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EVALUATION OF SHERWOOD SELPAC SRB-4100J AND SRB-3000 OPEN CIRCU--ETC(U)

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NAVY EXPERIMENTAL DIVING UNIT

REPORT 5-77

EVALUATION OF SHERWOOD SELPAC SRB-4100J AND SRB-3000 OPEN CIRCUIT SCUBA REGULATORS

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UNITED STATES NAVY

PANAMA CITY FLORIDA 32407

DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
Panama City, Florida 32407

NAVY EXPERIMENTAL DIVING UNIT REPORT

5-77

EVALUATION OF SHERWOOD SELPAC SRB-4100J AND SRB-3000 OPEN CIRCUIT SCUBA REGULATORS

by

James R. Middleton

April 1977

Approved for public release; distribution unlimited.

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The Sherwood Selpac SRB-4100J and SRB-3000 open circuit scuba regulators were tested by the Navy Experimental Diving Unit in accordance with military specification MIL-R-24169A. Test results indicate that the SRB-4100J regulator meets mil spec requirements and is recommended for Navy approval. However, due to excessive inhalation resistance, the SRB-3000 regulator does not meet mil spec requirements and is therefore not recommended for Navy approval.

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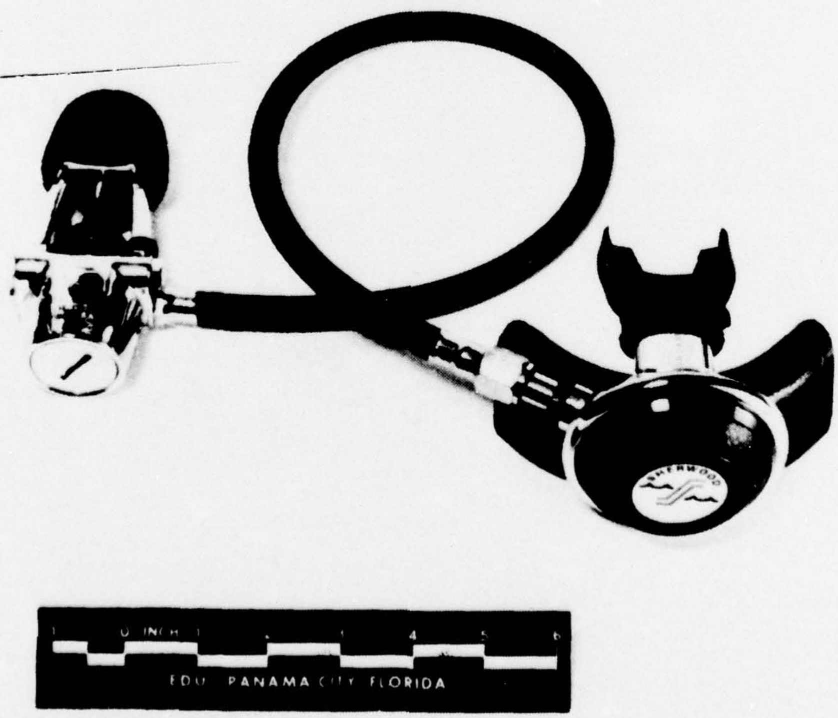
LIST OF ABBREVIATIONS

ABBREVIATION	DEFINITION
BPM	breaths per minute
cm H_2O	centimeters of water pressure (differential)
fsw	feet of seawater
kg·m/l	breathing work in kilogram meters per liter ventilation
mil spec	military specification MIL-R-24169A
NEDU	Navy Experimental Diving Unit
O/B	over bottom pressure
psig	pounds per square inch gauge
ΔP	pressure differential
RMV	respiratory minute volume in liters per minute

ABSTRACT

The Sherwood Selpac SRB-4100J and SRB-3000 open circuit scuba regulators were tested by NEDU in accordance with mil spec MIL-R-24169A. Test results indicate that the SRB-4100J regulator meets mil spec requirements, and it is recommended for Navy approval. However, due to excessive inhalation resistance, the SRB-3000 regulator does not meet mil spec requirements and is therefore not recommended for Navy approval.

SHERWOOD SELPAC SRB-4100J REGULATOR



SHERWOOD SELPAC SRB-3000 REGULATOR

INTRODUCTION

In October 1976, NEDU, by direction of the Supervisor of Diving (Reference 1), tested two single hose demand scuba regulators produced by Sherwood Selpac Corporation, 120 Church Street, Lockport, New York 14094. The regulators tested were models SRB-4100J and SRB-3000.

Unmanned tests of each regulator were performed in accordance with mil spec MIL-R-24169A (Reference 2). Both regulators were also tested at respiratory minute volumes to simulate light and heavy diver work rates. Measurements of the breathing work required to operate the regulators were obtained and were used as supplementary guides for evaluation.

Normally, regulator first-stage performance is monitored, but Sherwood O-ring design on the first stage low-pressure ports prevented interfacing with NEDU test equipment.

TEST PROCEDURE

TEST PLAN

In the plan followed during testing of the SRB-4100J and SRB-3000 regulators, a breathing machine was used to simulate respiration at various RMV's, representing light, moderate and heavy diver work rates. The chamber was pressurized at various depth increments to 300 fsw, and ΔP measurements were taken between the mouthpiece and ambient pressure. The various data and parameters that were controlled, measured, computed, and plotted are detailed below. The actual steps followed during the tests are presented in Appendix A, while the test equipment used is shown in the test setup in Figure 1 and is listed in Appendix B.

