AD-A048 017 NAVY EXPERIMENTAL DIVING UNIT PANAMA CITY FLA F/G 6/11
MK 1 MOD 0 DIVERS MASK PERFORMANCE AT REDUCED SUPPLY PRESSURES.(U)
NOV 77 J L ZUMRICK, R K O'BRYAN, W H SPAUR

UNCLASSIFIED NEDU-12-77 NL

NAVY EXPERIMENTAL DIVING UNIT

NO. 12-77

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GOLDEN ANNIVERSARY 1927-1977

EXPERIMENTAL DIVING UNIT
UNITED STATES NAVY

PANAMA CITY, FLORIDA 32407

NAVY EXPERIMENTAL DIVING UNIT REPORT

(14) NEDU [redacted] 12-77

(6) MK 1 Mod ∅ Divers Mask Performance

At Reduced Supply Pressures.

(10) J. L. ZUMRICK, R. K. O'BRYAN, W. H. SPAUR

(9) Final rept.,

(11) 6 Nov[redacted]977

(12) 24p.

Submitted by:

J. L. ZUMRICK
LCDR, MC, USNR

Reviewed by:

W. H. SPAUR
CAPT, MC, USN

Approved by:

C. A. BARTHOLOMEW
CDR, USN
Commanding Officer

253 650

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER ✓ NEDU REPORT NO. 12-77	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) ✓ MK 1 MOD 0 DIVERS MASK PERFORMANCE AT REDUCED SUPPLY PRESSURES	5. TYPE OF REPORT & PERIOD COVERED FINAL
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) J. L. ZUMRICK, R. K. O'BRYAN AND W. H. SPAUR	8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS ✓ NAVY EXPERIMENTAL DIVING UNIT PANAMA CITY, FLORIDA 32407	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS	12. REPORT DATE 6 Nov 1977
	13. NUMBER OF PAGES 20
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)

MK 1 Mod 0
Divers Mask
Performance

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

The performance of the USN Diver's Mask MK 1 Mod 0 at reduced supply pressures was studied. The oral-nasal differential pressures developed by divers working at near maximum levels were measured at supply pressures at and below 135 psig overbottom at depths from 30-190 FSW. Oral-nasal differential pressures with respiration were found to increase sharply for overbottom supply pressures less than 115 psig.

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S/N 0102-014-6601

UNCLASSIFIED (CONT)

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. (Continued)

To preclude slight variations in supply pressure from causing unacceptable breathing resistance and reducing a diver's ability to work, a minimum supply well in excess of 115 psig overbottom pressure is recommended. The relationship of respiratory flow, work of breathing, and carbon dioxide retention to increased oral-nasal mask differential pressures is discussed.

ABSTRACT

The performance of the USN Diver's Mask MK 1 Mod 0 at reduced supply pressures was studied. The oral-nasal differential pressures developed by divers working at near maximum levels were measured at supply pressures at and below 135 psig overbottom at depths from 30-190 FSW. Oral-nasal differential pressures with respiration were found to increase sharply for overbottom supply pressures less than 115 psig. To preclude slight variations in supply pressure from causing unacceptable breathing resistance and reducing a diver's ability to work, a minimum supply well in excess of 115 psig overbottom pressure is recommended. The relationship of respiratory flow, work of breathing, and carbon dioxide retention to increased oral-nasal mask differential pressures is discussed.

INTRODUCTION

The USN Diver's Mask MK 1 Mod 0 is an improved version of the standard lightweight mask. It is used for surface supplied diving operations using air to a depth of 190 FSW and helium-oxygen to 300 FSW.

The mask consists of a molded plastic frame, rubber face seal, head harness, faceplate lens, side block assembly, and an adjustable demand regulator. Air is delivered to the side block assembly of the MK 1 Mod 0 Mask and flows through a short pipe to the demand regulator which is similar to a standard second stage scuba regulator. A "dial-a-breath" feature allows adjustment of the demand regulator for minimum breathing resistance. Additional features designed to enhance diver safety include communications, free flow capability in the event of demand valve failure, and optional diver-carried emergency air supply.

A demand breathing system basically consists of a pressure sensitive diaphragm which actuates a low pressure valve assembly. Negative inspiratory pressure displaces the diaphragm and opens the low pressure valve permitting air to flow to the diver. Air flow increases with increasing inspiratory effort until the valve is fully opened. At this point, air flow is maximum for any specific depth and supply gas pressure and should meet or exceed the flow requirements for ventilation under all work conditions.

The demand system air requirement is based on the maximum instantaneous (peak) flow rate under severe work conditions. This instantaneous flow is not a continuous demand, but rather the highest rate of air flow attained during inhalation. Even though air will not be consumed at a rate anywhere near that of peak instantaneous flow, the supply systems must be capable of providing that maximum instantaneous flow when required.

During normal diving operations, the mask is supplied with air via a 3/8" ID supply hose approximately 300' long, from either a low pressure compressor and volume tank, or a high pressure gas supply reduced to an intermediate supply pressure via a facility regulator mounted aboard ship. While most facilities can supply large volumes of gas, many cannot supply gas at pressures in excess of 115 psig. In addition, long gas supply piping systems usually encountered cause further pressure reductions which may result in gas supply pressures at the manifold as low as 95 psig. Since gas density and supply pressure are the only variable factors affecting maximum flow, and density is fixed by depth, overbottom pressure controls maximum air flow.

