/water tests cross wind

Table 3 shows the data collected in 21 noise measurement runs. All measurements were taken at the operator's position using a standard microphone embedded in a styrofoam model of a human head. Thus, the noise levels were measured as they might occur if measured in the auditory canal of an operator. All "underway" runs were at 3700 rpm. The octave band data are presented as measured (linear) above the corrected values (dBA). The overall sound pressure level (SPL) is indicated for each run, as a function of the measured overall SPL, the intended SPL (for the experimental design), and the SPL as calculated from the octave band data. The comments include the relevant information concerning the weather and VAST apparatus for the tests. Tests were run with and without the windshield, and with the indicated noise levels (low = shroud + "high" amplification of VAST engine noise). A comparison of the measured and intended data indicates that the intneded data cannon be rejected as a good fit to the measured data ($\chi^2(12) = 1.70$, $p > 0.99$). Similarly, the intended data cannot be rejected as a good fit to the computed SPLs ($\chi^2(12) = 3.08$, $p > 0.98$).

Several comparisons can be made using the data in the table. The difference (essentially 0 change in measured SPL) between the fourth and fifth data collection runs was the noise of the idling motor. Apparently, the noise of the idling motor was effectively masked by the other noise sources (wind and water on the hull). The difference between runs 6 and 7 was the removal of the windshield for the seventh run. This resulted in an increase of 7 dBA in the SPL as measured and calculated.

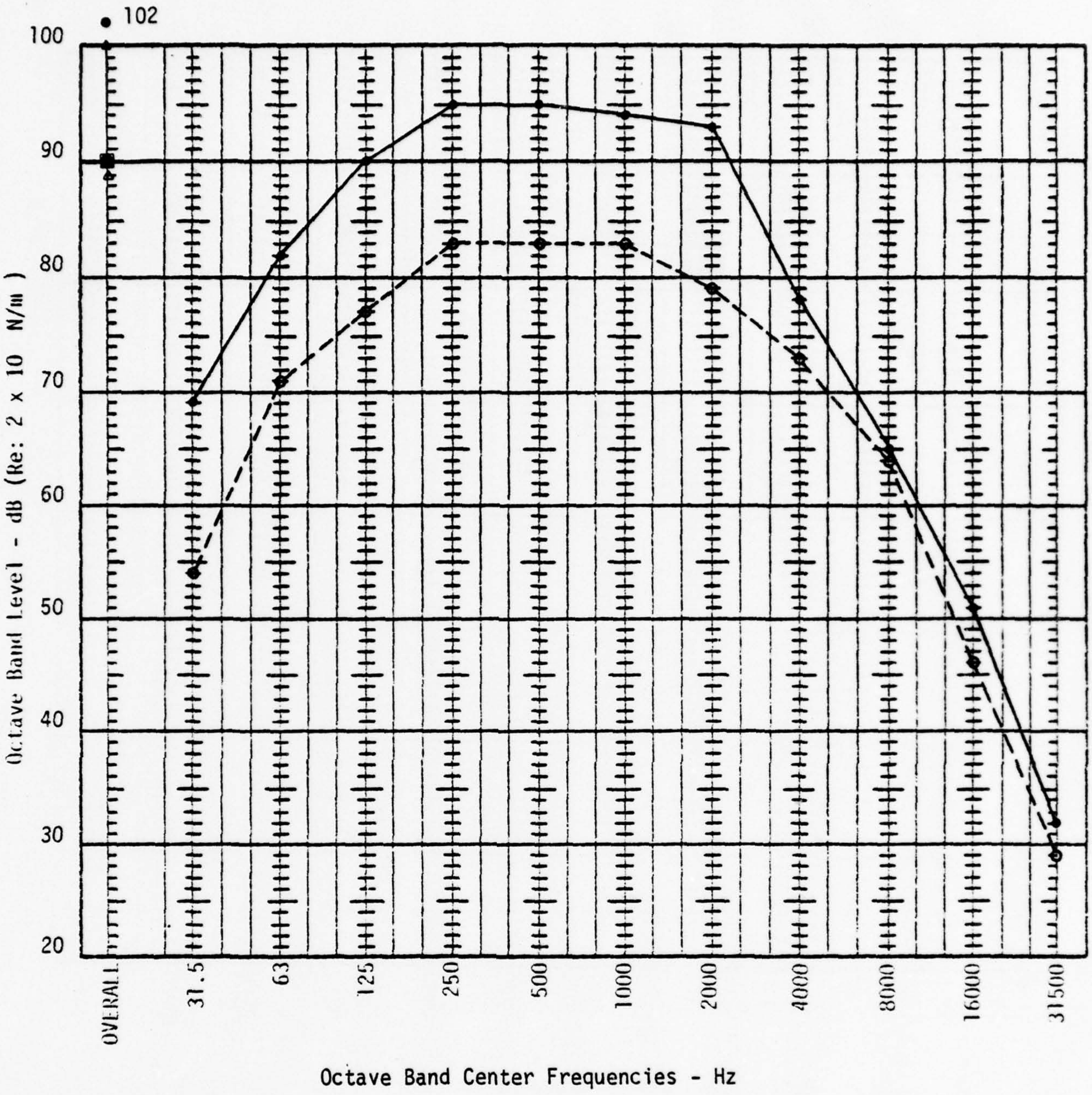
If the first three runs are compared to the last five (17-21), the data for each noise condition are very close. For example, runs 1 and 17 both generated around 90 dBA, despite the fact that run 1 was in a 10-12 knot wind and run 17 was in calm wind. The first five runs were made at an angle to the prevalent wind. It appears that the relative wind from the boat's motion was more important in those measurements than the true wind. Comparisons between runs 18 and 19, and 20 and 21 show the replicability of the noise measurements under the same conditions. The measured noise levels were within 2 dBA, but the spectra for the high noise conditions were different enough to generate a 6 dBA calculated difference in overall SPL.

Similarly, runs 11 through 16 provide data to compare running with or against an existing wind in a 4-6" (10.2-15.2 cm) chop, without the windshield. The numbers indicate an approximate 10 dBA difference at low noise levels, an approximate 5 dBA difference at medium noise levels, and a 3-4 dBA difference at high noise levels (see Figures 11, 12, and 13). The figures show that most of the changes in overall noise level attributable to moving with the wind are in the frequency range of 0-2000 Hz. Thus, the changes were not only in the overall SPL, but the frequency spectra as well. These data resulted in a decision to run at varying angles to the true wind during actual response data collection, so that the effects of running with or against the wind could be randomized, if not counterbalanced, in the response data.

Comparisons of data from similar conditions with and without the windshield reveal little overall difference in the measured SPL, except for low noise cases, such as run 10 (94 dBA without) versus run 17 (90 dBA with). These data will be discussed in more detail later.

To summarize the noise data, the results match the desired sound pressure levels well. There are noticeable increments in the overall noise levels with changes in the shroud, amplification system, and windshield. The effects of wind and rougher water could not be separated, but the acceptable conditions for testing were documented, along with the effects of running with or against the wind. The octave band data for all runs except those shown in Figures 11, 12, and 13 are graphed in Appendix C.

Several approaches were tried before the chosen noise manipulation system was implemented. It was necessary in this experiment that the acoustic environment be well defined and controlled. The first approach that was considered was to have a passive external shroud over the engine for low noise, and the "normal" noise could be achieved simply by removing the shroud. The amplified noise could then be achieved by removing the cowling. This approach was rejected for two reasons: 1) the nature (frequency spectrum, quality) of the noise would not be very consistent for all three conditions, and 2) the amplitude of the noise at the operator's ear would not be controllable.



Runs #11 & 12

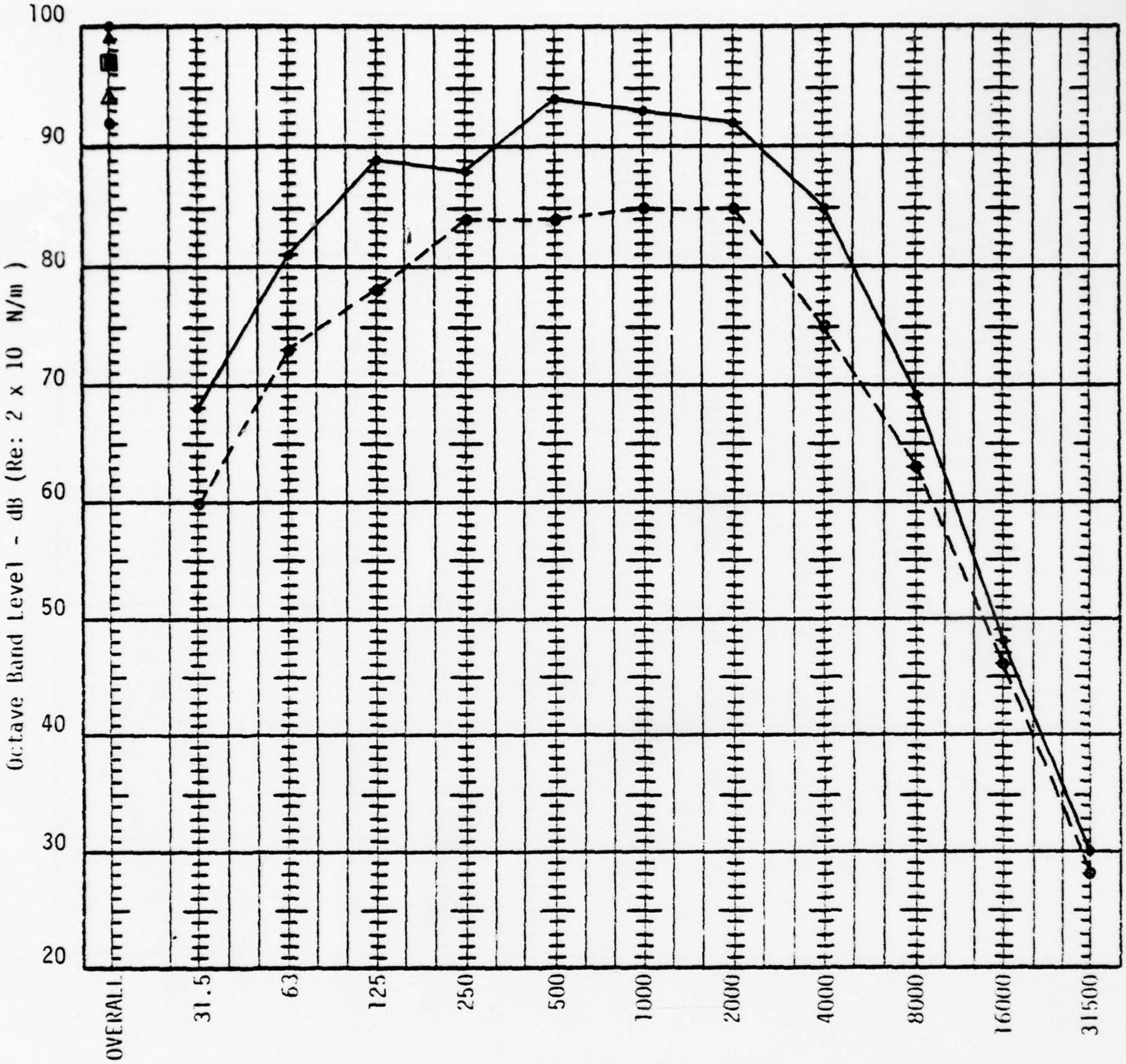
▲ Measured dB(A) 100
● Computed dB(A) 102
■ Intended dB 90

(Low noise into wind without windshield/ wind 15 mph/4-6" chop)

△ Measured dB(A) 89
○ Computed dB(A) 90
□ Intended dB 90

(Same as above except with the wind)

FIGURE 11. NOISE DATA - RUNS NO. 11 AND 12

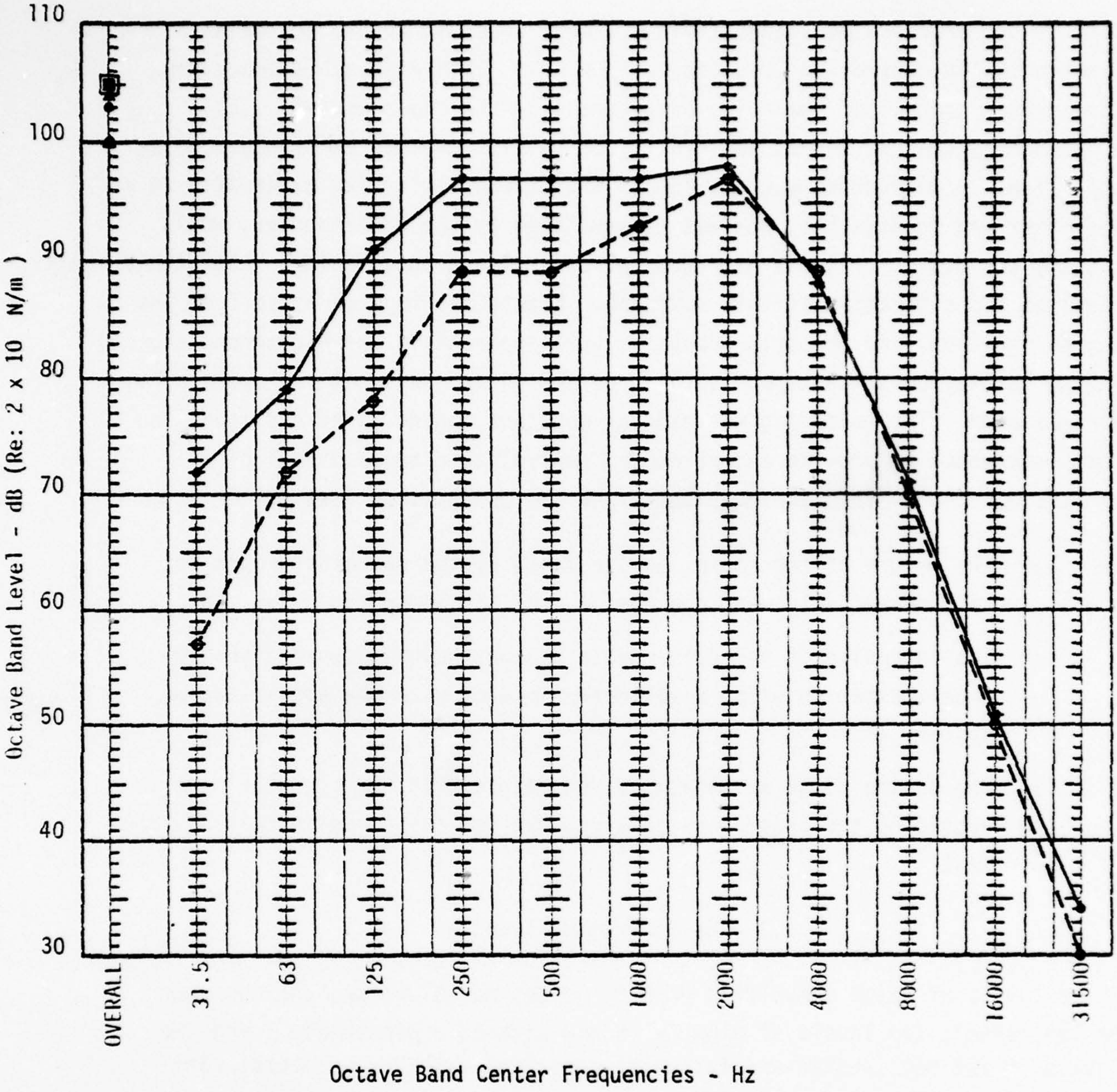


Octave Band Center Frequencies - Hz

Runs #13 & 14

▲ Measured dB(A) 99	(Medium noise into wind without windshield/ wind 15 mph/4-6" chop)
● Computed dB(A) 100	
■ Intended dB 97	
△ Measured dB(A) 94	
○ Computed dB(A) 92	(Same as above except with the wind)
□ Intended dB 97	

FIGURE 12. NOISE DATA - RUNS NO. 13 AND 14



Runs #15 & 16

▲ Measured dB(A) 104
● Computed dB(A) 103 (High noise into wind without windshield/ wind 12 mph/4" chop)
■ Intended dB 105
△ Measured dB(A) 100
○ Computed dB(A) 100 (Same as above except with the wind)
□ Intended dB 105

FIGURE 13. NOISE DATA - RUNS NO. 15 AND 16

Both of the problems mentioned above could be remedied by the use of an electronically controlled acoustic environment. This approach allowed for more direct control of the noise environment by the experimenter. The acoustically treated shroud would still be used to produce the subdued noise condition. A microphone mounted inside the shroud, which fed externally to an amplifier and loudspeaker, and was controllable by the experimenter, would satisfy the design criteria with greater control and specificity. Logistic problems required a modification of this approach. Electrical impulse noise from the engine ignition, and acoustic feedback, were apparent in the microphone signal. A high quality cassette tape recording of the engine noise at the operator's ear was made. The recording was made at constant engine speed and load, and then overdubbed to provide a continuous, controllable noise signal of 30 minutes duration. This approach satisfied the established test criteria:

1) The nature of the noise, as perceived by the operator, would not vary appreciably with changes in acoustic intensity,

2) The intensity of the noise would be continuously controllable by the experimenter by using a voltmeter in line with the amplification system, and

3) The engine noise was measured and recorded at the operator's ear, providing the proper spectral content for the acoustic test environment.

3.1.3 The Experimental Design

Three levels of noise (amplified or high noise, normal noise, and subdued or low noise), two levels of wind (with and without a windshield), and two levels of fatigue (rested and fatigued) constituted the experimental manipulations. Thus, data were collected in 3 x 2 x 2 = 12 data cells, as shown in Figure 14. Six male subjects were selected from Wyle personnel who were experienced boaters and had no known hearing impairments.

FATIGUE	WIND	NOISE		
		SUBDUED	NORMAL	AMPLIFIED
Rested	With Windshield	1	2	3
	No Windshield	4	5	6
Fatigued	With Windshield	7	8	9
	No Windshield	10	11	12

FIGURE 14. DATA CELLS FOR THE FOURTH VAST EXPERIMENT

The schedule for each subject for each day is shown in Figure 15. A total of 72 test runs were needed (six subjects x 12 data cells) over eight test days. The test conditions counterbalanced across test days in order to minimize spurious factors (such as possible learning effects or effects due to weather-related delays). The Ss are subjects; the Ns are amplified, normal, and subdued noise levels (1, 2, and 3, respectively); W_1 is with windshield on, while W_2 is without windshield; and F and R stand for fatigued and rested, respectively.

	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8
S_1	N_1RW_1	N_1FW_1	N_2RW_2/N_2FW_2	N_2RW_1/N_2FW_1	N_1FW_2	N_1RW_2	N_3RW_1/N_3FW_1	N_3RW_2/N_3FW_2
S_2	N_2RW_1/N_2FW_1	N_2RW_2/N_2FW_2	N_1RW_1	N_1FW_1	N_3RW_2/N_3FW_2	N_3RW_1/N_3FW_1	N_1FW_2	N_1RW_2
S_3	N_3RW_1/N_3FW_1	N_3RW_2/N_3FW_2	N_1FW_1	N_1RW_1	N_2RW_2/N_2FW_2	N_2RW_1/N_2FW_1	N_1RW_2	N_1FW_2
S_4	N_1FW_2	N_1RW_2	N_2RW_1/N_2FW_1	N_2RW_2/N_2FW_2	N_1RW_1	N_1FW_1	N_3RW_2/N_3FW_2	N_3RW_1/N_3FW_1
S_5	N_2RW_2/N_2FW_2	N_2RW_1/N_2FW_1	N_1FW_2	N_1RW_2	N_3RW_1/N_3FW_1	N_3RW_2/N_3FW_2	N_1RW_1	N_1FW_1
S_6	N_3RW_2/N_3FW_2	N_3RW_1/N_3FW_1	N_1RW_2	N_1FW_2	N_2RW_1/N_2FW_1	N_2RW_2/N_2FW_2	N_1FW_1	N_1RW_1

FIGURE 15. TEST SCHEDULE

The "wind" variable (the presence or absence of a windshield) included changes in the noise levels due to wind, and other stressors due to wind, such as spray and wind in the face and on the eyes. All subjects experienced the effects of exposure to glare, weather (temperature and humidity), shock and vibration during testing, etc. The experiment was conducted on the Tennessee River in the Huntsville area.