CONTROLLED PARAMETERS

The following parameters were controlled during the test.

1. Breathing rate/tidal volume
   a. 15 BPM/1.5 liters 22.50 RMV
   b. 20 BPM/2.0 liters 40.0 RMV
   c. 25 BPM/3.0 liters 75.0 RMV
2. Exhalation/inhalation time ratio: 1.10/1.00
3. Breathing waveform: modified sinusoid
4. Air supply pressure to first stage: 1000 psig at all depths except 0 fsw and 200 fsw where data will be taken at 1000 psig, 500 psig O/B and 200 psig O/B
5. Depth increment stops: 0 to 200 fsw in 33 fsw increments and 300 fsw

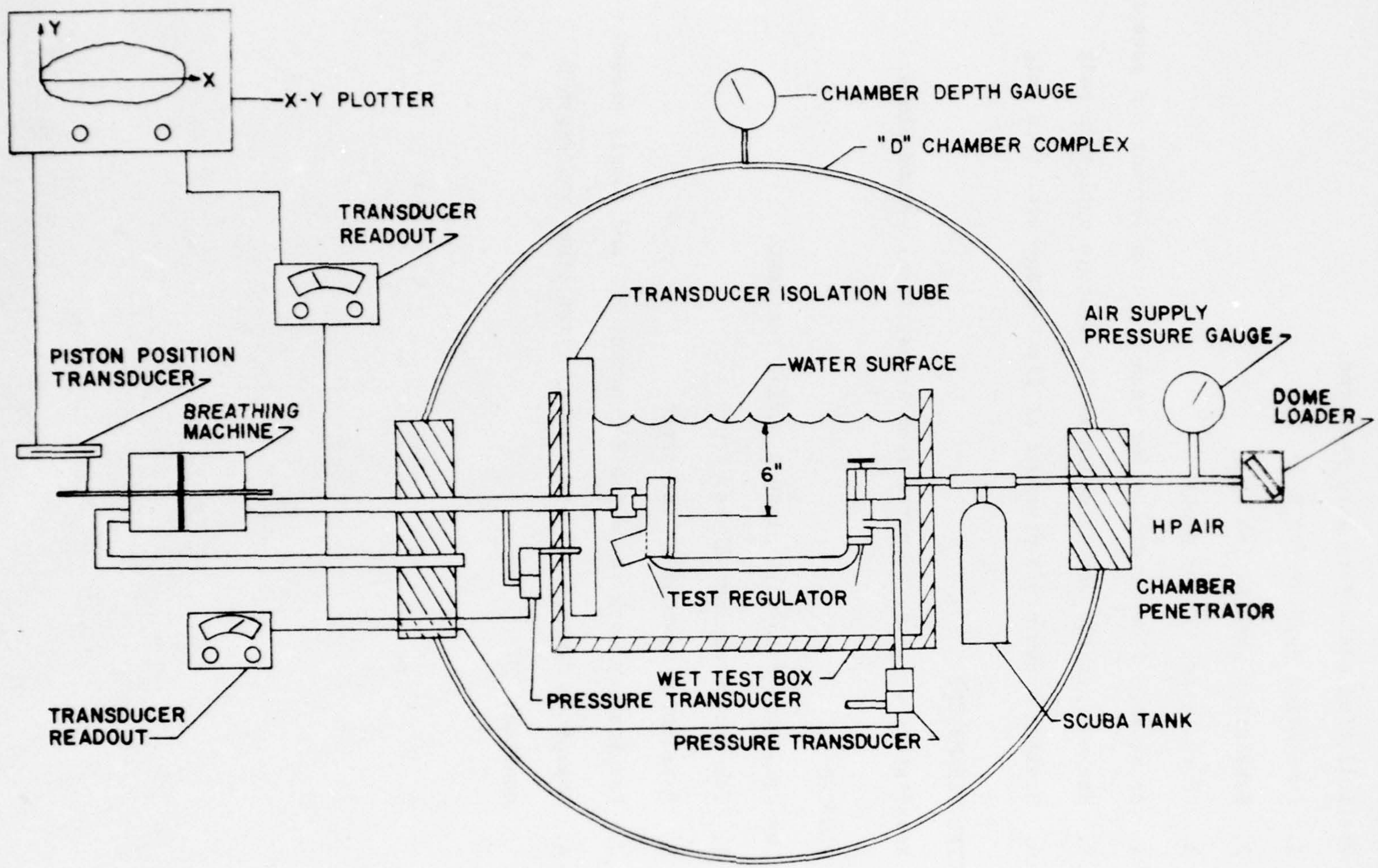


FIGURE 1. TEST SETUP
(SEE APPENDIX B FOR A COMPLETE DESCRIPTION OF EQUIPMENT.)

MEASURED PARAMETERS

The following parameters were measured.

1. Inhalation peak ΔP (cm H_2O)

2. Exhalation peak ΔP (cm H_2O)

3. ΔP vs. tidal volume plots

4. ΔP at zero flow condition for each depth on descent and ascent

5. Maximum dynamic O/B pressure at first-stage outlet in psig

6. Minimum dynamic O/B pressure at first-stage outlet in psig

COMPUTED PARAMETERS

Respiratory work was computed from ΔP vs. tidal volume plots.

DATA PLOTTED

The following data were plotted during the test.

