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Human factors evaluation of the AN/UYQ-21 display console.

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HUMAN FACTORS EVALUATION OF THE AN/UYQ-21 DISPLAY CONSOLE.

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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

Human Factors Evaluation of the

AN/UYQ-21 Display Console

by

Thomas Edward Klocek

March 1978

Thesis Advisor: D. E. Neil

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Human Factors Evaluation of the AN/UYQ-21 Display Console

by

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Submitted in partial fulfillment of the
requirements for the degree of

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from the

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March 1978

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This paper analyses the AN/UYQ-21 display console from a human factors standpoint. The AN/UYQ-21 is programmed for use in NTDS, acoustics displays and can have fire control applications. The paper is organized so that the current threat and the Naval Tactical Data System are discussed briefly in the introduction. A general discussion of man as a system component follows along with a description of the AN/UYQ-21. The man-machine engineering aspects of the console are discussed at length including controls, display, viewing angles, maintainability, symbology and physical dimensions. The paper concludes with comments and recommendations for improvement on this and follow-on systems.

TABLE OF CONTENTS

LIST OF FIGURES

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I. INTRODUCTION

A. THE THREAT

"The Soviet Union has embarked on a maritime strategy designed to help it break out of its long history of continential confinement."[1] "The Soviet Union most recently demonstrated its strength on the high seas with the naval exercise 'OKEAN 75'. The Red fleet let it be known that it has the ability to operate far beyond the coastal seas of the Soviet sphere on a global scale. Above all, these far-flung fleet movements proved the capability of Soviet commanders to move units from one ocean to another."[2] Admiral of the Fleet of the Soviet Union, Sergey G. Gorshkov, in describing the changes of the Soviet Navy in the past two decades states, "The Soviet Navy has been transformed into an important strategic factor, into a force capable of opposing aggression from the sea and of accomplishing major operational and strategic missions on the World Ocean."[3] Norman Polmar, a well known naval analyst has called the maritime program of the Soviet Union a challenge to the United States.[2]

Quotes and articles such as these are indicative of the potential threat posed to United States sea control by the Soviet Navy. More and more the Soviet Navy is expanding and producing ships capable of projecting power. In recent years the Soviet Navy has commissioned ships which are new concepts in sea control, particularly for what once was primarily a defensive fleet, almost coastal in nature. The

Soviet naval presence in Cuba, Africa and the Indian Ocean show an increasing interest in the world oceans, far beyond the waters contiguous to the Soviet land mass. They are deploying their Navy worldwide and are trying to make naval agreements with third world nations. There are frequently more Soviet units present in the Mediterranean Sea than there are United States units. The commissioning of the Soviet aircraft carrier KIEV (labelled a cruiser by them) may be very significant as to the changing nature of these units.

The Soviet Union is making significant technological advances. As they gain new technology and as their economy permits, they are putting this knowledge into practice. Admiral Gorshkov, the Soviet Navy's Commander in Chief, has always stated that the main arms of the Soviet Navy were submarines and aircraft.[5] The submarines are armed with torpedoes and cruise missiles and the aircraft are long range bomber type planes also armed with cruise missile. While this arm has been maintained and improved over the years a new dimension has been added, that of shipboard aviation, which Gorshkov describes as "one of the main directions of the qualitative transformation of the Soviet Navy."[6] However, the Soviet surface fleet has not been neglected during this time. The Soviet Navy was powering ships with gas turbine propulsion plants before the U.S. even decided to build the Spruance class destroyer. Gorshkov further describes surface ships as the main (and sometimes the only) platform to support the development of the submarines, which are the main attack forces of the Soviet Navy. The surface fleet is also the basis of amphibious and amphibious support forces. Furthermore, they play the major role in mine warfare and the protection of Soviet lines of communication.[7]

Thus, in a hostile environment at sea, the United States Navy would be faced with a three dimensional threat. This threat would be comprised of powerful surface, sub-surface and air units. Most Soviet surface ships can outrun U.S. ships. Many of their submarines are nuclear powered and can run at high speeds submerged. The air can be filled with aircraft, missiles launched from aircraft and missiles launched from submarines. These cruise missiles are capable of high speeds and have widely varying flight profiles.

The United States Navy must cope with the massive problem of detecting, tracking and identifying this multitude of threats before it can hope to defend against it effectively. Add to this one's own forces and the task of detection, tracking, telling the "good guys" from the "bad" and worrying about the unknowns becomes awesome.

B. MEETING THE THREAT

To meet this multifaceted threat, the U.S. Navy continously tries to develop new sensors utilizing the latest technology to detect and track targets in close and at long range. New weapons and weapons systems such as Harpoon, Basic Point Defense and Phalanx are tested which increase the kill probability of a detected incoming hostile threat. Ships are being built with the capabilities for these new systems and older ships are being updated to accommodate them. One need only compare a Jane's Fighting Ships of fifteen years ago with a current issue to see how the capabilities of the fleet are changing. Such a comparison would show the average destroyer of fifteen years ago with surface, air search and fire control radars, a few guns, an active sonar, and hedge hogs. In addition, a few might possibly have a variable depth sonar, ASROC or anti-aircraft missiles. These were sufficient to meet the less versatile threat of the time. Today, however, a ship so equipped could hardly be considered adequate. More ships today carry some form of anti-aircraft missiles, be it a Tartar, Standard or Basic Point Defense System. Almost all have ASROC and a newer, more capable VDS is almost standard. In addition, some ships carry passive arrays, helicopters or both. The current active sonars are more capable than those of fifteen years ago. Aircraft carriers today are carrying antisubmarine planes and helicopters as well as intercepters and attack planes.

In order to adequately defend itself as well as complete its mission a task group today may not have two ships with identical capabilities. For example, a seven ship screen for an aircraft carrier could contain one Belknap class cruiser, two guided missile destroyers of different classes (a "double-ender" missiles both fore and aft and a DDG-2 class, smaller, with 5 inch gun), a Forrest-Sherman class destroyer (all guns), a 1040 class frigate and two 1052 class frigates (one with a passive array and a Basic Point Defense System, the other with a LAMPS helicopter capability). Other combinations are possible using the FFG's now in the fleet, ASW modified Forrest-Sherman class destroyers or the new Spruance class destroyers.

By deploying such a variety of sensors, weapons and platforms the Navy hopes to effectively meet the multiple threat poised against it and still successfully carry out its sea control mission.

To effectively coordinate this conglomeration of men, ships, aircraft, weapons and electronics, a system is needed which can take inputs from radar and sonar, store these inputs, integrate these inputs and present the collated information in a meaningful and timely fashion. The system which the Navy has developed to fulfill this requirement is the Naval Tactical Data System (NTDS).

II. NTDS MISSION/REQUIREMENTS

The Naval Tactical Data System (NTDS) is described in a handbook entitled the NTDS User as a realtime computerized shipboard system designed to enable ships to handle tactical information rapidly and efficiently. The system receives inputs from sensors, processes the inputs, translates them to usable form, makes routine calculations and transmits the required information to the men in the system, and assists these men in executing orders. The system also provides for the rapid communications of combat information between ships.[8]

The system used when one does not have NTDS is manual collection of data, manual course and speed calculations and manual plotting of data on large status boards which are not always conveniently placed or easy to see. Due to the high data rate and need for high speed exchange of information between force units such a system of grease pencil plotting is obsolete.[9] In order for NTDS to remain a useful, modern system it must be continuously updated. It must be reliable and must meet the present and future requirements to collect and display information in a high data rate environment. This is done in two ways. First, by using computers and software (programming, etc.) of increased power and speed, with greater reliability and utilizing the latest computer technology. Second, by using new consoles which can display more data more clearly, utilize inputs from many sources, and which have more capability.

III. THE CONSOLE

The main tool of the NTDS system is the console. The computer stores information, makes routine calculations, communicates with other computers and, in a sense, is the heart of the system. But, if the computers are the heart, the consoles are the heads of the system. It is at the consoles where the decisions are made. These consoles are multipurpose. They have several functions, selectable by the operators. Such tasks as detecting, tracking, identifying, and other data gathering functions would be accomplished on an input console. Similarly one could use a utilization console for tasks such as intercept control, air coordination, surface operations (ASW), and other evaluating and decision making functions on both the ship and task force level.[10] In the evaluation and decision making functions, the console is the primary display mechanism of the system.

The typical console currently in use in the fleet is of the AN/UYA-4 series. It consists of a circular cathode ray tube (CRT) on which can be displayed various symbols (each with a distinct meaning) along with some alphanumerics. The CRT is accompanied by various controls and buttons. These controls perform a wide variety of functions, from changing the picture presented on the CRT, through inputting or extracting data, to changing the primary use of the console itself (e.g. from a tracker's console to an evaluator's console). Besides providing access to the basic functions of the console these controls are an important part of the overall display which, in effect, is the entire console. Since the operator must scan the switches, etc., to determine the mode of operation of the console the positions of the switches, handles and knobs are actually important ancillary types of display devices.[11] Figure 1 is a sample of a console face currently in use in the fleet. From it can be seen how the switches and buttons affect the entire display.[12] In addition, the controls associated with a display may affect its design. Ideally, displays and controls should be designed and located so that the correct control will easily be selected and operated as expected, even by the untrained operator.[13]

The software within each console is designed in by the manufacturer but is controlled and used by the computer installation aboard a particular vessel. Therefore, any console in use must be built so that it is compatible with the various computer installations available. One other important system component must be taken into account when designing or building NTDS consoles. That all important system component is MAN.

