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# UNDERWATER PRESSURE-COMPENSATED BREATHING CONTROL VALVES FOR PROLONGED WATER IMMERSION

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HENRY W. SEELER

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**UNDERWATER PRESSURE-COMPENSATED  
BREATHING CONTROL VALVES FOR  
PROLONGED WATER IMMERSION**

*HENRY W. SEELER*

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## FOREWORD

The design concepts reported herein were developed by the author, Chief, Design & Fabrication Branch, Biotechnology Division, Biomedical Laboratory. The work was performed as the result of a request by the Multienvironment Division, Aerospace Medical Research Laboratories, under Project No. 7222, "Biophysics of Flight." The research was initiated February 1960 and completed June 1962.

The author is grateful to Mr. Lonnie Yeary of the Aeronautical Systems Division for his participation in making all the valves and accessories; for standing by during the author's diving experiments; and for modifications made directly at the pool.

This technical report has been reviewed and is approved.

WAYNE H. McCANDLESS  
Technical Director  
Biomedical Laboratory

## ABSTRACT

Two water-pressure-compensated breathing devices for prolonged immersion have been designed, fabricated, and tested underwater. One valve is a continuous-flow regulator and the other is a demand regulator. Both valves allow exhalation through a hose directly into the surface atmosphere for air analysis. One of the two valves has been used extensively during prolonged weightlessness simulation tests by immersion.

## SECTION I

### INTRODUCTION

For prolonged water immersion experiments, an adequate breathing system, using filtered compressed air, was required. To analyze the subject's exhaled air continuously, it had to be brought above the surface through a hose while the subject's body was still subjected to water pressure.

Standard underwater demand valves, such as those used with various scuba outfits, could not be used without modification, because the exhaled air would bubble to the surface where it could not be collected effectively for analysis. However, standard equipment may be used if modified with an underwater-pressure-compensating device as described in this report, provided the breathing resistance is not too high, which unfortunately exists in most straight demand outfits commercially available.

This report describes two pressure-compensated, underwater breathing regulators suitable for use by a person immersed for a long period of time in a water tank or pool of any size and depth. Both regulators were designed, fabricated, and tested by the Aerospace Medical Research Laboratories.

## SECTION II

### DESIGNS

The first design, a continuous-flow valve, was used during prolonged immersion research tests.<sup>1</sup>

The second design, an advanced underwater-pressure-compensated demand valve, was tested underwater to a depth of 2.6 meters (8.5 ft) with the exhalation hose leading to the surface for the purpose of analyzing the exhaled air. This valve follows the breathing pattern during shallow or deep breathing and allows collection of the expired air for analysis.

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<sup>1</sup> Graveline, D. E., Maintenance of Cardiovascular Adaptability During Prolonged Weightlessness, ASD Technical Report 61-707, Aeronautical Systems Division, Wright-Patterson Air Force Base, Ohio, Dec 1961, (AD 273 605).

## WATER-PRESSURE-COMPENSATED CONTINUOUS-FLOW AIR CONTROL VALVE

Figure 1 shows the subject floating under water in the tank. His body is subjected to different pressure levels according to the depth of the different body parts. This fact was considered in determining the right depth position for the air control valve.

As shown on figure 1, the compressed air is taken from the house air line or from separate air tanks. After passing through an air filter, the air flows to a manually adjustable flow control valve connected to an air flowmeter, where the amount of adjusted air flow can be read. From here the air flows into a flexible air hose that floats in the water tank and leads to the subject's helmet. An airstream distribution system within the helmet circulates airflow around the subject's head, where part of the air is inhaled and the remainder flows with the exhaled air, through the water-pressure-compensated, continuous-flow air control valve into the exhalation hose. The exhaled air flows through the hose to the surface of the water either directly into the atmosphere or into an air analyzing system.

