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EVALUATION OF NORTHILL 'AIR-LUNG' REGULATOR WITH MODIFIED DIAPHRAGM AND PLUGGED RESERVE DEVICE

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Navy Experimental Diving Unit
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13. ABSTRACT

Following reported high breathing resistance in production models of the Northill "Air Lung" demand regulator, units were tested at EDU and found not to meet acceptance criteria. The manufacturer confirmed this and traced the defect to a faulty diaphragm mold. Modified regulators were submitted with an improved diaphragm and the reserve feature eliminated. Extensive mechanical respirator and subjective trapeze and pool tests revealed fully acceptable resistance characteristics. However, a noise-vibration condition exists at shallow depths during forced inhalation and on this basis the regulator is not accepted. A design defect in the new model, Northill "ON-OFF" mouthpiece is also noted.

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U. S. NAVY EXPERIMENTAL DIVING UNIT
U. S. NAVAL GUN FACTORY
WASHINGTON, D.C.

EVALUATION REPORT 11-59

EVALUATION OF NORTHILL "AIR-LUNG" REGULATOR WITH MODIFIED DIAPHRAGM AND PLUGGED RESERVE DEVICE

PROJECT NS 185-005 SUBTASK 4 TEST 36

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20 JANUARY 1959

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SUMMARY

PROBLEM

Initially - Does the production model Northill "Air-Lung" demand regulator meet resistance criteria.

Subsequently - Does the Northill "Air Lung" demand regulator with improved diaphragm and with the reserve eliminated meet resistance and other subjective criteria.

FINDINGS

Initially - The production model, as currently being used by fleet units, has high inhalation resistance and does not meet acceptance criteria.

Subsequently - The improved unit has highly acceptable breathing resistance criteria but is unacceptable due to a noise-vibration characteristic at shallow depth and hard inhalation. Also the new mouthpiece is unacceptable in that it readily goes beyond its arc of travel.

RECOMMENDATIONS

It is recommended that steps be taken to correct the high resistance in the Air Lungs now held by Naval activities.

It is recommended that the manufacturer further modify the Air Lung's diaphragm or inhalation air chamber to eliminate the characteristic vibration.

It is recommended that the Northill "ON-OFF" mouthpiece be redesigned to positively prevent over-travel of the inner barrel.

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ADMINISTRATIVE INFORMATION

Ref: (a) BuShips ltr S94/1 (538), serial 538-975 of 22 April 1957.
(b) BuShips ltr S94/1 (538), serial 538-985 of 30 April 1957.

The Northill "Air Lung", a product of the Garrett Corp. (manufactured at times by AiResearch and at times by Air Cruisers Division) has been evaluated in earlier models as cited in the Background Data in the basic report.

The Bureau of Ships had previously supplied a quantity of the Northill "Air Lungs" under contract NObs-65950 and the U.S. Naval School, Underwater Swimmers reported field evaluation of a production model. This report (Appendix B of the basic report) noted unsatisfactory breathing resistance.

The Bureau of Ships subsequently, by reference (a), requested the school to forward an "Air Lung" regulator having the high resistance characteristics to the Experimental Diving Unit for additional tests. By reference (b), the Bureau of Ships requested EDU to test the regulator "in accordance with standard procedure for the type apparatus" and recommended liaison with the Northill representatives. Reference (b) also assigned Project Number NS185-005, Subtask 4, Test No. 44.

Subsequent to the tests of the Underwater Swimmers School's regulator, the Garrett Corp. (Mr. Bob Wright) provided two improved Air Lung regulators, Serials 8-4469 and 8-4470, for testing.

G. W. Hanger, ME1(DV), USN and G. Haslip, GM1(DV), USN were assigned jointly as Project Engineers and LCDR W. F. Searle, Jr., USN as Project Officer. Work commenced in June 1957 on the Navy regulators and was completed in approximately September at which time conferences were held with the manufacturer. Work was suspended until the manufacturer furnished improved regulators. The two improved regulators were received 21 July 1958 and evaluation resumed in August and was completed in December 1958. Charges encurred in the execution of this project were lodged against allotment 16102/58 in fiscal year '58 and allotment 16102/59 in fiscal year '59.

The following breakdown indicates the estimated manpower expended for this project:

DESCRIPTION	MANHOURS
Production Model "Air Lung"	
Mechanical Respirator Runs	80
Adjustments and Repairs	15
Improved "Air Lung"	
Mechanical Respirator Runs	60
Trapeze - Subjective Depth Runs	200
Swimming Pool Runs	24
Exhaust Valve Steady State Runs	6
Drafting and Data Preparation	60
Report Preparation	20
Clerical Services	12
TOTAL	477

This is the fourth and final report under this project number. The report is issued in the Experimental Diving Unit's Evaluation Report series and is distributed only to the Bureau of Ships.

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LIST OF FIGURES

1. INTRODUCTION

1.1 Objective

1.1.1 At the outset of this project, the objective was a complete re-evaluation of a production model Northill "Air-Lung" (demand regulator portion) to ascertain its operating characteristics and general safety and to confirm, and correct if possible, the report from the field that the regulator had high breathing resistance.

1.1.2 After initial evaluation confirmed the high breathing resistance, the manufacturer requested an opportunity to study the regulator and subsequently modified the diaphragm and resubmitted the unit. The objective of the project as it evolved towards this report is, then, a formal evaluation of the breathing characteristics of the modified regulator with improved diaphragm to determine if it meets current EDU acceptance criteria.

1.2 Scope

1.2.1 The scope of this project is limited to an evaluation of the regulator's breathing characteristics only. Other components of the complete "Air-Lung" as described in NAVSHIPS 394-0057 such as mouthpiece and tube assembly, harness, and cylinders and manifold are not included.

1.2.2 In view of the above, this evaluation should not be considered as fulfilling the requirement of MIL-R-19558 for a complete and formal evaluation of a preproduction sample.

1.3 Background

1.3.1 The Northill "Air-Lung" has gone through a series of changes and improvements over the past seven years. The manufacturer has unfortunately not used any distinctive nomenclature (mark or model numbers) to differentiate the different basic models and/or model modifications and so there arises a problem in accurate identification both of the units tested and the units being used in the field. The Northill Company, Inc. was a wholly-owned subsidiary of the Garrett Corp. of Los Angeles. The regulator has at times been under the internal cognizance of the Air Cruisers Division of Garrett Corp. Dealings of the Experimental Diving Unit have in general been with the Washington Representatives of the Garrett Corporation.

1.3.2 Over the past several years, the Experimental Diving Unit has evaluated and reported on several models of the Northill "Air-Lung". Original models were unsatisfactory but redesign followed by field changes brought the apparatus to a point where it met U.S. Navy standards and in 1956 was accepted for Naval use and is one of the three open-circuit scubas described in the U.S. Navy Diving Manual, Part III (NavShips 250-538). The configuration of the model which was certified by EDU as acceptable was locally identified as containing "field change #4" but there being no distinctive markings on the manufacturer's name plate, the field forces have come to identify this as the "improved" Northill regulator (see Appendix B). It should be carefully noted that the regulator reported herein is a step or field change beyond this "improved" unit.

1.3.3 For purposes of background, a review of previous Northill regulator evaluations is included. AiResearch Manufacturing Co. report of 1952 (1) describes the manufacturer's tests of the initial model. This model (a single breathing tube unit) was reported not satisfactory by EDU letter serial 523 of 22 December 1952. A completely redesigned prototype model was submitted in September 1953 and was briefly evaluated at EDU (2) and subsequently sent to the Naval Amphibious Test and Evaluation Unit for field evaluation. The EDU evaluation reported generally satisfactory characteristics with several improvements required and recommended field evaluation.

1.3.4 The "Air-Lung" was subsequently given a series of modifications (locally identified as "field changes") in close association with informal EDU tests witnessed by the manufacturer's representatives. After field changes 2 and 3 a fairly acceptable unit was achieved and an extensive open-circuit scuba evaluation was conducted at EDU following procedures then "standard" for all open-circuit evaluations. This evaluation (3) reported the regulator unit as not acceptable for Naval service due to unsatisfactory breathing characteristics for the 0.85 knot swimming at 200 ft. depth. The regulator with the resulting #4 field change was subsequently given a limited evaluation (4) in the 0.85 knot/200 ft. range only and was found acceptable and therefore complete acceptability was assumed. All of the earlier evaluations having used air cylinder pressures of 2000 psi and below, a further limited evaluation on the regulator (field change #4) to investigate or confirm its breathing characteristics for high cylinder pressures to 3000 psi was conducted. The results of this evaluation (5) were satisfactory and it was in this form that the "Air-Lung" regulator was accepted by the Bureau of Ships, included in the Diving Manual and subsequently issued as a production model to fleet units. It should, however, be noted that Military Specification "Regulator, Air, Demand, Diver's" (MIL-R-19558 of 14 August 1956) was not in existence during the above evaluations and that the regulators tested were prototype, essentially "hand made" models and that a "Preproduction Sample" as specified in MIL-R-19558 was never tested.

1.3.5 The "Air-Lung", as indicated above, was issued to the fleet units and became identified as the "improved" Northill regulator. The Bureau of Ships requested the Underwater Swimmers School of Key West to perform field tests of the "improved" (#4 field change) model. The report, included herewith as Appendix B, indicated unsatisfactory breathing characteristics but otherwise generally satisfactory results.

1.3.6 In view of the Underwater Swimmers School's experience with high (subjectively) breathing resistance, the Bureau of Ships directed that activity to ship one of the "bad" regulators to the Experimental Diving Unit for confirmation and further evalaution. EDU tests confirmed that the production model, both "as received" from the school and after cleaning and readjustment produced higher than acceptable breathing resistance. Local efforts to readjust or otherwise track down the source of this unsatisfactory condition were fruitless and the manufacturer was so advised.

1.3.7 The manufacturer also confirmed the high resistance and subsequently undertook to modify the regulator's component parts. It is this modified, "improved" Northill Air-Lung which is evaluated and reported herewith.

2. DESCRIPTION

2.1 Underwater Swimmers School, production model Northill "Air-Lung"

2.1.1 The Northill "Air-Lung" production model received from the Underwater Swimmers School was the standard unit supplied the field activities by the Bureau of Ships under contract NObs-65950. This unit with its breathing hoses and "ON-OFF" mouthpiece is fully described in NAVSHIPS 394-0057, "Instruction Book - NORTHILL AIR-LUNG." The unit is further described in Appendix B.

2.1.2 The regulator (serial number 6-3151) and hose assembly was received from the school on 8 May 1957 and returned 28 January 1958.

2.2 Modified Northill "Air-Lung"

2.2.1 As indicated in 1.3 above, the manufacturer was advised of the higher-than-acceptable breathing resistance in the production model "Air-Lung" (the Underwater Swimmers School sample and also in EDU regulators tested to confirm the former) and subsequently confirmed this.

2.2.2 The manufacturer corrected the trouble and further modified the regulator as described in the below paragraphs excerpted from correspondence on the subject.

2.2.3 Excerpts from AiResearch Manufacturing Co. office memo of June 2, 1958, Dept. 93-2:

"As previously reported, the diaphragm was suspected of causing the Air-Lung to have high breathing resistance. The development of the diaphragm has shown very interesting results. The production multiple cavity mold was producing diaphragms .045" to .060" thickness in the convolution, compared to .020 to .025 in the walls. This variation could result in not properly closing the mold or, inaccuracy in the mold itself. The mold is not available for inspection but samples were originally approved, so it is suspected that molding technique is responsible.

"The single cavity development mold has been reworked to produce uniform wall thickness of .010" and used to produce test samples. Consideration is being given to the silicone materials presently used in many of our Cabin Pressure products. Samples have been produced in Neoprene, Silicone compound SC550, and Nylon cloth impregnated with Dow-Corning silicone compound 6-125.

"The following data compares the production Neoprene Air-Lung diaphragm with that of Silicone SC550, which presently shows the lowest breathing resistance. These tests are not conclusive, but indicate diaphragm design and material have a decided effect on breathing resistance. During these tests, the full range of bottle pressures was not covered and the breathing machine was not adjusted to exact specifications. The breathing machine was adjusted to 2 lpm and 22 respirations/min.

TEST RESULTS

AIR-LUNG DIAPHRAGM					SILICONE SC-550	
AIR TO AIR		AIR TO WATER			AIR TO WATER	
In-"H_2O	Ex-"H_2O	In-"H_2O	Ex-"H_2O	DEPTH-FT.	In-"H_2O	Ex-"H_2O
3.3	2.1	3.1	1.7	Surface	1.6	1.4
		4.0	1.8	30	2.0	1.8
		4.1	1.9	50	2.2	1.9
4.5	3.0	4.2	2.2	100	2.5	1.7
5.5	3.2	4.5	2.5	150	2.7	2.0
10 to 12	3.6	5.5	2.5	200	2.9	2.0

NOTE:

Inconsistency in readings at the greater depths can be explained by the response rate of the compound water manometer (used for pressure measurement). Proper recording instruments will be employed during final runs: Specification permits 8" H_2O resistance."

2.2.4 Excerpts from AiResearch Co. letter of 15 July 1958 (WTS:8773:0715) to Code 538, BuShips (referenceing contract NObs 72127):

"2. The following comments pertain to the Northill Air Lung. The increase in breathing resistance E.D.U. reported during requalification tests has been confirmed. It was found to be primarily due to the diaphragm aging and becoming stiff. It was further aggravated by uneven wall thickness, especially the thick section in the convolution.

"3. The development mold was reworked to produce a thin wall of uniform thickness. Silicone and Neoprene compounds, with and without fabric reinforcements, were tried. The Neoprene compound proved to be more satisfactory due to its added strength, and resistance to oils. The diaphragm remained interchangeable with the ones supplied on the original equipment. The high pressure block was redesigned to eliminate the reserve. This change further decreased the breathing resistance.