A. MAN AS A SYSTEM COMPONENT

Man is the key component of NTDS. He brings with him the ability to reason, the ability to utilize the aforementioned tools. If the computers represent the heart of

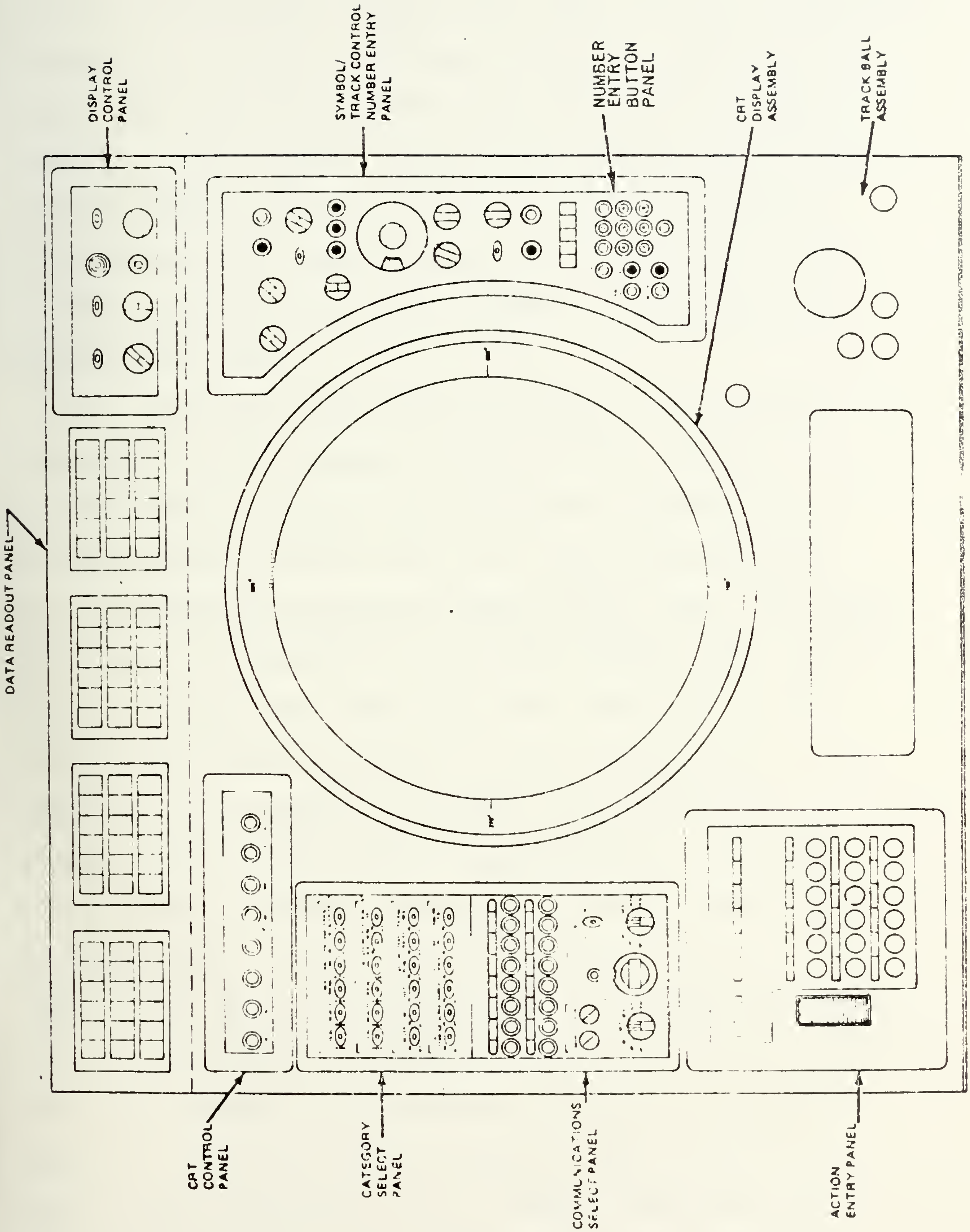


Figure 1. Sample of Current NTDS Console Face.

of the system and the consoles the heads, then the operators represent the brains. NTDS may relieve men of many of the tasks, such as routine course and speed calculations but it does not replace them.[14] Man is the decision maker of the system. Without man the system would serve no purpose. It is for man that the information is displayed and it is for man, supposedly, that the controls and displays were designed and built.

Man, however, though quite versatile, is not without limitations. Man fatigues and gets bored. There is no trouble light or buzzer on a man to tell someone that although there is power, he is not functioning properly. Man is affected by the environment; light, heat, the space around him, the stability of the deck beneath him, sounds, how much sleep he got last night, the last meal he ate, and countless other variables. Man's performance is also affected by his emotions; the last letter from home, an argument with a buddy, being reprimanded by a superior, cancellation of the next liberty port, etc. There may be six generations of NTDS consoles on active service in the fleet now but how many different men are there to use them.[15] Too often the extreme versatility of man is taken for granted, while the problems and constraints his use in a system imposes on its design are overlooked. What cause these problems and constraints are the physical and behavioral variations among men, the limitations of the body both structurally and functionally, the requirements for man's safety and comfort, and the need to maintain his physiological functions.[16] While the system may be required to perform many functions at once during high volume operations, much of the time is spent in performing routine duties. Careful consideration must be given to routine operation in the design of the crew station.[17] This is where the operator will spend most of his time and this is where he will become bored, his performance will drop, and his mind will wander. This is also where he needs to be alert so that he can identify a crisis as it arises and before it is too late.

A system such as NTDS is an example of man's utilization in a closed loop system. A closed loop system is shown in Figure 2.

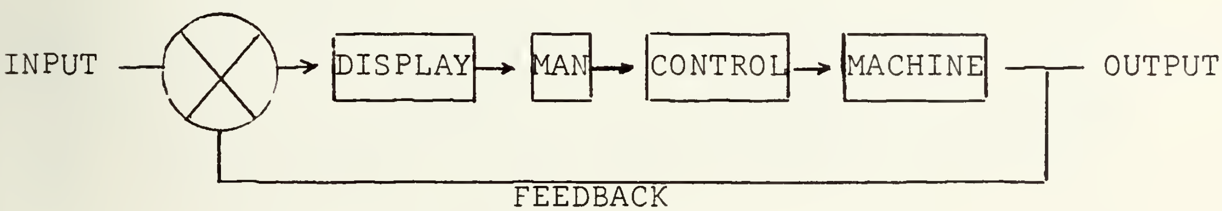


Figure 2. Typical Block Diagram of a Closed-Loop Systems. Such systems show continuous functions which require tracking by the operator.[18] (From Human Engineering Guide to Equipment Design)

It is a closed loop system because man's actions (man is the controlling element) affect the subsequent input thus providing feedback to the system. Some of the operator's actions (adjusting the display, moving the cursor, inputting the computer, etc.) are more readily seen at the display than the decisions made based on the data presented (ship movement, weapon orders, etc.) thus it is a more complicated system than a simple "tracking" system such as driving a car. (A tracking system is one which represents continuous functions which require the operator to make continuous inputs.)[19]

The design of the equipment must be such that it minimizes fatigue and includes man as a true component of the system. The space layout is important as well and its anticipated size limitations and configuration should be given some consideration during the design phase. Wolf J. Hebenstreit mentions this in his article entitled "Crew Station Configuration":

> "The best display, the finest control, or the safest and most reliable escape system loses its effectiveness if it is not arranged in such a fashion that it can be used by the operator in the fulfillment of his tasks. Thus the design of the workplace, or more specifically, the design of the crew station must be regarded as a crucial element which integrates all the components, including man, and synthesizes a space within which he can function efficiently and safely."[20]

IV. NEW DEVELOPMENTS - THE AN/UYQ-21 CONSOLE

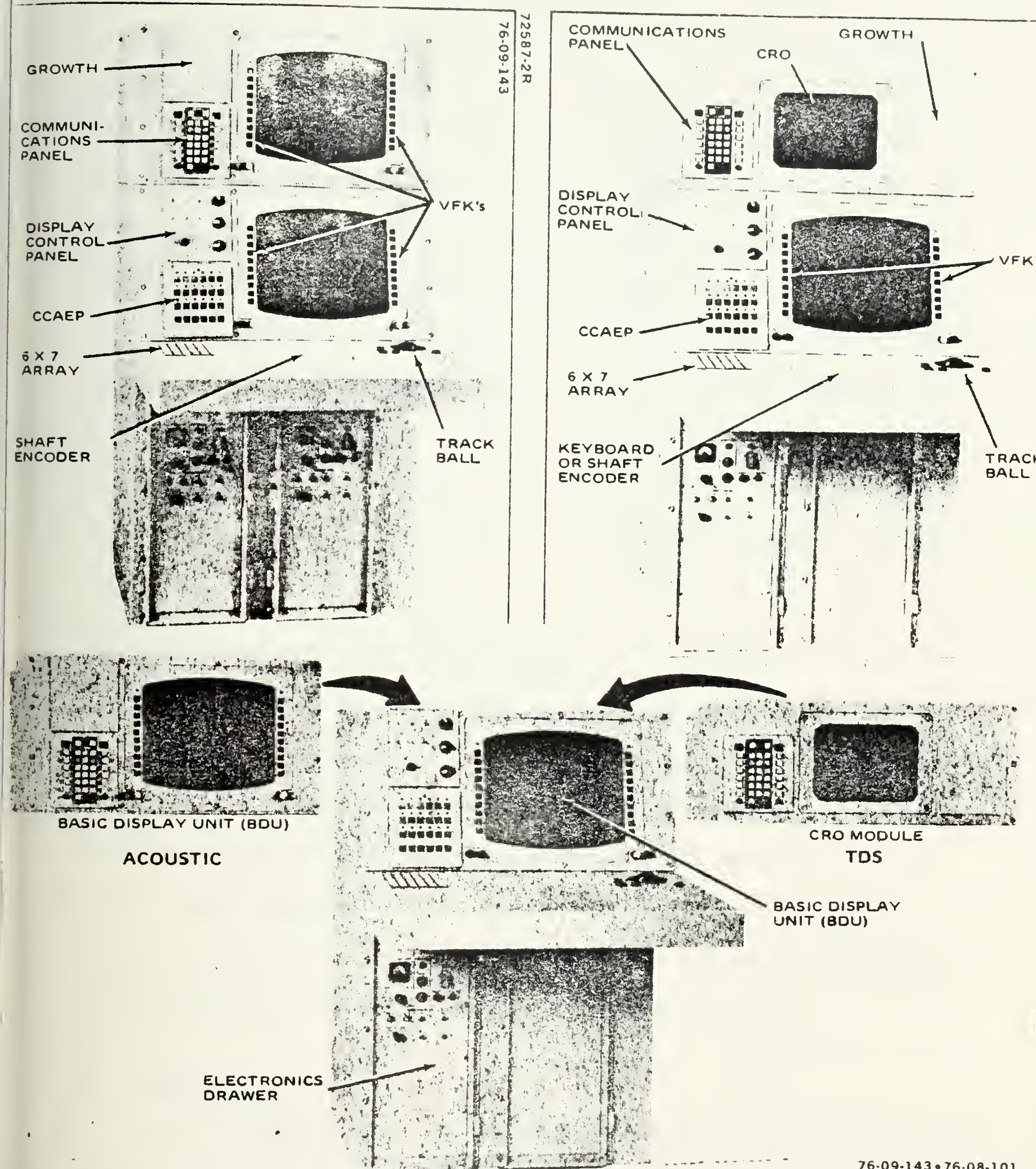
As previously mentioned, there are currently six generations of NTDS consoles in use in the fleet. In addition to NTDS, numerous other shipboard systems, some of which interface with NTDS, use a console with a CRT as a display mechanism, which inputs and controls a search, detection or weapons system. Hughes Aircraft Company, Ground Systems Group, Fullerton California has been contracted by the Naval Sea Systems Command to produce the AN/UYQ-21 Display System, the key feature of which is the AN/UYQ-21 console.[21]

The Hughes Company describes this console as having been designed to standardize the approach to the display requirements of the surface Navy.[22] The AN/UYQ-21 display system is the climax of 20 years of evolution of display requirements for the U.S. Navy. Hughes further indicates in their manual on the console that the standard U.S. Navy surface ship display of the future will be the AN/UYQ-21 system.[23] In discussing the capabilities of the console, the manual indicates that it is capable of meeting the needs of all shipboard applications. These include NTDS and other Combat Information Center applications, electronic warfare, fire control and acoustic applications. The console is capable of displaying the various types of computer generated synthetic data as well as video from commonly encountered shipboard sensors.[24]

The hardware has been modularly designed so that those features which best support a particular function can be placed together for a specific application (such as displaying video from acoustic sensors) while a general console design can be maintained for the more general and diversified requirements of a broad multi-purpose system such as NTDS.