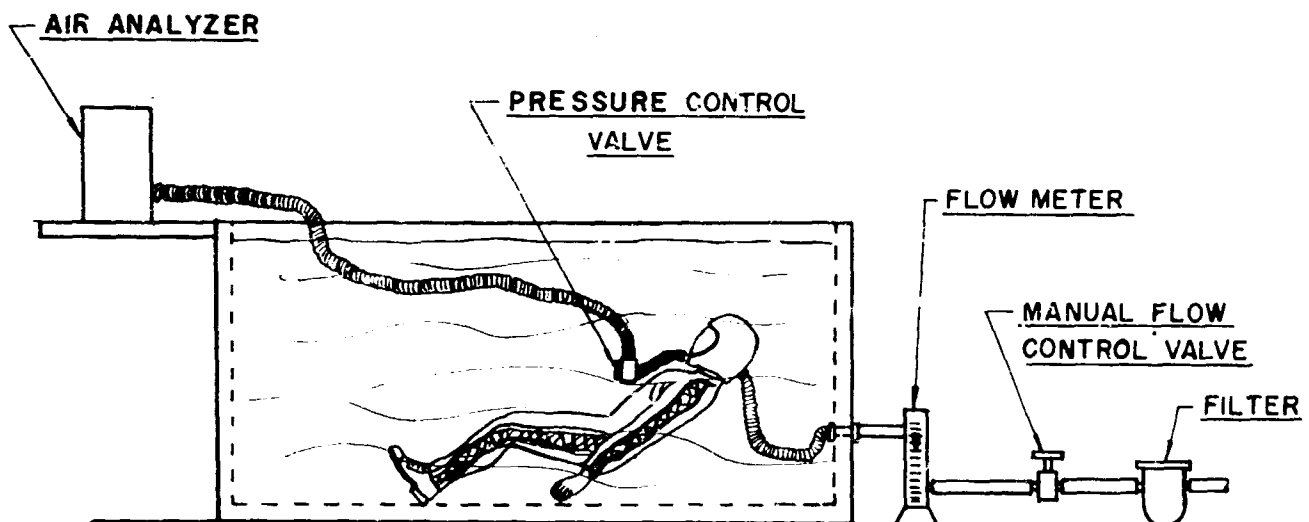


Figure 1. Underwater Application of Continuous-Flow Air Control Valve

Since the submerged subject is exposed to water pressure, he cannot exhale directly into the atmosphere by means of a hose, because of the pressure against his chest and the lower atmospheric pressure within his lungs. Therefore, the compensating breathing control valve is required between the surfacing exhalation hose and the helmet. The valve operates as follows (see figure 2): Port A may be connected either to the helmet or to a hose leading to the helmet. Port B is connected to an exhalation hose leading to the water surface. A free floating but guided valve plate touches the valve seat and shuts off the airflow coming through port A by means of a water pressure actuated diaphragm, the diaphragm plate and the guided pin. The effective area of the compensating diaphragm and the valve seat are equal. If the valve is balanced for the same water depth as the subject's chest, the pressure is equalized against his chest and the buildup air pressure within the valve, helmet, and lungs.

