DE[illegible]TMENT OF
TRANSPORTATION
U. S. COAST GUARD
CGHQ-4453 (Rev. 8-67)

ACTION MEMO -- ENE

A — Action designee
B — Coordinate between designators indicated
C — Comment to action designee
F — Retain in file
K — Information
N — Consult with action designee
P — Approval of content
R — Retain copy
S — Signature

ORDER	ACT.	INITIALS	ATTENTION	
			CHIEF, ENE	ENE-1
		DB	EXECUTIVE ENGINEER	ENE-3
5	KF	DB	DESIGN BRANCH	ENE-5
7	K	RLK	Hull Arrangement AFW	A
6	KF	[illegible]	Hull Scientific Border	B
3	K	JML	Machinery Technical	C
			Boat Technical	D
4	K	[illegible]	Electrical/Mechanical	E
			Specifications	F
			Plan Files	G
			MANAGEMENT BRANCH	ENE-7
			Programs	A
			Fiscal	B
			Materials	C
			Allowance	D
			Mail & Files	E
			PROJECTS: WAGB ENE-9	A
			WHEO	B
			WPB(L)	C

ORDER	ACT.	INITIALS	ATTENTION	
			ASST. CHIEF, ENE	ENE-2
	K	M	MAINTENANCE BRANCH	ENE-4
			Icebreakers	A
		[illegible]	HEC	B
			SAR	C
			A-to-N	D
			Systems	E
			Ordnance	F
			CONSTRUCTION	ENE-6
			HEC	A
			MEC	B
			A-to-N	C
			Ordnance	D
			BOAT BRANCH	ENE-8
			Maintenance	A
			Construction	B
			Forward to Office of Engineering	

REMARKS 2/11/68

To Schumacker
Fm Rice

Interesting report. I'm sure each of us could come up with several "human engineering" deficiencies on the 378' HEC's. Assume we intend to include some "human engineering" requirements in our RFP for Contract Design.

Please make sure Machy Section (5C), Electric Mech (5E), and HEC Maint Section (4B) see this report.

S. H. R.

HUMAN ENGINEERING INSPECTION
OF THE
USCGC "DALLAS" WHEC 716

Terrance K. Gibney

January 1968

Aerospace Medical Research Laboratories
Aerospace Medical Division
Air Force Systems Command
Wright-Patterson Air Force Base, Ohio

CONTENTS

INTRODUCTION

To the uninitiated, "human engineering" and "human factors engineering" are sometimes considered to be nebulous terms. Thus, a brief, specifically directed introduction to the topic is appropriate.

Human factors engineering has both scientific and professional aspects (Pew, 1967). The science of human factors aims to understand human performance capacities and limitations and to develop theoretical models, concepts, and principles of human behavior that can be used to predict and to optimize human performance. The profession of human factors engineering aims to improve the design of equipment and systems for human use, and to achieve more effective utilization of man in man-machine systems. A man-machine system can be defined as an assemblage of elements (including men) that are engaged in the accomplishment of some common purpose(s) and that are tied together by a common information flow network, consisting, in part, of controls and displays for human use; the output of the system being a function not only of the characteristics of the elements but of their interrelations and interactions.

The goals of particular interest in human factors engineering are:

1. Increased efficiency or productivity.
2. Increased dependability or reliability.
3. Minimum training and manpower costs of personnel subsystems.
4. Improved safety and habitability.
5. Increased operator acceptance of equipment.
6. Flexibility and adaptability to change.

For a more comprehensive introduction to human engineering, the reader is referred to Appendix A.

The "DALLAS" itself may be considered to be a system. On it there are many subsystems. Examples include the helmsman and his controls and displays, the Chief Engineman and his engineering control console, and the 1JV talker and his phones.

An in-port human factors evaluation obviously lacks insight into the dynamics of the system and subsystems "under way" and the conclusions drawn from any in-port, and therefore, generally static, evaluation must be considered in that light. Nevertheless, certain design features stand out and are worthy of mention in this report.

Many human factors problems were pointed out by the ship's personnel who had used, or attempted to use, various pieces of equipment at sea on the trip from New Orleans to Baltimore. More of the information gathered for this report was derived from discussions with the ship's personnel than from the actual observation of the equipment and its operation. In an at-sea evaluation this would not necessarily be the case; observation of specific man-machine systems in operation would be preferable.

The nature of the present report is such that it may provide relevant information for personnel aboard the "DALLAS" as well as for the planning and design of future vessels of the same (or similar) class. Information and suggestions presented herein are to be considered tentative since many factors enter into the design and selection of a particular system component in addition to the human factor. Furthermore, since this report is based on a short two-working-day evaluation, it is not to be considered as inclusive, but as a sampling.

PILOT HOUSE

Illumination Levels

One of the outstanding problems in the pilot house is illumination. The ship was visited only during daylight hours, but personnel aboard readily contributed comments related to night operations.

The four TV monitors, individually, or in combination, were reported to generate a light level which interferes significantly with dark adaptation and which produces reflections on the windows (and perhaps, on the overhead). Apparently, picture clarity is lost as brightness is reduced so that high brightness is required to adequately read the information displayed.

During daylight conditions there is considerable glare reflected from the cover glasses of the monitors. This renders reading of the display difficult. Even under optimum ambient lighting conditions picture clarity was reported to be poor. Resolution apparently suffered from an insufficient number of scan lines per inch and, more importantly, from camera vibrations. The mountings that hold the several cameras need better structural reinforcement.

There are several methods by which these particular illumination problems might be alleviated, but it appears significant to question first the desirability of installing the monitors in the pilot house. Do they perhaps present too much or too detailed information for personnel in the pilot house? Are they superior to the presently installed telephone systems? Technological capability to present complex visual information does not insure that it is valuable or that the observer will be able to receive it, assess it, and use if efficiently. It was noted that one of the monitors would display helicopter operations on the fantail. How much information concerning these operations is actually required in the pilot house?*

If there is clear justification for the type of information that the monitors were designed to present, various methods might be used to overcome the inherent viewing problems. For daylight conditions, there are glare reducing filters commercially available** for high contrast displays. These filters absorb ambient light and prevent reflections back to the observer's eye. For night conditions, high transmissivity red filters, placed over the screens might be utilized. Viewing hoods such as are currently used on radar scopes might also be used. This however, would destroy the dark adaptation of the viewer. If it is necessary that he maintain his adaptation, a combination of hood and red filter seems appropriate.

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* There is presently a helicopter operations display system under development in the Air Force Flight Dynamics Laboratory at Wright-Patterson AFB which will electronically generate, on a 3" CRT, a dynamic picture of a helicopter in its landing (or takeoff) phase. With appropriate modifications, this display could be utilized in the pilot house of a ship (Bertram, 1967). It would eliminate the need both for a large TV monitor <u>and</u> for a cameraman.

** Huyck Systems Co., Huntington, N. Y.
Polaroid Corporation, Arlington, Va.

There is, justifiably, a definite resistance to a preponderance of red (and, white and green) lights in the pilot house. One or more of these lights could easily reflect back from the windows and produce the disconcerting impression that another ship was nearby. This reasoning apparently was responsible for the statement in the specifications (Section 24, Ship Control) concerning the pilot house control console: "Lighting for the pilot house console shall not be red, green, or white." A combination of viewing hoods and red filters then, where the hoods shield the red light from surrounding areas, would act to solve the TV monitor viewing problem. In addition, the use of the hoods during daylight would preclude the necessity for glare reduction filters.

One might well question the specification cited above; certainly in practice it has been violated. There are, in addition to blue and yellow warning and indicator lights; red, green and white lights on the console. These lights should be provided with shields to prevent their reflecting from the windows. Also, the means by which their intensity can be varied should be modified so that lower levels of brightness can be achieved. (It was reported that warning and indicator light luminance levels could not be reduced to a satisfactory level to maintain adequate dark adaptation.)

Experimentally, it has been shown that blue, yellow, green and/or white lighting produces more of a decrement in dark adaptation than does red lighting. However, the decrement depends on intensity. If the level of illumination is low, the difference will not be large (Smith and Goddard, 1967). In view of the tradeoff with the advantages offered by color coding, a small additional decrement in dark adaptation seems tolerable. The magnitude of the difference will be largely a function of a given observer's task and the period of pre-exposure to the light source(s). In general, if an observer's task in the pilot house consists primarily of scanning (as opposed to fixating) dimly illuminated displays that are situated throughout the pilot house, his dark adaptation will not suffer appreciably if the illumination is provided by sources other than red. If, on the other hand, his task is primarily to monitor a specific display, or sets of displays, these are best illuminated with red light. The helmsman exemplifies the type of observer referred to in the latter case. The most efficient use of red illumination is where the luminance levels for visual tasks are high, such as the quartermaster's desk, the chart room and the TV monitors, and where there is concern over the individual's dark adaptation after leaving the illuminated area (Smith & Goddard, 1967).

Another relevant variable is area of illumination. Color of illumination should not be considered independently of the area illuminated since both factors influence dark adaptation. With this in mind, it was noted that tell-tale lights in the pilot house were close to 3/4" in diameter. It would appear that this diameter could be reduced considerably.

In addition, to optimally minimize illuminated areas, indicators should be transilluminated whenever practicable (Morgan, et al., 1963). Transilluminated displays are those which are illuminated from behind and only alpha-numerics, pointers, and graduations are lit.

Finally, while warning lights are lit concomitant with audible alarms it seems reasonable to look into the possibility of modifying the warning light circuitry such that when a light goes on it flashes until an observer takes corrective action. Flashing renders the light more detectable and also reduces the total amount of visual stimulation.

