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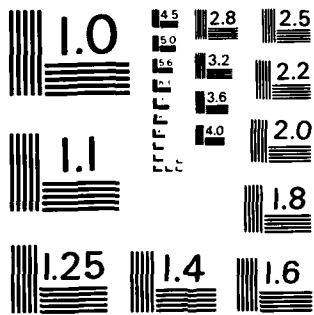   PERCEPTION LAB   W R UTTAL 30 NOV 84 PERLAB-5
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FINAL REPORT

The Discriminability of Signals from Noise
in a Dynamic Stereoscopic Space

AD-A148 406

William R. Uttal

Perception Laboratory
Institute for Social Research
The University of Michigan
Ann Arbor, Michigan 48106

November 30, 1984

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The results of this work have been presented in two short reports and two long monographs which have been published as books. During the three years the project has been in existence 40 separate experiments have been carried out. The main mission of the project was to determine the manner in which constellations of dots were detected when embedded in random arrays of dots in two and three dimensions.

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The main outcome of the contract has been the evolution of specific rules of dotted form perception. Specifically:

a. The Rule of Linear Periodicity
   Straight dotted lines consisting of dots spaced equally from each other are detected better than dots on curves or when they are irregularly spaced. Lines are the prepotent visual stimulus.

b. The Rule of Random Sampling of Surfaces
   Response surfaces are detected better when sampled with random samples than with regularly spaced ones when those surfaces are continuous and regular.

c. The Rule of Three-dimensional Noncomputability
   Some three-dimensional attributes of nonplanar stimuli can not be evaluated by the visual system and therefore do not affect detectability.

Throughout this contract period we have been able to simulate human performance by means of a mathematical model based on the autocorrelation function. The model continues to work well except with three-dimensional stimuli.

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A. Cover Letter

TO: Chief of Naval Research, Arlington, Virginia 22217
         Attention: Engineering Psychology Programs, Code 442EP
         Drs. Willard Vaughan, Jr. and J.J. O'Hare

FROM: Dr. William R. Uttal, Institute for Social Research
         The University of Michigan, Ann Arbor, Michigan 48106

SUBJECT: Final report of work completed under the support of Contract N00014-
         81-C-0266, Work Unit No. NR197-070, between the University of
         Michigan and the Engineering Psychology Programs, Office of Naval
         Research

1.   This document constitutes the final report of the contract and work unit
     mentioned above. The contract was initiated 1 October 1981 and terminated
     30 November 1984.

2.   The mission of this contract was to study how the dimensions of stimulus-
     form and psychological performance determine how human observers detect
     dotted forms in dotted visual noise.

B. Summary of Research Reports

1. Introduction

The dot-masking paradigm has proven over the years to be a rich source of data and ideas related to problems of form perception. This final report summarizes the last three years of research in this laboratory (mainly reported in two papers and in two book length monographs — Uttal, 1983; 1984). The purity of the stimulus-forms used in this kind of study (that is, their freedom from both energy-driven receptor influences and context-dependent semantic and cognitive influences) allowed us to examine some subtle information-processing attributes of visual detection processes that are often hidden or overwhelmed by other energy sensitive, peripheral, or meaning-dominated central effects if non-dotted, natural, or realistic stimulus-forms had been used.

One of the early major discoveries concerning detection that was made using this method is the very straightforward and undeniable fact that some constellations of dots are more detectable than others, even when dot numerosity, spacing and all other variables other than arrangement are controlled. That is, the global geometry, per se, of a constellation of dots (and presumably other kinds of stimulus-forms) influences their detectability above and beyond the specific details of their local features. Indeed, when dotted stimulus-forms are used, the local features have been reduced to nil. For the detection of two-dimensional forms, the general result can be formalized as a general law — The Rule of Linear Periodicity. This rule emphasizes the prepotency of straight, periodically spaced dotted lines in dotted form detection. The reasons for special visual sensitivity to straight-lines are suggested, but the underlying physiological mechanisms are not

