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EVALUATION OF THE GENERAL AQUADYNE DM-5 MASK.(U)

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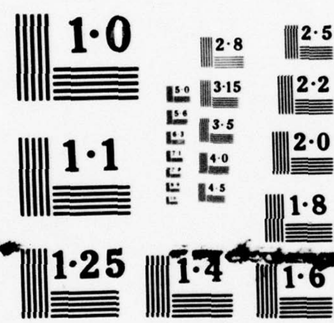

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DEPARTMENT OF THE NAVY
NAVY EXPERIMENTAL DIVING UNIT
PANAMA CITY, FLORIDA 32407

IN REPLY REFER TO

(14) NEDU-5-78

(9) Test rept.

NAVY EXPERIMENTAL DIVING UNIT

~~REPORT NO.~~ [redacted]78

(6) EVALUATION OF THE GENERAL AQUADYNE DM-5 MASK

(10) JAMES R. MIDDLETON

(11) MAR[redacted]978

(12) 30p.

Approved for public release; distribution unlimited

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UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NEDU REPORT 5-78	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) EVALUATION OF THE GENERAL AQUADYNE DM-5 MASK		5. TYPE OF REPORT & PERIOD COVERED Test Report
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) JAMES R. MIDDLETON		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Navy Experimental Diving Unit Panama City, FL 32407		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS		12. REPORT DATE March 1978
		13. NUMBER OF PAGES 28
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Open circuit	Exhalation	Tidal volume
Breathing resistance	Sideblock	
Work of breathing	Umbilical	
Over bottom pressure	Respiratory minute volume (RMV)	
Inhalation	Breaths per minute (BPM)	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The General Aquadyne DM-5 Mask was tested by NEDU in accordance with MIL-R-24169A. Results of unmanned tests which evaluated breathing resistance, sideblock and umbilical pressure drop and breathing work showed that the mask meets mil spec requirements. The mask is not recommended for inclusion on the list of equipment Authorized for Navy Use because the U.S.N. currently has no requirement for this type of equipment in addition to its own USN MK 1 Mod 0 Mask.

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S/N 0102-014-6601

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

Acknowledgements

The author would like to express his sincere appreciation to Mr. G.W. Noble and the personnel of the Naval Coastal Systems Center Hydrospace Laboratory.

In addition to the generous use of their sophisticated test facility, the high level of technical expertise, and tireless effort were instrumental to the successful and timely completion of these tests.

Table of Contents

Glossary

Abbreviation	Definition
BPM	breaths per minute
cm H_2O	centimeters of water pressure (differential)
fsw	feet of seawater
HeO_2	helium-oxygen breathing gas
I.D.	inside diameter
kg.m/l	breathing work in kilogram meters per liter ventilation
LPM	liters per minute (flow rate)
mil spec	military specification MIL-R-24169A
NEDU	Navy Experimental Diving Unit
O/B	over bottom pressure
ΔP	pressure differential
psig	pounds per square inch gauge
RMV	respiratory minute volume in liters per minute
USN	United States Navy

Abstract

The General Aquadyne DM-5 Mask was tested by NEDU in accordance with MIL-R-24169A. Results of unmanned tests which evaluated breathing resistance, sideblock and umbilical pressure drop and breathing work showed that the mask meets mil spec requirements. The mask is not recommended for inclusion on the list of equipment Authorized for Navy Use because the U.S.N. currently has no requirement for this type of equipment in addition to its own USN MK 1 Mod 0 Mask.

I. INTRODUCTION

In July 1977, NEDU retested the DM-5, a demand/free flow umbilical supplied full face mask produced by General Aquadyne Incorporated, 333 E. Haley Street, Santa Barbara, California 93101.

The mask was tested in accordance with MIL-R-24169A (reference 1) and other applicable standards. Various RMV's were used during the test to simulate light through extreme diver work rates. Pressure drops across the gas supply umbilical and mask sideblock were monitored to give an indication of total system performance. Breathing work required to operate the mask in the demand mode was also measured. These additional data points were used as supplementary guides to evaluation.

Previous tests (reference 4) had shown earlier models of the DM-5 to fall short of requirements set forth in reference 1. However, test results show that the DM-5 mask now meets or exceeds all mil spec requirements.

II. TEST PROCEDURE

A. Test Plan

NEDU test equipment was set up as shown in Figure 1 and all testing of the DM-5 was done in accordance with applicable mil specs. The actual test plan is given in Appendix A. A breathing machine simulated diver inhalation and exhalation at various depths. The instrumentation and test equipment shown in Figure 1 is listed in Appendix B. Parameters controlled, measured, computed and plotted are listed below.

B. Controlled Parameters

The following parameters were controlled during the DM-5 test.

