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NAVY EXPERIMENTAL DIVING UNIT
WASHINGTON NAVY YARD
WASHINGTON, D.C. 20390

(14) NEDU - Evaluation - ...

EVALUATION REPORT 6-56

(6) FLATUS II SEMI-CLOSED CIRCUIT
MIXED GAS SCUBA.

PROJECT NS186-202 SUBTASK 2 TEST 8

W. C. HOLLINGSWORTH

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CONDUCTED PREPARED
AND
SUBMITTED

(10) W. C./HOLLINGSWORTH
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(16) NS-186 ...

(17) NS-... -20212

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APPROVED

M. des GRANGES
CDR, USN
OFFICER IN CHARGE

ABSTRACT

This evaluation was made of the semi-closed circuit. Flatus II in order to prepare for comparison of it with the LES unit. The Flatus II was tested objectively by breathing machine depth runs with repiratory pressure instrumentation and subjectively by swimming runs. Breathing machine test results are summarized as graphs at peak respiratory pressures against depth. Subjective test results are summarized narratively. The results are discussed contructively and lead to the following conclusions:

1. The unit is uncomfortable.

2. Swimmability is poor.

3. Maintenance is a problem.

4. Unit diving ability is good to 250 feet.

5. Further research and test are needed.

SUMMARY

PROBLEM

(1) To prepare the Flatus for a comparison with the LES Unit.

(2) To evaluate the Flatus in such a manner as to prepare for the determination in a final report as to whether the LES or the Flatus is more suitable to meet navy requirements.

(3) To determine advantageous features.

FINDINGS

(1) The Flatus was tested in accordance with the standard procedure for mixed-gas scuba. The LES Unit will also be tested by the same procedure.

(2) A tentative instruction manual is presented for use in the initial field test.

(3) The advantageous features will be determined in a comparison report of the LES and Flatus.

RECOMMENDATIONS

(1) The design of harness and positions of bottles should be considered,

(2) A field test of a modified model should be made even though time does not permit further laboratory tests.

(3) The sensing valve idea is sound and should be improved and retained.

(4) An instruction manual would be of great assistance in an evaluation test.

FOREWORD

A satisfactory, reliable interim mixed-gas SCUBA in urgently needed to provide an apparatus suitable for mixed-gas diving limits now being established. The most successful mixed-gas scuba to date has been the British C.D.B.A. (Formal Report 4-53). The Bureau of Ships wished to incorporate the same basic principles into a U. S. Navy design for an interim mixed-gas Scuba. At the present time two variations of such an apparatus have been developed under Navy Contracts. The primary purpose of this project is to determine which of the two is more suitable for adoption as the Navy interim model.

L.E.S. was developed by Old Dominion Research and Development Company under Contract Nos-66432. One unit was delivered 11 July 1955.

Flatus was developed by Dr. C. J. Lambertsen under Contract N 189s-96746. One unit was tested under project NS 186-200 Subtask 4 test 41 in April 1954, Formal report 13-54. That unit was subsequently returned to Dr. Lambertsen for modifications recommended in the report. The modified unit was delivered by Mr. J. H. Emerson on 18 August 1955.

Bureau of Ships (Code 588) monthly conference for July 1955 provided verbal direction to evaluate LES and Flatus simultaneously.

CONTENTS

1. OBJECT

1.1 Objectives

This evaluation has three objectives:

(1) To prepare for a comparison of the Flatus and the L.E.S.

(2) To evaluate the Flatus in such a manner as to prepare for the determination in a final report as to whether the LES or the Flatus is more suitable to meet navy requirements.

(3) To determine advantageous features.

1.2 Scope

This evaluation covers mechanical breathing resistance tests to 132 feet, subjective tests to 297 feet, flow stability tests to 300 feet and pool swimming tests. It also describes narratively and with pictures the assembled apparatus.

2. DESCRIPTION

2.1 General

Flatus II is a modification of the 1952 Lambertsen Amphibious Respiratory Unit into a semi-closed system. The major changes are addition of a constant mass flow injector and an exhaust valve. The prototype has the following dimensions and weights:

With cylinders empty	41 pounds
Overall Length	44 inches
Overall thickness	6-1/2 inches

2.2 Specific Features

The apparatus is assembled on a nylon vest. The two mixed-gas cylinders are mounted horizontally across the small of the back with a common high pressure manifold on the right hand side. A single stop valve controls both cylinders. A small semi-compensated regulator is mounted on the manifold. The semi-compensated regulator has two outlets One provides gas to the breathing bag through an orifice. Five orifices providing flows from 8.5 to 35 liters per minute were furnished with the prototype. The other outlet supplies pressure to a sensing valve which acts as a safety and warning device in the event of abnormal pressure drop in the gas supply either from failure of the regulator or exhaustion of the cylinder pressure. A small cylinder on the front of the vest is designed to furnish an emergency supply of oxygen to the bag when the safety device operates. The breathing bag is the same as the 1952 LARU except that it is devided at the back. (Ref. fig. 1). The cannister, breathing tubes with check valves, and mask are the same as the 1952 LARU (Ref. fig. 1). The pop-off valve is located on the mask in the position of the water ejection valve on the 1952 LARU.

2.3 Details

2.3.1 The two N2-02 cylinders are nominal 2 liters internal volume, aluminum alloy cylinders of French manufacture. They can be charged to 3000 psi with any desired mixture. The oxygen emergency cylinder has an internal volume of 0.35 liters. The maximum working pressure is not indicated.

2.3.2 The regulator on the N2-02 manifold is a special, semi-compensated design intended to vary the over-bottom pressure in such a way that the orifice will deliver a nearly constant mass of gas within certain limits of operating depth. The regulator on the oxygen emergency cylinder is compensated and thus places a constant over bottom pressure on the sensing valve.