completely illuminated or explained, by the mathematical transformation embodied in the earlier versions of our computational model that has been used to describe these data. The autocorrelation model is a means of processing approximations of stimulus-forms in a manner that has been shown in many cases to be analogous to the way in which the same stimuli are processed by the human visual system. To the degree that the autocorrelational transformation and psychophysical phenomena agree, it can be asserted that the model is sensitive to many of the same attributes of the stimulus as is the perceptual skill. Beyond this statement of analogy, however, interpretations concerning the exact details of the underlying physiological mechanisms become highly speculative.

It has been extremely instructive to apply the autocorrelation model, which does a surprisingly competent job of actually predicting the psychophysical detectability of two-dimensional dotted stimuli to the psychophysical data. This is so even though the model does not work well in a three-dimensional stimulus environment.

The autocorrelation transformation is a special case of a convolution integral based on the following formula:

$$A_c = \iint f(x,y) \cdot f(x+\Delta x, y+\Delta y)\, dy\, dx$$

where Δx and Δy are shifts in the positions of the points of a stimulus-form $f(x,y)$ required to produce a shifted replica — $f(x + \Delta x, y + \Delta y)$.

Some more pure mathematicians than I have suggested that the discrete

form in which we evaluate this algorithm is not exactly an autocorrelation but, rather, an "autocorrelation-like" transformation. A complete description of the discrete computational algorithm actually used to compute the autocorrelation has been presented in Uttal (1975).

A family of $A_c(\Delta x, \Delta y)$ values must be computed for all possible Δx and Δy combinations to fill the autocorrelation space. The autocorrelational surface is made up of a number of peaks distributed in the $\Delta x, \Delta y$ space. By applying the following empirical expression:

$$F = \frac{\sum_{n=1}^{N} \sum_{i=1} (A_n \times A_i)/D}{N} \qquad i \neq n$$

a single numerical "Figure of Merit" (F_m) can be generated for each autocorrelated stimulus pattern. In this expression, A_i and A_n are the amplitudes of peaks taken pairwise, D is the Pythagorean distance in the $\Delta x, \Delta y$ space between the two peaks, and N is the number of peaks. The purely arbitrary and ad hoc Figure of Merit produces families of F_m's that are closely associated with the relative psychophysical detectability of sets of stimulus-forms.

2. Technical Report: PERLAB 1 - Distribution of Stereoanomalies in the General Population (ADA115229)

Millicent Newhouse and William R. Uttal

Large proportions of the general population have frequently been reported

to be stereoscopically anomalous. However, when we tested a large sample (103 persons) we found all (with the exception of three truly stereoblind observers) to be able to initially detect depth in Julesz random dot stereograms within two minutes. Some persons, however, were not able to detect depth when retested immediately with reversed disparity, but half of those were able to see depth on retesting a few days later. We conclude that stereoanomalies are much rarer than previously suggested and that any putative one-way (i.e., restricted to crossed or uncrossed disparity) perceptual deficiencies are actually due to attentive strategy or sequence effects rather than to neural limitations.

3. Technical Report: PERLAB 2 – Visual Form Detection in 3-dimensional Sapce (ADA120448)

William R. Uttal

In the first of the two main series of experiments we turned from two-dimensional stimuli hidden in two-dimensional masks to stimuli that, while still two-dimensional themselves (single dots, lines, and planes), were embedded among random visual masking-dots that were arrayed in three-dimensional space. This series of experiments was published in the archival literature as: Uttal, W.R. Visual Form Detection in Three-Dimensional Space. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1983.

This work also achieved a number of interesting results:

1. As an unmitigated generality, increasing the number of masking-dots monotonically reduced the detectability of a dotted stimulus-form when all other variables are held constant. In other words, the raw signal (stimulus-dot numerosity)-to-noise (masking-dot numerosity) ratio was a powerful determinant of dotted-form detection. Although

not surprising, this outcome is an important cross-referencing parameter between different experiments and is of interest in its own right. This outcome confirmed and extended the findings concerning signal-to-noise ratios from the earlier study with two-dimensional stimuli.