1. Inhalation maximum ΔP vs. depth

2. Exhalation maximum ΔP vs. depth

3. Respiratory work vs. depth @ constant RMV and supply pressure

4. Change in dynamic O/B pressure at first stage vs. depth @ constant RMV

RESULTS

DESCRIPTION

The SRB-4100J regulator has a balanced piston first stage with four low-pressure ports and one high-pressure port for a submersible pressure gauge; this regulator also has a built-in, manual J-type reserve mechanism. The SRB-3000 has an unbalanced piston first stage, no reserve mechanism, three low-pressure ports and one high-pressure port. Both regulators have identical downstream-type second stages.

BREATHING RESISTANCE

During the test of the SRB-4100J and SRB-3000 regulators, breathing resistance was measured at three RMV's to simulate light, moderate and heavy work rates. Light work was measured at 22.5 RMV with a 1.5 liter tidal volume and 15 BPM; moderate work was measured at 40 RMV with a 2.0 liter tidal volume and 20 BPM; heavy work was measured at 75 RMV with a 3.0 liter tidal volume and 25 BPM. The mil spec calls for only a 40 RMV at 1000 psig supply pressure (Reference 2). However, the other RMV's were measured to obtain information on the full spectrum of regulator performance.

Breathing resistances plotted in Figures 2 through 7 are the maximum resistances measured, excluding cracking pressure, during one complete inhalation/exhalation cycle at a given depth and RMV. Air supply pressure to the first stage is 1000 psig. Resistance measurements were also taken at 500 psig O/B and 200 psig O/B supply pressure on the surface and at 200 fsw at each RMV. The mil spec does not require the 300 fsw data. However, this information was obtained to simulate regulator performance at extreme depths on mixed gas (HeO_2).

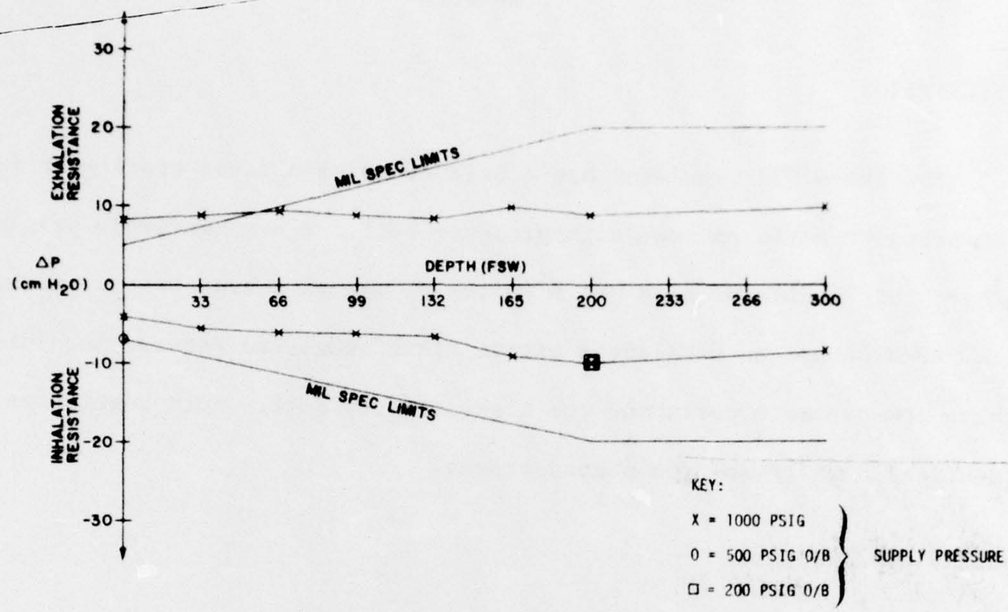


FIGURE 2. BREATHING RESISTANCE VS. DEPTH FOR SRB-4100J REGULATOR AT 15 BPM, 1.5 TIDAL VOLUME, 22.5 RMV (NOTE - RESERVE ON)