2.3.3 The sensing valve is normally held closed by pressure from the N_2O_2 main regulator. Whenever regulator falls below the pressure of the emergency gas supply (which has its own regulator), the valve open admitting oxygen from the emergency supply to the breathing bag.

2.3.4 An audible warning devise is installed in the breathing bag on the end of the tube leading from the sensing valve.

3. PROCEDURE

3.1 Breathing Machine Test

The breathing machine was set at 2 liters per breath and 20 breaths per minute.

The 1 psi strain gage was rigged in the recompression chamber. The Brush recorder was calibrated and attenuation adjusted to give 1 line of deflection for 1 centimeter of water pressure. On the recording tape the name of the equipment, the date, the calibration, the attenuation, and the direction of deflection for inhalation was noted.

The cannister was filled with absorbent but the apparatus was not charged with oxygen and all cylinder valves were closed.

A large air cylinder was rigged with a demand valve coupled into the breathing circuit to fill the breathing bag.

The breathing machine was started, and the chamber was run down at 20 feet per minute to 132 feet. Every 10 feet and each atmospheric increment (33, 66, 99, and 132 feet) was marked. The breathing bag was kept full during descent. At 132 feet the breathing machine was stopped and the breathing pressure analyzer was recalibrated and balanced.

The breathing machine was then started again and returned to the surface, at 20 feet per minute. Every 10 feet and each atmospheric increment was again marked.

After each run the tapes were given to the draftsman and the data put in graph form.

3.2 Depth Flow Stability Test

A test was performed to determine the flows of each orifice in the following manner (See fig. S-1).

The chamber port plate for gas sampling was used. A tee fitting connected the downstream side of the orifice to a mercury manometer and to the chamber port plate. A line was led from the outside of the chamber port plate through a stop valve to the flowmeter.

The flow of each orifice was checked from the surface to two hundred feet and return in 20 foot increments.

All information was recorded and given to the draftsman to place in graph form.

3.3 Sensing Valve Tests

3.3.1 In the first test the sensing valve assembly was rigged in the chamber with approximately 90 lbs. pressure from the N2-02 regulator and 22 lbs. pressure from the oxygen regulator. The rubber hose that normally leads to the breathing bag was secured to a flowgage, and another rubber hose was led from the flow gage to a beaker of water.

The chamber was run down in depth while a continuous watch was maintained on the flow gage and water beaker for the first indications of flow. The descent was stopped at 93 feet when small bubbles indicated functioning of the sensing valve. The flow of oxygen was not sufficient to register on the flowgage until the descent was resumed and 110 feet was reached. At this depth, the flow was approximately 1.8 liters per minute.

3.3.2 In a final test in the presence of the designer, the test outlined in 3.3.1 was repeated. In this run, the sensing valve functioned consistently at 130 to 135 feet. The maximum flow was about 1.8 liters per minute and occured at 150 to 160 feet. The flow was not consistent.

The designer noted that the orifice was not installed in the line from the oxygen bottle. He could not understand the reason for the low, inconsistent flow when the sensing valve functioned.

The pressure was reduced to zero on the N2-02 side of the sensing valve while the oxygen pressure was varied from zero to twenty pounds. The flow varied from a normal amount for the size of the tubing, (exceeded the upper limit of the flowgage) to one liter per minute.

The test was secured when the designer was satisfied that the rubber tube in the sensing valve was actually metering the oxygen flow in an irregular pattern.

3.4 Subjective Depth Runs

3.4.1 The Flatus II was charged to 1600 psi cool with the required gas mixture and the cannister was filled with Baralyme. The flow rate jet was checked with a spirometer and stop watch and a record made of each run.

3.4.2 The following runs were made:

Run	Depth ft.	Work Pull lbs.	02 Mix %	Flow Rate LPM	Duration Min.	Subject
1	0	6	50	4.5	60	Suglia
					60	Hollingsworth
					43	Goggeshall
2	0	12	50	9.0	12	Kohl
					60	Funderburk
3	33	6	50	4.5	60	Kohl
					27	Willoughby
4	33	12	50	9.0	10	Rickert
5	150	6	30	14.	30	Leyden
6	150	8	30	18.	30	Hanes
7	150	12	30	30.	10	Adams
8	198	8	Air	50.	11	Mannam
					15	Suglia
9	297	6	Air	50.	10	Willoughby

3.4.3 A continuous gas sample was drawn on each run and analyzer for carbon dioxide and oxygen with a recorded minute to minute oxygen level.

3.4.5 A record was kept for each run from the time commenced to the time secured.

3.5 Swimming Test

3.5.1 Preliminary preparations included charging bottles to 1600 psi cool and filling cannister with Baralyme.

3.5.2 Four different subjects made four swimming runs in the Receiving Station pool. These subjects were experienced swimmers who are familiar with SCUBA units. Each subject carried out the following routine:

(1) Before each run the subject performed barrel rolls, somersaults, and checked for leaks in the shallow end of the pool.

(2) Each run was 8 laps around the pool, (about a quarter of a mile) at a swim rate of 0.8 knots.

3.5.3 After each run the subject filled out a data sheet, covering the following items:

(1) How is the general comfort of the apparatus?

(2) How is the comfort of the harness?

(3) Describe the swimmability of the apparatus.

(4) Describe the general buoyancy characteristics of the appartus.

(5) Describe the general torque characteristics of the apparatus.

(6) Describe breathing resistance in all positions, if any.

(7) Describe buoyancy in all positions.

(8) Describe torque in all positions.

(9) At neutral buoyancy what is the direction of twist?