Bow Propulsion Unit

Reportedly, there was some operator difficulty experienced in the bow propulsion control-display situation. The design of this system, with stated objectives of precision control of the ship's position clearly required a considerable amount of thought. Based on an in-port evaluation, it is impractical to discuss how optimal this system is from a human factors point of view. Observations during maneuvering are necessary. The following, therefore, is in the nature of illustrative conjecture.

In the evaluation of the controls and displays of this unit, the point of analytical origin should be with the watch officer's command to the unit's operator. Perhaps this command should be standardized, as are other commands in the pilot house, and the control-display configuration modified as necessary so that the operator can most efficiently follow the command. If the command is to change the ship's heading, right or left to x°, the primary display should be heading with secondary displays consisting of main shaft RPMs, bow propulsion RPM and relative angle, where the latter is the angle between the bow propeller's shaft and the ship's longitudinal center line. If the command is to bring the unit to a certain angle and speed, then bow propeller RPM and relative angle should be the primary displays.

The design and types of operator controls for this unit require some preliminary questioning. There are apparently two methods by which angular ship's motion may be induced with the unit; the speed of the propeller may be varied, or, since the unit may be rotated through 360°, the relative angle may be varied. Are both methods of angular motion control necessary? Offhand, it seems possible that if both are manually used simultaneously, there is ample opportunity for operator confusion to arise. Would two speeds (full and half) be sufficient? A single, variable control for relative angle and a detent switch for propeller speed would seem to make both command information and operator response less complex.

Rudder Control

The rudder control handle was noted to overhang the side of the control console by a few inches. During rough weather and/or high activity in the pilot house, this control, as presently situated, is susceptible to accidental movement. Consideration should be given to installing a shield or perhaps a trigger arrangement to prevent inadvertent movement of the handle.

The scales of desired rudder angle and course change on the rudder control are situated such that the operator must lean forward and over the control handle to see the pointer on the scales. Since the operator's vision is generally directed forward to the steering compass, this design would seem to result in an uncomfortable position. While it does not appear necessary to confine, within the same visual field, the steering compass and the desired course change and rudder angle scales, the scales should be located such that the operator does not have to bend over and such that he can easily shift his vision back and forth with no more than head and eye movements.

Depth Indicator

The depth indicator, located forward over the windows, warrants discussion, if not modification. From a human engineering point of view, it is poorly designed. The most prominent feature of the present display is the circular dial face which does nothing more than relate the names of the device and the manufacturer. This may in fact be distracting to the viewer. This information is actually more readily apparent than the indication of depth in fathoms or feet. Whether the display is reading in fathoms or feet is also difficult to discern, especially at night.

Since depth is a vertical, linear concept, a vertical scale display might be easier to read and interpret. Depending on the degree of reading accuracy required, a vertical scale display might not have to be any longer from top to bottom than the diameter of the existing circular dial.

The reading accuracy requirement for this display should be determined from the shipboard personnel who need depth information. Once this requirement is established, the overall size and then the most effective design of the display can be ascertained.

Audible Alarms

Audible alarms in the pilot house which signal the function or malfunction of equipment do not indicate whether a particular unit is located port or starboard. Personnel in the pilot house must refer to associated lights on the control console which do indicate the unit's location. It remains to be determined by Coast Guard officials whether or not this technique presents alarm information optimally.

There is a potential method, however, by which the audible alarms may be pulse coded such that the listener will be immediately cognizant of the equipment's location, port or starboard. When an alarm sounds, instead of producing a constant buzzing or ringing, it could be modified electrically to generate pulses. Consistent with standard shipboard numbering, a series of single buzzes or rings would signal starboard, and a series of double buzzes or rings would signal port equipment. The operator then could make his decisions concerning corrective action while he was enroute to the control console instead of having to wait until he could get to it. This might save valuable seconds. The degree of operator acceptance of an alarm option like this on the "DALLAS" might best determine its usefulness on later ships.

Pilot House Catwalk

It was reported that the catwalk and shield forward of the pilot house are to be removed. This modification will reduce or eliminate the partial occlusion of the foredeck area as is presently the case. However, it will also prevent access to the pilot house forward bulkhead and windows from the outside. This may or may not be a problem, depending upon the provisions available for such activities as window cleaning, windshield wiper maintenance, etc., under steaming conditions.

Floor Mats

The rubber floor mats on the pilot house deck were reported to be quite skid-proof in normal conditions. However, water or other liquids inadvertently spilled on the mats might result in a slippery situation. If it has not already been accomplished, a simple test with one of the ship's crew (wearing a new pair of shoes) and a spilled glass of water could be used to determine how slippery the mats become under those conditions. If in the opinion of shipboard personnel, the mats are excessively slippery, procedures to keep them clean and dry should be stressed. Ideally, in this event, recommendations to change the texture of the mats should be made.

BRIDGE WING

The layout of controls and displays on the bridge wing was noted to be less than optimal. Design engineers apparently had problems fitting a considerable amount of equipment into a small space.

Main Engine Propulsion Controls

These handles, which are mechanically linked to those in the pilot house, should be designed with less slack in the linkage. The handles were also reported to be too stiff. If an operator who is accustomed to using the pilot house controls is going to use the bridge wing controls with equal effectiveness, they should be functional duplicates of each other.

Rudder Control

The bridge wing rudder control, when compared to that in the pilot house, provides a situation which increases the probability of human error. In order to change course with the bridge wing rudder control, its lever must be moved in a direction opposite to that required with the pilot house control. This control reversal might easily be forgotten in the stress of maneuvering and should definitely be corrected so that the two controls are made directionally compatible.

Steering Compass

This instrument, on the bridge wing, is located such that it stands directly behind an operator at the control console. In order to steer from the bridge wing, an operator must continually turn around from a position facing the control and console (forward) to one facing the compass (aft). This situation also provides for increased probability of human error and should be corrected if efficient steering from the bridge wing is to be accomplished.

Instrument Lighting

Lighting for instruments on the bridge wing was reported to have two levels: "bright and very bright." Since this is an area where dark adaptation is required, these instruments should be red lighted and provided with continuous (to zero) lighting controls. They should also be fitted with shields so that their light cannot be seen from the pilot house.

ENGINEERING SPACES

Engine Room Control Booth

The control booth seemed, in general, to include many good design features and to generate a fairly high degree of personnel acceptance. Certain features, however, require further consideration, additional testing and/or modification.

Overhead Gauge Board. One of these features is the lower right corner of the overhead gauge board. This corner is situated low enough and near enough to the entrance door to be a definite safety hazard. The ship's force had made arrangements to have the corner padded and probably painted brightly. Specifications for future vessels should refer to this hazard to prevent its recurrence.

There was some disagreement noted concerning the utility of the information presented by the gauge board. The question of whether this information should be qualitative (e.g. on-off, high-medium-low, hot-normal-cold) or quantitative, as it presently exists, remained unanswered. There are several people stationed in the control booth who use the information provided by this display, but each needs different kinds or amounts, depending upon the nature of his task. The present display design makes check reading or the acquisition of dichotomous or qualitative information difficult. Without full knowledge of each observer's task and need-to-know, it is not appropriate to suggest major changes in the design of this display. On the other hand, there is a relatively simple method of improving the display for enhancing qualitative reading, should this be felt necessary. Differently colored and/or striped tape, placed over individual dial faces could be used to define, for example, hot, normal and cold zones.

The gauges are standard marine temperature and pressure indicators and their legibility is optimal at the standard 28" viewing distance. They are, therefore, difficult to read to all observers except those standing immediately in front of the control console. With this deficiency in mind, the ship's force installed under each gauge on the board a label plate which, in sufficiently large letters, related the nature of the information displayed. To an observer more than 28" distant from the board, the nature, if not the exact quantitative reading of the information, then became more readily apparent. This modification should not have been a ship's force item. The readability requirements for the gauges should have been considered before their installation.

There was insufficient time to evaluate the functional location of the gauges on the board and console, but this should be attempted if it has not already been done. That is, those gauges that are used primarily for monitoring equipment performance, such as lube oil temperature and pressure, are best located up on the board. Those gauges or other types of indicators that are viewed by an operator while he is starting, stopping or otherwise controlling a specific piece of apparatus should be located within the same visual field as the control.

Ship's Service Generators Switchboards. The positioning of the ship's service generators switch boards might also be questioned. As presently installed, these two boards are positioned longitudinally, face to face, with space between for one or more operators. However, an individual operator cannot see the face of one board while looking at the other. This may or may not be a disadvantage. Operating procedures and requirements would determine how advantageous it might be to turn each board 90 degrees so that they faced forward. Repositioning of the board would, at least, result in an increase in accessible floor space.

Battle Lanterns

In general, the engineering spaces, as well as other spaces throughout the ship, seemed to be well fitted with battle lanterns. However, it was not apparent whether their utility had been tested under actual darkened conditions. Will they provide enough light in the right places when used? Will the light, either direct or reflected, blind or otherwise interfere with the performance of personnel? In other words, has the optimum location of battle lanterns throughout the ship been empirically established? The actual need for these light sources will most likely be infrequent, but the need, when and if it arises, will be during a period of high operator stress. Their locations then, are a critical item.

Port Ship's Service Generator Gauge Board

This gauge board, located on the port side of the engine room, adjacent to the port gas turbine, seems to be poorly designed. In order to see all of the gauges simultaneously, an observer must stand back at a viewing distance which brings his head very close to, if not in contact with, the port main propulsion diesel engine.