Such standardization has many advantages such as: (a) the need for special interface equipments to integrate various shipboard systems can be reduced or eliminated; (b) some existing functions can be shared between electronics cabinets thereby reducing the number of cabinets required; (c) commonality of equipments facilitates meeting casualty back-up needs and cross training of operators and maintenance personnel.[25] Acquisition, support and maintenance costs can be reduced because of quality buying, and fewer technicians can service a higher percentage of equipment.[26]

Hughes Company has established two standard console configurations which should meet the requirements of diverse users and applications. Figure 3 illustrates these two versions which differ only in the nature of the upper display. The TDS configuration, whose primary function would be NTDS and command and control, includes a single BDU (Basic Display Unit) with a CRO (CRT Read Out) module mounted above it. The 11" x 13" CRT of the BDU is for display of synthetic and sensor data while the 12" diagonal CRT of the CRO module can display auxiliary alphanumeric data or any other data in a standard 525 line TV format.[27]



Jsing a Common Lower CRT and Structure, the AN/UYQ-21 Display Console is Easily Configured or Acoustic or TDS Type Applications by the Addition of the Appropriate Upper Display Module

Figure 3. Example of Modular Construction and Two Basic Configurations of AN/UYQ-21 Consoles.[28]

The electronics for each BDU are enclosed in a drawer in the base of the console (one drawer for each BDU) while the CRO module houses all its own support electronics.[29]

The display capabilities of the BDU's include radar and acoustic formats (raw data or computer processed) as well as a wide variety of graphics and symbols.[30]

Each console will contain a variety of entry and control panels by which it can be tailored to the requirements of a specific application (such as tracking, detection, weapons control, etc.).[31] A brief summary of panel types and operations as outlined in the AN/UYQ-21 Standard Display Console manual follows.

A. VARIABLE FUNCTION KEYS (VFK's)

A column of ten VFK's are mounted on each side of the CRT on the BDU (see Figure 4). They are standard on each basic display unit and are operated by a light interrupt switch. The label for each is displayed on the CRT adjacent to the VFK. When actuated by the operator a function code is transmitted to the computer. These are software controlled switches (i.e. can be programmed as desired).[32]

B. TRACKBALL

The Trackball is a standard console feature adapted from present NTDS consoles and with the same functions (cursor positioning for track entry, track update, etc.). In console configurations utilizing two BDU's, the Trackball can be used for position entry on either CRT.[33] (See Figure 5)

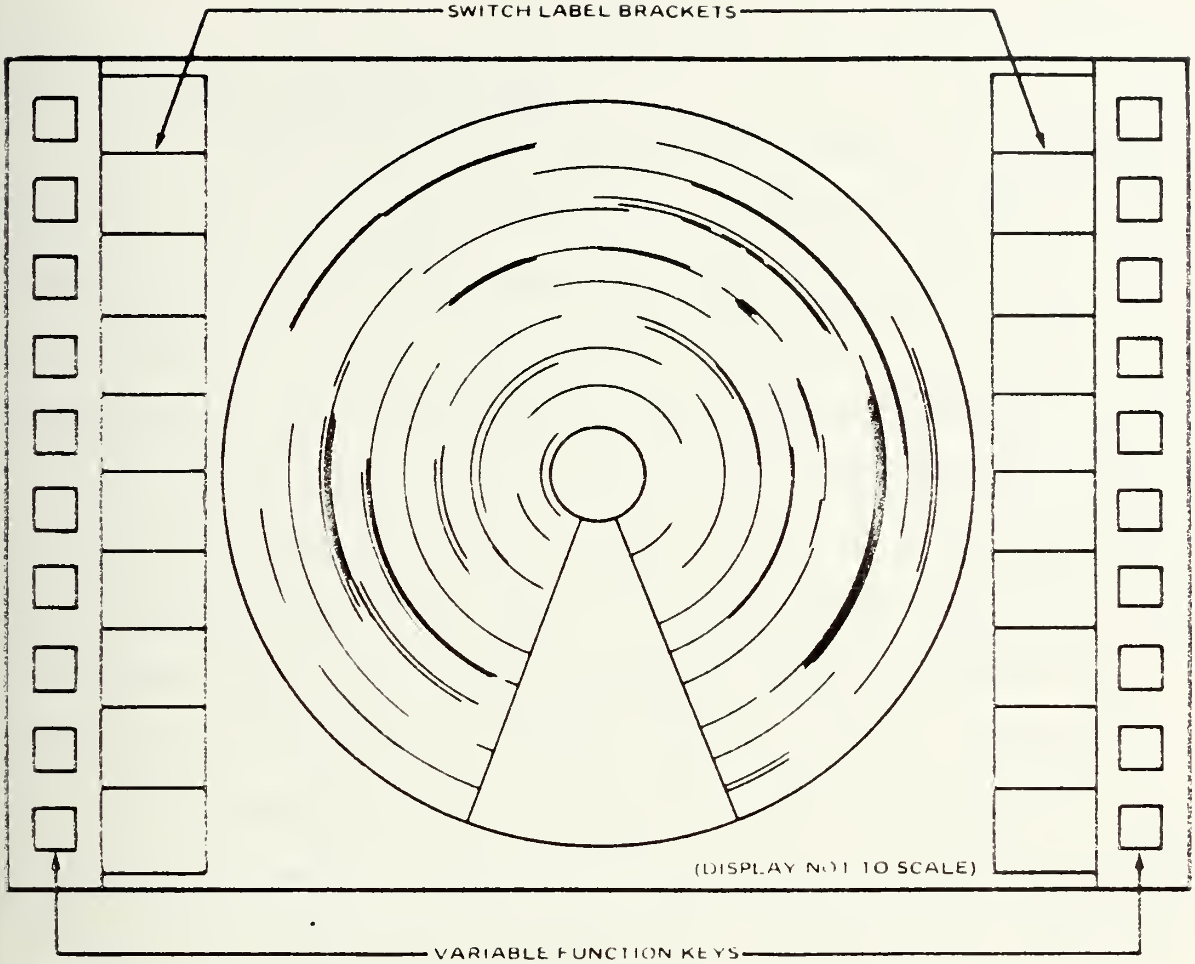


Figure 4. Variable Function Key Switches.

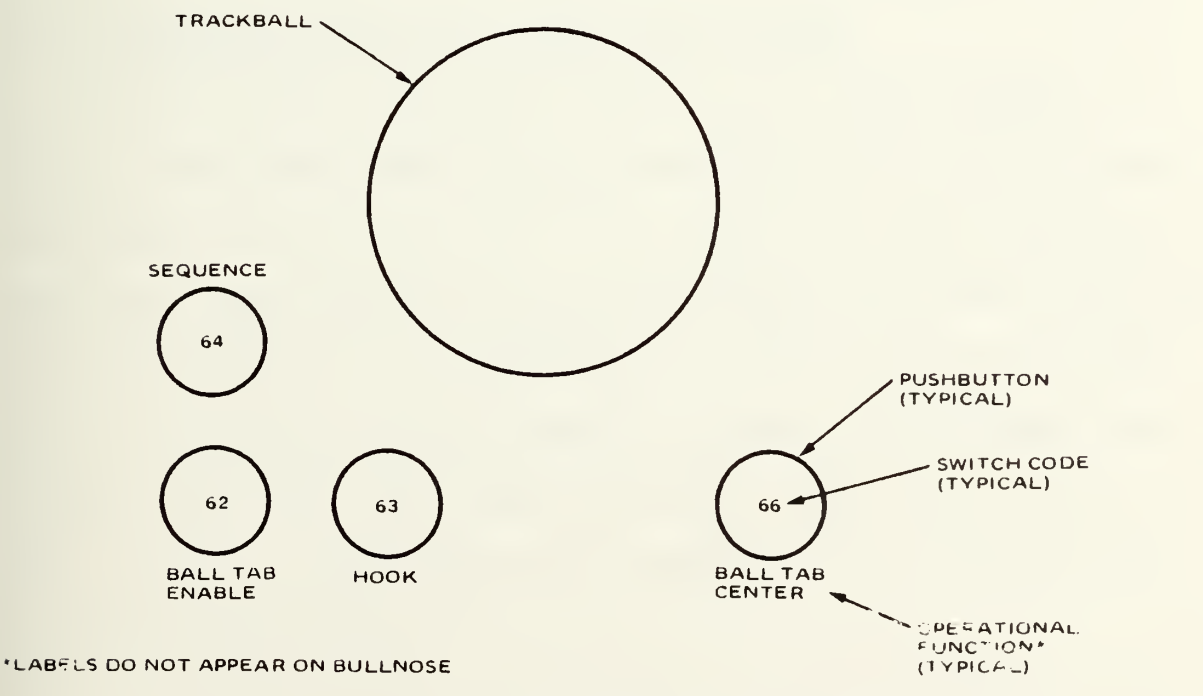


Figure 5. Trackball Assembly Switch Codes.