Because of the stress associated with the amplified noise condition, subjects could be tested in that condition only once per day. The noise literature (see Reference 21) suggests that one-half hour of exposure to 100 dBA should be followed by more than eight hours of time off. This precluded more than one test per subject per day at the amplified noise levels. Therefore, for each subject, the tests corresponding to cells 3, 6, 9 and 12 in Figure 14. were run on separate days.

There are two types of stress with noise. One is due to the temporary effects of noise on performance and one is due to the cumulative effects one suffers when exposed for several hours. Basically, this experiment was very similar to previous VAST experiments. Subjects were tested in rested/unexposed and rested/exposed states where the "unexposed" state meant exposure to reduced noise and/or wind levels. Comparisons of these data allowed measurement of the temporary noise and wind effects at various levels, as well as the interaction between noise levels and wind. Then, subjects underwent fatigue as in previous VAST studies (light physical exercise followed by rest in half hour cycles for a total of three hours). The afternoon testing, including various exposed and unexposed states, allowed analyses of exposure to noise and wind and the interactions of noise, fatigue, and wind. However, this study was one of temporary effects of noise and wind, not cumulative effects.

The primary data to be analyzed in this experiment were the response times and error scores of the six subjects in each of the 12 sets of conditions shown in Figure 14.

The on shore microcomputer provided a list of events for each test run and a corresponding list of times (or other information). These data were to be processed using a Hewlett-Packard 97 programmable calculator to generate mean response times and error scores (the number of failures to respond and the number of improper responses). The error scores were used to compute an overall sensitivity measure (or error score) called d' (see Appendix A). This measure has theoretical and statistical significance. It allows for the evaluation of speed-accuracy tradeoffs, which enables the differentiation of true response time effects from those that may be attributed to a change in the subjects' response strategies. For each subject, a d' score and a mean response time were determined for each of the 12 sets of conditions to be tested. An analysis of variance was performed on the 72 mean response times and on the 72 d' scores, according to the experimental design.

3.2 Subtask 2: Data Collection and Analysis

3.2.1 Execution of the Experimental Design

Subtask 2 of the current project began with the implementation of the experimental design. The subjects and experimenters practised operating the VAST boat and negotiating the Tennessee River for three days prior to actual testing. All subjects and experimenters were checked for hearing difficulties. The data were collected on 10 days in the months of October and November. Two additional days were required (above the eight in the design) because data for two original test days were discarded due to weather changes during those days.

An inlet to the Tennessee River near Decatur, Alabama, was used because it provided areas of relatively sheltered water in most weather conditions. The experimenters varied course headings in order to balance (within each test run) the effects of any wind that may have been present. A speed of approximately 30 mph (3700 rpm) was used as much as possible. Past experience had demonstrated that this throttle setting provides adequate speed and handling characteristics.

The problems that were encountered in the execution of the experimental design were minimal, especially when compared to the problems from previous VAST experiments. There were occasional minor difficulties with the engine on the VAST boat, and with the printer for the on shore microprocessor. The weather for the test days included partly cloudy and sunny days. The high temperatures for test days ranged from near 60°F (15.6°C) to approximately 75°F (23.9°C). Winds ranged from calm to near 10 mph, and were invariably blowing across the river when present. Thus, sheltered water was always accessible, and 80% to 90% of the data were collected in relatively calm water conditions.

3.2.2 Results and Analysis of VAST-4

The VAST microprocessors provided a complete listing of all responses, errors, "off course" signals, and other relevant data at the conclusion of the data collection phase of this project. Noise and wind data were presented earlier in this report. This section will concentrate on the reporting and analysis of the response time and error data. The error data include "missed signals" and "false alarms" (failures to respond when a response was warranted, and responses in the absence of signals, respectively). The data acquisition and analyses followed the general outline presented in Figure 16. This process was often completed in less than five minutes.

3.2.2.1 Response Time Data - VAST is a visual detection/manual response task. As such, one of the critical measures of performance on the task is subject response times. In all VAST experiments, a response time was measured from the onset of the "signal" (one or one-half second after onset of the light) to the initiation of the response (the depression of the response button on the throttle) in milliseconds. The subjects were required to respond to the various light patterns described previously, and twenty signals were presented in each experimental run (the new microprocessors were 100% reliable during testing). Thus, twenty response times were obtained for each run. A total of 1440 response times were obtained for the 72 experimental runs in eight test days. An additional 300+ data points were gathered on practice trials and test runs which were eventually discarded (these additional data are not reported here).

As in previous VAST experiments, there was quite a range of response times. The shortest times were on the order of a minimal reaction time (about 500 milliseconds), while the longest times were approximately ten seconds (about 10,000 milliseconds). There were some signals that were not responded to. These were arbitrarily included as 10,000 millisecond response times in the data (slightly longer than the longest true response time). Since the subject never responded in these cases, his true response time would have exceeded 10 seconds if the light had remained on until he had responded to it. The vast majority of the response times were between 1500 and 3000 milliseconds. In order to perform an analysis of variance on the response time data, the data were scaled using the logarithmic transformation shown in equation (6) to normalize the positive skewness of the distribution of

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response times (see Reference 23, pages 400-401).

$$\chi' = \log \chi \tag{6}$$

The data in all cells (including missed signals) were reduced to means for each cell. The means were transformed using equation (6), and the data were analyzed.

The response time data for VAST-4 were subjected to an analysis of variance with three fixed factors (wind: two levels; noise: three levels; and fatigue: two levels) and one random factor (subjects: six). The analysis of variance proceeded as outlined in Reference 23, Chapter 7, and Reference 24, Chapter 13. The results of the analysis of variance are shown in Table 4.

The only significant result in terms of response times in the experiment was a significant wind effect. More precisely, the subjects performed significantly better without the windshield than with it. The mean response time overall when the windshield was used was 2525 milliseconds, while the mean response time without the windshield on was 2333 milliseconds. This cannot be accounted for in terms of overall noise level, since very little difference was found between the noise levels measured with and without the windshield. However, the sound quality was different. If the octave band data for runs 6 and 7 of the noise measurements are inspected (see Table 3 and Appendix C), then the shift in spectral characterics can be seen. When the windshield is removed, the overall sound level (SPL in dB(A)) does not change, but the sound is more heavily weighted toward the lower frequencies, below 750 Hz. Similar arguments can be made for comparing noise data runs 10 and 17, 9 and 18, and 8 and 19. McCormick (Reference 21) reports several studies which have shown that if noises are roughly equal in loudness, then the one which has the greater high frequency content will be judged as the most annoying.

The data in Table 4 cannot be explained on the basis of annoyance factors alone. However, the known changes in the noise spectra with and without the windshield may account for some of the observed wind effect.

One of the dangers in relying strictly on response time data in any analysis is that changes in mean response times may represent changes in the strategies of the subjects rather than true effects. Thus, error data are always needed. The subject can always improve his performance (lower his response time) somewhat by

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TABLE 4. VAST-4 ANOVA SUMMARY TABLE: RESPONSE TIMES

Source	Sum of Squares	Degrees of Freedom	F	P	Significance
S(subjects)	0.233	5			
W(wind)	0.018	1	9.08	p<0.05	Significant
WxS	0.010	5			
N(noise)	0.015	2	0.99	p>0.25	Not Significant
NxS	0.076	10			
NxW	0.008	2	1.25	p>0.25	Not Significant
NxWxS	0.032	10			
F(fatigue)	0.000	1	0.01	p>0.25	Not Significant
FxS	0.052	5			
FxW	0.000	1	0.00	p>0.25	Not Significant
FxWxS	0.013	5			
FxN	0.010	2	2.17	p>0.10	Not Significant
FxNxS	0.023	10			
FxNxW	0.014	2	2.69	p>0.10	Not Significant
FxNxWxS	0.026	10			
TOTAL	0.530	71			

sacrificing some accuracy. On the other hand, the subject's response time performance may not change, while the true effect appears in his error data. In effect, the subject may choose to trade speed for accuracy. The analysis of such speed/accuracy trade-offs requires the use of a special statistical tool in the case of VAST, since more than one type of error can occur.

3.2.2.2 Error Data: Course Corrections - There are three types of errors that a subject could make on VAST: getting off course, false alarms (responses when there was not an appropriate signal) and missed signals (failures to respond when there was a signal).

The purpose in documenting the first kind of error was to make sure that the workload corresponding to the primary task (operating the boat) remained constant and high, while the stressors were given the opportunity to affect performance on the secondary task (responding to the lights). If performance changed on the primary task, then corresponding changes in performance on the secondary task could be due to the changing workload, and not due to the effects of stressors, as intended by the experimental design. The only measure of primary task performance available in the VAST program is the number of "off course" signals given to the operator. The experimentors subjectively manipulated their criteria for keeping the subjects on course, depending upon each subject's abilities. Some subjects could handle the boat very well, and rarely received the course correction horn signal. Other subjects heard the horn three or four times per trial. For all subjects except one, the course correction signals were uniformly distributed across test conditions, indicating a (subjectively) constant primary task load. For one subject, most of the course corrections occurred on medium noise trials. However, his other errors (false responses and missed signals) and response times were not unusual. If he had maintained his primary task performance in the medium noise conditions, then his response times and/or errors would have increased. Since the overall data show no statistically significant noise effect, and the existing trend in those data were for better secondary task performance at medium noise levels, correcting this subject's data for the observed change in primary task performance would not alter any of the stated results.

The other two types of error (false responses and missed signals) generated most of the data relevant to the issue of speed/accuracy trade-offs. The error measure used in these analyses is d'. The measure d' increases with the increasing accuracy of the subjects. If the subjects were faster in one condition than another, but less accurate (lower d'), then the response time effect (if any) was due, at least in part, to a trade-off between speed and accuracy. However, if the subjects were slower with the same level of accuracy, then the response time effect was a "true" effect due to the specific stressor conditions.

Before proceeding with the analyses of the error data, a discussion of signal detection theory (the origin of the measure d') will be presented. The interested reader is referred to Appendix A for a more detailed description of signal detection theory, and its relevance to VAST. The following paragraphs may be skimmed (as opposed to being read in detail) as long as the reader realizes that d' is merely a convenient statistic for the combining of two types of error data into one "error score." The discussion of VAST error data renews with Section 3.2.4.

3.2.2.3 Signal Detection Theory - The theory of signal detection in psychology has been developed over the past twenty years to systematize knowledge in the field of psychophysics. It provides the means of analyzing the behavior of the subject in decision/detection experiments (see Reference 25). One of the behavioral measures derived from signal detection theory and the theory of statistical decision making is known as d'. This is an error measure. The subject's probability of correctly identifying a signal (known as his "hit rate" = 1 - probability of a missed signal) and his probability of responding incorrectly (known as a "false alarm" = responding when no signal was present) are used to calculate d'. The use of this measure does not depend upon the verification of signal detection theory or the theory of statistical decision making. It is merely a means of transforming two types of error scores (false alarms and missed signals) into a single score for each subject. The following paragraph relates the method of computation for d'. The reader who is interested in the derivation of d' and its theoretical importance is referred to Appendix A.

The value of d' for a particular subject is calculated using his hit rate and false alarm rate. The hit rate is the probability of a correct response given a signal was presented, and the false alarm rate is the probability of an incorrect response given no signal was presented. Given these two numbers, d' is calculated using the

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Gaussian (normal) probability distribution. The Gaussian distribution is tabled in many reference books as a value in standard deviation units (expressed as z) and the corresponding value of the Gaussian distribution (expressed as F(z)). To determine d': 1) find the z score that gives the cumulative normal value equal to the subject's hit rate (find z_1, such that $F(z_1)$ = hit rate), 2) find the z score that gives the cumulative normal value equal to the subject's false alarm rate (find z_2, such that $F(z_2)$ = false alarm rate), then $d' = z_1 - z_2$. If the hit rate is high, then z_1 is positive. If the false alarm rate is low, than z_2 is negative, and therefore, d' is large. Thus, the better the subject's overall error performance, the greater is d'.

For example, suppose a subject missed one out of twenty signals on a test run, and made one incorrect response when no signal was presented in twenty "no signal" trials during the same test run (i.e., trials when a non-signal was presented, see Section 2.2). His false alarm rate is 0.05 and his hit rate is 0.95. Then,

$$
\begin{aligned}
F(1.65) &= 0.95, \text{ hit rate} \\
F(-1.65) &= 0.05, \text{ false alarm rate} \\
\rightarrow &= 1.65 - (-1.65) = +3.30
\end{aligned}
$$

This subject would be given a d' score of +3.30 based upon his error scores (false alarm rate and hit rate where hit rate = 1 - probability of a missed signal).

<u>3.2.2.4 Error Data: False Responses and Missed Signals</u> - These error data (false responses and missed signals) were reduced to d' scores for each run as outlined in the previous section.

The distribution of d' scores was not heavily skewed either positively or negatively. The scores were distributed over a large range of values. A perfect score (no errors of either type) was assigned a d' value of 5.16 to correspond with the accuracy of the estimates of the error rates. The subjects were exposed to twenty signals and as many as thirty non-signals. The accuracy in estimating their error rates was better than to the nearest 0.05. Thus, the score of ± 2.58 was chosen (to represent 0.005 accuracy) as the highest possible score. If a subject made no false alarms, for example, $F(-\infty) = 0$, but the subject cannot be credited with a d' of ∞. Therefore, -2.58 was used to correspond to the approximate accuracy

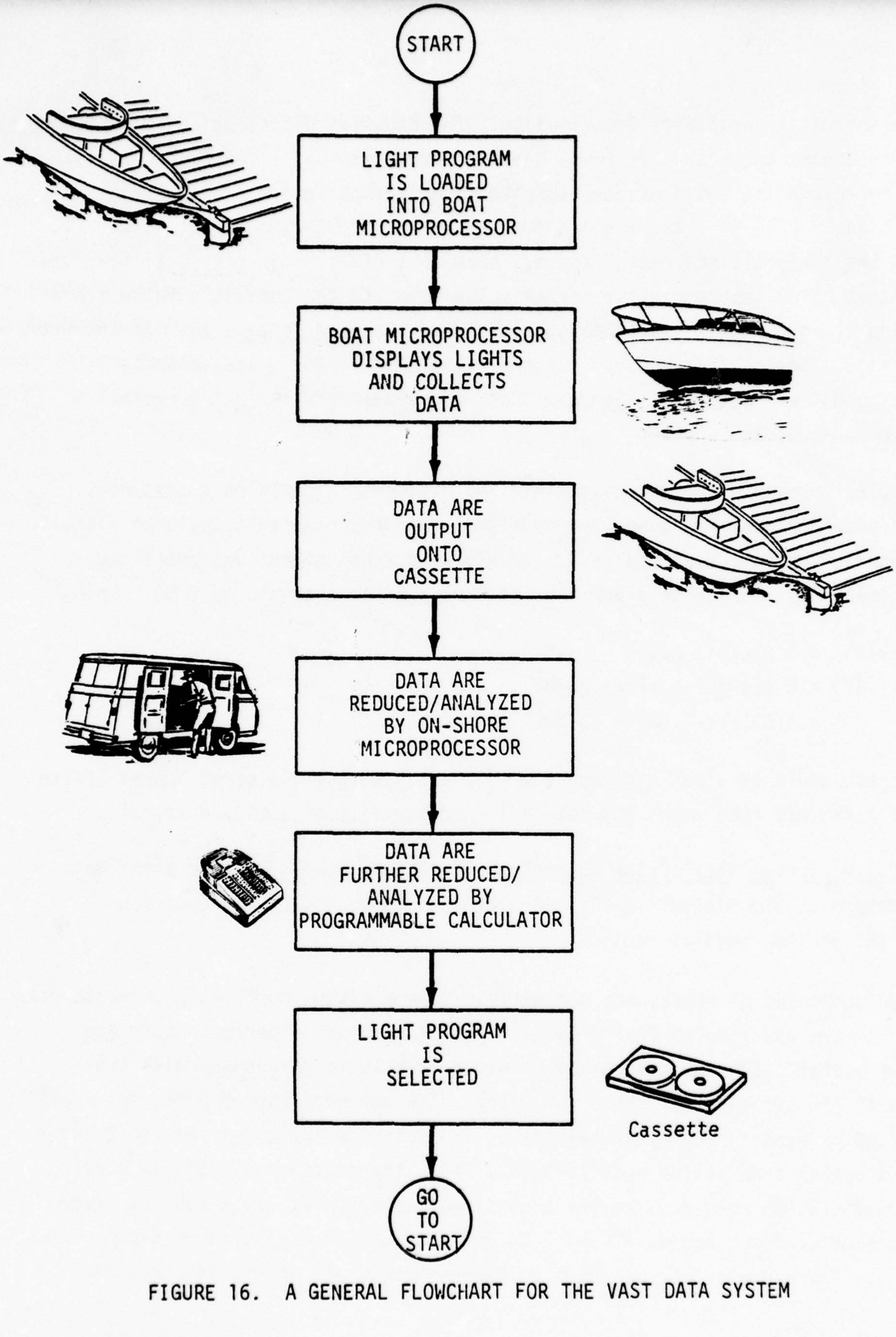

FIGURE 16. A GENERAL FLOWCHART FOR THE VAST DATA SYSTEM

95%

(50)

4 1864

9520

of the estimates of the error rates. If the subject had a hit rate of 1.00, then his score would be +2.58, since $(F(+2.58) = 0.99506 \approx 1.00$ rate. If the subject missed one signal but made no false alarm, then,

$F(1.65) = 0.95$ hit rate
$F(-2.58) = 0.00494 \approx 0.00$ false alarm rate (-2.58 assumed as best score possible for false alarms)
$\rightarrow = d' = 1.65 - (-2.58) = +4.23$

An analysis of variance was performed on the error scores (d' scores). The results are summarized in Table 5. The distribution of d' scores for all subjects was neither positively nor negatively skewed; therefore, the ANOVA was performed on the raw d' scores.

A highly significant interaction between fatigue and noise was found in the error data, along with a significant interaction between fatigue, noise, and wind. Also, a marginally significant interaction between fatigue and wind was indicated. None of the primary variables (fatigue, noise, and wind) produced a significant effect in the error data individually.

The interaction between fatigue and noise shows that subjects were significantly more accurate (higher mean d') when rested at low and medium noise levels, but more accurate when fatigued at high noise levels (see Table 6). The effect was particularly pronounced at the medium noise level, where many fewer errors were made when the subjects were rested. Thus, the subjects probably could have performed better in terms of response time in the rested/medium noise condition, if they had had an error rate similar to the fatigued/medium noise condition. This interaction provides some evidence similar to results obtained in other studies for stressors. Figure 17 shows the data from Table 6 in an idealized form, and as such, the axes are not marked. The U-shaped relationship shown in the rested data is common in research of this type. An optimal level of stress for a given set of circumstances is usually not the lowest level of stress. In the data at hand, it may be that the boat noise tends to arouse the subject or make him more alert, and that when he is fatigued, more noise may be needed to generate the aroused state.

