AD642799

HUMAN FACTORS IN THE DESIGN OF THE SUBMARINE CONTROL ROOM.

DUNLAP AND ASSOCIATES INC STAMFORD CT

14 OCT 1949

CONFIDENTIAL

This publication is classified CONFIDENTIAL. It is a nonregistered document but shall be handled, stowed, and transported as prescribed by the applicable regulations for other official publications of CONFIDENTIAL classification. When no longer required by the using agency, it shall be destroyed by burning. No report of such destruction is necessary.

TECHNICAL REPORT - SDC 641-2-4

HUMAN FACTORS IN THE DESIGN OF THE SUBMARINE CONTROL ROOM

(Human Engineering Systems Studies)

Dunlap and Associates, Inc.
10 East 49th Street, New York City
14 October 1949

SDC Human Engineering Project 20-F-2
Contract N8onr-641, T.O. II
Project Designation NR-784-002

Ralph C. Channell,
Project Director

86

FOR THE SPECIAL DEVICES CENTER:

Reviewed for Human Engineering Branch:

V. J. Sharkey
V. J. Sharkey, Project Engineer
Head, Code 911

Submitted:

C. S. Rhoads
C. S. Rhoads, Technical Director

Approved:

F. D. Walker
F. D. Walker, Commander, USN
(Acting) Commanding Officer & Director

[redacted]

Acknowledgements

Grateful acknowledgement is expressed to the Naval personnel who cooperated in the preparation of this report. We are particularly indebted to the officers and men of the USS Halfbeak and USS Pickerel, and to the engineers who are constructing the SS 563/564.

The data for this study were collected by F. W. Trabold, W. W. Cumming, J. Orlansky, and R. C. Channell. F. W. Trabold and W. W. Cumming analyzed the data and, with G. S. Chan and E. Girden, prepared the report.

Table of Contents

I. SUMMARY AND RECOMMENDATIONS

Purpose

The purpose of this report is to make recommendations for improving the design and operation of the Control Room in the SS 563/564. The emphasis is upon the general arrangement of equipment and personnel, although controls and indicators on present submarines are also evaluated. Where present equipment is duplicated in the SS 563/564, the specific criticisms and recommendations apply directly to the new submarines. A subsequent report will contain a detailed analysis of the instruments designed especially for the Control Room of the SS 563.

These new submarines involve major changes in the distribution of equipment and personnel. One compartment, extending from frames 42 to 55, will be divided into three areas: The Periscope Area, Attack Center, and Control Room. The last will occupy the port section of the compartment and will have less than half the space previously available. Because of the reduced space, it is essential that the activities of the men be closely integrated. This in turn requires that Control Room operations be thoroughly evaluated in terms of basic principles of human engineering.

Procedure

An earlier report offered recommendations for improving the operations at the Diving Control Station.[1] This report is based upon an investigation of the equipment and activities at the other main stations in the Control Room: the hydraulic, air, and trim manifolds. Since the new boats are still in the developmental stage, data were collected aboard present Guppy-type submarines, the USS Halfbeak and USS Pickerel, and also at the Submarine School at New London, Connecticut. A functional analysis of each control and indicator for the three manifold stations was made aboard the USS Pickerel. Equipment Evaluation Data Sheets were used to analyze the presently installed equipment from the standpoint of those factors pertinent to ease of operation, e.g., design, location, function, and frequency of use.

In order to determine the duties of each operator, several methods of collecting data were employed aboard the USS Halfbeak. The Submarine Engineering Orders were inspected to determine the operators' duties. An overall picture of submerged operations was obtained through the use of photography, sound recording, and observers with stop watches. All verbal communications were recorded automatically by means of a Navy V-F Sound Recorder. The microphone was placed near the Diving Officer so that all commands and acknowledgements were transcribed. Observers recorded simultaneously at each work station the time for each separate activity of the operators. Then, a frame-by-frame analysis

---

[1] Trabold, F. W., Tolcott, M. A., and Channell, R. C. Human factors in the design of the submarine diving control station. SDC 641-1-1, 27 October 1948 (CONFIDENTIAL).

of motion pictures provided a finer breakdown of performance-time. Interviews were held with experienced Diving Officers and enlisted personnel, both aboard the submarines and at the New London Submarine School, in order to determine the operations and equipment which cause difficulty. From all these data, it was possible to construct time-activity charts showing the integration of the performances of the Diving Officer and the three manifold operators.

In order to relate the analysis of equipment and activities aboard present submarines to the Control Room of the SS 563/564, visits were made to the Electric Boat Co., Groton, Connecticut, and the Portsmouth Naval Shipyard, Kittery, Me. Full scale models of the new type submarine were inspected. Tentative plans which were made available for study were discussed with the design engineers. As far as could be determined at this stage of development, much of the equipment on the SS 563/564 will be similar to that now in use. The operating procedures, on the other hand, will change somewhat because of the new layout. The extent to which they will change was estimated from the analysis of present activities.

Recommendations

As a result of this study, certain recommendations are made. Some of these apply basic human engineering principles to indicators and controls on all submarines. Others involve minor changes which could be incorporated in present submarines as well as in the SS 563/564. Still others involve major modifications specifically directed to the SS 563/564 because the introduction of such fundamental changes on present submarines would be too expensive. Finally, it is strongly urged that certain important problems be subjected to further research. The data for this study were gathered during normal maneuvers. For a complete evaluation of the Control Room, emergency procedures, snorkeling, and the process of bleeding air should be similarly investigated. Moreover, a final evaluation of the new submarines can be made only when operational tests are possible.

All the recommendations in this report are based upon principles of human engineering. The extent to which these recommendations can be incorporated in present or future submarines must, because of practical and engineering considerations, be determined by consultation with submarine and engineering personnel. From a review of the tentative plans, it appears that some of the suggested improvements will be realized in the SS 563, whereas they apparently have not been considered in the development of the SS 564. In the SS 563, for example, the hydraulic manifold station has been redesigned and the number of required personnel can be reduced. On the other hand, as far as can be determined, no such steps have been taken with respect to the SS 564.

For the detailed discussions of each of the following recommendations, refer to the text pages given in parentheses.

A. Controls and Indicators (principles of human engineering)

Certain modifications in the design of controls and indicators are recommended. These are summarized in Table 1, along with the instances in which poor design has been noted at each of the three manifold stations.

Table 1. Human Engineering Principles Applicable to the Design of Controls and Indicators*

	Instances at the Manifold Stations Where Design Can Be Improved: Hydraulic	Air	Trim
Controls			
1. Place important and frequently used controls within easy reach of the operator (p. 17).	Negative vent; flooding manifold	Low pressure flappers; high pressure air bleeder valve; bow buoyancy blow	
2. Group controls with respect to function and locate them near their associated indicators (p. 17).	Negative flood and negative gauge; negative vent; safety vent; safety flood; negative flood; main induction valves and their indicator lights on the Christmas Tree	Controls and indicators used in blowing negative	Trim line after suction valve and trim line after discharge valve and their associated indicators; trim pump meter
3. Label all controls adequately and mark them for easy identification (p. 18).	All important controls, particularly negative vent and main induction	10 pound main ballast tank flappers; other valves with engraved lettering on highly polished brass	Nos. 1 and 2 auxiliary suction and discharge valves; the two suction and discharge valves for the negative, safety, and auxiliary tanks
4. Design controls so that they are identifiable by touch (p. 18).	Safety vent and safety flood, and all other important controls except for the negative flood and main induction valves	Air bleeder and main ballast tank blow, both for forward and after groups; 10 pound main ballast tank flappers; two list levers	
5. Design controls for quick and effective operation (p. 19).	Negative vent control	Air bleeder valve	Portable handles recuired to turn valves
Indicators			
1. Make letters and numbers on all displays vertical with respect to the line of sight (p. 19).	Negative tank gauge	Manometer; list angle indicator ("bubble"); oil gauge	Forward and after trim tank gauges; auxiliary ballast tank gauges, Nos. 1 and 2
2. Provide maximum contrast between markings and their background (p. 29).	Lettering on Christmas Tree display for hull openings and snorkel valves		
3. Label displays clearly (p. 20).	Christmas Tree display for hull openings and snorkel valves; abbreviation for conning tower hatch	List indicator; oil gauge; high pressure air distributing and receiving manifolds	Trim pump tachometer
4. Use indicator scale units which are simple and easily understood (p. 20).	Negative tank gauge	High pressure air distributing and receiving manifolds; the 6 high pressure air banks; oil gauge; negative tank air gauge	
5. Avoid excessive numbering on dials (p. 20).	Negative tank gauge		Forward and after trim tanks; auxiliary ballast tanks Nos. 1 and 2; safety tank gauges
6. Avoid scale numbers well in excess of maximum reading (p. 21).		High pressure distributing and receiving manifolds and high pressure air banks; list angle indicator; low pressure blower	Trim pump suction gauge
7. Do not allow pointer to cover numbers and scale graduations; place numbers outside of scale markings (p. 21).	Negative tank gauge	All indicators	All indicators
8. Include all scale graduations which are within operating range of meter (p. 21)		All meters with the exception of the oil gauge for the low pressure blowers	Trim pump discharge; trim pump suction; trim tachometer

*The controls and indicators used during normal operations are evaluated in this table. (For a complete listing of the equipment evaluated, see Appendix 2.) A blank space in the table indicates that the equipment is acceptable with respect to the design characteristic being discussed.