"4. Two (2) requalification test units have been shipped direct to EDU. The recorded data supporting the performance of these units will be transmitted to you through the Garrett Corporation, Washington, D.C.

"5. The curves were produced on a recording type oscillograph with signals from pressure transducers. They show compliance to Paragraphs 4.1, 4.4.1, 4.4.2 and 4.4.3 of BuShips Specification MIL-R-19558 (Ships)."

2.2.5 Two Northill Air-Lung regulators, serial numbers 8-4469 and 8-4470, were delivered to the Experimental Diving Unit on 21 July 1958 for evaluation.

Figure 1 is a photograph of one of these unit. showing the plugged reserve device. The units are essentially the same as described in NAVSHIPS 394-0057 except as modified above.

2.2.6 The two regulators above were supplied with breathing tunes and the usual Northill "ON-OFF" mouthpiece as pictured in figure 1. Though not especially a part of this evaluation, it should be noted that the mothpiece barrel in figure 1, and as routinely supplied by Northill for the past two years, differs slightly from the original model as shown in figure 5 of the Instruction Book, NAVSHIPS 394-0057. The original model had a fairly large dog by which to operate the mouthpiece's inner barrel through its arc from open to closed. The more recent model does not carry the central dog and depends on gripping the barrel in the swimmer's hands to rotate and a small axial dog at one end to limit the arc of travel. There have been unanimous complaints from the field that this new model is unsatisfactory in that it is somewhat more difficult to move and also, of major consequence, that the inner barrel can be rotated past the limiting arc because the inner barrel's small axial dog tends to ride up and over the outer barrel beyond the arc's operating slot. The difference in the two models is indicated by comparison in figure 2.

3. PROCEDURE

3.1 Mechanical Respirator

3.1.1 The standard EDU mechanical respirator procedure as described by Janney and Searle (6) was followed throughout. The original checks of the Underwater Swimmers School regulator and confirmation on EDU regulators were done following the "old standard procedure". The evaluation tests reported herein of the modified, manufacturer-submitted reguators followed the current (revised) procedure. All tests reported were with the MSA mechanical respirator set for 2 liters (air) per breath, 20 breaths per minute.

3.2 Exhalation Valve Pressure Drop (Steady State)

3.2.1 In view of unanticipated high exhalation resistance experienced in another open-circuit scuba being evaluated concurrently with the "Air-Lung", the steady state pressure drop through the exhalation tube and integral diaphragm exhalation mushroom valve was measured for flow rates up to the maximum peak rate experienced in the respirator tests.

3.2.2 An ordinary air control valve was installed upstream of a 0-30 cfm Fisher-Porter, 12-P flowmeter. A short transition tube with pressure tap was attached to the flowmeter's outlet. The exhalation tube nipple of the regulator was attached to the transition tube. A V-tube water manometer was connected to the pressure tap in the transition piece, immediately upstream of the nipple. With the air exhausting to the atmosphere, steady state pressure drop across the exhalation valve was measured as a function of flow rate.

3.3 Depth Runs at Specified Swimming Rates

3.3.1 Depth runs were conducted with the subject swimming against a weighted trapeze in the manner outlined in the appendix of (6) and generally similar to that described in (2), (3), and (7).

3.3.2 These runs were conducted in conjunction with another project (8) concerning the broader aspects of swim trapeze ergometer test procedure. In all cases, inhalation and exhalation resistance, respiratory minute volume (RMV) and respiratory rate were measured. Each subject wore the same type fin (of his own choice) for each of his runs.

3.3.3 Each of the subjects is well trained and experienced in scuba depth test swimming. Pertinent data on each of the subjects is as follows:

(a) LCDR W. F. SEARLE, Jr., USN, Age 35, Height 5'11", wieght 180, build-stocky, two years scuba swimming at Experimental Diving Unit and one year in field.

(b) LT P. G. LINAWEAVER, MC, USN, Age 29, Height 5'10 1/2", weight 140, build-slender, graduate of Deep Sea Divers School Submarine Medical Officer Course and one year experinence at Experimental Diving Unit.

(c) ENS G. M. JANNEY, USNR, Age 24, Height 5'8", weight 165, build-medium, graduate of U.S. Navy Underwater Swimmers School and one year experience at Experimental Diving Unit.

(d) JENSEN, F. G., BM1(DV), USN, Age 29, Height 5'6", weight 146, build - rugged, graduate of Deep Sea Divers School and extensive experience in trapeze swimming at Experimental Diving Unit.

(e) GWINN, R. L., MM1(DV), USN, Age 26, Height 5'11", weight 140, build - slender, graduate of Deep Sea Divers School and one year experience at Experimental Diving Unit.

3.4 <u>Subjective Pool Tests</u>

3.4.1 The subjective pool tests were conducted in accordance with the appendix (standard evaluation procedure) of (6). Three experienced scuba swimmers were used. The tests were conducted in a large indoor swimming pool with maximum depth of 11 feet. No field (river or open sea) tests were conducted. Specific subjective test questionaires were filled out by each subject and further general comments were recorded.

3.4.2 In addition to the five subjects listed above, a sixth experienced scuba swimmer was used. Pertinent data as follows:

(a) HASLIP, G., GM1(DV), USN, Age 30, Height 6'1", weight 165, build - medium, graduate of Deep Sea Divers School and three years experience at Experimental Diving Unit.

3.4.3 In view of the initially unanticipated reports of excessive noise and vibration on inhalation at the near-surface ("zero" depth) condition, all subjects were requested to pay particular attention to this characteristic. The results were repeatedly confirmed.

4. RESULTS

4.1 Mechanical Respirator Tests

4.1.1 Figures 3 and 4 show the results of the mechanical respirator tests for the Underwater Swimmers School's (serial #6-3151) Northill "Air-Lung" regulator. The results of similar exploratory runs on EDU regulators confirming these values are not plotted as they are essentially the same.

4.1.2 Figures 5 and 6 show the results of the mechanical respirator tests of the manufacturer - submitted, modified "Air-Lung" (serial #8-4469). Figure 7, included for information and sake of completeness of data only, is the result of the mechanical respirator test of the modified "Air-Lung" when used as if surface supplied with constant low pressure (100 psig).

4.2 Exhaust Flapper Valve Pressure Drop

4.2.1 The steady state pressure drop (cm. of H_2O) as a function of air flow rate (liters per minute) for the Northill's exhalation assembly as compared to another widely used scuba's exhalation assembly is plotted in figure 8.

4.3 Trapeze Swim Ergometer Depth Tests

4.3.1 The results of the trapeze swim ergometer (subjective) depth tests of the manufacturer - submitted, modified Northill "Air-Lung" are plotted in figures 9 through 15. In view of the high breathing resistances experienced in the mechanical respirator tests of the Underwater Swimmers School's regulator and the willingness of the manufacturer to modify it, ergometer depth tests were not made.

4.3.2 As indicated previously, these depth tests were conducted in conjunction with another project studying the basic test techniques and results. The tests of Searle, Linaweaver and Janney were at multiple depths and required many more runs, the results of each consecutive run being indicated by run number. The earlier (lower numbered) runs for these three subjects (and Jensen) did not include an initial surface reading and therefore each run carries only two points (for example, figure 9 run 1, at depth 100 and 200) whereas later runs included a surface check as well as the 200 ft. check and an intermediate depth (for example, figure 8 run 6, at surface, 100 and 200). Linaweaver and Janney performed the tests for two work rates (8# and 12#) and a comparison between the pairs of figures (10 and 11 for Linaweaver; 12 and 13 for Janney) is possible. Gwinn's runs were modified as a result of a considerable amount of experience (the runs of Searle, Linaweaver and Janney reported here as well as similar runs on other equipment) and only the two end/points were investigated but the length (of run at the two depths (surface and 200 ft.) was increased. Jensen's one run is presented for information only. He was transferred during the project and his series could not be completed.

4.4 Subjective Pool Runs and Specific Further Investigation of Noise

4.4.1 The subjective pool runs were executed using the modified "Air-Lung" with Northill mouthpiece and hose assembly but with the current standard (U.S. Divers) cylinders and harness and so only the comments concerning breathing and regulator characteristics were pertinent. Except for the noise-vibration characteristic reported below, all subjects reported favorably, especially noting practically non-existent inhalation resistance. Free-flow characteristics were reported as "about Normal" for comparative open-circuit, manifold-mounted demand scuba regulators. Specific comments remarked on the less-than-optimum ease-of-clearing-when-flooded could not be cleared of water by rolling to the left side and forcibly exhaling, but rather that the hoses could be cleared by holding the mouthpiece above the demand regulator, causing a hard free flow. In connection with this resulting comment, reference is made to Appendix B.

4.4.2 Several of the subjects remarked on a sort of chatter or vibration occuring during heavy inhalation. This seemed to occur only at shallow (near-surface) depth and if the subject was under heavy exertion (12# pull or sprint swim) and inhaling vigorously. This condition was noted both in the pool tests and during surface swim checks on the trapeze. Not all subjects reported this condition at first, but those who had not were given special surface swims on the ergometer at high exertion and asked to specifically observe the vibration and to try to bring it on by forced inhalation similar to that experienced in heavy breathing. All subjects ultimately reported the vibration at shallow depths. This phenomenon not only is troublesome as a noise source but it is onerous to the swimmer's respiratory efforts and at times borders on being painful. There appears to be an oscillation of the air flow in the inhalation half-cycle. This condition did not occur at depth.

5. DISCUSSION

5.1 Demand Regulator - Mechanical Respirator Evaluation

5.1.1 Figure 16 is the acceptance criteria from MIL-R-19558 (articles 3.14 and 4.1(a)) for the mechanical respirator (breathing machine) tests as specified therein. Figures 3-6 are compared to these criteria. It will be noted that the production model "Air-Lung" (figures 3 and 4) gave consistently high inhalation resistance. This result was confirmed on EDU "Air Lungs" and also by the manufacturer. Comparing figure 6, for the modified "Air-Lung", to figure 16 it will be seen that the inhalation and exhalation resistances are well within acceptable limits. The flat inhalation resistance characteristic of the "Air Lung" is especially interesting and desirable.

5.1.2 The tests of resistance (respiratory pressure) as a function of falling cylinder pressure (figures 3 and 5) are actually not called for in the MILSPEC but they are pertinent and are included in EDU standard evaluation. It will be noted in figure 5 that both at surface and at depth the "Air Lung's" resistance characteristics are not a function of cylinder pressure down to a very low pressure. This test is essentially a measure of the first stage's regulating capacity.

5.1.3 Figures 5 and 6 both indicate that the modified "Air Lung" meets EDU and MILSPEC mechanical respirator criteria.

5.1.4 The steady state exhalation characteristics of the Air Lung (figure 8) are well within acceptance criteria and are lower than other comparable open circuit scuba.

5.2 Demand Regulator - Trapeze Depth Test Evaluation

5.2.1 MIL-R-19558 (Articles 3.14, 3.15, and 4.1(b)) specifies that the breathing resistance (inhalation or exhalation) shall not exceed 20 cm. of water at a depth of 200 ft. for a man swimming against a weighted trapeze at a rate of 1 knot or at an "8 pound pull".

5.2.2 The criteria covers only breathing resistance, however, the results as presented give the additional information generally considered necessary for a complete physiological evaluation of scuba. The dangerous physiological effect of high breathing resistance (either inhalation or exhalation) is reduced pulmonary ventilation and is indicated by a change in respiratory minute volume (RMV) and/or respiratory rate (RR). Though comparative data for other (accepted) demand regulators is not presented in this report, the results for the three primary subjects (Searle, Linaweaver and Janney) have been compared to their RMV and RR for other scuba.*

5.2.3 Figures 9-15 indicated that the resistance values for all subjects fell within the 20 cm. of water criteria. The flat inhalation resistance curve experienced on the mechanical respirator runs was confirmed in the case of each subject. The fact that the diver is not burdened with increased inhalation resistance as he goes down is especially desired.

5.2.4 Special mention should be made of Janney's results (figures 12 and 13). His unique breathing pattern consistently produces random resistance values with a wide spread. The pattern is not even but is jerky and the rapid attack of both inhalation and exhalation produces short duration - high peak flow rates. Subjectively, however, Janney does not report untoward resistance and the solid line "mean" values presented are considered to be representative values. This characteristic of Janney's is not unique in the "Air Lung" and is discussed in more detail in (8).

5.2.5 The RMV and RR values for the three primary subjects has been compared with other test data on the same subjects but wearing other scuba. In all cases for the "Air Lung" the subject's RMV is at least as high or slightly higher than other acceptable scuba and markedly above an unaccepted regulator with high resistance and consequent reduced RMV. In general, the RR comparison was as the RMV but not as marked.

5.2.6 The results of the trapeze tests indicate acceptable respiratory characteristics for the "Air Lung" as modified. It is especially interesting to note that the change in the diaphragm material had such a significant change in the breathing characteristics of the demand regulator. The statement of the manufacturer in his memorandum of 2 June 1958 (article 2.2.3, third quoted paragraph) is confirmed.

5.3 Subjective Comments

5.3.1 Aside from the noise problem discussed below, the demand regulator appears to be subjectively acceptable. The slight difficulty in clearing, which

*See EDU Evaluation Report 8-59

is inherent in the design location of the exhaust valve, is mastered by training as indicated both by the EDU subjects and the field trial, Appendix B.

5.3.2 The shallow - depth noise or vibration problem as described in 4.4.2 is not at all satisfactory. This characteristic was never noted before and should not be confused with the noise problem mentioned in earlier evaluations. The oscillatory nature of the phenomena and the fact that the material and thickness of the diaphragm have been changed leads to the suspicion that a resonant condition may be occuring in the inhalation chamber below the diaphragm when the incoming air (near surface) is of the lesser density. A slight redesign of diaphragm or inhalation chamber may be indicated. The condition as it now exists is not acceptable. The noise is an obvious problem in the possible actuation of acoustic ordnance and the new painful effect on some subjects stands by itself.