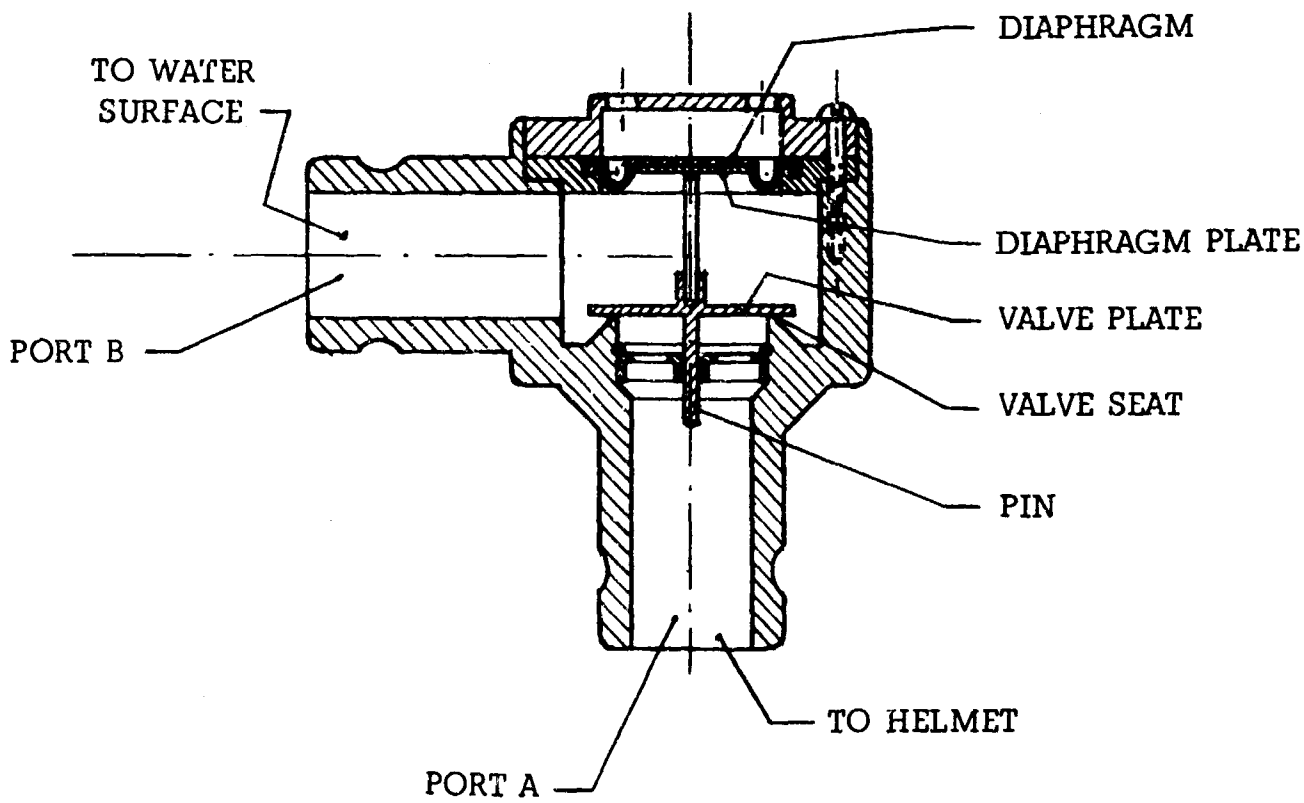


Figure 2. Continuous-Flow Air Control Valve



During inhalation, the water pressure against the diaphragm and pin closes the valve against the seat. During exhalation, the air within the system accumulates and builds up pressure equal to the water pressure against the diaphragm. When the pressure within the system exceeds the water pressure, the valve opens and both the exhaled air and the unused supply air flow freely through the exhalation hose to the surface.

Through use of the described pressure-compensated, airflow pressure control valve, the air pressure within the helmet can be balanced with the water pressure against the subject's chest. This can be accomplished at any depth, and the most suitable and comfortable pressure can be obtained for the subject by moving the control valve up or down.

Figure 3 shows the water-pressure-compensated air control valve in actual use.

Figure 4 shows a system almost equal to figure 1, except that the airflow can be regulated from within the tank by the subject instead of from outside the tank by the attendant.

#### UNDERWATER-PRESSURE-COMPENSATED DEMAND VALVE

The continuous-flow air system previously described has certain disadvantages. For example, analysis of expired air is difficult because it is diluted with unused compressed air that flows during the exhalation phase and during shallow breathing.

For exact air analysis and to provide more comfort for the subject, an underwater-pressure-compensated demand valve was developed by Aerospace Medical Research Laboratories. This valve, designed to have very low breathing resistance, was tested under water at the maximum depth of the pool [2.6 meters (8.5 ft)] with the exhalation hose leading to the surface. Figure 5 shows this valve during a pressure compensating underwater test with the subject's chest at a depth of 1.2 meters (4 ft).