B. SS 563/564 and Present Submarines (minor changes)

1. Provide the hydraulic manifold operator with a quick blow valve for blowing negative tank (p. 26).

2. Provide the Diving Officer with a flapper valve for bleeding air (p. 27).

3. Provide the Diving Officer with a trim indicator panel showing the flooding, blowing, discharging, and shifting of water from the several variable ballast tanks (p. 28).

4. Design one single control for blowing all main ballast tanks on Portsmouth boats (p. 28).

5. Locate the main ballast blow valve and the bow buoyancy blow valve within working distance of each other (p. 28).

6. Christmas Tree displays

   a. Align the indicator lights for the Christmas Tree displays on the hydraulic manifold station with their respective controls (p. 28).

   b. Move hull opening board aft, nearer to the diving control station (p. 22).

   c. Separate indicator lights for main induction valve from the others on the board so they can be more easily distinguished and observed (p. 22).

   d. Use red and green lights, instead of white, for the snorkel valves display (p. 22).

C. SS 563/564 (major modifications)

1. Adopt the recommendation (Proposal A) given in a previous report for the diving control station (p. 29).[2]

2. Eliminate idle personnel from the Control Room by combining the duties of either the trim and air or the hydraulic and air manifold stations (p. 29).

3. On all manifold stations, separate the equipment which is always used from the emergency and preset equipment (p. 33).

D. Further Research

1. Analyze emergency, snorkeling, and bleeding air operations aboard present submarines. Evaluate the data and apply the findings to the SS 563/564 (p. 34-35).

---

[2] Cf. footnote 1.

2. Investigate the complaints and difficulties related to maintenance, working areas, safety hazards, and communication difficulties (p. 35).

3. Perform a thorough activity analysis aboard the SS 563/564 when these new submarines become available (p. 36).

II. ANALYSIS OF CONTROL ROOM ACTIVITIES

A. The Diving Control Party

The diving control party consists of the Diving Officer, the bow and stern planesmen, and the hydraulic, air, and trim manifold operators. These men are responsible for diving and surfacing operations, as well as for maintaining boat angle and depth during submerged operations.

The Diving Officer has charge of all activities in the Control Room and is responsible for the prompt and efficient execution of orders from the Commanding Officer.

"The means and aids at his disposal are:
- a) Speed (until 'Trim satisfactory' has been reported, after which he may request a change of speed from the Conning Officer).
- b) Angle on the diving planes.
- c) Angle on the submarine.
- d) Shifting of variable ballast, by pumping, blowing, or flooding.
- e) Blowing or venting main ballast tanks and bow buoyancy tanks."[3]

The bow planesman is responsible for attaining and maintaining the ordered depth, while the major responsibility of the stern planesman is to regulate the boat angle.[4] The air manifold operator must blow the main ballast bow buoyancy, safety, and negative tanks and make sure that all parts of the boat receive air from the various air systems. The hydraulic manifold operator is the chief of the watch and is in command of the Control Room when the Diving Officer is not present. The trim manifold operator must follow the commands of the Diving Officer in trimming the boat, i.e., flooding or draining any of the variable ballast tanks or shifting water from one tank to another. (A more thorough treatment of the duties of these men is given in Appendix 1.)

---

[3] Submarine School Officer's Memorandum No. 38-47, 31 December 1947.
[4] Cf. footnote 1.

B. Time-Activity Charts

To facilitate the analysis of Control Room activities, the operations have been divided into four "maneuvers" or phases.[5] They are: diving, submerged, surfacing, and snorkeling.[6]

Time-activity charts have been prepared to illustrate graphically the activities and integrated operations of the personnel in the Control Room. Each set of charts represents the activity during a given phase. Preceding each set is an explanatory section, defining the phase and emphasizing certain features of the integrated activities. The first chart in each set contains the Diving Officer's commands and, in some cases, the commands that come from the Captain. Following this are the time-activity charts for each of the three manifold stations.

The charts are so constructed that it is possible to see at a glance when the operator at any station is busy, and when the activities of the several operators coincide. Each analysis covers an arbitrary period of four minutes. Dark areas represent activity, cross-hatched areas show periods of watching an indicator or waiting in position for a signal, and white represents idle time.

---

[5] These phases include all the important activities in the Control Room with the exception of those which follow the order, "Rig ship for dive." The latter are performed soon after the submarine gets underway and consist mainly of presetting certain controls so that they can be operated quickly when the ship is actually to dive.

[6] The snorkeling operation occurs during the submerged phase on Guppy submarines. The snorkel tube is an innovation which gives the submarine the advantage of being able to run on any one or combination of engines at a submerged depth of approximately 50 feet which is not at all possible on the conventional Fleet-type submarine.

The snorkel phase begins with the order from the Captain, "Make preparations for snorkeling," and lasts until all operations following the command, "Secure from snorkeling" have been completed. Most operations for snorkeling are preset. The data collected on this "maneuver" are far from complete. For these reasons, no activity chart has been prepared. A list of duties for each operator is given in Appendix 1.

A brief description is given of each activity together with the time necessary to complete the operation. These times should be considered only as representative estimates; they should not be considered as standard or precise.

1. <u>The diving phase</u>. The diving phase begins with the diving alarm and terminates when the boat reaches the desired depth. For our purposes, the duration of this phase has been arbitrarily set at four minutes, although the desired depth is often reached in less time. In any case, within four minutes after the sounding of the diving alarm, all the operations which usually are considered part of the diving process have been completed. The diving phase is the most crucial period in the operation of a submarine and must be performed with split-second timing.

An examination of the activity charts shows that several of the operations connected with diving are extremely awkward. The first of these is "bleeding air" (air manifold). The signal is a pilot light (on the Christmas Tree), about 15 feet away from the operator and not in his line of sight. Theoretically, this operation follows "shutting the main induction" (hydraulic manifold), but our records show that this was not always the case. It is apparent from the charts that such a mistake could easily occur.

The process of "blowing negative" is also awkward. As the charts show, this performance involves the close integration of the hydraulic and air manifold operations. Since the two stations are located at some distance from each other, smooth and efficient performance is almost impossible. This fact has been supported by interviews with experienced operators who report that often the negative tank is blown past the "mark" or not enough.

It should be mentioned here that the hydraulic manifold operations of "venting negative" and "cycling the vents" are not necessarily performed in the order shown and can be done in any order and at any time during the dive.

Time

Diving Officer

Diving Alarm — 0

"Stand by negative."

"B̄ow negative."

1

"Vent negative."

"Flood No. 1 auxiliary from sea, ____ lbs."

"Cycle the vents."

2

Diving Officer

"Flood No. 2 auxiliary from sea, ____ lbs."

3

4

DIVING PHASE

[redacted]

Hydraulic Manifold

Opens all vents except safety. (3 sec)

Shuts main induction. (1.5 sec)

Shuts all main vents and opens safety. (3 sec)

Shuts safety vent.

Opens negative flood. (3 sec)

Watches negative tank gauge.

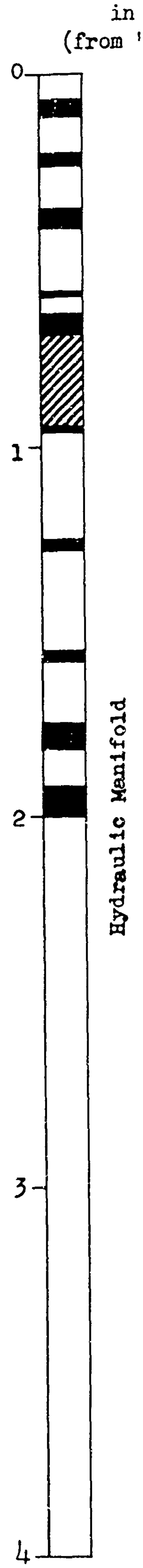
Closes negative tank flood. (.5 sec)

Opens negative vent. (1.5 sec)

Closes negative vent. (1.5 sec)

Opens all vents. (4 sec)

Closes all vents. (5 sec)



DIVING PHASE

[redacted]

Air Manifold

Opens and closes air bleeder valve. (5 sec -- somewhat longer on boats which have no handle on this valve.)

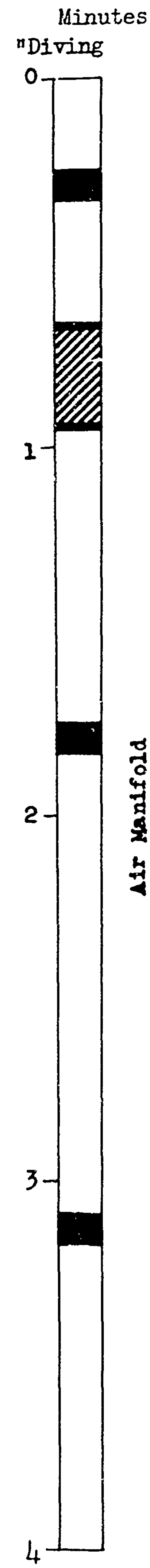
Opens negative blow valve. (.5 sec)

Watches for signal from hydraulic manifold.