5.3.3 Though not specifically a part of this evaluation, the slight defect in the current Northill "ON-OFF" mouthpiece is mentioned here in order to take official cognizance of it. As indicated in figure 2 and described above, there has been an unannounced change in design. The latest model is not satisfactory in that it is possible (and it always happens) for the inner barrel to turn beyond the intended arc. In the new design, the strength of the stop-dog is not adequate and the height of the stop at the end of the arc of travel is not enough. The old design with the center dog was satisfactory. The new design has been modified at EDU to make a more positive stop (brass ring) at the end of the arc of travel and this design is also satisfactory.

6. CONCLUSIONS

6.1 Conclusions

6.1.1 It is concluded that the Northill "Air Lung" as modified by the manufacturer to improve the diaphragm and eliminate the reserve feature, has superior breathing resistance characteristics, both subjectively and on machine test, to the older production model "Air Lung" and that the regulator now meets resistance criteria.

6.1.2 It is concluded that the modification of the diaphragm has occasioned a noise or vibration characteristic in the "Air Lung" at shallow depth and which is unsatisfactory from a noise standpoint and can be painful the diver.

6.1.3 It is concluded that the new desing of the Northill "ON-OFF" mouthpiece is faulty in that excessive travel is easily achieved.

6.2 Recommendations

6.2.1 It is recommended that the noise - vibracion problem experienced in the "Air Lung" be investigated and eliminated. If the diaphragm is again changed, additional evaluation will be required. From a resistance standpoint alone, the "Air Lung", as modified, is fully acceptable. If the noise - vibration characteristic can be corrected, it is recommended that the numerous "Air Lungs" (regulators only) previously supplied to various Naval activities be called in for modification or that field change kits be furnished.

6.2.2 It is recommended that the manufacturer correct the defect in his "ON-OFF" mouthpiece.

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U. S. NAVAL SCHOOL
UNDERWATER SWIMMERS
U. S. NAVAL STATION
KEY WEST, FLORIDA

2 October 1956

Improved Northill Air Lung Regulator Performance Tests

Conducted by:
Instructor personnel

Prepared by:
LTJG H.A. JONES, USNR

APPROVED:

U. C. ROE
LCDR, USN
Commanding Officer

Informal Report 2-56

CONTENTS

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FOREWORD

In accordance with the Chief, Bureau of Ships, request that this command conduct performance test in order to obtain depth and work performance on this regulator, a series of ten (10) one hundred foot descents, two (2) 500 yard, four (4) 750 yard and eight (8) 1000 yard open water swims were conducted with the new regulator along with five (5) balancing dives in a twelve (12) foot fresh water tank. Operational characteristics between the old regulator and the improved model were observed together with a comparison between this model and the Aqua-Lung. This report is submitted in compliance with BuShips request.

ABSTRACT

Eight (8) swimmers conducted the series of descents and swims to evaluate the improved Northill regulator. In view of the fact that each man was thoroughly qualified in use of the old model Northill regulator, only five balancing dives were conducted with the improved regulator in the twelve (12) foot fresh water tank at this command. Open water swims consisted of ten (10) - 100 foot descents and twelve (12) thousand yards of underwater swimming in depths up to thirty feet. No major difficulties were encountered, however, the regulator is not considered to be the ultimate in design and thorough evaluation is needed before the regulator can be judged completely satisfactory.

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I. OBJECT:

This performance test was conducted to provide Chief, Bureau of hips with information on the performance of the improved Northill Air Lung Regulator under various swimming and diving conditions and to evaluate the maintenance problems in comparison with the old regulator and other types of open circuit SCUBA.

II. DESCRIPTION:

The improved Northill Regulator is a further development of the Northill Regulator. In the improved model, the complete body is cadminum plated and is die cast with a weight difference of 1 1/2 pounds compared to the sand-cast body of the old regulators with the thicker walls. The die-cast and sand-cast parts are inter-changeable although it is not considered practical to inter-change the two unless in an emergency. Further improvements consist of; (1) a redesigned diaphragm assembly to incorporate a very large exhalation valve (2) a non-return valve added to the inhalation circuit near the mouth valve to make water purging easy, (3) the elimination on both the metering valve and the reserve valve section of the truarc lock rings to provide an adjustment to assure easy assembly and proper heights of the levers. The removal of the lock-ring on the high pressure block provides a more rigid connection and eliminates the need for special tools, (4) re-designing the mouth valve to incorporate adequate bridging at the mouth bit opening to eliminate the tendency of the "O" ring to bind, thus making operation easy with either hand by grasping the hose near the mouth valve and rotating, (5) re-designing the reserve valve to eliminate the occasional whistle present in the old model.

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III PROCEDURE:

A. Balancing dives in 12' tank:

The regulator was tested by five dives in the 12 foot fresh water tank to insure its proper operation before using for any open water swimming or diving. No difficulty was encountered during these dives and the regulator was found to be operating correctly. Disassembly followed after these tests to inspect all parts and to observe the improvements in the regulator.

B. Distance Swims (Open Water):

Instructor personnel employed the improved regulator for underwater swims over a period of four months as the opportunity arose so as not to interfere with the training schedule. They were dropped into the water from a standard Navy landing craft at distances from 500-1000 yards over a course marked by buoys. The buddy system using two swimmers, a buddy line, and a flotation bladder was employed and a compass course was swam to the beach. These swims consisted of two (2) 500 yard swims, four (4) 750 yard swims and eight (8) 1000 yard swims for a total of 12000 yards.

C. Distance swims (Open Water):

Further testing continued using the improved regulator for 100 foot descents. These were done from a mobile diving barge using three (3) inch line as a descending line. At the 100 foot mark, a 25 foot diameter circle was swam to evaluate the regulator at the deeper depth.

D. Maintenance:

As the instructor personnel were thoroughly familiar with all phases of maintenance of the old Northill regulator, only the differences in the regulators were pointed out and these discussed.

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IV. CONCLUSIONS:

A. Each man was given a questionaire to complete on his use of the improved regulator and to evaluate it in comparison to the old regulator and also to other types of open circuit SCUBA, particularly the Aqua-Lung. The following conclusions are based upon these comments and evaluations.

B. Noise encountered:

No noise was encountered in any instance of use. This is in direct opposition to the old regulator where the excess noise was one of the dislikes noted by instructor and student personnel trained in its use.

C. Ease of breathing:

(1) Inhalation was considered to be harder than the old type regulator and somwhat harder than the Aqua-Lung. Several cases were reported in which the volume of air received was insufficient and inhalation so hard as to prevent controlled breathing thusly higher air consumption.

(2) Exhalation improved due to the enlarged diaphragm opening of the exhaust valve.

D. Ease of clearing of water:

Water clearance of the hose was improved due to the larger exhaust valve. Several attempts were required in the old regulator to complete water clearance, whereas with the new regulator, a single roll onto the left side and exhaling resulted in complete clearance. The non-return valve (II.a.) prevented influx of water into the inhalation hose thus reducing the amount of water to be cleared in case the hose was flooded. This is considered an ideal improvement, as it is the only type in use with such a characteristic.

E. Maintenance:

The coating on this type regulator has considerably reduced the maintenance problems. One of the major complaints with the old regulator was due to the corrosion of the brass parts and thusly a higher incidence of maintenance problems. The old regulator could never be depended upon to operate properly after stowage. In comparison to the old regulator, the maintenance is negligible and replacement of parts is minor compared to the Aqua-Lung. Maintenance problems in the field have been decreased with the new regulator because no special tools are needed. The elimination of the truarc lock rings on both the metering valve and the reserve valve made possible the disassembly of the regulator with a screwdriver and a crescent wrench, and further eliminated any trouble due to the lockring coming off as has happened.

F. Air consumption:

Air consumption in the new regulator is less than with the old regulator but in comparison to the Aqua-Lung it is still greater by 10-15 percent. In comparison runs, every case resulted in greater air consumption using the improved Northill regulator than with the Aqua-Lung. The cause is unknown but is thought to be due to the combination of poor balance of the unit (neutral buoyancy at 1100 psi) and the difficulty in developing controlled breathing because of inhalation being harder and the volume of air delivered being insufficient.

G. Difficulties encountered in use:

One major difficulty was encountered in use of the regulator. Two cases of water entry into the hoses resulted; one on a 100 foot descent and due to the diaphragm being crimped when replaced on the regulator and the other on a 1000 yard swim due to the hose being installed with the mouthpiece 120° from the normal position thus forcing continual opening of the surface breather. The major problem that was encountered was the blowing out of the non-return valve ending in its lodging in the exhalation chambers, as shown in enclosure (1). This was believed to have occurred because the non-return valve in supply hose was improperly installed.

SUMMARY

In view of the facts found during this test, the improved Northill regulator was found to be far superior to that of the older model. With the decreased maintenance problems brought about by coating the regulator and eliminating the truarc lock rings, it is now on a scale with the Aqua-Lung. Further improvements should be incorporated to ease the breathing level of the regulator and deliver the volume of air comparable to that of the Aqua-Lung. Should these improvements be developed, it is recommended that the improved Northill regulator be accepted for service use to implement the SCUBA equipment now being issued to those activities in which its use is required.

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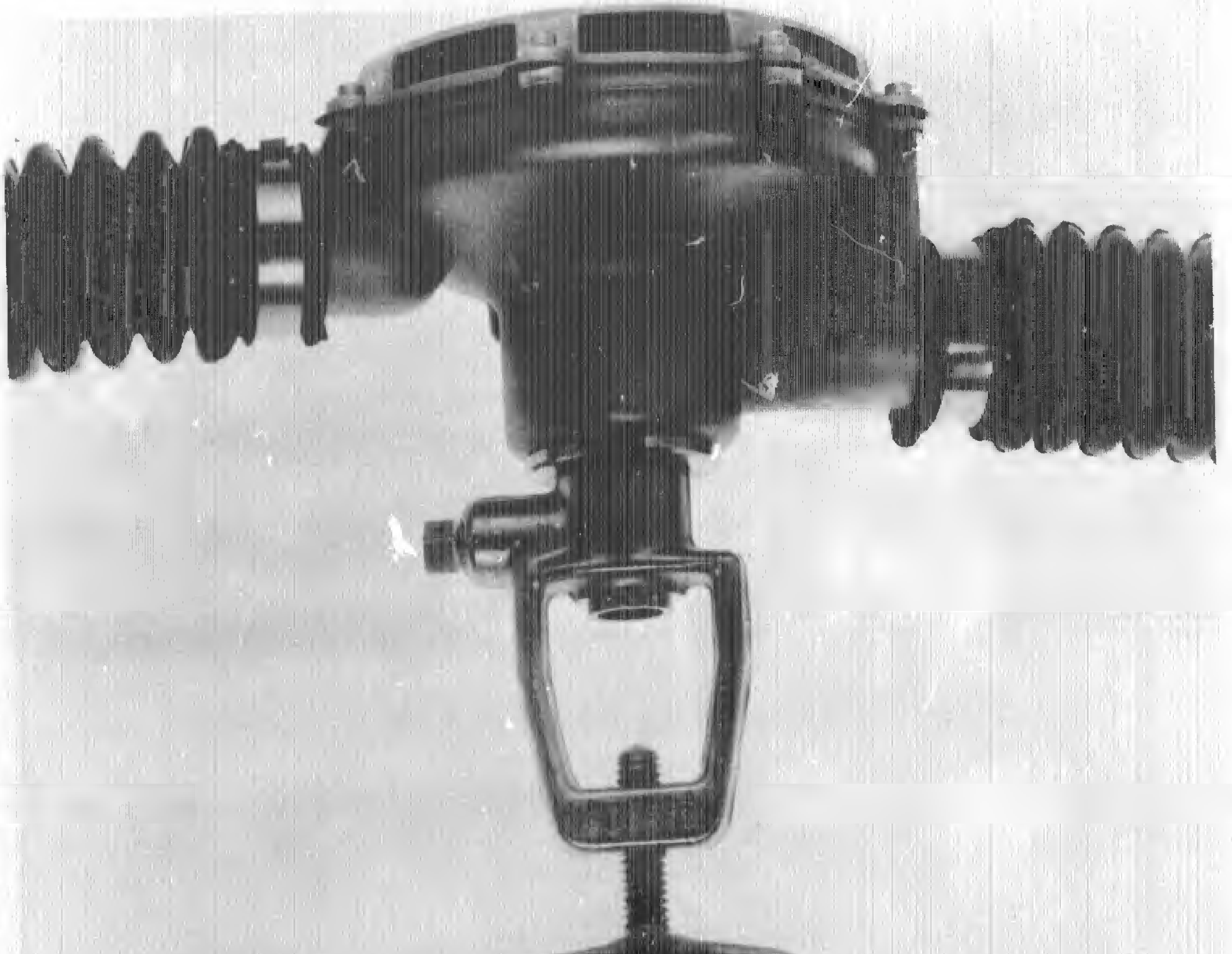