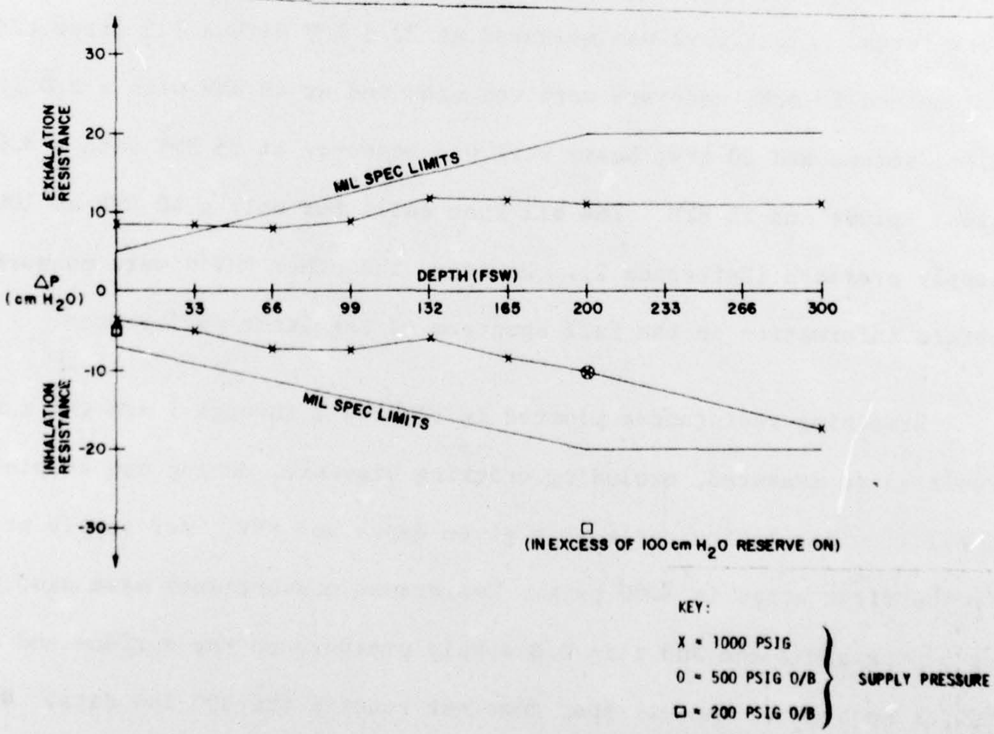


FIGURE 3. BREATHING RESISTANCE VS. DEPTH FOR SRB-4100J REGULATOR AT 20 BPM, 2.0 TIDAL VOLUME, 40 RMV--MIL-R-24169A REQUIREMENT (NOTE - RESERVE ON)

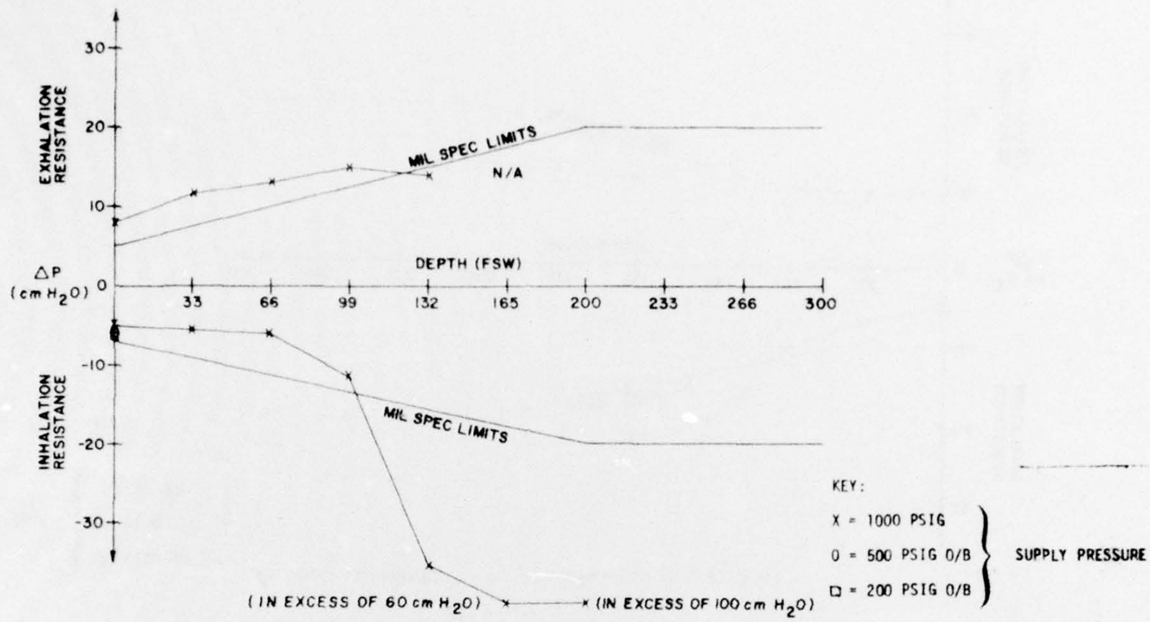


FIGURE 4. BREATHING RESISTANCE VS. DEPTH FOR SRB-4100J REGULATOR AT 25 BPM, 3.0 TIDAL VOLUME, 75 RMV (NOTE - RESERVE ON)