(10) Do you have any additional comments?

4. RESULTS

4.1 Breathing Machine Test

Figure G-1 shows breathing resistance from surface to 132 feet and return.

4.2 Depth Flow Stability Test

Figure G-2 shows depth stability test from surface to 200 feet and return to the surface for the 8.5, 12, 19, 27, and 35 LPM jet.

4.3 Subjective Depth Runs

4.3.1 The depth runs were made in accordance with section 3.4.2. The following comments are applicable:

(1) Run 1 was secured after 164 minutes because the carbon dioxide level became 2 per cent.

(2) Run 2 was satisfactory.

(3) Run 3 was poor in that the subject was forced to surface 4 times to clear the mask of water.

(4) Run 4 was secured after 14 minutes because gas became hot and subject had difficulty breathing.

(5) Run 5 was unsatisfactory. The subject reported exhalation resistance. After the run the Baralyme was found to be 50% wet.

(6) Run 6 was poor in that the subject reported he felt disoriented during the run.

(7) Run 7 was secured because subject felt he was getting carbon dioxide poisoning however CO2 was only .125 per cent.

(8) Run 8 was secured because the subject was taking water in the breathing system. Run 8 was later satisfactorily repeated without interruption.

(9) Run 9 was poor even though the subject reported on ill effects, in that the Baralyme was 50% wet.

INSTRUCTION BOOK

FLATUS II

Semi-closed circuit Mixed-Gas
Breathing Apparatus

4.4 Swimming Test

The four subjects made the following remarks in answer to the questions in 3.4.3.

(1) All four subjects reported that the general comfort of the apparatus was very poor.

(2) Three subjects reported the harness was too small and hard to secure; one subject reported the harness was large enough but he did not like the way its weight was distributed.

(3) All four subjects reported the swimmability of the apparatus was bad in comparison with other scuba units.

(4) All four subjects reported general buoyancy good however two subjects used a 2.5 lb. lead weight, and two subjects obtained a good general trim without additional weight.

(5) All subjects reported a general torque to the right believed to be caused by the control valves and connections on that side.

(6) Three subjects reported a small exhalation resistance in all positions, and all four subjects reported greater resistance while lying face up.

(7) Two subjects reported neutral or near buoyancy with weights, and two subjects reported neutral or near neutral buoyancy without any weights.

(8) All subjects reported they did not like the apparatus. "The design should be changed; it was too easy to flood out; and vision was poor."

5. DISCUSSION

5.1 Breathing machine test

The maximum exhalation resistance was reached during descent at 98 feet. The maximum inhalation resistance was at 110 to 132 feet.

5.2 Depth flow stability test

5.2.1 The flow test was performed with orifices ranging in size from one calculated to deliver 8.5 liters per minute to one calculated to deliver 35 liters per minute at the surface with 80 pounds per square inch supply pressure. The regulator pressure was set at 80 pounds per square inch before the test was started. However during the time between each run the regulator varied and the runs were made with initial regulator pressures between 83 and 95 pounds per square inch.

5.2.2 The semi-compensated regulator is satisfactory in its consistency of operation and reaction to depth pressure. The resultant flow of gas is sufficiently near a constant mass flow down to 250 feet.

5.3 Sensing valve

5.3.1 The sensing valve was not included in the circuit during the breathing machine, subjective depth or swimming pool tests.

5.3.2 The unsatisfactory performance of the sensing valve due to the difference of response to depth of the two regulators was calculated. The test was established to verify the calculated performance.

5.3.3 The designer was present during the sensing valve tests and witnessed the initiating action due to depth as well as the unexpected throttling by the rubber tube itself.

5.3.4 No attempt was made to evaluate the tonal quality, intensity, or consistency of operaion of the audible warning device.

5.4 Subjective depth test

5.4.1 All of the subjective depth tests were performed in the Experimental Diving Unit pressure tanks.

5.4.2 Only one run was secured because of CO_2 build up and it was a surface run after 164 minutes.

5.4.3 All of the subjects were normal after the runs and suffered no ill effects.

5.5 Swimming test

5.5.1 The swimming test was influenced by the fact that the unit is uncomfortable to don and to wear in air. The subjects were biased before they actually tried the performance of the apparatus eventhough some of the discomfort was due to experimental strapping that will be discarded.

5.5.2 The unnecessary complexity of the strapping was pointed out to the designer.

5.6 Modifications

5.6.1 This report covers the evaluation of the apparatus described and pictured herein. There are no other copies of this model.

5.6.2 The Bureau of Ships desires that this apparatus be field tested with the British CDBA, the LES and the Mike units. The Bureau also realizes that the apparatus has already been severely used in the evaluations conducted to date.

5.6.3 The designer and the manufacturer have agreed to refurbish the apparatus and to provide a duplicate if time will permit.

5.6.4 The Bureau has agreed that certain obvious modifications to the sensing valve and harness arrangements are desireable and should be made during the refurbishing.

5.6.5 Time will not permit this activity to evalu[illegible] cument those modifications prior to the conduct of the field te[illegible]

5.7 Maintenance and Instruction Manual

5.7.1 As in all evaluations of prototype models, [illegible]is early realized that a semblance of a maintenance and instruction manual is desirable. Much time was lost and many tests suffered from the lack of adequate instructions.

5.7.2 Appendix A is a bare outline of a maintenance and operation manual prepared from experience and knowledge gained during this evaluation.

5.7.3 Experimental Diving Unit personnel assigned to witness the field tests will have instructions to complete and improve on Appendix A during the conduct of those tests. The Unit will then be in position to submit a better manual if recommendations of the field test render it advisable.