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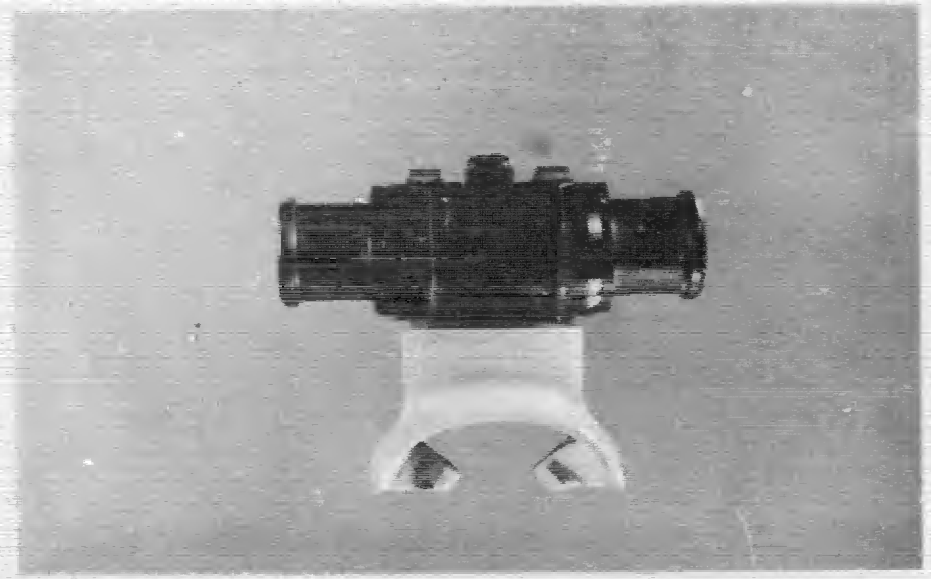
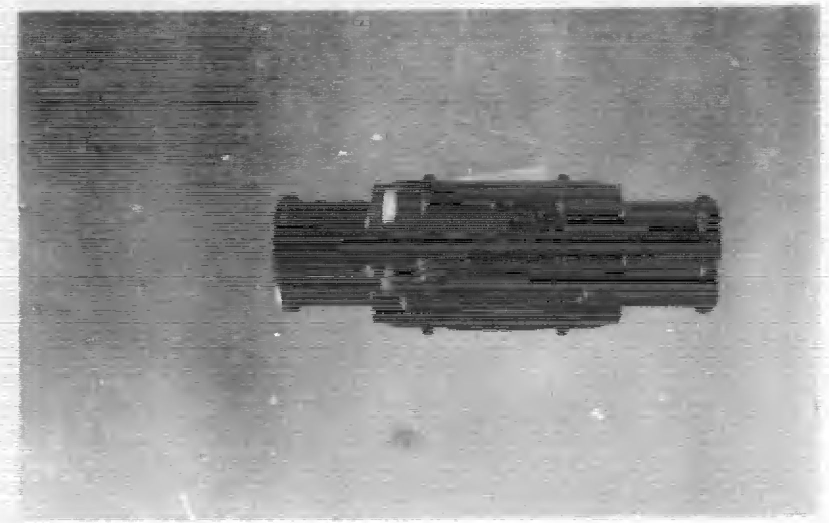
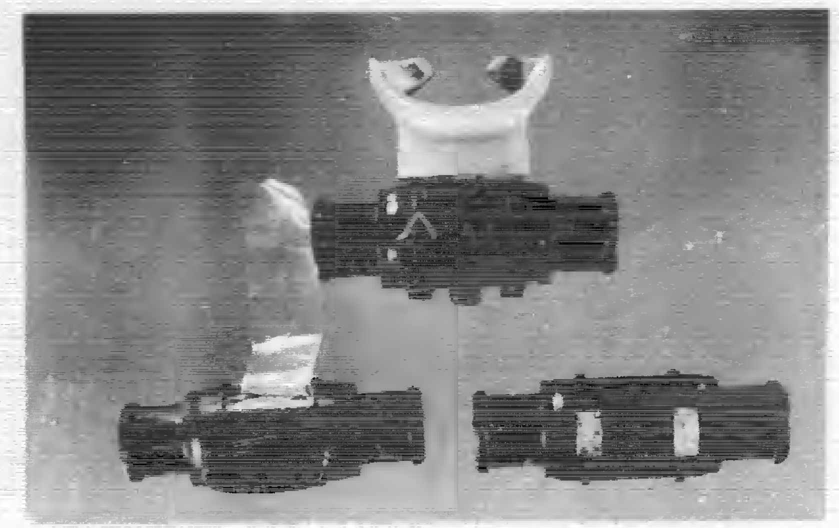
FIGURE 1 — NORTHILL "AIR LUNG" REGULATOR WITH MODIFIED DIAPHRAGM AND PLUGGED RESERVE DEVICE (GARRETT CORP. PHOTO. NR. 33700)



(A)



(B)



(C)

FIGURE 2 NORTHILL "ON-OFF" SCUBA MOUTHPIECES.

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(A) OLD STYLE WITH CENTER DOG.
(B) NEW STYLE WITH LEFT SIDE DOG.
(C) OLD STYLE AT TOP, TWO VIEWS. OF NEW STYLE AT BOTTOM.

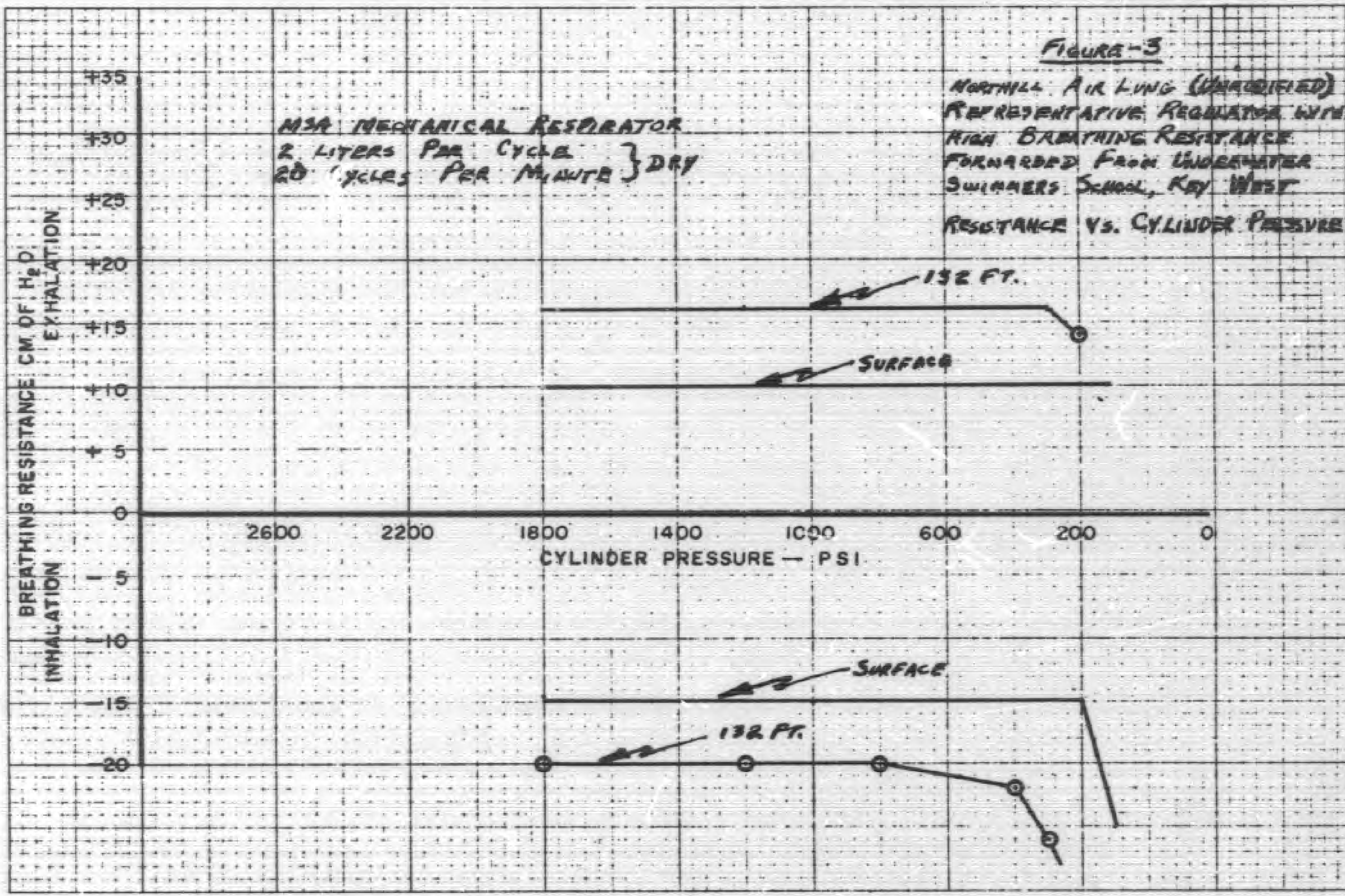


FIGURE-3
NORTHILL AIR LUNG (UNMODIFIED)
REPRESENTATIVE REGULATOR WITH
HIGH BREATHING RESISTANCE
FORWARDED FROM UNDERWATER
SWIMMERS SCHOOL, KEY WEST
RESISTANCE VS. CYLINDER PRESSURE
MSA MECHANICAL RESPIRATOR
2 LITERS PER CYCLE
20 CYCLES PER MINUTE } DRY
BREATHING RESISTANCE CM. OF H_2O
INHALATION
EXHALATION
+35
+30
+25
+20
+15
+10
+5
0
-5
-10
-15
-20
2600
2200
1800
1400
1000
600
200
0
CYLINDER PRESSURE — PSI
132 FT.
SURFACE
SURFACE
132 FT.

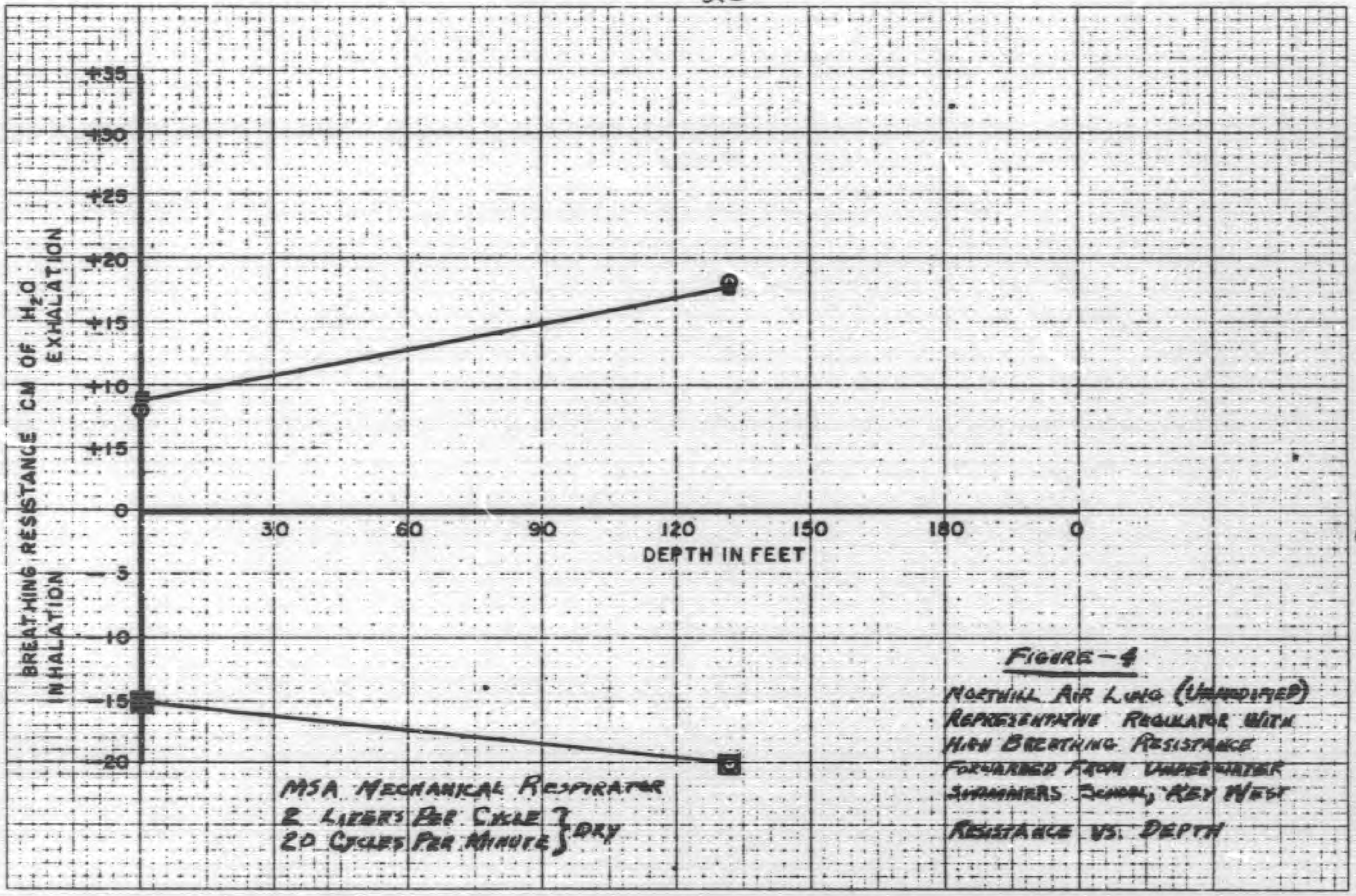


FIGURE – 4

NORTHILL AIR LUNG (UNMODIFIED)
REPRESENTATIVE REGULATOR WITH
HIGH BREATHING RESISTANCE
FORWARDED FROM UNDERWATER
SWIMMERS SCHOOL, KEY WEST