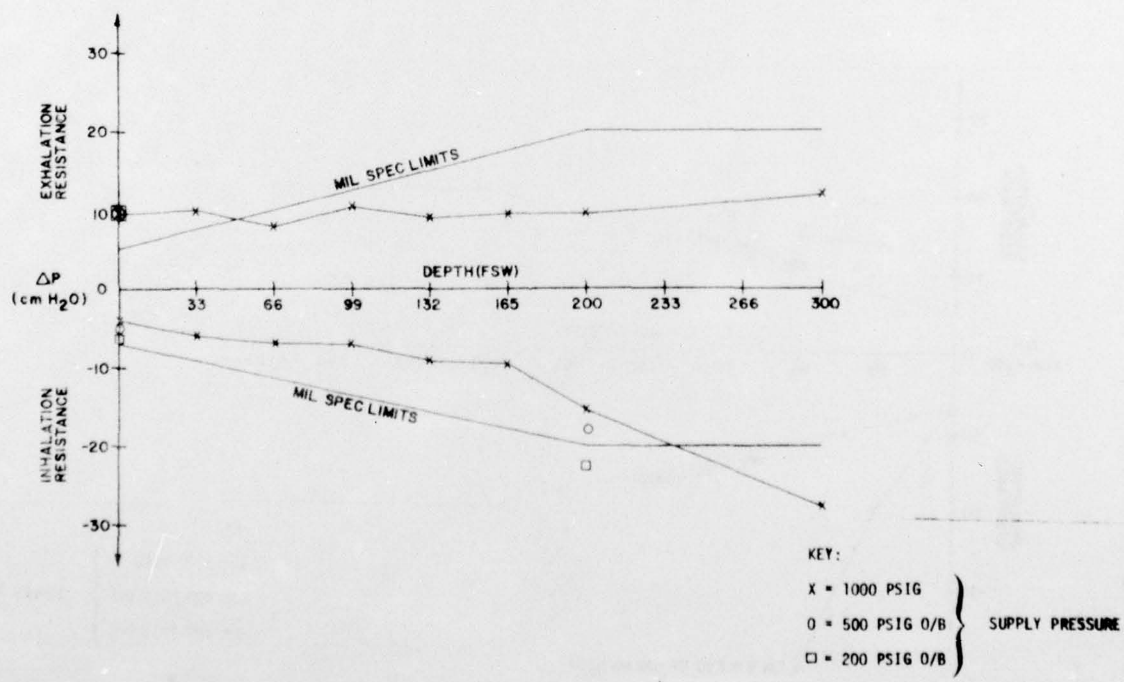


FIGURE 5. BREATHING RESISTANCE VS. DEPTH FOR SRB-3000 REGULATOR AT 15 BPM, 1.5 TIDAL VOLUME, 22.5 RMV

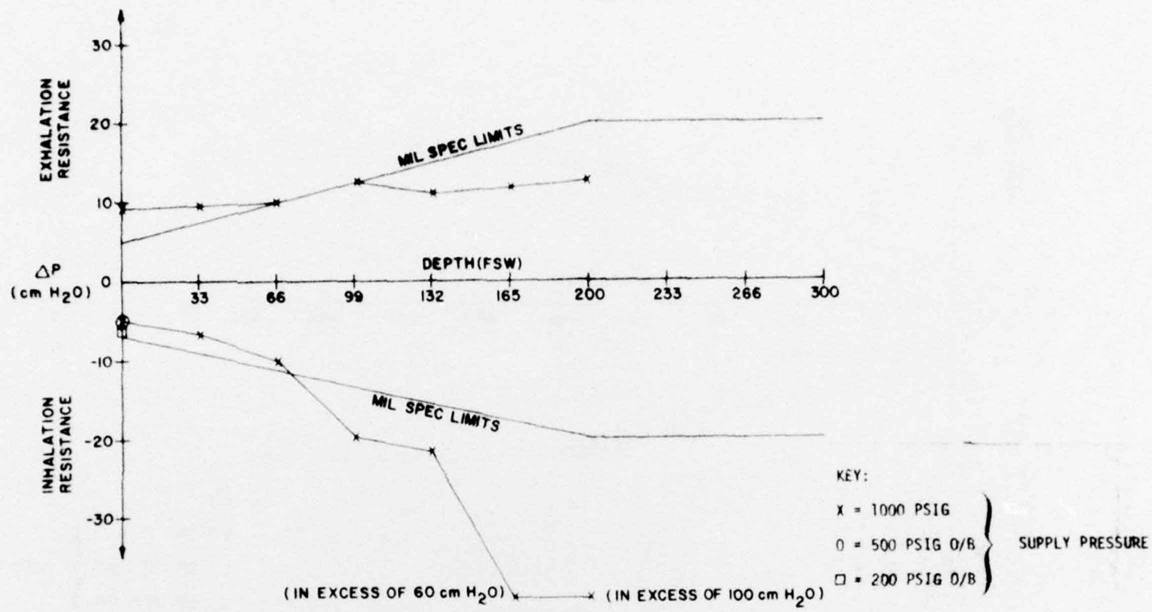


FIGURE 6. BREATHING RESISTANCE VS. DEPTH FOR SRB-3000 REGULATOR AT 20 BPM, 2.0 TIDAL VOLUME, 40 RMV--MIL-R-24169A REQUIREMENT

