SIMULATOR MEASUREMENT OF
THE WORK OF BREATHING
FOR UNDERWATER BREATHING APPARATUS

by

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Title of Thesis/Project/Extended Essay

Simulator Measurement of the Work of Breathing

for Underwater Breathing Apparatus

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ABSTRACT

In the design of diving equipment, one of the most important considerations is the underwater breathing apparatus. The need for revision of the existing operating standards of breathing resistance for this apparatus is a topic under current discussion. One suggested, but not established standard for respiratory devices recommended that the ratio between work of breathing for the apparatus (kg.m./min.) and minute volume (liters/min.) should not exceed one-eighth.

Measurement of the work of breathing for underwater breathing apparatus using a respiration simulator permits evaluation of apparatus performance in terms of physiologically acceptable respiratory work rates. The purpose of such measurement is to establish revised limits for the work of breathing and consequent increase in diver comfort, performance, and safety in underwater operations.

The ventilatory power requirements of two open circuit demand underwater breathing apparatus were calculated using steady state flow measurements and dynamic respiratory simulations at 1 atmosphere. In calculating the work of breathing, flow rates were sinusoidal and in the physiological range of up to 3 liters tidal volume and 30 cycles/min. respiratory frequency. Dynamic resistive

work of breathing attained values as high as 18.56 kg.m./min. at 95.9 liters/min. ventilation for a mouth-held demand regulator. A back-mounted demand regulator attained values as high as 20.22 kg.m./min. at 80.1 liters/min. dynamic ventilation.

Approximations of the steady-state work of breathing consistently underestimated the ventilatory requirements of the breathing apparatus, apparently as a result of hysteresis losses and exhaust bubble formation in the apparatus. Steady-state flow testing was thus found invalid as a means of evaluating the work of breathing in underwater breathing apparatus.

The difference in hydrostatic pressure between the diver's lung centroid and the demand regulator diaphragm of his open circuit breathing equipment (i.e., the ambient respiratory pressure) was also measured for ten divers. This was done at several swimming orientations and in a working position using both mouth-held and back-mounted demand regulators. Mean values of hydrostatic pressure in swimming were found to be of the form $40.0 \sin(a-14.5\ ) + 4.3$ cm. H O with a mouth-held regulator and $27.9 \sin(a+33.8\ ) + 2.9$ cm. H O with a back-mounted regulator, where "a" represents the orientation of the diver with respect to the horizontal, $(-90.\ <a<90.\ )$ In the upright working position

the mean values of hydrostatic pressure difference were 24.1 + 3.7 cm. H O with a mouth-held regulator and 24.7 + 2.6 cm. H O with a back-mounted regulator. This data was used to determine the effect of hydrostatic pressure imbalance on the inspiratory and expiratory components of the total work of breathing. Results indicate that in the worst cases, hydrostatic pressure imbalance may cause a two to four fold increase in inspiratory or expiratory work.

The results of this study support those of other investigations, that even at 1 atmosphere some underwater breathing apparatus presently in use exceed recommended respiratory power requirements at ventilatory rates associated with heavy exercise.

ACKNOWLEDGEMENTS

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TABLE OF CONTENTS

Related Literature

Methods & Apparatus

Results

LIST OF FIGURES

LIST OF APPENDIXES

INTRODUCTION

The ability of man to not only survive, but also to perform useful work in the ocean has become increasingly important to scientific, military, and economic interests. For the working diver, bottom time, pressure, thermal-balance, mobility, and equipment all represent physiological challenges whose consideration becomes more and more important as his task requirements increase. An understanding of the relationship between these conditions and the diver is necessary for increased underwater work capacity. Additional information on energy expenditures of divers is needed. Ergonometric tests which reproduce real conditions must therefore be devised, (Bradley, 1973.)

In the design of the man/machine system, the most critical of the diver's equipment is the underwater breathing apparatus, (UBA). At present, however, the only breathing resistance standards in operation for UBA are U.S. Navy peak inhalation and exhalation pressure limits for open circuit scuba (Reimers, 1973). The potential importance of simulator measurement of UBA resistance as done in this investigation is in providing a means for the assessment of existing units on a physiological basis with possible incorporation into two long term aims:

1. Increased diver performance through minimization of the physiological cost of meeting equipment respiratory demand.
2. Establishment of standards of maximum allowable UBA resistance.

Finally, an increase in general diver comfort will favorably affect the efficiency of the diver and thus have a direct bearing on safety in underwater operations.

RELATED LITERATURE

PART I. RECENT DIVING PRACTICE

In order to prolong a diver's stay underwater, he must be supplied with a breathable gas mixture. This can be furnished remotely from either an underwater habitat or from the surface via hose, as with helmet diving, but this has the disadvantages of restricted mobility and the possibility of the hose fouling on obstructions. A second method, which supplies air through personally transported cylinders and is known as self-contained underwater breathing apparatus, (scuba), may be one of three types. Open circuit scuba supplies gas through a demand valve system and all expired gas is exhausted into the water. The semi-closed circuit scuba delivers nitrogen-oxygen or helium-oxygen mix from the cylinders to a collapsible breathing bag. Exhaled gas passes through a carbon dioxide scrubber and returns to the breathing bag for reuse. A purge valve permits excess gas to escape from the bag to prevent overpressure. The closed circuit unit, similar to the semi-closed circuit device, utilizes the oxygen in the breathing gas mixture without overpressure purge by measuring the exact amount of oxygen required for make-up. While extending dive time for a given amount of gas mixture, this requires reliable oxygen sensors to insure correct composition for a particular depth.

PART II. FACTORS IN DIVER RESPIRATION

Man's functional capacity in the hyperbaric environment is limited by his respiratory system and suppporting equipment. The amount of physical work expenditure, the breathing gas density, and the mechanical resistance imposed by his breathing apparatus all create respiratory loads that the diver must be able to sustain. Inadequate lung ventilation resulting from the inability to tolerate such increased loads leads to elevated alveolar CO2 and thus arterial CO2 distubances, (Lanphier, 1969: and Craig, et.al., 1970.)