Closes negative blow valve. (.5 sec)

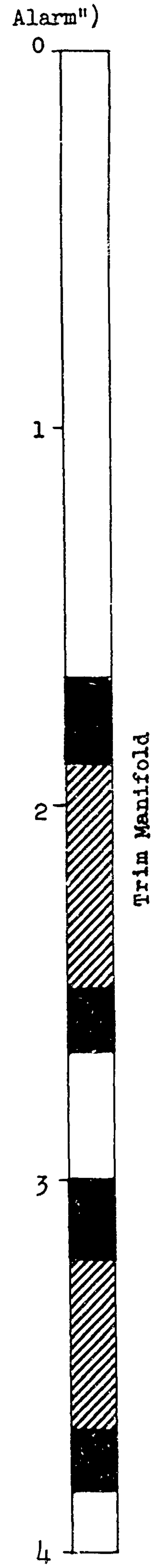
Checks suction in the pumps. (5 sec)

Checks suction in the pumps. (5 sec)



[redacted]

Trim Manifold



Opens number one auxiliary tank flood valve and sea suction valve. (13 sec)

Watches trim meter.

Closes sea suction valve and number one auxiliary tank flood valve. (10 sec)

Opens number two auxiliary tank flood valve and sea suction valve. (13 sec)

Watches trim meter.

Closes sea suction valve and number two auxiliary tank flood valve. (10 sec)

2. <u>The submerged phase</u>. The submerged phase begins when the boat reaches the desired depth and lasts until the Commanding Officer orders, "Standby to surface." For this reason, no arbitrary time can be given for its duration. For purposes of illustration, the thirty-second through the thirty-fifth minutes of a typical dive aboard the USS Halfbeak are represented on the charts. This period is typical of any four-minute interval during submerged operations. As will be seen from the charts, there is very little activity in this phase. Operators may be idle as long as ten minutes without being required to do any trimming at all. The particular operation shown is to be considered only as representative. Different ballast tanks may be involved and the amount of water pumped or flooded may vary. The time taken to complete the operation will, of course, change with the amount of water required.

The hydraulic manifold operator has no duties during this phase except that he may occasionally be ordered to vent the bow buoyancy tank. The only regular duty of the air manifold operator is to check suction or venting in the pumps. During submerged operations the trim manifold operator must follow the orders of the Diving Officer in adjusting the trim of the boat by shifting water, or flooding or draining any of the variable ballast tanks.

Time

Diving Officer

32

33

"Pump from number one auxiliary to sea. 1000 pounds."

34

Diving Officer

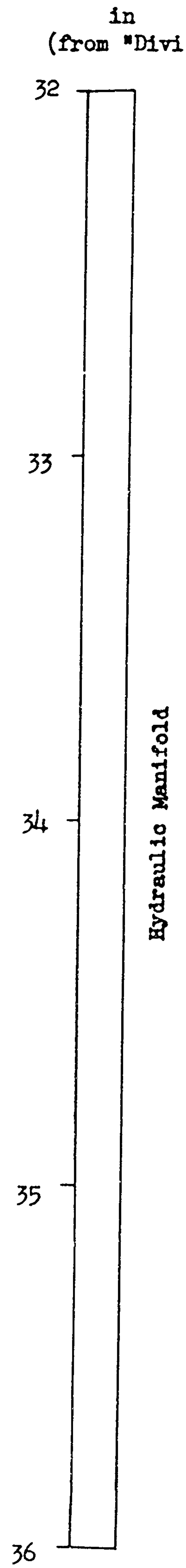
35

36

SUBMERGED PHASE

[redacted]

Hydraulic Manifold



SUBMERGED PHASE

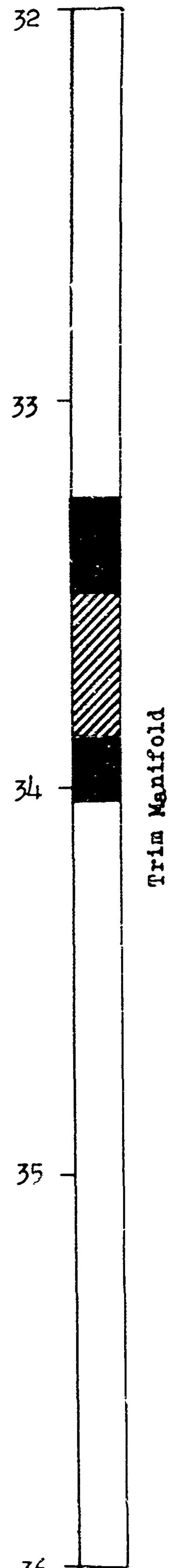
[redacted]

Trim Manifold

Opens auxiliary ballast tank number one drain and discharge to sea valve. (13 sec)

Watches trim meter.

Closes discharge to sea valve and auxiliary ballast tank number one drain valve. (10 sec)



SUBMERGED PHASE

3. The surfacing phase. The surfacing phase begins with the order from the Captain, "Standby to surface," and continues until the low pressure blowers have been secured and negative tank has been flooded. The example shown is, therefore, not complete since neither the securing of the low pressure blowers nor the flooding of negative is represented. The amount of time that the low pressure blowers are operated, however, depends on the length of the "blow" ordered by the Captain. In neither the securing of the low pressure blowers nor the flooding of negative is the integration of activities important. It is believed, therefore, that vital information has not been lost by omitting these operations from the time-activity charts. The trim manifold operator has no duties during the surfacing phase.

The only awkward operations during this phase are the blowing of the main ballast and the bow buoyancy tanks. The air manifold operator must walk from valve to valve in order to complete this critical operation. The process itself is extremely noisy and the commands of the Diving Officer may be almost inaudible. Occasionally, the Diving Officer has to shout several times before his commands are understood; in some cases it may even be necessary to blow the main ballast tanks more than once if the operation is inefficiently performed the first time. Such difficulties are only part of the larger, important problem of communication which should be thoroughly investigated (See Section V, p. 35).

[redacted]

Diving Officer

Time
(from

Captain: "Stand by to surface on ________main engines."

0

"Put main induction in power."

"Blow all main ballast."

"Blow bow buoyancy."

1

"Secure bow buoyancy."
"Secure the air."

Captain: "Start the blowers. Blow for_______minutes."

2

Diving Officer

"Open the main induction."

3

4

SURFACING PHASE

[redacted]

Hydraulic Manifold

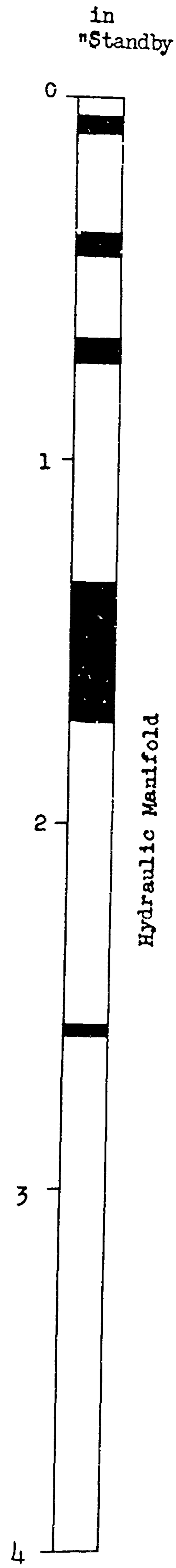
Shuts conning tower drain.

Puts main induction in power.

Reports: "Main induction in power, all main vents shut. Ready to surface."

Reports depth to bridge.

Opens main induction.



SURFACING PHASE

[redacted]

Air Manifold

Closes conning tower ventilation

Opening main ballast tank blow valve. (3 sec)
Walks to Bow Buoyancy blow valve.
Opening BBT Blow valve. (.6 sec)

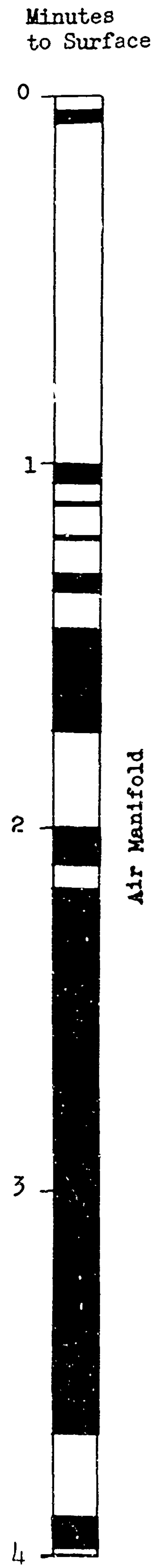
Closes BBT blow valve. (.6 sec)
Walks to MBT blow valve.
Closes MBT blow valve. (3 sec)

Opens trunk flapper, shuts trunk drain, and starts cooling fan.

Starts low pressure blowers.(6 sec)

Operates list lever.

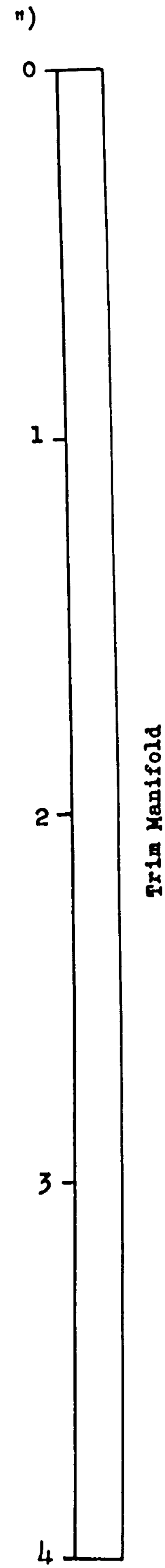
Opens conning tower ventilation.