C. CATEGORY SELECTION PANEL

The category selection panel (see Figure 6) is mounted on the left hand side of the desk top area (referred to as the "bullnose" in NTDS terminology) and consists of a 6 x 7 array of trans-illuminated switches.[34] The panel may serve one of two functions, either a category selection device or an action entry device. For either application, a portion of the switches provide a number entry function in a standard push button telephone format. As a category selection device (normally used in CIC-NTDS consoles) switch actions are hardware controlled to present synthetic data (symbols, circles, leaders, etc.) on the CRT. The action entry function is more typical of a console used for sensor control (acoustics, fire control radar, etc.) and in this case the switches are controlled by the programmer.[35]

D. COMPUTER CONTROLLED ACTION ENTRY PANEL

The computer controlled action entry panel (CCAEP) is an optional panel which can be installed in the lower panel opening of a BDU. It is a 4 x 6 array of light interrupt switches. The bottom row of six switches are fixed labelled while the upper three rows have a 48 label projection read-out for display of switch labels. Above each of these top 18 switches is a light emitting diode (LED) indicator or cue light. All switches and indicators in this panel are software controlled.[36]

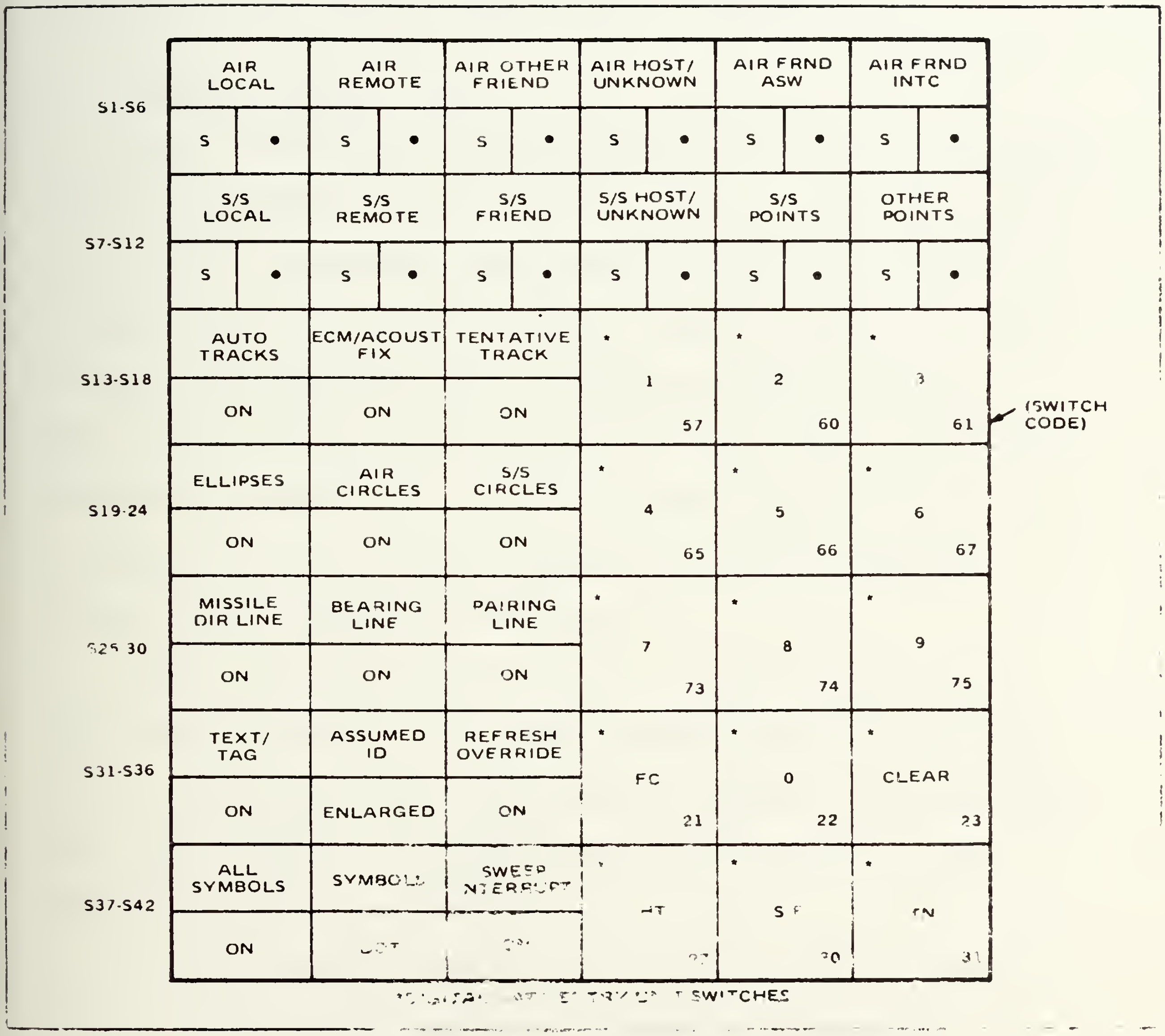


Figure 6. Category Select Panel.

E. COMMUNICATIONS PANEL

The communications panel is an option which can be installed in either a BDU or CRO module. It has sufficient capability to cover full NTDS communications requirements including split earphone operation, secure and non-secure radio and five sound powered phone channels.[37]

F. DISPLAY CONTROL PANEL

This is an optional panel which is installed in the BDU above either the communications panel or the CCAEP. Herein are selector switches, rotary and toggle, for control of range scale and the sensor data (radar, sonar, etc.) and video to be displayed on the respective CRT. It also has a time switch which allows entry of "time to go" for adjustable leaders as well as selectors which control the challenge sector and gate size for SIF/IFF (aircraft/ vessel identification) functions.[38]

Other optional panels include a shaft encoder panel (software controlled, intended primarily for acoustic and fire control use) and a typewriter keyboard (for data entry and edit either on the basic CRT or on the CRO). See Figures 8 and 9 respectively.

The data display capability of the console is extensive and consists of two separate channels; synthetic data and sensor data. The console can display a wide selection of computer specified (hardware capable, software controlled) synthetic data including 224 hardware stored (in read only

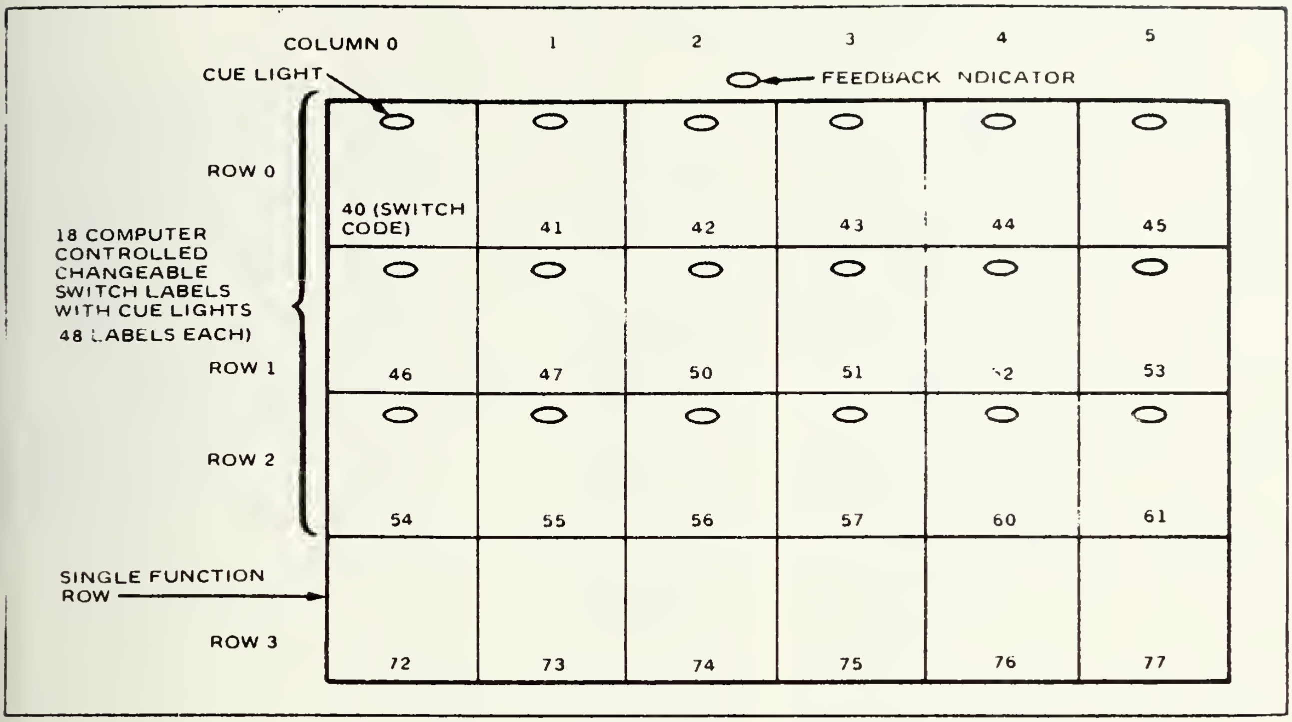


Figure 7. Computer Controlled Action Entry Panel Switch and Cue Light Codes.

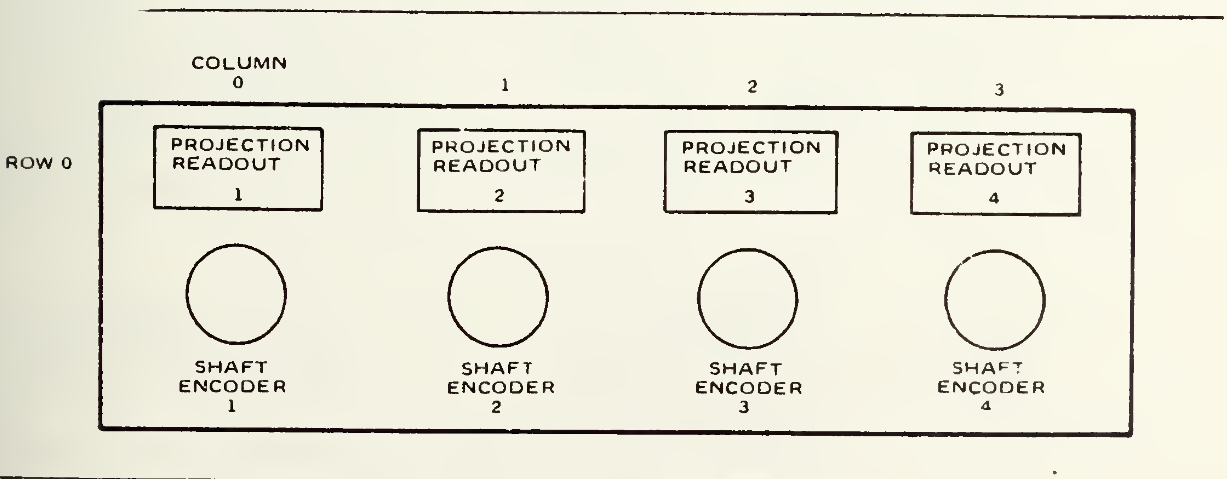


Figure 8. Shaft Encoder Panel. (Optional Panel)

KEY CODE	KEY
16	SEND
25	DIRECT
26	16 X 32 FORMAT
27	32 X 64 FORMAT
30	25 X 80 FORMAT
31	PFK 1
32	PFK 3
34	PFK 4
35	PFK 5
36	PFK 6
37	PFK 7

KEY CODE	KEY
00	NOT USED
01	DELETE WORD
02	DELETE LINE
03	DELETE DISPLAY
04	DELETE CHAR
05	ENLARGE
06	INSERT
07	BLINK
10	CURSOR UP
11	CURSOR DOWN
12	CURSOR RIGHT
13	CURSOR LEFT
14	CURSOR HOME
15	RETURN
16	SEND
17	UNASSIGNED

KEY CODE	KEY
20	COLOR A
21	COLOR B
22	COLOR C
23	COLOR D
24	INDIRECT
25	DIRECT
26	16 X 32 FORMAT
27	32 X 64 FORMAT
30	25 X 80 FORMAT
31	PFK 1
32	PFK 2
33	PFK 3
34	PFK 4
35	PFK 5
36	PFK 6
37	PFK 7
40–77	SPARE

CODE NO. ↓ →	0	1	2	3	4	5	6	7
0	BLANK	A	B	C	D	E	F	G
1	H	I	J	K	L	M	N	O
2	P	Q	R	S	T	U	V	W
3	X	Y	Z	[		]		
4	SPACE	≤	≥	≠	$	|	—	'
5	(	)	*	+	,	-	.	/
6	0	1	2	3	4	5	6	7
7	8	9	:	;	<	=	>	?