6. CONCLUSIONS

6.1 Conclusions

6.1.1 The following conclusions apply to the Flatus II N_2O_2 scuba unit only.

(1) The unit is uncomfortable (Section 4.4.1)

(2) The unit swimmability is poor (Section 4.4 (3)).

(3) The unit performs satisfactorily up to 250 feet (Section 4.3.1 (9)).

(4) The unit was not liked by any of the subjects (Section 4.4 (8)

(5) The sensing valve is not satisfactory.

6.2 Recommendations

(1) A new design of harness and position of bottles should be considered.

(2) Test of a modified model should be made.

(3) The sensing valve idea is sound and should be improved and retained.

(4) An instruction manual would be of great assistance in an evaluation test.

7. FIGURES

7.1 Photographs

7.1.1 Figure P-1 is a front view of the unit laid out.

7.1.2 Figure P-2 is a front view of the unit as worn.

7.1.3 Figure P-3 is a back view of the unit as worn.

7.1.4 Figure P-4 is a right side view of the unit as worn.

7.2 Graphs

7.2.1 Figure G-1 shows inhalation and exhalation breathing resistance up to 132 feet.

7.2.2 Figure G-2 shows flow in LPM against depth up to 300 feet.

7.3 Schematic

7.3.1 Figure S-1 shows method of rigging chamber for depth flow stability test.

7.3.2 Figure S-2 show schematic diagram of Flatus II.

GENERAL DATA

The diving principles given in the instruction book are presented only to clarify the operational characteristics of the Flatus II. This book is not intended as a complete manual on diving. For full instructions refer to the U.S. Navy Bureau of Ships Diving Manual (Proposed).

This instruction book provides information necessary for the operation and maintance.

Preventative maintenance carefully exercised will prolong the life of equipment and assure trouble-free operation. Corrective maintenance when required is to be preformed by qualified personnel only.

WARNING

Use of a breathing device cannot eliminate the inherent risks of swimming and diving. Personnel are reminded that there is no substitute for alertness, common sense, and self-discipline.

TABLE OF CONTENTS

SECTION I

GENERAL DESCRIPTION

Introduction

The Flatus is manufactured by J. H. Emerson Company and was designed by Dr. C. J. Lambertsen. The Flatus II is a complete self-contained semi-closed circuit diving and swimming device. It is a modification of the 1952 Lambertsen Amphibious Respiratory Unit into a semi-closed system. The major changes are addition of a constant mass flow injector and an exhaust valve. The prototype has the following dimensions and weights.

With cylinders empty	41 pounds
Overall length	44 inches
Overall thickness	6-1/2 inches

Regulators

(Reference Evaluation Report 6-56, Section 2.3.2).

Compressed gas cylinders

(Reference Evaluation Report 6-56, Section 2.3.1)

Sensing valve

(Reference Evaluation Report 6-56, Section 2.3.3)

Assembly

(Reference Evaluation Report 6-56, Section 2.2)

Mixture of gas and depth limitation

(Reference Proposed Diving Manual)

SECTION II

PRINCIPLES OF OPERATION

General

The Flatus II operates on the same principles as a closed circuit and in addition employs a non-return exhaust valve to allow spill over of that portion of the gas flow which is not actually consumed bv the diver. It also has an emergency bottle of oxygen and sensing valve that operates automatically (Reference Evaluation Report 6-56).

Precautions

The following pertains to the use of the Flatus II.

(1) Must be psychologically and physically fit.

(2) Must be thoroughly qualified in open and closed-circuit scuba before training with the Flatus II.

(3) Great care should be employed during filling of the cylinders and no oil should come in contact with oxygen or N_2O_2 under high pressure.

(4) Periodic check of the orifices to insure proper flow. (Evaluation Report 6-56, Section 2.2).

Unit assembly

(Reference Evaluation Report 6-56, Section 2.1 and 2.2).

SECTION III

PREPARATION FOR USE

Unpacking

The Flatus II is packed completely assembled and ready for use except for charging the N_2O_2 cylinders, oxygen emergency bottle and filling the absorbent canister with Baralyme.

Inspection of equipment

Check all connections, valves, regulators to make sure they are firmly attached. After the equipment is checked, a pressure test should be made on both regulators to insure proper pressure setting. This check should be made with an oil free gas or with filtered air.

Filling cylinders and canister

The emergency oxygen cylinder is to be charged with breathing oxygen not to exceed the I.C.C. working pressure of 2150 psi. The N_2O_2 cylinders are to be charged with the desired mixture from a pre-mixed gas storage bank not to exceed I.C.C. working pressure of 2150 psi.

SECTION IV

OPERATING INSTRUCTIONS

The percent of gas

To determine the percent of oxygen to use refer to U.S. Navy Diving Manual (Proposed), Chapter-------------.

Training instructions

The diver should be qualified in both open and closed circuit scuba before receiving training instructions in the semi-closed circuit scuba.

SECTION V

PREVENTATIVE MAINTENANCE

Until the Flatus II is in production, preventative maintenance will not be developed.