No hand-hold provisions have been made in this area and the manual recording of readings is no doubt taxing and therefore prone to errors. In rough seas it would not be uncommon for an operator to be thrown against the engine's hot, uninsulated manifold flange which is located opposite and below the gauge board.

If this board must remain in its present location, hand holds should be provided. Consideration should be given to using smaller guages and making this display more compact.

Gas Turbine Access Doors

Turbine access doors were noted to be heavy and free to swing uncontrolled when not latched closed. As presently installed, these doors are capable, in rough seas, of causing personal injury and/or equipment damage. The ship's force had made arrangements to provide means to secure the doors while in an open position, but this provision should have been incorporated at the design stage.

ADDITIONAL COMMENTS

Flourescent Lighting Fixtures

In general, overhead flourescent lighting fixtures, throughout the ship's living and operating spaces, seemed to be too numerous. The pilot house, the ward room, and the C.O.'s stateroom are prime examples of the apparent over-installation of fixtures. They will present a time consuming task when bulb replacement is required. In addition to being numerous, the fixtures are not easy to disassemble for access to the bulbs.

Communication Systems

The locations of telephone systems throughout the ship seemed in many cases to be poorly situated. The Executive Officer, for example, could not reach his phone while he was seated at his desk. Operators at the engine room control console had similar problems. In the pilot house, operators were required literally to kneel on the deck to use the radio phone unit.

Minor Personal Injuries

A brief perusal of the sick bay log revealed that many of the crew members were suffering cuts and abrasions from the sharp edges of newly installed equipment. The ship's galley seemed to contain most of this equipment. Apparently, rough and sharp edges had not been smoothed over or adequately protected prior to installation. The "HAMILTON'S" sick bay log, since it spans a greater period of time, may be even more useful in isolating safety hazards of this nature.

ESTABLISHING DESIGN CRITERIA

The reader will have noticed the frequent references to the dependence of equipment design and layout decisions on the nature of, and the environmental conditions surrounding, the operator's tasks. During the inspection it became apparent that in some cases design engineers had not been particularly cognizant of this dependence. The directional reversals in the steering controls on the bridge and the inadequate gauge board legibility in the engine room control booth are prime examples of this. Such problems, of course, are not peculiar to the Coast Guard.

However, there are procedures available which are used by trained human factors analysts that can provide valuable criteria for the design engineer. These procedures have been used in the U.S. Navy (Channell, 1950) as well as in the U. S. Air Force (Christensen, 1948). Channell's report is available from DOD by AD Number (See references). A copy of Christensen's report appears in Appendix B.

The operator analyses presented in these reports are flexible and can be adapted to the specific situations existing on board the "DALLAS." They permit observation of overall multi-man-machine systems as well as individual analyses of such basic, but important, tasks as those of an engineman's rounds in the engineering spaces.

In its operational stage, the "DALLAS" can present itself as a "human engineering laboratory" undergoing analyses like these without in any way impairing its mission. Resultant conclusions and recommendations from the analyses will be applicable to the "DALLAS" and the succeeding vessels of her class. In addition, the human engineering experience gained will, in general, be transferable to other classes of vessel.

Since the Coast Guard does not have an in-house human engineering group, it would do well to have work like this done on a contractual basis. There are commercial organizations which furnish these services. However, in order to obtain optimum results, an in-house human factors contract monitoring group (or individual) would be most desirable. Assistance in establishing a group of this nature could best be supplied by the Navy where system missions are most nearly similar to those of the Coast Guard.

Acknowledgements

I would like to acknowledge the assistance and direction that many individuals here in AMRL and in the USCG provided me. Such names as Col. W. Stobie, Col. W. Watkins, Col. R. Andrews, Dr. J. Christensen, Dr. M. Warrick, and Mr. R. Voelker came to mind immediately. In addition, there are many whose names I have failed to note and to whom, although anonymous, I am indebted.

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APPENDIX A

HUMAN ENGINEERING IN THE AEROSPACE AGE

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What is "human engineering"? Why and how did it originate? What are some of its past accomplishments? What are its prospects for the future? These are some of the questions which this article will attempt to answer.

With respect to the first question, "What is human engineering?" — it is the development of the specific information regarding man's physical, physiological and psychological characteristics that engineers must have to design effective man-machine systems. Engineers receive considerable theoretical and practical training in the physical sciences but receive little if any instruction with respect to those characteristics of man that might make their equipment easier and safer to operate and maintain. Fortunately one outstanding characteristic of man, the user, keeps this situation from developing into complete chaos. This characteristic is his adaptability, including his ability to learn and to profit from past experience.

But adaptability is not enough to cope with present and future complex systems. By the end of World War II it appeared that the abilities of even our best men, receiving the finest of training, would be inadequate to keep pace with engineering progress. For example, some questioned whether or not man ever could handle aircraft faster than the F-51. Yet, a few years later, Captain Yeager flew the X-1a at 1632 miles per hour. Today, rendezvous between vehicles travelling over 17,000 miles per hour is being seriously considered. What happened in the meantime? Essentially, a new attitude developed toward man as a system component. Whereas a decade ago some engineers were dedicated to "getting man out of the system", we now find that the missions contemplated for the near and distant future can only be accomplished with man's intelligence in the vehicle and in the ground system supporting the vehicle. General Shriever in an AF Information Policy Letter dated 1 January 1962 has put it this way ". . . basically, the requirement for man in space is the same as the requirement for man in any other realm of military operations. No machine can replace him. He is unique in his ability to make judgments, to exercise control, and to cope with unforeseen situations." F. C. Durant, III, former president of the American Rocket Society, testified as follows before the 86th Congress of the United States, "Pound per pound, automated equipment will never be able to compete with man where judgment is to be exercised and unanticipated facts are to be recorded and transmitted. Another role to be filled by man in space is that of repair and maintenance . . ." Brigadier General Boushey testifying before the same Congress stated "If for no other reason than that of reliability, man will more than pay his way . . ." It is evident that our attitude today is not "how to get man out of the system", but rather "how to get his abilities into the system".

As technology advances the number of relationships between man and machine increases markedly. Consider the number of contacts that you as an individual have with the products of engineering in a single day — you arise in a house built from engineering products, shower under an engineering product (often finding that the hot water turns on opposite to what you expected and, as a result, you almost scald yourself!), shave with an engineered electric razor, prepare breakfast on engineered devices, jump into a device called an automobile designed to propel you along an engineered road at a velocity guaranteed to get you to work on time (but, unfortunately, designed, along with the highway, also to kill almost 40,000 persons per year in the United States alone), and so on. In one day you interact with a greater variety of machines than your grandfather did in a month. The human engineer simply tries to help the engineer assure that his products will be designed as well as possible in terms of such considerations as safety, maintainability, operability, and reliability.

"Safety", of course, is but one of the many measures which the engineers use. It is conceivable that the automobile, for example, could be designed so as never to cause the death of anyone, but it would not meet the designers' ideas of speed, comfort, appearance and cost. The designer of military systems has a similar problem. His final product always represents a compromise among these and many other factors. Fortunately there is much he can do regarding safety that does not compromise any of the other performance criteria; in fact, may even improve them.

THE PAST

Some of the past accomplishments of human engineering are now so commonly accepted in the Air Force that their origin has long since been forgotten. Figure 1, for example, shows the results of an experiment on the design of altimeters — an instrument that has been considered responsible for numerous aircraft accidents. Notice how relatively poor the old standard altimeter (first one in the photograph) is with respect to both errors and the time it takes to read it. Notice also that those instruments that are read quickest tend also to be good design from the standpoint of speed. And, while we can't prove it, don't you feel that such design is also best from the standpoint of safety?

Horizontal alignment of pointers, which is now widely accepted, was based largely on the experimental results shown in Figure 2. Notice again that the arrangement which was best from the standpoint of accuracy (9 o' clock alignment position) was best also from the standpoint of speed.

Psychologists have also studied the arrangement of instruments by photographing the eye movements of pilots flying aircraft under various conditions. The "link values" in Figure 3 essentially show the strength of the relationships among the various instruments. You will recognize the central six instruments as the famous "sacred six". This arrangement of these six instruments prevailed for many years in virtually all Air Force aircraft. It made it easier for a pilot to fly in different aircraft.

Psychologists in human engineering also worked on the design of controls. Figure 4 shows some of the various designs that resulted from these studies. This work formed a foundation for the current and past emphasis on "coded controls" and undoubtedly prevented many pilots from grasping and actuating the wrong control.

The direction that a control should move with respect to the plane of the display was also considered. From Figure 5 it is clear that some control-display relationships are much less confusing than others. For example, it is clear that a control and its associated display should lie in the same plane if at all possible.

Precisely where controls should be located in the workplace has been carefully studied by anthropologists and psychologists, both for the unencumbered condition and for men wearing all varieties of protective clothing and survival gear. (See Figure 6.) The Mercury test bed, for example, was checked out in this apparatus.

Psychologists have also flown with SAC and MATS in an attempt to determine exactly how crew members spend their time. This enabled them to make recommendations regarding the layout of workplaces for safety and efficiency, more efficient work procedures and ideas for the design of labor-saving instruments and tools. Figure 7, for example, shows how the first navigator spent his time on arctic flights at the time the study was made.

The "before and after" contrast is vividly brought out by an inspection of museum aircraft for the periods prior to and after about 1946. A high degree of sophistication in human engineering is now commonplace throughout the aircraft industry.