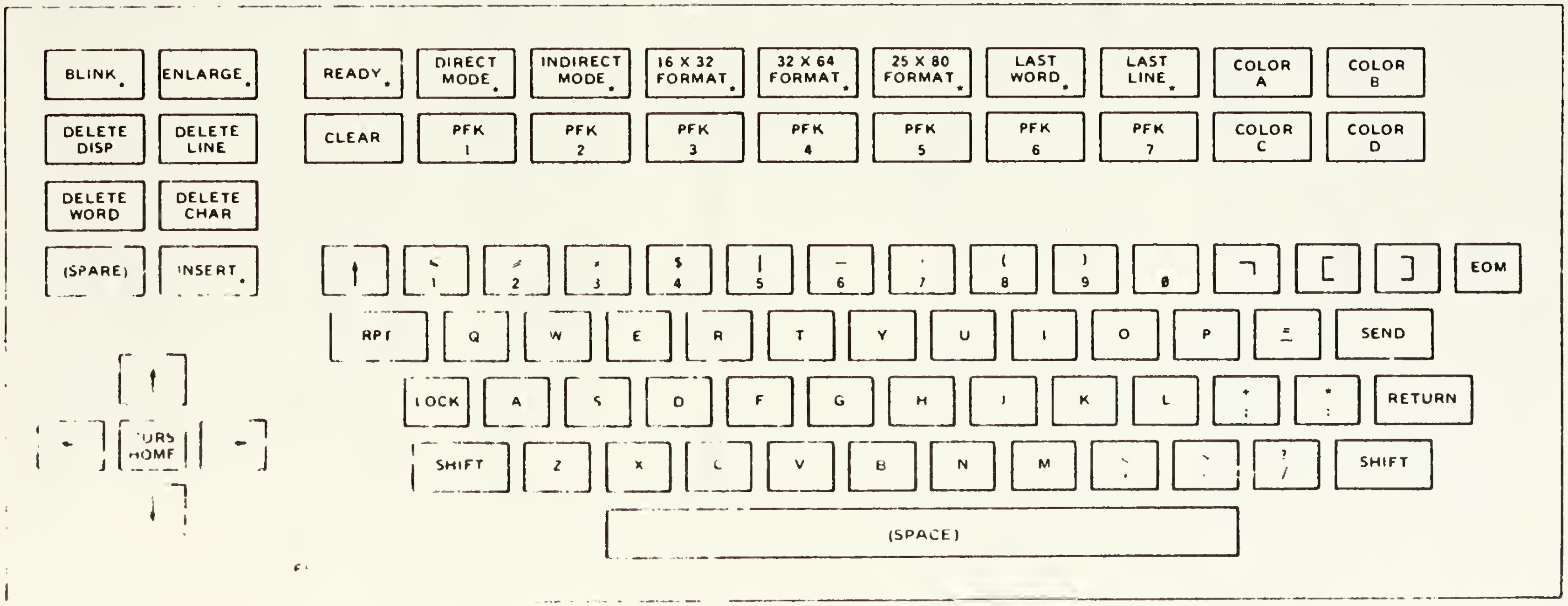


Figure 9. Keyboard Layout (Typical) and Key Codes.

memory) symbols, alphanumerics, tactical symbols and symbol modifiers. An additional 32 computer programmable symbols can be stored in a writeable memory. Further, conics, vectors and cursors are available and can be programmed for a variety of uses. Some can be blinked, dashed or displayed in multiple intensity levels depending on the programming.[39]

The console is also capable of displaying the full spectrum of sensor data (provided by ancillary electronics cabinets) including real time, time compressed video, stored or processed data, high density rosters, environmental ray traces, and others.[40]

G. MAN MACHINE INTERFACE

In a discussion of the crew station design process, Arthur S. Romero stated,

> "Unless it is our intent to design machines that are entirely automatic, man must be considered an integral component of the system. As such, his performance is as vital to the successful completion of the mission as any of the systems components.[41]

An idea of just how critical the consideration of the human in the design process can be is brought out in an article entitled "Engineering Anthropology." Here author H. T. E. Hertzberg states,

> "The human body, in its structure and mechanical function, occupies a central place in man-machine design. Failure to provide a few inches, which might be critical for the operator, can jeopardize performance, operator safety and machine reliability."[42]

As stated previously, no two humans are alike. How, then, does one account for this variability in systems design? Some of the variables of human beings, such as temperament, emotional stresses, intelligence, etc., are beyond the designer's control. Some of these can be estimated for the anticipated user population and these estimates can be taken into account in the design process. Others, however, are well within the ability of the designers to accommodate. Known relationships exist between display sizes, controls, indicators and the human sensory system. The comfort of the operator and the ease with which he can operate the controls are also factors in his performance. Some of these relationships are complicated by the variability of human beings in such matters as size, reaction time, etc. For example, there are wide differences in body dimensions between and within national or ethnic groups.[43] The population of the United States with its mixed racial origins is, as a population, among the larger sized members of the human species.[44]

What steps can be taken to account for such variability? First, the equipment should be designed to accommodate the body dimensions of the population that will be using it. It should be designed such that nearly the entire population can use it because many situations require human interchangeability.[45] This is especially true in the military where one operator or watchstander may be only five feet six inches tall and the one who relieves him might be six foot five. Does the designer then design for the average size? No, he must design for a range of value. To use the average alone would be wrong. Then, only those close to the average would be accommodated. What is needed is to incorporate adjustability (as in seat height) whereby the range size of the operators is covered.[46] The current guidelines set up by the U. S. Government for design of military equipment are contained in Military Standard 1472B, Human Engineering Design Criteria for Military Systems, Equipment and Facilities. This publication states that "design and sizing shell insure accommodation, compatibility, operability, and maintainability by at least 90 per cent of the user population."[47] It goes on to specify that design limits should normally range from the fifth to ninety-fifth percentile values and it provides these values to be applied.[48]

Figure 10 shows the general dimensions, in inches, of the AN/UYQ-21 console utilizing one BDU and with a CRO module above it. (The overall hieght using two BDU's is 60.5 inches.) By comparing the values in Mil Std 1472B with the dimensions of Figure 10 it can be determined if, dimensionally, the AN/UYQ-21 will suit 90 per cent of the user population. Since dimensions which restrict or are limited by the extension of the body (reaching distance, control movement, displays, etc.) should be based on 5th

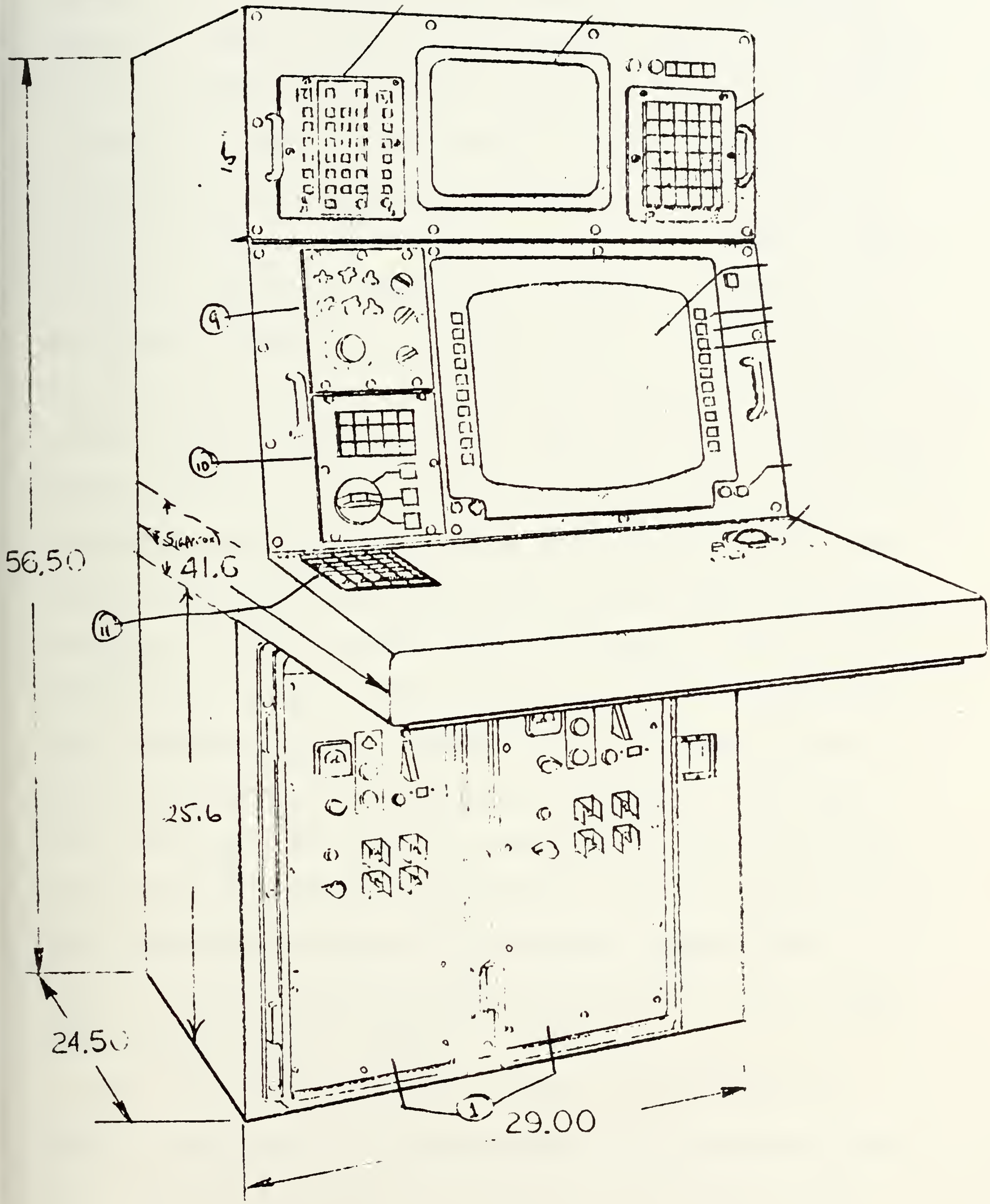


Figure 10. NTDS Console - Artist's Drawing

percentile body dimensions we must calculate some of these dimensions.[49] The vertical arm reach of a 5th percentile operator, seated, would be 56.6 inches (169.2 cm).[50] Since this is vertical reach, such an operator would not be able to reach the top of the console in either configuration. However, since the operator is expected to be seated and not need to have a view over the top of the console, these dimensions are within the overall dimension criteria as set forth in Table XVIII of the Mil Std. One basic dimension of the UYQ-21 does not meet the criteria. Article 5.7.3.2 of Mil Std 1472B specifies that "desk tops and writing tables shall be 29 to 31 inches (740-790 mm) above the floor, unless otherwise specified."[51] Table XVIII, however, deals with consoles and specifies that, for consoles, the shelf height should be 32 to 36 inches (810 to 915 mm).[52] Some of this discrepancy could be compensated for by using adjustable seats thereby allowing even the 5th percentile operator to reach his controls. The depth and breadth of the shelf are within the limits of Mil Std 1472B.[53] And while the bottom of the shelf will apparently clear the knees of the 95th percentile operator,[54] it does not provide the 7.4 inches (165 mm) thigh clearance specified.[55] (27.1 inches from floor to top of thigh)