RESISTANCE VS. DEPTH

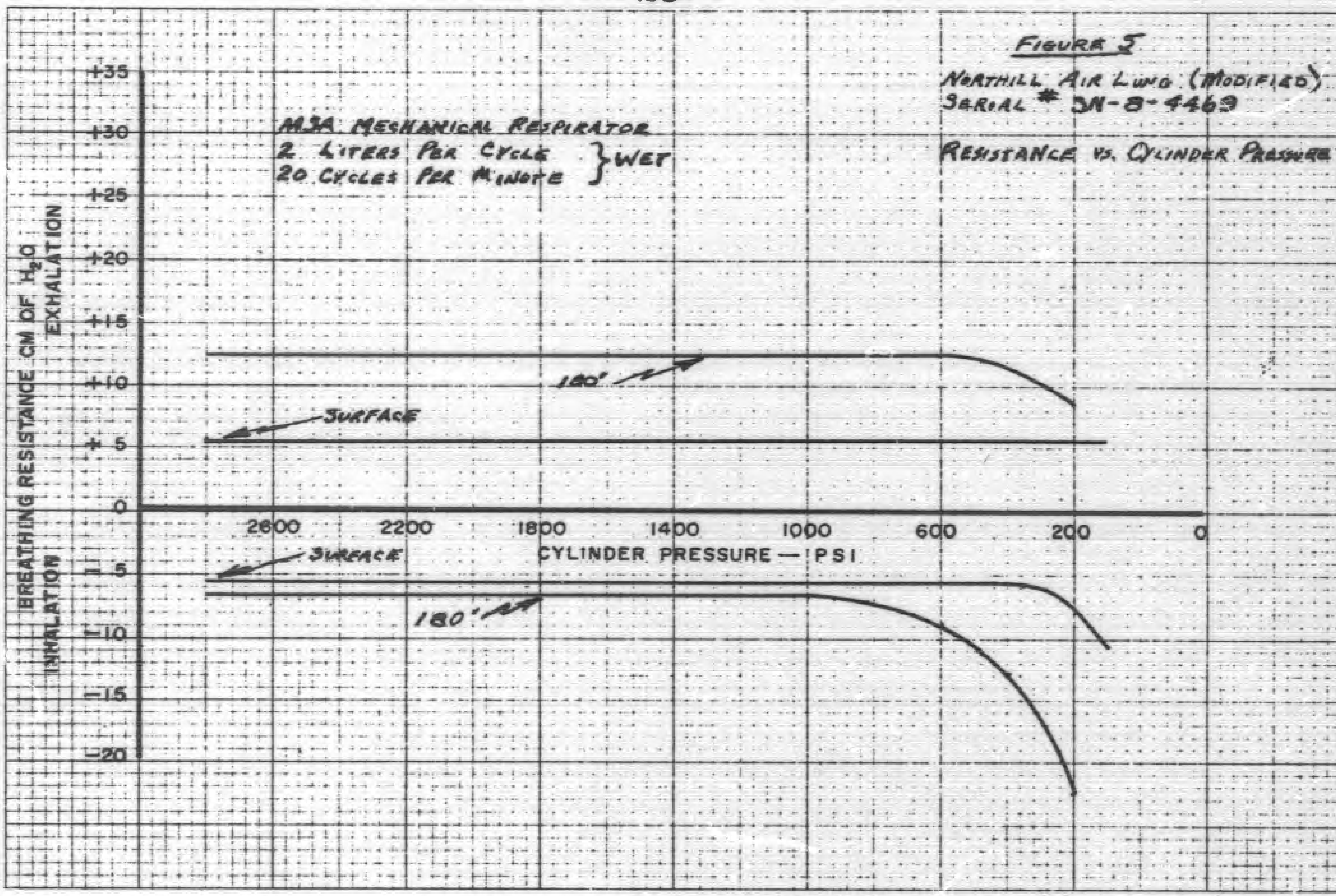


FIGURE 5
NORTHILL AIR LUNG (MODIFIED)
SERIAL # 3N-8-4469
RESISTANCE VS. CYLINDER PRESSURE
MSA MECHANICAL RESPIRATOR
2 LITERS PER CYCLE
20 CYCLES PER MINUTE
WET
BREATHING RESISTANCE CM OF H2O
EXHALATION
INHALATION
+35
+30
+25
+20
+15
+10
+5
0
-5
-10
-15
-20
SURFACE
180'
SURFACE
180'
2600
2200
1800
1400
1000
600
200
0
CYLINDER PRESSURE — PSI

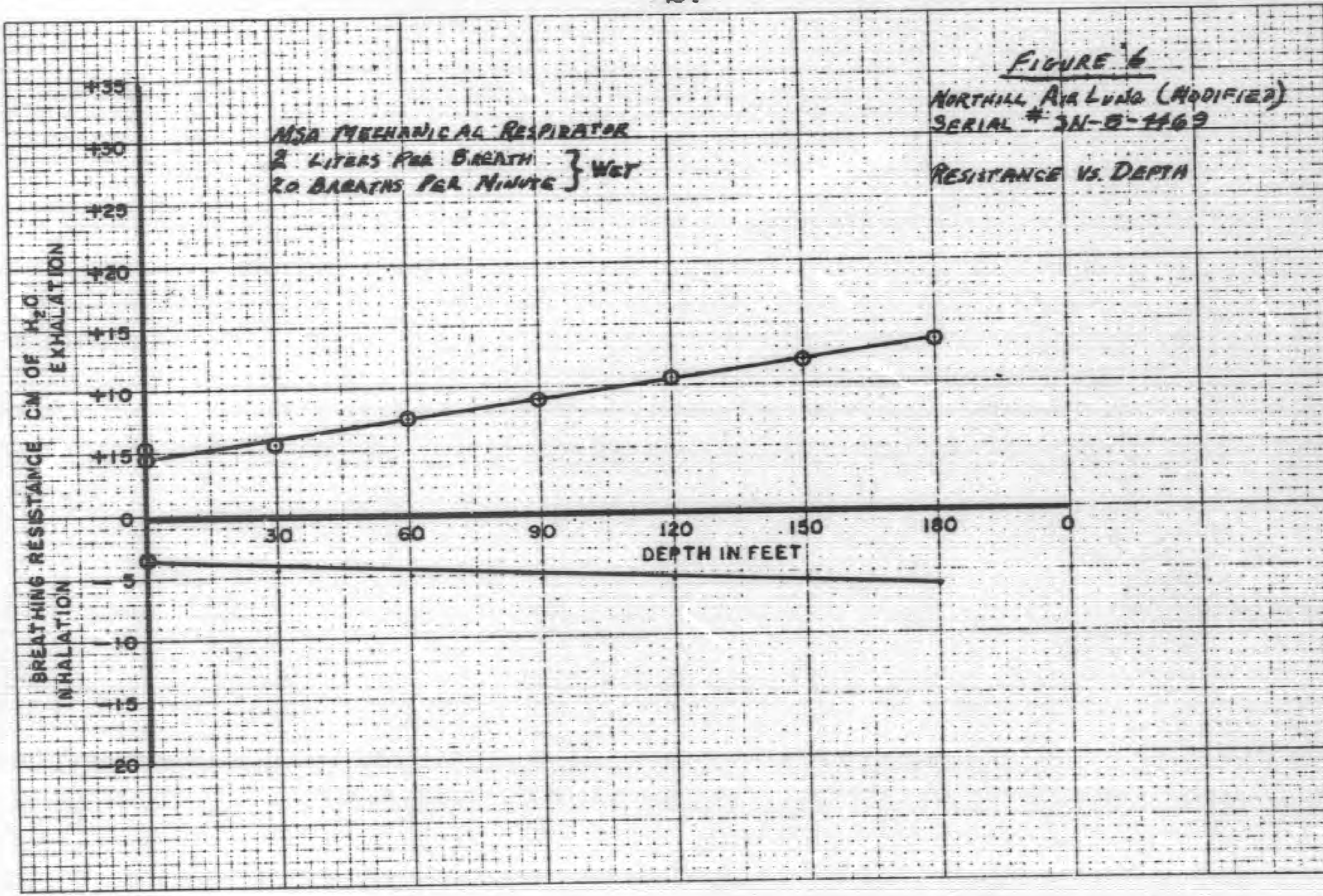


FIGURE 6
NORTHILL AIR LUNG (MODIFIED)
SERIAL # 3N-8-4469
RESISTANCE VS. DEPTH
MSA MECHANICAL RESPIRATOR
2 LITERS PER BREATH
20 BREATHS PER MINUTE
WET
BREATHING RESISTANCE CM OF H_2O
INHALATION
EXHALATION
+35
+30
+25
+20
+15
+10
+15
0
−5
−10
−15
−20
30
60
90
120
150
180
0
DEPTH IN FEET