SURFACING PHASE

[redacted]

Trim Manifold



SURFACING PHASE

C. <u>Implications for the SS 563/564</u>

The techniques used in developing the time-activity charts for the present submarine can be applied to the SS 563/564 when it is available. However, the analysis of current procedures has some immediate implications for the new boats still under construction.

A study of the design of the new boats revealed that the work area in the Control Room will be extremely limited. Furthermore, the Control Room is to serve as the main passageway from bow to stern when the Attack Center is in use. Since the quarters will be cramped, it would be wise to integrate activities so that a minimum number of personnel will be required. The time-activity charts for present boats disclose that the manifold operators are idle a large part of the time. The charts are useful for evaluating three plans to reduce the number of men in the Control Room. These are discussed below.

1. <u>Operation of the trim and air stations by one man</u>. This is the simplest possible combination of duties which might be effected since, as the charts reveal, there is almost no overlap of activity at these two stations. If this combination is contemplated, however, provision should be made for an automatic check on trimming operations, which at present is done manually by the air manifold operator. With this combination of stations, it will be necessary to provide the Diving Officer with a "trim Christmas Tree." This device is contemplated by engineers designing the SS 563 (Portsmouth) but not by those developing the SS 564 (Electric Boat).

2. <u>Operation of the hydraulic and air stations by one man</u>. The desirability of this arrangement arises from the fact that it would permit an efficient integration of activities while still allowing the operator (presumably the chief of the watch) to be free during the submerged phase. This combination would permit efficient blowing of the negative, main ballast and bow buoyancy tanks.

It provides further assurance that the main induction be closed before air is bled into the boat.

3. <u>Operation of the hydraulic and trim stations by one man</u>. While it might be possible for one man to operate these stations, this combination of activities would not prove satisfactory for several reasons:

a. This does not permit the hydraulic manifold operator to be free for his duties as chief of the watch.

b. The activities which follow the command, "Make preparations for snorkeling" at the trim and hydraulic stations probably could not be handled by one man.

c. There is some doubt that the hydraulic manifold operator could complete his duties in the Diving Phase before the first trimming operation is required.

Therefore, the duties of either 1) the trim and air stations or 2) the hydraulic and air stations should be combined.

The elimination of personnel from the Control Room has been discussed in detail because it is one of the major implications of the time-activity charts. Other recommendations, derived from the analysis, are contained in Section IV.

III. EQUIPMENT EVALUATION

The present manifold stations will probably be duplicated on the SS 564, while changes are contemplated only for the hydraulic manifold on the SS 563. Thus, the evaluation of the design and layout of present equipment can, in many instances, be applied directly to the new boats.

The controls and indicators on present boats were carefully analyzed during the various types of operations. The evaluation in this section applies only to the equipment on present boats as observed during normal operations.[7] Such factors as safety hazards, illumination, working areas, and maintenance difficulties are also noted and mention is made of a few problems peculiar to the Christmas Tree displays.

A. Controls

1. <u>Place all important and frequently used controls within easy reach of the operator</u>.

   a. Hydraulic manifold: The negative vent is placed on the extreme left side of the station and set far back in the equipment panel. The flooding manifold, containing the safety flood, negative flood, and main induction valves, is placed so low that the operator must stoop in order to open and close valves.

   b. Air manifold: The low pressure flappers, 76 inches from the deck, are much too high above the operator's head for efficient operation. The high pressure air bleeder valve, only 20 inches from the deck, forces the operator to stoop in order to open and close this valve. The bow buoyancy blow, although frequently used, is as far out of reach as some controls which are pre-set or seldom operated.

   c. Trim manifold: Satisfactory.

2. <u>Group controls with respect to function and locate them near their associated indicators</u>.

   a. Hydraulic manifold: The negative flood and the negative gauge are

[7]Unless otherwise specified, all comments refer to the equipment on the USS Pickerel. For a complete list of the controls which were evaluated, cf. Appendix 2.

approximately 42 inches apart and it is extremely difficult to operate the valve and watch the gauge at the same time. The negative vent, safety flood, negative flood, and main induction valves should be aligned with their indicator lights on the Christmas Tree.

b. Air manifold: The negative tank gauge is at present located only at the hydraulic manifold station. It is suggested that a duplicate of it be provided for the air manifold station. The negative pressure gauge should be so located that it can be observed while operating the associated negative blow valve.

c. Trim manifold: The trim line after suction valve and the trim line after discharge valve are on the right side of the main control panel. Their indicators, however, are above the opposite end of the panel. The trim pump meter should be located centrally on the display panel.

3. Label all controls adequately and mark them for easy identification.

a. Hydraulic manifold: None of the important controls are marked clearly enough for an operator unfamiliar with the equipment to assume control of the station. Negative vent is not labeled and the main induction is ambiguously marked with a "V."

b. Air manifold: Some controls on the existing equipment are poorly or ambiguously labeled. Because of location, all labels on the 10 pound main ballast tank flappers are extremely difficult to read. On other valves, the engraved lettering on the highly polished brass on the name plates is difficult to read because of poor visual contrast.

c. Trim manifold: Labels should not be abbreviated because there is plenty of space on the main control panel. Inadequate abbreviations appear on the Nos. 1 and 2 auxiliary suction and discharge valves and on the two suction and discharge valves for the negative, safety, and auxiliary tanks.

4. Design controls important during emergencies so that they are identifiable by touch.

a. Hydraulic manifold: Should the electric power in the Control Room fail, except for the negative flood and main induction valves, the important controls could be identified only by position. It seems especially important that safety vent and safety flood be given hand grips identifiable by touch alone.

b. Air manifold: During emergency situations, especially failure of electric power, controls must be reached and identified as quickly as possible. On the present equipment, the air bleeder and main ballast tank blow, both for forward and after groups, have no identifiable hand grips. Of less importance, although equally easy to remedy, is the lack of identification for the 10 pound main ballast tank flappers and the two list levers.

c. Trim manifold: None of the controls at this station are identifiable by touch. With the present design, however, it would be difficult to satisfy this principle without major reorganization.

5. Design controls for quick and effective operation.

a. Hydraulic manifold: The negative vent control is undesirably large. The reason for this may be that at times pressure builds up in the valve, making operation difficult. If this is true, an attempt should be made to add a booster to the control. Then the control could be made the same size as the other vent levers and placed with them on the vent manifold. This control should also be identifiable by touch.

b. Air manifold: The operation of bleeding air must be done quickly and with some degree of accuracy. The present design of the air bleeder valve involves a rotary crank which the operator must turn as many as three complete revolutions. This makes it difficult to bleed the required amount of air into the boat.

c. Trim manifold: Operation at this station is highly inefficient. It involves portable handles which must be moved from valve to valve. Furthermore, for every complete operation, at least two valves require 12 complete revolutions each, six one way for opening, and six the other for closing.

B. Indicators

Fundamental principles for meter design are given below. Violations of these principles are listed separately for the hydraulic, air, and trim manifold stations. Since the required changes could be made with little difficulty, the indicators should be modified so as to satisfy good design characteristics.

1. Make letters and numbers on all displays vertical with respect to the line of sight. It is particularly important that all scale numbers, on indicators with a fixed dial and moving pointer, be vertical to the observer's line of sight. Otherwise, the numbers at the bottom of the dial appear upside down and are difficult to read. This occurs as follows:

a. Hydraulic manifold: negative tank gauge.

b. Air manifold: manometer, list angle indicator ("bubble"), and oil gauge.

c. Trim manifold: forward and after trim tank gauges, and auxiliary ballast tank gauges, Nos. 1 and 2.

2. Provide maximum contrast between meter markings and their background. With external illumination maximum contrast is obtained with white-on-black or black-on-white, the former having been proven slightly superior in situations requiring the maintenance of dark adaptation.

a. Hydraulic manifold: The lettering on the Christmas Tree display for hull openings and snorkel valves.

b. Air manifolds: (All indicators evaluated were satisfactory.)

c. Trim manifold: (All indicators evaluated were satisfactory.)

3. Label all displays clearly.

a. Hydraulic manifold: 1) On the Christmas Tree display for hull openings, the word "closed" is used on the top half and the word "shut" on the bottom half of the panel. It is recommended that "shut" be used throughout. Abbreviations such as "CT" for the conning tower hatch should be eliminated. 2) On the Christmas Tree display for snorkel valves, meaningless labeling, such as the word "Dive," should be omitted, and the sub-title "Snorkel Valves" should be printed in larger letters.

b. Air manifold: 1) List indicator and oil gauge should be so marked. 2) The high pressure air distributing and receiving manifolds should be marked "Forward Group" and "After Group," in order to distinguish between them.

c. Trim manifold: The trim pump tachometer should have a descriptive label besides "RPM."

4. Use indicator scale units which are simple and easily understood. Scales should increase by integral units of 1, 10, 100, or 1000. Graduations should be spaced about 3/8" apart.

a. Hydraulic manifold: Negative tank gauge.

b. Air manifold: High pressure air distributing and receiving manifolds, the six high pressure air banks, oil gauge, and negative tank air gauge.

c. Trim manifold: Variable ballast tank meters.

5. Avoid excessive numbering on dial faces.

a. Hydraulic manifold: Eliminate the "ton" scale on the negative tank gauge.

c. Trim manifold: Eliminate the "ton" scale on the forward and after trim tanks, auxiliary ballast tanks Nos. 1 and 2, and safety tank gauges.