(1) Breathing Rate / Tidal Volume / RMV

(a) 15 BPM / 1.5 liters / 22.5 LPM

(b) 20 BPM / 2.0 liters / 40.0 LPM

(c) 25 BPM / 2.5 liters / 62.5 LPM

(d) 30 BPM / 2.5 liters / 75.0 LPM

(e) 30 BPM / 3.0 liters / 90.0 LPM

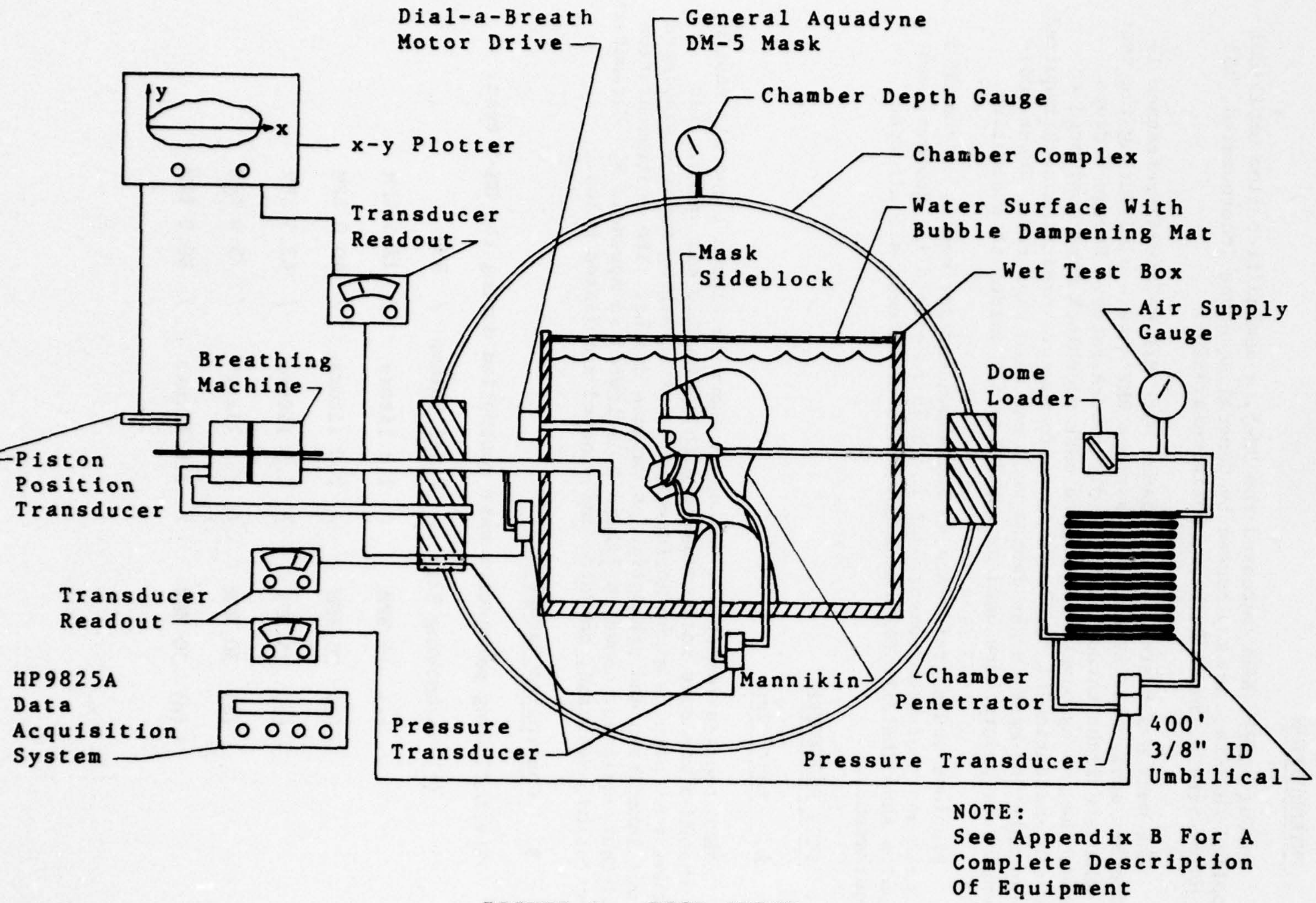


FIGURE 1. TEST SETUP

(2) Exhalation/Inhalation time ratio: 1.00/1.00

(3) Breathing waveform: sinusoid

(4) Umbilical supply pressure: 165 psig O/B at all depths

(5) Supply gas: air

(6) Supply gas mode: umbilical only

(7) Incremental depth stops: 0 to 198 FSW in 33 FSW increments

(8) Dial-A-Breath position: set on surface so that 0.15 cmH_2O pressure of free flow pressure is achieved and then the valve is closed 1.5 turns and left in this position for the duration of the test

C. Measured Parameters

The following parameters were measured on the DM-5 test.

(1) Inhalation maximum ΔP

(2) Exhalation maximum ΔP

(3) ΔP vs. tidal volume plots

(4) Dynamic pressure drop across sideblock

(5) Dynamic pressure drop across 400 foot umbilical

D. Computed Parameters

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

E. Data Plotted

The following data are plotted in this report.

(1) Inhalation maximum ΔP vs. depth at each RMV tested

(2) Exhalation maximum ΔP vs. depth at each RMV tested

(3) Respiratory work vs. depth at each RMV tested

(4) Dynamic pressure drop across sideblock vs. depth at each RMV tested

(5) Dynamic pressure drop across umbilical vs. depth at each RMV tested

III. RESULTS AND DISCUSSION

A. Description

The Aquadyne DM-5 is an open circuit full face mask with oral-nasal cavity which is designed for surface supplied or saturation umbilical diving. The mask has the capability of operating in either the demand or free flow mode. The demand mode incorporates a "Dial-A-Breath" valve which allows a diver to maintain low breathing resistance regardless of gas supply pressure. The "Dial-A-Breath" valve is also used to create a free flow mode through the demand regulator. The divers exhaled gas is vented through the exhaust valve in the demand regulator assembly or through supplemental exhaust valves located beneath the demand regulator housing.

A gas supply umbilical connects to the sideblock assembly on the right side of the mask. The sideblock houses a non-return valve in the umbilical supply port and also incorporates a separate gas supply valve and connector for an emergency gas supply. The emergency supply normally consists of a standard scuba tank and first stage regulator assembly which is worn on the divers back.