THE PRESENT

Has this sophistication extended to the missile industry? The answer appears to be "yes, but only to a limited extent". This is a little surprising when one considers that the present major missile manufacturers are or were also the major manufacturers of military aircraft. The same human engineering problems that cropped up in the design of aircraft are again appearing in missiles. Pearson and Anderson in their book "U.S.A. Second Class Power" state "One Pan Am technician lost a $2,000,000 Thor missile by carelessly crossing the wrong wires in the DOVAP system, which shows the ground officer whether the missile is on or off course. The big 1200 mile Thor headed out over the Atlantic perfectly, but the crossed wires made it appear to be looping in the opposite direction, ... the safety officer pushed the 'destroy' button." (our underline — incidentally, may we suggest that we wouldn't even want the technician to cross the right wires!!). Later in the same book, the authors state as follows regarding the failure of another missile, "Failure analysis disclosed that a technician had carelessly mismated two electrical connectors . . ." (again, our underline).

As in the aircraft industry twenty years ago, these errors are attributed to "careless technicians". But the designer must bear some of this responsibility. Simply coding the wires or mismatching the design of adjacent pairs of connectors almost certainly would have prevented both mishaps — a simple application of well-established human engineering principles. This is the fundamental point of this article. Many of the simple design errors of the aircraft industry are being repeated in the missile industry. It would appear that some feel that an environment as exotic as space requires a completely new set of principles for the use of men in systems. This is simply not so. Fundamental information regarding control coding, instrument design and the characteristics of man's senses and higher faculties is still relevant.

Without meaning to be impertinent, we would like to suggest that the missile and space systems divisions of the defense industries could profit from a greater exchange of information with personnel of the now more prosaic aircraft divisions. It is reliably documented that approximately 50 percent of the missile failures are due to so-called "human-initiated failures", many of which could have been prevented by careful attention to established human engineering design principles, principles that were developed in the pre-space era of airplanes.

THE FUTURE

Although the traditional principles of human engineering are equally applicable in the space age, there are obviously many new problems also and new information will be required. What is the nature of this information? Research has been and is being conducted on the effects of weightlessness on man's performance, including problems related to the design of personal propulsion systems for use in space, behavior of man on a tetherline, tethering of man at his workplace, optimal work-rest cycles for extended space missions, visual and motor capabilities of man to effect rendezvous and precise control in space, design of remote manipulators, design of ground control consoles and procedures, design for ease of maintenance, to list but a few. Suffice it to say that the Air Force has anticipated at least some of the human engineering requirements of the missile and space age and is supporting programs that will generate information of direct value to the design engineer. Nor is this effort restricted to the Air Force. The other military services, NASA, academic institutions and industry all have related interests and programs.

Finally, it should be made clear that the human engineer is <u>not</u> a design engineer. The human engineer simply tries to provide information regarding a most versatile sub-system to the design engineer. The human engineer asks only that this information about man be considered along with the wealth of other information which the designer has with respect to his electro-mechanical-hydraulic subsystems. Such a design philosophy will yield systems that represent the maximum effectiveness possible in any given situation. We hope that you tend to agree.

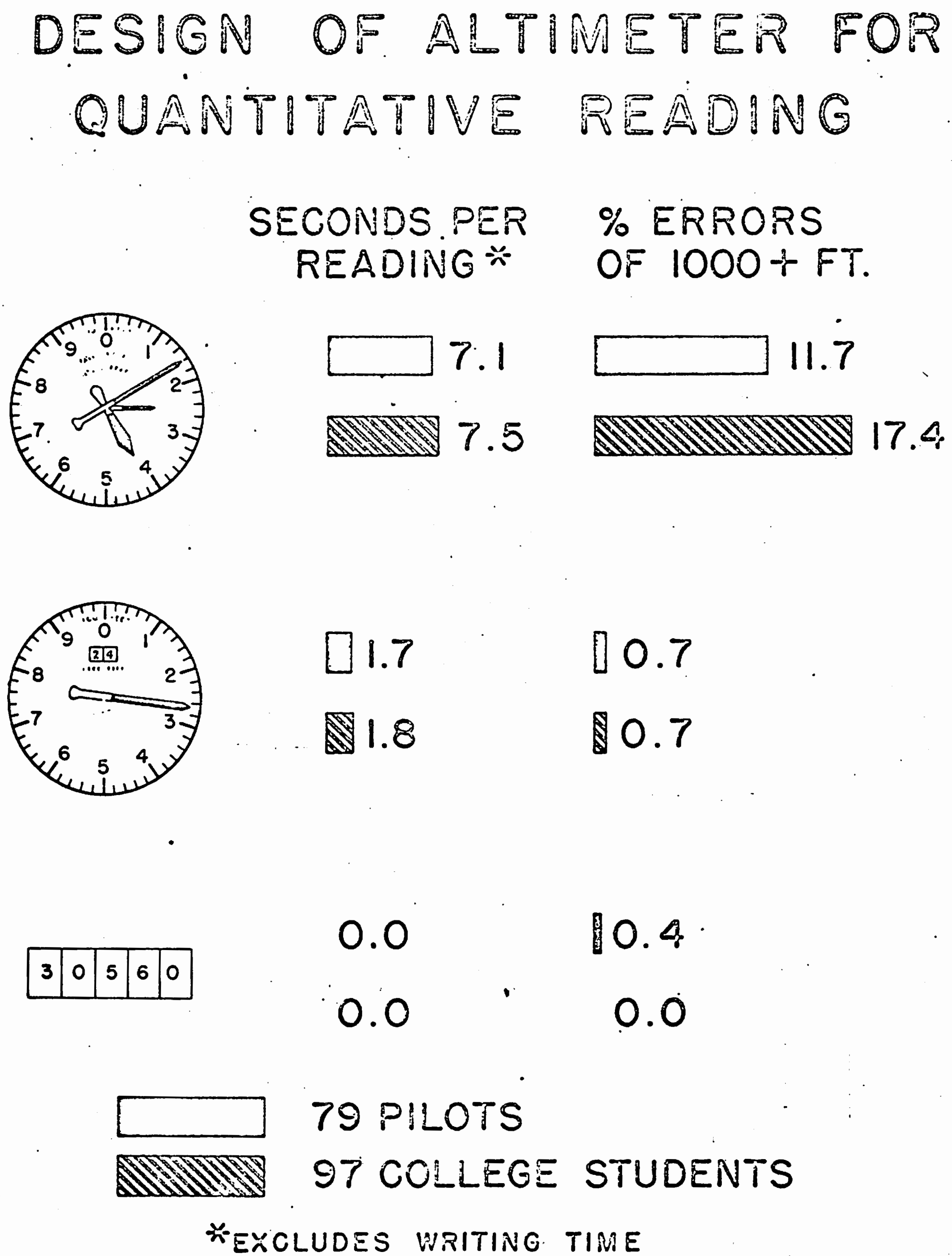
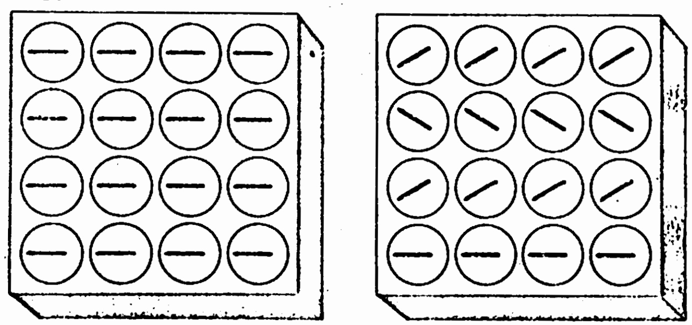

DESIGN OF ALTIMETER FOR QUANTITATIVE READING
SECONDS PER READING*
% ERRORS OF 1000+ FT.
7.1
11.7
7.5
17.4
1.7
0.7
1.8
0.7
30560
0.0
0.4
0.0
0.0
79 PILOTS
97 COLLEGE STUDENTS
*EXCLUDES WRITING TIME

FIG. 1

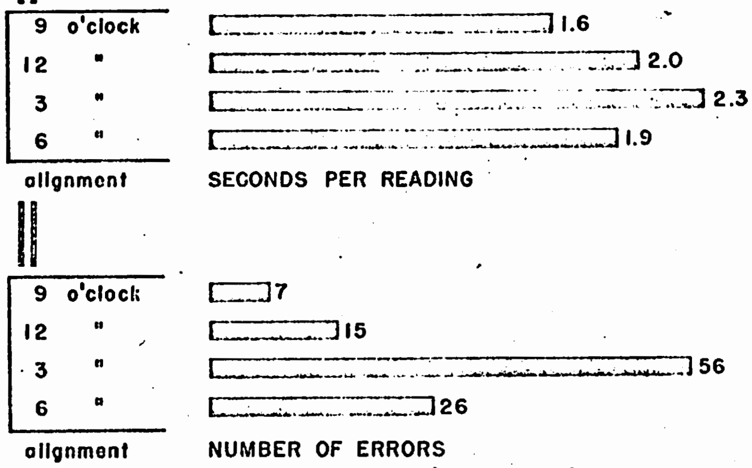


0.66	SECONDS PER READING	1.64
3.0	PERCENT ERRORS	16.7

Check Reading

Only 0.66 seconds is required to check this panel when pointers are aligned.

Qualitative Reading



Experienced pilots and preflight cadets performed best at the 9 o'clock alignment position when requested to judge the direction of pointer deviation.