6. Avoid numbering of scales well in excess of maximum reading.

a. Hydraulic manifold: (All indicators evaluated were satisfactory.)

b. Air manifold: Eliminate markings above 4000 on the high pressure distributing and receiving manifolds and high pressure air banks. Eliminate markings above 30 degrees on the list angle indicator, and eliminate markings above 20 pounds on the low pressure blower.

c. Trim manifold: The trim pump suction gauge is used only to determine the presence of, but never the amount of, suction. The dial, therefore, might be eliminated and replaced by an indicator light. If the dial is retained, markings from -30 to +30 ("inches of vacuum") would be sufficient.

7. Do not allow pointers to cover numbers and scale graduations; place numbers outside the scale markings.

a. Hydraulic manifold: Negative tank gauge.

b. Air manifold: All indicators.

c. Trim manifold: All indicators.

8. Include all scale graduations within operating range of meter.

a. Hydraulic manifold: (All indicators evaluated were satisfactory.)

b. Air manifold: All meters with the exception of the oil gauge for the low pressure blowers.

c. Trim manifold: The trim pump discharge, trim pump suction and trim tachometer.

C. Christmas Tree Displays

1. General. At the onset of the dive, all lights on the hull opening board are green while all lights on the vent and flood board are red. Although the danger of confusing the two boards is slight, this probability exists nevertheless, and one mistake of this type could prove costly. Furthermore, the air manifold operator is required to look at the conning tower hatch light on the hull opening board before bleeding air. To do this, he must come forward and bend down, since his view is blocked by the fathometer, book-shelf, and chart table.

It is recommended that the hull opening board be moved aft, nearer to the diving control station. This would separate it from the vent and flood board, thus reducing the chances of confusion. It would also bring it into a better position to be viewed by the air manifold operator.

2. Hull opening display. The most important set of lights are those for the main induction. These indicator lights should be separated from the others on the board so that they can be more easily distinguished and observed.

3. Vent and flood valves display. Indicator lights for opening vents and shutting floods are red, whereas the lights for opening floods and shutting vents appear green. This paradoxical lighting system undoubtedly adds to the difficulty of operating this station. It would seem advisable for each color to have a specific meaning. Thus, red might signify open vents and floods, and green, closed vents and floods. This problem should be given further study. Furthermore, the alignment of the flood indicator panel lights needs complete revision. It may be advisable to separate the flood from the vent panel, thus making possible an alignment of indicator lights and controls.

4. Snorkel valves display. Lighting for the snorkel Christmas Tree on the USS Halfbeak is comparatively poor in contrast to the red-green lighting for the same display on the USS Pickerel. Interviewees complained that the bright white lighting was so strong that it was difficult to observe the red-green lights on the other two Christmas Trees. During dark adaptation conditions this difficulty was increased. It is recommended that red and green lights be used on the snorkel valves display.

D. General Comments

1. Communication. The overall noise level is so high that verbal communication between the Diving Officer and the manifold operators is extremely difficult. Loud verbal commands and hand signals are the techniques currently

used by Control Room personnel. The vision of the Diving Officer, however, is blocked by the radio shack and the periscope and snorkel wells. Thus, even hand signals are inadequate for certain operations such as blowing the after group of main ballast tanks, operating the low pressure blowers or preparing the boat for snorkeling. Another communication difficulty is the terminology used by the Diving Officer. The manual of "Standard Submarine Phraseology," issued by ComSubLant, represents an attempt to increase the general efficiency of voice communications. The phraseology, however, apparently needs further study and improvement. In training trim manifold operators, the U.S. Naval Submarine School uses the words pump and flood "to insure prompt and correct action."[8] Errors in performance, however, resulted from the operators' failure to distinguish between these two words. Interviewees strongly urged that Diving Officers use the term "pump" only when removing water from a variable ballast tank to the sea. It would be even more desirable for the word "pump" never to be used. Such words as "drain," "discharge," "shift," and "flood" would be less equivocal. Other words, confused by the hydraulic and air manifold operators, are "close," "open," and "blow."

2. Working space. No serious criticism can be made of the working space at the hydraulic manifold station. However, the space provided at the trim manifold station is very inadequate, i.e., 92 inches long by 18 inches wide by 67 inches high; and much of the area is occupied by the SJ radar equipment. This console was operated frequently, on the USS Halfbeak, during the approach phase of attacks under submerged conditions. At such times, the radar operator causes further crowding. As for the air manifold station, it is 12 feet long

---

[8] Fyfe, J. K. Training device, lesson plans for, and diving procedure. U.S. Naval Submarine School, U.S. Naval Submarine Base, New London, Conn., 1 March 1949.

but only 20 inches wide at some points. Sometimes, the operator must move from one end of the station to the other and his work may be hindered by passing personnel.

3. Maintenance. Many interviewees, including representatives from all manifold stations and a number of auxiliary men, mentioned maintenance as a source of difficulty. No recommendations are offered here with respect to this problem; data are lacking and the question probably should be investigated independently.

4. Safety hazards. Several safety hazards were noted, especially at the trim manifold station. At this station, there are jagged edges from an overhead light which protrudes at a level of 67 inches above deck. When the operator takes up his normal operating position, he stands on the pump room hatch cover which is circumscribed by a four-inch high rail guard. A locking latch which holds the hatch in an open position also protrudes from the station at about knee height. The hazards encountered in operating at this station were pointed out several times during the interviews.

5. Illumination. In general, illumination in the Control Room is inadequate, particularly at the hydraulic manifold station. At the trim manifold station, there is glare on the major indicators because of poor overhead lighting. On the USS Halfbeak, the controls have little lighting, while on the USS Pickerel, the highly polished stainless steel control panel produces glare. A study of the illumination in the Attack Center and Periscope Area of the SS 563/564 has already been made.[9] The tentative specifications

---

[9] Orlansky, J. et al. Illumination in the Attack Center and Periscope Area of the SS 563/564. Technical Report SDC 641-2-2, 22 August 1949 (CONFIDENTIAL).

developed for general and instrument illumination, both for day and night conditions, should be used for the lighting conditions in the Control Room.

IV. RECOMMENDATIONS

The following recommendations have been derived from an analysis of the activities in the Control Room of present submarines and a study of the tentative designs for the SS 563/564.

Modifications can be introduced into any complex operation so as to make for more efficient performance. However, such changes must be tempered by the cost which may be incurred. The following recommendations, therefore, are grouped in several categories. The first group consists of relatively minor modifications which would permit increased efficiency without fundamentally disturbing the present equipment design and organization. They are, therefore, practical not only for the SS 563/564, but also for present boats. The second category of recommendations consists of major changes intended specifically for the SS 563/564 and succeeding boats of its class.

A. Recommendations for SS 563/564 and for Present Boats

1. Provide the hydraulic manifold operator with a quick blow valve for blowing negative tank. This would eliminate the need for the close coordination between the air and hydraulic operators in the blowing of this tank. It would increase the efficiency of this operation by placing the responsibility on one individual and eliminate the need for hand signals.

Present plans for the new boats give no attention to the improvement of the process for blowing negative. On both the SS 563 and SS 564, the air and hydraulic manifold stations will be separated by a considerable distance, and the positions of operating personnel will make it almost impossible to use hand signals. Moreover, the attempt at verbal signalling for the blowing of this tank will interfere with the performance of the Diving Officer and planesmen at a very critical stage of the diving phase. Blowing negative on the new boats will be a much more awkward operation than before. This recommendation is, therefore, strongly urged in the construction of the new submarines.

Alternative: Provide the air manifold operator with a negative tank gauge and a signal light which would indicate when the hydraulic manifold operator has opened the negative flood. Although this suggestion would not prove as satisfactory as the first recommendation, it would eliminate the necessity for hand signals and make possible a more efficient blowing of the negative tank.

2. Provide the Diving Officer with a flapper valve for bleeding air. This would eliminate the need for hand signals or long distance observation of the Christmas Tree by the air manifold operator. It would provide much more accuracy in the bleeding of air, eliminate the possibility of bleeding air while there are hull openings, and minimize present difficulties in this operation. If the Diving Officer is not provided with such a valve, it should be given to the hydraulic manifold operator.

The operation of bleeding air will be somewhat improved on the SS 564 because of the proximity of the Diving Officer to the air manifold operator. However, the air manifold operator will not be able to see the Christmas Tree on either the SS 563 or the SS 564. It is, therefore, urged that the responsibility for this operation, one of the most important in the diving process, be handled entirely by the Diving Officer.

Alternative: Provide the air manifold operator with a manometer and a green light which will signal when all hull openings have been closed ("green board"). This would serve to give the complete responsibility for this operation to one operator and would make the operation much more automatic.

(Note: The air bleeder valve should always be provided with a handle, which the present Electric Boat submarines do not have. The air manifold operator should always be provided with a manometer to add to the accuracy and safety of this operation.)

3. Provide the Diving Officer with a trim indicator panel showing the flooding, blowing, discharging, and shifting of water from the several variable ballast tanks. This would provide an automatic check on the operations of all three manifold stations. It would also eliminate the process of checking the suction in the pumps which, at present, is highly unsatisfactory. Verbal communication in the Control Room would be greatly reduced.

This recommendation becomes especially important on the SS 563 where a combination of the duties of the air and trim stations is contemplated. This innovation would eliminate the manual check on trimming operations, thus necessitating some form of automatic check.