In addition, the sideblock houses a defogging valve which may be used to supplement normal demand/free flow operation or to keep the face plate clear by directing a continuous flow of gas across the lens.

The mask frame is constructed of fiberglass. It is sealed in place on the divers head with a rubber foam face seal and adjustable five point head harness.

B. Breathing Resistance Tests

Breathing resistance was measured at five RMV's to simulate light through extreme diver work rates. Light work was simulated at 22.5 RMV, moderate work at 40 RMV, moderately heavy work at 62.5 RMV, heavy work at 75.0 RMV and extreme work at 90.0 RMV. The mil spec (reference 1) calls for 40 RMV only. The other RMV's were measured, however, to indicate the full range of mask performance.

The breathing resistances plotted in the figures are the maximum values measured, excluding cracking pressure, during one complete inhalation-exhalation cycle at a given depth and RMV. On plots where data is incomplete, the test was terminated due to excessive breathing resistance. Air supply pressure was maintained at 165 psig O/B.

The following table lists equivalent depth densities for air versus HeO_2 down to 200 FSW on air. This provides a means of comparing mask performance on HeO_2 mixes at depths greater than 200 FSW.

Air Depth (FSW)	Equivalent HeO_2 Depth (FSW)
50	230
100	625
150	1000
200	1350

(1) Inhalation Characteristics

The inhalation resistances plotted are the maximum pressures recorded, except for cracking pressures, at all RMV. Maximum flow resistance always occurred at the point of peak flow rate during inhalation and exhalation cycles. It was observed that breathing resistance was very sensitive to "Dial-A-Breath" position. Consequently, the valve was set as previously described for minimum breathing resistance at a specific over bottom pressure and left for the duration of the test.

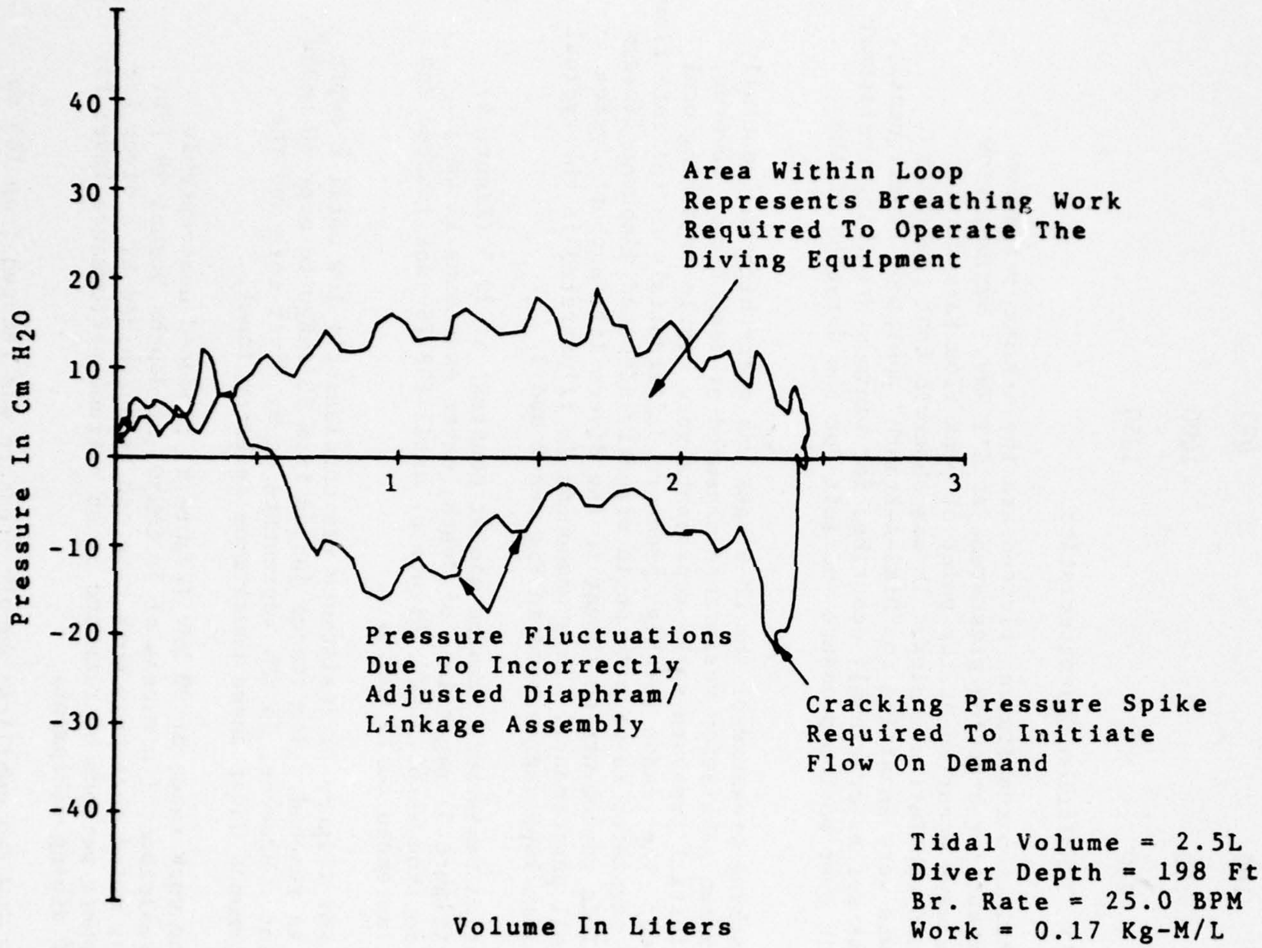
The cracking pressure of the DM-5 mask was quite high and generally exceeded maximum inhalation resistance measured at peak flow. However, since this initial pressure spike represents very little breathing work it is ignored. The reason for high pressure differentials to initiate flow in a demand regulator is usually an incorrectly adjusted diaphram/linkage assembly. This represents no threat to the divers life support system or its overall performance. This phenomena is illustrated in the typical pressure-volume loop represented in Figures 2 and 3.