5689-C

FIG. 2

EYE MOVEMENT LINK VALUES BETWEEN AIRCRAFT INSTRUMENTS
SECOND HALF OF CONTACT TAKE-OFF

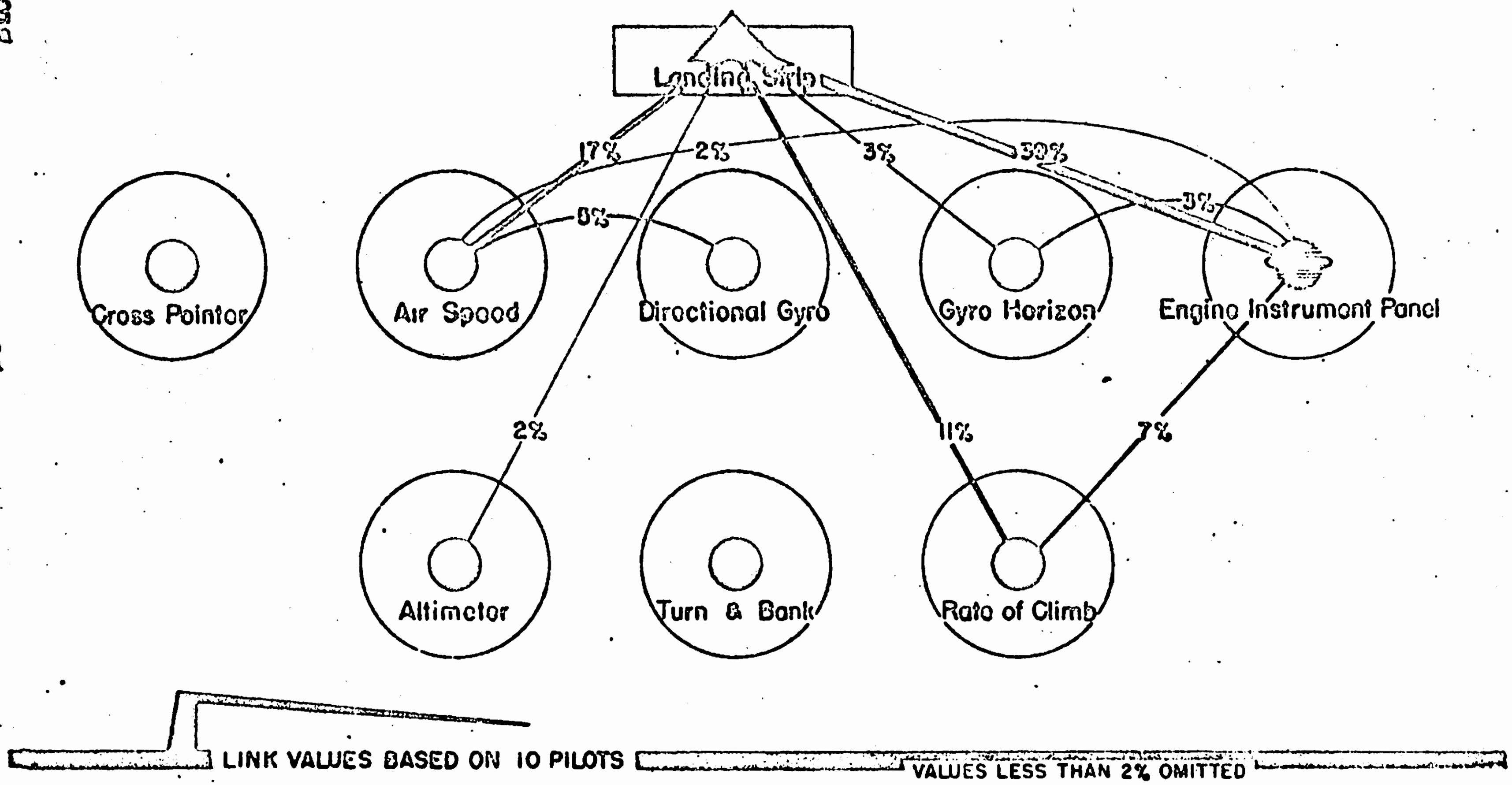
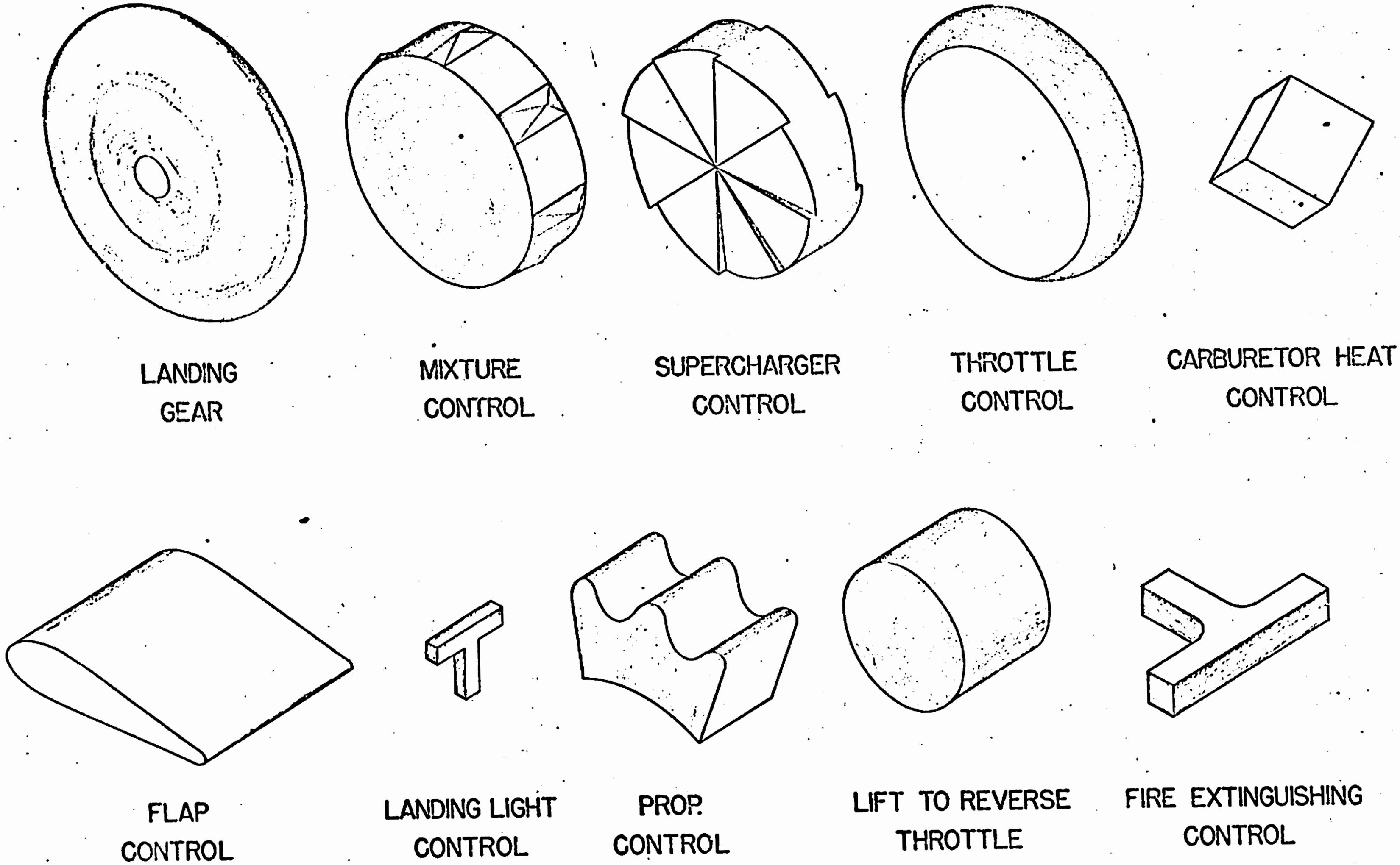