4. A single control should be designed for blowing all main ballast tanks on Portsmouth boats. Such a control is provided on present Electric Boat submarines. But it is impossible to blow all main ballast tanks in one operation on present Portsmouth boats. Operators frequently have time for blowing only one group of ballast tanks, which could seriously affect the boat's ability to surface speedily. This is especially important for the SS 563 where every effort should be made to provide the greatest possible speed in every phase of operations.

5. The main ballast blow valve and the bow buoyancy blow valve should be located close together. This is done on present Portsmouth boats. However, the air station operators on Electric Boat submarines must walk some distance to complete the blowing and securing of these two tanks, a critical aspect of the surfacing phase. These valves should be placed within easy view of the Diving Officer in order to relieve the present difficulty of verbal communication during noisy tank blowing operations.

6. The indicator lights for the Christmas Tree displays on the hydraulic manifold station should be aligned with their respective controls. This change

would enable the hydraulic manifold operator to associate more easily all controls with their respective indicators. At present, this is contemplated in conjunction with a reduction in size of the clumsy controls on this station for the SS 563 (Portsmouth).

This recognition of the human factor in the design of equipment at the hydraulic manifold station is highly commendable, and it is hoped that this attitude will persist in the design of the trim and air stations.

B. Recommendations for the SS 563/564

1. It is again strongly urged that the previous recommendation (Proposal A) for the Diving Control Station be adopted.[10] This proposal contained many recommendations which would relieve congestion and increase efficiency of operation at this station. Portsmouth is planning a new simplified Diving Control Station which appears to constitute a great improvement over the old one. (More information would be necessary before one could determine the degree to which the tentative plans for the trim status follow our previous recommendation.)

2. Every effort should be made to reduce the number of men in the Control Room. As has been indicated in Section II, this could be done by combining the duties of either a) the trim and air or b) the hydraulic and air operators.

It is reassuring to find that engineers responsible for designing the SS 563 are cognizant of the problem of reducing the number of men in the Control Room. The tentative layout is shown in Figure 1. It was indicated that this layout was developed with the following considerations in mind:

---

[10] Cf. footnote 1.

[redacted]

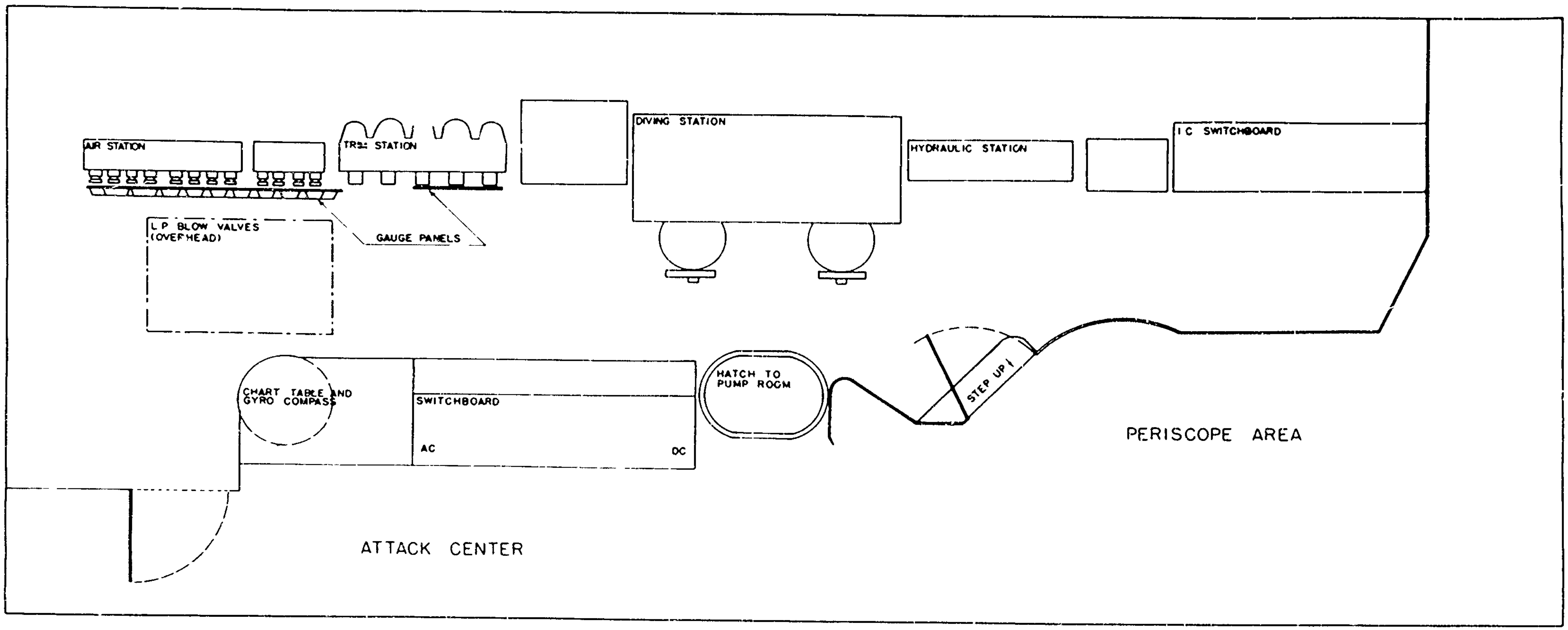


Figure 1. Schematic layout of proposed Control Room for the SS 563. This diagram was developed from information obtained during an inspection of the full scale model at the shipyard. (Scale: 3/8" = 1')

a. With the new layout, the air and trim stations could be operated by one man.

b. The hydraulic manifold operator could leave the Control Room as soon as his duties in the initial phases of the dive were completed. It is somewhat doubtful, however, that this would ever become a matter of actual practice. No changes in the duties of the hydraulic manifold are contemplated. At present it is possible for him to leave the Control Room as soon as the boat has reached the desired depth; in practice he does not leave the room. The hydraulic manifold operator can most efficiently execute his duties as chief of the watch if he remains in the Control Room, since there he can most quickly learn of any trouble which may have arisen. Furthermore, he is needed in the Control Room in case the Commanding Officer should give orders for snorkeling.

c. With an automatic diving control, it may be possible to eliminate one of the planesmen or to have the bow planesman take over the duties of the hydraulic manifold operator. It would be greatly desirable to simplify the Diving Control Station so that it could be operated by one man. It would not seem so desirable, however, to have the bow planesman take over the hydraulic manifold station for the reasons given above.

Thus, it will be possible in the SS 563 (Portsmouth) to eliminate the presence of one man in the Control Room. It is strongly urged that Commanding Officers take advantage of the improvement which this makes possible.

The design of the Electric Boat Company submarine does not result in the reduction of the number of operating personnel in the Control Room. This would have been desirable since the space in the Control Room of the SS 564 is extremely limited (see Figure 2). Tentative plans call for the location of the trim and hydraulic manifold stations next to each other. As was indicated in Section II, this arrangement probably would not permit the elimination of unnecessary operators.

With present and proposed equipment, at least two manifold operators are required. With improved equipment design and layout, however, all three manifold stations might be operated by one man. The Portsmouth designs for the hydraulic manifold station and the Diving Control Station are steps in this direction. With equal improvement in the other two stations, the number of

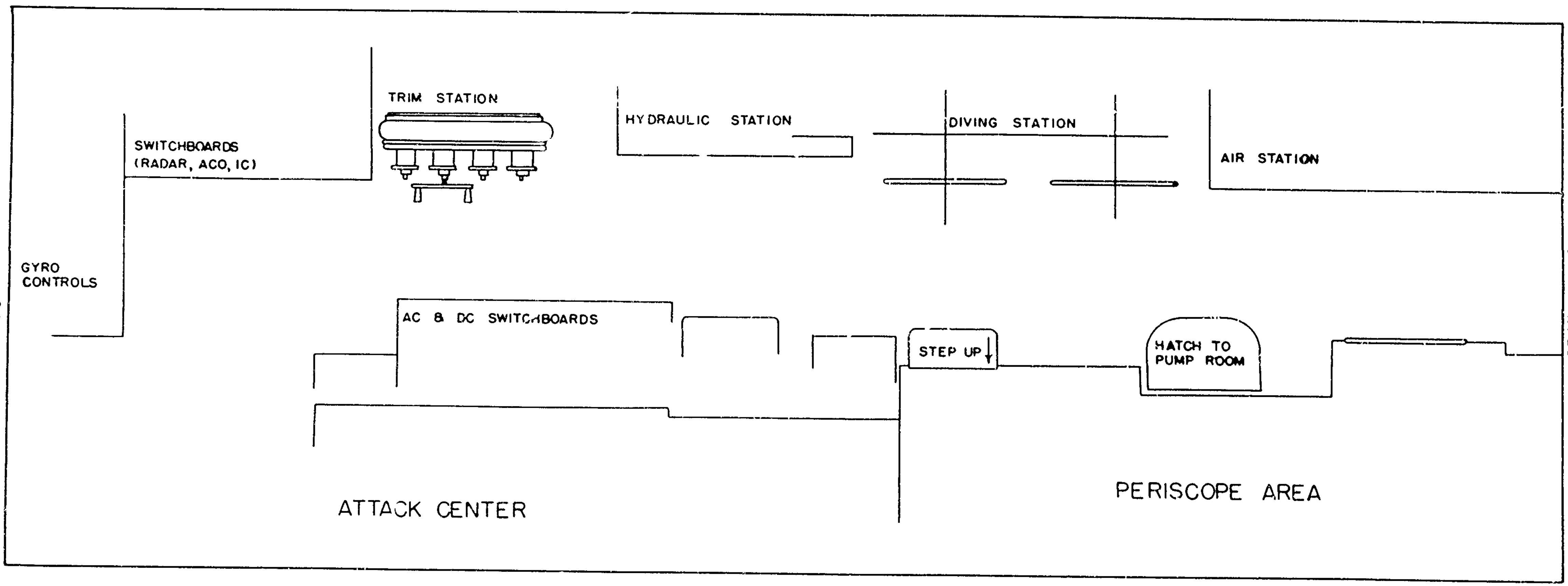


Figure 2. Schematic layout of proposed Control Room for the SS 564. This diagram was developed from information obtained during an inspection of the full scale model at the shipyard. (Scale: 3/8" = 1')

operating personnel could be reduced to a minimum without seriously impairing Control Room efficiency.