One other feature of the overall console does not exactly comply with the Mil-standard. The standard states that for stacked consoles with vision over the top not required by the seated operator the stacked module's view surfaces should be perpendicular to the operator's line of sight with little or no head movement.[56] In any case, "the operators should be stationed so that their lines of sight to the display surface form an angle between 60° and 90° (never less than 45°)."[57] Furthermore, maximum eye rotation up from the horizontal should not exceed 25°.[58] (See Figure 11)[59]

With a vertical face on the upper module some head and eye movement of the seated operator will be required with the resulting angle of view of other than 90°. As a result of this angle of view some parts of the display may not be visible to the seated operator. Another effect of the vertical face is significant parallax distortion of the line-up of the variable function keys (VFK's are located on either side of the BDV screen) and their labels which are displayed on the screen. The screen itself is recessed significantly from the front face of the console and some parallax distortion is noted even in the main CRT. This could be of great significance because of the tendency an operator might have to activate the wrong VFK. In the preliminary model lines have been drawn between the keys and their labels on the screen. This should sufficiently correct for parallax in the main screen. This should also reduce the possibility of error where the upper screen is concerned provided the lines are visible with the illumination present during normal system operations

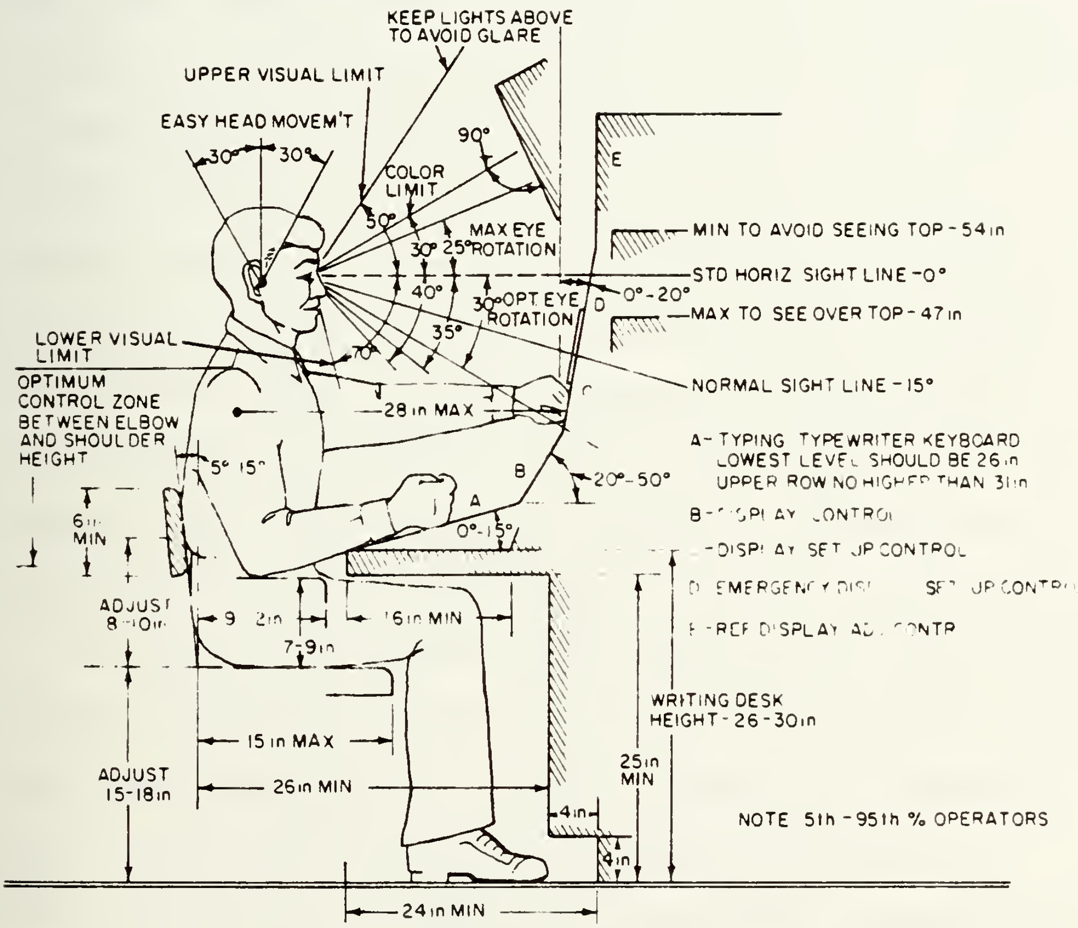
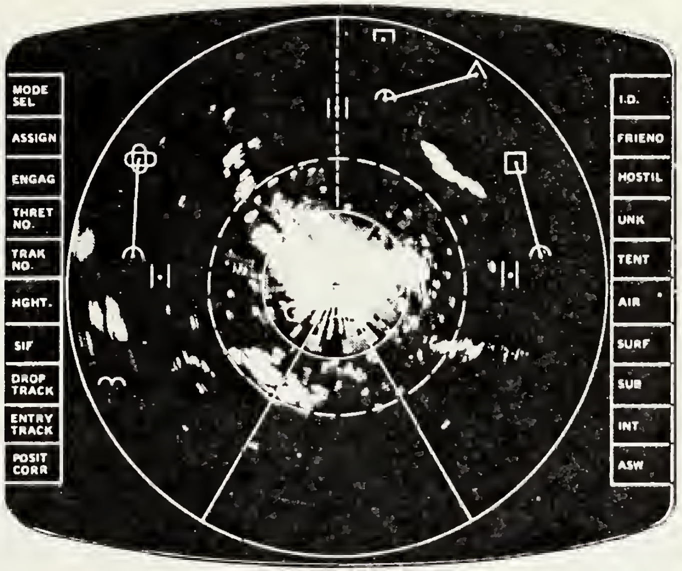


Figure 11. Suggested parameters for mockup of a seated operator console (after Dreyfuss, 1959; Kennedy and Bates; 1965, Woodson, 1964).

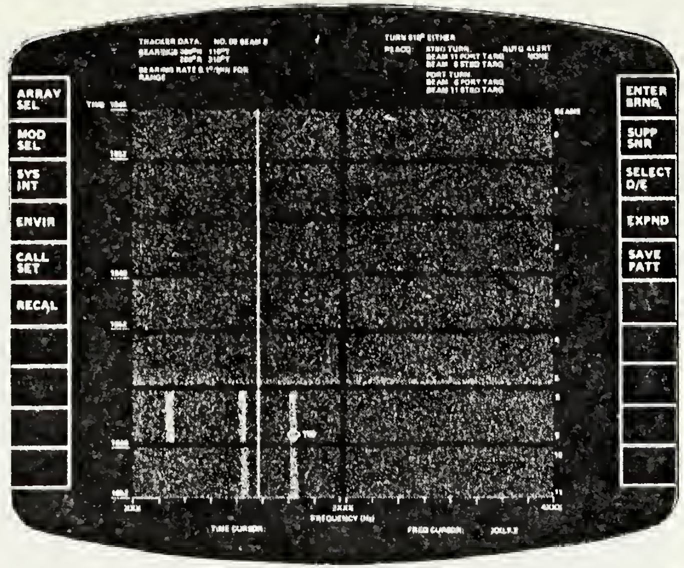
(i.e., a dark CIC). While the angle of vision to the center of the vertical display is less than 90° for the seated operator the range is greater than 45° for either model 5th through 95th percentile operators. Both these limits and any associated head movements which the operator may require are within the maximum limits of the Mil Std. (The ranges for angle of vision (or head movement) to the center of the CRO are 40.4° to 33.9° and for the center of the upper BDV they are 42.9° to 36.8°.) The secondary, auxiliary nature of the upper module tends to reduce the criticality of these parallax problem. Also, the fact that cursors, bearing indicators, range rings, etc. will be displayed on the face of the CRT as part of the regular picture should have a similar effect. This does not eliminate parallax problems, it merely reduces the detrimental effect. Nor is parallax distortion the only problem presented by the vertical face. By not utilizing a slanted face, any problems of glare for the operator could be amplified.

As for the information presented on the screen one must remember that there is much more to a good visual display than merely the fact that it is visible. The operator must make his decisions without unacceptable delay and so the presentation of information must be easily understandable.[60] The ease with which the operator can understand the display has a great effect on the speed of his actions. Reaction time is present whenever man is involved in information processing.[61] The more information to be processed and the larger the number of responses to presented stimuli, the longer the reaction time. Uncertainty will also affect reaction time. Boredom is also prevalent where vigilance tasks are concerned as a result of long continued work under low stress conditions. Consequently, the display must adequately present information but not faster boredom. Figures 12 and 13 show a sample of the displays on the BDU. Figure 14 is an example of available symbology. It contains existing NTDS symbology and modifiers plus numerous other possibilities. The fact that it contains existing NTDS symbology is good. It is interesting to note that some of the additional symbology available takes on a pictorial appearance. This is an excellent idea since such shapes which depict the real-world objects they represent can be more easily learned, remembered and use.[62] One drawback of these symbols, however, is that many of them are too similar. While they may be pictorial representations of military objects (a display method superior to geometric forms) their similarity will increase both search time and errors.[63] However, since some of the symbology can be programmed in and since the use of the symbols in controlled by the software, some modification is possible.