2. The position of a repetitive flashing dot in the apparent cubical space exerted only a minor effect on its detectability. A dot placed far off the rear, lower, right-hand corner was seen slightly less well than dots at other positions, and one centered in space was seen slightly better. Although I presented no equivalent data concerning the translations of lines or planes, within similar limits and on the basis of my two-dimensional results, I believe this result also holds for such multidimensional stimuli.

3. Repetitively flashed dots with interdot intervals of 100 msec were seen better than those with shorter or longer intervals when the number of flashed dots was held constant. The function relating single-dot detectability to interdot interval was thus nonmonotonic and suggests the existence of an optimum interval of about this duration.

4. In dotted-form discrimination, there was a substantial advantage gained by using a dichoptic viewing condition that allowed the perceptual construction of depth compared to either binocular or monocular viewing conditions in which no disparity cue to depth was present. Somewhat surprisingly, binocular viewing produced higher detection scores than did monocular viewing, in spite of the fact that there was no information difference between the stimuli in the two nondisparity viewing conditions.

5. Increasing the interdot interval between sequential dots in a plotted straight-line of dots led to a monotonic and nearly linear reduction in the detectability of the line. It is unclear whether this was a result of the increase in the interval per se or due to the increased number of masking-dots encompassed by the duration of the dot train. What is certain is that apparent movement did not substitute in any way for simultaneity.

6. Very surprisingly, irregularity of the temporal intervals between the plotting of successive dots did not appreciably diminish dotted-line detection. A high degree of interdot-interval irregularity could be tolerated without reduction in detection scores.

7. Spatial irregularity of the dots along a straight-line affected detectability at short interdot-intervals (less than or equal to 30 msec). However, at longer dot intervals these same spatial irregularities exerted little influence on detectability. In some manner, visual mechanisms seemed to be able to compensate for these spatial distortions if sufficient time elapses between the plotting of sequential dots.

8. An increase in the disorder of the sequence in which a series of regularly spaced (in time and position) lines of dots was plotted produced only a modest, though monotonic, decrease in the detectability of the form. This form of irregularity, so extreme that it violated the spatio-temporal topology of the stimulus-form, could still be partially overcome, presumably by the same mechanisms that were capable of "smoothing" temporal and spatial irregularity.

9. Dotted-line orientation in space was ineffective in influencing detectability scores. Visual space was isotropic for diagonal lines.

10. When two planes were to be discriminated from each other with regard to their respective depths:

a. The greater the dichoptic disparity between the two planes, the more easily one was discriminated from the other.

b. The effect of the number of dots in the two planes was relatively small. Indeed, discrimination of a highly reduced stimulus consisting of only two dots was easily accomplished.

c. A reduction in viewing time led to a progressive though modest reduction in the discrimination of the two planes.

d. When a burst of masking-dots followed the presentation of a dichoptic stimulus, stereoscopic performance was especially degraded at intervals less than 50 msec.

11. The form of a planar stimulus composed of even a relatively large number of randomly arrayed dots had a surprisingly small effect on its detectability, given what we had previously learned in the earlier two-dimensional studies with dotted-outline forms. Even when the viewing time was reduced, further impoverishing the dot-masked stimulus, the form defined in this way remained an ineffective variable and any putative effect of form was not enhanced. Furthermore, the effect of even as drastic a manipulation as changing the stimulus-form from a square to an elongated rectangle was slight. However, this conclusion did not hold for forms defined by dotted-outlines. Dotted-outline forms showed a strong increase in detectability as they became more oblong.

12. There was virtually no effect on detectability when a planar stimulus-form defined by a random array of dots was rotated around the y axis. When the form was rotated in more complex ways around two or three

axes the experimental outcome was equally unaffected. Space also appeared to be isotropic for planes of this kind.