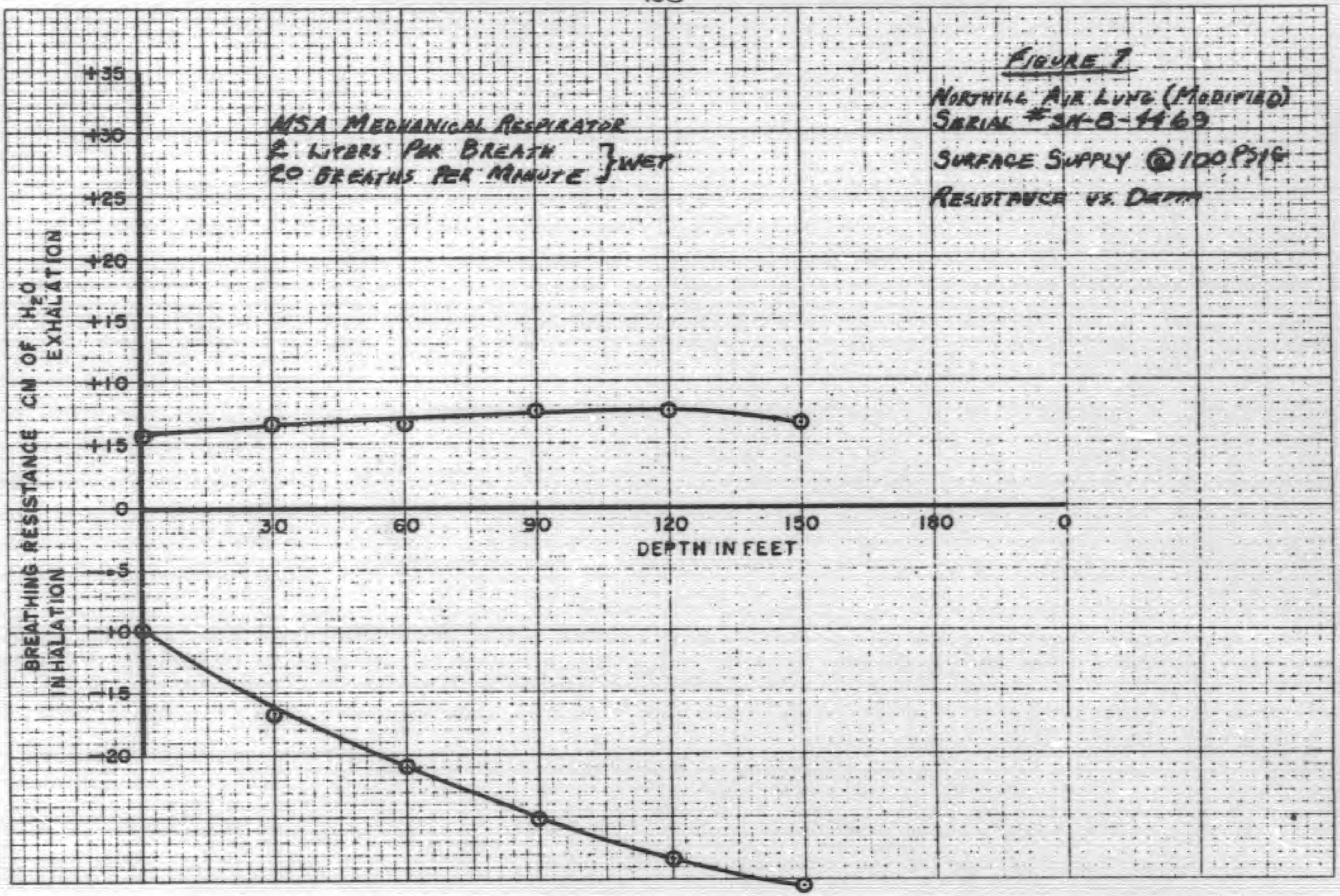


FIGURE 7

NORTHILL AIR LUNG (MODIFIED)
SERIAL #3H-8-4469

SURFACE SUPPLY @ 100 PSIG

RESISTANCE VS. DEPTH

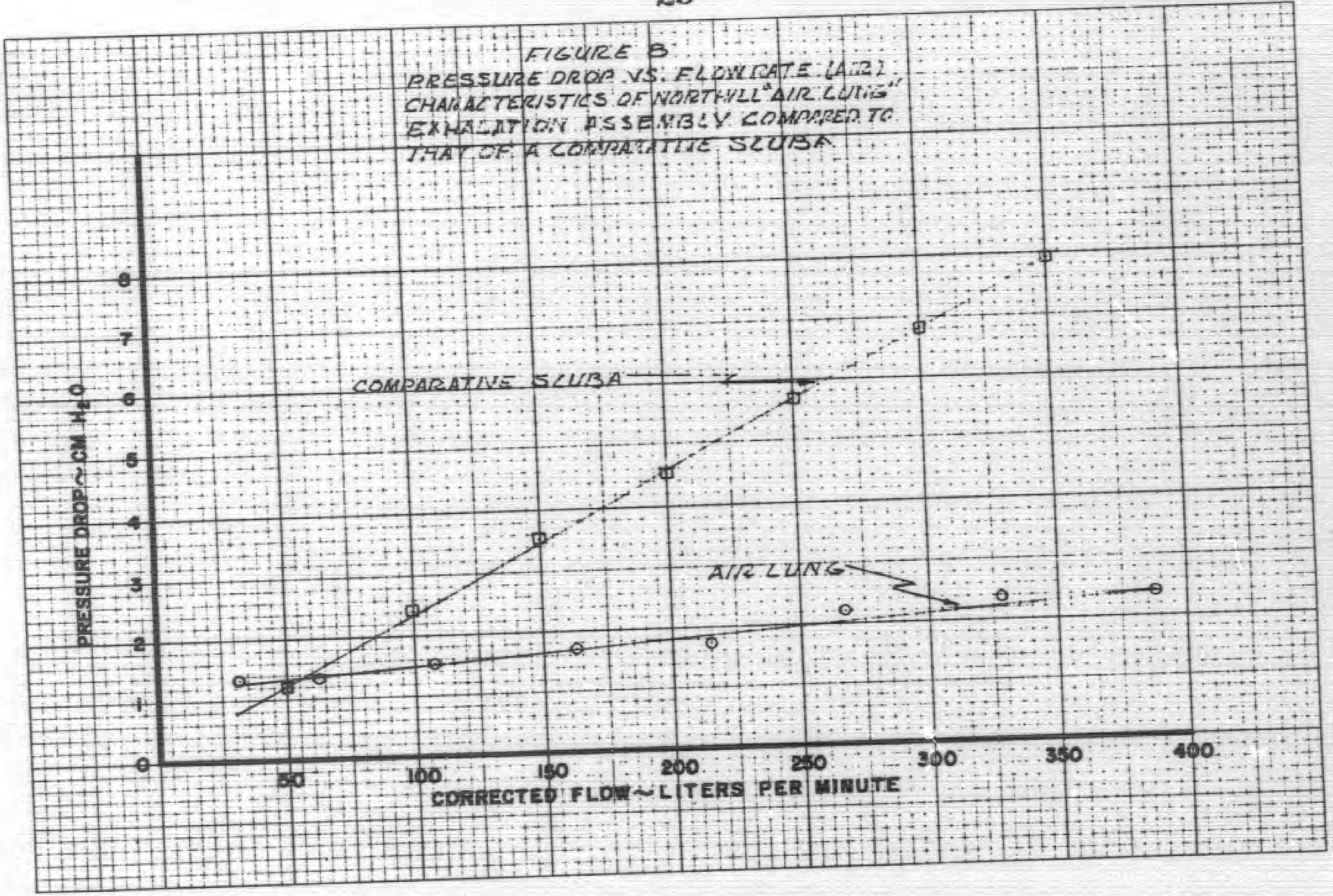
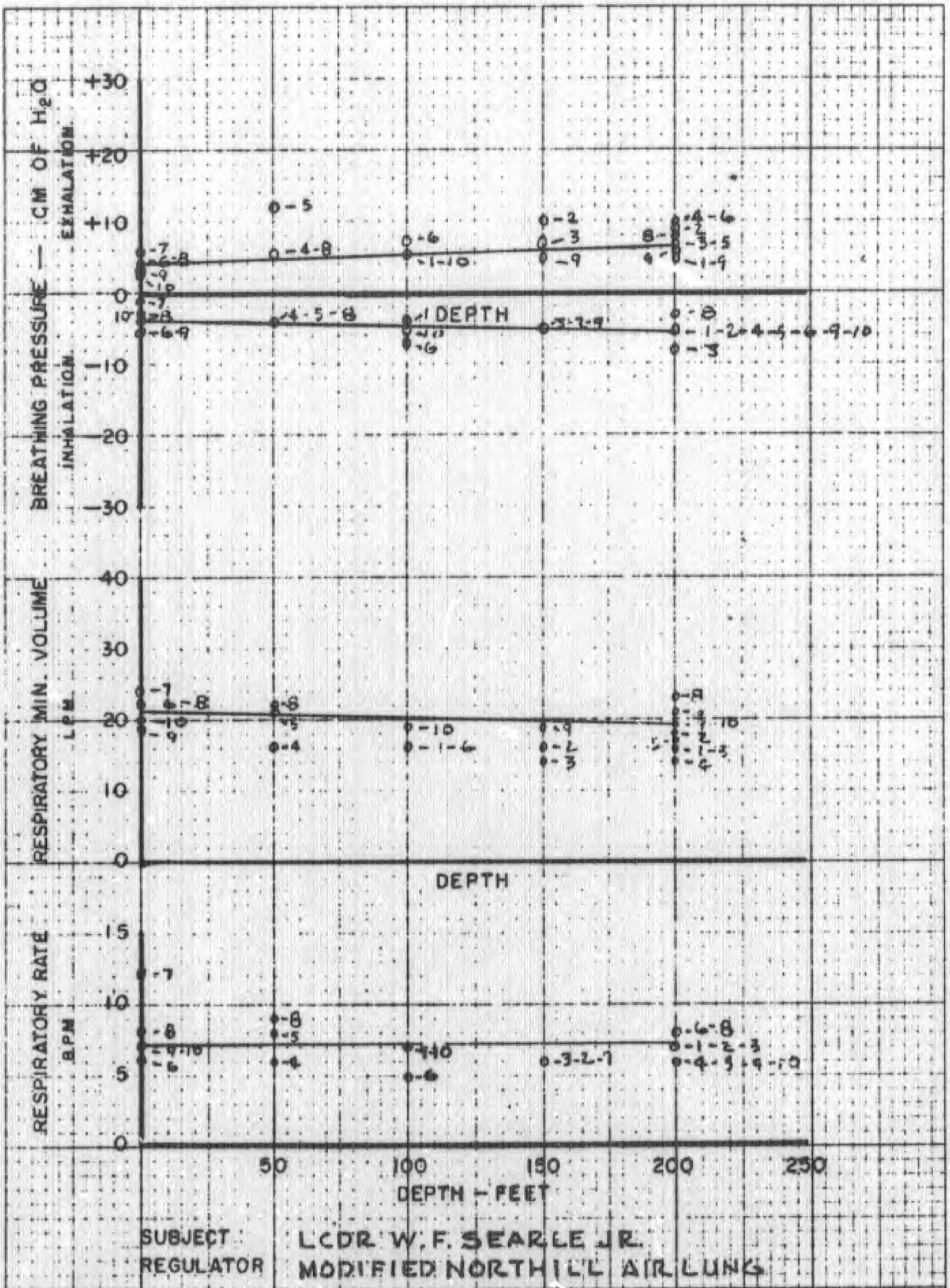
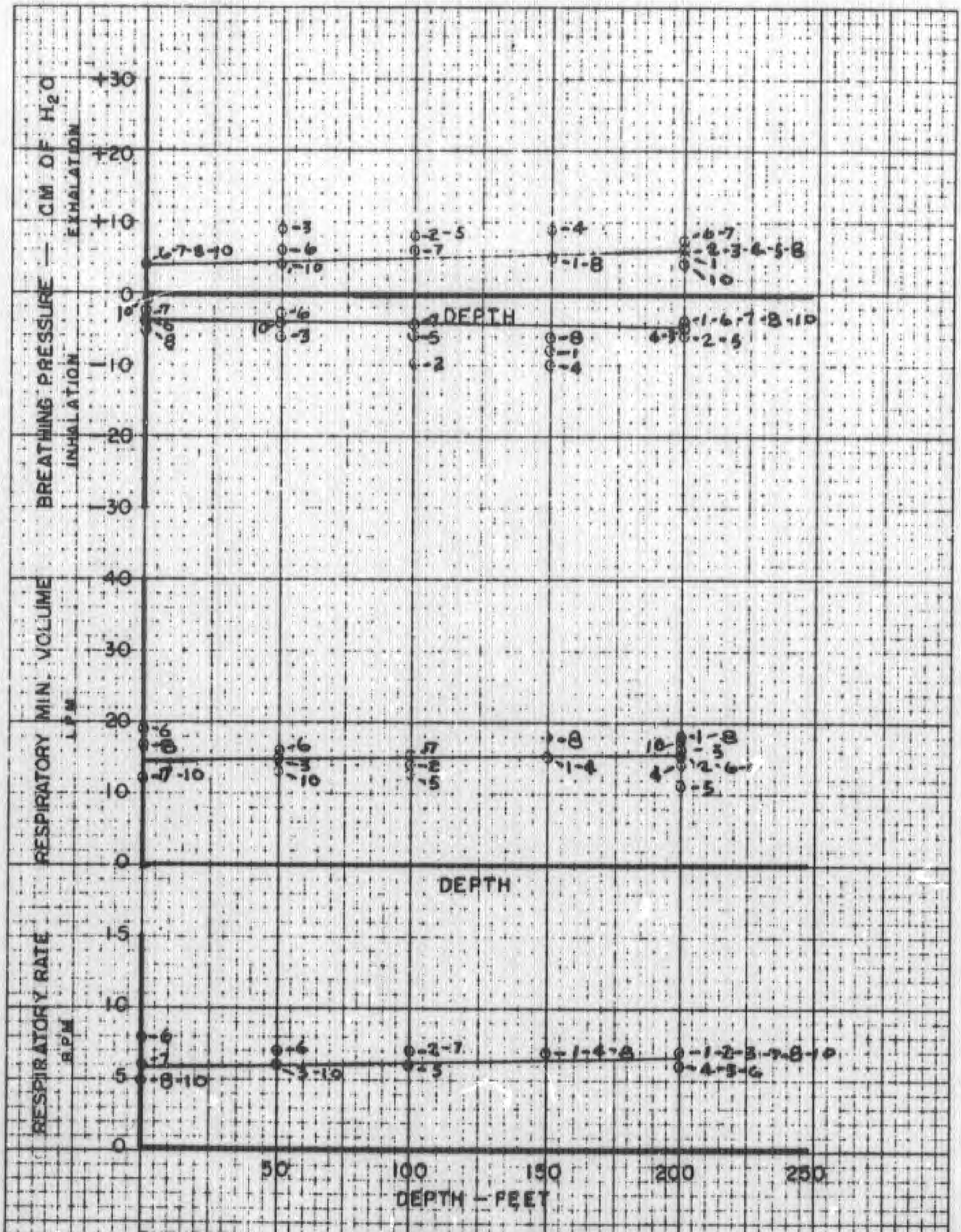
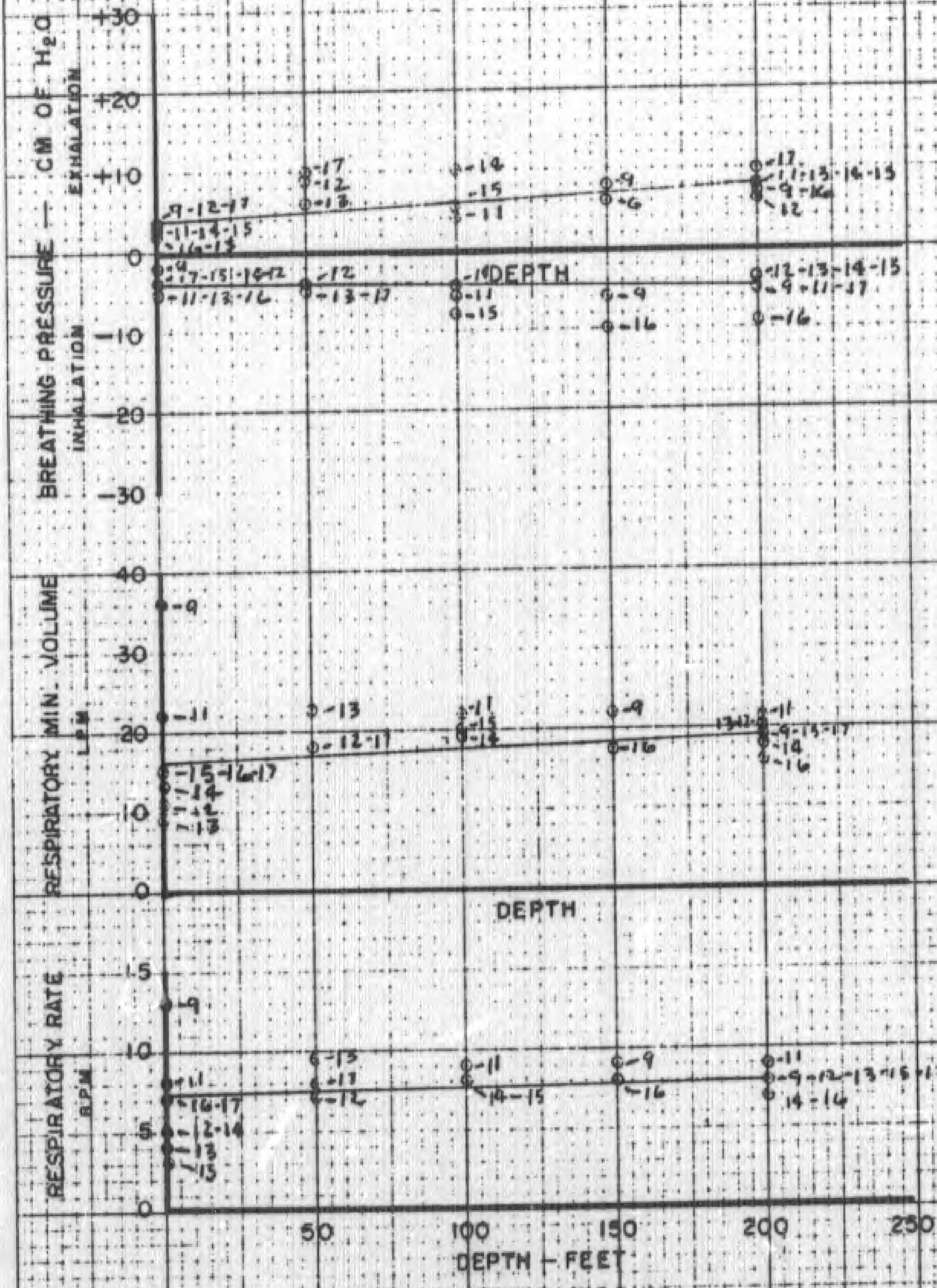


FIGURE 8
PRESSURE DROP VS. FLOW RATE (AIR) CHARACTERISTICS OF NORTHILL "AIR LUNG" EXHALATION ASSEMBLY COMPARED TO THAT OF A COMPARATIVE SCUBA