SECTION VI

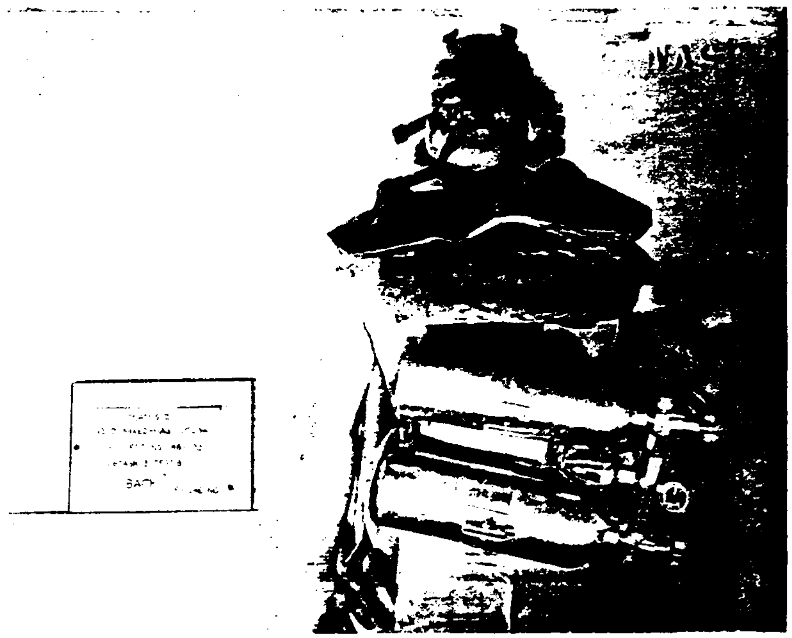
CORRECTIVE MAINTENANCE

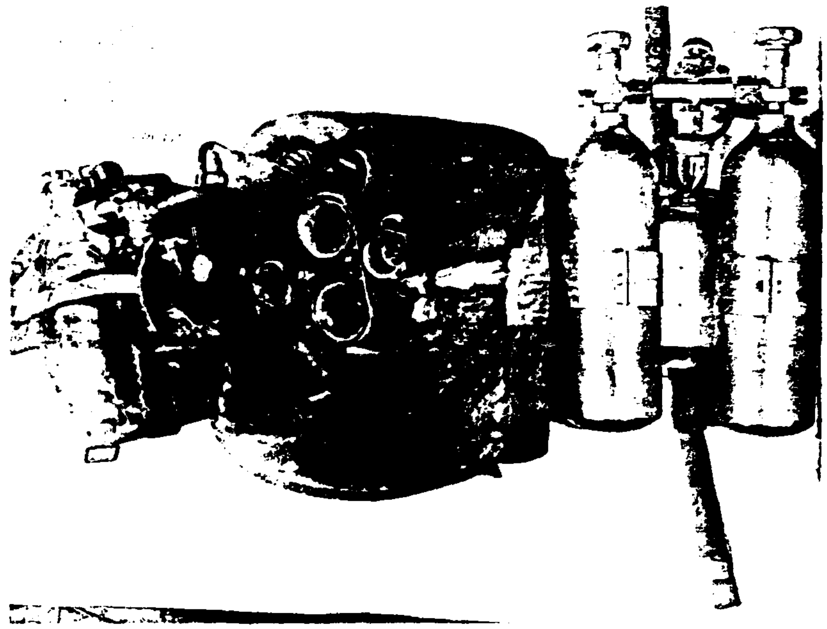
Until the Flatus II is in production corrective maintenance will not de developed.

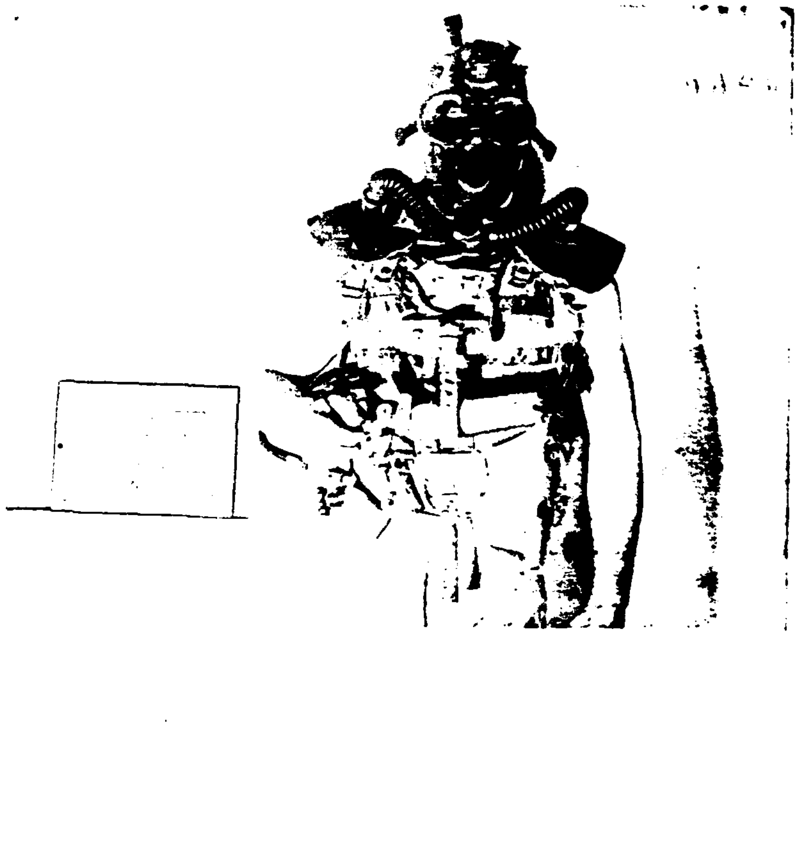
SECTION VII

PARTS LIST

Until the Flatus II is in production parts list will not be developed.