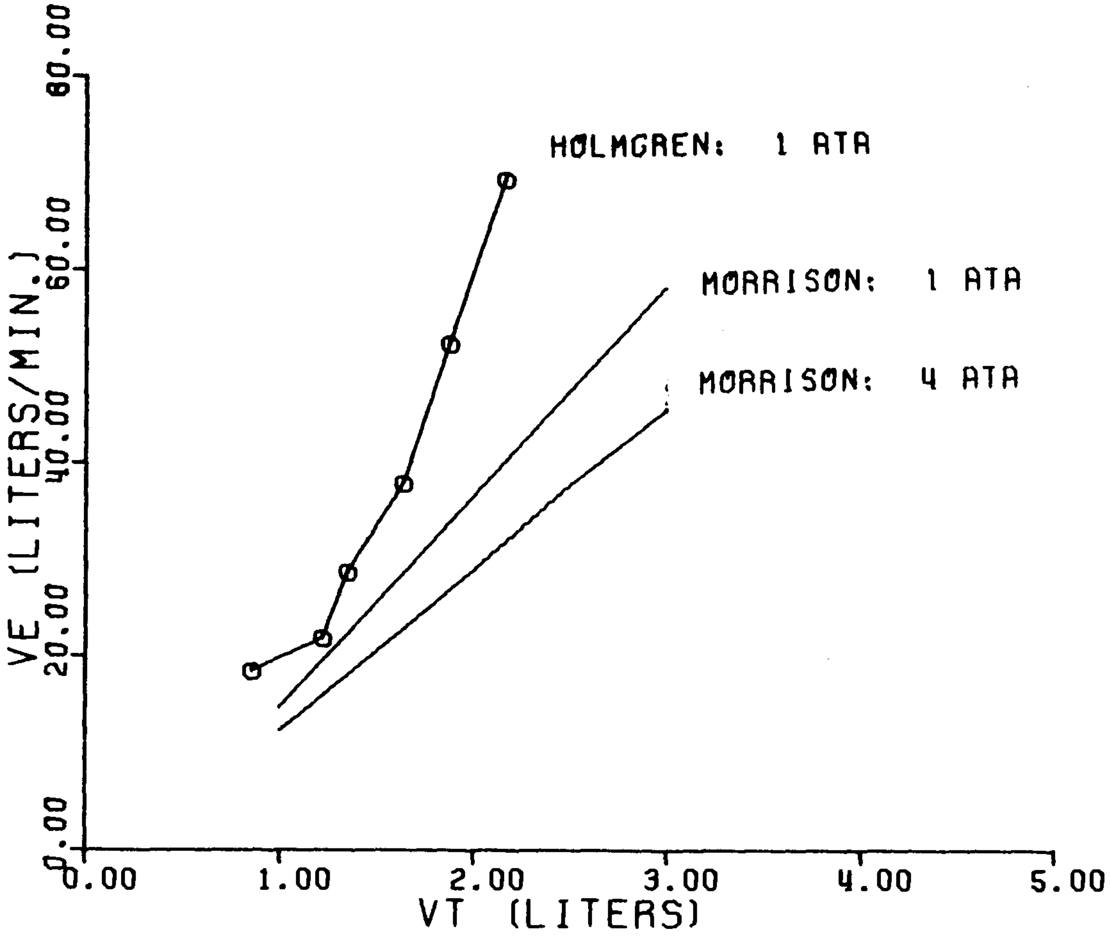
Human simulator testing measures "the critical performance characteristics of a piece of equipment over its entire intended operational envelope," (Reimers, 1973.) UBA simulator testing requires detailed information on diver respiration, particularly ventilation rate, (VE), and tidal volume, (VT), collected under field conditions for constructive evaluation.

A. WORK OF BREATHING

The large ventilation required to meet the metabolic demands of heavy exercise result in a considerable increase in the work of breathing. The total physical work of breathing, which includes both tissue and gas flow resistance, by resting subjects at 1 ATA is approximately 0.3 kg.m./min., (McIlroy, et.al., 1954: Otis, 1954: and Hedstrand, 1969.)

The mechanisms which control frequency and tidal volume with variations in ventilation are not completely clear, but an optimal frequency of breathing exists for a given rate of ventilation and is sensitive to external resistances, (McIlroy, et.al., 1954 & 1956: and Crosfill & Widdicombe, 1961.) Otis, (1954), suggested that frequency was adjusted to minimize the work of breathing, while Mead, (1963), put forth least average muscle force as the determining factor for breathing rate. Hey, et.al., (1966), found a linear relationship between VE and VT up to a VT of about half vital capacity. Further increases in VE were a result of increased respiratory frequency while VT remained constant. This "break point" variation in VT has been reported by other investigators during underwater swimming trials and hyperbaric chamber tests to 4 ATA, (Bradner, 1953: and Morrison, et.al., 1976.) Tidal volume, (liters), is plotted as a function of ventilation, (liters/min.), in Figure 1 from Holmgren, et.al., (1973): and Morrison, et.al., (1976.)

Figure 1 Ventilation, (liters/min.), as a function of tidal volume, (liters), at 1 and 4 ATA breathing air. From Holmgren, et.al., (1973), and Morrison, et.al., (1976.)



TIDAL VOLUME VS. VENTILATION

Elevated end tidal CO2 and marked slower and deeper breathing with long post-inspiratory pauses has been noted in trained underwater swimmers when compared to sedentary and athletic non-divers, (Goff, & Bartlett, 1957: Morrison & Florio, 1971: and Lally, et.al., 1974.) This has been suggested as being partially the result of a significantly lower oxygen ventilation equivalent, (the ratio of ventilation to oxygen consumption), in trained subjects, (Goff & Bartlett, 1957.) No specific advantage has been found for intermittent negative-pressure breathing, or "skip-breathing," sometimes performed by divers, (Daigle, 1975.)

Physiological dead space, the volume of inspiratory air remaining unmixed in the airways and alveoli, has been found during heavy exercise to be approximately twice resting values as a result of larger tidal volumes, (Asmussen & Nielsen, 1956: Hedenstierna, 1972: and Sidorenko, 1972.) During maximal expiratory effort airway resistance also increases mainly because of the collapsing of large airways due to elasticity, frictional pressure losses, and Bernoulli effect, (Clement, et.al., 1974: and Zamel, et.al., 1974.) Thus, beyond a certain point flow becomes effort-independent and additional expiratory effort does not increase expiratory flow, (Miller, et.al., 1971.)

The breathing component of underwater work, the ventilatory power requirement, is commonly measured in kg.m./min. The two components of this effort result from external resistance and hydrostatic pressure imbalance.

Computer monitoring of the mechanics of breathing, including tidal volume, respiratory frequency, and work of breathing, has been developed by several authors to greatly facilitate the analysis of pulmonary function, (Fletcher, et.al., 1966: and Lewis, et.al., 1966.) Inspiratory and expiratory phases were separated at points of zero flow. Digitized flow values were then multiplied by corresponding differential pressures and the product intregrated to obtain work.