Another important feature of a display is its compatibility with related controls. The controls for the picture quality are below and on either side of the CRT. They are not labeled on the console but are color and shape coded. One

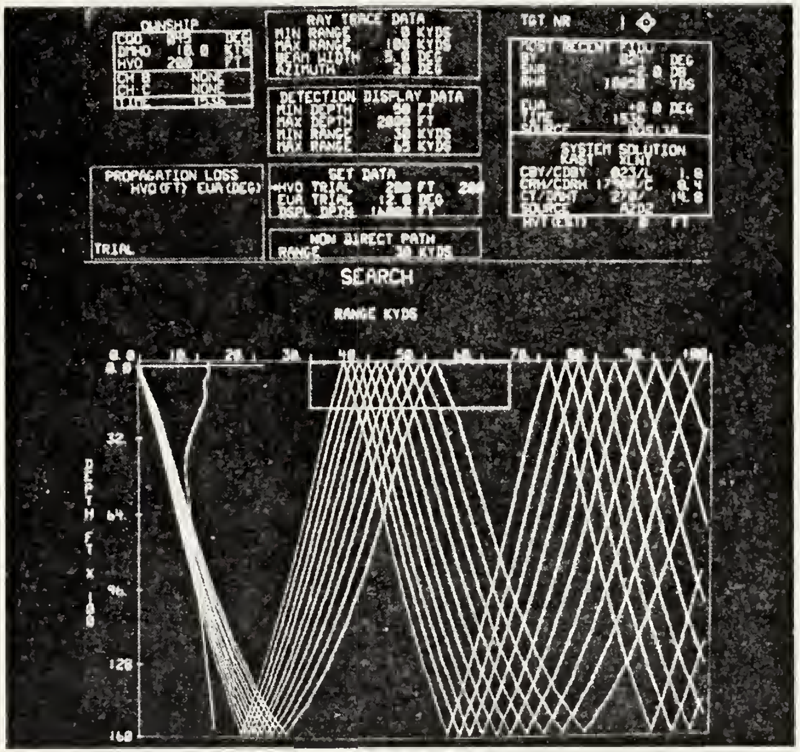


RADAR PPI
(WITH CLUTTER MAPPING)

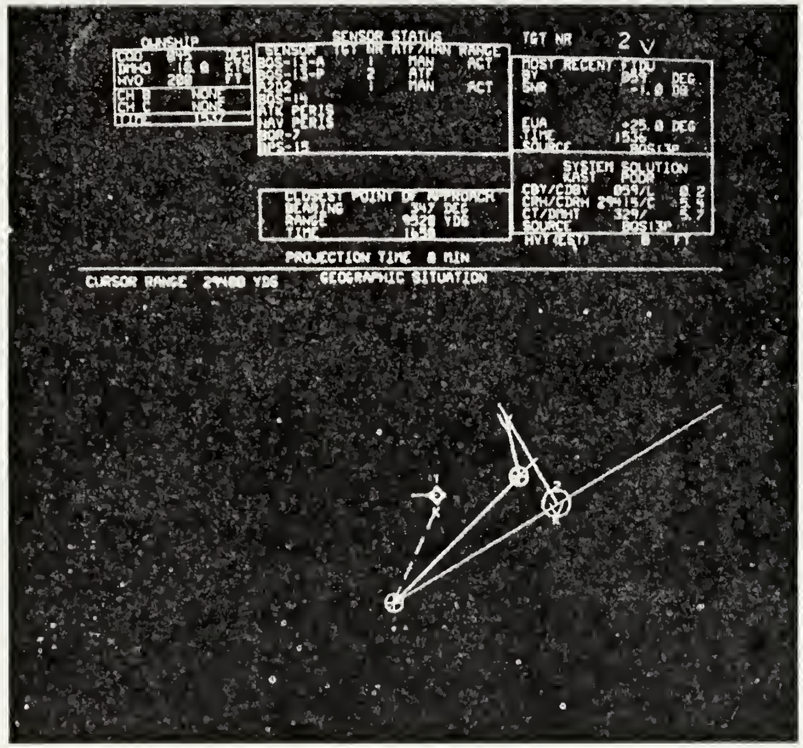


HIGH DENSITY ACOUSTIC RASTERS

Figure 12. Typical AN/UYQ-21 Display.



SOUND WAVE RAY TRACE



GEOGRAPHIC — CPA PROJECTION

Figure 13. Typical AN/UYQ-21 Display.

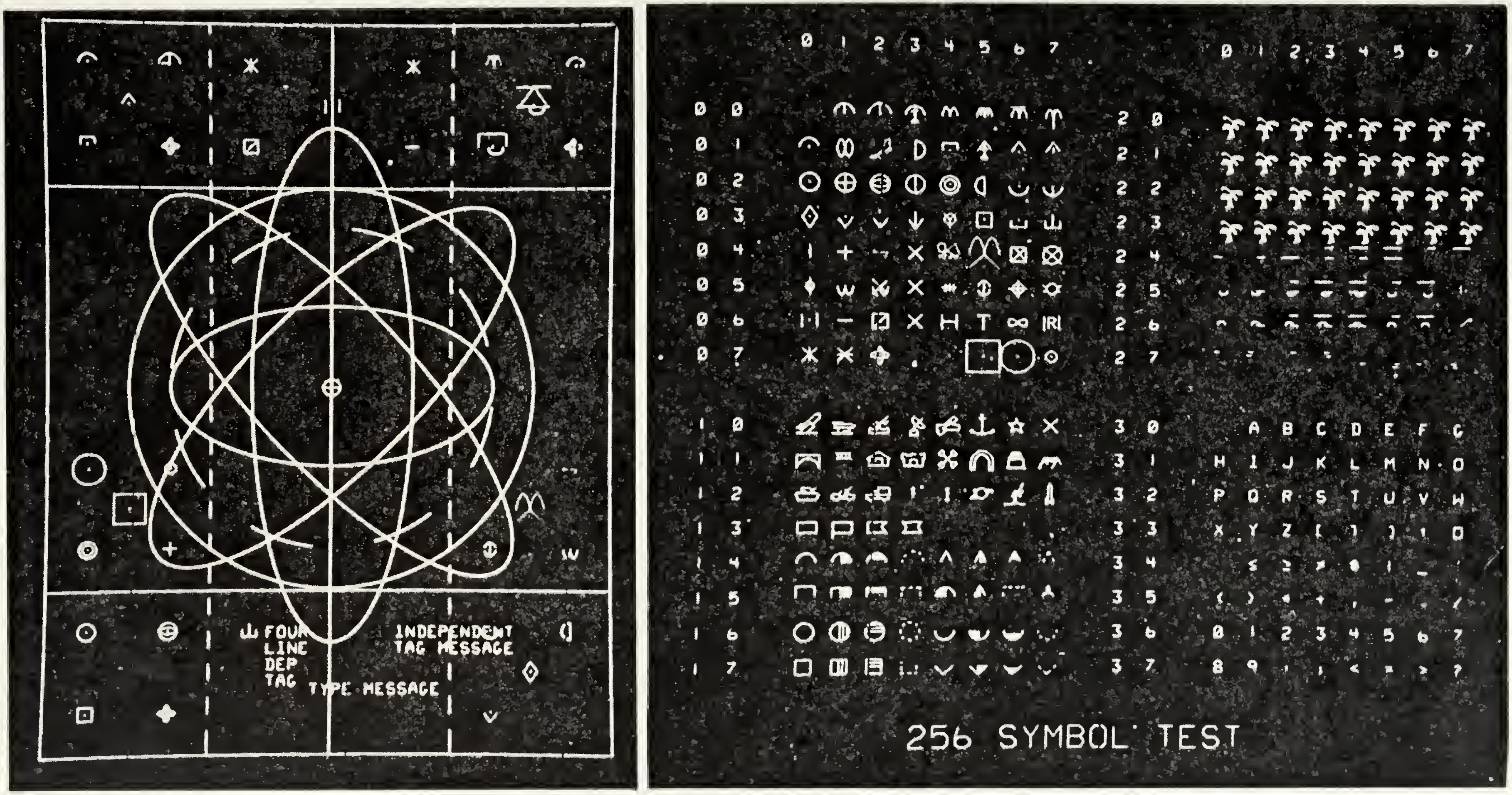


Figure 14. AN/UYQ-21 Symbology Repertoire.

advantage of this positioning is the continuous presence of certain portions of the display (VFK's, outlines, etc.) which should enable each operator to adjust the picture to suit his own desires. The controls used to adjust the geographical aspects of the display appear simple enough for accurate use. Certain aspects of the control panel, however, do not comply with Mil Std 1472B or are not in agreement with the best human factors engineering methods. These are the use of toggle switches for functions having more than two positions and the design of the "time to go" dial. Toggle switches for military use should be of the two position type unless space or other requirements dictate otherwise. (Three position switches are permitted if they are of the spring loaded type allowing intermittent activation then return automatically to the normal position.)[64] Good engineering practices permit 3 position toggle switches provided the control arm is one-half inch or longer and positions are separated by at least 30°.[65] Because of the small amount of space required for toggle switches it is felt that they are acceptable in this circumstance provided they meet the above requirements. As for the "time to go" dial, it should have an adequate index so that it will not be misread. A back lighted open window or digital indicator would provide the best design for the time to go dial.[66]

One other aspect of the controls on the AN/UYQ-21 console may foster operator error. This is in the area of feedback to the operator. Errors are less frequent or quickly corrected when some signal or stimulus is sent back to the operator informing him that a certain action or sequence of actions has been carried out.[67] These cues can be provided by the positive feel of a switch clicking into place, by the snap sound a switch might make or by some kind of indicator such as a light. Tactual feedback is provided on all the switches of the AN/UYQ-21 and in most respects is good. For some of the light interrupt switches, however, some uncertainty of operation will be presented to the operator. Tactual feedback in these switches is provided by a bump in a plastic plate at the back of the switch which the operator hits when he activates the switch. For some (18) of the switches on the CCAEP on LED above the switch lights up also. For the others, there is no indication as to which switch was activated (if any). This could result in errors, particularly in the matter of VFK activation which already suffers from parallax distortion discussed earlier. Further, the lack of positive indication of activation could lead to hitting the same key repeatedly to ensure activation thereby producing delays or errors. Furthermore, if the operator has a writing implement, such as a grease pencil, in his hands he might have a tendency to use it to activate the switch thereby eliminating the tactual feedback (and adding the possibility of dirt buildup in the switches). To an experienced operator these may not be significant but nonetheless they are factors which must be considered. To the inexperienced operator, these factors could produce time consuming (and, in a tactical situation, perhaps costly) errors.