TABLE 5. VAST-4 ANOVA SUMMARY TABLE: ERROR DATA

Source	Sum of Squares	Degrees of Freedom	F	P	Significance
S(subjects)	5.862	5			
W(wind)	1.540	1	3.838	p>0.10	Not Significant
WxS	2.006	5			
N(noise)	1.463	2	0.535	p>0.25	Not Significant
NxS	13.665	10			
NxW	0.199	2	0.277	p>0.25	Not Significant
NxWxS	3.590	10			
F(fatigue)	0.714	1	0.480	p>0.25	Not Significant
FxS	7.431	5			
FxW	3.063	1	4.877	0.05< p<0.10	Marginal Significance
FxWxS	3.140	5			
FxN	2.020	2	22.684	p<0.01	Very Significant
FxNxS	0.445	10			
FxNxW	5.818	2	5.639	p<0.05	Significant
FxNxWxS	5.159	10			
TOTAL	56.115	71			

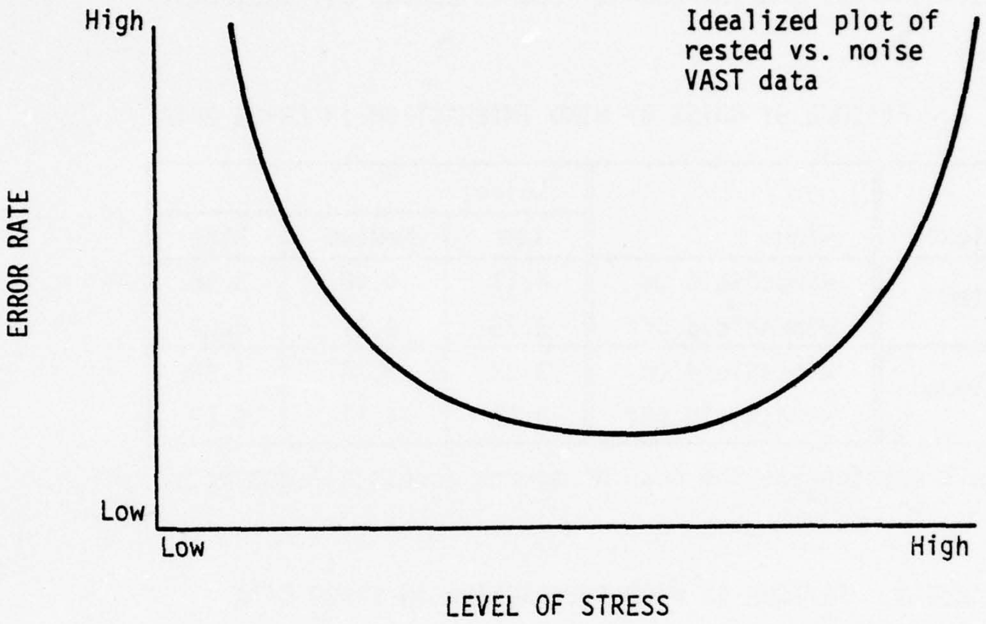

FIGURE 17. HUMAN PERFORMANCE AS A FUNCTION OF LEVEL OF STRESS

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TABLE 6. FATIGUE BY NOISE INTERACTION IN ERROR DATA

	Noise:		
Fatigue:	Low	Medium	High
Rested	3.93	4.35	4.09
Fatigued	3.75	3.73	4.29

Note: Cell entries are the mean d' scores across all subjects.

TABLE 7. FATIGUE BY NOISE BY WIND INTERACTION IN ERROR DATA

		Noise:		
Fatigue:	Wind:	Low	Medium	High
Rested	Windshield On	4.11	4.48	3.96
	Windshield Off	3.75	4.21	4.22
Fatigued	Windshield On	3.38	3.34	3.99
	Windshield Off	4.12	4.11	4.59

Note: Cell entries are the mean d' scores across all subjects.

TABLE 8. FATIGUE BY WIND INTERACTION IN ERROR DATA

	Wind:	
Fatigue:	Windshield On	Windshield Off
Rested	4.18	4.06
Fatigued	3.57	4.28

Note: Cell entries are the mean d' scores scross all subjects.

The fact that no interaction between fatigue and noise was significant in the response time data indicates that subjects were sacrificing speed in favor of accuracy in the medium noise/rested and high noise/fatigued conditions, while sacrificing accuracy in favor of speed in the other fatigued conditions.

The fatigue by noise by wind interaction data in Table 7, and the fatigue by wind data (marginally significant) in Table 8, show similar trends. The subjects tended to be more accurate (higher d') with the windshield on when rested, and more accurate without the windshield when fatigued. The latter was true at all noise levels. In the rested state, the effect of the windshield varied across noise levels.

3.2.2.5 Discussion - There was some evidence of slight learning effects. The data for a typical subject across time are plotted in Figure 18, along with the best fitting line for the data. They show a gradual trend toward reduced mean response times as the subject became more familiar with VAST and the light programs. Four different light programs were used in order to minimize the learning problem. The counterbalanced design also distributed learning effects randomly throughout the data.

Thus, the learning effects represent overall improvement with practice by the subjects, at all levels of all factors, but the facts that they occurred in all subjects, across all counterbalanced conditions, and were gradual, indicate that the chances that they introduced anomalies in the data are relatively remote.

Since the subjects were still improving their performance after nearly twenty hours of testing and practice, it is probable that they would have continued to improve gradually over time. This trend probably would have continued until the subjects had memorized all the light programs. At that point, learning would discontinue, but their behavior would no longer be of interest, since they could anticipate the light sequences. The behavior that was witnessed was far from this eventuality.

The error scores were somewhat better for this VAST experiment than for previous ones. One reason for this was that the response button was replaced. The previous response button had been a three-position power trim switch, and was easily accidently activated, leading to unintentional false responses. The new response button was a spring-loaded post, and was not easy to activate accidentally.

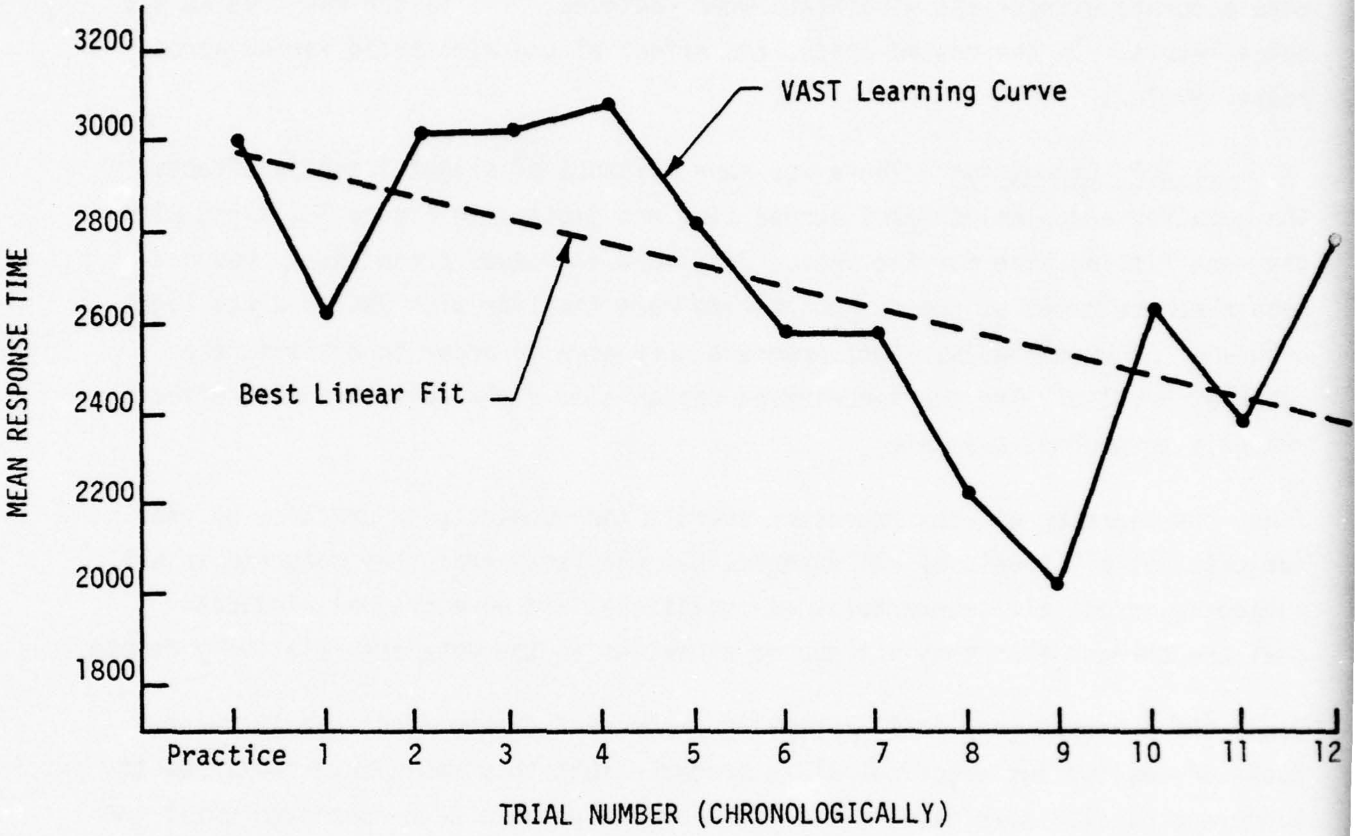

FIGURE 18. VAST LEARNING CURVE FOR A TYPICAL SUBJECT

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Individual differences accounted for a large part of the variation in the data, as shown by the entries under "sum of squares" in Tables 4 and 5. The ranges of individual response time means were 900 milliseconds or more for every subject (best mean response time for a run minus the worst). For three subjects, the range in mean response times exceeded 1500 milliseconds. One subject's best mean response time was roughly equivalent to another subject's worst mean response time. Such individual differences contributed to the lack of statistical significance for some results. This had not been as big a problem in previous VAST studies where the subjects had not differed as much in performances and the observed stressor effects had been of sufficient magnitude to overcome the variation caused by individual differences. In VAST-4, sample size may have been increased over previous studies at the expense of increased individual differences.

Also contributing to the lack of statistical significance for some results was the counterbalancing in the experimental design. Such counterbalancing compensates for random and spurious effects in the testing, but it also makes the F ratios in the analyses of variance somewhat conservative. The ANOVAs ignored learning and other effects which were known to have had some influence on the data. This is why marginally significant (0.10>p>0.05) results are reported here and have been reported in previous studies.

A major problem with respect to fatigue in this study was the lack of heat. Those subjects who had been in previous VAST experiments stated that the exercise did not have the same psychological effect at 65-75°F (18.3-23.9°C) as at 85+°F (29.4+°C). No overall fatigue effect was found in either the response times nor the error data. However, significant interactions involving fatigue were discovered.

A comparison of audiograms obtained before, during, and after the noise testing revealed no changes in the hearing capabilities of any subjects or experimenters that could not be explained in terms of errors of replication in obtaining the data.

Finally, no significant differences were observed in the data obtained with the various light programs. It appears that they were all of approximately the same level of difficulty.

3.3 Conclusions of the 1976 - 1977 VAST Research

The results of the VAST-4 experiment indicate that:

- the technology exists for changing the noise environment on small boats in terms of the overall noise level (through the engine shroud) and the noise spectra (through windshields),
- subjects performed better without a windshield than with one, possibly because of changes in the noise spectra,
- fatigue tends to cause performance degradations in low and medium noise environments, but not in high noise,
- the wind effects mentioned above are more pronounced when the operator is fatigued as opposed to when he is rested, and
- neither proposed countermeasure (the windshield for wind, the engine shroud for noise) produced statistically significant improvements in performance.

These results, particularly the significant interactions, confirm the basic premise of the VAST program from the beginning. This premise was recorded in Reference 28 over two years ago:

> "Stress, then, is not a simple idea, but a complex one. The effects of stress are not static, but dynamic, i.e., they change as the task goes on...Of critical importance then, is the complex nature of stress and stressor effects, and the ability of the individual to maintain his attention upon relevant information in the performance of his tasks."

Stressors have been shown to be complicated and interactive in their effects on a boat operator. It has been suggested that a major component of the degradation in performance due to stressors is a degradation in human information processing functions. The fact that the psychological and safety research literatures suggest that the major effects of stressors are on the central processing capabilities of man confirms this position.

It should be noted that the VAST-4 results (and all previous VAST results) were obtained in a real-world setting, and not in a laboratory. This experiment was carried out in a setting which lacked one of the critical elements of fatigue from previous studies: heat.

Similar studies to this one have been conducted for automobile and truck drivers. These studies also failed to show an overall noise effect on operator performance. Harris and Mackie (Reference 26) found that heat was considered a fatigue or alertness problem of approximately ten times the importance of noise in trucks and buses. They felt that drivers could adapt to noise and vibration more easily than to heat. Mackie, O'Hanlon, and McCauley (Reference 27) reported noise levels sufficient to cause permanent hearing damage did not affect driver performance. They found, however, that:

> "Heat stress was shown to significantly affect both driver performance and various indices of central nervous system arousal felt to be important to driving safety."

Therefore, the fact that the VAST testing was done in fall weather probably had a significant bearing on the outcome in terms of fatigue.

The apparatus is still in need of improvements in terms of measuring performance on the primary task. These improvements were beyond the scope of this project and previous efforts.

4.0 FUTURE DIRECTIONS FOR STRESSOR-RELATED RESEARCH

Potential stressor problems abound in all phases of Coast Guard work. In recreational boating, the need remains for establishing the credibility of the stressor problem in the accident data base. Previous collision research has shown that high noise levels may have been present in many boats prior to collisions, but the current study failed to show a statistically significant effect due to noise alone.

From the stressor literature in other modes of transportation, heat appears to be a stressor with considerable importance, deserving futher study on the part of the Coast Guard. Another potential factor is glare, both during the day and at night. Limited visibility has been indicated as a significant contributor to collisions.

What can be done about such factors in recreational boating? This is where stressor research ties in with education and human factors. Obviously, the boating public needs to be made aware of stressor effects and countermeasures. Additionally, cockpit design could be encouraged which reduce the potential for stressor effects, and encourage the operator to pay attention to what he is doing. Techniques such as those used in job enrichment programs could be implemented to get the operator to pay attention to his navigational concerns and not have a collision out of "neglect" or "operator inattention."

Similar stressor problems exist in the merchant marine and in Coast Guard operations. In these cases, action may be taken beyond education if the need is found. Coast Guard search-and-rescue crews are subjected to heat, glare, fatigue, and other stressors whether in the air or on the sea. Their stressor problems could be studied using VAST-like techniques as part of an overall program to improve the human factors design of Coast Guard equipment and the design of S-A-R jobs. Issues such as how long a SAR crew should be deployed and what their visual search patterns should be are closely related to stressors and the human factors engineering in the design of their equipment.

The issues of stressors and human factors in cockpit design also arise in the operation of large, ocean-going vessels. The issues are complicated by the special control problems (delays between operator action and the ship's reaction, etc.).

In general, much remains to be done, within the Coast Guard's jurisdiction, on stressors and related issues. Future research in these areas should be tied more directly to documented problems and should be integrated into programs which also investigate human factors and operational concerns.

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APPENDIX A. SIGNAL DETECTION THEORY

Although it is true, as stated in the body of the report, that the measure d' can be considered merely as a means of transforming two types of error scores (the probability of missing a signal when one is presented and the probability of responding to a non-signal) into a single score (d'), the measure has theoretical and statistical importance. The purpose of this appendix is to provide the interested reader with insight into the derivation and significance of d'.

A major concern of psychology for over a century has been the identification of sensory thresholds. The theory of signal detection (first proposed in 1954) has challenged the concept of sensory thresholds, proposing instead response thresholds. The theory can trace its origins to statistical decision theory and electrical engineering (out of concern for the design of sensing devices). The major contribution of psychology, causing the development of the theory, was the identification of the distinction between the sensor and the decision maker in the human observer. These two aspects are confounded in sensing machines and human performance. The theory of signal detection (hereafter abbreviated TSD) makes possible the precise distinction between these two functions of the observer of signals who must: 1) sense the signal, and 2) decide it was indeed a signal that he sensed. The theory can be used as an application of statistical decision theory to single trials in psychophysical experiments. The subject in such an experiment must be aware that there are two possible states of the world: 1) one state when a signal is present, and 2) another state when there is a non-signal. Once the subject is aware of the nature of these two states, information is presented to him on a trial by trial basis. On each trial, he must decide whether a signal was present or not. VAST is an experiment of this type, where light patterns are displayed trial by trial and the subject must decide whether or not to respond.

On any one trial, the subject may respond, "Yes, I detected a signal," or, "No, I didn't," and a signal may or may not be present. Thus, each trial can be represented in the matrix shown in Figure A-1. When there was a signal and the subject responds correctly, a "hit" is scored. In VAST, the subject depressed the response button on the throttle to respond "Signal," and did nothing to respond "No Signal."

		Response	
		Signal	No Signal
Stimulus	Signal	"Hit"	"Miss"
	No Signal	"False Alarm"	"Correct Rejection"

FIGURE A-1. STIMULUS/RESPONSE MATRIX

Similarly, a payoff matrix can be constructed to show the rewards or punishments for various results. The entries in the payoff matrix can be monetary rewards/punishments, or whatever is used in the particular experiment or situation. If the signal were ICBMs approaching the USA and the radar operator were to "miss" the signal, the payoff could be complete annihilation, without retaliation. In the case of VAST-2, VAST-3, and VAST-4, the payoffs were as shown in Figure A-2. In VAST-1, there were no payoffs (no feedback to the subject).

		Response	
		Signal	No Signal
Stimulus	Signal	V_{ss} = Happy Face	V_{ns} = Nothing
	No Signal	V_{sn} = Buzzer	V_{nn} = Nothing

FIGURE A-2. PAYOFF MATRIX

In the experiment described above, the observer has an observation (let us call it z) for which he can compute (estimate) the probability of the observation given that no signal was presented ($p(z/n)$) and the probability of the observation given a signal was presented ($p(z/s)$). Using these two quantities, the likelihood ratio ($l(z)$) can be computed. This corresponds to the probability of the observation given a signal divided by the probability of the observation given no signal was presented, as shown in Equation A-1.

$$l(z) = \frac{p(z/s)}{p(z/n)} \qquad \text{(A-1)}$$

If the subject knows, or can estimate, the prior odds of a signal versus a non-signal $\left(= \frac{p(s)}{p(n)}\right)$, he can compute the odds in favor of a signal as opposed to a non-signal given his observation by Bayes' Theorem (Equation A-2).

$$\text{Posterior Odds} = \frac{p(s/z)}{p(n/z)} = \frac{p(z/s)\,p(s)}{p(z/n)\,p(n)} = \text{Likelihood Ratio} \times \text{Prior Odds} \qquad \text{(A-2)}$$

If the observer chose to respond according to his expected payoff, then he would respond "Signal" if, and only if, the payoff for a "hit" times the probability of a "hit" ($V_{ss} \cdot p(s/z)$) minus the probability of a false alarm times the payoff for a false alarm ($V_{sn} \cdot p(n/z)$) is greater than the expected value of a "No Signal" response ($= V_{nn} \cdot p(n/z) - V_{ns} \cdot p(s/z)$). This response rule is equivalent to responding "Signal" if, and only if, Equation A-3 is true.

$$\frac{p(s/z)}{p(n/z)} \geq \frac{V_{nn} + V_{sn}}{V_{ss} + V_{ns}} \qquad \text{(A-3)}$$

Substituting Equation A-2 for the left-hand side of Equation A-3 yields,

$$\frac{p(z/s)}{p(z/n)} \geq \frac{p(n)}{p(s)} \cdot \frac{V_{nn} + V_{sn}}{V_{ss} + V_{ns}} \qquad \text{(A-4)}$$

If we call the expression on the right β, using Equation Equation A-1 yields,

$$l(z) \geq \beta \qquad \text{(A-5)}$$

Thus, β is that number which accounts for the prior odds and payoffs so as to maximize the expected payoff. The subject can maximize his expected payoff if he responds "Signal" when $l(z)$ is at least as great as β, and "No Signal" otherwise. Thus, β represents the subjects optimal decision criterion based upon the likelihood ratio and the payoff matrix.