13.   The gradient of form detectability was very steep between 88 and 90 deg of rotation, but virtually flat over the entire range from 0 to 88 deg.

14.   When a frontoparallel-oriented plane was placed in different positions within a cubical space filled with masking-dots, it was most easily detected at the center of the cube.   Detectability diminished, therefore, where disparity was greatest in either the crossed or uncrossed direction.

These, then, are the major findings that were obtained in the study of the influence of stimulus-form on the detectability of two-dimensional dotted forms in stereoscopic space.

The autocorrelation transformation also successfully modeled these psychophysical data. Because of the essentially two-dimensional nature of the stimulus-forms it was easy to represent many of the stimuli that were utilized in these experiments with the autocorrelation mathematics and to calculate the Figure of Merit. Some striking surprises emerged when this was done—most notably, evidence to support the prediction of both qualitative and quantitative differences between planes composed of random arrays of dots and those composed of dotted-outlines.

4. Technical Report: PERLAB 3 - Detection of Dotted Forms in a Structured Visual Noise Environment (ADA138853)

Michael J. Young

Five experiments were carried out to explore the human observer's ability to detect single dotted lines masked by other dotted lines. Stimuli were presented tachistoscopically on a computer controlled cathode ray tube. Results indicate that: 1) Rotations of the stimuli, relative to the orientation of the noise lines, improve detection performance only if the rotations are made around the Z axis. Rotations around the Y axis fail to influence detection performance. 2) The mechanism involved in the detection of dotted forms uses different strategies or algorithms depending upon the density of the noise mask. 3) Orienting the stimulus and masking lines to other than the horizontal decreases detection performance.

5. Technical Report: PERLAB 4 – The Detection of Nonplanar Surfaces in Visual Space (ADA138761)

William R. Uttal

In the second of the two experimental series using this paradigm, our laboratory concentrated on the detection of truly three-dimensional forms nonplanar surfaces that were created by elastically stretching planar prototypes. This work was published in the archival literature as: Uttal, W.R., The Detection of Nonplanar Surfaces in Three-Dimensional Space. Hillsdale, New Jersey: Lawrence Erlbaum Associates, 1984.

A number of interesting results also came from this work.

1.   Different nonplanar stimulus types are detected with varying degrees of ease in the dotted-surface-in-dotted-mask type of task. A parabolic arch is detected slightly better than the average, and a double cubic and hyperbolic paraboloid are detected slightly less well than the average.

However, these effects were surprisingly small.

2.   Distributing the dots of the mask throughout the perceived space by means of disparity-controlled stereopsis has the effect of dedensifying the mask and increasing performance when the stimulus-forms are generated from random-dot arrays but not when they are generated from regular grids.

3.   The degree of deformation of simple types of polynominal-generated, nonplanar, surfaces, however, has little effect on detectability. Simple types are those in which the surfaces have less than two maxima or minima. This null result obtains in spite of the fact that the apparent surface of an elastically stretched stimulus may have a greatly enlarged area compared to its planar prototype and thus lower apparent stimulus-form dot density.

4.   The degree of deformation from a plane to a nonplanar stimulus surface, however, does exert a measurable, though modest, influence on detectability when more than a single maximum or minimum is present on the nonplanar surface.

5.   As the number of maxima and minima increases — for example, as regulated by the spatial frequency of a sinusoidal surface undulating in depth — detectability decreases further. However, close examination of such stimulus-forms indicates that a major portion of the effect of this parameter of form can be attributed to inadequate information being available to define the shape. At lower stimulus-form dot densities, the sampling density is insufficient for even an ideal observer to reconstruct the form. The human observer does only slightly less well than the limits imposed by the sampling theorem — a remarkable outcome in itself.