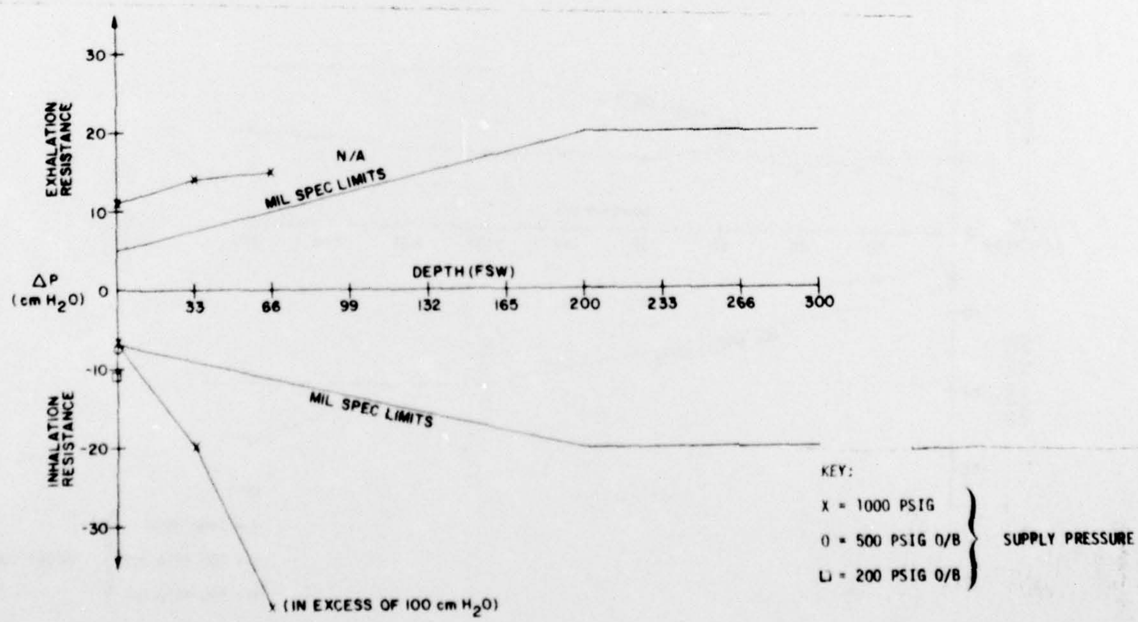


FIGURE 7. BREATHING RESISTANCE VS. DEPTH FOR SRB-3000 REGULATOR AT 25 BPM, 3.0 TIDAL VOLUME, 75 RMV

SRB-4100J Regulator

Inhalation Characteristics. When the SRB-4100J regulator was operating at RMV's of 22.5 (Figure 2) and 40 (Figure 3), its inhalation resistance was well within the mil spec, and inhalation cracking pressures were very low. This resulted in a smooth, uniform inhalation flow. At 75 RMV (Figure 4), the regulator stayed within limits to 99 fsw; beyond this depth, inhalation resistance increased drastically. Resistance was measured at 35 cm H_2O at 132 fsw and increased to over 100 cm H_2O at 200 fsw.

Inhalation resistance at first-stage supply pressures of 200 psig O/B and 500 psig O/B (reserve in "on" position) was not affected at 22.5 RMV either on the surface or at 200 fsw. At 40 RMV no significant change appeared on the surface at either pressure. No increase in resistance was measured at 200 fsw with 500 psig O/B, but resistance increased to over 100 cm H_2O at 200 psig O/B.

The reserve assembly built into the first stage operated properly by severely restricting flow at supply pressures less than 300 psig until it was switched to the "on" position.

Exhalation Characteristics. When the SRB-4100J regulator was operating at RMV's of 22.5 (Figure 2) and 40 (Figure 3), its exhalation resistance was well within the mil spec at all depths other than very shallow. From 0 to 50 fsw, resistance was slightly greater than is allowed. This is common in many regulators and, for practical purposes, does not affect regulator performance. (Data also revealed that the pressure at the exhaust port varied greatly at shallow depths, probably due to a phenomenon called bubble collapse.)

At 75 RMV (Figure 4), exhalation resistance was beyond mil spec limits at all depths tested. When the regulator exceeded 100 cm H_2O inhalation resistance, the test was terminated; that is why some of the graphs are incomplete.

SRB-3000 Regulator

Inhalation Characteristics. When operating at an RMV of 22.5 (Figure 5), the SRB-3000 regulator had a low cracking pressure and a smooth, uniform flow that was well within the mil spec at a 1000 psig supply pressure. When the supply pressure was reduced to 200 psig O/B at 200 fsw, breathing resistance slightly exceeded the mil spec.

At 40 RMV (Figure 6), the inhalation resistance exceeded the mil spec limit at 70 fsw. Beyond this depth, resistance increased drastically and was completely inadequate for meeting a diver's needs at 165 fsw.

Under heavy working conditions of 75 RMV (Figure 7), the SRB-3000 regulator exceeded the specification at all depths. The test was terminated when inhalation resistance reached 100 cm H_2O at 66 fsw.

Exhalation Characteristics. The exhalation characteristics of the SRB-3000 regulator (Figures 5-7) were almost identical to those of the SRB-4100J. These similarities were expected because the second stages of the two tested regulators are identical. See the section on the exhalation characteristics of the SRB-4100J regulator for a complete discussion.

WORK OF BREATHING

All underwater breathing apparatus is tested to specifications which use peak inhalation and peak exhalation pressures as the standard for evaluation (Reference 3). However, recent research has shown that the measure of external respiratory work performed by the diver to operate his breathing apparatus is useful in equipment evaluation (Reference 4). Breathing work is defined as the area enclosed by a typical pressure-volume loop generated during one complete breathing cycle. In breathing apparatus other than open circuit demand, breathing work is probably the most valid measure of equipment performance. With open circuit scuba, breathing work provides a useful supplementary guide to regulator performance. A standard of 0.170 kg·m/l ventilation (liter ventilation is defined as the tidal volume at a given RMV) has been proposed as the maximum external respiratory work allowable (Reference 4). In this report, .17 kg·m/l is used for comparative purposes only.

SRB-4100J Regulator

The breathing work required during operation of the SRB-4100J regulator (Figure 8) was almost the same for RMV's of 22.5 and 40 at depths to 99 fsw. Approximately 0.120 kg·m/l was measured at 99 fsw for both RMV's, representing a low work of breathing. At depths greater than 99 fsw, breathing work increased rapidly at 40 RMV and approached the proposed limit at 200 fsw. Breathing work at 75 RMV exceeded the proposed limit at 85 fsw. The slope of the graph at 75 RMV indicates that the SRB-4100J regulator exceeded its design limits at heavy work rates, even in shallow water.

SRB-3000 Regulator

The breathing work required during operation of the SRB-3000 regulator (Figure 9) at 22.5 RMV was not excessive until a depth of 200 fsw was reached. Although this regulator was well within the mil spec limits at 22.5 RMV and 200 fsw (Figure 5), it required the maximum proposed breathing work under these conditions.