The performance of any sensing device (human or otherwise) can be described in TSD by a receiver operating characteristic curve, or ROC curve. For the value β described previously there will be a corresponding observation z_c (c for "criterion") such that all observations exceeding z_c will lead to Equation A-5 being true. Thus, whenever the subject's observation exceeds z_c, he should respond "Signal" to maximize his expected payoff. The ROC curve plots the hit rate (the probability the subject responds "Signal" when a signal was present) versus the false alarm rate (the probability the subject responds "Signal" when a non-signal was present) as shown in Figure A-3. Each point on the curve corresponds to one value of β. Various points are plotted as β is manipulated using changes in the payoff matrix or the prior odds.

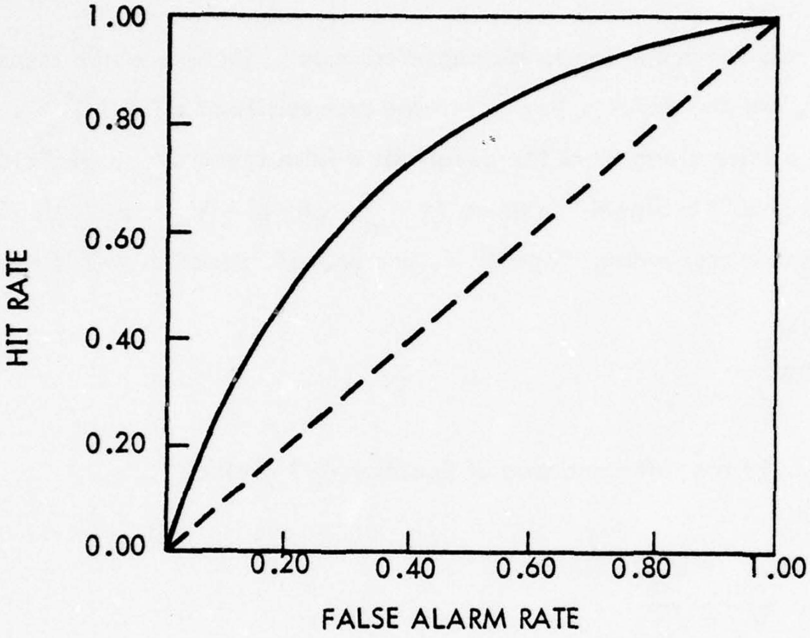

FIGURE A-3. ROC CURVE

For example, if the subject were always punished for responding "Signal," he would never respond and his false alarm and hit rates would both be zero. On the other hand, if he were always rewarded for responding "Signal," he would always respond "Signal," and his hit rate and false alarm rate would both be one. In the former case, β and z_c would be set as high by the subject as to never be exceeded, while in the latter case, they would be so low as to always be exceeded by an observation.

If the signal were somehow to be intensified or increased, so that it was easier to distinguish from a non-signal, then the subject's error rates would drop while his hit rate increased (assuming the same β). He would have moved to a higher ROC curve as shown in Figure A-4.

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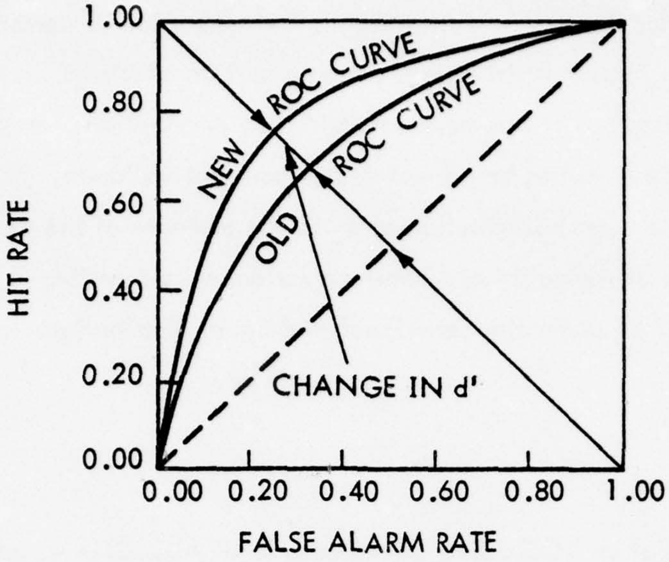

FIGURE A-4. MULTIPLE ROC CURVES

The difference between the two curves can be expressed in terms of the differences in d', which relates to the distance from the major diagonal in the figure to the ROC curve, along the minor diagonal. Since the greater d' is, the higher the possible hit rate under a fixed false alarm rate, d' is a measure of the subject's accuracy, or sensitivity to the difference between a signal and a non-signal.

How can d' be determined? Figure A-5 shows hypothetical distributions of the probability of an observation given no signal was presented (p(z/n)) and the probability given a signal was presented (p(z/s)), and a criterion value of z_c (any z observed which is greater than z_c results in the response "Signal"). The shaded area under the p(z/s) distribution shows the proportion of hits. The shaded area under the p(z/n) distribution shows the proportion of false alarms.

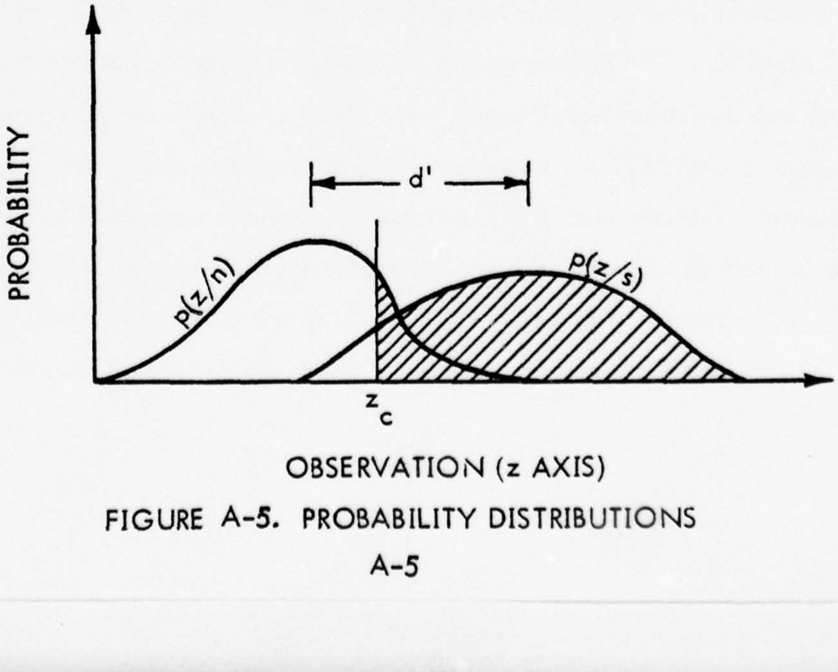

FIGURE A-5. PROBABILITY DISTRIBUTIONS

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Similarly, the white area under the p(z/n) distribution is the proportion of correct rejections, while the white area under the p(z/s) distribution is the proportion of missed signals. The quantity d' represents the separation of the means of these two distributions, as shown in the figure. The distributions are assumed to be normal and of constant variance. β is equal to the ratio of the ordinate of the p(z/s) distribution at z_c to the ordinate of the p(z/n) distribution at z_c. Under the assumptions of normality and constant variance, and letting Z_n and Z_s be the standard (normalized) score of z_c under the non-signal and signal distributions, respectively, then,

$$d' = Z_n - Z_s \tag{A-6}$$

Note that the major diagonal of an ROC curve corresponds to d' = 0. This happens when the two distributions in Figure A-5 have the same mean and the subject is essentially guessing. In those circumstances z_c is equal to the shared mean (assuming balanced payoffs) and a response of "Signal" is just as likely to be in error as it is to be correct. The greater d' is, the easier it is for the subject to discriminate between a signal and a non-signal, and the fewer the number of errors he makes of both types (false alarms and missed signals), assuming a fixed β. His ROC curve is closer to the point (1,0). If d' is small, then the subject has difficulty distinguishing between a signal and a non-signal, his error rates are high, and his ROC curve is close to the major diagonal in Figure A-4. Boosting the signal intensity adds a constant to the p(z/s) curve in Figure A-5 and results in an increase in d'. Note that the variance is assumed to be constant; i.e., it is assumed that there is no inherent variation in boosting the signal.

To summarize the twenty-plus years of development of "The Theory of Signal Detection" in a few pages is impossible. The preceding was merely an attempt to indicate that the measure d' has theoretical and statistical significance. The theory has been applied to numerous circumstances analogous to the VAST experiments with great success, and to other circumstances with equivalent success. TSD and statistical decision theory have been used to study the existence of ESP (a "weak" signal), and to evaluate the performance of sensory devices in the space program, such as the recent Mars explorations. There are many more implications and ramifications of TSD in the field of sensory psychology alone which are not reported here. It is

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hoped that the reader has gained an appreciation for TSD and the measure d'. It appears from past research that for a given observer and signal to non-signal ratio (i.e., constant definition of signal and non-signal), d' is reasonably constant over variations in β (prior odds and payoff matrices) and in experimental procedures (form of responding: "Signal" versus "No Signal," confidence ratings, matching techniques, etc.). It is the accomplishment of TSD in providing predictability and integration over a range of experimental conditions and procedures that has prompted a great deal of interest in the theory.

In the case of the application of TSD to VAST-4 data in the form of computing d' scores, it should be noted that the payoff matrix for the subjects was not monetary or reward oriented. The subjects in VAST merely became aware of the appropriateness of their responses through feedback. Thus, the values of the entries in the payoff matrix were the corresponding subjective desire, competitive drive, or motivation of the subjects to perform well. The subjects in VAST-1 were USCG personnel who expressed competitive sensitivities since they each represented different USCG units. In later VAST experiments the subjects appeared to be self-motivated, attempting to perform well as a matter of pride in accomplishment as well as in response to competitive drives.

APPENDIX B. THE VAST MICROPROCESSORS

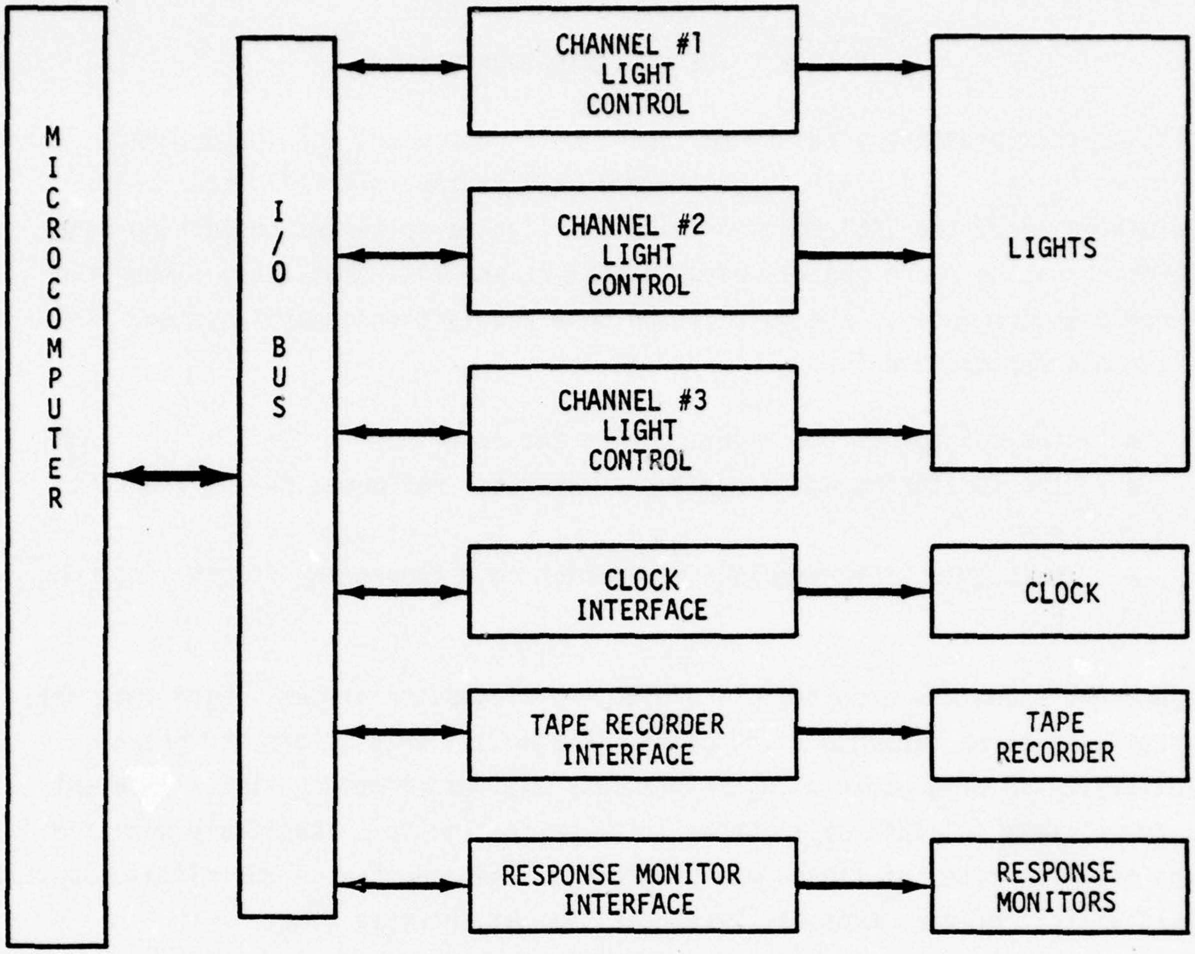
This appendix presents some of the logic and architecture for the new VAST microprocessors. Two mini-computers were used in the 1977 VAST experiments. One was on board the VAST boat, driving the light display and collecting data. The other was on shore and was used to analyze and interpret data. These two microprocessors made up the bulk of the data acquisition/control system. This system was responsible for:

- the control of the lights during the test,
- the monitoring and recording of operator responses during the test, and
- outputting the response information in a convenient format after the test.

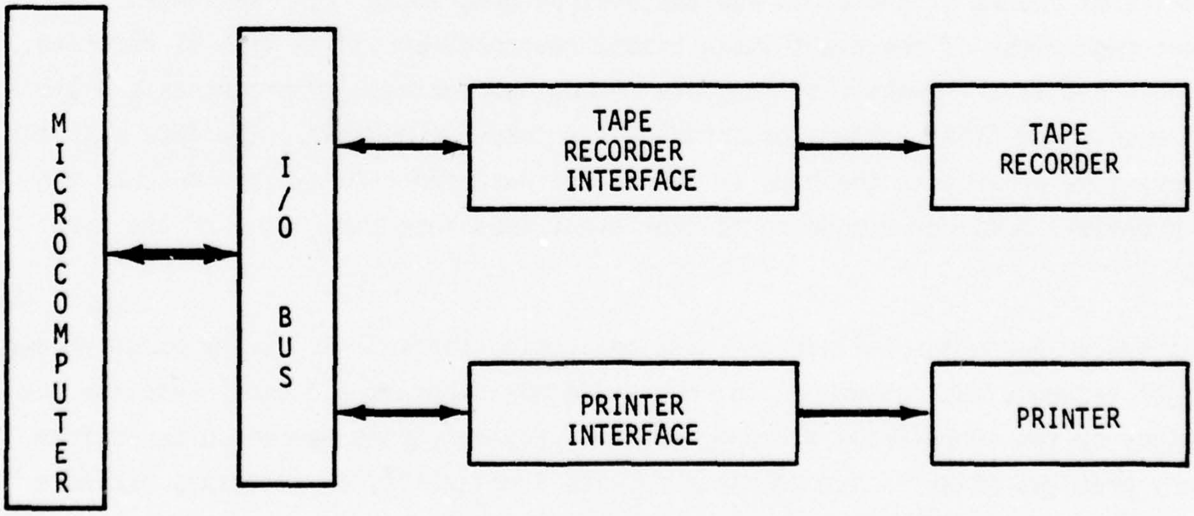
Figure B-1 shows the architecture of the micro-computer system. Note that the system uses three separate light control channels. This allows for great flexibility in programming. As in previous VAST experiments, lights were able to "move" left to right or right to left, or come on in a stationary position. Each of these types of lights was programmed independently in the micro-computer. Thus, a light of each type may have been "on" at the same time.

Figure B-2 is a flowchart of the response monitoring logic. Basically, it is a series of checks of the clock and the desired program of light sequences. Note that regardless of the event (horn blast, response, etc.) the time is recorded. Figure B-3 is a flowchart of the data output subroutine. It processes the list of events and times that is produced by the response monitor. The data output subroutine determines the type of event that has been recorded and outputs the appropriate data corresponding to that event (response time, time of the event, etc.).

The system performed well in the data collection for VAST-4. Every programmed light sequence was output by the on board mini-computer, and every response was output by the shore-based micro-processor. However, this system suffered from many problems prior to its completion. The availability of necessary hardware components was a continuing problem, and this problem was documented in the Interim Report.