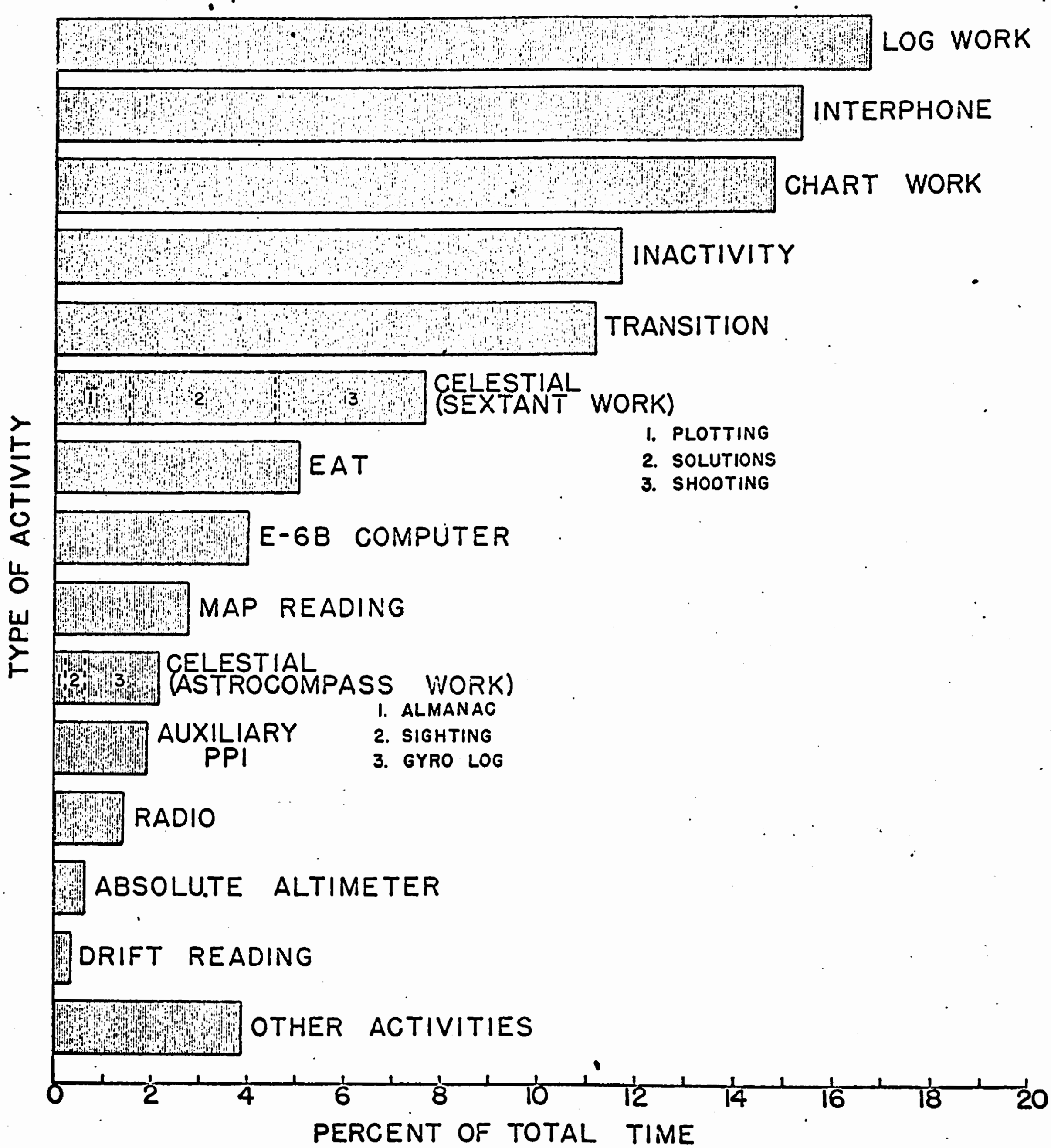
FIGURE 3



STANDARD KNOB SHAPES

FIG. 1

FIG. 6



DISTRIBUTION OF FIRST NAVIGATOR'S TIME ON ARCTIC MISSIONS

4896-A-AML

FIG. 7

APPENDIX B

U. S. AIR FORCES
HEADQUARTERS, AIR MATERIEL COMMAND
ENGINEERING DIVISION

No. of pages - 48

MCREXD-9/JKC/mec

MEMORANDUM REPORT ON

Date: 2 February 1948

SUBJECT: Aerial Analysis of Navigator Duties with Special Reference to Equipment Design and Workplace Layout. II. Navigator and Radar Operator Activities During Three Arctic Missions.

SECTION: Aero Medical Laboratory.

SERIAL NO.: MCREXD-694-15A

Expenditure Order No. 694-29

A. PURPOSE:

1. An aerial analysis was made during three arctic missions of the activities of the First Navigator, the Second Navigator and the Radar Operator.* The work was undertaken at the request of and carried out in close cooperation with the Equipment Laboratory. The investigation was planned in order to obtain objective data regarding the following questions:

a. What new equipment and what changes in existing equipment will result in the greatest improvement of Navigator efficiency?

b. What is the best layout of the equipment in the Navigator's and Radar Operator's workplaces, and what is the optimal design of these workplaces with regard to convenience, efficiency and reduction of fatigue?

c. What are the minimal crew requirements for navigation and bombing operations in the Arctic?

B. FACTUAL DATA:

2. Arctic missions were flown with the 46th Photo Reconnaissance Squadron, 9 September 1947 and 17 September 1947. An arctic mission was flown with the 59th Weather Reconnaissance Squadron, 12 September 1947. Each mission lasted approximately 15 hours. This was two hours less than the average mission flown by the 46th Squadron and approximately the length of the average mission flown by the 59th Squadron.

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* Appreciation is expressed to the personnel of the 46th Photo Reconnaissance Squadron and the 59th Weather Reconnaissance Squadron without whose cooperation this study would have been impossible.

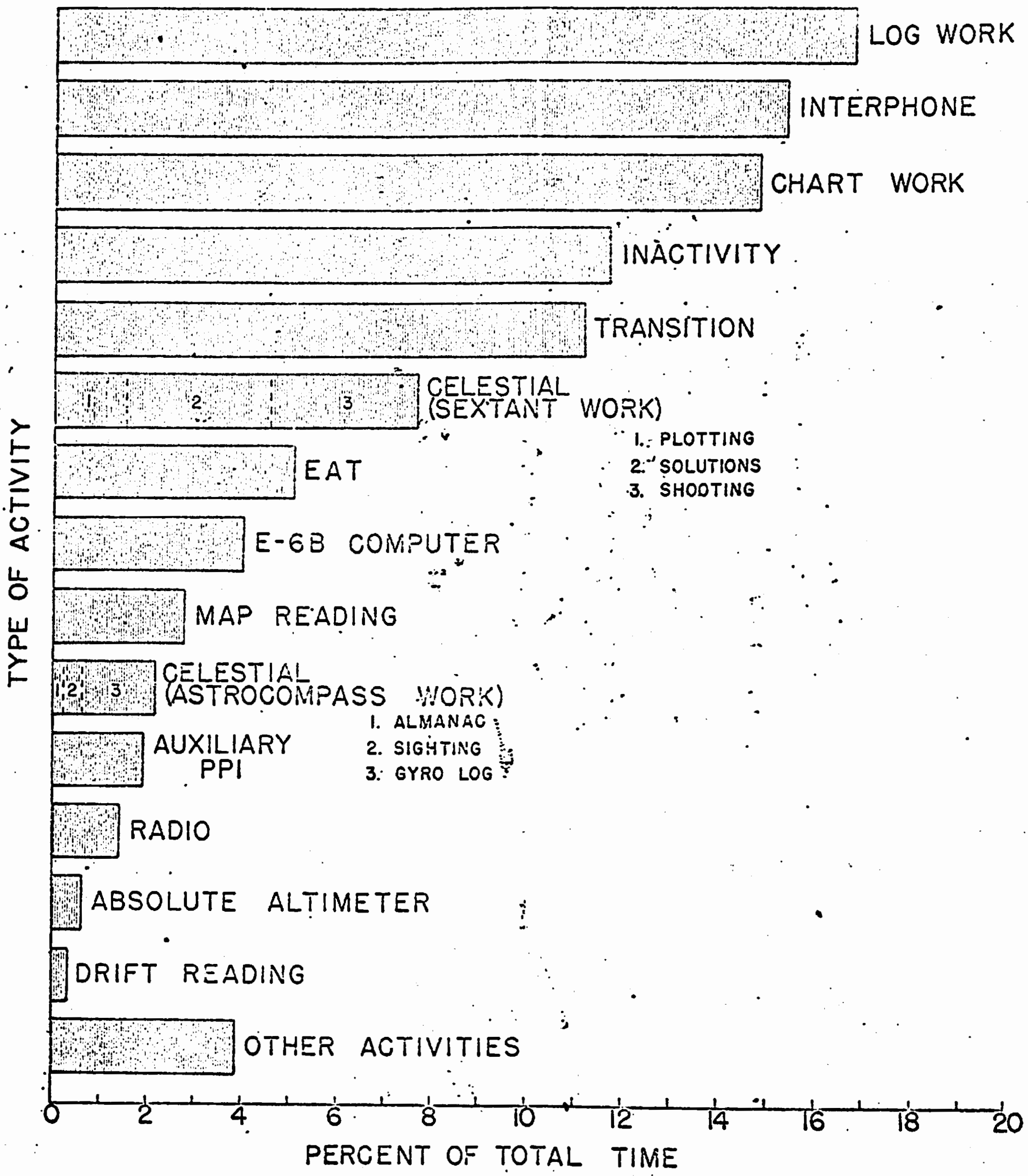
3. The 46th Squadron and 59th Squadron assign two Navigators and, if available, two Radar Operators to each mission. One RCAF Observer flies on each mission with the 46th Squadron and sometimes relieves one of the Navigators. No RCAF Observer accompanies the 59th Squadron. Details of the duties of the First Navigator, Second Navigator, and Radar Operator are given in Appendix II.

4. Activity analysis, as the term is used in this report, is a new concept. It involves the objective recording of the time devoted to different aspects or functional elements of a complex activity, and of the sequence in which those elements are performed. Further definition and the difference between activity analysis and motion and time study are discussed in Appendix I. Data for the activity analysis were obtained by means of sampling technique. A timer set for five second intervals triggered a buzzer audible to only the observer. When the buzzer sounded the observer recorded the activity in which the Navigator was engaged at that instant. During the first mission the observer recorded data during the first 45 minutes of each hour. The remaining 15 minutes were spent in rest and in preparation for the next period of observation. During the second and third missions a period of 40 minutes of observation was followed by a period of 20 minutes of rest and preparation.

5. During the first mission seven periods were spent recording the activities of the First Navigator and two periods were spent obtaining activity data on the Radar Operator. During the second mission five periods were spent obtaining activity data on the Second Navigator, and three periods were spent observing the Radar Operator. During the third mission (which was aborted at photo destination because a heavy undercast precluded any possibility of photography) five periods were spent recording the activities of the First Navigator and two were spent obtaining activity data on the Second Navigator.