The purpose of the present study is to evaluate effects of supply gas pressure on life support characteristics of the Diver's Mask, USN MK 1 Mod 0.

METHODS

This study was conducted during the decompression phase of a 380 FSW helium-oxygen saturation dive. Decompression was interrupted at 190, 130, 100, and 60 FSW to allow completion of the study. Baseline studies were conducted prior to the dive at a depth of 30 FSW.

Six qualified USN saturation divers ranging in age from 25 to 29 years served as test subjects for this study. A six week course of physical conditioning and dive training was conducted in two phases prior to the dive in order to familiarize the divers with all aspects of the equipment and the experimental protocol, and to minimize any training effect during the actual study. During the first phase, the divers participated in general physical conditioning. This consisted of daily calisthenics and runs of up to 7 kilometers. In addition, each diver pedaled daily on an underwater bicycle ergometer. The work periods imposed were six minutes in length and were separated by four minutes of rest. Exercise began at a work load of 50 watts, and the load was increased 25 watts with each successive work period until the divers could no longer complete the entire six minute cycle. During the second phase, the general physical conditioning continued, but all in-water training duplicated the experimental sequence. The water temperature was maintained to allow diver comfort while wearing swim trunks.

Controlled, reproducible work loads were made possible through the use of a Collins Bicycle Ergometer especially modified for underwater use.[1] The ergometer was calibrated to a Collins control box using a Collins ergometer calibration instrument.

Divers wore one of two standard USN MK 1 Mod 0 Diver's Masks. Gas supply was derived from a supply regulator located in the chamber immediately above the wet chamber. This regulator reduced the supply pressure from 1200 psig to that utilized in the study. Air then flowed through a 400 foot length of 3/8" internal diameter diver's hose to the MK 1 Mod 0 Mask. Overbottom pressures were set utilizing a 0 - 200 psig Roylyn gauge which was calibrated prior to the study. Supply pressure variations were measured with a Validyne Model DP-15 differential pressure transducer connected to a Validyne CD-12 control box and Gould Brush Model 2400 dual channel recorder mounted outside the chamber. The Validyne transducer was calibrated to agree with the Roylyn gauge prior to each day's diving. The supply pressures were adjusted while the diver was breathing. Comparison of the overbottom pressure settings during flow and no flow conditions were identical.

The differential pressure between the oral-nasal cavity and the ambient water was continuously recorded utilizing a Validyne Model DB-15 transducer modified for underwater use. A 0-5 psig diaphragm was used. The oral-nasal cavity was referenced to water pressure at the level of the MK 1 Mod 0 faceplate, and each transducer was calibrated daily with a water filled manometer. Figure 1 shows an instrumented MK 1 Mod 0 Diver's Mask.

The oral-nasal peak differential pressure was the criterion by which the life support characteristics of the USN MK 1 Mod 0 Diver's Mask was judged. This parameter was selected because differential pressures rapidly increase from a baseline level when maximum regulator flow is approached or exceeded.[2]

The test procedure consisted of two phases (Figure 2). During the initial phase, the ergometer work load that the individual diver would perform during the actual test was determined. This was conducted at 30 and at 190 FSW and was accomplished by subjecting each diver to graded exercise levels for 6 minute intervals beginning at 75 watts. The exercise level at which the mask was tested was established as 25 watts below the maximum level that could be tolerated by each diver for an entire six minute cycle. For studies at intermediate depths, a six minute warm-up at 75 watts was utilized prior to phase two.

The second test phase consisted of two periods during which a diver worked at his exercise level as determined above. During the first test period, supply pressure was reduced in 15 psig increments at 30 second intervals until the differential pressure developed exceeded that attained by the diver during his maximal work. Each diver then rested for 4 minutes. During this rest period, the demand regulator "dial-a-breath" was adjusted to induce free flow and then backed off until free flow stopped. The facility regulator was readjusted to a pressure 5 psig above the terminating pressure in the first test. During the second exercise period, overbottom pressure was reduced in 5 psig increments at 30 second intervals. This continued until differential pressures rose sharply.

RESULTS

During each exercise period, oral-nasal differential pressures rose continually for the first three minutes, and then stabilized. Table 1 shows the work rates performed by each diver, and the stable differential pressures generated at the depths and overbottom pressures tested. With the supply gas pressure set at 135 psig, the mean differential pressures increased from 9cm H_2O at 30 FSW to 30cm H_2O at 190 FSW (Table 2).

As overbottom pressure was reduced from 135 psig, the differential pressures remained stable until a supply pressure of 115 psig was reached. With each reduction in supply pressure below 115 psig there was an increase in the differential pressures recorded. Figures 3 through 7 show the mean changes in differential pressure at each depth as a function of overbottom pressure. Figure 8 represents the mean changes for all depths tested.

Comparison of the differential pressures generated prior to and after adjustment of the "dial-a-breath" showed no significant differences. In a few instances, the differential pressures actually increased following this adjustment.