ON BOARD MICROCOMPUTER



VAN-MOUNTED MICROCOMPUTER

FIGURE B-1. MICROCOMPUTER SYSTEM ARCHITECTURE

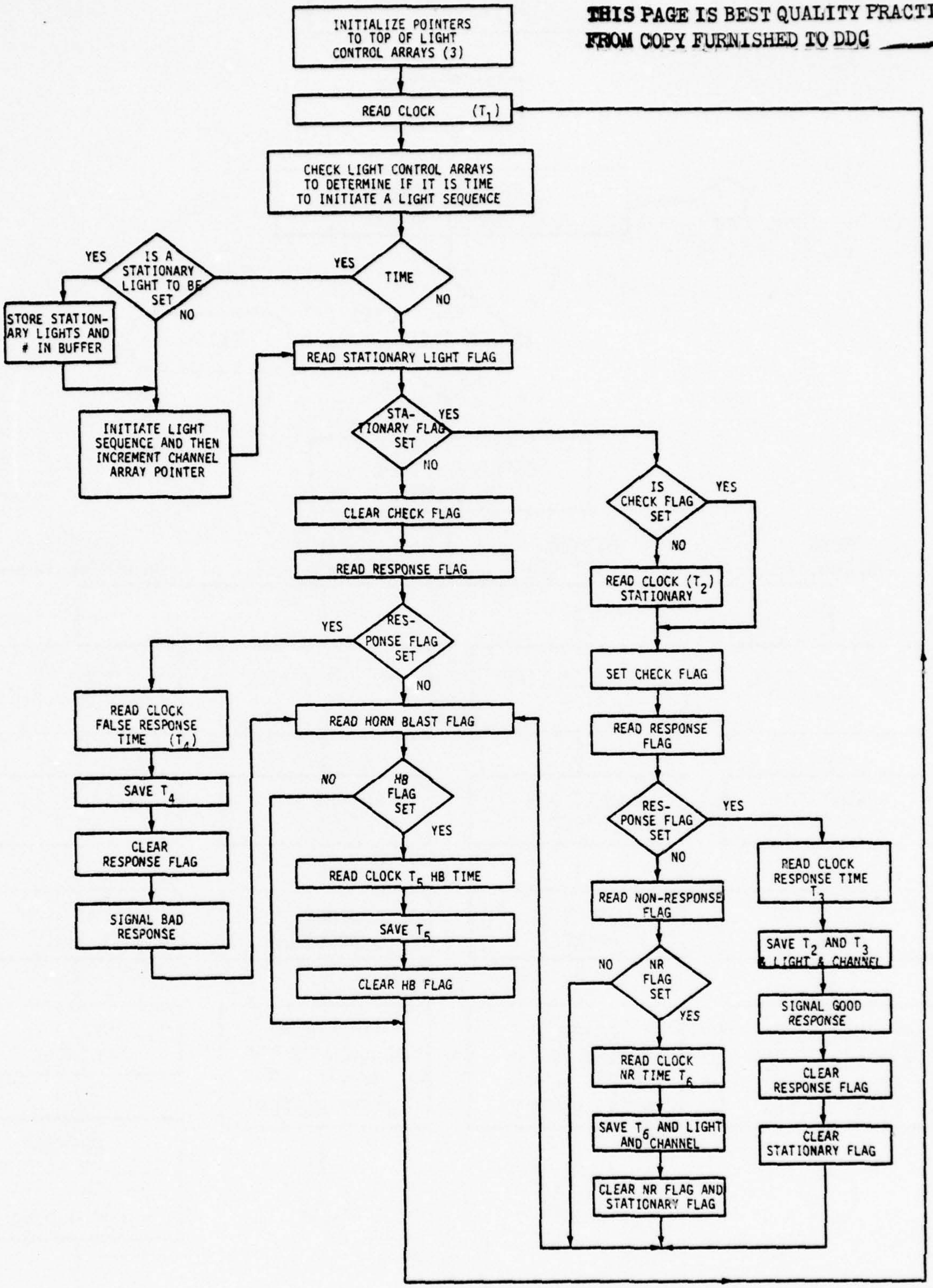


FIGURE B-2. FUNCTIONAL FLOWCHART OF RESPONSE MONITORING SUBROUTINE

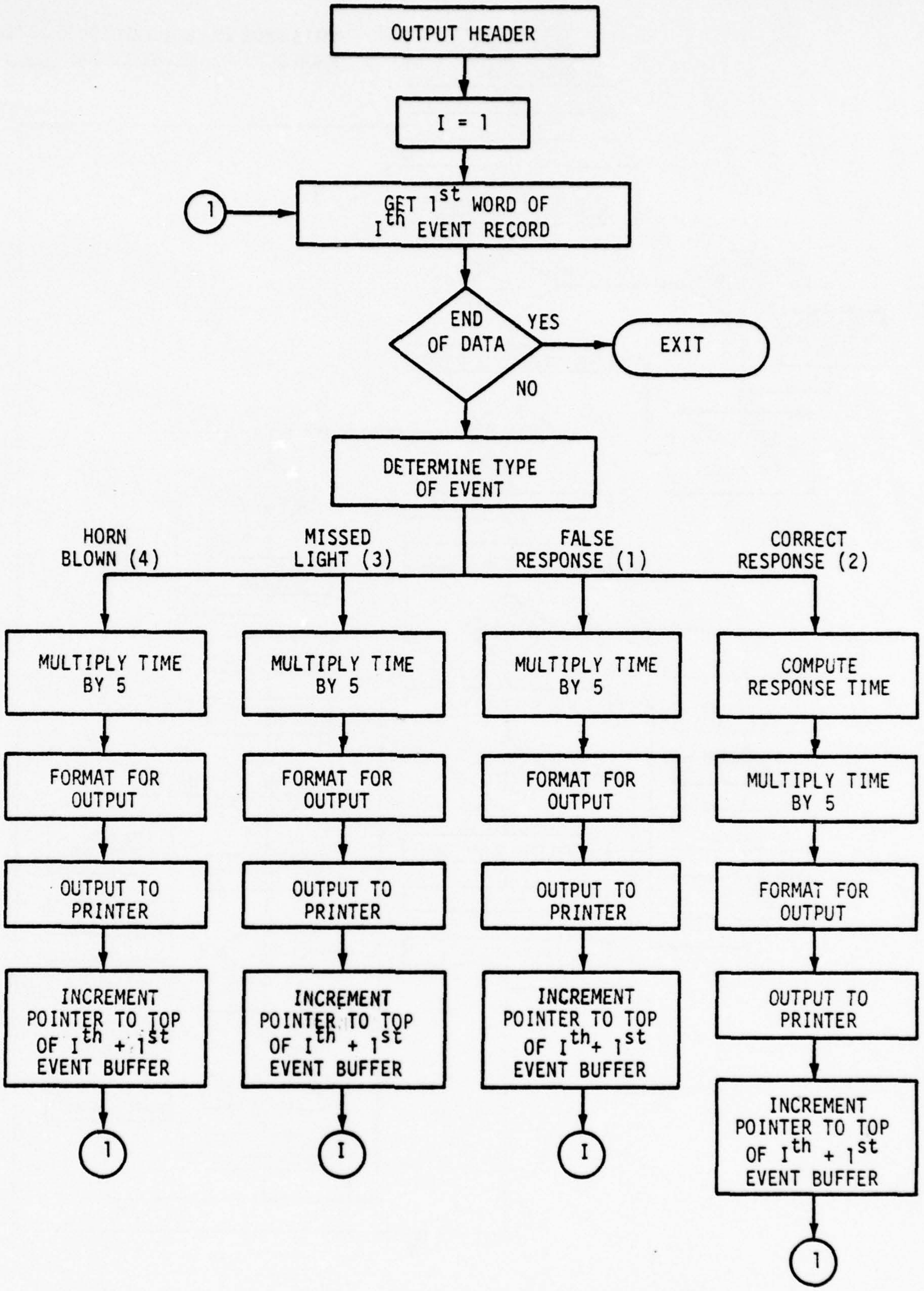
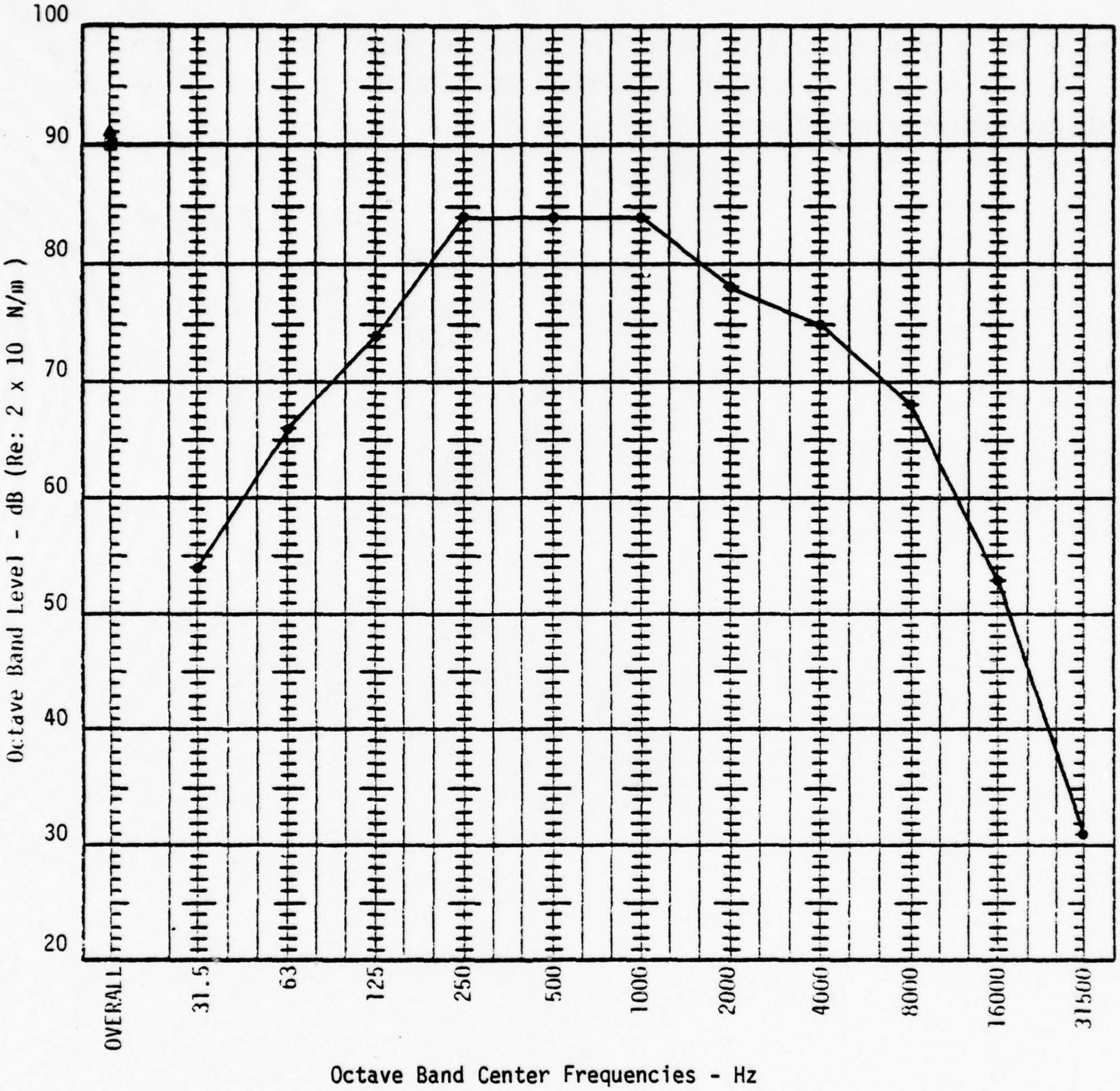


FIGURE B-3. FUNCTIONAL FLOWCHART OF DATA OUTPUT SUBROUTINE

APPENDIX C. VAST NOISE DATA

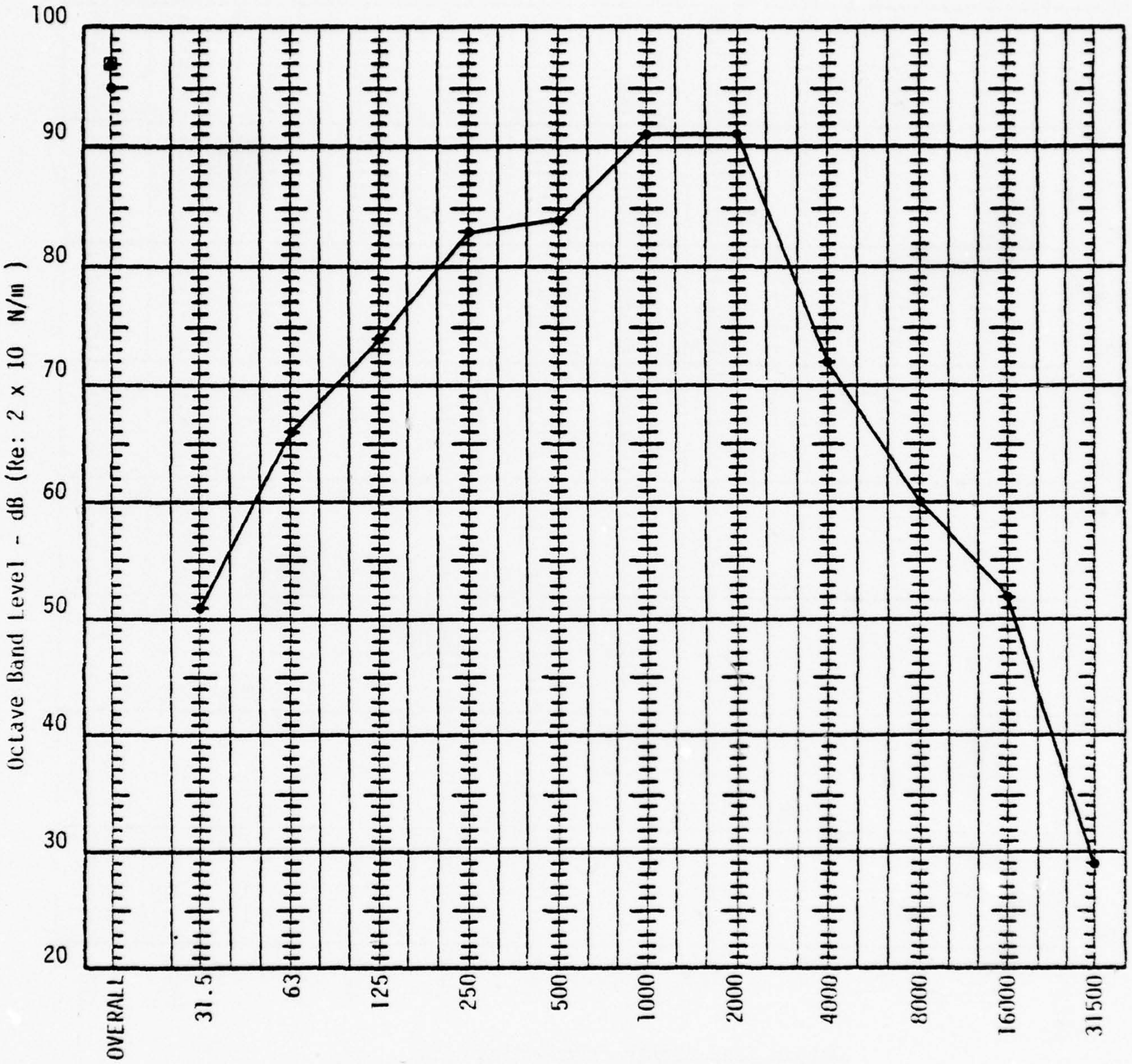
The following pages contain the data from Table 3 in graphic form. They are in the same order as indicated in the table. The figures that were used in the text are not repeated here.



Run #1

▲ Measured dB(A) 91
● Computed dB(A) 90
■ Intended dB 90

(Low noise with windshield/wind 10-12 knots)



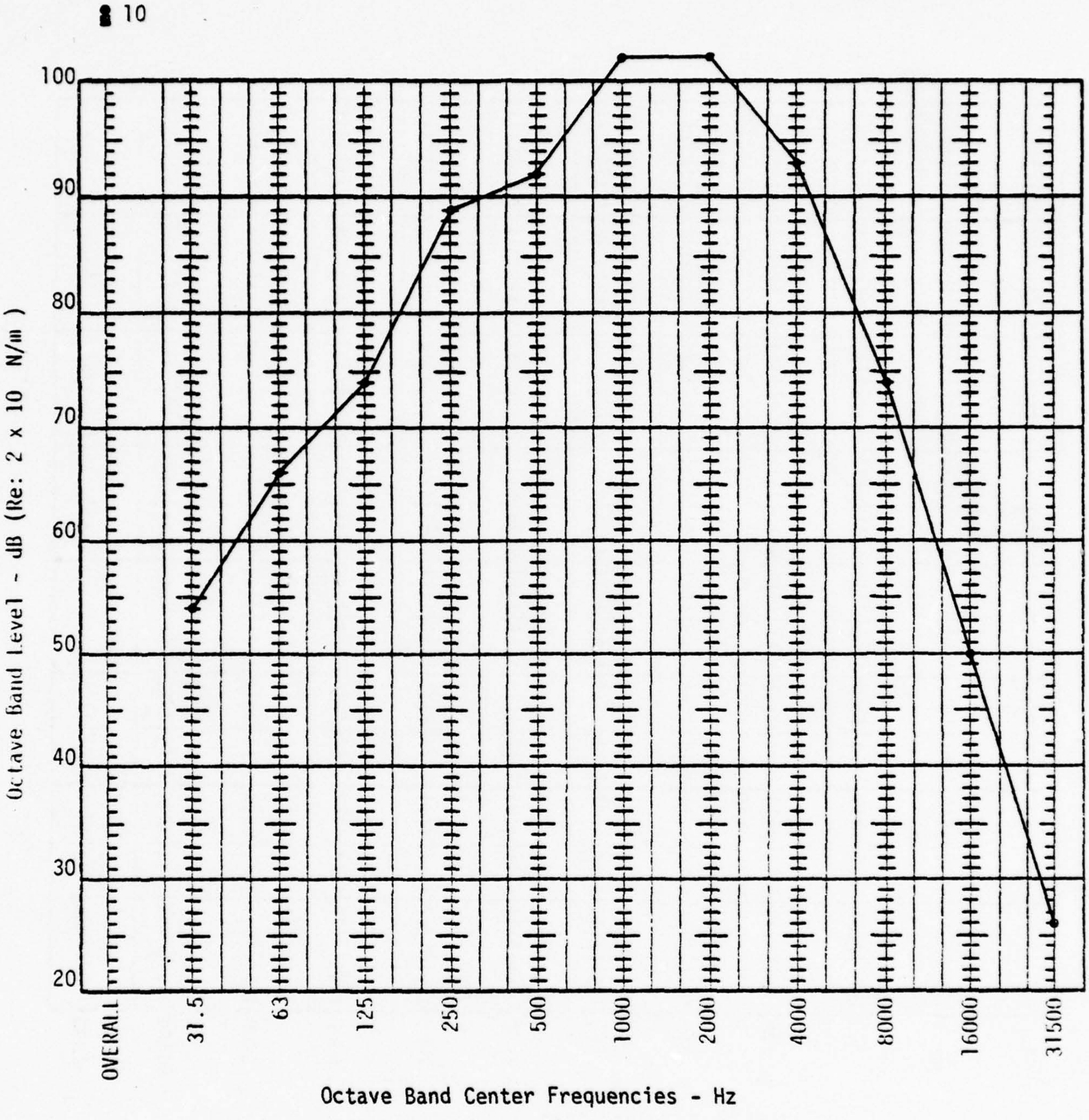
Run #2

▲ Measured dB(A) 97

● Computed dB(A) 95

■ Intended dB 97

(Medium noise with windshield/wind 10-12 knots)