6.   The signal-to-noise ratio is a strong determinant of the detectability of a form. Either increasing the stimulus-form dot density or decreasing the masking-dot density increases the detectability of the form. In sample

experiments in which the effect of form is negligible, over 90 percent of the variance in performance scores is accounted for by the signal-to-noise ratio alone.

7.   Three-dimensional nonplanar stimuli can be formed from either random arrays of dots or regular grid-like arrangements of dots. Surprisingly, grid-like stimuli are detected less well than those formed from random arrays of dots except at the very highest stimulus dot densities.

There are several paradoxical or puzzling results reported in Uttal (1984) that should be especially noted.

a.   Dedensifying the dots of a random-dot array stimulus-form by stretching it into three-dimensional space did not reduce the form's detectability.   However, the stereoscopic procedure did strongly reduce the effect of a given number of masking-dots compared to monocular viewing.

b.   The size and mix of the stimulus set often influenced the detectability of individual members of the set.

c.   The autocorrelation model, which had been so successful with two-dimensional stimuli, failed to predict the outcome when three-dimensional stimuli are tested.

d.   Grid stimulus-forms do not exhibit even the slight sensitivity to nonplanar shape compared to that exhibited by forms generated from random-dot arrays.   Yet, the grid stimulus-forms are both less and more susceptible to masking, depending upon the number of stimulus dots present. In this case, stereoscopic dedensification seems to offer no advantage at high densities and to even be detrimental at low densities.

From a theoretical point of view, the most interesting implication of the surprising and counterintuitive outcome that grid-like stimuli are more strongly influenced by masking dots than are the random array stimuli is that a random sampling procedure is used more effectively by the visual system than a regular or systematic sampling procedure to reconstruct the sampled surface. While initially startling and unexpected, this result is not totally unprecedented in the literature of sampling theory. Madow and Madow (1944) and Madow (1946) have studied this problem and have ascertained that there do indeed exist certain conditions in which random sampling procedures provide better estimates of the properties of a population than does systematic sampling.

Similar results have been obtained by Quenouille (1949) and Das (1950) who have both described statistical tests that show that random or unaligned samples are often more precise means of determining the characteristics of a surface than regularly placed grids. Even more relevant is a report by Milne (1959) in which it was reported that for those situations in which regular grid sampling definitely worked best, the "autocorrelation effects are weak." Weak autocorrelation means that there is no tendency for nearby samples to be related, a situation that assuredly does not obtain with the geometric surfaces used as stimulus-forms in this study. Mathematically, if not perceptually, nearby points on these surfaces are more highly correlated than distant ones. Thus, Milne's results are also consistent with both the other statistical studies and the present psychophysical results.

It seems in general, therefore, that if the points on a surface are themselves unrelated, then a systematic sample is more precise. If, on the other hand, nearby points are related (for example, by being more likely to be at the same depth than distant points are likely to be) then the random sample is more precise. This statistical subtlety is reflected in the psychophysical performance of our

observers. It is quite probably also associated with the reduced tendency to create pseudoforms, a process better known as aliasing.

Thus, the obtained superiority of random arrays over grid arrays makes sense from a statistical sampling theory point of view. This explanation rings true at least for the lower density stimuli. At higher densities, the grid stimuli are very resistant to masking for another reason — the monocular advantage provided by the rule of linear periodicity mentioned earlier. The reason that the loss of stereoscopic information is so devastating to random-dot stimuli and so much less significant with the grid stimuli may also be related to this interaction between the monocular cue of linear periodicity and the loss of the advantage enjoyed by randomly sampled stimuli as stereoscopic information is lost. Nevertheless, there are still many mysteries concerning these data. Statistical considerations like these only begin to shed some light on a few of the more counterintuitive outcomes of this study.