3. On all manifold stations, emergency and preset equipment should be separated from the equipment which is always used. Concentration of normally used equipment would make for more efficient operation in the Control Room. It would reduce the amount of required movement, improve communication, and help to prevent accidental activation of controls. This applies particularly to the air manifold station.

V. FURTHER RESEARCH

The data obtained for this report were gathered during normal submerged operations. For a complete evaluation of the Control Room, the following important areas should be similarly investigated: emergency operations, snorkeling, and the process of bleeding air. These could be studied on present boats and the findings applied to the SS 563/564. A final evaluation of future boats, however, can be made only after they are completed. Research dealing with these questions is suggested below.

A. Research on Present Submarines

1. Emergency operations. Two methods could be used to derive data pertinent to emergency operations.

   a. By interviewing Commanding Officers, Diving Officers, and Control Room operators, authoritative opinions could be procured concerning the effect of emergencies upon operations.

   b. Emergency conditions could be simulated during submerged operations. The data obtained in the Control Room under such conditions could be subjected to the type of activity analysis and evaluation used in the present study. In this way it might be possible to improve the operating efficiency during emergencies.

2. Snorkeling. Since snorkeling is a relatively new innovation, procedures and equipment vary from boat to boat. Such variation might easily lead to serious difficulties when personnel are transferred. The entire process of snorkeling should be thoroughly analyzed. Where possible, operations should be simplified and equipment and procedures standardized. One of the manifold operators (e.g., the hydraulic operator) could probably be given responsibility for all snorkel operations in the Control Room. Research should resolve this question. The techniques to be employed would include: a) interviews with Diving Officers and manifold operators, b) examination of engineering orders on several boats, and c) analysis of activity during actual submerged operations.

3. Bleeding air. This study, as well as an earlier one, suggests that the process of bleeding air needs to be thoroughly reviewed.[11] It is possible that pressure will hold in the boat when the main induction is open and the rest of the boat is watertight. Thus, there is reason to doubt the value of the process. Furthermore, the boat must dive in emergency situations even if pressure does not hold. Finally, the process is extremely noisy and disturbs Control Room activity.

It is recommended that data be procured to answer the following questions:

a. Will pressure hold in the boat if the main induction is open but the main induction flapper is closed?

b. Will pressure hold if any other valves or hatches are open?

c. How fast does the air pressure become equalized within the boat, and how long does it take the air pressure to build up in the extreme forward and after compartments?

d. Would it be practical to bleed air into the forward and after compartments and thus build up the pressure in the center of the boat? (This would reduce noise in the Control Room and would provide a much more thorough check for watertightness.)

4. Communications. In Section II, there was brief mention of the difficulties and complaints related to working areas, safety hazards, maintenance, and communication. It is recommended that all of these problems, particularly the last, be thoroughly investigated. Operating efficiency is influenced to a great extent by the flow of information. During both normal and emergency operations, it is essential that the men be able to communicate quickly, easily,

---

[11] Tolcott, M. A. and Channell, R. C. The human factor in the design and layout of submarine equipment. Analysis of war patrol reports and interviews. Contract N6-ori-151, Project 20-F-2, Progress Report No. 6, 8 September 1947 (CONFIDENTIAL).

and without danger of misunderstanding. Communication is hampered by noise and confusing terminology. Further research should expose the specific sources of difficulty which require correction.

B. Research on SS 563/564

This report has demonstrated that recommendations for the design and layout of future boats can be derived from research on present boats. A final evaluation of Control Room activities on the new submarines must await their completion. A thorough and realistic analysis of the activities on the SS 563/564 should be accomplished at that time by applying the techniques used in the present study. The recommendations in this report could thus be verified and a fourdation would be laid for even further progress in the design and operation of later submarines.

Appendix 1.

This appendix describes the activities at the hydraulic, air and trim manifold stations, in response to specific orders during various types of submarine operations.

HYDRAULIC MANIFOLD OPERATOR

The Diving Phase

1. Open all vents except safety.[12] This should be done on the second blast of the diving alarm. The following vents are opened in the order named: bow buoyancy, and main ballast tanks No's. 1, 2, 3, 4, 6, and 7.[13] The safety vent is not opened at this time since safety precautions demand that it never be open while other vents are opened. This enables the safety to be blown speedily if an emergency should arise.

2. Shut main induction. This is done when green lights indicate that the engine outboard exhaust valves (in the maneuvering room) have been closed. If these valves have not been closed by the time that the boat reaches a depth of thirty feet, the main induction is closed anyway. The reason for this is that the men in the maneuvering room must be given an opportunity to secure the engines before the main induction is shut. If they are not given that opportunity, the engines will rapidly draw up the air in the boat. At a depth of thirty feet, the danger of flooding the entire boat becomes so great that the main induction must be closed.

3. Shut bow buoyancy vent. This is done at a depth of forty feet at a command from the Diving Officer.

4. Shut all main vents and open safety. This is done at a depth of fifty feet.

5. Shut safety vent. This is done a few seconds after opening safety. After this, vents are never opened except at the command of the Diving Officer, and safety vent is never opened when other vents are open.

---

[12] The underlined phrases designate either the order given by the cognizant officer or a routine duty performed without a direct order.

[13] This sequence may vary to some extent from boat to boat. The sequence given is for the Halfbeak.

6. Blow negative. This consists of opening the negative flood, signalling the air manifold operator when the negative tank gauge reads 6000 lbs., and then closing the negative flood. This operation is begun when boat is twenty feet from ordered depth, and is ordered by the Diving Officer.

7. Vent negative. This is done at the command of the Diving Officer. Negative tank is vented inboard to prevent bubbles from coming to the surface and giving away the boat's position.

8. Cycle the vents. This is done to make sure that all air is out of the flooded tanks and is performed at the command of the Diving Officer.

This completes the hydraulic manifold operations during the diving phase.

The Submerged Phase

The hydraulic manifold operator has no regular duties during this phase of the operation.

The Surfacing Phase

1. Shut conning tower drain. This is done on the order from the Captain, "Standby to surface, _________ main engines."

2. Check all main vents for shut.

3. Put main induction in power position.

4. Report to conning tower. "All main vents shut. Main induction in power. Ready to surface."

5. Report depth. Reports are made every five feet over MC system.

6. Open main induction. This should be done on the command from the captain.

7. Flood negative. This operation takes place at the command of the Diving Officer when all other surfacing operations have been completed.

AIR MANIFOLD OPERATOR

The Diving Phase

1. Bleed air. This is done when the conning tower hatch light shows green (closed) or is reported closed. Pressure in the boat is raised two-tenths of an inch. At a command from the Diving Officer, the air is shut off. The purpose of this operation is to determine whether or not the ship is watertight. If the pressuer holds steady, the Diving Officer reports to the captain, "Green Board, pressure in the boat."

2. Blow negative. Negative tank is blown at a command from the Diving Officer. The air is shut off at a hand signal from the hydraulic manifold operator indicating that 6000 lbs. of water remain in the tank.

3. Check suction in the pumps. This is done every time the Diving Officer gives the trim manifold operator an order, and consists of feeling several vents to note suction or venting. The purpose is not only to see that the pumps are operating but also to make sure the trim manifold operator has not started the incorrect pump. A report is immediately made to the Diving Officer, e.g., "No. 1 Auxiliary is venting, sir".

The Submerged Phase

During any trimming operation, the air manifold operator must check the pumps for suction or discharge (as described above). In each case a report is immediately made to the Diving Officer. In addition, on Portsmouth model boats, the air manifold operator must blow water from No. 1 to No. 2 auxiliary ballast tank at the command of the Diving Officer. On Electric Boat models, this water is pumped instead of blown by the trim manifold operator.

The Surfacing Phase

1. Blow main ballast. This is done on an order from the Diving Officer,

in order to lighten the submarine so that it can surface. The main vents must be shut before the tanks can be blown.

2. Blow bow buoyancy. This is done on an order from the Diving Officer immediately after blowing main ballast. It is usually done while the main ballast tanks are being blown. The purpose is to lighten the bow, in order to obtain an up angle.

3. Secure bow buoyancy and main ballast tanks. This is done on an order from the Diving Officer.

4. Start the low pressure blowers. This is done on an order from the bridge when the submarine reaches the surface. The purpose of starting the low pressure blowers is to complete the blowing of the main ballast tanks without wasting high pressure air. It is immediately succeeded by the following operations:

a) Start resistor fan.

b) Open trunk flapper.

c) Start blowers.

d) Open hull flappers, shut drain.

e) Operate list lever to direct air to port or starboard side.

f) Allow low pressure air to blow for 14 minutes (or as directed).

g) Stop blowers.

h) Close trunk flappers.

i) Close hull flappers.

j) Open drain.

k) Stop resistor fan.