DISCUSSION

Reduction of the overbottom pressure supplied to the MK 1 Mod 0 Diver's Mask caused a striking increase in oral-nasal differential pressure with respiration as the supply pressure was reduced below 115 psig overbottom. At lower supply pressures in the range of 100 to 85 psig, the demand regulator performance became exquisitely sensitive to minor variations of supply pressure. All these results were consistent between 30 and 190 FSW and among all the test subjects. Furthermore, the "dial-a-breath" setting did not significantly influence the results. If 115 psig overbottom pressure is considered the minimum supply pressure before MK 1 Mod 0 Diver's Mask performance begins to deteriorate, then the supply pressure guideline as given in the U.S. Navy Diving Manual is inadequate shallower than 150 FSW,[3] as graphed in Figure 9.

These results were obtained from highly fit divers performing 100 or 125 watts work on a bicycle ergometer at an estimated oxygen consumption of 2.5 liters per minute, purposely below the divers' maximum work capabilities.

An oxygen consumption of 3.0 liters per minute might be sustained by a diver of average size and fitness. Work loads of this magnitude would be expected to cause even greater oral-nasal differential pressures than were observed in the present study.

In a demand system the differential pressures are closely related to the work of breathing. For the diver, work of breathing is the mechanical work done against the resistance to air flow. Work of breathing represents the product of oral-nasal differential pressure and air flow. In this study air flow was assumed to be reasonably constant at the sustained work rates. Therefore, a rise in oral-nasal differential pressure was considered to be an indication of increased work of breathing.

Excessive work of breathing is a common problem of diving and may result in inadequate pulmonary ventilation. In the usual diving situation, inadequate ventilation of the lungs will manifest itself in insufficient elimination of carbon dioxide and results in excessive carbon dioxide levels in the blood and tissues.

The retention of carbon dioxide indicates a compromise by the body. In the face of excessive work of breathing, the body tolerates some rise in carbon dioxide tension in preference to expending the effort that would be required to keep it at the original level.[4]

This rise in carbon dioxide tension in the arterial blood and tissue of the diver makes him more susceptible to oxygen toxicity and probably decompression sickness. In addition, the retained carbon dioxide enhances nitrogen narcosis, making it far in excess of that ordinarily experienced during air diving.

SUMMARY

In summary, the results of the present study indicate that reduction of overbottom supply pressure below 115 psig leads to a deterioration of the life support characteristics of the Diver's Mask with an increase in the work of breathing and possible retention of carbon dioxide. To assure under all circumstances that the air pressure supplied will not limit a diver's ability to work and will not reduce the margin of safety, it is recommended that the MK 1 Mod 0 be supplied with an overbottom pressure well in excess of that shown to be associated with deterioration in life support.

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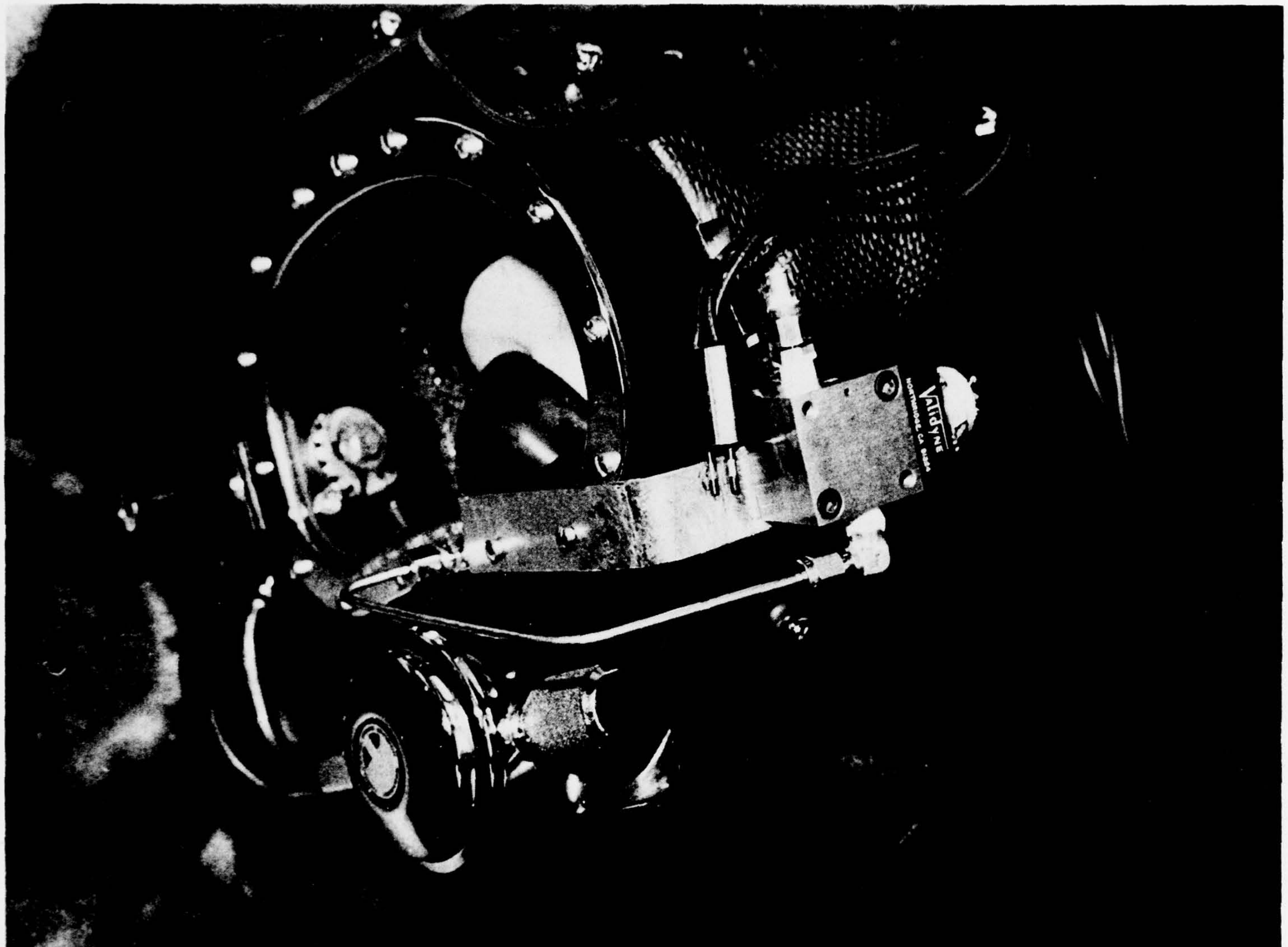