Inhalation resistance remains almost constant at 22.5 (Figure 4) and 40 RMV (Figure 5) regardless of depth, never exceeding 12 cmH_2O. This was also true at 62.5 RMV (Figure 6) until 198 FSW was reached and resistance increased to 15 cmH_2O.

At 75 RMV (Figure 7) resistance was consistently low until a depth of 165 FSW is reached. Resistance jumped from 12 cmH_2O to over 30 cmH_2O at this point. However, 75 RMV represents heavy diver work and the masks performance under these conditions is exceptional.

Extreme work rates of 90 RMV (Figure 8) produced unacceptable breathing resistance (in excess of 50 CmH_2O) at depths beyond 99 FSW. It should be noted that this work rate can be sustained by a diver for only very short periods of time and is an extreme performance level for any type of diving equipment.

At 198 FSW the umbilical supply pressure was reduced from 165 to 135 psig O/B to evaluate mask performance at reduced supply pressures.



Breathing Pressure Versus Tidal Volume Loop

FIGURE 2. AQUADYNE DM-5 MASK TEST

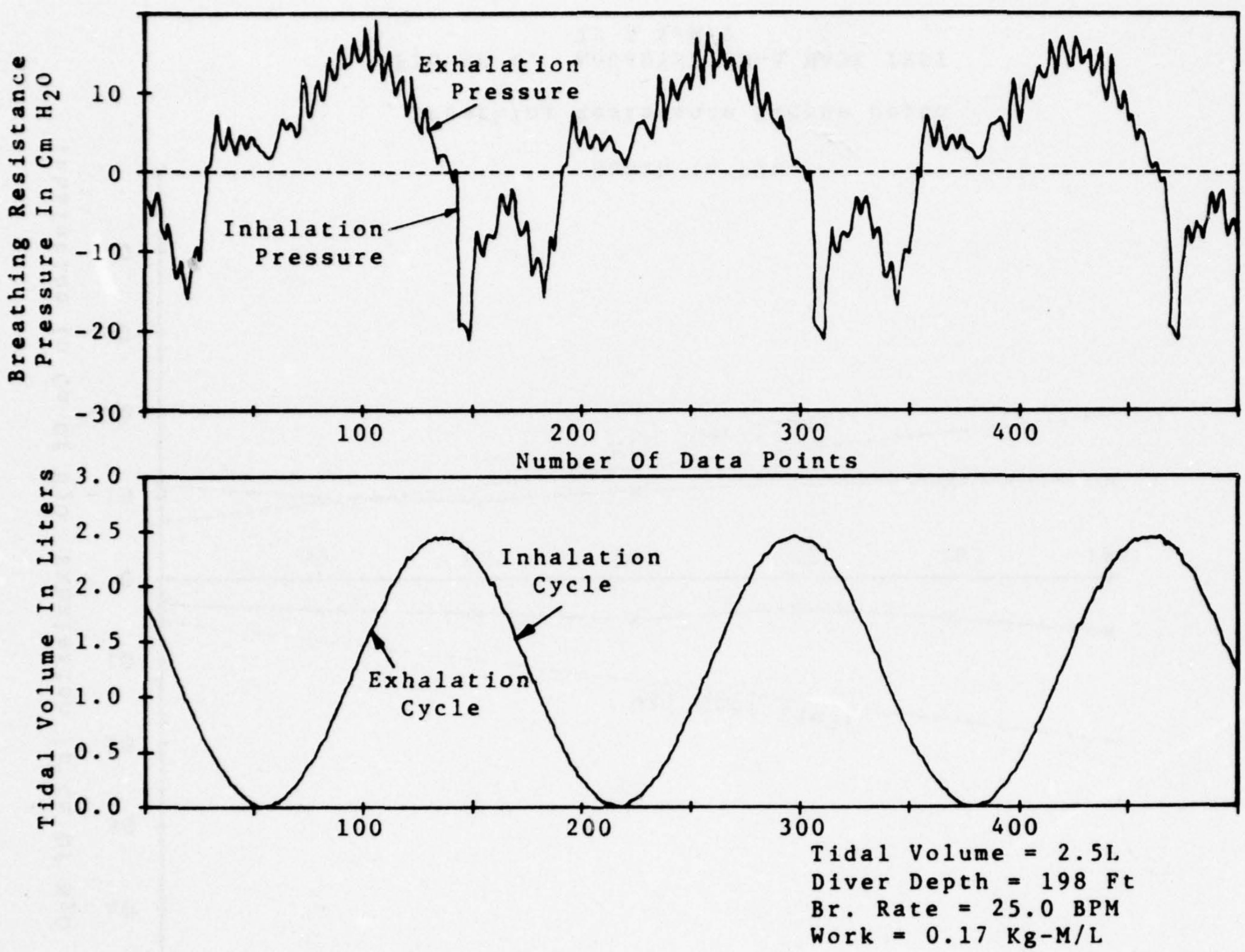
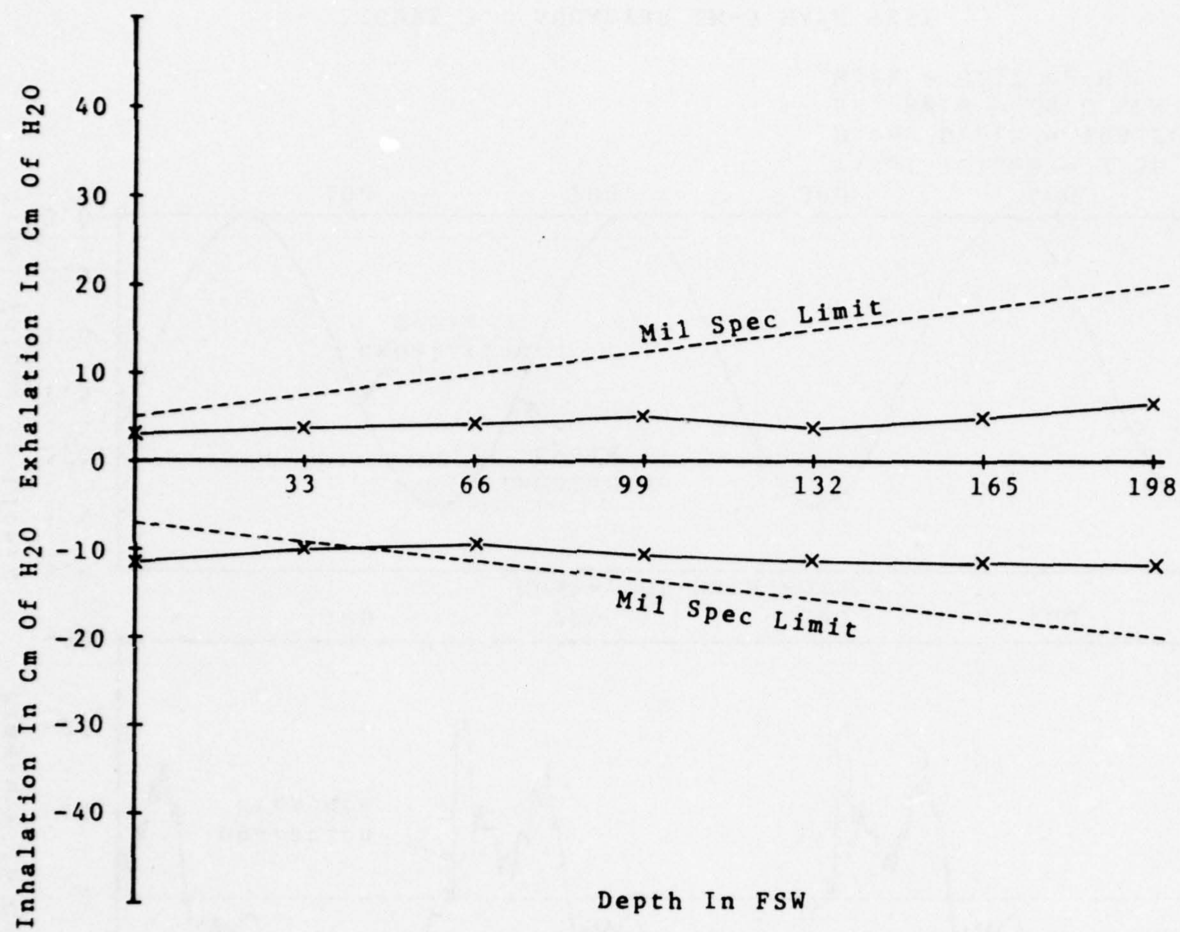
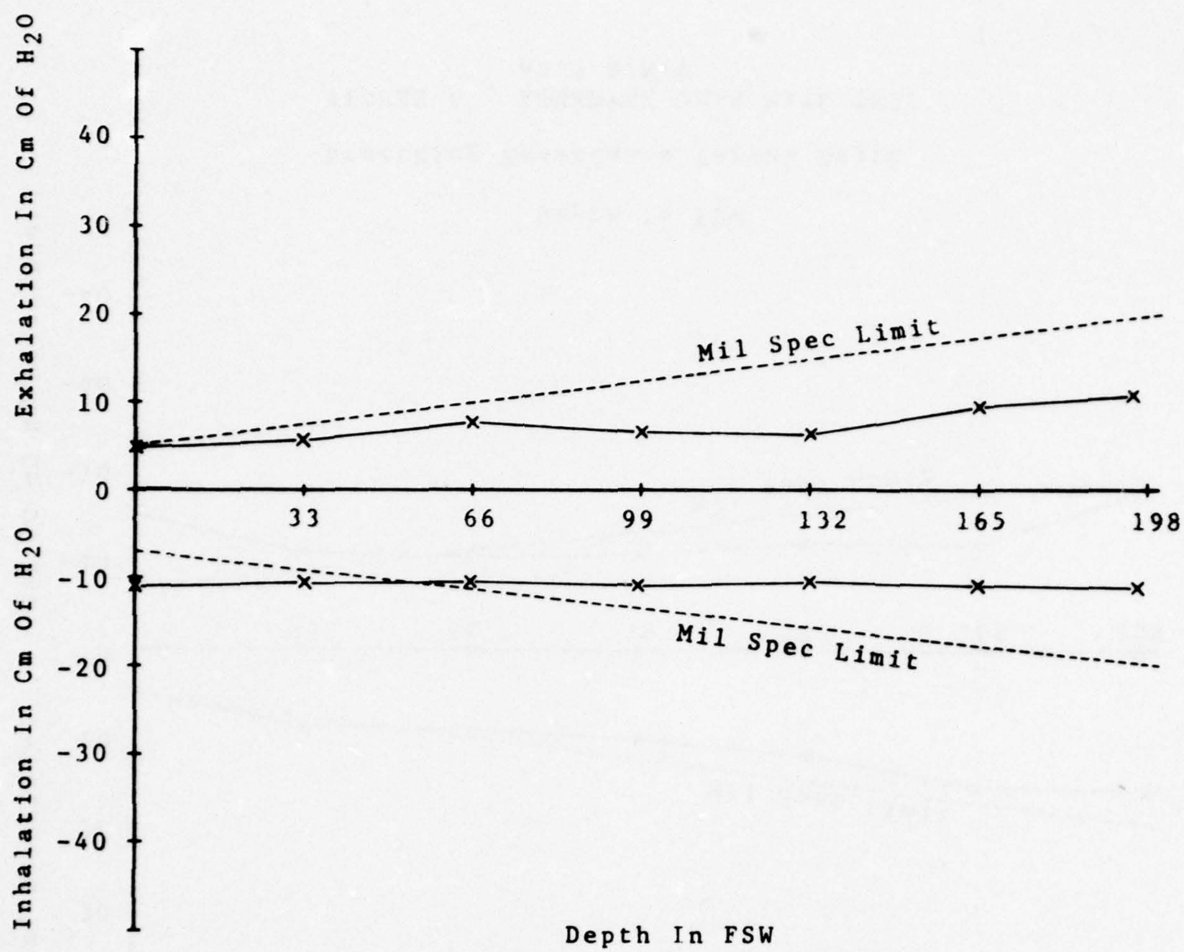