B. PHYSICAL WORK LOAD

One of several factors affecting diver respiration, and thus UBA design considerations for breathing gas delivery, is the amount of work exerted by the diver. Respiratory rate, amplitude, and minute volume all vary with changes in the work rate, (Silverman, et.al., 1951.) Divers wearing lead soled shoes are usually unable to reach high levels of oxygen uptake except while working in deep mud, where values of approximately 2 liters/minute have been reported, because of the relatively passive role played by his legs, (Donald & Davidson, 1954.) The oxygen uptake of 'finned' underwater swimmers, however, attains values of 2.5 to 3.0 liters/min., and is representative of levels for other athletic activities, (Donald & Davidson, 1954: Carroll, 1970: and Morrison, 1973.)

While physical work load alone is significant in affecting diver respiration under optimum conditions in shallow water, the additional factors discussed in the following sections are present in increasing amounts with increasing depth and operating difficulty.

C. GAS DENSITY

With increased barometric pressure respiration at rest becomes slower and deeper, probably an adaptation to minimize the increasing work of breathing dense gas. Decreases in both respiratory minute volume for a given ergonometric work load and maximum voluntary ventilation have been reported by several investigators, (Hesser & Holmgren, 1959: Maio & Farhi, 1967: Hesser, et.al., 1968: Bradley, et.al., 1971: Morrison & Florio, 1971: and Schaefer, et.al., 1971.) Decreasing respiratory rates during rest and moderate exercise with increasing pressure were also found, (Hesser &

Holmgren, 1959: Russell, 1971: and Morrison, et.al., 1976.) Figure 1 illustrates the increased tidal volume, (decreased respiratory rate), for a given ventilation at 4 ATA compared to 1 ATA, (Morrison, et.al., 1976.) In trained surface swimmers, however, increased minute volumes and oxygen uptake and decreased swimming times were reported with oxy-helium breathing, (decreased gas density), compared with oxy-nitrogen or oxy-argon mixtures during maximal performance, (Kebkalo & Ponomarev, 1971.)

For gas densities less than six, relative to air at 1 ATA, maximum inspiratory and expiratory flow both vary inversely with approximately the square root of gas density, primarily due to turbulent flow in the airways, (Buhlmann, 1963: and Wood & Bryan, 1971.) Increased airway resistance and reduced maximum breathing capacity are also effects of high pressure caused by the increased density of the breathing gas, (Marshall, et.al., 1956: Dougherty & Schaefer, 1968: Schaefer, et.al., 1971: and Morrison & Butt, 1972.) High molecular weight gases of equal density have been found to produce similar respiratory changes, (Lord, et.al., 1966.)

This progressive increase in expiratory resistance and decreasing maximal expiratory flow with depth, rather than the increased oxygen cost of breathing, has been suggested as the limiting respiratory factor in diving, (Glauser, et.al., 1967: and Varene, et.al., 1974.)

Added non-elastic breathing resistance has been found to result in an increased respiratory cycle time, particularly for the expiration phase, with accompanying decreased peak expiratory flow, (Cain & Otis, 1949.) The relatively shortened inspiratory phase with resulting higher peak inspiratory flows, may thus cause inspiratory work to be greater than expiratory work for equal resistances. This is supported by Silverman's findings, (1951), that exercise tolerance is less with expiratory resistance than with an equal inspiratory resistance. In addition, the mechanical efficiency of extra work is less in expiration than inspiration and the expiratory reserve volume increases with increasing resistance, favoring the muscles of expiration, (Cain & Otis, 1949.) In a study by Campbell, (1957), unconscious patients made no expiratory effort with expiration resistances of 15-20 cm. H2O, rather, the depth of inspiration was increased until the elastic recoil of the chest and lungs overcame the added resistance.

D. EXTERNAL RESISTANCE

At 1 ATA reduction in work capacity, oxygen consumption, and pulmonary ventilation with the addition of external resistance to breathing have been reported by several investigators, (Silverman, et.al., 1951: Cooper, 1960a: Craig, et.al.) At 4 ATA Morrison, et.al., (1976), found lower oxygen uptakes for given work loads while breathing from UBA than without external breathing resistance. This is an opposite effect to that resulting from the internally generated resistance of increased gas density described earlier, and increased oxygen recovery consumption values have been recorded that may partially explain this, (Thompson & Sharkey, 1966.)

Adaptations to external resistance have been noted by several authors, (Goff & Bartlett, 1957: Doughterty & Schaefer, 1968: and Watson, 1972.) Maximal tolerable inhalation resistance has been given as 75 cm. H2O, (Freedman & Campbell, 1970.) Under prolonged conditions, Janney, (1958), recommended exhalation and inhalation resistances of 5 cm. H2O/(liters/sec) at 1 ATA and twice that at 5 ATA.

E. ADDITIONAL FACTORS

"There is a tremendous difference between a diver in the (dry) chamber and a diver in water," (Bradley, 1971.) The causes for this are cold, hydrostatic pressure, wet immersion, supportive difficulty in jobs requiring force application in an essentially weightless environment, and psychological factors relevant to environmental hazards.

The first of these, cold, is probably the most important additional factor. One of the body's responses to excessive heat loss is an increase in metabolic rate. Oxygen uptake increases from 0.5 liters/min. to 1.5 liters/min. during severe shivering at rest, and continues as long as skin and core temperatures remain low, (Anthonisen, 1969.) On land, warming may be accomplished through exercise, but underwater, exercise may actually increase cooling as a result of water flushing through or past the diver's suit, (Hayward, et.al., 1975.) This heat loss occurs because the conduction of heat through water is 20 times greater than that of air at the surface, (Keatinge, 1969.)

Respiratory heat losses, especially during Helium/Oxygen diving operations also play an important role which may not be adequately reflected in chamber tests when combined with immersion heat loss. Cold air inhalation results in a significant increase in inspiratory resistance, probably as a result of mild local airway obstruction, (Guleria, et.al., 1969.) In Arctic Helium diving, masking of the onset of shivering was found to occur during heavy work loads. In some cases continued exposure resulted in inadequate ventilation due to pulmonary edema, (Nuytten, 1973.)

Although minimizing heat loss during immersion has received much attention, (Keatinge, 1969: Webb, 1975: and Hayward, et.al., 1975), it remains a problem for the working diver. Although a particular UBA may not be found to be restrictive at normal work levels during chamber tests, use of such apparatus by a cold, shivering diver could result in performance impairment even at low work loads as a result of CO2 retention or dyspnea, (Anthonisen, 1969.)