FIG. 1. Divers Mask Mk 1 Mod 0 instrumented with Validyne Model DP-15 Differential Pressure Transducer.

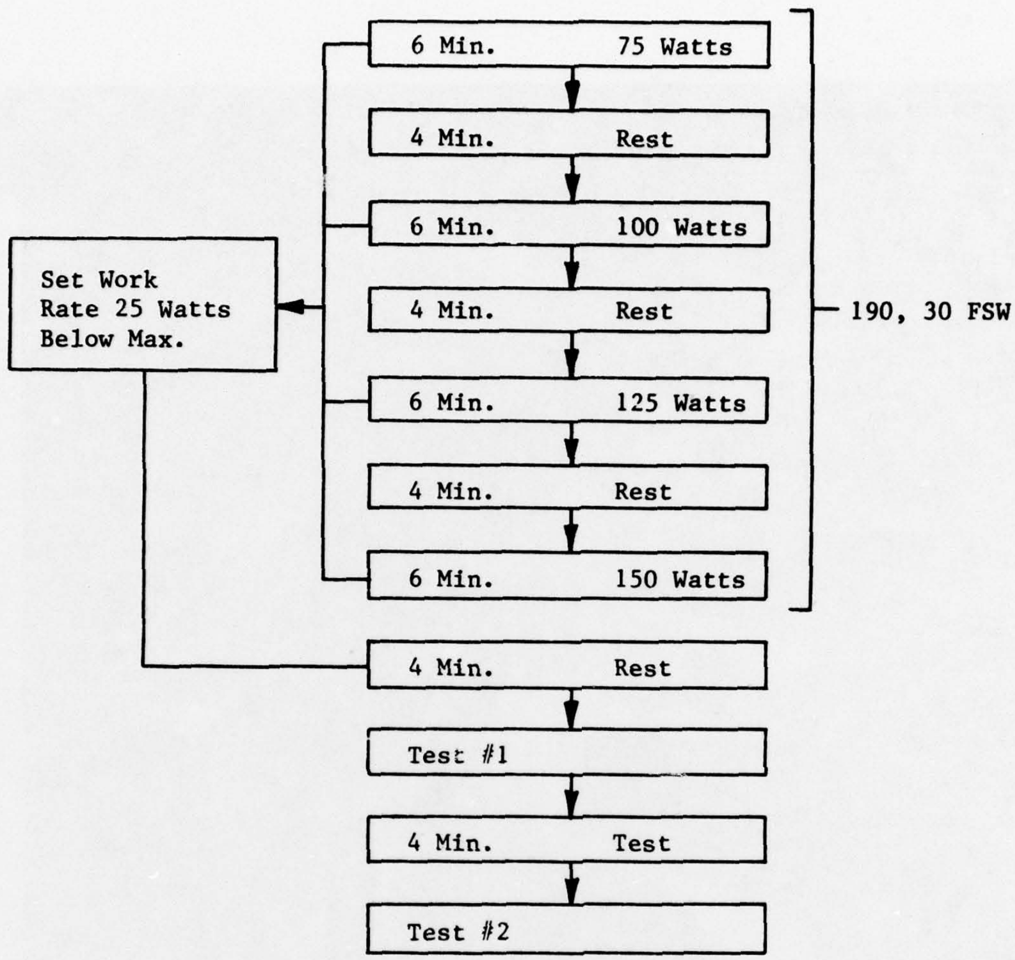


FIG. 2. Diagramatic representation of the work cycle used. Each diver exercised at the indicated work rates for 6 min interspersed with 4 min rest periods to maximum tolerance. Tests #1 and #2 were conducted at progressively decreasing supply pressures until differential pressures became excessive. At depths other than 30 and 190 FSW, 75 watt warm up was used and test #1 begun.