FIGURE 3. AQUADYNE DM-5 MASK TEST



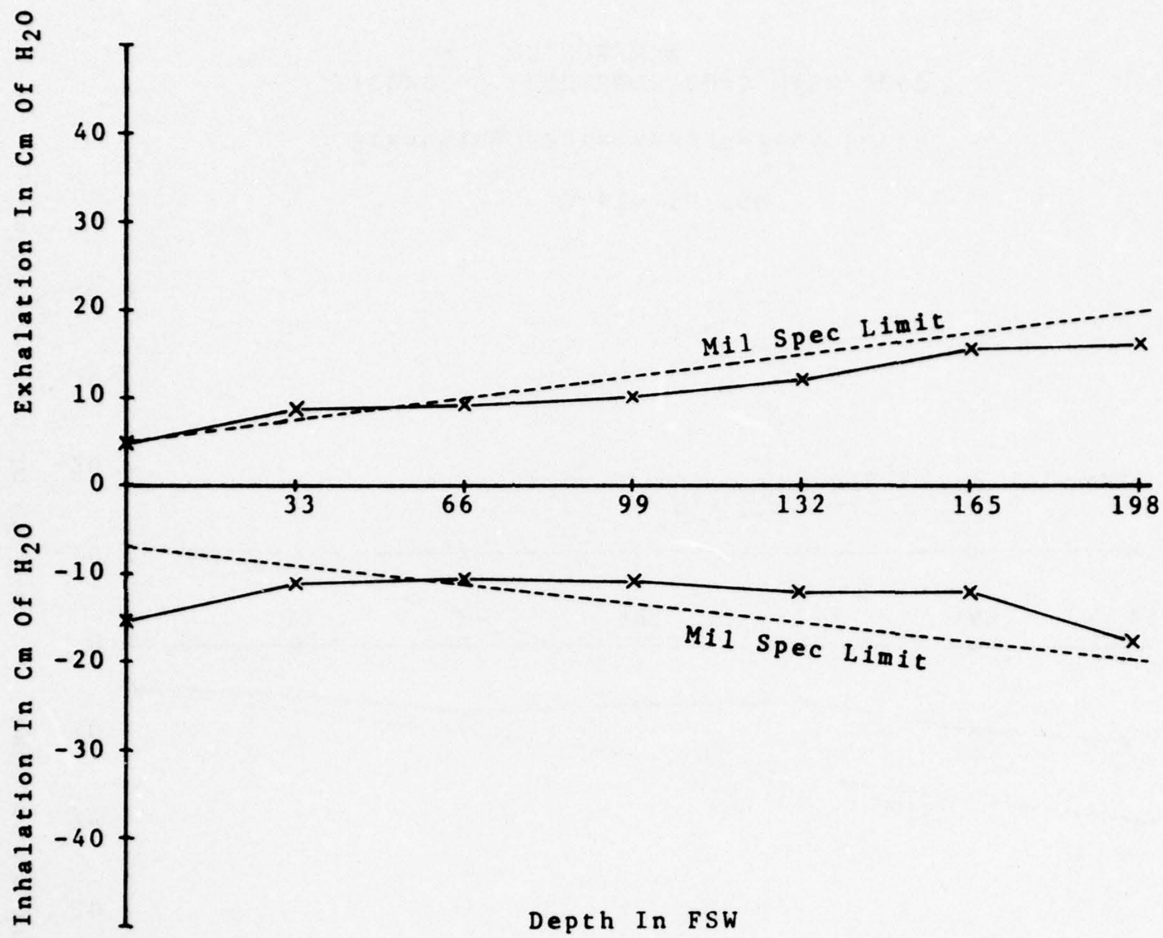
Breathing Resistance Versus Depth

FIGURE 4. AQUADYNE DM-5 MASK TEST
22.5 R/M/V



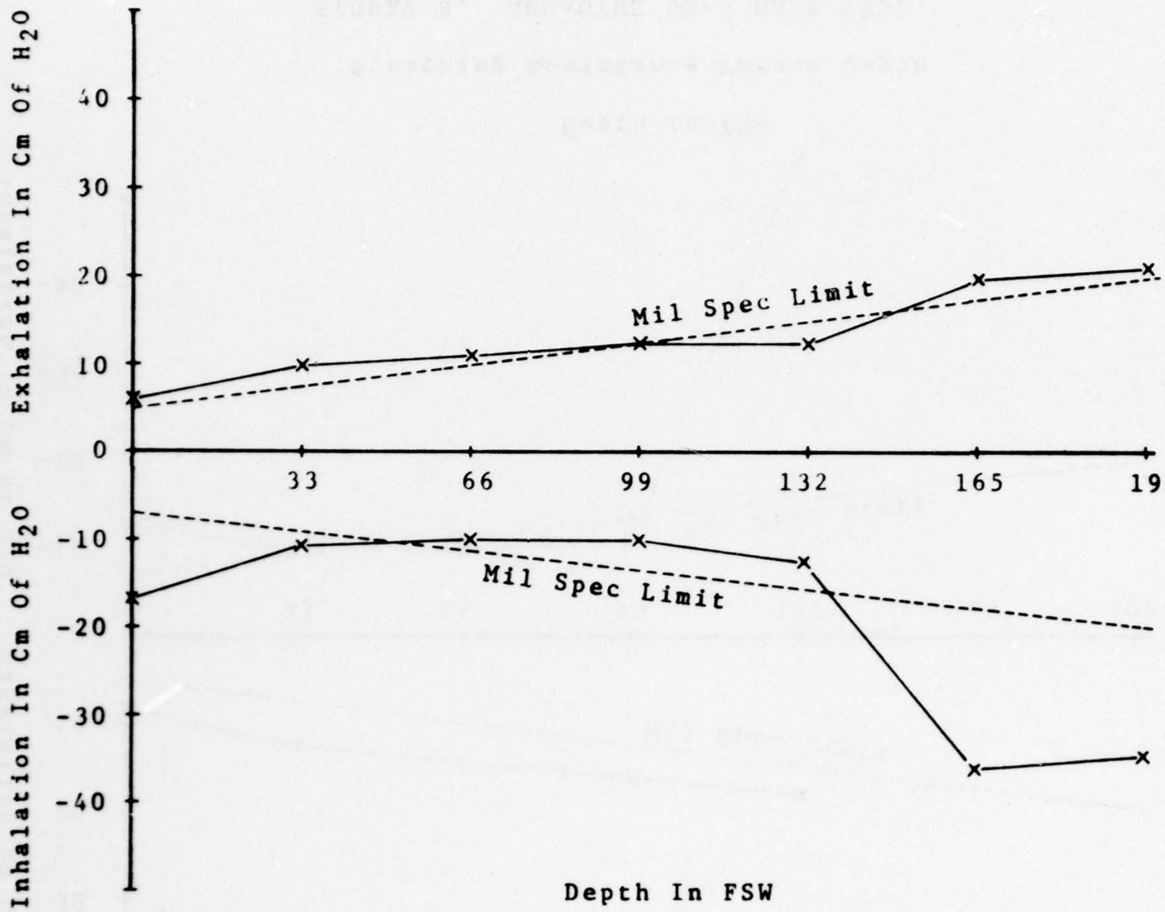
Breathing Resistance Versus Depth

FIGURE 5. AQUADYNE DM-5 MASK TEST
40.0 R/M/V



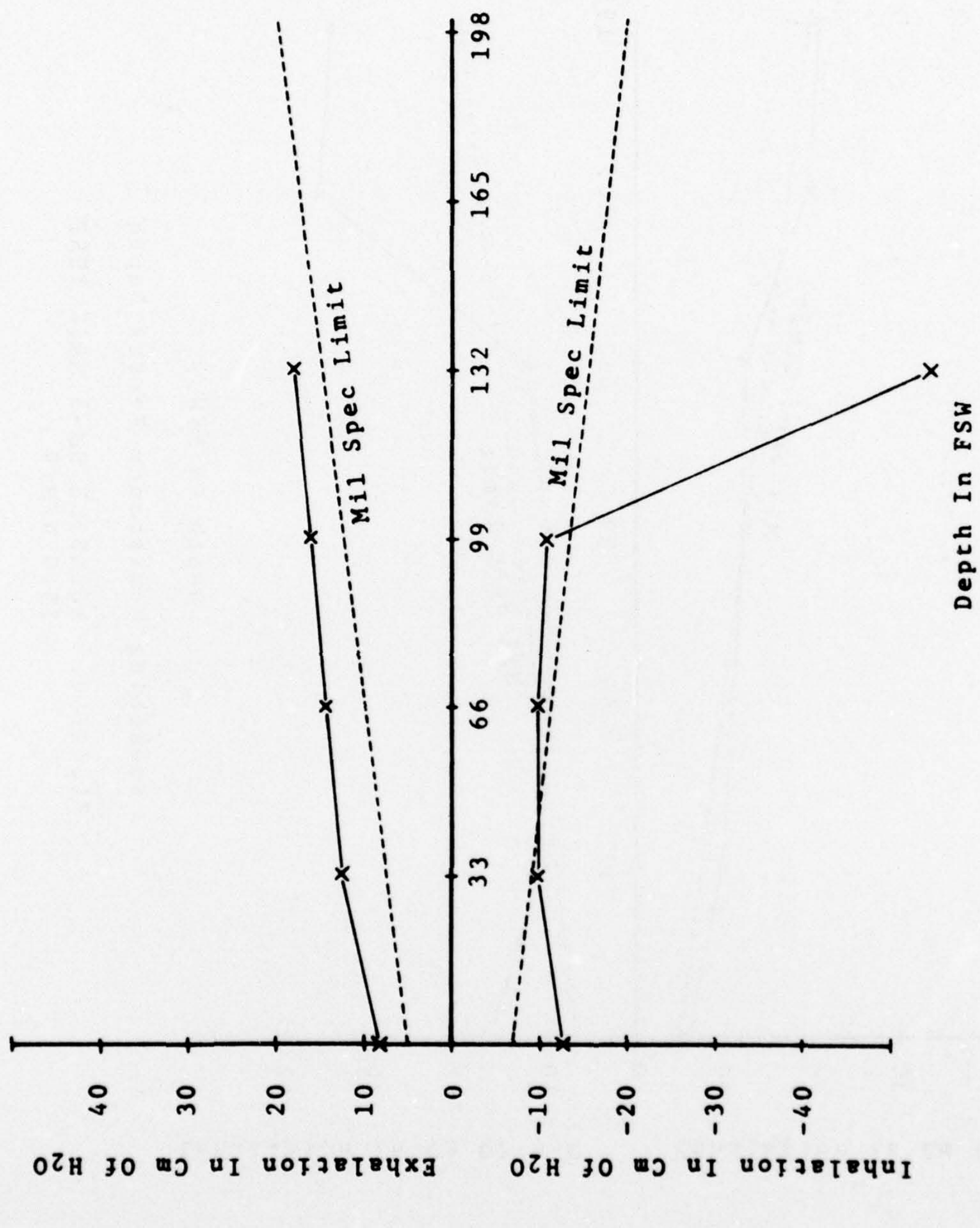
Breathing Resistance Versus Depth

FIGURE 6. AQUADYNE DM-5 MASK TEST
62.5 R/M/V



Breathing Resistance Versus Depth

FIGURE 7. AQUADYNE DM-5 MASK TEST
75.0 R/M/V



Breathing Resistance Versus Depth

FIGURE 8. AQUADYNE DM-5 MASK TEST
90.0 R/M/V

A test was run at 40 RMV (20 BPM/2 liter tidal volume), representing moderate diver work, and no measurable degradation in mask performance was observed. It is likely that mask performance would be effected at the higher RMV's with reduced supply pressures. However, under normal working conditions 135 psig O/B was found to be adequate.