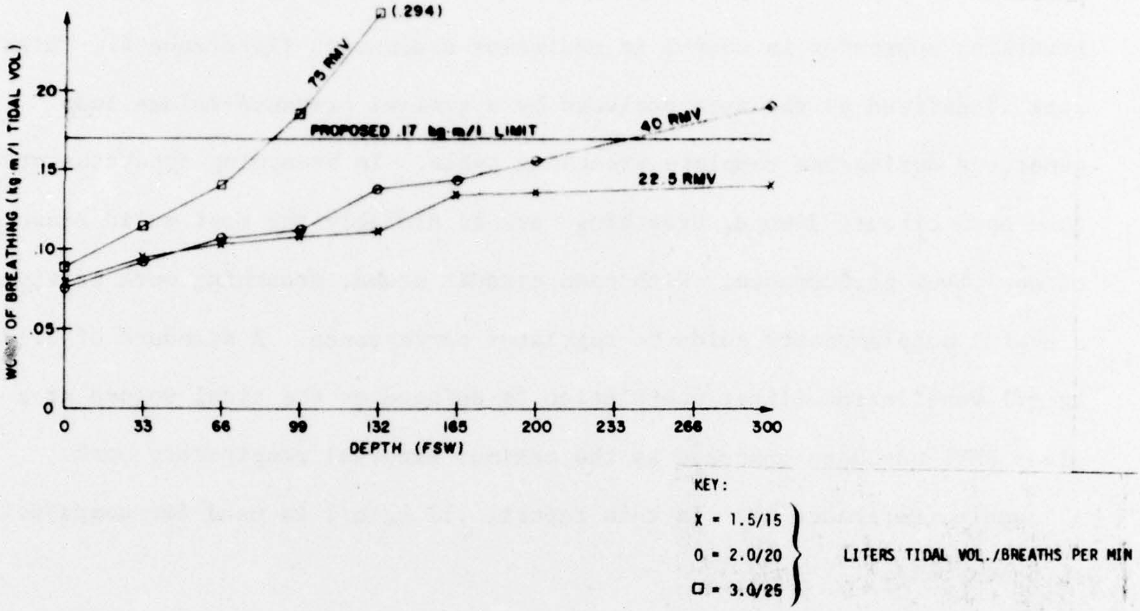


FIGURE 8. WORK OF BREATHING VS. DEPTH FOR SRB-4100J REGULATOR

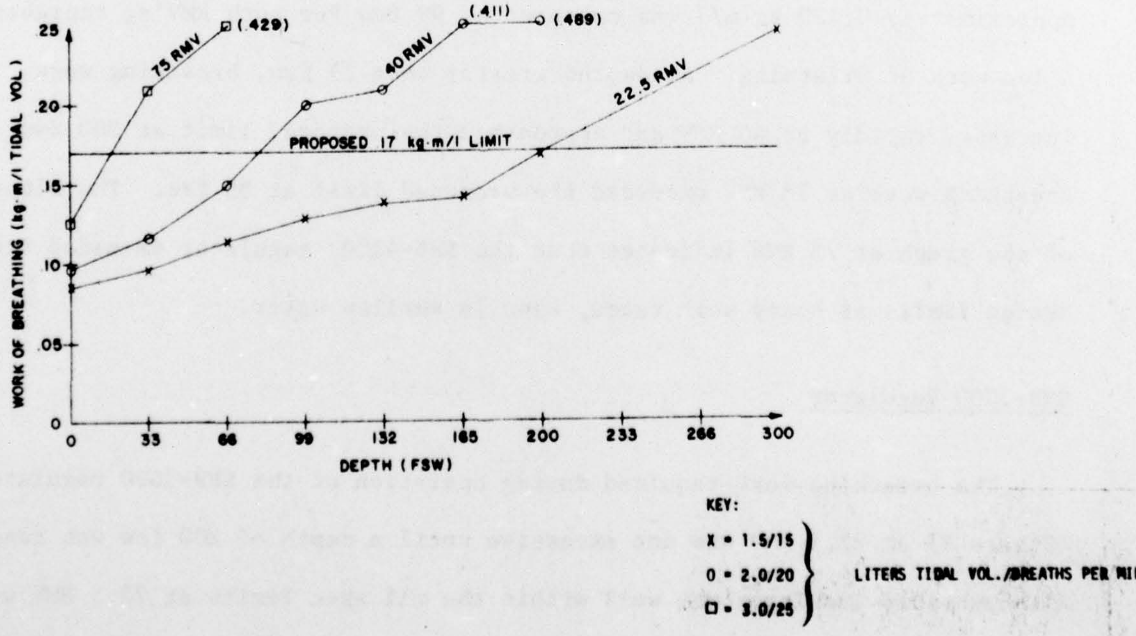


FIGURE 9. WORK OF BREATHING VS. DEPTH FOR SRB-3000 REGULATOR

At RMV's of 40 and 75, the breathing work required increased rapidly with depth, exceeding the proposed limit at 70 and 17 fsw, respectively. Breathing work at 33 fsw with a 75 RMV was beyond practical limits, although the breathing resistance experienced at 33 fsw (Figure 7) was similar to that experienced on other regulators at deeper depths.

CONCLUSIONS AND RECOMMENDATIONS

SRB-4100J REGULATOR

The Sherwood SRB-4100J is a reliable and functional regulator which meets all mil specs and is recommended for U.S. Navy approval. However, the tests conducted at NEDU revealed several areas that warrant improvement but do not affect safety or overall performance; these areas are listed below with possible methods of correction.