BREATHING PRESSURE — CM OF H_2O
EXHALATION
INHALATION
+30
+20
+10
0
-10
-20
-30
DEPTH
RESPIRATORY MIN. VOLUME
LPM
40
30
20
10
0
DEPTH
RESPIRATORY RATE
BPM
15
10
5
0
50
100
150
200
250
DEPTH – FEET
SUBJECT LCDR W. F. SEARLE JR.
REGULATOR MODIFIED NORTHILL AIR LUNG
FINS AQUAMATIC
WORK RATE TRAPEZE PULL 5
SCHEDULE BALANCE & READ AT SURFACE, 5 MIN AT 200 FT., 5 MIN AT INTERMEDIATE DEPTH.
FIGURE 9

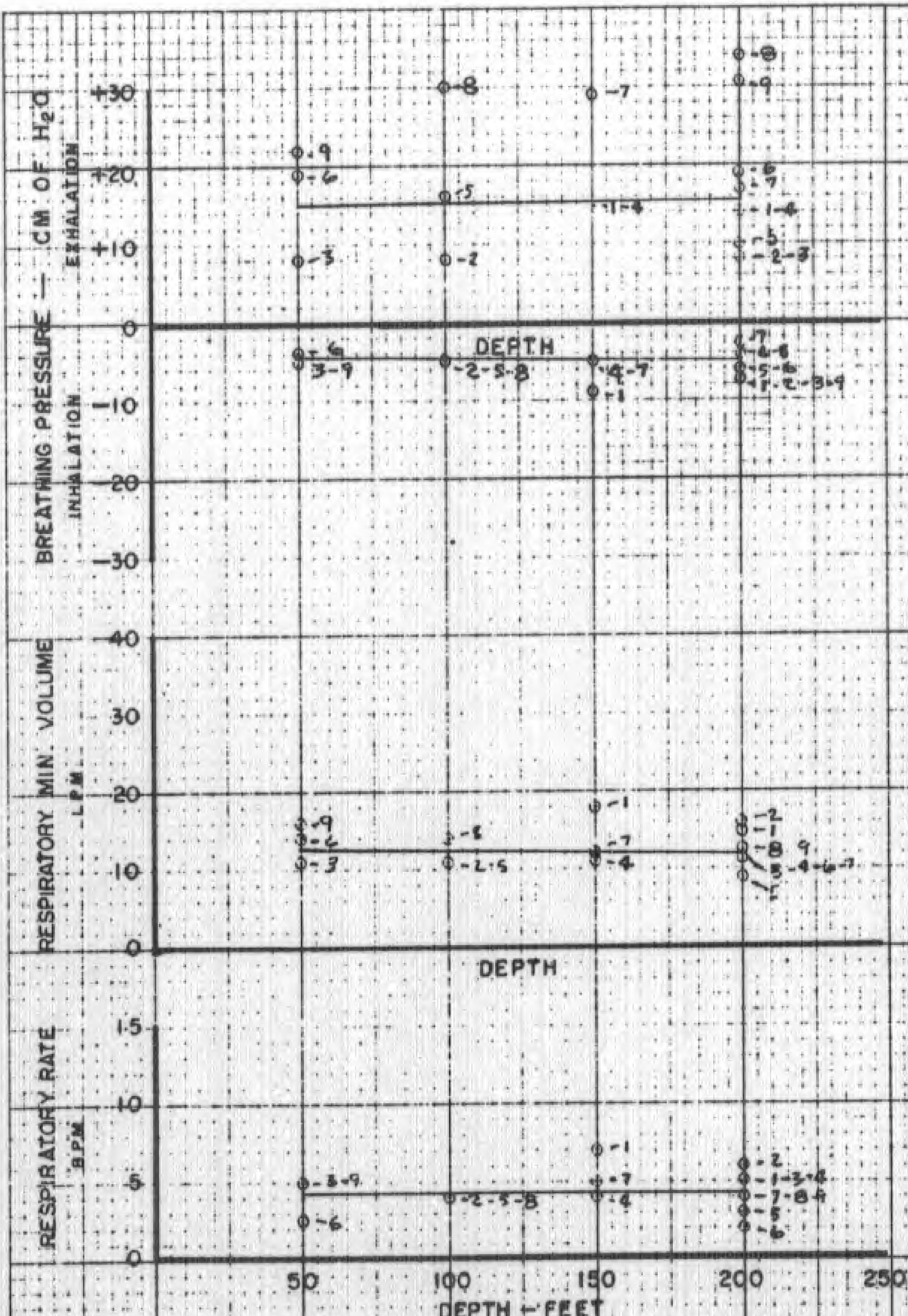

BREATHING PRESSURE — CM OF H_2O
EXHALATION
INHALATION
RESPIRATORY MIN. VOLUME
LPM
RESPIRATORY RATE
RPM
DEPTH
DEPTH
DEPTH — FEET
SUBJECT: LT. P. G. LINAWEAVER (MC)
REGULATOR: MODIFIED NORTHILL AIRLUNG
FINS: CRESSI
WORK RATE: TRAPEZE PULL
SCHEDULE: BALANCE & READ AT SURFACE, 5 MIN. AT 200 FT., 5 MIN AT INTERMEDIATE DEPTH.
FIGURE 14



SUBJECT LT. P.G. LINAWEAVER (MC)
REGULATOR MODIFIED NORTHILL AIR LUNG

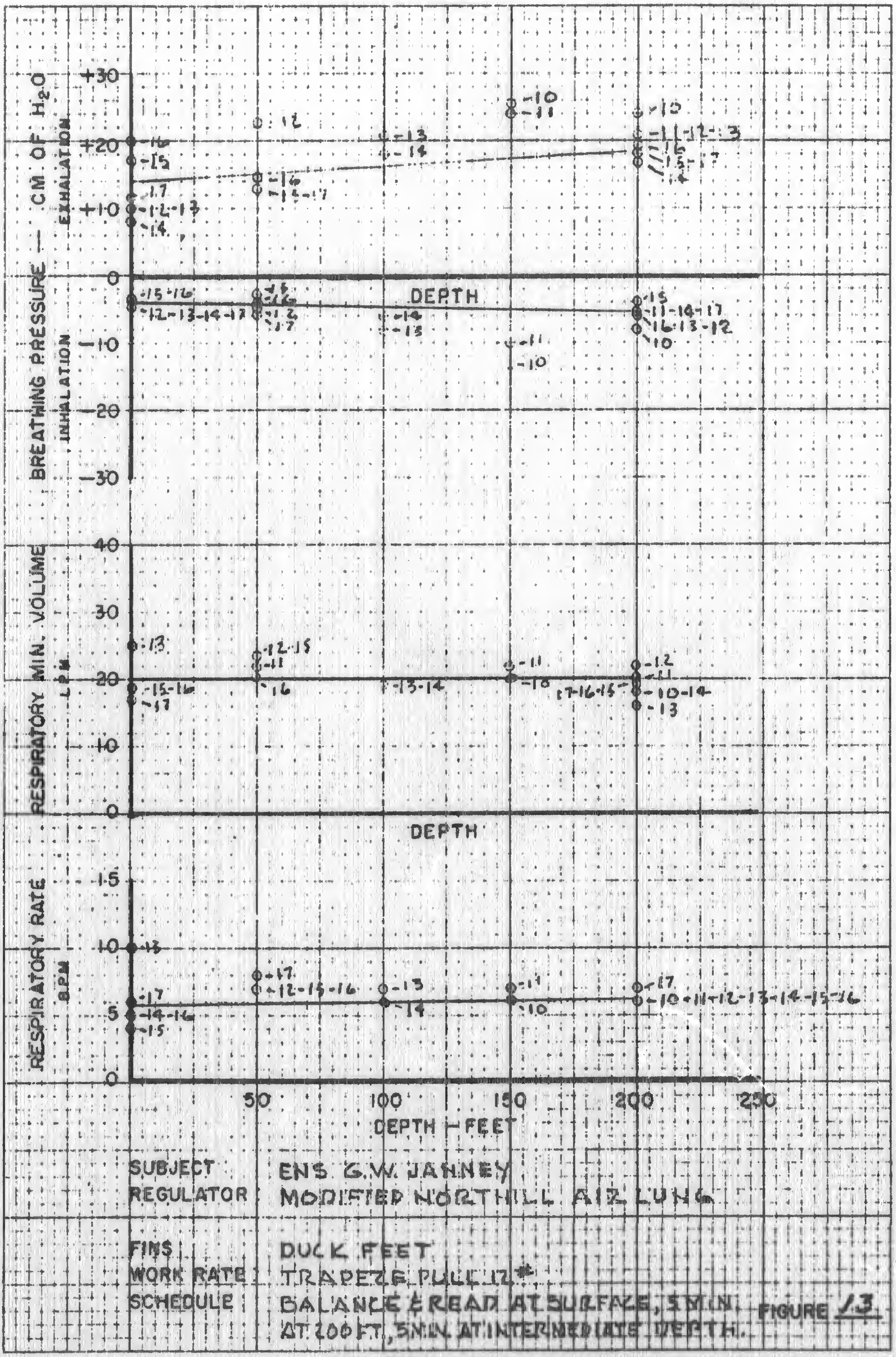
FINS CRESSI
WORK RATE TRAPEZE PULL 12
SCHEDULE BALANCE BREAD AT SURFACE, 5 MIN. AT 200 FT., 5 MIN. AT INTERMEDIATE DEPTH.