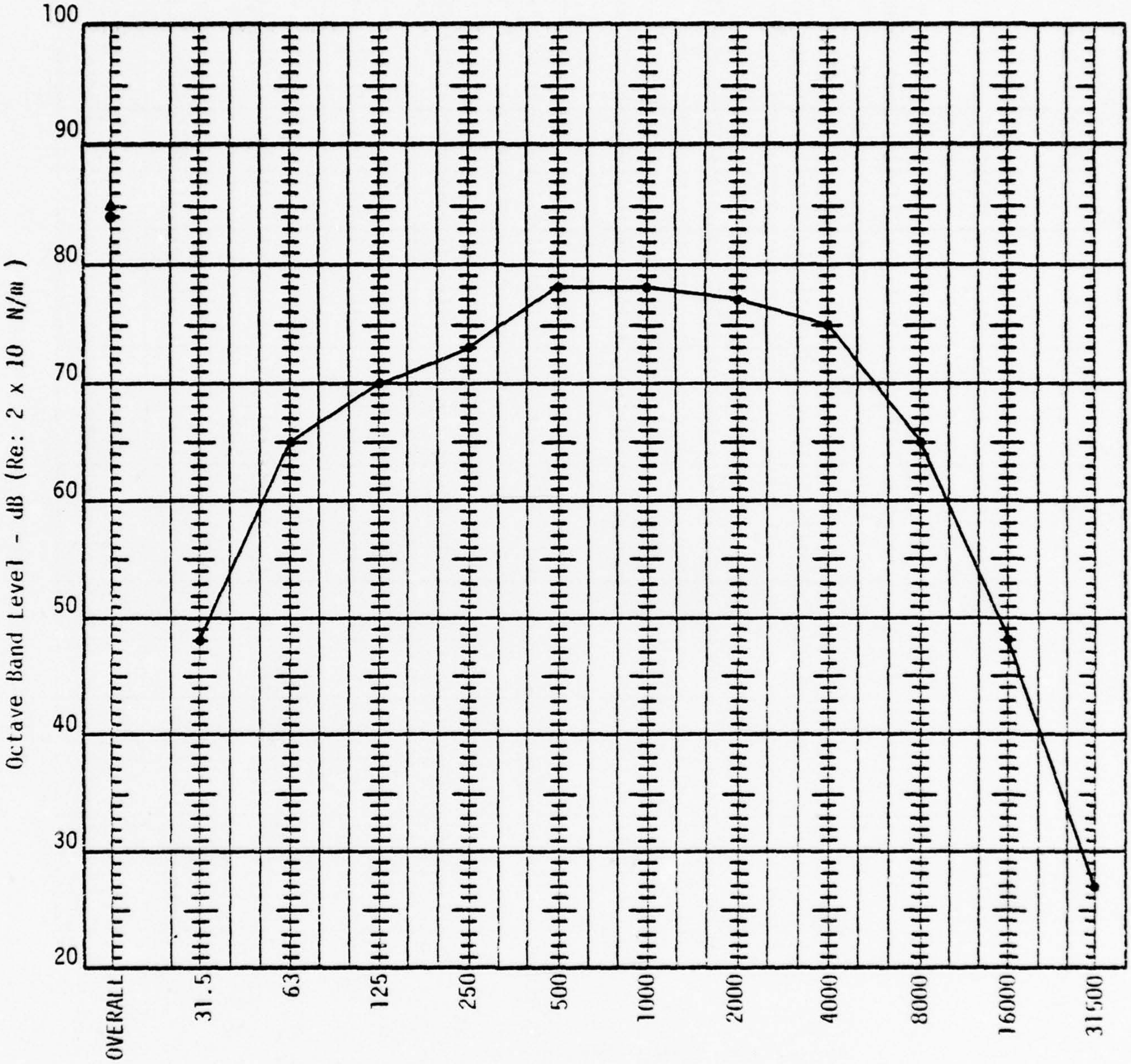
Run #3

▲ Measured dB(A) 105

● Computed dB(A) 106

■ Intended dB 105

(High noise with windshield/wind 10-12 knots)



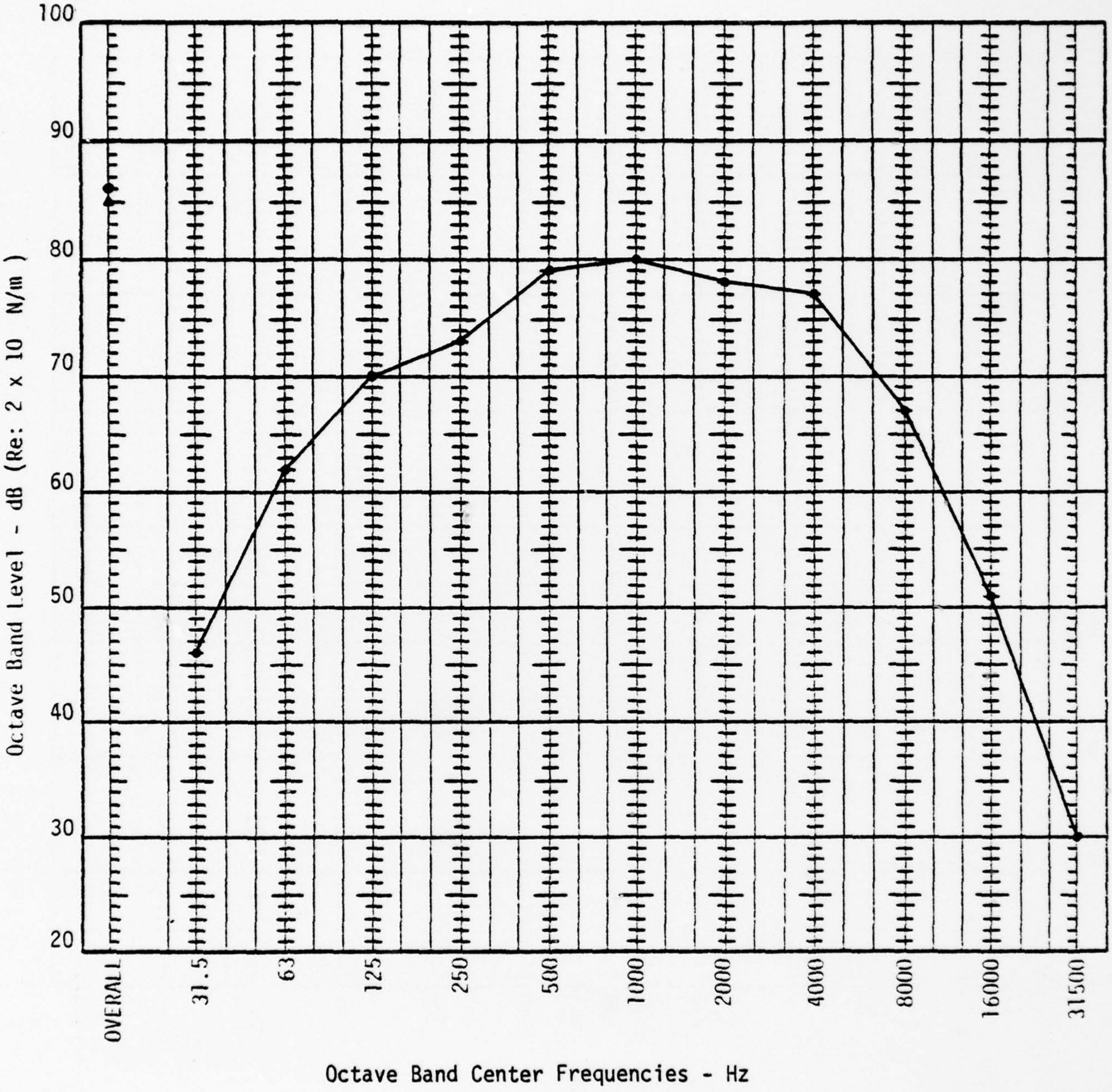
Octave Band Center Frequencies - Hz

Run #4

▲ Measured dB(A) 85

● Computed dB(A) 84

(Tow test with windshield/wind 12 knots/4" chop/motor idling)

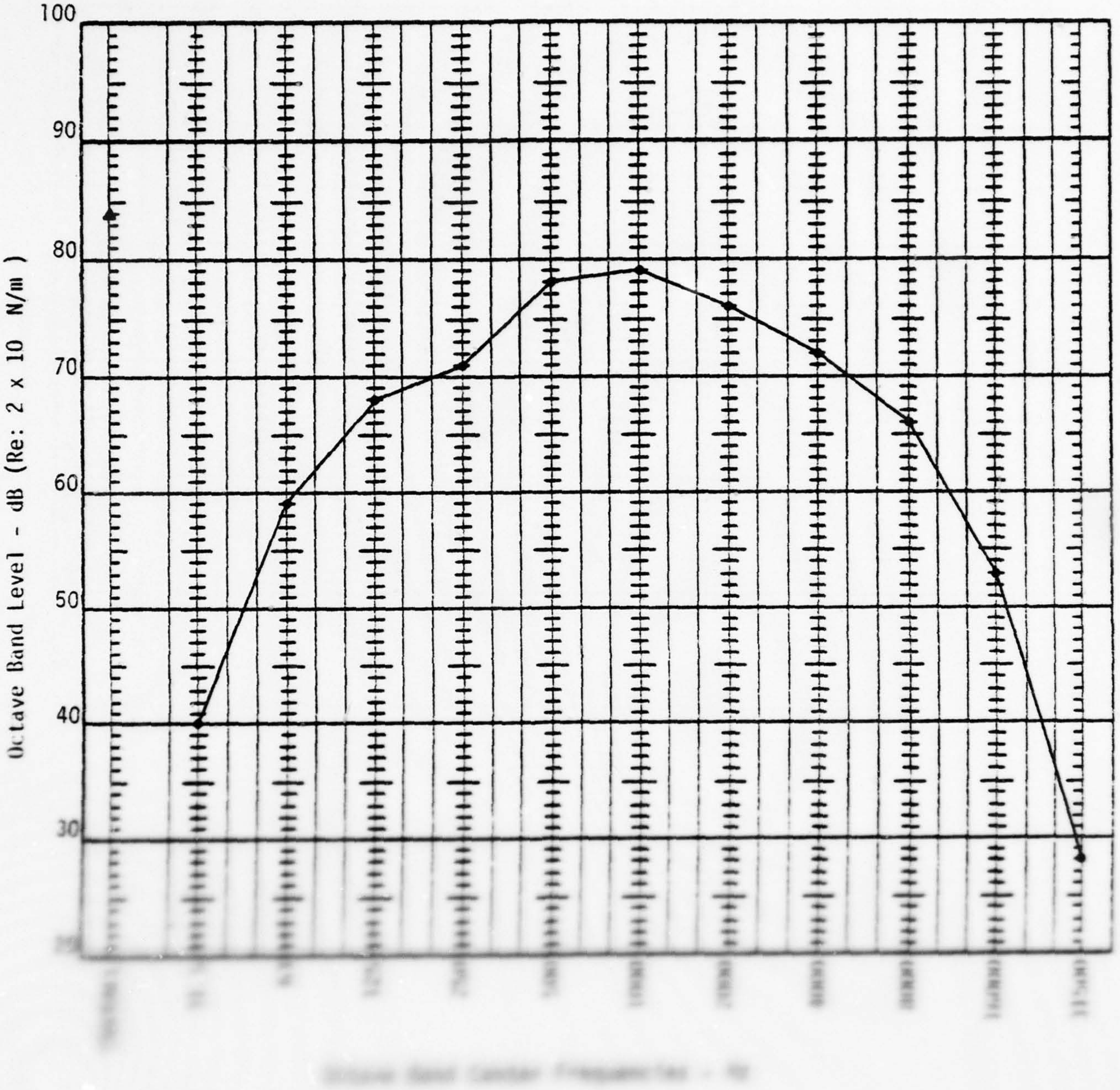


Run #5

▲ Measured dB(A) 85

● Computed dB(A) 86

(Tow test with windshield rerun/wind 12 knots/4" chop/motor off)

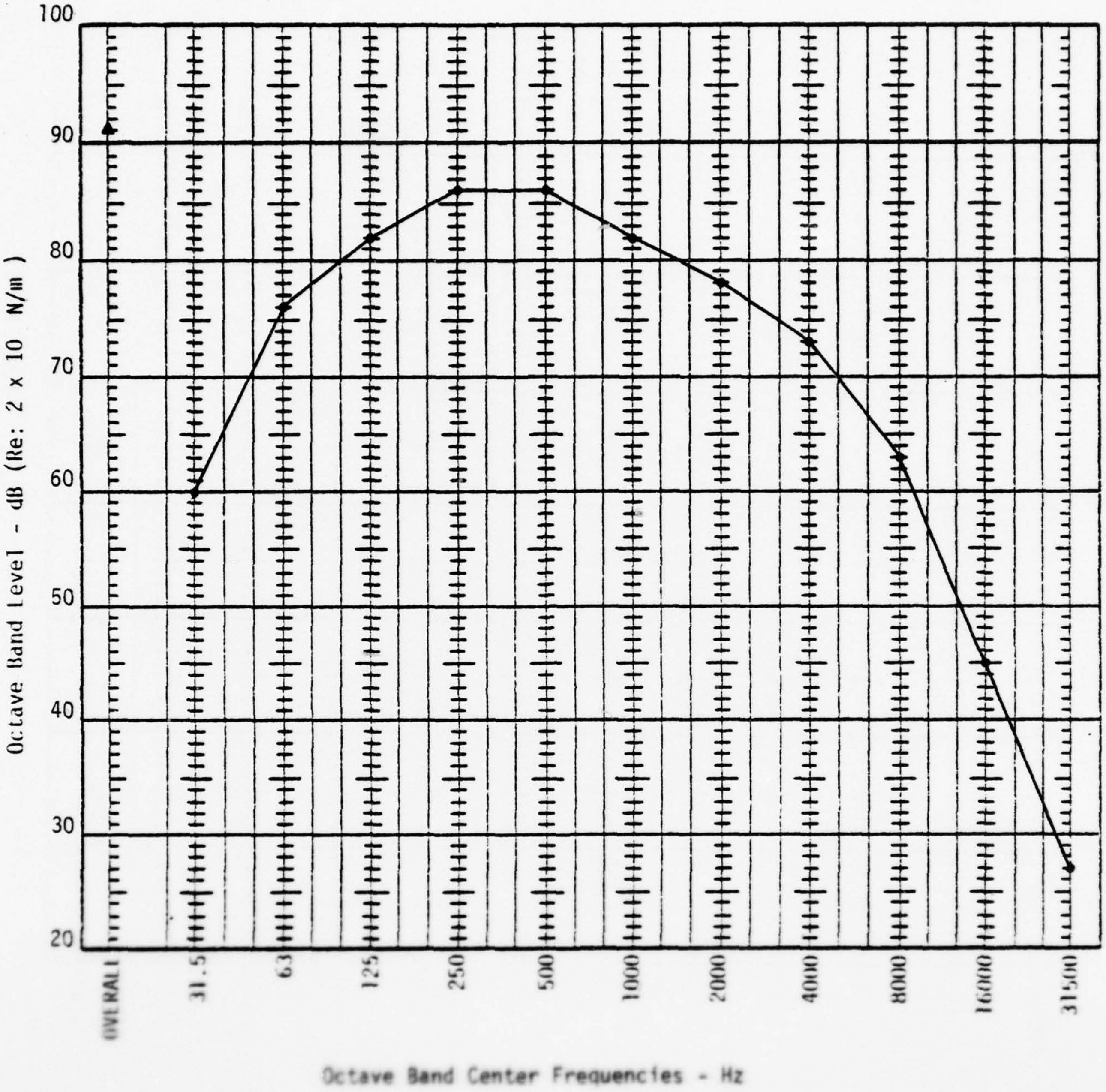

100
90
80
70
60
50
40
30
20
Octave Band Level - dB (Re: 2 x 10 N/m)
Octave Band Center Frequencies - Hz

[illegible]

[illegible]

[illegible]

[illegible]