Other items worthy of comment in regard to switches are the category select panel swithces and trackball assembly switches. The category select panel switches are label backlighted, provide a positive "click" feel and sound when activated and activation is also indicated by a light within each switch. A portion of the category select panel switches is reserved for number entry switches (see Figure 6). Hughes has selected the three by three matrix with a bottom center zero starting with the "1" in the upper left hand corner and ending with the "9" in the lower right (this is the same arrangement as normally found on pushbutton telephones). This is a good choice. Research has shown that the 3 x 3 matrix is the best arrangement for number entry. Furthermore, the above arrangement (the "1-2-3" arrangement) is a faster and more accurate arrangement for the unskilled operator than its competitor, the "7-8-9" arrangement. (The "7-8-9" arrangement has the digits 7, 8, 9 across the top row and 1, 2, 3 across the bottom row.) For the skilled operator there is no appreciable difference. However, people "expect to find" the 1-2-3 arrangement. In fact, about five times as many people expect the 1-2-3 arrangement as expect the 7-8-9 and it is better to design for such expectations.[68]

As far as the trackball assembly is concerned, it is something which was developed for the earlier NTDS models and has been very successful. The trackball is used to move a cursor and it has switches adjacent to it for the sequencing, enabling and hooking functions plus one which automatically centers the ball tab indicator. Upon initial test of these push/click buttons it was felt that perhaps they were too stiff for thumb operation. The personnel at the Hughes plant made assurances that, with use, the switches would "loosen up" sufficiently so as to be comfortable to the operator. Some favorable features incorporated into these switches are their layout (which has been in NTDS usage for many years) and the fact that they are of different heights. Thus, the experienced operator could tell which switch he was about to use by two sources of feedback - the height of his thumb off the surface and its angular position.[69] There is one minor drawback in that the labels for the switch functions do not appear on the console. The reason for this is that these switches are so basic to the function of the console that it was not deemed necessary. Labeling is nonetheless important from a human factors standpoint and should be present.[70] (Mil Std 1472B states that controls, etc. shall be labeled.)[71]

Another important aspect of this console is the electronics drawer. From an engineering standpoint this is a plus since the electronics for each console is self-contained within the console with room to spare. From a human factors point of view, however, the arrangement is incomplete. One the front of each electronics drawer there is a panel with a few switches and dials on it (for power and for maintenance indicators). A problem exists in that these switches can be accidentally kicked and thereby activated, deactivated or damaged by the operator. Some guards have been placed on the sides of the switches but they are not completely covered.[72] This could easily be remedied by placing a door type cover over these switches with a plexiglass window to allow visibility of indicators, if required. These switches would not normally be utilized by the operator during normal operation (i.e. while he is seated with the console in operational status) so there should be no conflict with regard to the door.

Training requirements for the new console are another important consideration. While man is a very trainable component he does have his limitations. As mentioned previously, the more choices he has to make to various stimuli, the slower the reaction time and the greater the possibility of error. Further, past learning influences present learning and affects the transfer of information in the learning process. Learning improves and is accelerated when this transfer is positive; when the situation and actions involved are similar to those learned previously.[73] With this point of view, those aspects of the console which are similar to consoles used previously and perform the same functions (trackball assembly, some of the symbology, etc.) or which do not interfere with the transfer of information from past experience are good design characteristics. It is difficult at this stage, without any operator data and with most of the software programming yet to be done, to determine what learning effect this console will have in the fleet. It would be a drastic mistake to assume that a human operator could adapt to virtually any complex situation. Such an assumption could result in such complication of equipment and tasks that no reasonable amount of practice or learning could assure reliable performance.[74] On the other hand, failure to take into account man's ability to learn could lead to over-simplification. A once difficult task can sometimes become routine and boring. The AN/UYQ-21 has what appears to be a good mix of new operations and capabilities combined with old well known and well used operations. However the potential exists because of these expanded capabilities to overload the operator if care is not taken in the programming of the system.

V. CONCLUSIONS AND RECOMMENDATIONS

The AN/UYQ-21 represents an improvement in console capabilities for the Navy. It should also represent an improvement in the field of man/machine engineering. Here it falls a little short of the goal. The AN/UYQ-21 is not yet in production (prototypes have been built) and, although generally a good design, there are a number of changes which could be made which should improve operator performance. Most of these are relatively minor, probability relatively inexpensive changes which could greatly improve this console from a human factors standpoint. There are other items for which decisions might not have been made at this time which should get careful consideration when the time comes. There are still others which are installation items and should be dealt with when the units are actually placed aboard ship.

One of the installation items should be an adjustable seat. The operator could then adjust the seat height to improve his ability to reach all necessary controls. He would also be better able to find a comfortable position to perform his task. Serious consideration should also be given to the actual installation of the console. Its location in the layout of the entire space is important. Furthermore, if the console is to be placed on shock mounts or some other special mounts, the height of these (coupled with the adjustable seat) should be considered as a possible means for providing the necessary thigh clearance for the 95th percentile humans.

The placement of controls appears to be satisfactory. In all likelihood the communications controls would be the least adjusted (the operator would have a push to talk switch in hand) and therefore the configuration with these in the uppermost unit should be the one chosen in most cases.

As mentioned previously, labeling is an important aspect of human engineering. In addition it is required by Mil Std 1472B. Consequently the control knobs for the scope focus, brightness, etc. and the trackball switches should be labeled.

Another minor change could be made in the "time to go" dial. By converting this dial to an open window type (see Figure 15) and providing backlighting to the digits of interest the operator could see at a glance the setting on the dial. Another possible alternative could be the use of a digital readout instead of the dial. This, however, may be more costly and difficult to incorporate at this stage of production.

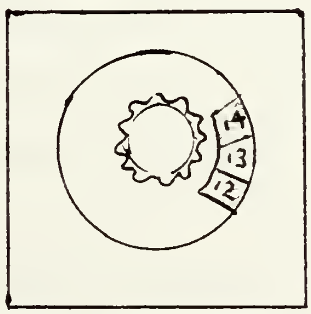


Figure 15. Open Window Type Dial.[75]

In the area of switches it is felt that more positive feedback is required to indicate activation of certain switches. It would seem simple to include LED indicators on the bottom row of switches on the CCAEP (especially since they are already on the other three rows). Another group of switches requiring more feedback is the group of VFK's. As it stands now the VFK's provide the tactual feedback when the finger hits the back of the switch and an LED above the whole column lights to indicate that a switch has been activated. There is no other feedback to indicate which switch was activated. One remedy could be to have the appropriate label flash for two seconds, four flashes per second with equal intervals of light and dark.[46*]

The "operator-proof-ness" (ability of the operator to inadvertantly damage the equipment) should be checked. Hughes personnel indicated that a coffee spill on the desk-top (bullnose) would not cause failure of the equipment. This should be confirmed. The effect of dirt buildup and the ease of cleaning of the light interrupt switches should be investigated. A door type cover should be provided for the font panel of switches and dials on the electronics drawer. If it is important to see the position of the switches and indications on the dials the door could be fitted with a plexiglass panel. If it is important that these switches be readily accessible when the drawer is open and, if space is a problem, the door could be hinged in the

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*This rate of four flashes per second, equal periods of light and dark has been shown to be the optimum rate when flashing is used as a signal. It also conforms with Mil Std 1472B. The publications for the UYQ-21 used for this study did not indicate what rate was used. If it is other than the above, it should be changed to conform.

center of the panel and be a drop type cover. It would be latched at the top (for the closed position) and it could be latched at the bottom so it can be latched open.

The most significant problem is presented by the vertical faces of the upper modules of the consoles. If it is going to be the responsibility of the seated operator to use these displays in the performance of his primary duties, they should be slanted appropriately (see Mil Std 1472B) regardless of the presence of a supervisor behind him. In many cases a supervisor, particularly in a sonar space, will be seated behind the main operator and only slightly above him so as to provide good visibility to the display. Thus, with a slanted face on the upper module, much could be done to ensure good visibility by all concerned simply by proper space layout. At the same time, parallax problems and the possibility of operator error in using this upper screen would be reduced or eliminated. If it is not feasible to change the angle of the upper screen at this time care should be taken to ensure that glare and parallax problems are reduced to an absolute minimum. In addition it would become the task of the programmers to ensure that operations on this display are kept to a minimum and that critical operations on the upper display are eliminated if possible.

The programmers can also influence the effectiveness of the console by their use of the symbology. Again, learning is enhanced by familiar symbols (such as those used previously in NTDS) and by pictorial representations of real world items. Here it should be noted that the symbology repertoire presented by Hughes shows almost no naval or aviation symbols in the pictorial group. If this can be changed by the programmer it should. If not, Hughes should be tasked to change some of the repertoire to more appropriate symbols.

The AN/UYQ-21 system represents an update in console design for the Navy and an expansion of console capabilities. It provides room for growth in the coming years for its capabilities exceed current needs. What remains now is for the Navy to make effective use of this system. Most of this can be done by the programmers although some of it can be specified by the Navy. For example, it may be possible to combine the jobs of some operators to reduce the total number of personnel required. This is especially important with the anticipated manpower shortage of the 1980's.[77] Care must be taken to ensure that such programming would not overload the operators. The programmers must keep in mind the detrimental effects of fatigue and boredom and program to reduce or eliminate these. For example, knowledge of results helps maintain interest and reduce boredom so some sort of feedback to the operator on his performance should be beneficial.[78]

Other items mentioned previously concerning the design of the console itself must also be kept in mind by the programmers to ensure that they take advantage of and do not negate those aspects of the console which enhance the man-machine interface. For example, excessive use of the flashing capability could be detrimental. While it is true that a flashing light is more attention getting than a steady one it is also true that it is more disturbing.[79] A disturbed or annoyed operator will not perform as effectively or be motivated as favorably as one who feels good about his job.

The Navy must be careful in its use of the consoles. Improper space layout could have a detrimental effect. Positioning an operator in an uncomfortable position will effect his motivation. The Navy should review the tasks assigned each operator to ensure that he is neither overloaded nor underloaded, either by redefining his job or allowing or providing some form of irrelevant stimulation in easy or underloaded situations. (This is part of the concept of "optimal stress.")[80] Another way to improve operator performance during routine operations might be to program the system in such a manner that under low load conditions it provides some sort of extra stimulation to the operator. One method might be to provide false targets and after the operator has successfully detected and tracked it for a short time, the system tells the operator he has been successful. Such feedback is like a pat on the back and could greatly enhance motivation. The Navy needs also to be careful about the standardization of programming for the system. Since the programming is not currently scheduled to be done by just one group care must be taken to ensure that the systems can properly interface with each other regardless of platform. Also, operator functions on each console should remain constant from one ship to the next. One of the most error producing characteristics a device can have is that it violates population stereotypes. In other words, it is not the way people expect it to be.[81] An operator who transfers to another ship would have to relearn the system in such a case and he would have to unlearn some of what he already knows including what might be almost a reflex action. Truly a difficult task and one prone to producing errors.

Overall the AN/UYQ-21 will be a good addition to fleet capabilities. The learning ability of the human should probably be able to overcome most of its shortfalls (a possible exception being problems caused by the vertical face of the upper module). However, the development of this system does show that the man-machine interface in the design process is still a relatively low attention item and its position in the hierarchy of design considerations can and should be improved. The Department of Defense has taken the time and trouble to publish a Military Standard for Human Engineering Design Criteria for Military Systems, Equipment and Facilities. While it is not all encompassing and allows tradeoffs and compromises it outlines much of the known aspects of good human engineering design practices. Every project manager, every specification writer and every contractor and designer should have this publication and be made aware of its importance to good engineering design. Even more important, it should be dog-eared from use. One need not be a human factors engineer to read it; one need only be human to realize the positive contribution its use will have in equipment design and operator performance.

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