SUBJECT NO.	WORK WATTS	DEPTH (FSW)	DIFFERENTIAL PRESSURES (cm H_2O) OVERBOTTOM SUPPLY PRESSURE (PSIG)									
			135	115	95	90	85	80	75	70	65	60
#1	100	190	26	26	36	38	40		54			
	125	130	32	32	36	44	49		60			
	125	100	28	28	34	36	48		60			
	125	60	19	23	24			28	35	42		
	125	30	8	9	9	11	13					
#2	100	190	30	30	40							
	100	130	18	18	38	38	54					
	100	100	23	24	23	32	41	72				
	100	60	16	22	25				44			
	100	30	9	9	8	8	12	16				
#3	125	190	28	30	29	38	44					
	125	130	23	23	28	29	33		42			54
	125	100	20	20	18	20	22	23	26	36		
	125	60	14	17	19	20	22	23	26		36	
	125	30	5	5	6				6		6	9
#4	125	190	36	36	42	50	60					
	125	130	19	18	26	30				35		37
	125	100	26	27	31	36	38		43			
	125	60	19	19	19				23			30
	125	30	12	14	18	22						
#5	125	190	28	28	32	36	54					
	150	130	22	22	25	28	29	32	40	58		
	150	100	22	24	30	30						
	125	60	19	20	26				48			
	125	30	12	15	20	22						
#6	125	190	31	31	34	54						
	125	130	25	25	30	39	45					
	125	100	20	20	29							
	125	60	17	20	30				52			
	125	30	10	10	16	24						

TABLE 1. DIFFERENTIAL PRESSURES DEVELOPED AT THE DEPTHS TESTED FOR VARIOUS AIR SUPPLY PRESSURES.

DEPTH (FSW)	Δ P (cm H_2O)
190	30
130	23
100	23
60	17
30	9

TABLE 2. Baseline Mean Oral-Nasal Differential Pressure (ΔP) At 135 (PSIG) Overbottom Supply Pressure

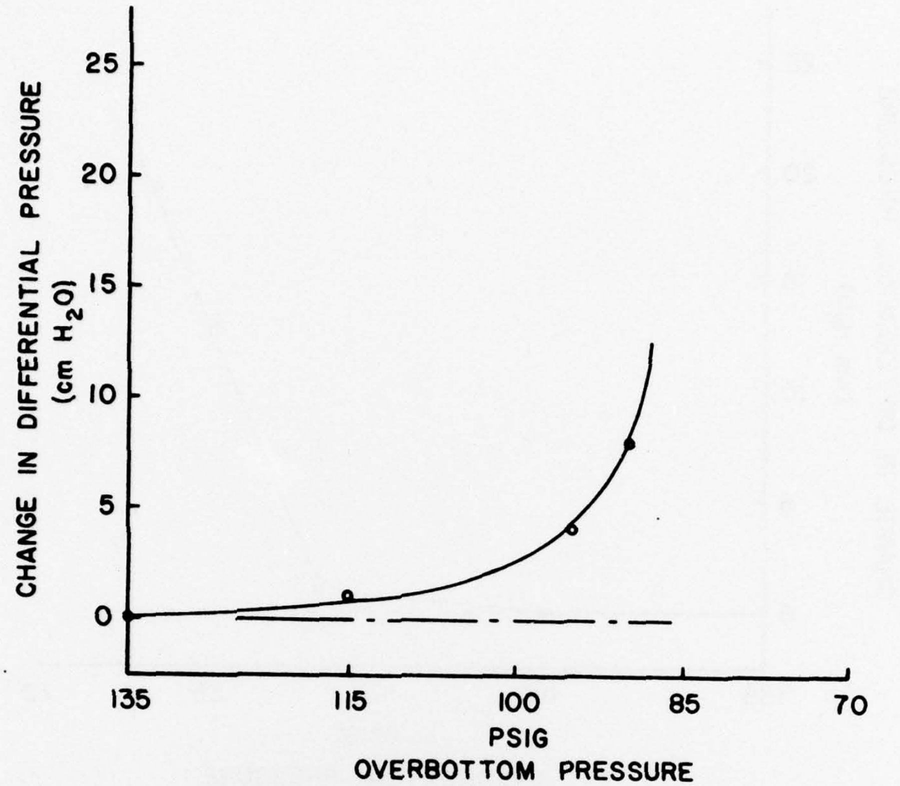


Figure 3. **Mean change in differential pressure versus overbottom pressure at 30 FSW.**