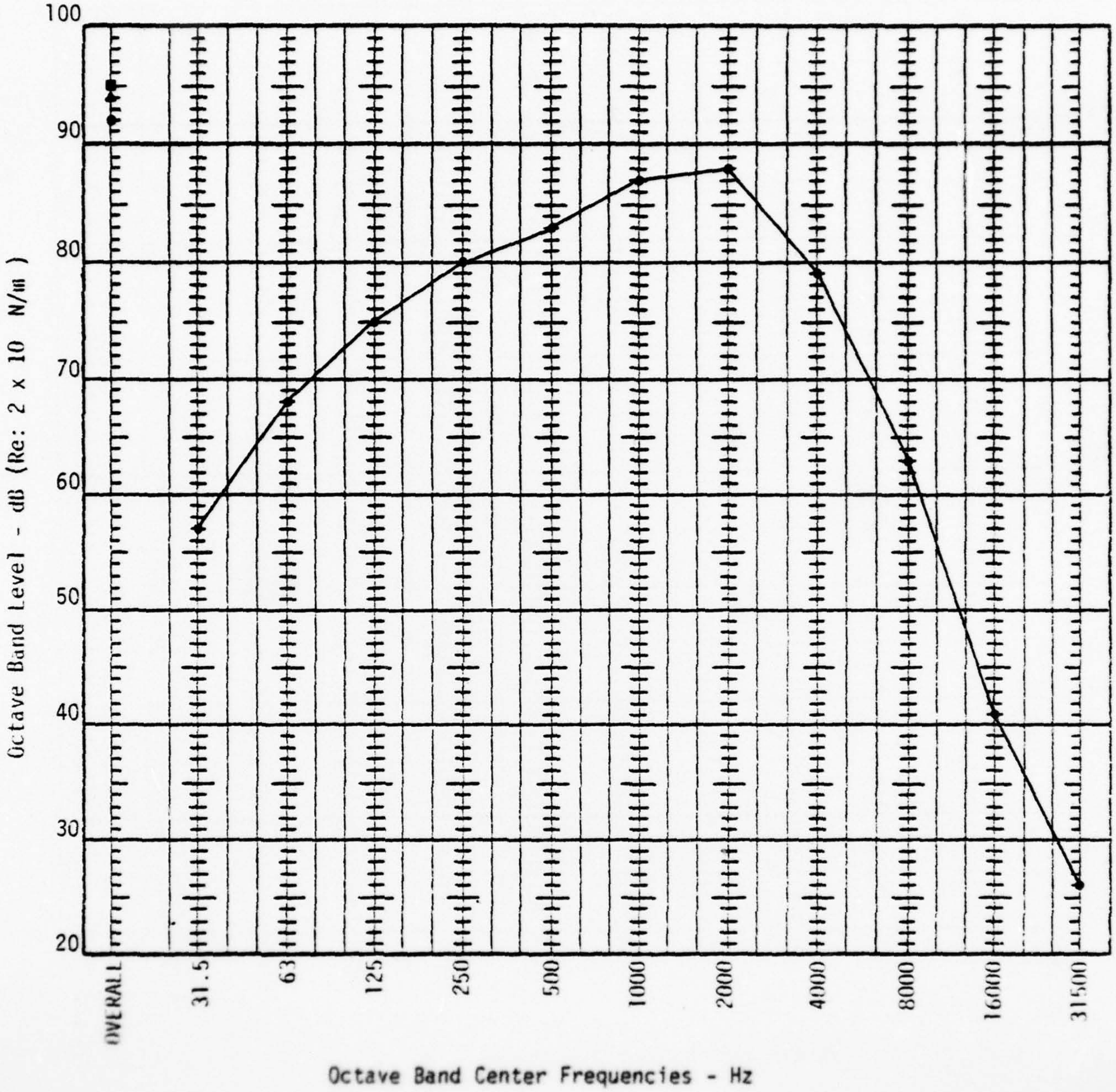


Run #7

▲ Measured dB(A) 91

● Computed dB(A) 91

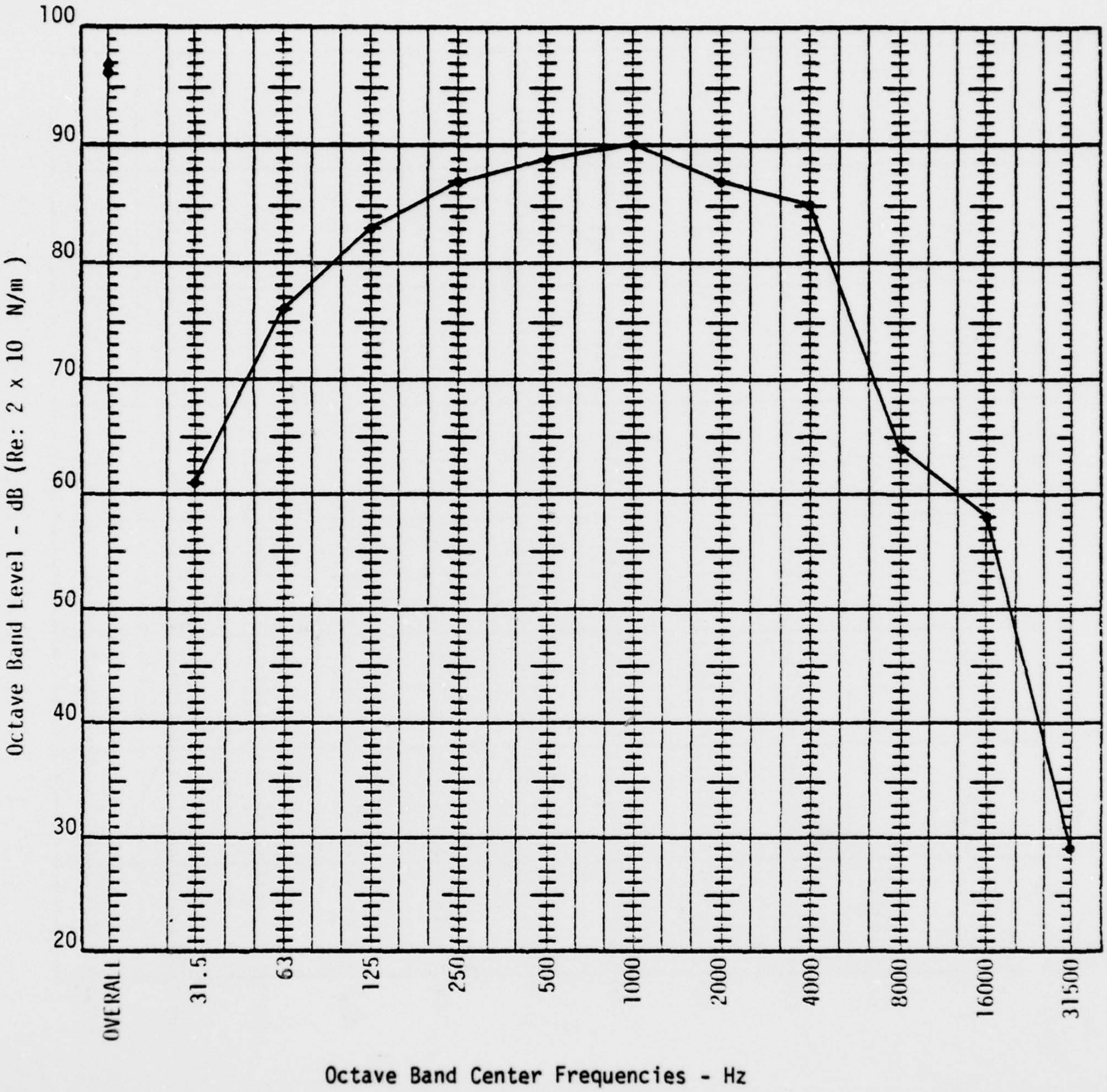
[illegible]



Run #8

- ▲ Measured dB(A) 104
- ● Computed dB(A) 102
- ■ Intended dB 106

(High noise powered without windshield/[illegible] wind and water)

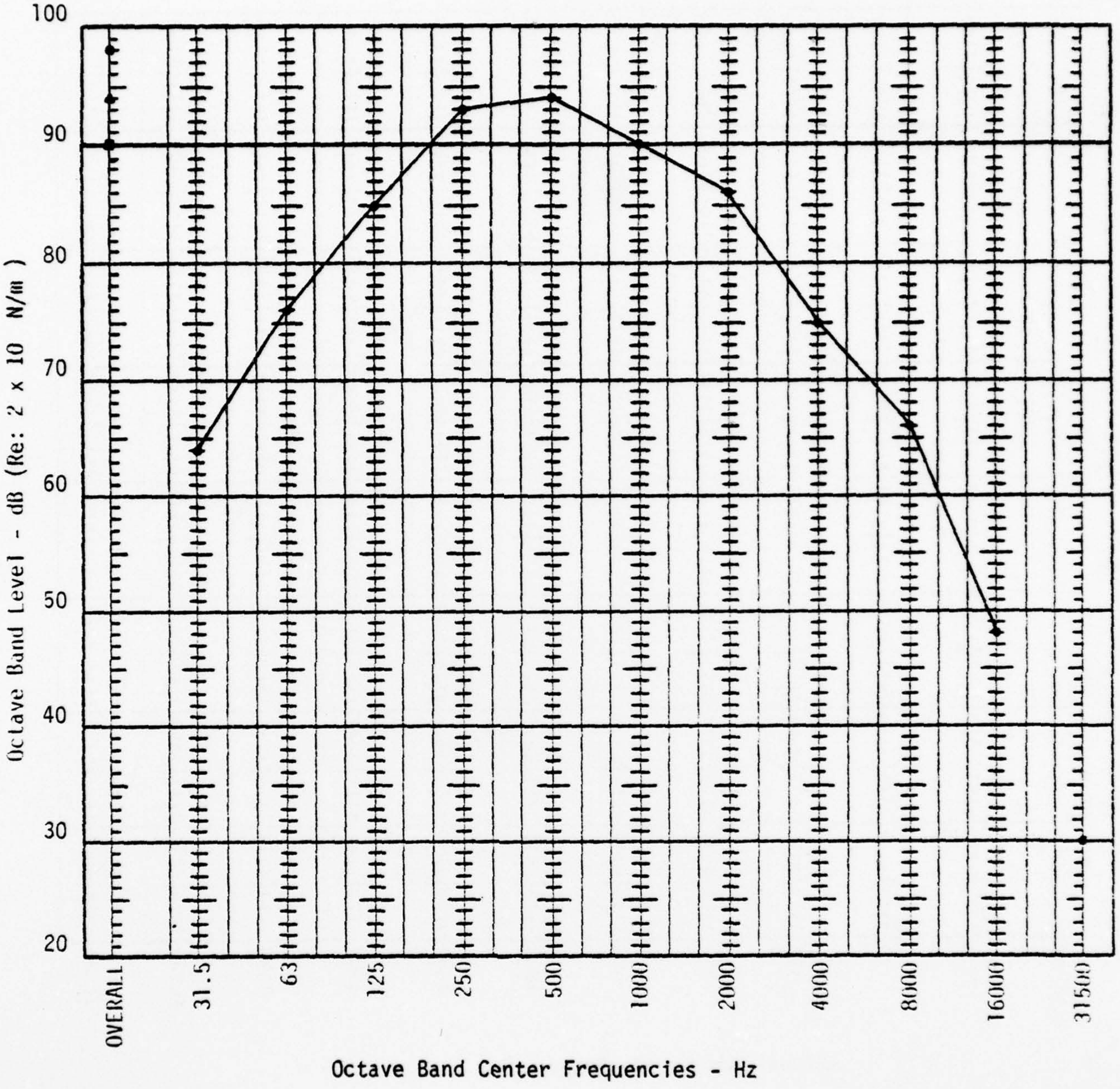


Run #9

▲ Measured dB(A) 97

● Computed dB(A) 95.5

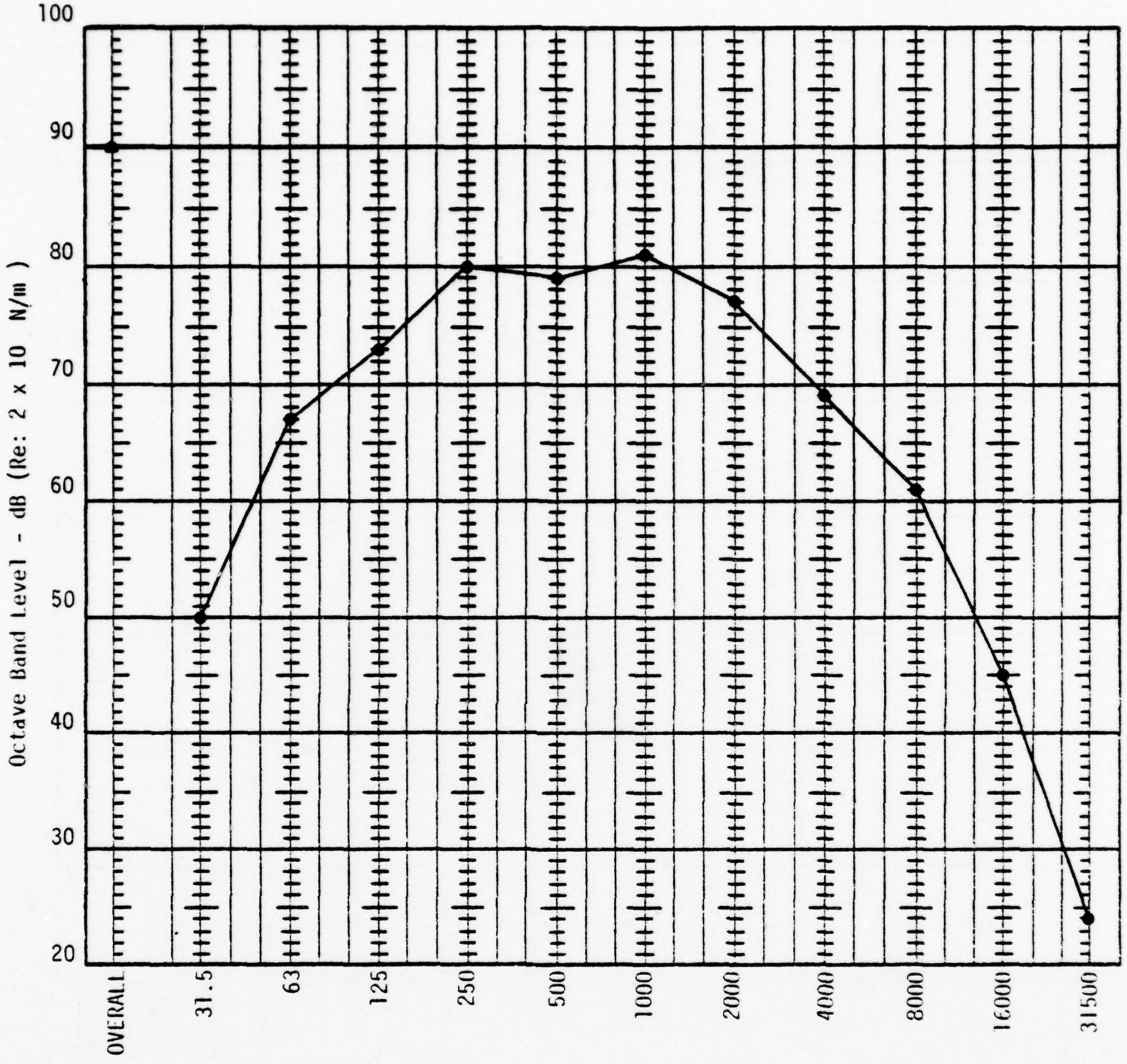
(Medium noise powered without windshield/calm wind and water)



Run #10

- ▲ Measured dB(A) 94
- ● Computed dB(A) 98
- ■ Intended dB 90

(Low noise without windshield/calm wind and water)



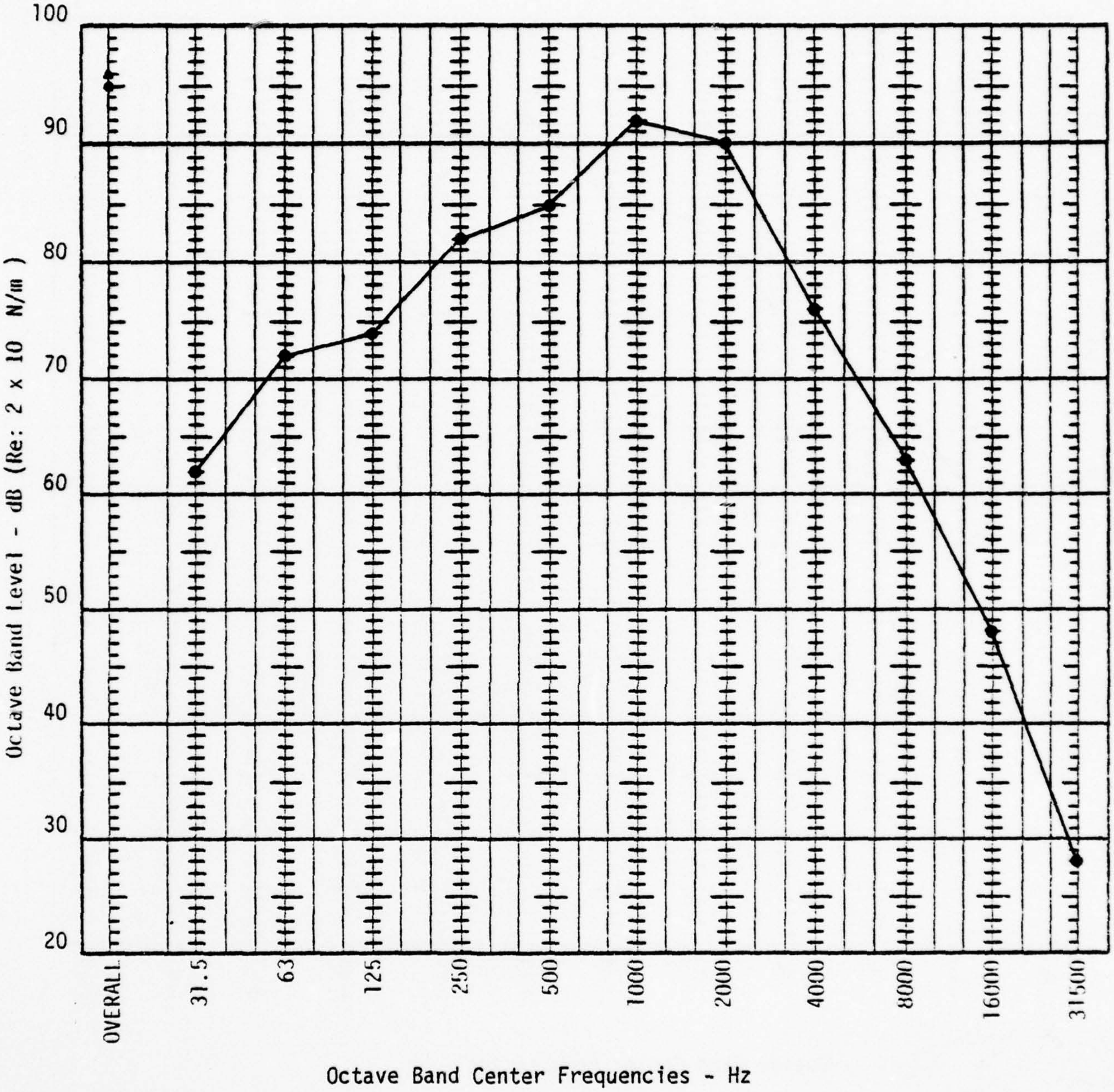
Octave Band Center Frequencies - Hz

Run #17

- ▲ Measured dB(A) 90
- ● Computed dB(A) 90

(Low noise with windshield/calm water and wind)

88

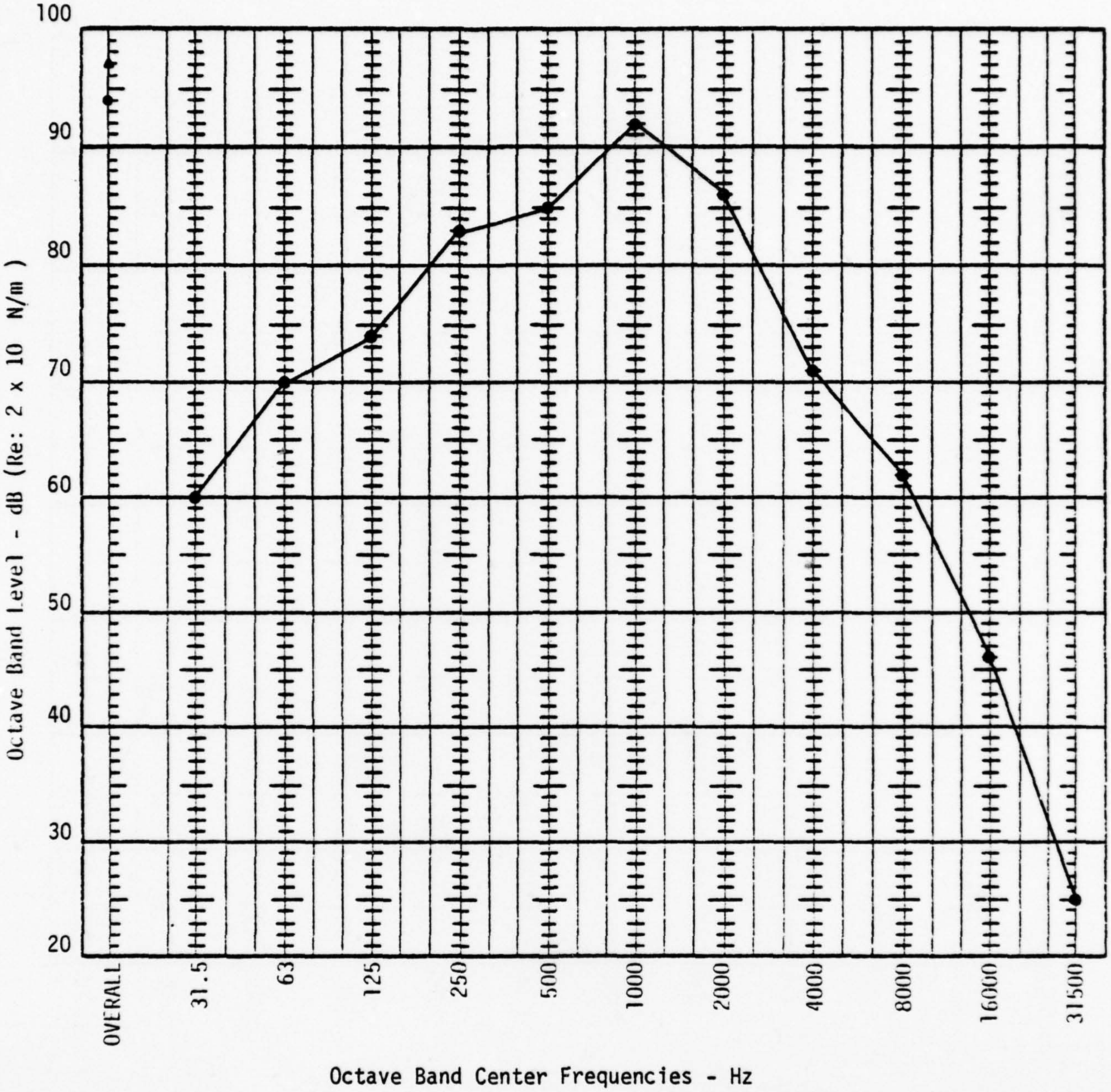


Run #18

▲ Measured dB(A) 96

● Computed dB(A) 95

(Medium noise with windshield/calm water and wind)