A second important additional factor is hydrostatic pressure. Open circuit demand underwater breathing apparatus supplies breathing gas to the diver at the ambient pressure sensed by the diaphragm of the regulator. Because this pressure is usually not equal to the external ambient pressure at the level of the lung centroid, the center of pressure of the lungs, this imposes a hydrostatic imbalance upon the diver's respiratory system in addition to the resistive loading of the breathing apparatus. Correction in work of breathing calculations must be made for this additional external load which varies with diver inclination from the horizontal. This correction has an important consequence. Although the effect of hydrostatic pressures on inhalation and exhalation pressures is equal and opposite, and thus does not alter the total work of breathing, it may cause a large distortion in the balance of inspiratory and expiratory work, and an increase in the actual work of the respiratory muscles. In addition, excessive levels of negative pressure breathing may result in adverse pulmonary effects in the form of atelectasis, apparently as the result of airway closure, (Lundgren, 1973.)

The effect of immersion on intrapulmonary pressure was studied by Jarrett, (1965). Subjects were supplied breathing gas via an oral-nasal mask. The center of pressure of the immersed chest, (the lung centroid), was found to lie 19 cm. below and 7 cm. posterior to the supra-sternal notch. A determination of the most comfortable breathing gas supply pressure during immersion, termed the 'eupnoeic pressure,' was made by Paton and Sand, (1947.) Subjects were supplied with breathing gas using mouthpiece and noseclip. The eupnoeic pressure was found to be at the level of the supra-sternal notch for prone and supine positions. In the vertically upright position the eupnoic pressure was above the notch at rest but increased to approach the notch at higher ventilation rates. Without the supportive assistance of the oral-nasal mask positive mouth pressure with mouthpiece alone did not allow simultaneous complete chest relaxation and retention of the mouthpiece, accounting for differences in test results, (Jarrett, 1965.)

Thompson and McCally, (1967), investigated this preference of immersed subjects to breathe at a negative pressure relative to the chest, rather than at a mean external thoracic pressure and confirmed Jarrett's findings. Subjects breathing through mouthpiece, facemask, and helmet with intrapulmonary pressure variations found large transthoracic pressure gradients subjectively more comfortable than slight increases in transpharyngeal pressure. These differences are thus a result of the influence of pressure sensations in the upper airways on the subjective selection of comfortable pressure.

As it is not possible to position the demand valve at the lung centroid, the inhalation and exhalation effort experienced by a diver varies as a function of his orientation. O'Neill, (1970), calculated the hydrostatic imbalance imposed by rebreathing apparatus as a function of diver orientation. In addition, he designed a counter-lung breathing system with two sensitive relief valves on the chest and back at lung centroid level to give minimum hydrostatic imbalance at all diver orientations.

There has been no comparable work to quantify hydrostatic pressure effects of open circuit breathing apparatus. In testing of apparatus, only the pressure-flow characteristics have normally been considered while inspiratory and expiratory work, and hydrostatic pressure imbalance have generally been ignored. Sterk, (1973), has emphasized the need for underwater breathing apparatus testing in situ. The inclusion of hydrostatic pressure values in work of breathing calculations is essential in calculating the relative contribution of inspiratory and expiratory work to the total respiratory work demanded by the underwater breathing apparatus and in development of satisfactory physiological design criteria.

PART III. BREATHING APPARATUS EVALUATION

The various types of UBA all have one built-in disadvantage; resistance to gas flow, (Sterk, 1973.) While a certain amount of resistance can be tolerated by the diver, the fact that it is an additional stress makes its minimization desirable to ensure that respiratory flow is limited primarily by the diver's lungs, (Bradley, 1973.) This is complicated by the fact that what seems acceptable at the surface may not be so at depth, and tests of UBA must be adjusted according to worst case employment.

A. SOURCES OF MECHANICAL RESISTANCE

Major sources of UBA impedence are a result of poor check valve design, inadequate orifice size, and radical redirection of flow. Significant variations in the ease of breathing through units of the same model, apparently the result of inadequate fabrication control, have been noted, (Bradley, 1973.)

If it is assumed that the gases involved in the diver's breathing supply behave as ideal gases, then;

$P * V = n * R * T$

where P = absolute pressure of the gas

V = gas volume

n = total number of moles of the gas

R = universal gas constant

T = absolute temperature of the gas

Ideally, for the conditions of constant body and environmental temperature at depth, gas density is an approximately linear function of total pressure, P. The gas density, in turn, affects the Reynold number which governs whether turbulent or laminar flow conditions exist for a particular situation:

$Nr = \rho * d * v/\mu$

where Nr = Reynold Number

ρ = gas density

v = linear tube velocity of the gas

d = tube diameter

μ = gas viscosity

The large airway cross-sectional areas and low peak flows of gas mask and filter type respiratory protective devices make their resistance directly proportional to the air flow rate through the canister. Small tube diameters and higher peak flow rate for scuba units, however, cause their flow characteristics to be essentially turbulent even during quiet respiration. The pressure caused by the elasticity of rebreathing bags found in closed and semi-closed circuit scuba further adds to respiratory resistance, (Cooper, 1960a.) Suggested methods of resistance reduction in the latter have included the provision for a second breathing bag and placement of the exhaust valve as close to the mouthpiece as possible to reduce flow losses, (Riegel, 1970.)

In the presence of the turbulent flow conditions encountered in UBA, respiratory work increases with minute volume and absolute pressure. Demand inhalation from orifice-type SCUBA regulators essentially delivers constant mass flow per unit time for a given valve opening. Thus volume delivery at depth compared to surface volume delivery will be the reciprocal of the absolute depth pressure ratio. Because UBA exhaust valves are not simple orifices, expiration resistance at depth is more difficult to estimate from surface values.

A reduction in inhalation resistance is achieved in many UBA through venturi action to increase demand valve pressure drop relative to the mouth pressure. The initial opening resistance, however, is not affected by the venturi.

Perhaps the most important UBA development from studies to specifically minimize demand regulator breathing resistance at depth has been the pilot valve regulator, which utilizes a small downstream pilot valve to generate air flow for air supply valve activation, (Christianson, 1975: and Scubapro, 1976.) Such optimally designed regulators have dynamic inhalation and exhalation pressures with little hysteresis, stable inhalation resistance without freeflowing, and inhalation pressure essentially independent of operating depth.

If the work of breathing becomes limiting to man in the sea, mechanically assisted inspiration, considerably diminishing respiratory impairment at depth by decreasing inspiratory work, may be an even better solution than a simply passive UBA, (Wood & Bryan, 1971: and Uhl, et.al., 1972.)