(2) Exhalation Characteristics

Exhalation resistance at 22.5 (Figure 4) and 40.0 RMV (Figure 5) was well within mil spec limits. At 62.5 (Figure 6) and 75.0 RMV (Figure 7) the exhalation resistance substantially increased but still remained within specification. Ninety RMV (Figure 8) produced exhalation pressures which were outside the mil spec but posed no hindrance to diver performance.

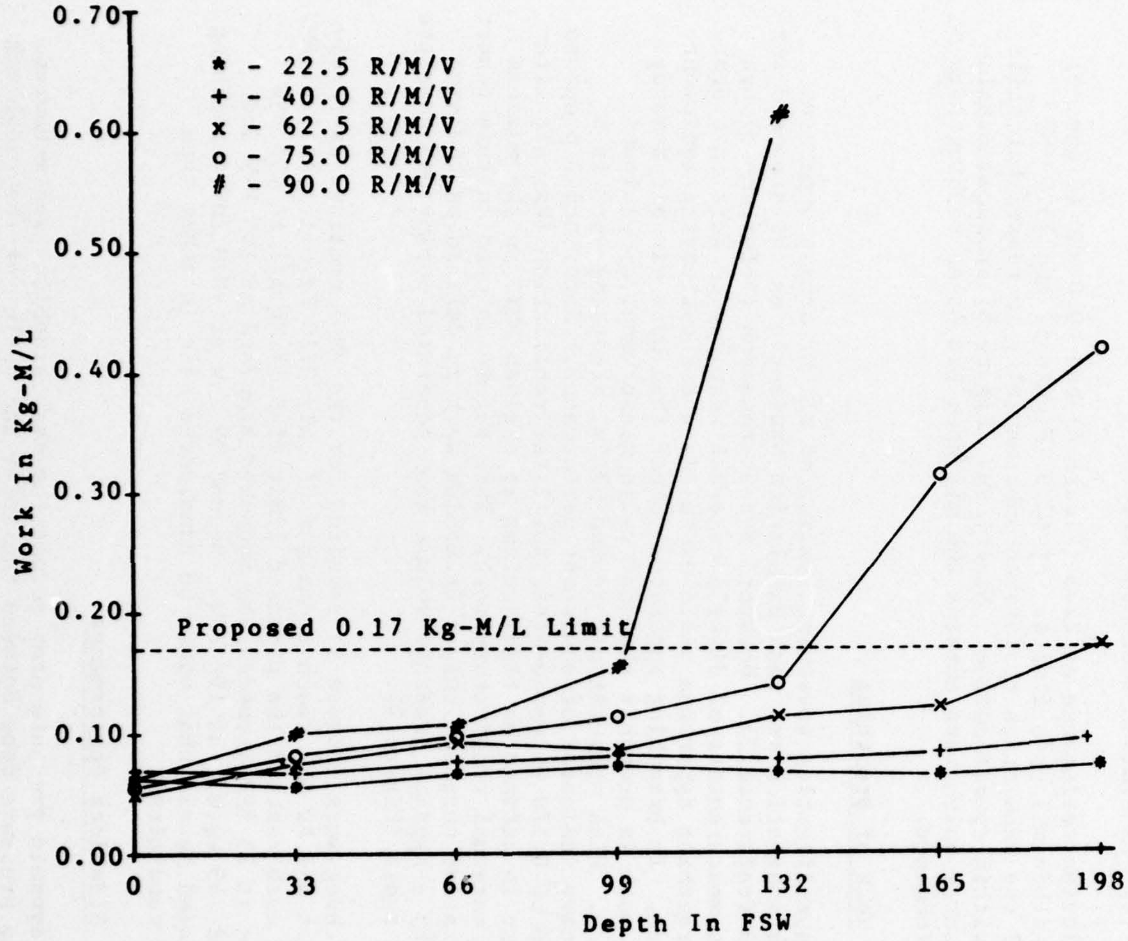
C. Work of Breathing

The specification governing testing of all breathing apparatus cites peak inhalation and peak exhalation pressures as the standard for evaluation (reference 2). However, recent research (reference 3) has shown that measurements of diver's external respiration work in operating his breathing apparatus yield useful data for evaluating equipment performance. In breathing apparatus' other than open circuit demand, breathing work is probably the most valid measurement of equipment performance. With open-circuit demand UBA's, breathing work is a supplementary indicator of equipment performance. Reference 3 proposes a standard of 0.170 kilogram-meter per liter ventilation (kg.m/l; liter ventilation is defined as tidal volume at a given RMV) as the maximum allowable external respiratory work. This figure is used in this report for comparative purposes only. Breathing work is defined as the area enclosed by a typical pressure-volume loop generated during one complete breathing cycle (Figure 2).

Breathing work (Figure 9) required for the DM-5 remained extremely low at 22.5 and 40 RMV reach a maximum of only 0.10 Kg.m/l. At 62.5 RMV breathing work reached the proposed limit of 0.17 Kg.m/l at 198 FSW. Work rates at 75 RMV exceeded the proposed standard at 165 FSW and approached .45 kg.m/l at 198 FSW. Beyond 99 FSW at 90.0 RMV, breathing work exceeded levels that would be considered safe in other than emergency conditions.

D. Sideblock Performance

The dynamic pressure drop across the mask sideblock was measured. Monitoring pressure drop between the inlet and outlet of the sideblock gave information as to how much affect sideblock pressure loss contributed to breathing resistance. By correlating this information with breathing resistance plots, changes in mask performance can be traced.



Breathing Work Versus Depth

FIGURE 9. AQUADYNE DM-5 MASK TEST

Figure 10 is an example of the dynamic pressure drop plots that were made during the test. Pressure losses were extremely low even at 90.0 RMV (Figure 11) and reached a maximum of only 7 psig at 198 FSW. The porting of the sideblock assembly is adequate to handle any type of diver work rate without affecting breathing resistance. In addition, as can be seen in Figure 10 the operation of the non-return valve was smooth with very low cracking pressures.

E. Umbilical Performance

To closely simulate more actual diving conditions the DM-5 was tested with 400 feet of 3/8" I.D. U.S. Navy diving hose supplying the breathing gas (air). Over bottom pressures supplying the umbilical were maintained at 165 psig O/B. Pressure drop across the umbilical was measured and was found to contribute substantially to reduced mask performance at depths over 99 FSW.

At any RMV over 40 and depths over 99 FSW, pressure drops exceeded 20 psig and approached 50 psig at 75 RMV at depths over 165 FSW (Figure 12).

In essence, this reduces driving pressure to the mask by 10% to 30%. This is a problem in any diving situation regardless of the type of life support equipment the diver is wearing. The U.S. Navy is currently shifting from 3/8" I.D. to 1/2" I.D. diving hose when using its MK 1 Mod 0 mask to help reduce pressure loss and increase flow capability. Increasing supply pressure above 165 psig O/B at the console will also help offset umbilical losses.