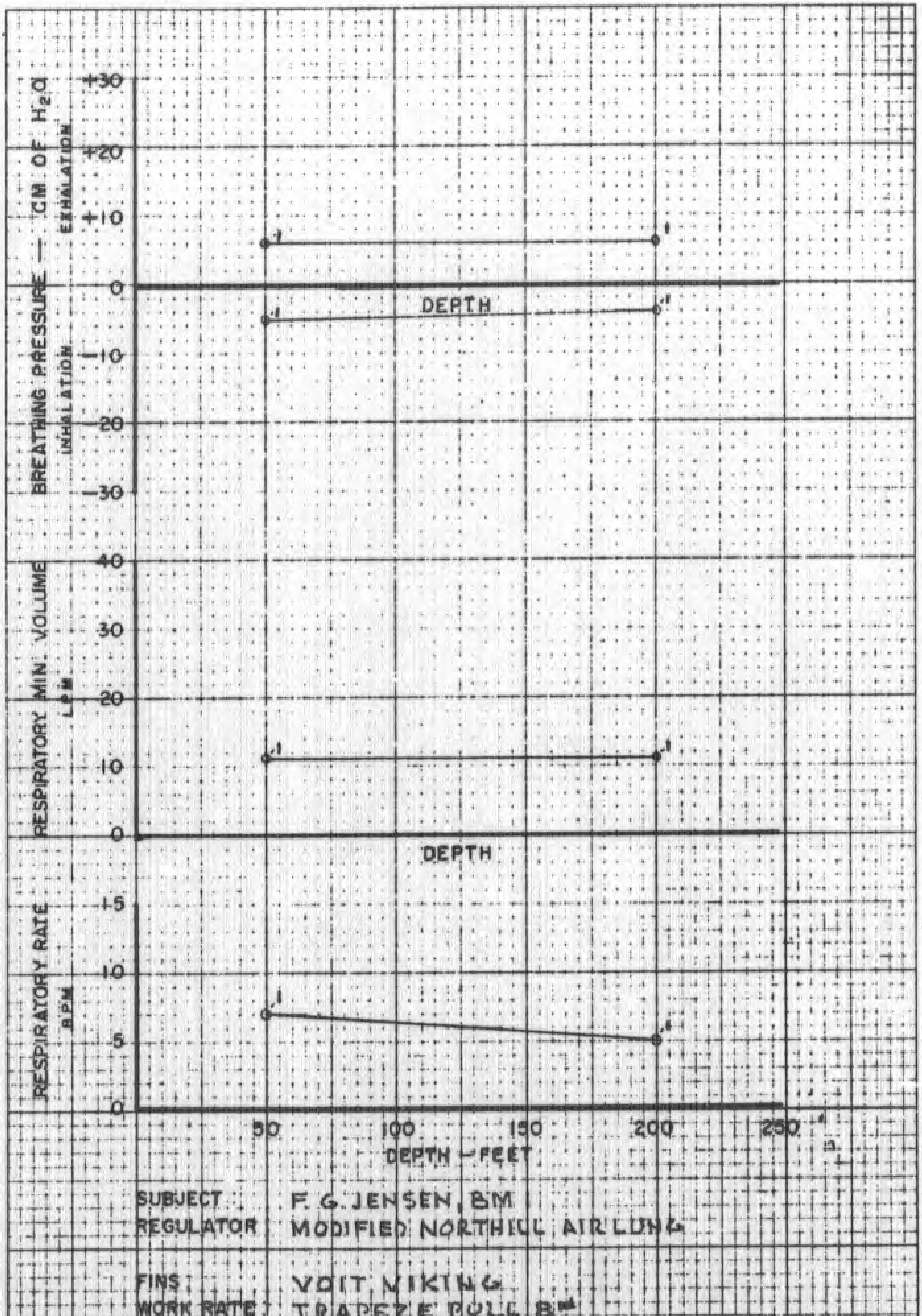
FIGURE 11

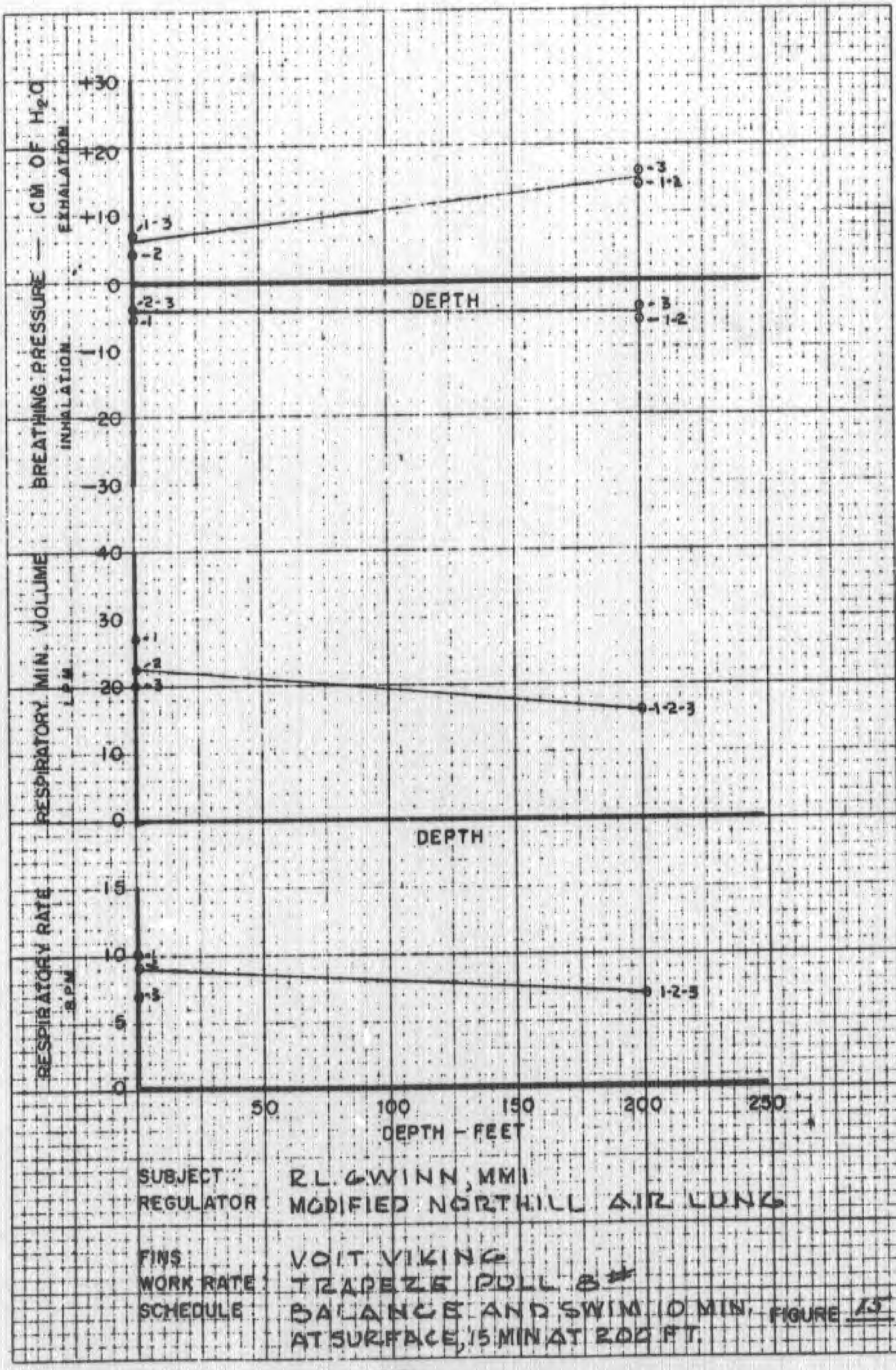


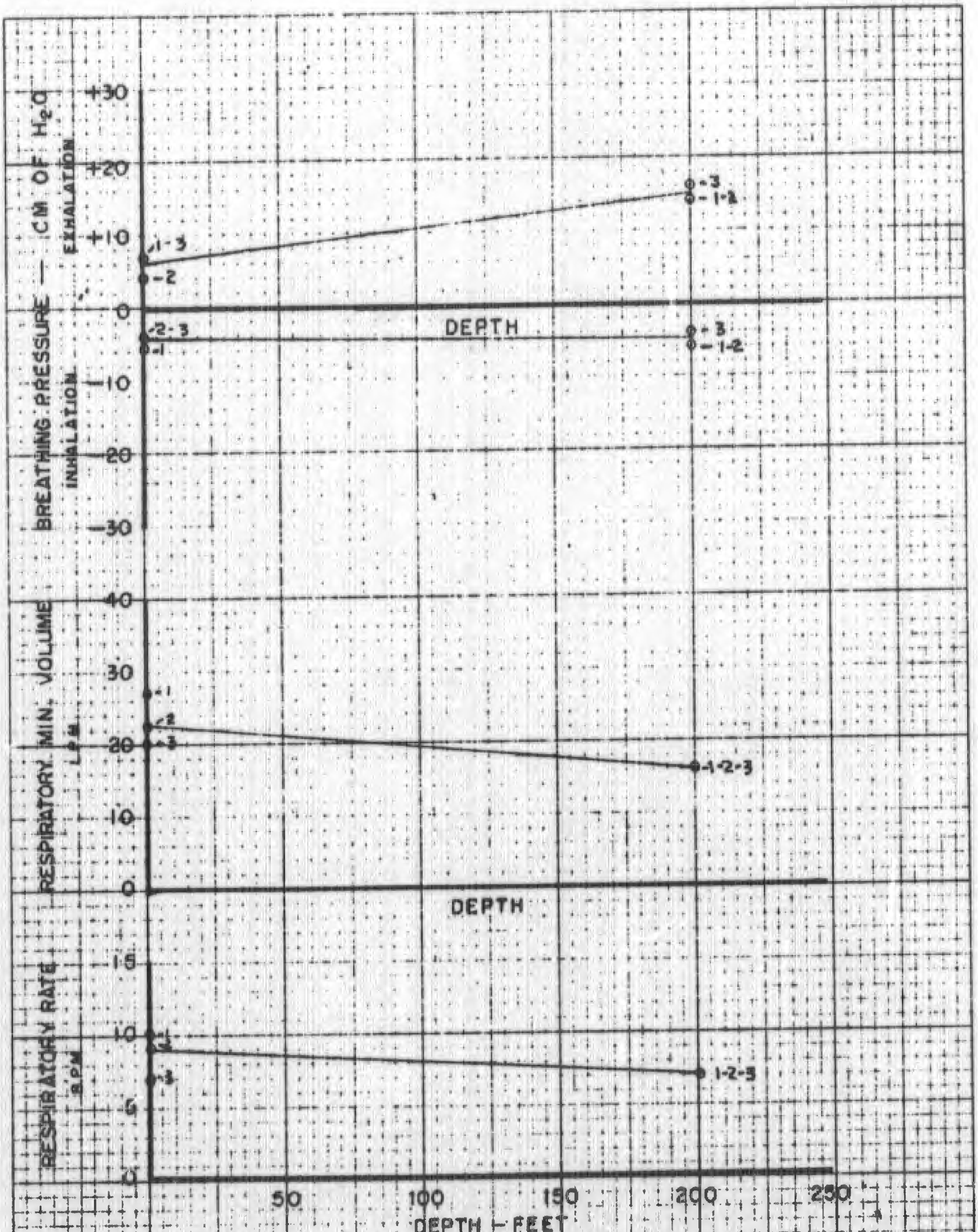
SUBJECT	ENS. G. M. JANNEY
REGULATOR	MODIFIED NORTHILL AIR LUNG
FINS	DUCK FEET
WORK RATE	TRAPEZE PULL 8"
SCHEDULE	BALANCE AT SURFACE, 5 MIN AT 200 FT, 5 MIN AT INTERMEDIATE DEPTH

FIGURE 12


BREATHING PRESSURE — CM OF H_2O
EXHALATION
INHALATION
DEPTH
RESPIRATORY MIN. VOLUME
LPM
DEPTH
RESPIRATORY RATE
BPM
DEPTH — FEET
SUBJECT ENS G.W. JANNEY
REGULATOR MODIFIED NORTHILL AIR LUNG
FINS DUCK FEET
WORK RATE TRAPEZE PULL 12#
SCHEDULE BALANCE & READ AT SURFACE, 5 MIN. AT 200 FT, 5 MIN. AT INTERMEDIATE DEPTH.
FIGURE 13


BREATHING PRESSURE — CM OF H_2O
EXHALATION
INHALATION
+30
+20
+10
0
-10
-20
-30
DEPTH
RESPIRATORY MIN. VOLUME
LPM
40
30
20
10
0
DEPTH
RESPIRATORY RATE
RPM
15
10
5
0
50
100
150
200
250
DEPTH — FEET
SUBJECT : F. G. JENSEN, BM
REGULATOR : MODIFIED NORTHILL AIR LUNG
FINS : VOIT VIKING
WORK RATE : TRAPEZE PULL 8
SCHEDULE : BALANCE AT SURFACE, 5 MIN. AT 200 FT., 5 MIN. AT INTERMEDIATE DEPTH
FIGURE 14


BREATHING PRESSURE — CM OF H_2O
EXHALATION
INHALATION
RESPIRATORY MIN. VOLUME
LPM
RESPIRATORY RATE
RPM
+30
+20
+10
0
-10
-20
-30
40
30
20
10
0
15
10
5
0
DEPTH
DEPTH
1-3
-2
-3
1-2
-2-3
-1
-3
1-2
-1
-2
-3
1-2-3
-1
-2
-3
1-2-3
50
100
150
200
250
DEPTH - FEET
SUBJECT R.L. GWINN, MM1
REGULATOR MODIFIED NORTHILL AIR LUNG
FINS VOIT VIKING
WORK RATE TRAPEZE PULL 8#
SCHEDULE BALANCE AND SWIM 10 MIN AT SURFACE, 15 MIN AT 200 FT.
FIGURE 15



SUBJECT: R.L. GWINN, MM1
REGULATOR: MODIFIED NORTHILL AIR LUNG

FINS: VOIT VIKING
WORK RATE: TRAPEZE PULL 8 #
SCHEDULE: BALANCE AND SWIM 10 MIN. AT SURFACE, 15 MIN AT 200 FT.

FIGURE 15

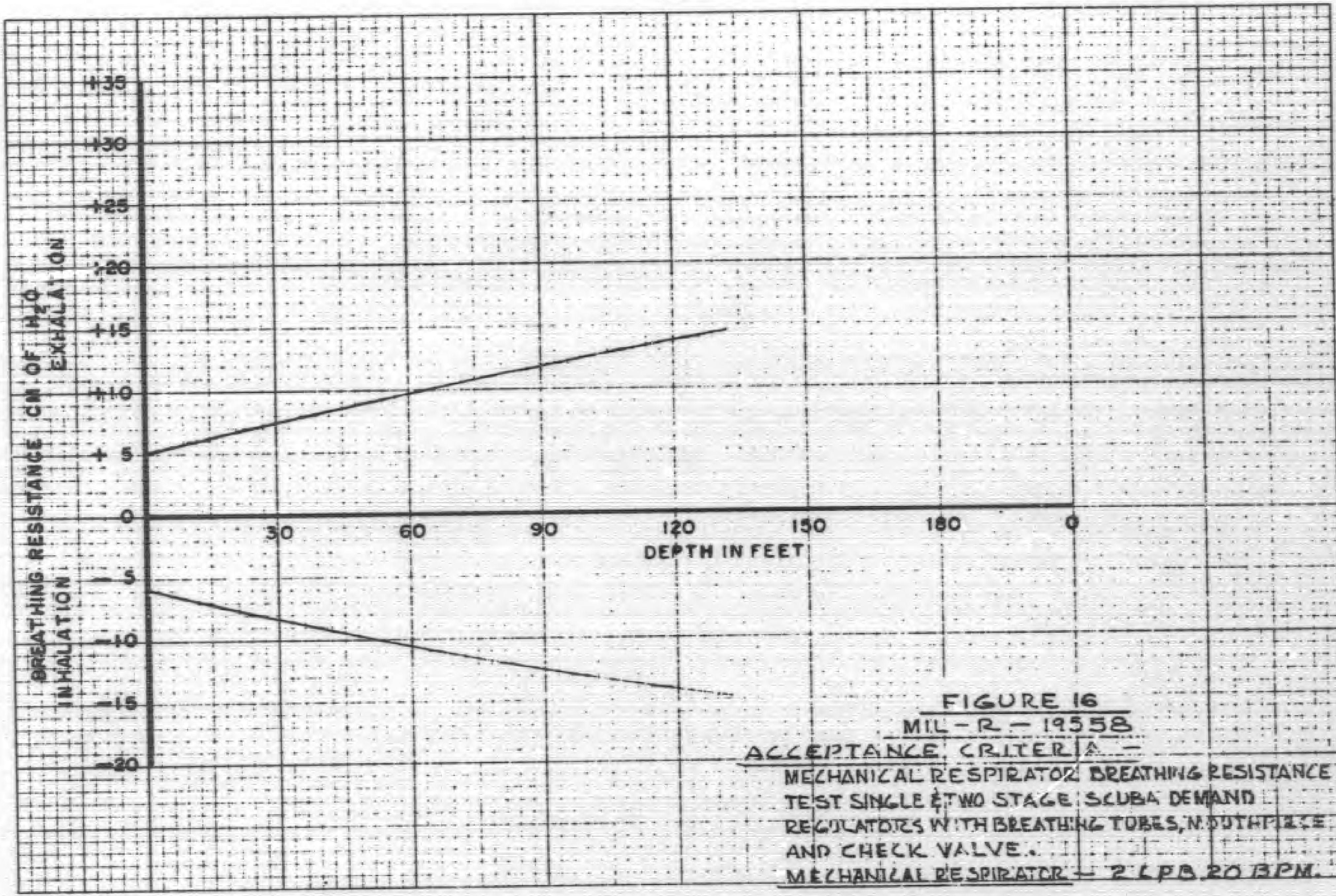


FIGURE 16
MIL-R-19558
ACCEPTANCE CRITERIA -
MECHANICAL RESPIRATOR BREATHING RESISTANCE TEST SINGLE & TWO STAGE SCUBA DEMAND REGULATORS WITH BREATHING TUBES, MOUTHPIECE AND CHECK VALVE.
MECHANICAL RESPIRATOR - 2 LPB 20 BPM.