B. TESTING AND STANDARDS

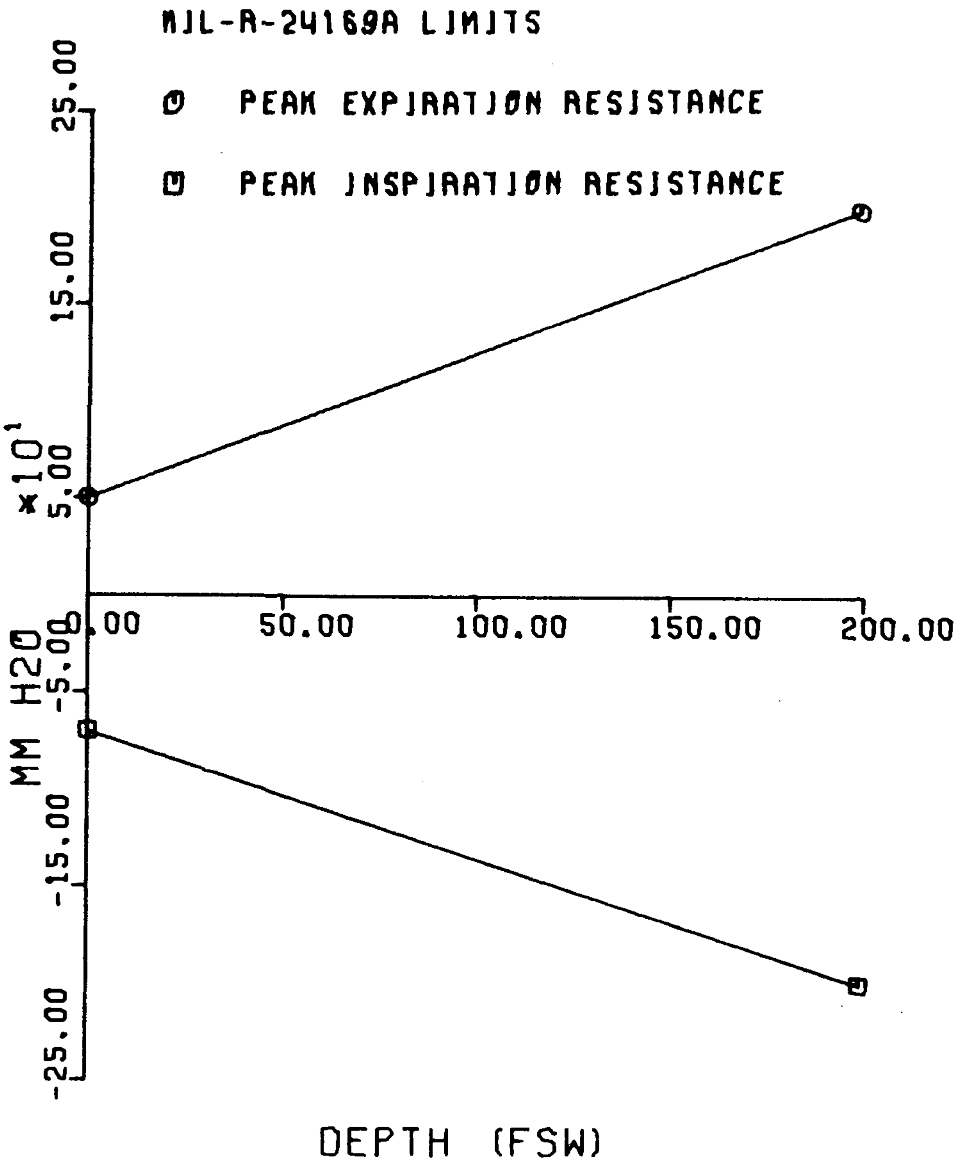
Until recently, evaluation of diver breathing apparatus was limited to the often unreliable subjective responses of divers, (Bradner, H., 1953: Bradley, 1973: and Hughes, M., 1974.) Because of adaptation by the diver to the same variations in breathing work as those being investigated, this has been useful only for the noting of gross deficiencies in respiratory demand and not for the comparative measurement of such resistance, (Doughterty & Schaefer, 1968: and Goff & Bartlett, 1957.)

With the aim towards design improvement, standards for allowable resistance of respiratory protective and life support devices were suggested in 1945, (Silverman, et.al., 1951.) In a later study, Cooper, (1960b), found that human respiration during respiratory work against an external resistance closely approximates a sine wave, and thus human simulation using a sine wave pump, instead of physiological testing, is possible. Such studies form a useful basis for similar comparative evaluation of UBA. Pressure and volume measurements of breathing apparatus when ventilated by a sine wave pump give valid estimates of the external respiratory work otherwise performed by the diver, (Cooper, 1960a.) Most of these simulators have relied upon cam driven piston and cylinder arrangements. This has the advantage of being able to produce either uniform sine waves or allow for pauses in the breathing cycle, (Adams, et.al., 1950: Nelson, et.al., 1972: and Wilson & Harrod, 1956.)

The only breathing resistance standards for UBA in operation are peak inhalation and exhalation pressure limits for open circuit SCUBA established in the early 1950's by U.S. Navy MIL-R-24169A and MIL-R-1955A. Test protocol for these limits uses a respiratory simulator at a tidal volume of 2 liters and 20 breaths per minute under hyperbaric chamber dynamic wet conditions to measure peak inhalation and exhalation pressures. Regulators meeting U.S. Navy specifications must lie within the acceptance band of peak pressure as a function of depth to 199 feet sea water, as shown in Figure 2. A need for downward revision of the established limits and possible replacement with standards of external work of breathing, a value which has especially greater significance with the neck seal helmets currently used in commercial oil field diving, has been noted by several authors, (Cooper, 1960a: and Reimers, 1973.)

Cooper's standards specified that the maximum work of breathing for the apparatus, (kg.m./min.), should not exceed one-fourth of the minute volume, (liters/min.) The recommended rate of respiratory work was one-half of this. Expiratory work percentage of the total work of breathing should not be more than 50% at high minute volumes. Tests were to be performed using sinusoidal ventilation on the apparatus with tidal volumes of 1, 2, and 3 liters and respiratory frequencies of 20, 25, and 33.3 breaths per minute respectively.

Figure 2 U.S. Navy MIL-R-24169A(SHIPS) underwater breathing apparatus acceptance criteria. Peak inspiratory and expiratory resistance, (mm H20), as a function of depth, (FSW.)


MIL-R-24169A LIMITS
PEAK EXPIRATION RESISTANCE
PEAK INSPIRATION RESISTANCE
25.00
15.00
5.00
-5.00
-15.00
-25.00
×10¹
MM H2O
0.00
50.00
100.00
150.00
200.00
DEPTH (FSW)

Despite the present limited criteria for evaluation, UBA submitted to the U.S. Navy and the commercial diving industry for consideration and adoption continue to be unacceptable when subjected to dynamic wet tests at depth, (Gibson, 1975 & 1976.) Measured ventilatory power requirements for a recent semi-closed circuit UBA have exceeded Cooper's standards even at low ventilations, (Sterk, 1973.) The pilot valve regulator described earlier represents an achievement in minimizing diver respiratory work requirements.