To obtain the right breathing resistance and good valve performance, the valve must be moved up or down with respect to the chest position and then fastened in place when the correct position is achieved.

The underwater application of the compensated demand valve is shown in figure 6, and the valve operates as shown in figure 7. A hose supplying air at approximately  $4-5 \text{ kg/cm}^2$  (60-70 psi) pressure is connected to the demand valve at A. Fitting B is connected to either a mouthpiece or to two short helmet hoses, and fitting C is connected to the exhalation hose leading to the water surface.

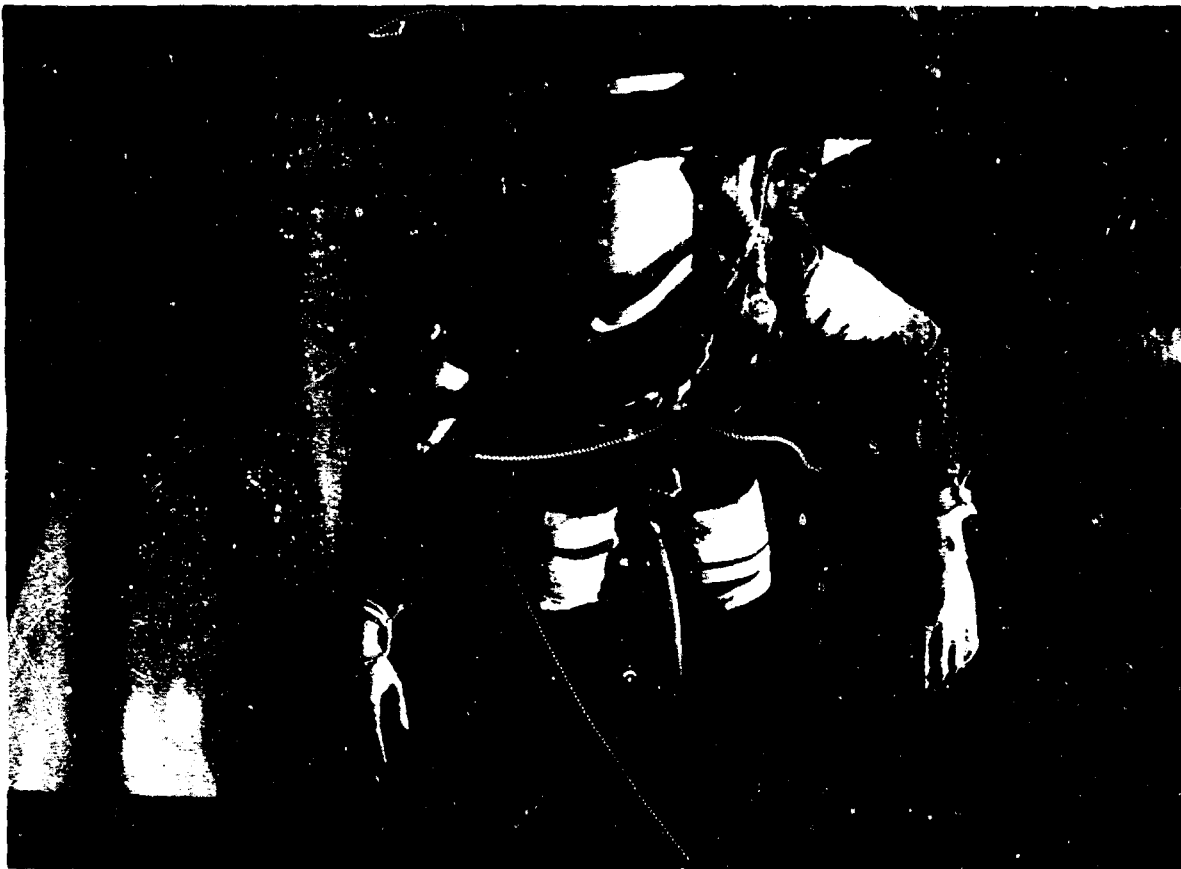


Figure 3. Testing the Continuous-Flow Air Control Valve

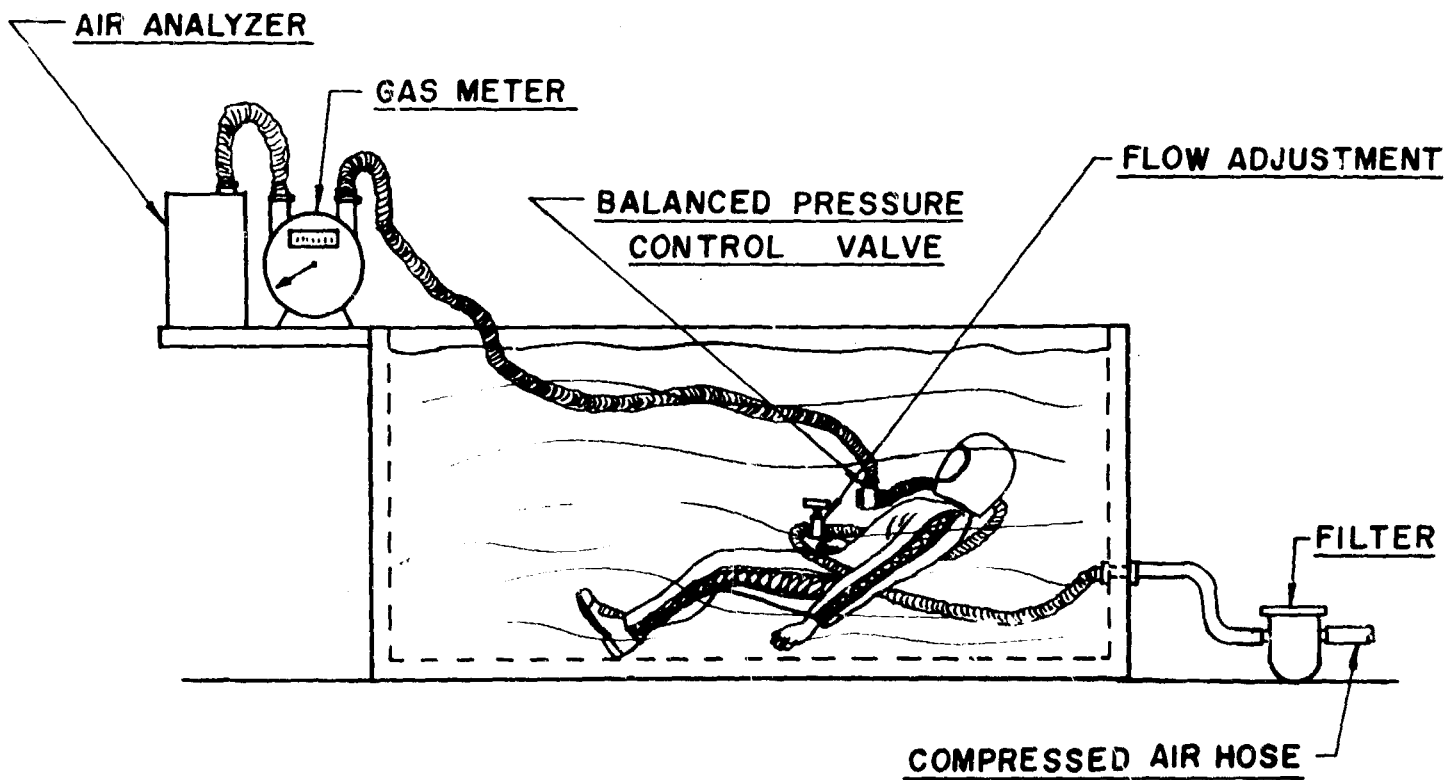


Figure 4. Underwater Application of Airflow Adjustment