6. The Navigators observed were representative of present Arctic Navigators. All had 2000 hours or more in the air; all had extensive experience in theatres throughout the world before going to Alaska. This diversity of talent and experience has been brought to bear on the unique problems of arctic navigation.

7. Summaries of the activity analysis data for the First Navigator, Second Navigator and Radar Operator are shown in Figures 1, 2 and 3. The complete analysis will be found in Appendix I. The following are the most important facts revealed by the analysis.



DISTRIBUTION OF FIRST NAVIGATOR'S TIME ON ARCTIC MISSIONS

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Figure 1. Distribution of First Navigator's Time on Arctic Missions.

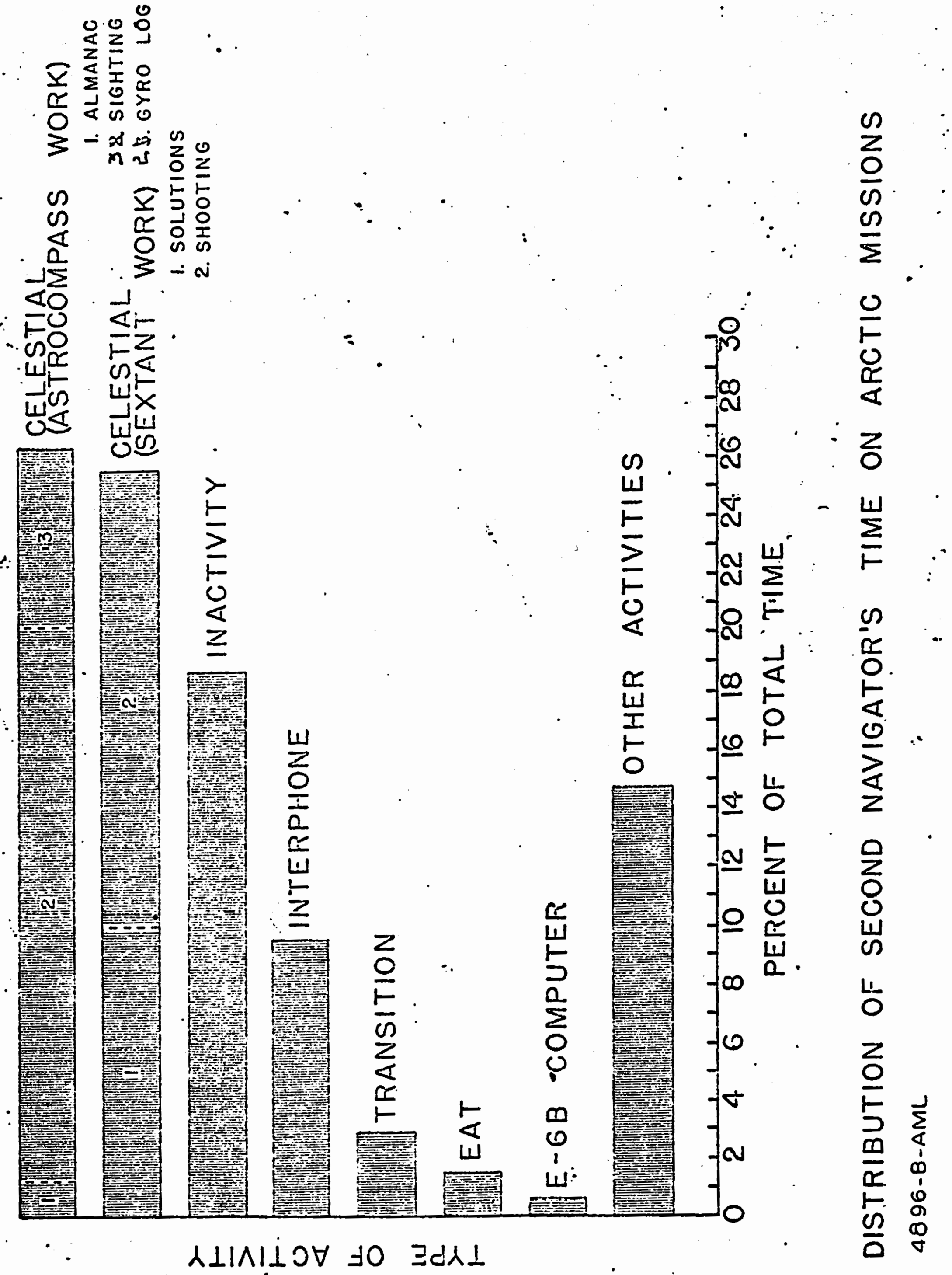

Figure 2. Distribution of Second Navigator's Time on Arctic Missions.

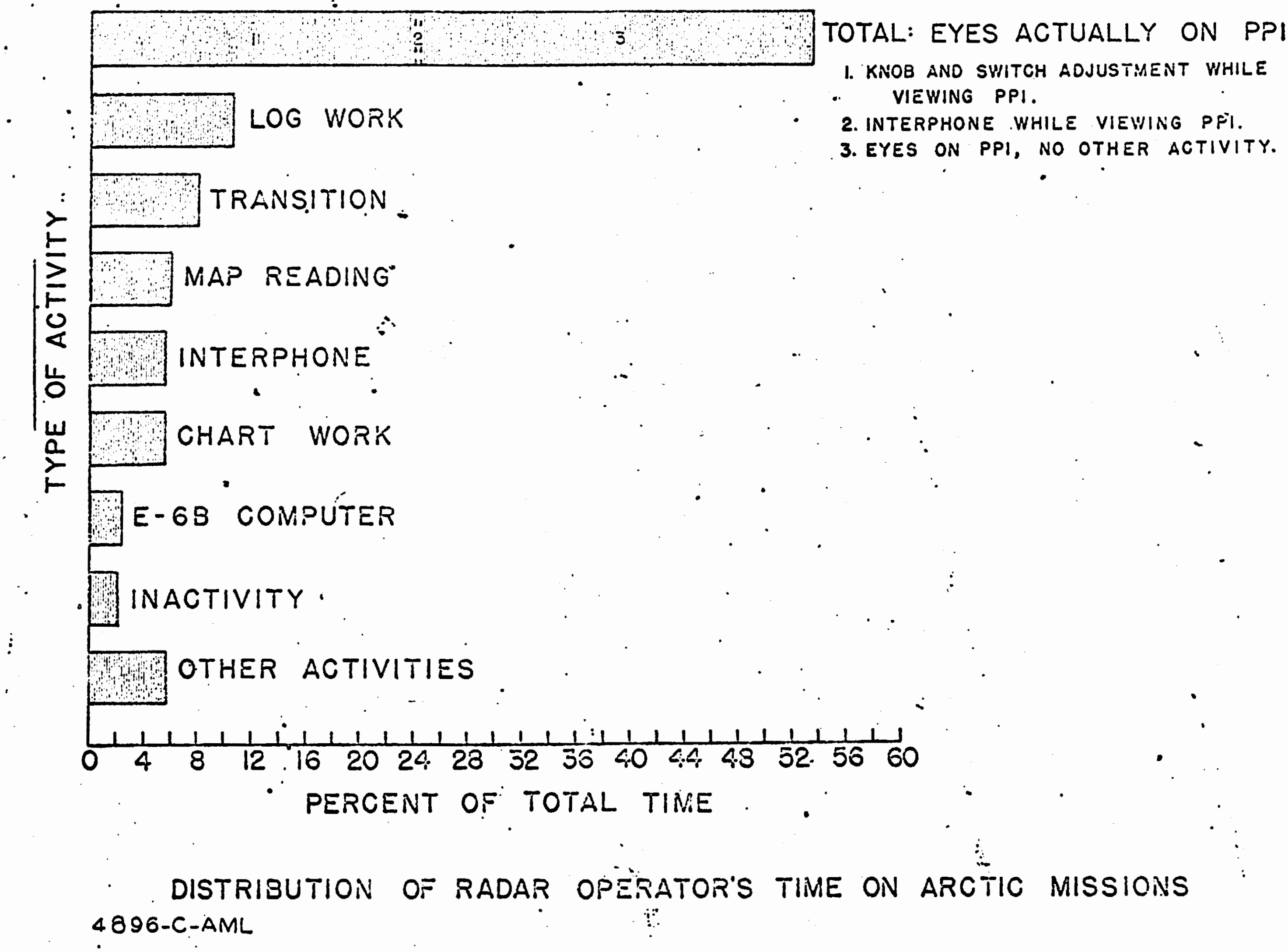

Figure 3. Distribution of Radar Operator's Time on Arctic Missions.

a. The First Navigator is required to spend most of his time on log work (including reading and recording air speed, altitude, compass heading and temperature), interphone, chart work and transition (i.e., transferring from one activity to another). (See Figure 1) These four activities require 58 percent of the First Navigator's time and permit him to devote a minimum of time to the gathering of basic data with the sextant, astrocompass, drift meter and other instruments.

b. Navigators in the Arctic seldom, if ever, use the air position indicator. This is true even in those zones where the flux-gate compass can be and is used.

c. The absolute altimeter (SCR-718) is seldom used in Arctic Navigation. Its inclusion is possibly justified as emergency equipment (Bellamy drifts).

d. The auxiliary PPI is used very little by the First Navigator.

e. Navigation by radio at any distance from home base is impossible at the present time.

f. To date, Loran is of very limited value because of lack of stations and unreliability of the information when available.

g. Little time was devoted to drift reading. However, the figure is misleading because on two of the missions weather conditions precluded regular reading of drift. The drift meter is a valuable item of equipment. It quickly and directly provides highly accurate essential information.