The combined effects of cold, exertion, and carbon dioxide retention must be included in establishing experimental limits for respiratory work, (Anthonisen, 1969: Guleria, et.al., 1969: Lindbergh, 1967: Morrison, 1973: and Nuytten, 1973.) Subjects studied in hyperbaric environments without using breathing apparatus exhibited pulmonary responses suggesting that divers breathing oxy-helium gas mixture at a pressure of 2,000 FSW, (an atmosphere about ten times as dense as surface air), may successfully perform moderate exercise, (Anthonisen, et.al., 1971.) This is, of course, provided that the diver's equipment does not complicate his existing stress. Performance in the field has shown that the ideal UBA has yet to be attained. Within the last few years commercial diving requirements have extended to depths greater than 1,000 FSW at offshore oil rigs, (Hughes, 1974: and Huquenin, 1973.) Many previously acceptable UBA designs have consequently become at best marginal due to insufficient delivery volume or unacceptable resistance, (Bradley, 1973: Lindbergh, 1967: MacInnis, 1966: and Morrison & Butt, 1972.)

METHODS & APPARATUS

PART I: RESISTIVE WORK/STATIC TESTS

Mouthpiece pressures were measured for steady state flow rates of, where possible, at least 325 liters/min. for a Poseidon single hose open circuit demand regulator, (Poseidon Mfg.), and a Trieste II two hose open circuit demand regulator, (Voit Mfg.), in both dry and water immersion tests. Using the Fortran program listed in Appendix A this permitted work of breathing simulations for sinusoidal flow patterns with minute volumes of up to approximately 100 liters/min.

The UBA was mounted either in air, for dry static tests, or in a water tank at a depth of 20-30 cm., for wet static tests. The demand valve was oriented as for operation in the horizontal swimming position for both regulators. This placed the exhaust valve in the vertical position for the Poseidon single hose and in the horizontal down position for the Trieste II two hose UBA. A static tube for differential pressure measurement was affixed to the mouthpiece of the regulator. This in turn was connected to a respiration meter, (Parkinson Cowan , Eng.), via flexible tubing. A 3-way control valve joined the flowmeter to either a low pressure air supply or to a vacumn cleaner nozzle for inhalation or exhalation measurements respectively.

The static head tube was 5 1/2 in. in length with an internal diameter varying from 1 to 1 3/8 in. At its midlength there were eight 1/8 in. diameter holes equally spaced around the circumference and leading into a collar of rectangular cross section 3/8 in. x 1/8 in. The collar outlet was a 1/8 in. tubing fitting which connected to the differential pressure transducer.

In order to correct for the air flow resistance of the static head tube, the pressure drop across the tube was subtracted from the measured differential pressure values. This correction was small compared to the resistance of the parts tested, (0.5% worst case), and is in accord with values for a similar correction by Cooper, (1960a.)

Inspiratory and expiratory pressure-flow data for the wet and dry static tests were plotted for both UBA tested. Air flow values in liters/min. were selected at 30 equally spaced intervals up to maximum recorded flows. Corresponding instantaneous differential pressures were obtained from the plots. These pressure-flow paired values formed the computer program test data.

Tidal volumes of from 1.0 to 3.0 liters were used in simulated work of breathing calculations. Corresponding respiratory frequencies at 1 ATA were determined from the formula $VE = -7.2 + 21.8 * VT$ where VE = Ventilatory Flow and VT = Tidal Volume, from Morrison, (1976.) A sinusoidal flow pattern was generated by the computer program, (Appendix A), with maximum flow equal to π times breathing frequency times the tidal volume. Flow values were sampled at thirty equal time intervals throughout one generated breathing cycle and differential pressure values were obtained from interpolations of the test data.

Work of breathing was simulated by summation of the incremental products of flow rate times interpolated differential pressure times the time interval for one complete inspiration or expiration respectively. Total work of breathing and inspiratory and expiratory work percentages of the total work of breathing were also calculated.