TRIM MANIFOLD OPERATOR

The Diving Phase

The trim manifold operator has no duties which, strictly speaking, are part of the diving phase. However, our data show that the trimming has begun before the end of the first four minutes. In this phase, the usual operations are flooding No. 1 and 2 auxiliaries. These are done at the command of the Diving Officer and are for the purpose of trimming the boat (leveling off and staying at the desired depth, and compensating for shifting weight within the boat).

The Submerged Phase

After the boat has reached the desired depth, it is the duty of the trim manifold operator to pump or flood the auxiliary ballast tanks Nos. 1 and 2 and the after and forward trim tanks, or to pump water from one of these trim tanks to the other. These operations are done at the command of the Diving Officer who specifies the amount in pounds to be flooded, discharged, or shifted.

The Surfacing Phase

The trim manifold operator has no regular duties during this period.

BOW PLANESMAN

The Diving Phase

1. Moves to station. On the sounding of the diving alarm, the bow planesman is relieved of his duties as a lookout on the bridge and moves as rapidly as possible to his station in the Control Room.

2. Rigs out the bow planes. By means of a lever which operates a hydraulic pump, the bow planes are rigged out at 15 degrees dive. On some boats the hydraulic manifold operator performs this duty so that the planes are already rigged out when the bow planesman reaches his station.

3. Attain ordered depth. The chief duty of the bow planesman is to attain and maintain the desired depth by means of the bow plane tilting control. On the diving operation he generally uses a 15 degree angle on his planes and continues to do so until he approaches the ordered depth, at which time he assists the stern planesman in leveling the boat to a zero angle.

The Submerged Phase

1. The major function of the bow planesman during submerged operation is to maintain the ordered depth. During this phase he continually operates his plane tilting control using rise and dive angles. This last operation is more or less dependent on the trim of the boat.

The Surfacing Phase

1. Attaining surfacing depth. Upon a verbal command from the Diving Officer or the signal of the surfacing alarm, the bow planesman puts a "hard" rise angle on his plane tilting control.

2. Rigging in the bow planes. The bow planesman rigs in the bow planes upon the command from the Diving Officer. This is done by placing the planes near a zero angle and setting the rigging control on "rig in."

STERN PLANESMAN

The Diving Phase

1. Moves to station. When the diving alarm rings, the stern planesman, similar to the bow planesman, leaves his post at the bridge and takes up his position in the Control Room.

2. Attaining ordered boat angle. The chief function of the stern planesman is to attain and maintain the boat angle ordered by the Diving Officer. The angle of dive varies between boats but a five degree down angle is usually ordered.

3. Leveling the boat angle. Upon the order "zero bubble" from the Diving Officer, the stern planesman shifts his planes from "hard" dive to a rise angle. He uses his plane tilting control with his own discretion to attain a zero boat angle.

The Submerged Phase

1. The major duty of the stern planesman during the submerged phase of the operation is to maintain the desired boat angle, which is normally zero. The amount of plane angle necessary to maintain the desired boat angle is dependent on the trim of the boat.

The Surfacing Phase

1. Attaining ordered surfacing angle. When the surfacing alarm rings, the Commanding Officer orders the desired up angle of the boat, which is usually about 5 degrees. It is the duty of the stern planesman to see that this angle is attained and maintained until the boat reaches surface.

2. Puts planes on zero. When the boat has surfaced, the stern planesman puts his planes on zero and shuts off the hydraulic system by means of a switch. He then prepares to take up his position as a lookout on the bridge.

THE SNORKELING PHASE

Little information has been collected concerning the duties of the manifold stations during snorkeling. It is suspected that these operations vary greatly from boat to boat. Such information as is presented here is incomplete and possibly inaccurate. It has been taken in part from the boat orders for the Halfbeak and from scanty information collected during one snorkel "run."

Hydraulic Manifold Operator

1. Turn on electrical control panel. This is done on the command from the bridge, "Make preparations for snorkeling." Available information indicates that this operation may include:

    a) Turning on power to snorkel head valve control circuit.

    b) Turning on one or both electrode circuits.

    c) Turning on electrode heating circuit in freezing weather.

2. Raise snorkel tubes. This is done on an order from the Diving Officer.

3. Open negative vent. This is also done on an order from the Diving Officer.

4. Receive reports from all departments and report to Diving Officer, "Ship ready to snorkel."

5. Open snorkel induction. This is done on an order from the Diving Officer following his report to the bridge, "Ship ready to snorkel."

6. Shift control to engine room. This automatically follows the opening of the snorkel induction.

7. During snorkeling, the hydraulic manifold operator must always watch the negative gauge for any intake of water which raises the content of the negative tank more than 2000 over the "mark." If this should happen, the Diving Officer's attention should be immediately called to the fact.

8. Shut negative vent. This is done following the order "Secure from snorkeling," and is done at the command of the Diving Officer.

9. Shut snorkel induction. This is done at the command of the Diving Officer.

10. Lock exhaust valve.

11. Lower snorkel mast.

12. Open negative flood.

13. Close negative flood at 6000 lbs.

14. Vent negative.

15. Secure electrical control panel.

Air Manifold Operator

1. Open snorkel head valve and hold open while snorkel tubes are being raised.

2. Put snorkel head valve in automatic on the command of the Diving Officer.

3. After the order, "Secure from snorkeling," place the snorkel head valve in hand position.

4. Blow negative to the mark at the command of the Diving Officer.

Trim Manifold

1. Open snorkel drain.

2. Open snorkel intake housing drain.

3. After the command, "Secure from snorkeling," close snorkel drain valve.

4. On surface, close upper snorkel wheel.

Appendix 2.

This Appendix lists the controls and indicators employed at hydraulic, air, and trim manifold stations during normal submerged operations.

HYDRAULIC MANIFOLD OPERATOR

An analysis of the duties of the hydraulic manifold operator shows that the following controls and displays are used one or more times during the three phases of operation studied.

Controls

Negative Vent
Safety Vent
Number 6 C-D Main Ballast Tank Vent
Number 6 A-B Main Ballast Tank Vent
Number 3 & 5 Main Ballast Tank Vent
Number 1 & 2 Main Ballast Tank Vent
Bow Buoyancy Vent
Safety Flood Valve
Negative Flood Valve
Main Induction Valve
Bow Plane Rigging Control

Indicators

Negative Tank Gauge
Snorkel Indicator Light Panel
Hull Indicator Light Panel
Flood and Vent Indicator Light Panel

AIR MANIFOLD OPERATOR

The analysis of duties for the air manifold operator shows that the following controls and indicators are used during the three phases of operations studied:

Controls

High Pressure Air Bleeder Valve
Negative Tank Blow
Main Ballast Forward Group Blow
Main Ballast After Group Blow
Bow Buoyancy Blow
List Lever for 2C-2D Main Ballast Tanks
List Lever for 6A-6B Main Ballast Tanks
Low Pressure Start and Stop Switch
10 Pound Blow Main Ballast Tank Number 1 Flapper
10 Pound Blow Main Ballast Tank Number 2A-2B Flapper
10 Pound Blow Main Ballast Tank Number 2D Flapper
10 Pound Blow Main Ballast Tank Number 2C Flapper
10 Pound Blow Main Ballast Tank Number 3A-3B Globe Valve
10 Pound Blow Main Ballast Tank Number 5A-5B Globe Valve
10 Pound Blow Main Ballast Tank Number 6B Flapper
10 Pound Blow Main Ballast Tank Number 6C-6D Flapper
Conning Tower Ventilation Flapper - (E.B. Boats Only)

Indicators

Manometer
High Pressure Air Receiving and Distributing Manifold (Forward)
High Pressure Air Receiving and Distributing Manifold (After)
Main Ballast Tank Blow Forward
Main Ballast Tank Blow After
Negative Tank
High Pressure Air Bank Number 1
High Pressure Air Bank Number 2
High Pressure Air Bank Number 3
High Pressure Air Bank Number 4
High Pressure Air Bank Number 5
High Pressure Air Bank Number 6
List Angle (Bubble) Indicator
Oil Gauge
Trim Pump Vents and Suction for 225 pound air manifold

TRIM MANIFOLD OPERATOR

An analysis of the duties of the trim manifold operator shows that the following controls and displays are most frequently used during submerged operations.

Controls

- Discharge to Sea Valve
- Sea Suction Valve
- Number 1 Auxiliary Suction and Discharge Valve
- Number 2 Auxiliary Suction and Discharge Valve
- Negative, Safety, and Auxiliary Discharge Valve
- Negative, Safety, and Auxiliary Suction Valve
- Trim Line Forward Discharge Valve
- Trim Line Forward Suction Valve
- Prime Pump Switch
- Trim Pump Switch
- Trim Line After Discharge
- Trim Line After Suction
- Trim Pump Field Rheostat Control

Indicators

- Trim Meter
- Forward Trimming Tank Indicator
- Auxiliary Ballast Number 1 Indicator
- Auxiliary Ballast Number 2 Indicator
- Trim Pump Discharge Indicator
- Trim Pump Suction Indicator
- Tachometer of Trim Pump
- After Trim Tank Indicator