1. High inhalation resistance was observed at 200 fsw when the supply pressure reached 200 psig O/B; this could be improved by increasing the flow area in the vicinity of the reserve valve.

2. At shallow depths, exhalation resistance exceeded mil specs and exhalation pressure was quite unstable. Both problems are probably results of bubble collapse at the exhaust port. This condition could be improved by a modification of the exhaust tee which would cause a bubble to be "captured" at the end of each exhalation cycle.

SRB-3000 REGULATOR

Because of extremely high inhalation resistance, the Sherwood SRB-3000 regulator does not meet mil specs and is not recommended for U.S. Navy approval. This regulator was seriously deficient on inhalation under all operating conditions except those involving light work at shallow depths. Since the second stage of the SRB-3000 is the same as that of the SRB-4100J, the SRB-3000's problem appears to involve its first stage. Consequently, the piston and associated flow passages of the first stage of the SRB-3000 should be redesigned.

REFERENCES

1. OOC Letter WRB:lf 3960/2003, Serial 1038, 23 June 1976.

2. Department of the Navy Military Specification MIL-R-24169A, Regulator, Air, Demand, Single Hose, Nonmagnetic, Divers, 22 March 1967.

3. Navy Experimental Diving Unit Report 23-73, U.S.N. Procedures for Testing the Breathing Characteristics of Open Circuit Scuba Regulators, by S. D. Reimers, p. 5, 11 December 1973.

4. Navy Experimental Diving Unit Report 19-73, Proposed Standards for the Evaluation of the Breathing Resistance of Underwater Breathing Apparatus, by S. D. Reimers, p. 36, 30 January 1974.

APPENDIX A

TEST PLAN

The test plan for examination of the SRB-4100J and SRB-3000 regulators included the following steps.

1. Insure that the regulator is set to factory specifications and is working properly.
2. Insure that the chamber is on the surface.
3. Calibrate the transducers and zero the transducer by regulator position after water is added to the wet test box.
4. Open the air supply valve to test the regulator and set the supply pressure at 1000 psig.
5. Adjust the breathing machine to 1.5 liter tidal volume and 15 BPM and take readings.
6. Stop the breathing machine.
7. Establish zero flow ΔP position on the x-y plotter.
8. Adjust the air supply pressure to 500 psig O/B.
9. Repeat steps 5 through 7.
10. Adjust the air supply pressure to 200 psig O/B. (Be sure that the breathing resistance transducer stays within its range.)
11. Repeat steps 5 through 7.
12. Pressurize the chamber to 33 fsw.
13. Adjust the air supply to 1000 psig.
14. Repeat steps 5 through 7.
15. Pressurize the chamber to 66 fsw.
16. Adjust the air supply to 1000 psig.
17. Repeat steps 5 through 7.
18. Pressurize the chamber to 99 fsw.

19. Adjust the air supply to 1000 psig.

20. Repeat steps 5 through 7.

21. Pressurize the chamber to 132 fsw.

22. Adjust the air supply to 1000 psig.

23. Repeat steps 5 through 7.

24. Pressurize the chamber to 165 fsw.

25. Adjust the air supply to 1000 psig.

26. Repeat steps 5 through 7.

27. Pressurize the chamber to 200 fsw.

28. Repeat steps 4 through 11.

29. Pressurize the chamber to 300 fsw.

30. Adjust the air supply to 1000 psig.

31. Repeat steps 5 through 7.

32. Set the breathing machine to 2.0 liter tidal volume and 20 BPM. (This replaces step 5.)

33. Repeat steps 4 through 31 in reverse order (as chamber is being brought to surface making incremental stops in reverse order).

34. Set the breathing machine to 3.0 liter tidal volume and 25 BPM. (This replaces step 5.)

35. Repeat steps 4 through 31.

36. Bring the chamber to the surface (no stops).

37. Check the calibration on the transducers.

APPENDIX B

TEST EQUIPMENT

The following equipment was used in testing the SRB-4100J and SRB-3000 regulators and is shown in Figure 1.

1. NEDU breathing machine
2. Validyne model DP-15 pressure transducer with 1 psid diaphragm
3. NEDU wet test box
4. Validyne model DP-15 pressure transducer with 250 psig diaphragm
5. MFE x-y plotter, model 715M, serial number 30925002
6. Validyne model CD-12 transducer readout, 2 each, serial numbers 12247 and 5538
7. 7.12-cu. ft. scuba tank
8. NEDU "D" chamber complex
9. Roylyn air supply pressure gauge, model 0-2000 psig with accuracy to 0.25 percent, calibration date August, 1976
10. Marotta dome loader
11. Roylyn chamber depth gauge, model 0-2300 fsw with accuracy to 0.25 percent, calibration date December, 1975
12. Test regulators (first and second stage)
    a. Sherwood model SRB-4100J, serial number 108107
    b. Sherwood model SRB-3000, serial number 106966
13. Bourns piston position transducer, model 2001764008
14. Transducer isolation tube

APPENDIX C

MAN-HOURS REQUIRED

The man-hours required for the test of the SRB-4100J and SRB-3000 regulators are computed below.

	Men	Hours	Man-Hours
Test set-up	3	2	6
Test operation	3	4	12
Chamber operation	1	4	4
Post-test cleanup	2	1	2
Data reduction/report production	1	80	80
Duplicating	4	30	120
TOTAL			224