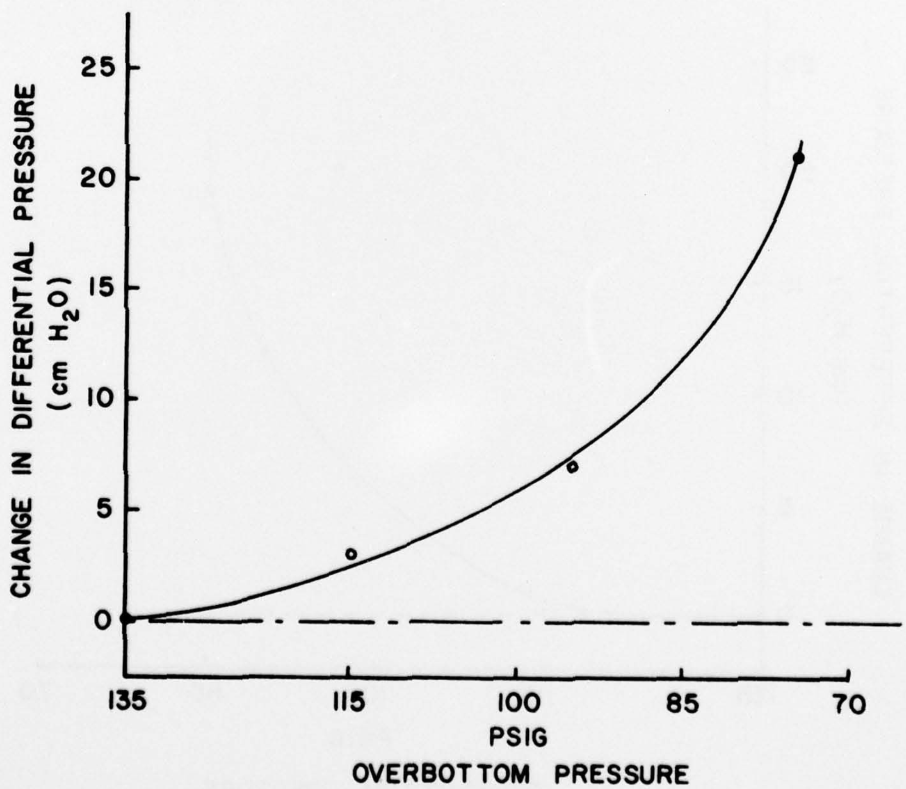


Figure 4. **Mean change in differential pressure versus overbottom pressure at 60 FSW.**

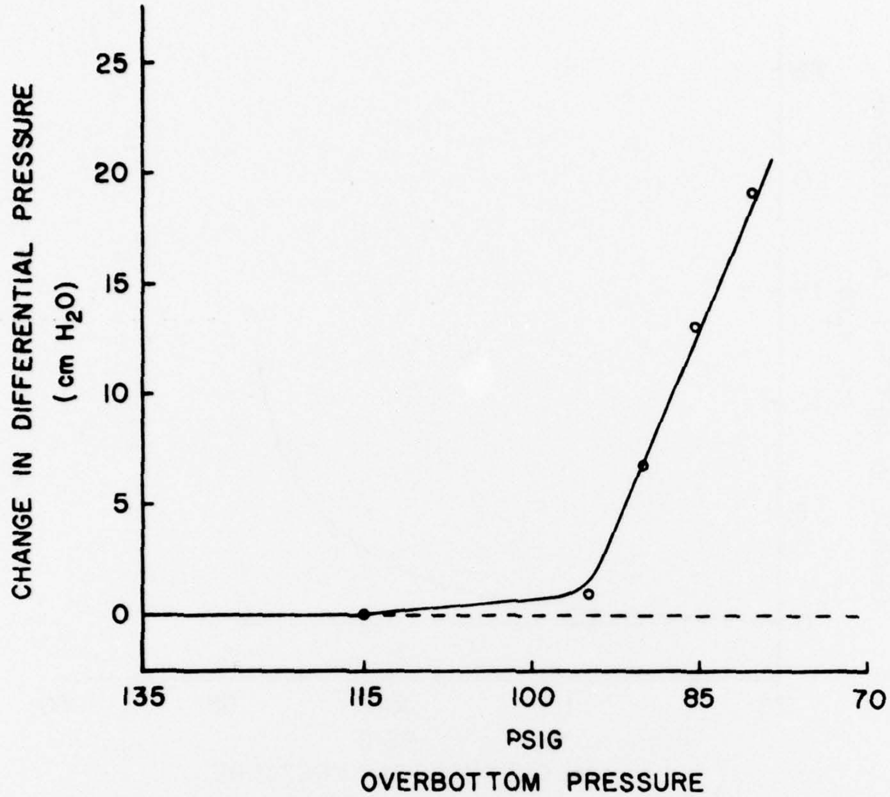


Figure 5. Mean change in differential pressure versus overbottom pressure at 100 FSW.