8. The Second Navigator, who is supposed to be primarily a celestial observer, devotes only 5 percent of his time to astrocompass sighting and 16 per cent to sextant sighting. He is required to spend what seems to be an inordinate amount of time (20 per cent) on the gyro log. Celestial solutions require another 10 per cent of his time. He spends 10 per cent of his time on interphone.

9. The Radar Operator spends 54 per cent of his time viewing the PPI. Complaints of eye fatigue and headaches are common. Six per cent of his time is spent on interphone. Practically all of his interphone conversations are with the First Navigator. Eight per cent of the Radar Operator's time is spent transferring from one activity to another. In one aircraft the radar control panel was located 90 degrees to the Radar Operator. Each time he wanted to check the dials on the control panel he had to leave his chair.

C. CONCLUSIONS:

10. The method of activity analysis employed in this study provides objective data that are useful in determining what new equipment is needed, how the workplace should be designed and arranged and the minimal number of crew members required to handle specific aerial jobs. The technique is judged to be suitable for analysis of the activities of crew members other than the Navigator and Radar Operator.

11. With the equipment, layout of workplace and navigational aids now being employed, it is judged to be impossible for one Navigator to do the work now done by two Navigators under arctic conditions. A minimum of 92 minutes per hour is required to do all this work. (See Figure 4.)

12. With the equipment, layout of workspace and navigational aids now being employed, it is judged to be impossible for two 1037 Operators (Navigator-Bombardier-Radar Operator) to handle all the navigation and radar on arctic missions. A minimum of 146 minutes per hour is required to do all this work. (See Figure 5.)

13. If the Radar Operator were moved to the forward compartment and the Radio Operator were moved to the rear compartment, the front turret removed or relocated and automatic recording of some data introduced, it is concluded that two 1037 Operators could handle all the navigation and radar on arctic missions of 15 hours. However, this would allow a minimum of time for radar and celestial work. On missions of over 15 hours, an additional 1037 Operator should be added.

14. The workplace provided for the Navigators is small, restricting, and wholly unsatisfactory. The general layout would be improved if the front turret were removed from reconnaissance aircraft and replaced by a satisfactory astrodome. A hydraulically operated stool with a back rest should then be provided for the celestial observer.

15. Relief from much detailed work could be accomplished by automatic recording of such variables as airspeed, altitude, temperature and heading.

16. Control consoles for the radar sets should be arranged functionally with respect to the inherent capacities and tendencies of the operator. Almost certainly the effectiveness of the use of radar information is being affected by the amount of time and conditions under which he must observe the PPI.

17. Because of the unusually close coordination required between First Navigator, Second Navigator and Radar Operator, all should be in the forward compartment.

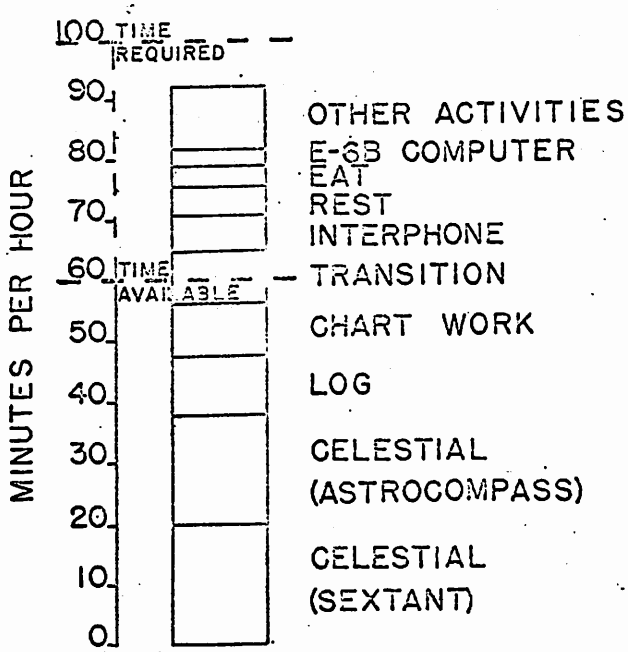

Figure 4. Estimated Time Requirements - Both Navigators Combined.

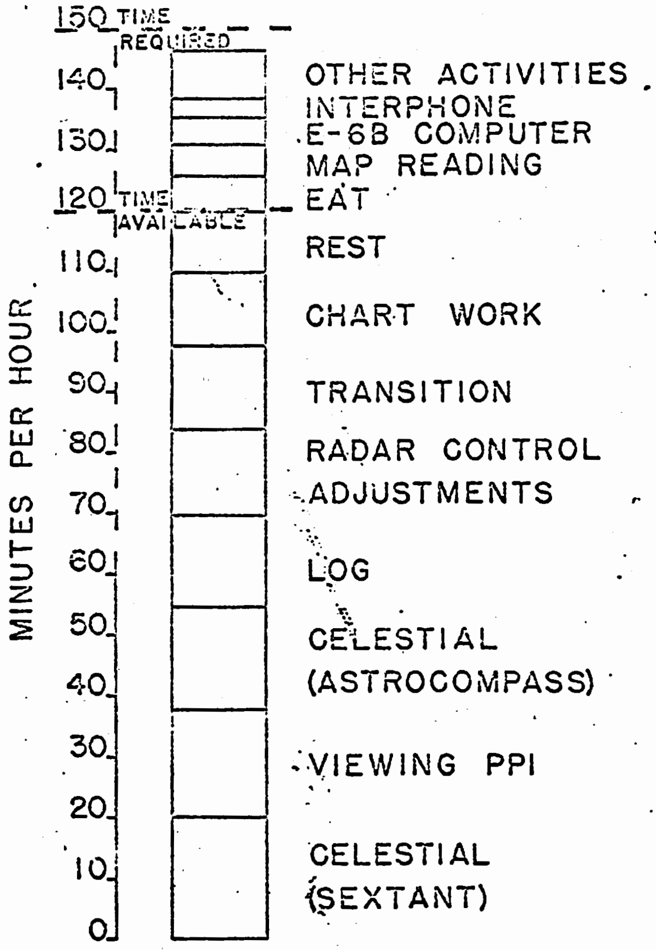

Figure 5. Estimated Time Requirements - Both Navigators and Radar Operator Combined.

D. RECOMMENDATIONS:

18. That the Equipment Laboratory review the factual data above and suggestions 1, 2, 3, 6, 7, 8, 9 and 10 listed in Appendix I with respect to early incorporation in a program designed to increase the efficiency and dependability of arctic navigation.

19. That the Communications and Navigation Laboratory review suggestion 4 with respect to increasing intercommunication efficiency in heavy bombardment and other long range aircraft.

20. That the Bombardment Branch of Aircraft Projects Section review suggestion 11 and the technique in general with respect to its worth in obtaining objective data as a basis for determining future crew requirements.

21. Recommendations resulting from the study have already been made on the B-50B and B-50C aircraft mock-ups. These can be found in Memorandum Report Number TSEAA-720-110A (Confidential).

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2/11/68
Noted
S. H. R.

DEPARTMENT OF THE AIR FORCE
6570TH AEROSPACE MEDICAL RESEARCH LABORATORIES (AFSC)
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

17 FEB 1968

REPLY TO ATTN OF: MRH

SUBJECT: Human Engineering Inspection of the USCGC "DALLAS" WHEC 716

TO: U. S. Coast Guard
ATTN: Captain S. H. Rice (ENE-9)
Chief, Naval Engineering Division
Washington, D. C. 20591

1. The attached report is the result of a human engineering inspection which was conducted aboard the USCGC "DALLAS" WHEC 716 at the U. S. Coast Guard Shipyard, Curtis Bay, Baltimore, Maryland, 4 and 5 December 1967. The inspection was made at the request of the Coast Guard (letter dated 5 October 1967).

2. The report has two primary objectives: (1) to identify and summarize outstanding and potential observed human engineering problem areas, and (2) to refer Coast Guard personnel to appropriate literature and to methods of more sophisticated and lengthy evaluations, in port and at sea, which they might wish to make or have made while the vessel undergoes real and simulated maneuvers consistent with its mission.

3. The report is by no means a detailed, conclusive effort. It should be considered only as suggestive of what a more comprehensive review might indicate. In general, the specific areas of concern during the two-day visit were the bridge and engine room operating spaces. A considerable amount of time would have been required to inspect all of the operating spaces.

4. The text of the report concentrates on "negative" items in terms of some of the more obvious human engineering design deficiencies, omissions and errors. The positive aspects have not been emphasized. Positive, or appropriate, human engineering design stands on its own merit and does not require specific comment in a report of this nature. Moreover, based upon casual observations of the generally high degree of crew acceptance of the vessel and its subsystems, it is felt that the better human engineering design features are, at least implicitly, apparent to the crew.

5. The author wishes to express his sincere appreciation to those members of the crew of the "DALLAS", both officers and enlisted, with

whom he came into contact. They exhibited interest in the inspection procedures and were exceedingly cooperative and informative. Their helpful comments, suggestions, and explanations, contributed immeasureably to the content of the report.

FOR THE COMMANDER

William H. Stobie

WILLIAM H. STOBIE, Lt. Colonel, USAF
Chief, Behavioral Sciences Laboratory

Copy to: CDR Fenlon, USCG (MCLCG)

1 attch.
Rpt., "Human Engineering Inspection of the USCGC 'DALLAS' WHEC 716"