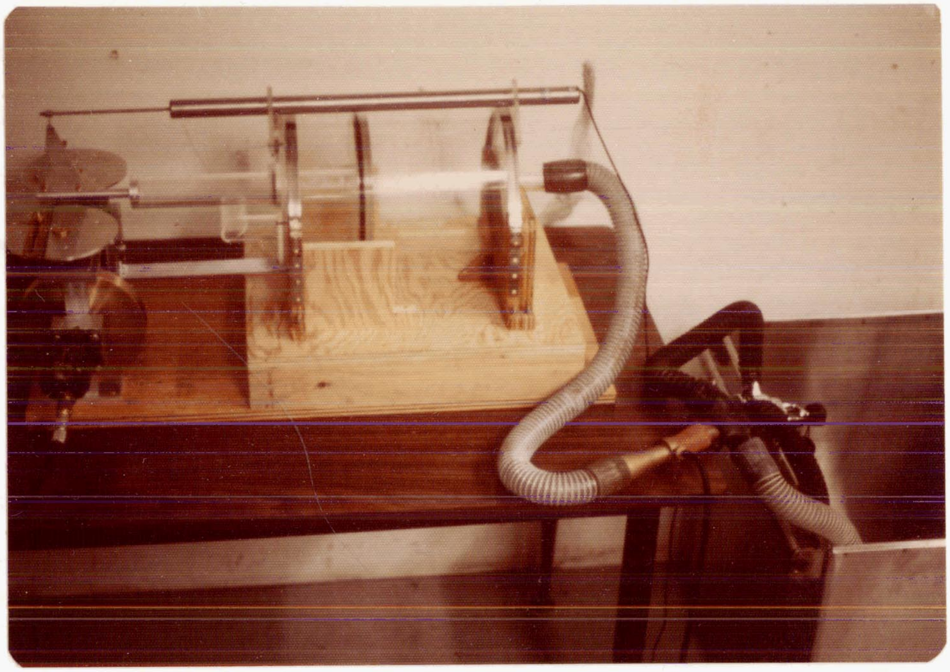
PART II: RESISTIVE WORK/DYNAMIC TESTS

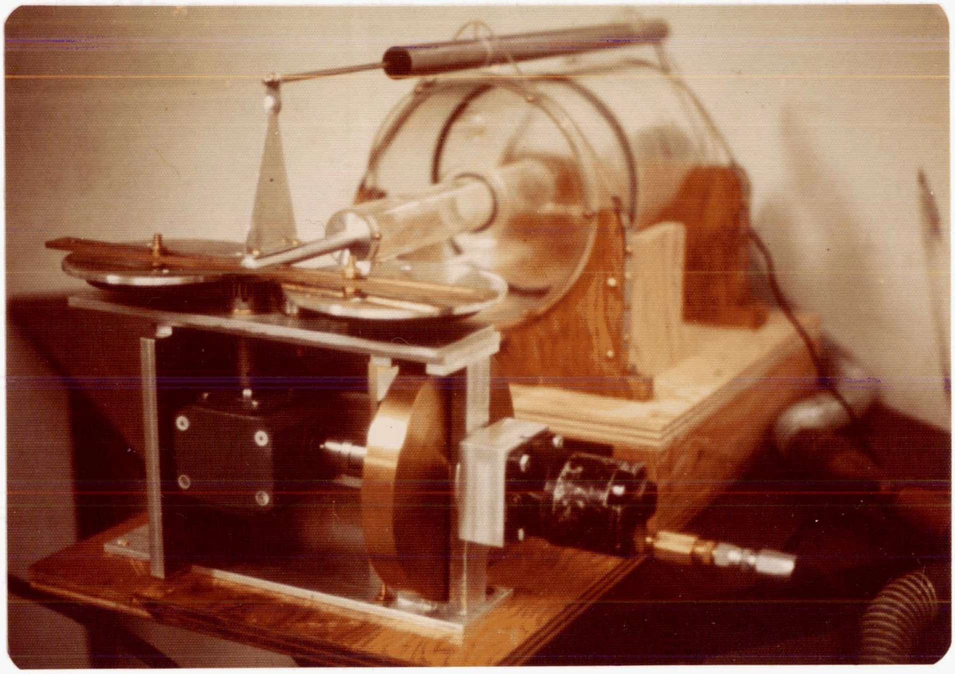
Flow and pressure data was collected using a mouth held Poseidon regulator and a back mounted Trieste II regulator at five different breathing levels representative of physiological requirements based upon studies by Morrison, et.al., (1976), shown earlier in Figure 1. These levels were approximately 1 liter VT at 10 breaths per minute, (BPM), 2 liter VT at 15 BPM, and 3 liter VT at 20, 25, and 30 BPM, resulting in minute volumes of 10, 30, 60, 75, and 90 liters/minute respectively. Breathing frequencies were selected as being physiologically in accord with ventilatory flows as described in static test methods.

In addition to the UBA being tested, the apparatus consisted of a pneumatic motor, (Lear/Romec No. RD-7440-A); 20:1 gear reduction unit, (Boston Gear Cat. 310-20-01); plexiglass piston-cylinder unit of 7.75 inch bore x 3.1 inch maximum stroke with "O" ring seal, flexible hose connections, water bath for UBA immersion, and wood and metal support assemblies. Side and end views of the simulator are shown in Figures 3 and 4. Additional external equipment included one 0-1 psi differential pressure transducer, (SE Labs Eng., Ltd. Type SE1150/0.5964.25WG); a ±6 inch displacement transducer, (SE Labs Type SE353/150MM); transducer/converter, (SE Labs

Figure 3 Side view of respiration simulator and associated apparatus.

Figure 4 End view of respiration simulator showing drive train.





Type SE905); an FM tape recorder, (Hewlett Packard Model 3960 Instrumentation Recorder); low pass filter, (Rockland Systems Model 432 Dual Hi/Lo Filter); and air cylinders with control valves and pressure gauges for pneumatic motor and UBA operation.

The rotary gear type pneumatic motor, rated for 1500 psi, was directly connected to a 7 inch diameter x 1 inch thick brass flywheel in order to minimize motor speed fluctuations with variations in the work load and thus maintain conformity with a sinusoidal flow pattern. Reduction in the speed of rotation utilized a 20:1 worm gear reduction assembly which drove two 4 1/2 inch diameter spur gears through a 1 1/2 inch diameter spur gear for a further 3:1 reduction, resulting in a total 60:1 reduction in output rpm relative to the motor. Faceplates attached to the two 4 1/2 inch spur gears had holes bored for the placement of drive pins. A slotted bar attached to the drive pin on each faceplate and was fixed to the piston connecting rod. With rotation of the motor at a constant speed, the two 4 1/2 inch spur gears, rotating in opposite directions, caused the slotted bar to drive the piston in uniform sinusoidal motion without torque on the connecting rod. The centers of the faceplate holes were at 0.82, 1.64, 2.46, 3.29, 4.11, and 4.93 centimeters from centers of rotation, resulting in simulator tidal volumes of 0.5, 1.0, 1.5, 2.0, 2.5, and 3.0 liters respectively from the cylinder, depending on placement of the two drive pins.

A 1 1/2 inch outside diameter plexiglass pipe connected the cylinder to the test UBA via flexible tubing. An air cylinder provided high pressure air to the first stage of the UBA, which was immersed in a 2' x 2' x 2' water tank. The demand valve was oriented as for operation in the horizontal swimming position for both regulators. This placed the exhaust valve in the vertical position for the Poseidon single hose and in the horizontal down position for the Trieste II two hose UBA. The differential pressure transducer measured the pressure at the mouthpiece relative to atmospheric pressure. Changes in diver position which result in variations in hydrostatic pressure imbalance at the lung centroid with respect to the demand valve were reflected by changing the value of the hydrostatic pressure imbalance in the computer calculation of the work of breathing. The displacement transducer, mounted on the connecting rod end of the piston-cylinder assembly, provided information on piston velocity and thus on inhalation and exhalation air flow.

A separate air cylinder with low pressure regulator and control valves regulated the speed of the pneumatic motor for simulation output of respiratory frequencies in the range of 10-30 breaths per minute. The low pressure supply was also connected to the respiratory pump in back of the piston. A 1' x 1' x 6" open bottom box was immersed in the tank to a depth approximately equal to that of the demand valve and was also connected to the cylinder in back of the piston. This provided backpressure to offset the hydrostatic load on the simulator during exhalation, thus minimizing apparatus speed variations. Fire hazard in a compressed air environment during proposed future hyperbaric testing of the apparatus decided the use of a pneumatic rather than electric motor.

The choice of this particular mode of sine wave generation, rather than through the use of cams, was made due to the difficulty and expense in obtaining accurately milled cams, although these could be substitued at a later date, as in a simulator by Nelson, (1972.) Some points of consideration with both this device and those in previous works were backlash in the mechanism of the pump, fluctuations in motor rotation with load variation, and distortion resulting from binding forces. These sources of error were compensated for by the displacement transducer in calculating gas flow rates.

A comparison between actual and predicted average flow rates was made to check for leaks around the piston O-ring seal. Actual average flow rates were obtained from flow meter volume and time measurements. Predicted flow rates were calculated from piston stroke, cylinder bore, and rpm. Discrepancies of less than 4% at 20 liters/min. ventilation and 2% at 40 liters/min. ventilation were noted.