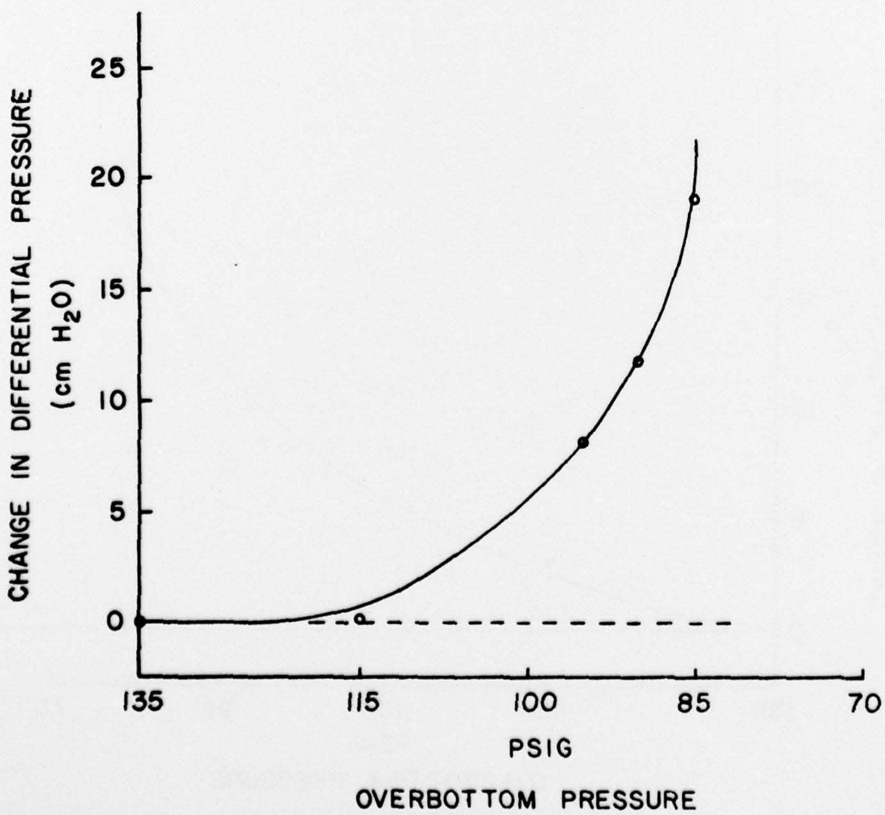


Figure 6. Mean change in differential pressure versus overbottom pressure at 130 FSW.

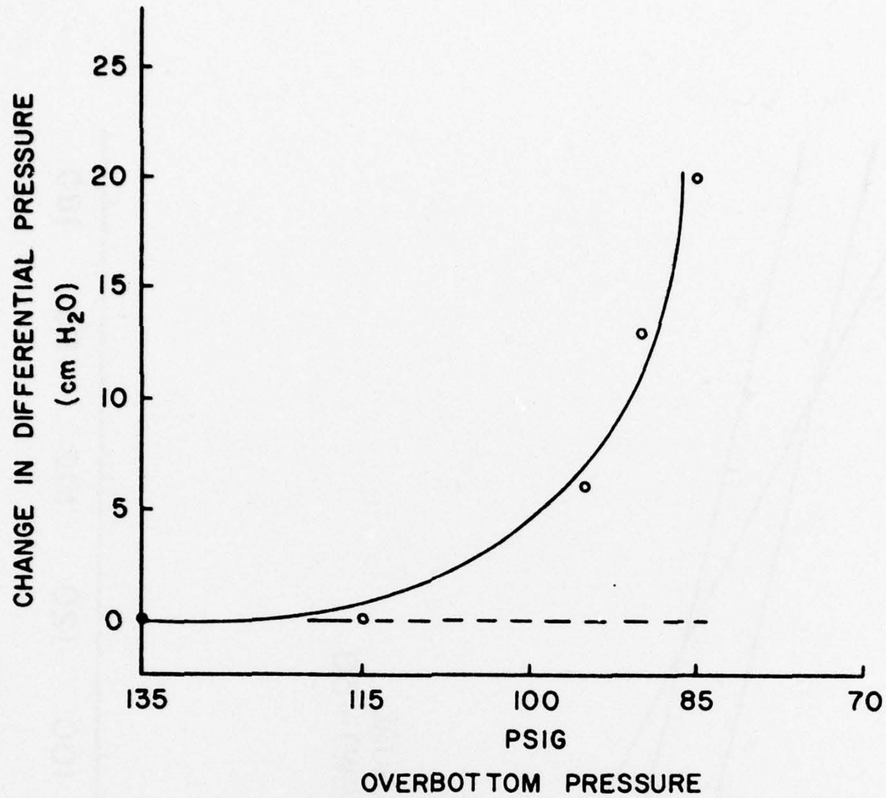


Figure 7. Mean change in differential pressure versus overbottom pressure at 190 FSW.