Finally, the absence of a strong form-effect in three dimensions comparable to that observed in two dimensions can be interpreted in terms of our ability to process the constructed three-dimensional information. Some computer theorists have suggested that true three-dimensional form recognition is not possible (even though we can construct three dimensions from two and can recognize three-dimensional objects by processing their two-dimensional projections). If this is true, the inability of the visual system to differentially detect different three-dimensional form is at least consistent with the mathematical limitations observed in artificial intelligence work.

In summary, the data reported in Uttal (1984), suggests two new rules or laws of dotted, nonplanar form detection that can be added to the "Rule of Linear Periodicity" that worked so well for planar and linear structures.

1.   The Rule of Random Sampling — Nonplanar stimulus-forms can be detected better if they are constructed from random arrays of dots than if constructed from regular arrays if the constructed surfaces are regular and have high autocorrelations (i.e., if regions near each other are more alike than regions distant from each other).

2.   The Rule of Three-Dimensional Noncomputability — Nonplanar surfaces (and presumably also solid objects) cannot be processed in the same way as two-dimensional objects.   Geometrical sensitivity existing in two dimensions do not exist in three dimensions because the nervous system (and possibly many other computers) does not have the power to directly evaluate three-dimensional geometry.

C. Archival Publications Other Scholarly Activity

I. Archival Publications

a. Books

1. Uttal, W.R. Visual Form Detection 3-D Space. Hillsdale, NJ: Lawrence Erlbaum Associates, 1983.

2. Uttal, W.R. The Detection of Nonplanar Surfaces in 3-D Space. Hillsdale, NJ: Lawrence Erlbaum Associates, 1984.

b. Articles

1. Uttal, W.R. Neuroreductionistic dogma: A heretical counterview. In Albrecht, D.G. (Ed.) Lecture Notes in Biomathematics Recognition of pattern and form. Berlin: Spriger-Verlag, 1982.

2. Uttal, W.R. Codes, messages, and media. Commentary in The Behavioral and Brain Sciences, 1981, 4, 207-208.

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13. Uttal, W.R. An analytic success: A synthetic bust. (Review of Geissler, Buffart, Leeuwenberg, and Sarris, (Eds.) Modern Issues in Perception) Contemporary Psychology, In Press.

II. Other Scholarly Activities

W.R. Uttal

a. Quest for Technology Award, University of Michigan, 1982 & 1983

b. MacEachran Memorial Lecturer, University of Alberta, 1982

c. Scholar-in-residence, Rockefeller Foundation Bellagio (Italy) Study Center, 1983

d. Visiting Scientist (Japan), Japanese Society for the Promotion of Science, 1983

D. Personnel Associated With Project

Teresa Garland	Programmer
William Robertson	Secretary
John Brogan	Programmer
Cheryl Slay	Secretary
Mark Azzato	Research Assistant
Yu Bo-lin	Visiting Scientist
Millicent Newhouse	High School Science Apprentice
Susan Robertson	Research Assistant/Secretary
Shuba Deshpande	Systems Analyst
Michael Young	Research Assistant
Katherine McReight	Research Assistant
Larry Spino	Programmer
Brian Wanty	Secretary
Phyllis White	Research Assistant/Secretary

E. Recommendations

Perhaps the most serious difficulty with the paradigm with which we have worked during the last three years is that it is so rich. It is rich both in the possibilities that exist for psychophysical experimentation and for modelling. In the latter case, the discrete abstraction to real scene stimuli provided by the dotted environment makes it a perfect vehicle for the development of mathematical models. Similarly, the rich variety of controllable dimensions permits us to explore well defined aspects of visual performance that would not be amenable to analysis with ordinary stimuli. The dotted environment thus becomes a fruit-fly for research in a wide variety of pattern recognition, discrimination, and detection problem areas.

One practical application which obviously come from this line of research is a three-dimensional display for a variety of geographical, oceanographic, medical, and other related applications. So far, no one seems to have followed up on this obvious application and it is strongly recommended that this be done. Many devices are easily engineered that use the stereocues that are now appreciated to be very important in a wide variety of visual and motor tasks.