IV. CONCLUSIONS AND RECOMMENDATIONS

The General Aquadyne DM-5 mask meets all mil spec requirements and is considered to be a safe and effective diver life support system. The DM-5 is not recommended for placement on the list of equipment authorized for Navy use because the U.S.N. MK 1 Mod 0 mask currently meets all fleet needs for this type of equipment.

Breathing resistance was low even at heavy diver work rates with uniform inhalation and exhaust characteristics. Results did indicate a need to insure correct diaphram/linkage adjustment on the demand regulator. This will prevent high cracking pressures to initiate flow on demand.

Additionally, as seen in Figure 2, a slight instability (pressure fluctuations) was observed in the demand regulator, at the shallow depths and low RMV's. While this is not normally a problem to the working diver, it is also due to an incorrectly adjusted second stage

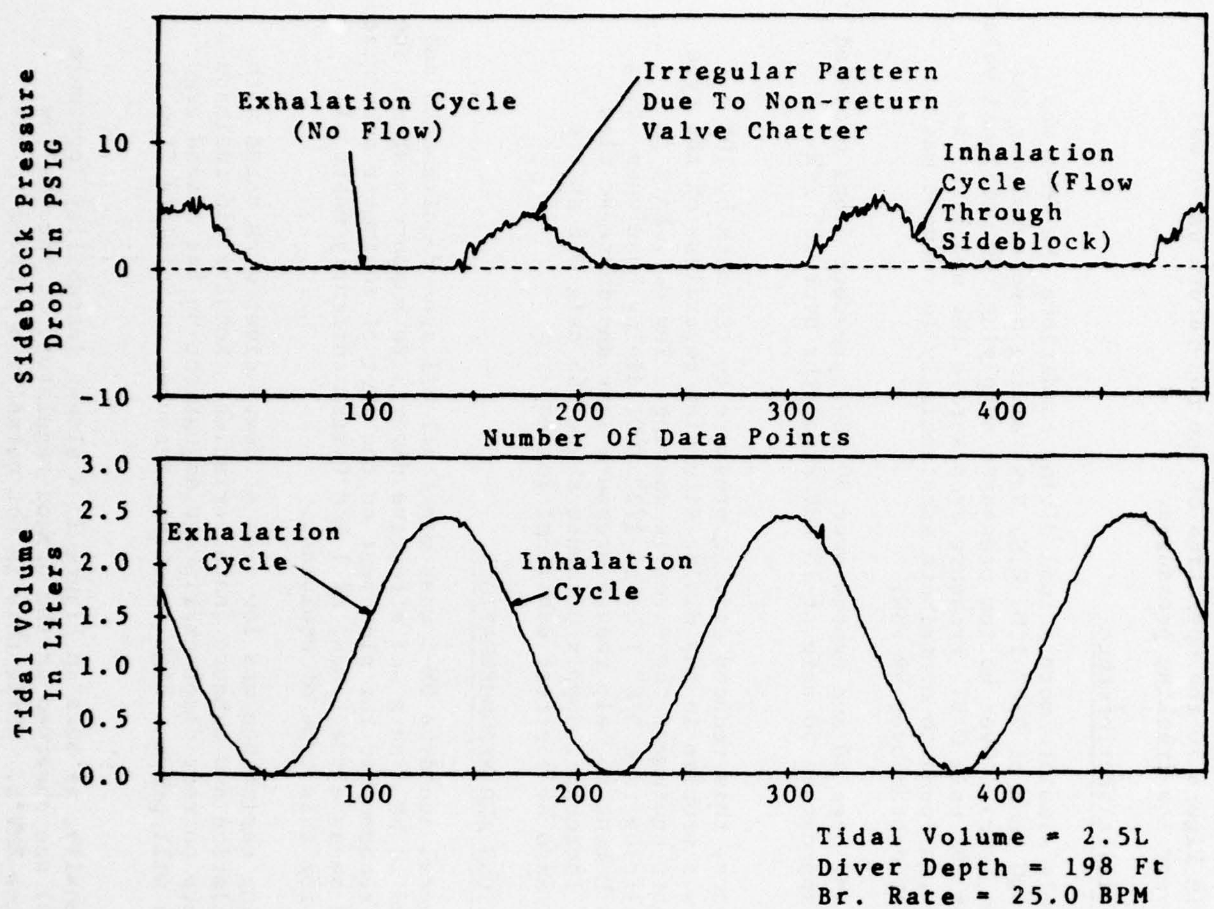
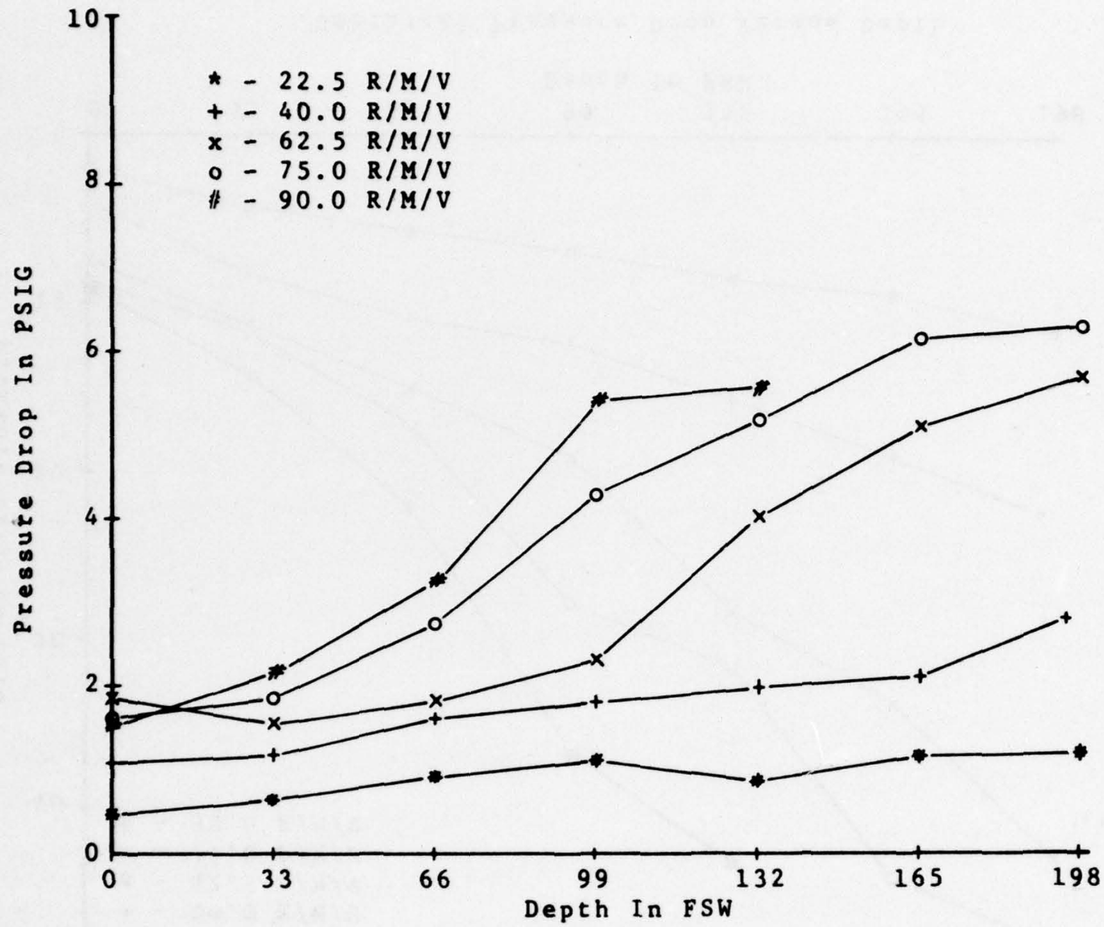
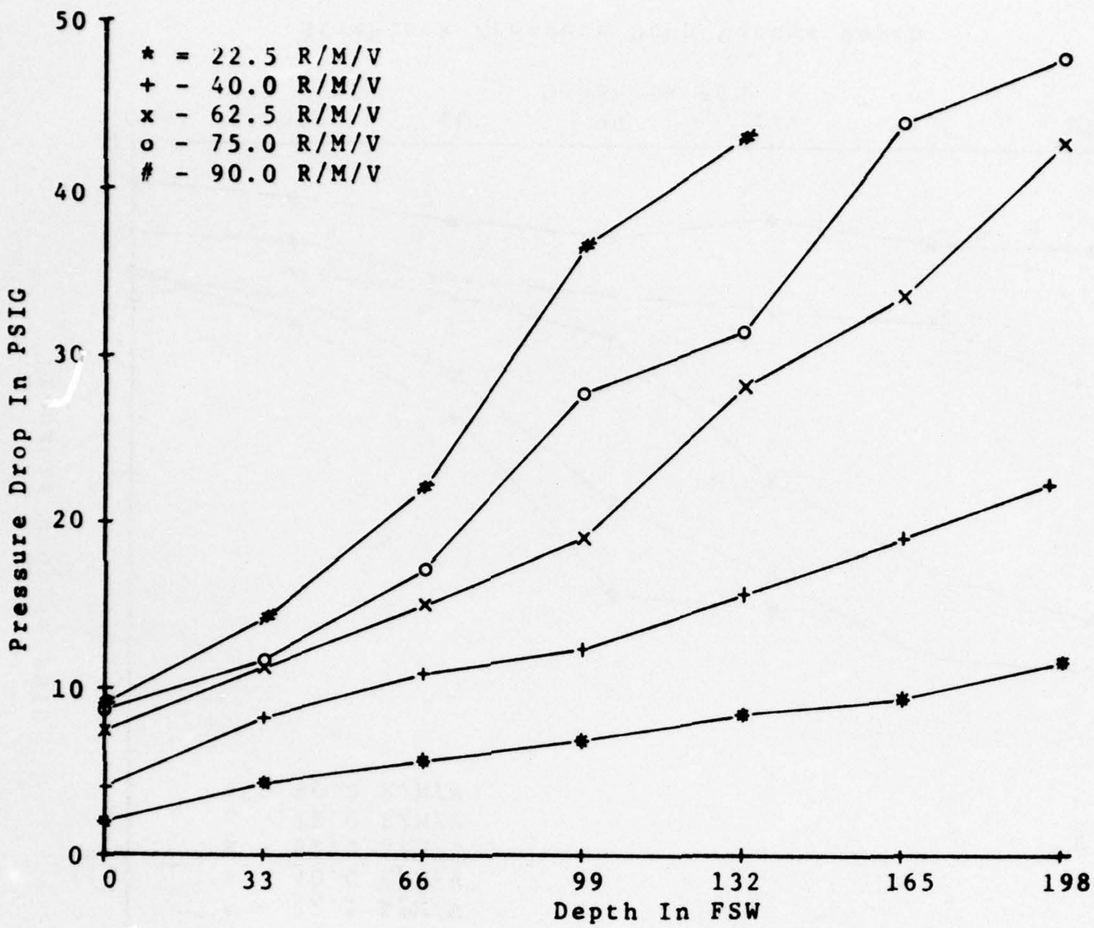