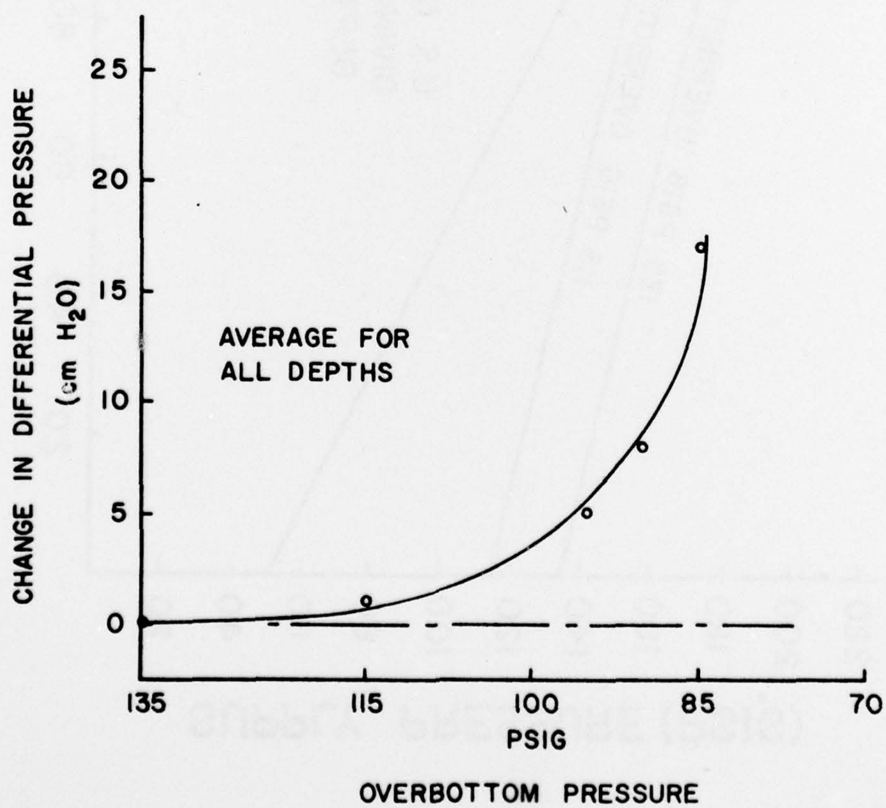
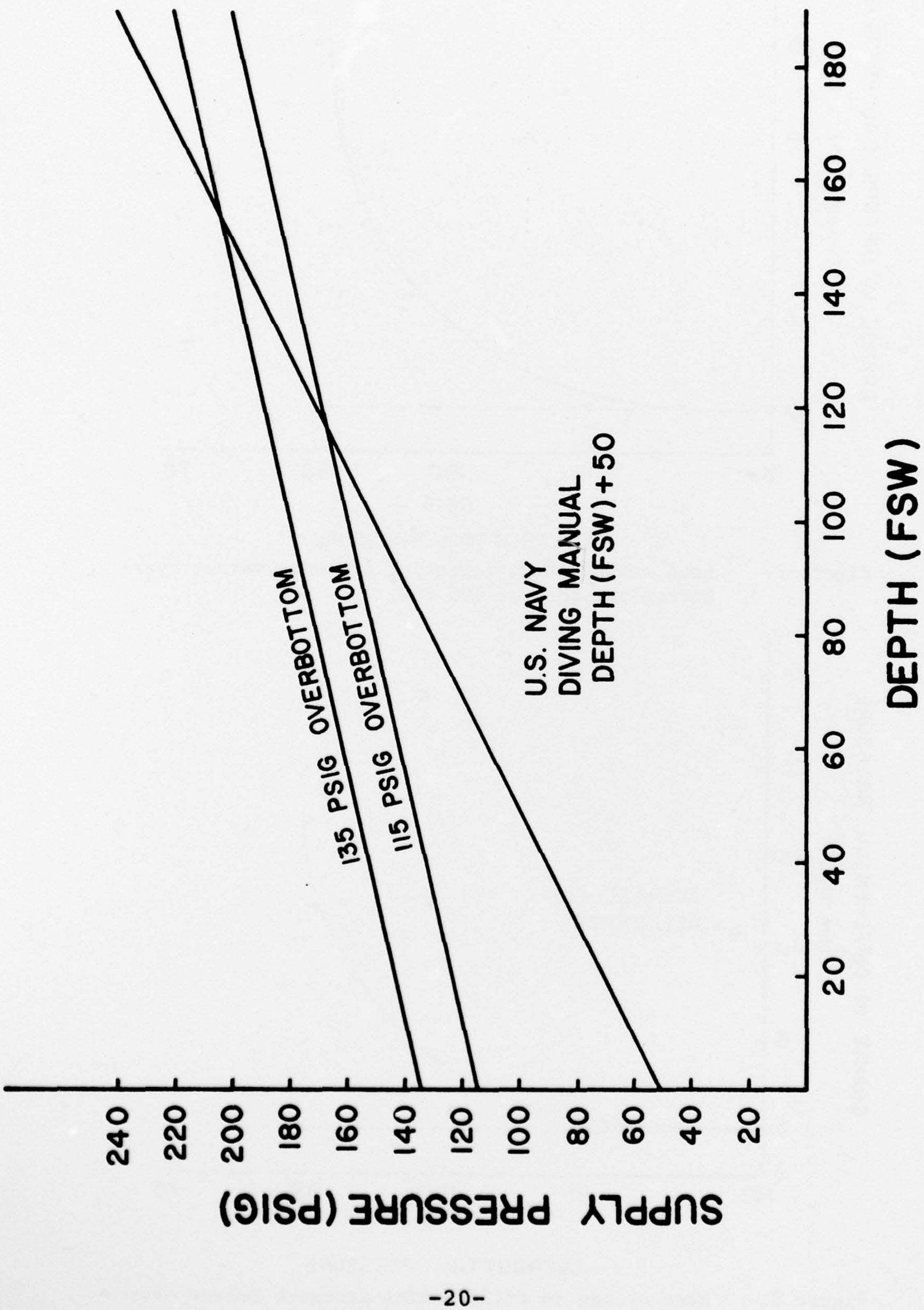


Figure 8. Mean change in differential pressure versus overbottom pressure for all depths tested.



135 PSIG OVERBOTTOM
115 PSIG OVERBOTTOM
U.S. NAVY
DIVING MANUAL
DEPTH (FSW) + 50
DEPTH (FSW)
SUPPLY PRESSURE (PSIG)
20
40
60
80
100
120
140
160
180
200
220
240

Figure 9