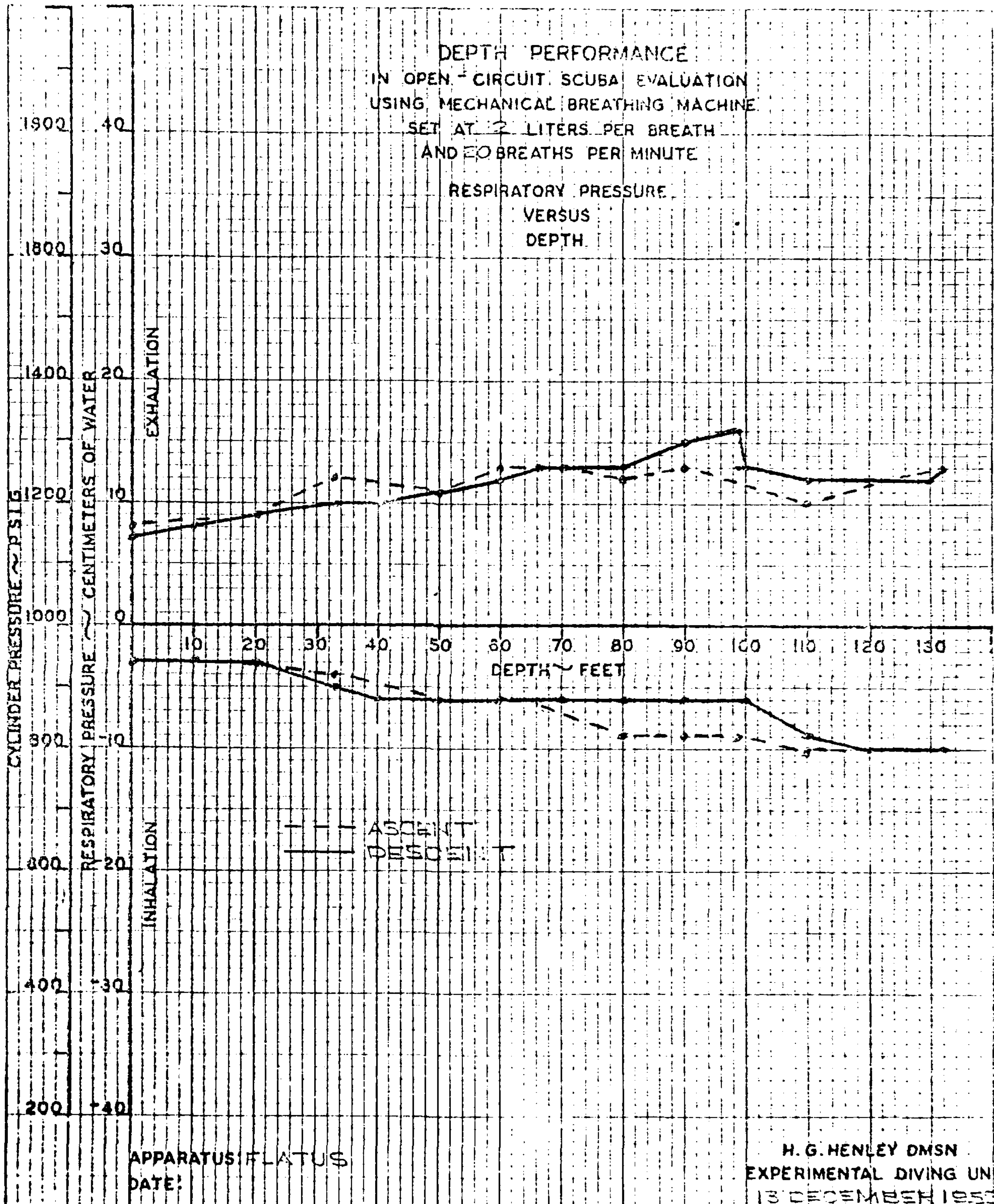

DEPTH PERFORMANCE
IN OPEN - CIRCUIT SCUBA EVALUATION
USING MECHANICAL BREATHING MACHINE
SET AT 2 LITERS PER BREATH
AND 20 BREATHS PER MINUTE
RESPIRATORY PRESSURE
VERSUS
DEPTH
CYLINDER PRESSURE ~ P.S.I.G.
RESPIRATORY PRESSURE ~ CENTIMETERS OF WATER
EXHALATION
INHALATION
DEPTH ~ FEET
ASCENT
DESCENT
APPARATUS: FLATUS
DATE:
H. G. HENLEY DMSN
EXPERIMENTAL DIVING UNIT
13 DECEMBER 1955