FIGURE 10. AQUADYNE DM-5 MASK TEST



Sideblock Pressure Drop Versus Depth

FIGURE 11. AQUADYNE DM-5 MASK TEST



Umbilical Pressure Drop Versus Depth

FIGURE 12. AQUADYNE DM-5 MASK TEST

diaphram/linkage. A correctly adjusted linkage will insure smooth mask operation under all operating conditions.

Breathing work required to operate the mask was generally low and would not inhibit a divers ability to perform useful work except in extreme cases.

Pressure and flow characteristics of the mask sideblock were good. Pressure losses were low and smooth non-return valve operation was observed throughout the test.

The 3/8" umbilical, which is currently the standard of the commerical and military diving community, exhibits high pressure loss at depths over 99 FSW and high diver work rates. While the mask performed well under all but extreme work rates, performance could be increased by the use of 1/2" I.D. umbilical.

The DM-5 is well built and easy to use and maintain. It should provide the working diver with a functional and dependable piece of life support equipment.

V. REFERENCES

Reference	Credits
1.	Department of the Navy Military Specification MIL-R-24169A, Regulator, Air, Demand, Single Hose, Nonmagnetic, Divers, 22 March 1967.
2.	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.
3.	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.
4.	Navy Experimental Diving Unit Report 2-75, Test and Evaluation of the DM-5 Bandmask, by HTC(DV) C.G. Gibson, November 1975.

APPENDIX A

TEST PLAN

1. Install Aquadyne DM-5 Mask in chamber and connect instrumentation as shown in Figure 1.
2. Calibrate all sensors.
3. Fill test box until manikin head is submerged.
4. Install wave suppressor in test box.
5. Set umbilical supply pressure at 135 psig over bottom pressure.
6. Record static reading on all transducers.
7. Adjust Dial-A-Breath to proper setting.
8. Record regulator offset.
9. Set breathing machine tidal volume to 1.5 liters.
10. Turn on breathing machine at 15 BPM.
11. Record, plot, print, and store data.
12. Turn off breathing machine.
13. Change tidal volume to 2 liters.
14. Turn on breathing machine at 20 BPM.
15. Repeat steps 12 and 13.
16. Change tidal volume to 2.5 liters.
17. Turn on breathing machine at 25 BPM.
18. Repeat steps 12 and 13.
19. Turn on breathing machine at 30 BPM.
20. Repeat steps 12 and 13.
21. Change tidal volume to 3.0 liters.
22. Turn on breathing machine at 30 BPM.

23. Repeat steps 12 and 13.

24. Close chamber.

25. Open compliance chamber solenoid valve.

26. Compress chamber to 33 ft. H_2O.

27. Close compliance chamber solenoid valve.

28. Repeat steps 5 through 23.

29. Open compliance chamber solenoid valve.

30. Compress chamber to 66 ft. H_2O.

31. Close compliance chamber solenoid valve.

32. Repeat steps 5 through 23.

33. Open compliance chamber solenoid valve.

34. Compress chamber to 99 ft. H_2O.

35. Close compliance chamber solenoid valve.

36. Repeat steps 5 through 23.

37. Open compliance chamber solenoid valve.

38. Compress chamber to 132 ft. H_2O.

39. Close compliance chamber solenoid valve.

40. Repeat steps 5 through 23.

41. Open compliance chamber solenoid valve.

42. Compress chamber to 165 ft. H_2O.

43. Close compliance chamber solenoid valve.

44. Repeat steps 5 through 23.

45. Open compliance chamber solenoid valve.

46. Compress chamber to 198 ft. H_2O.

47. Close compliance chamber solenoid valve.

48. Repeat steps 5 through 23.

49. Open compliance chamber solenoid valve.

50. Close umbilical supply valve.

51. Decompress chamber.

52. Bleed supply regulator dome and umbilical supply hose.

APPENDIX B

TEST EQUIPMENT

(Note: Equipment corresponds to that in Figure 1.)

1. Breathing machine
2. Validyne pressure transducer w/1.00 psid diaphram
3. Wet test box
4. Validyne pressure transducer w/50.0 psid diaphram (2 ea)
5. X-Y plotter
6. Validyne CD-19 transducer readout (3 ea)
8. NCSL Hydrospace chamber complex
9. External air supply pressure gauge
10. Dome loader
11. Chamber depth gauge
12. Test mask: General Aquadyne DM-5
13. Breathing machine piston position transducer
15. Bubble dampening mat
16. Hewlette Packard 9825 Data Aquisition System
17. Motor drive to adjust dial-a-breath knob
18. 400' 3/8" I.D. umbilical

APPENDIX C

MAN-HOURS REQUIRED

The man-hours required for the test of the General Aquadyne DM-5 Mask are computed below.

	Men	Hours	Man-Hours
Test set-up	3	4	12
Test operation	3	16	48
Chamber operation	1	16	16
Post-test cleanup	2	1	2
Data reduction/report production	1	80	80
Duplicating	4	25	100
TOTAL			258