Figure 5. Testing the Water-Pressure Compensated Demand Valve

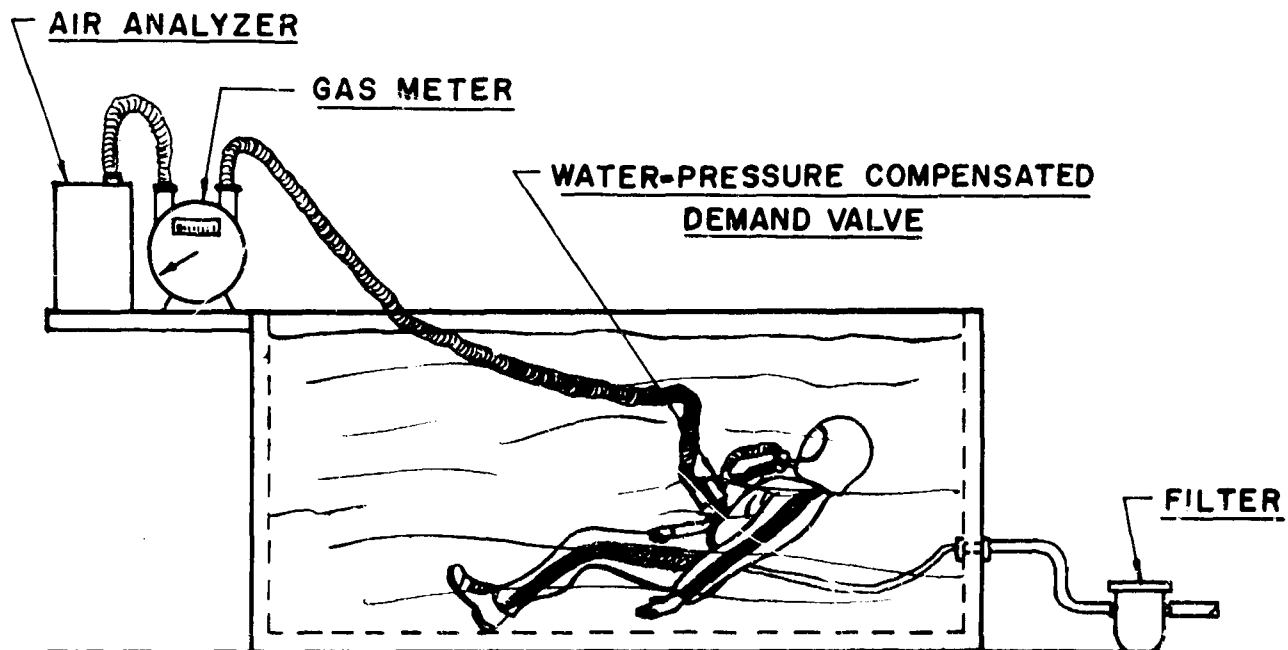


Figure 6. Underwater Application of Water-Pressure Compensated Demand Valve

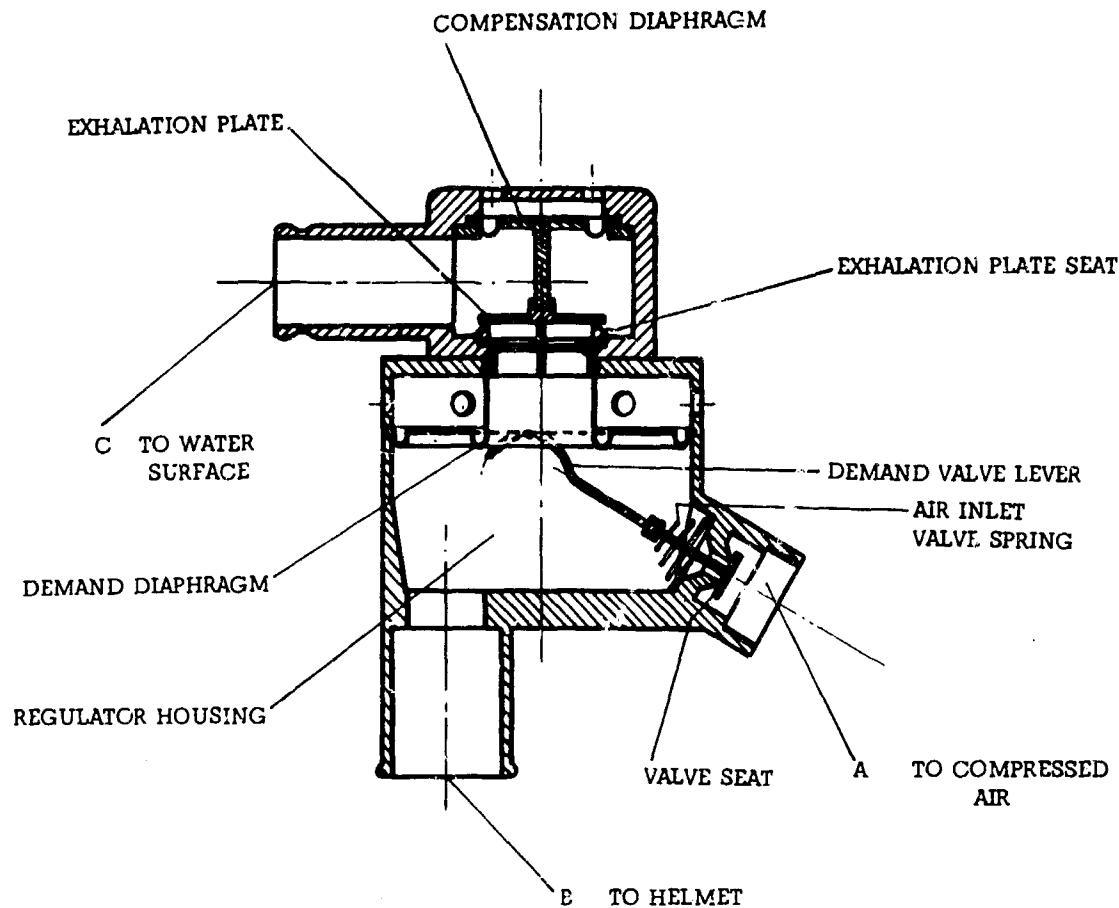


Figure 7. Water-Pressure Compensated Demand Valve

When the subject inhales, he creates a slight negative pressure within the regulator housing which forces the demand diaphragm inward, whereby the demand valve lever is pressed inward also and the valve seat within the compressed air line is unseated, allowing compressed air to flow into the housing and from there into the lungs of the subject. When the subject ceases to inhale, the negative breathing pressure within the regulator housing ceases to exist and, therefore, the diaphragm moves back into its neutral position which then removes the opening force from the demand lever and valve seat, closing and cutting off the airflow.

During the subject's exhalation phase, the air passes into the regulator housing and from there to the exhalation plate. The exhalation plate is pressed against the seat by water pressure transmitted by means of the diaphragm. Since the effective area of the diaphragm is the same as the effective area of the valve plate, the exhalation force is balanced with the water pressure regardless of the water depth, assuming that the subject's chest is at the same depth as the demand valve. If the exhalation air pressure exceeds the water pressure on the compensating diaphragm, the seat opens and the exhalation air flows freely through fitting C into the exhalation

hose and to the atmosphere outside the water tank. If this demand valve system is to be used for a limited time only, a mouthpiece can be connected directly to fitting B (figure 7) and the subject may wear goggles for eye protection.

For a prolonged underwater test period with the subject wearing a helmet, a second tube system (figure 5) with built in inhalation and exhalation valves between helmet and regulator should be supplied to reduce the dead volume of the system used during the tests.

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Protective clothing Respiration Breathing apparatus Breathing masks Pressure breathing Pressure regulators (water-pressure-compensated) Weightlessness (simulated)						

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