FIGURE G1

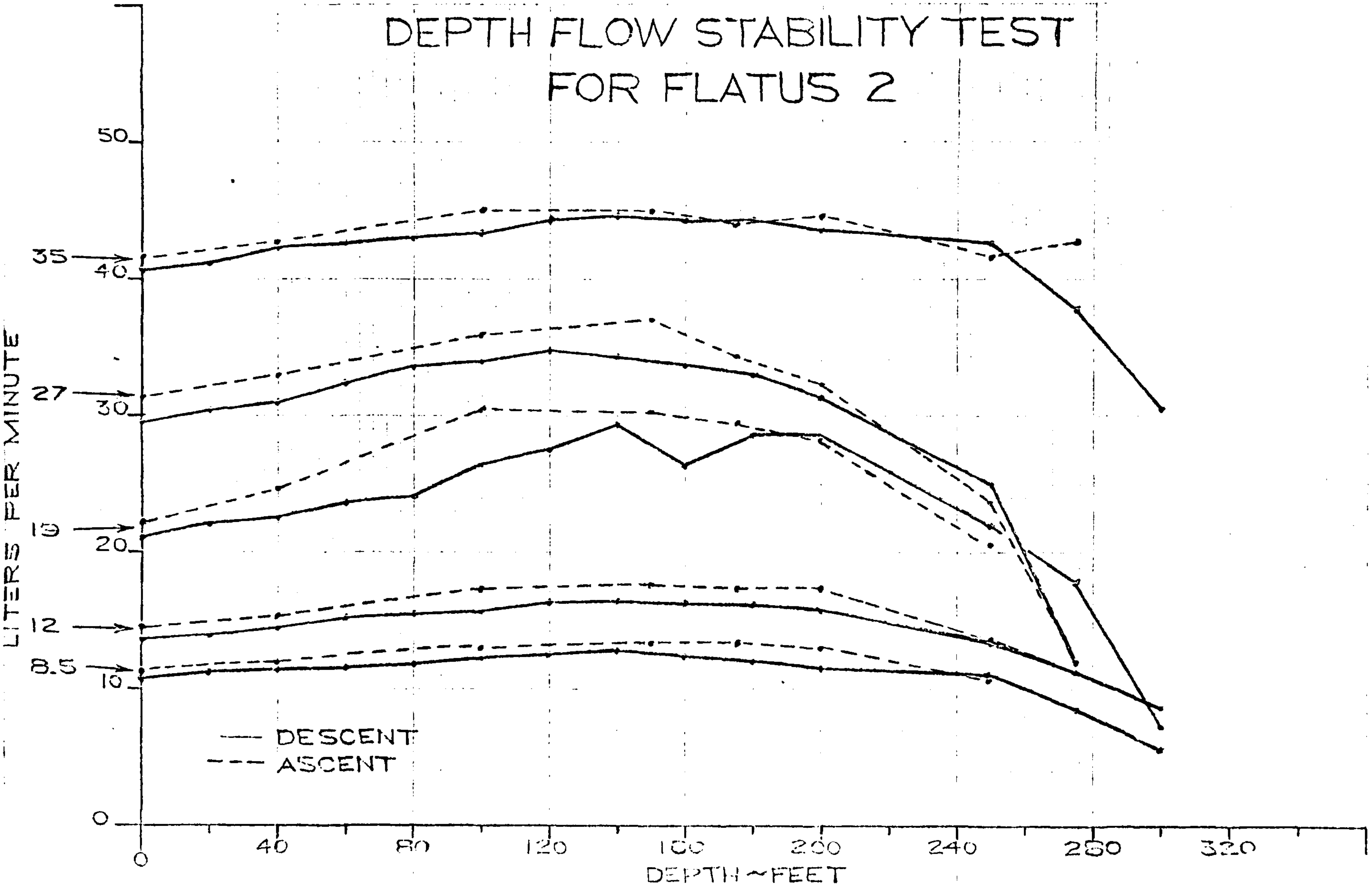


FIGURE G2

H.G. HENLEY DM3
EXPERIMENTAL DIVING UNIT
7 JANUARY 1956

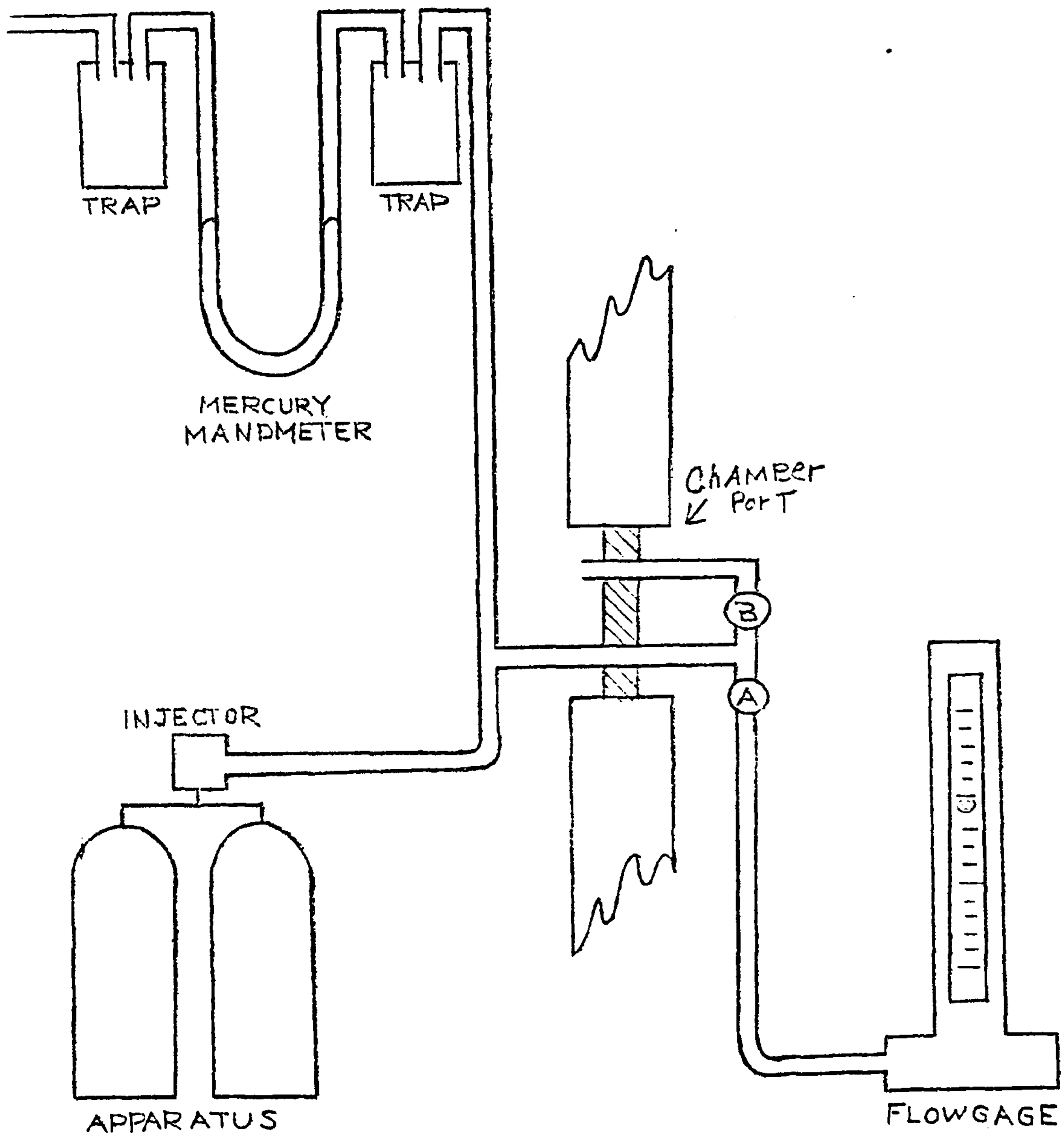

TRAP
TRAP
MERCURY
MANOMETER
ChAMBer
PorT
B
A
INJECTOR
APPARATUS
FLOWGAGE

FIGURE 51

SCHEMATIC DIAGRAM OF FLATUS II

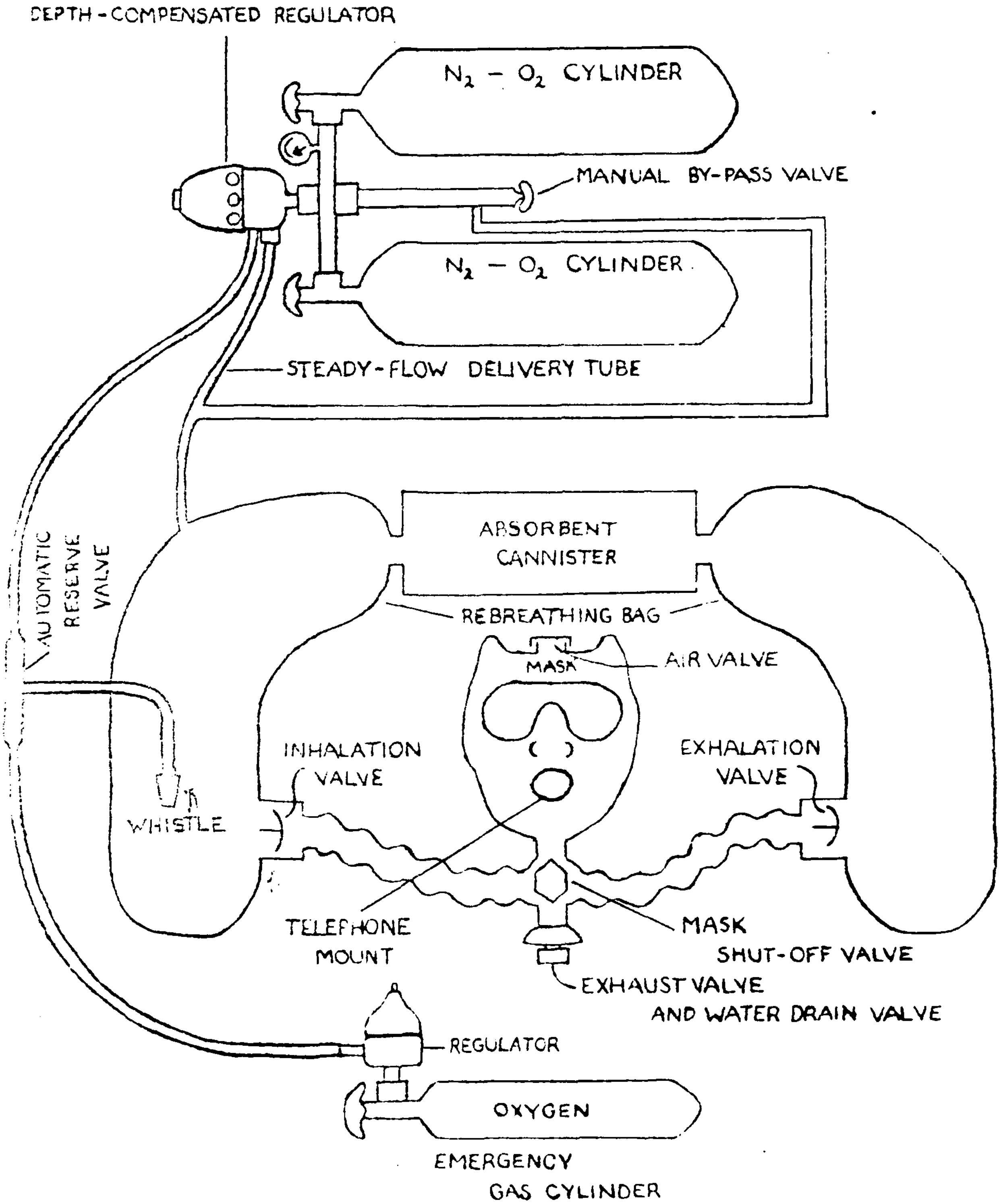


FIGURE S2

C. J. LAMBERTSEN, M.D.
5 AUGUST 1955

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	Navy Experimental Diving Unit Washington Navy Yard Washington, D.C. 20390

13. ABSTRACT

This evaluation was made of the semi-closed circuit. Flatus II ~~in~~ order to prepare for comparison ~~of it~~ with the LES unit. The Flatus II was tested objectively by breathing machine depth runs with repiratory pressure instrumentation and subjectively by swimming runs. Breathing machine results are summarized as graphs at peak respiratory pressure against depth. Subjective test results are summarized narratively. The results are discussed. contructively and lead to the following conclusions:

1. The unit is uncomfortable.
2. Swimmability is poor.
3. Maintenance is a problem.
4. Unit diving ability is good to 250 feet.
5. Further research and test are needed.

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Security Classification

KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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