Further development of mathematical models of this genre is also recommended. The advantages of the analytic as opposed to the statistical approach are manifold. In particular, they lend themselves very well as suggestions for specific hardware.

In sum, there is much yet to be done in the field in which this project has it roots and it is strongly recommended that further basic science activities of this kind be supported in the future.

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  Operations, OP987H
Personnel Logistics Plans
Washington, D.C. 20350

Combat Control Systems Department
Code 35
Naval Underwater Systems Center
Newport, RI 02840

Human Factors Department
Code N-71
Naval Training Equipment Center
Orlando, FL 32813

Dean of Research Administration
Naval Postgraduate School
Monterey, CA 93940

Human Factors Engineering
Code 8231
Naval Ocean Systems Center
San Diego, CA 92152

Dr. Ross Pepper
Naval Ocean Systems Center
Hawaii Laboratory
P. O. Box 997
Kailua, HI 96734

Mr. Paul Heckman
Naval Ocean Systems Center
San Diego, CA 92152

Department of the Navy

Dr. A. L. Slafkosky
Scientific Advisor
Commandant of the Marine Corps
Code RD-1
Washington, D.C. 20380

Office of the Chief of Naval
  Operations (OP-115)
Washington, D.C. 20350

CDR C. Hutchins
Code 55
Naval Postgraduate School
Monterey, CA 93940

Human Factors Technology Administrator
Office of Naval Technology
Code MAT 0722
800 North Quincy Street
Arlington, VA 22217-5000

CDR Tom Jones
Naval Air Systems Command
Human Factors Programs
NAVAIR 330J
Washington, D.C. 20361

Commander
Naval Air Systems Command
Crew Station Design
NAVAIR 5313
Washington, D.C. 20361

Mr. Philip Andrews
Naval Sea Systems Command
NAVSEA 61R
Washington, D.C. 20362

CAPT Robert Biersner
Naval Biodynamics Laboratory
Michoud Station
Box 29407
New Orleans, LA 70189

Dr. George Moeller
Human Factors Engineering Branch
Submarine Medical Research Lab
Naval Submarine Base
Groton, CT 06340

Foreign Addressees

Human Factors
P.O. Box 1085
Station B
Rexdale, Ontario
Canada M9V 2B3

Dr. A. D. Baddeley
Director, Applied Psychology Unit
Medical Research Council
15 Chaucer Road
Cambridge, CB2 2EF England

Other Government Agencies

Defense Technical Information Center
Cameron Station, Bldg. 5
Alexandria, VA 22314 (12 cps)

Dr. Clinton Kelly
Defense Advanced Research
   Projects Agency
1400 Wilson Boulevard
Arlington, VA 22209

Dr. M. C. Montemerlo
Human Factors & Simulation
Technology, RTE-6
NASA HQS
Washington, D.C. 20546

Other Organizations

Dr. Jesse Orlansky
Institute for Defense Analyses
1801 N. Beauregard Street
Alexandria, VA 22043

Dr. T.B. Sheridan
Department of Mechanical
   Engineering
Massachusetts Institute
   of Technology
Cambridge, MA 02139

Dr. Stanley Deutsch
NAS-National Research Council (COHF)
2101 Constitution Avenue, NW
Washington, D.C. 20418

Other Organizations

Dr. James H. Howard, Jr.
Department of Psychology
Catholic University
Washington, D.C. 20064

Dr. Edward R. Jones
Chief, Human Factors Engineering
McDonnell-Douglas Astronautics Co.
St. Louis Division
Box 516
St. Louis, MO 63166

National Security Agency
Attn: N-32, Marie Goldberg
9800 Savage Road
Ft. Meade, MD 20722

Dr. Stanley N. Roscoe
New Mexico State University
Box 5095
Las Cruces, NM 88003

Dr. David J. Getty
Bolt Beranek & Newman, Inc.
50 Moulton Street
Cambridge, MA 02238

END

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