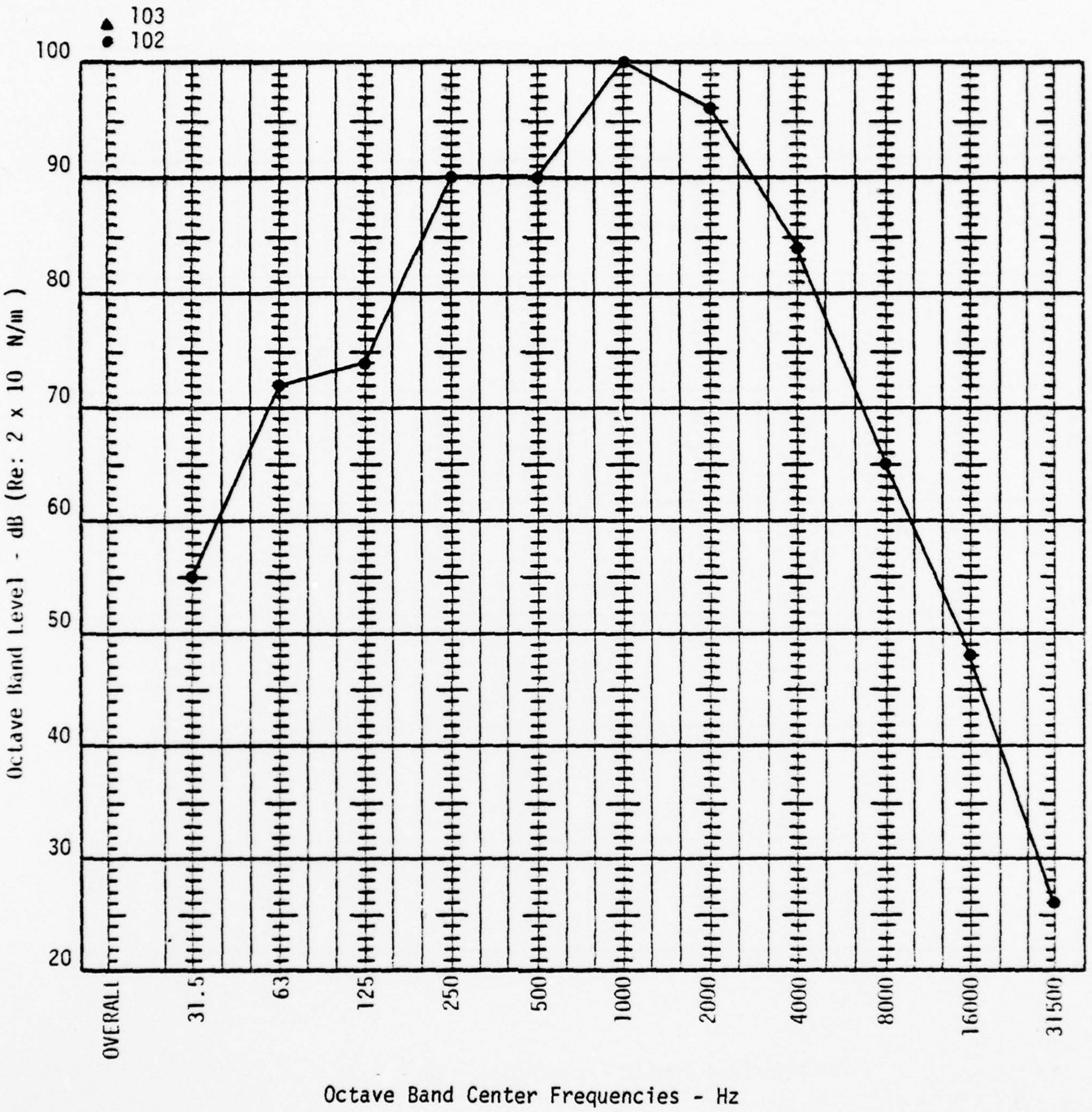


Run #19

▲ Measured dB(A) 97

● Computed dB(A) 94

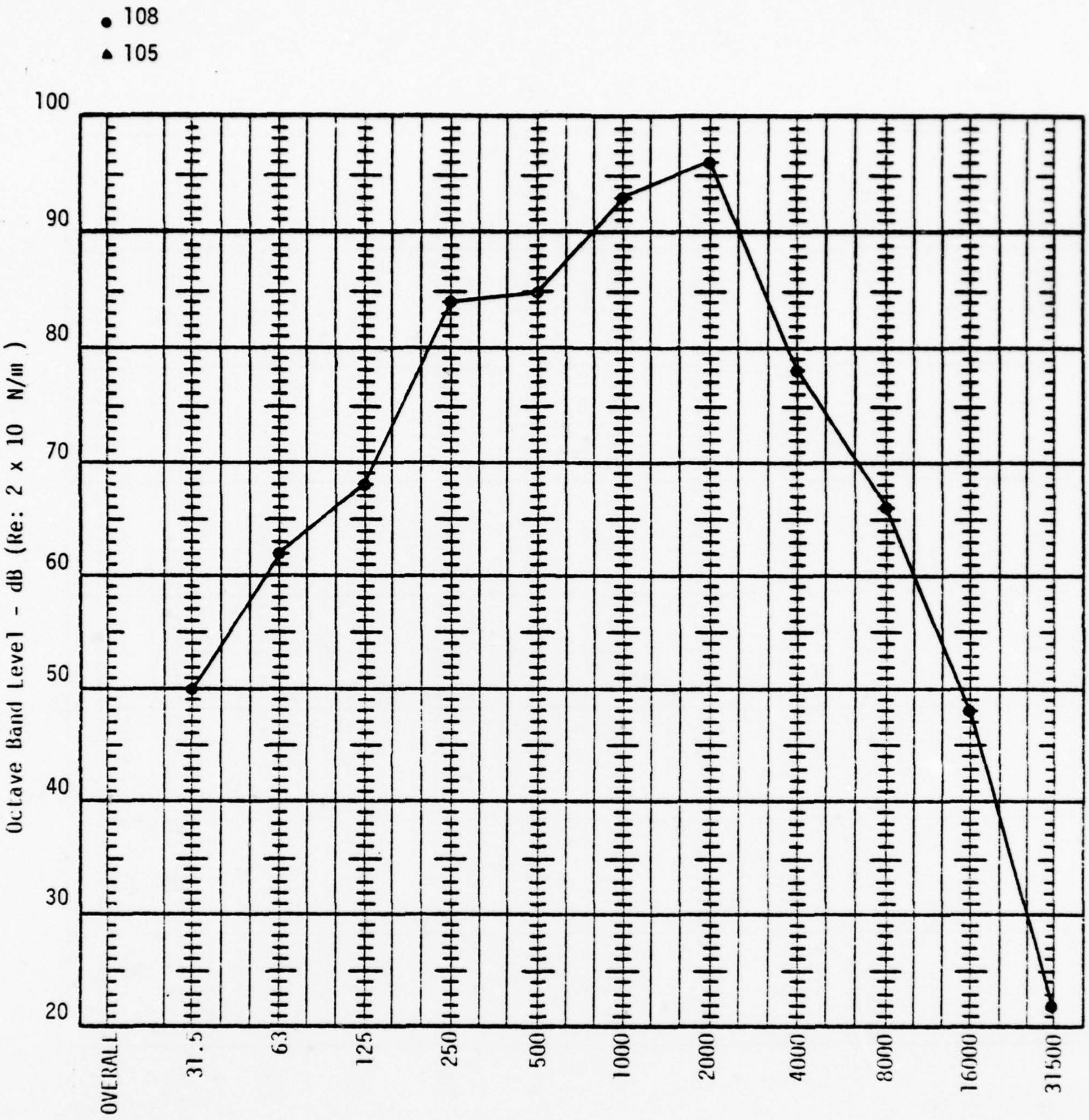
(Medium noise with windshield/calm water and wind)



Run #20

▲ Measured dB(A) 103
● Computed dB(A) 102

(High noise with windshield/calm water and wind)



Octave Band Center Frequencies - Hz

Run #21

▲ Measured dB(A) 105
● Computed dB(A) 108

(High noise with windshield/calm water and wind)

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APPENDIX D. GLOSSARY

This glossary of psychological, industrial engineering, and statistical terms is provided for those readers who may not be familiar with their technical meanings. The glossary has taken the form of conceptual discussions and examples rather than terse dictionary definitions.

dB(A) and SPL

The decibel is a measure of sound intensity (loudness) which is determined by multiplying the logarithm (to the base 10) of the ratio of two intensities by one-tenth. The decibel is actually used to measure the difference in two sound intensities, with one of the two being a standard reference pressure (1 dyne/cm^2). The A-weighted measure (dB(A)) is used to reflect equal-loudness curves for humans. Two sounds that may have the same physical intensity, but at different frequencies, may be perceived as having different loudnesses by people. The dB(A) measure compensates for the human response to sounds (the fact that we are not equally sensitive to all frequencies), and weights the contributions of various frequencies to an overall noise level in order to correspond to the human equal-loudness contours. SPL is an abbreviation used instead of "sound pressure level," and can be used with any of the decibel scales, although it is closely associated with dB measured with equal weight given to all frequencies.

F Statistic/Analysis of Variance

The usual hypothesis under test in an analysis of variance (using the F statistic) is that the mean scores under all treatments (score = whatever you are measuring, treatment = set of levels of variables, the conditions corresponding to a data cell or set of data cells) are equal. Call this hypothersis H_0. The alternative is called H_1: not H_0; i.e., H_1; all population mean scores are not equal. Another way to express these hypotheses is as follows:

H_0: all effects of variables in the experiment are zero

H_1: one or more effects are non-zero.

The F statistic is used to test for the rejection of one of the two hypotheses. In order to compute the F statistic, one must have data (scores) which are normally distributed in the population being investigated. In cases where the data are not normally distributed (such as the response times in VAST), then a transformation can sometimes be found so that the transformed data are more normally distributed. Then the analysis of variance can be performed on the transformed data.

In the computations, the scores are subtracted from the mean within a group of scores and the differences are squared and summed. This is done for each possible combination of variables within an experiment. The results are typically listed in an analysis of variance summary table under "sum of squares." An example can be found in Table 4. The total sum of square is found by summing the squared differences between the individual scores and the overall mean. The degrees of freedom are euqal to the number of categories minus one for an individual variable. For an interaction of variables, the degrees of freedom is equal to the product of the degrees of freedom for the variables in the interaction. This concept originates from the fact that if one knows the overall mean score for a variable, the means for the individual categories are "free" to vary except that once all but one is determined, it can be calculated from the overall mean and the other category means. When data are estimated from existing data, a degree of freedom is lost for each datum that is estimated. This occurred in VAST-3.

The F statistic is computed for any factor or set of factors by dividing the mean square (mean square = sum of squares divided by degrees of freedom) for the factor or factors by the mean square for the appropriate error term. The appropriate error term is chosen by procedures which are too lengthly to discuss for every case here. Basically, the error term is chosen to measure variability <u>within</u> each category of a variable (while the mean square for the factor or factors of interest measures variability <u>between</u>, or, <u>due to</u>, that factor or factors). In Table 4 the error terms corresponded to the factor or factors crossed with the subjects variable, since the subjects were the only factor varying within all levels of each factor. In that example, the factor of subjects had its own sum of squares, representing the residual variance attributable to individual differences between subjects after all other sources of variation had been accounted for. The label "source" is at the top of the table to indicate the source of variation for the computations to the right in the table. To study this table further, the entries to the right of noise represent the variation in the data attributable to differences between noise levels, while the entries to the right of NxS represent the variation attributable to individual differences within those noise levels. F is computed as the ratio between the sums of squares divided by degrees of freedom. Thus,

$$F = \frac{0.015}{2} \div \frac{0.076}{10} = 0.99$$

Under the assumptions described above (normality of the population distributions), when the null hypothesis (H_0) is true, then this ratio is distributed as the random variable F. Thus, one can consult a table of the random variable F for two and ten degrees of freedom to find the value corresponding to a particular significance level (see this term in the glossary) and compare this to the obtained value. For α (significance level) = 0.25 the corresponding F value is 1.60. Our computed value based upon the data in Table 4 is 0.99. Thus, the probability of obtaining these data under H_0 is greater than 0.25. H_0 is accepted; i.e., there is not a statistically significant difference in the scores due to noise.

Feedback Cues

In order for a person's behavior to be controlled or altered, it is necessary that the consequences of his responses be communicated to him (specifically to the mechanisms that initiated his behavior). This communication is the process of feedback. The communication can take the form of presenting cues (sensory inputs in the case of VAST) to the person which portray the result of the person's action. In VAST, the negative feedback cues were the buzzer for an incorrect response and the horn for being off course. The happy face was a positive feedback cue. Feedback has the property of providing motivation for behavior and hastening learning.

Individual Differences

People vary on many parameters. Among other things, they vary on their susceptibility to stressors and their abilities to perform on tasks such as VAST. These individual differences contribute to the variability in data on experiments such as the VAST experiment and are responsible for techniques developed for such

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experiments to compare data and account for that subject-induced variability. One of the faults of all-encompassing standards that are applied to people is that they often fail to account for individual differences. Thus, new guidelines or programs designed to affect people (whether they are oriented toward stressors, or cockpits, or something else) should allow for individual differences in abilities, reactions, physical dimensions, etc. - and at least specify the range or types of people that the guideline or program is supposed to help or apply to.

Information Processing

In psychology the term "information processing" refers to the perceptual and cognitive functioning of people. Viewed as an input-output system, the human accepts data or information through his senses, processes it, and emits responses through his skeletal, muscular, and/or vocal systems. Theories and fields of psychology have been developed to investigate each aspect of the human information processing system. A great amount of research has been performed to study the processing functions from the sensory input to the output of electrical potentials to the muscular and vocal systems. The dimensions of these studies have defined the "information processing capabilities" of man. There are more technical definitions of these terms in the psychological literature (technically, information is defined as that which opposes entropy), and the interested reader is referred to Reference 29.

Interaction

To say that two or more variables interact significantly with each other means that the effect of one variable does not remain the same across different levels of the other, or others. An example is found in Table 8, where the interaction between fatigue and wind in VAST-4 is illustrated. Note that within the "rested" category, "windshield on" led to an average increase in accuracy (d') of 0.12, while within the "fatigued" category, "windshield on" led to an average decrease in accuracy of 0.71. The effect of wind varied across different levels of fatigue, indicating the interaction of the two variables. If the effect of "windshield on" under fatigue had been an average increase in d' of approximately 0.12 (as it was under "rested"), then there would have been no evidence of an interaction between fatigue and wind; i.e., the effects would have been additive and the interaction

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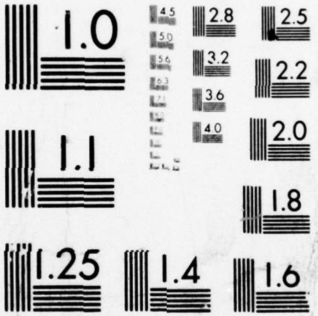

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

would have been zero. To the extent that the effects of variables in combination do not reflect simply adding their individual effects, there is interaction. F tests and other statistical procedures are available to test for the significance of interactions.

Octave Bands

Since the human ear is sensitive to a large range of sound intensities and frequencies, logarithmic scales are used to measure sound intensity (dB) and sound frequencies are usually plotted on logarithmic scales. If the range of frequencies that the human ear can hear is indicated on a logarithmic scale, and that range is subdivided in eight equal spacings on the scale, then the centers of those spacings represent the midfrequencies of the octave bands (62.5 Hz, 125 Hz, 250 Hz, ..., 4000 Hz, 8000 Hz). In order to analyze the spectrum of frequencies composing a sound, the intensity within each octave band (spacing) of frequencies can be measured using a special filter in a sound level meter. Thus, octave band analysis provides a means of differentiating sounds that may have the same overall loudness, but differ in "noisiness" (their frequency spectra).

Reaction Time/Response Time

The two terms "reaction time" and "response time" are often confused, or thought of as being equivalent. As long as it is understood that they are being treated as equivalent terms, no problem exists. However, within the context of this report (and according to some psychologists), there is a distinction. The reaction time of a subject is the time from the onset of a stimulus to the completion of his internal processing of that event prior to the execution of a response. The response time would include the reaction time plus the time required to execute a response. In practice, response times are observable and are usually what are measured. Reaction times can be measured in some cases using electrodes planted in the central nervous system and making some assumptions about neural functioning. However, such techniques and measurments are beyond the scope of this project. The term "one psychological reaction time" is often used to refer to the fastest known signal-response human processing time (pushing a button with a finger in response to a mild shock felt through that button) of about 200 msec. This concept was used in the 1976 Olympics to judge false starts. Anyone who started a race sooner than 200 msec from the signal to start was charged with a false start.

Signal/No Signal/Proportion of Missed Signals/Trials

Within any stimulus-response experiment, the subject must be made aware of what is to be responded to. This is known as the "signal." If the subject is to respond only when no lights are on on the VAST apparatus, for example, then the "signal" would be "no lights." In VAST the "signal" was any light which stayed on for more than one second. Sometimes lights were on for periods equal to or less than one second and the pattern of these appeared to be one (or more) "moving" light(s). These light patterns (any without a "non-moving" light) were classified as non-signals. The proportion of missed signals was calculated by dividing the number of signals that were not responded to by the total number of signals in the VAST test run. Each presentation of a light pattern or patterns (contiguous in time) constituted a trial. The hit rate equals the number of signals responded to divided by the total number of signals. The false alarm rate equals the number of responses to non-signals divided by the total number of non-signals, while the proportion of correct rejections equals the number of non-signals that were not responded to divided by the total number of non-signals in the VAST test run.

Significance/Marginal Significance

When statistical results are reported, the level of significance is usually indicated. As indicated above with the discussion of the F statistic, hypotheses are generally accepted or rejected with some probability of error. In the example of wind in Table 4, H_0 was rejected at the 0.05 level of significance (usually reported "significant at $p<0.05$). This meant that the probability of obtaining those data given H_0 was true was less than 0.05. However, the probability that one has falsely rejected the null hypothesis (falsely rejected H_0) is equal to that small probability that is less than 0.05. This is known as the "significance" of the result or "the probability of Type I error." By convention, a significance level of 0.05 has been chosen by many professionals in the behavioral sciences as the accepted probability of Type I error. A result with a significance level greater than 0.05 is labelled "not significant" by the same convention. Type II error refers to the probability of falsely rejecting H_1 when H_0 is accepted.

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This is known as the "power" of the statistical test. "Marginal significance" is a term that is used to define results that are nearly significant (but not quite) when the investigator is willing to tolerate a slightly higher probability of Type I error than 0.05. This is often the case when the probability of observing a significant result is small due to large individual differences, counterbalancing, or some other reason (this is equivalent to having a high probability of Type II error). Significance levels are often expressed using the Greek letter α or the English letter p.

Stress/Stressors

In terms of the VAST experiments, stress can be defined by the combination of levels and durations of exposure to manipulated environmental factors and alcohol experienced by the subjects. Individual stressors were the individual factors that were manipulated (noise, wind, and fatigue). Other stressors (glare, humidity, etc.) were present and neither controlled (other than by using counterbalancing in the design) nor analyzed.

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