Transducer outputs for piston displacement and differential pressure were collected on an FM tape recorder. Signal to noise ratios were improved by adjusting the displacement transducer position to give small positive signals in the minimum position and zero offsetting the differential pressure signal using a preamplifier. The pressure signal was filtered using a 10 Hz. cutoff low-pass filter. The two channels of information were then sampled at 60 times per second and 33 seconds of each test, (the maximum computer storage capacity), were digitized on a PDP 11 computer, (Digital Equip, Corp.) This permitted analysis of at least four complete breathing cycles at 1 liter tidal volume and approximately 10 breaths/min. frequency, the slowest dynamic setting. Digitized displacement and pressure information was then transmitted to an IBM 370 computer for data storage and processing. Sampling rate was selected to exceed twice the frequency of any desired information.

The computer program, (Appendix B), first set up data arrays, initialized internal variables, and established a time increment equal to 1/60 second, (the reciprocal of the sampling rate.) A five point smoothing formula described by Lanczos, (1967), was used to calculate velocity from displacement data. Initial inspiratory or expiratory incomplete half cycles were rejected by testing for change in direction of velocity. Complete respiratory half cycles were identified in the same manner. Corrections for the immersed depth of the demand valve regulator diaphragm and offsetting of the differential pressure values were also included. Swimming position hydrostatic pressure imbalance data from the results of Part III permitted calculation of variations in inspiratory and expiratory work percentages of the total work of breathing.

Dead space in the respiration simulator cylinder and connective tubing to the UBA necessitated an additional correction factor for the piston displacement values in the computer program. Compression of the air in the dead space with each pump exhaust, (UBA inhalation), caused a decrease in the effective initial piston displacement and thus a skewing of the sinusoidal flow. Pump intake, (UBA exhalation), resulted in a similar but slightly smaller effect in the opposite direction.

Work of breathing was calculated using the pressure-flow data by summation of the incremental products of flow rate times differential pressure times the time interval. Tidal volume, respiratory frequency, minute volume, resistive and hydrostatic work components, and total work of breathing were also calculated for each simulator run.

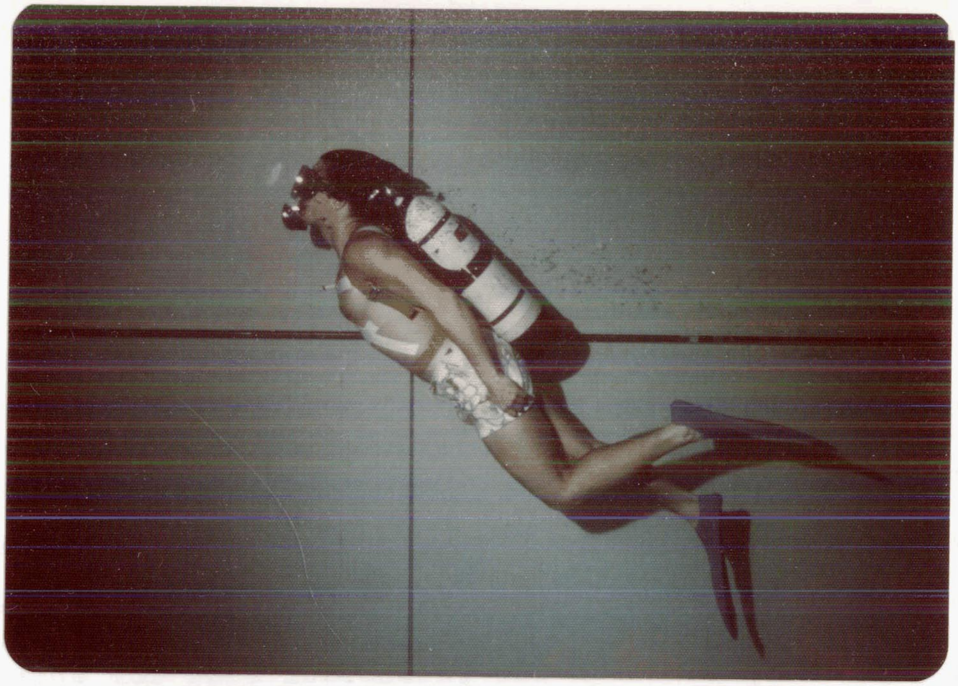
PART III: HYDROSTATIC PRESSURE IMBALANCE

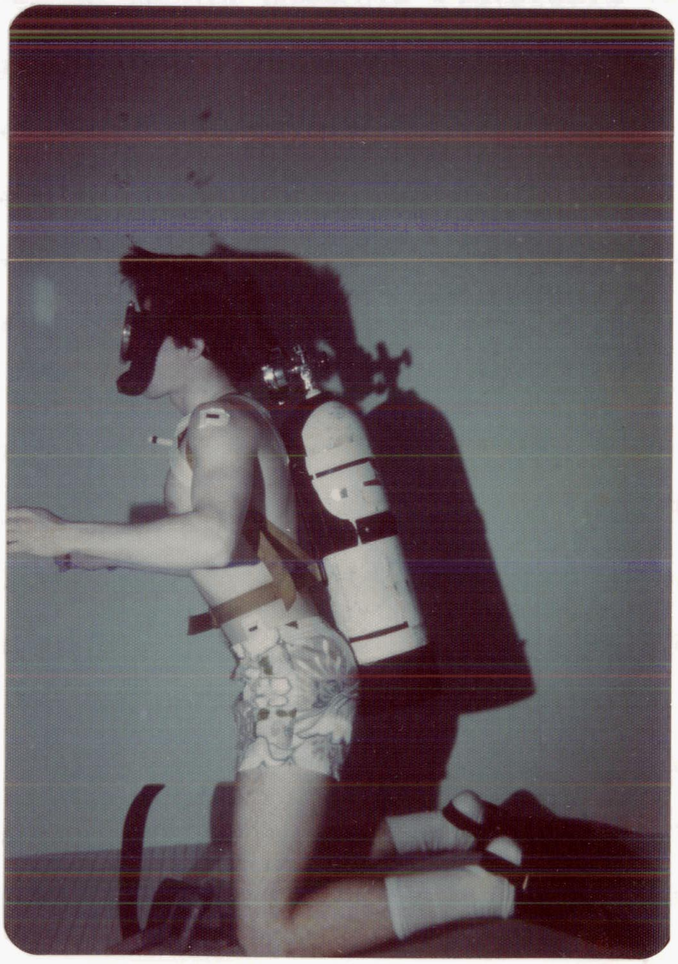
The inclusion of representative hydrostatic pressure values in work of breathing calculations is essential in determining of the relative contribution of inspiratory and expiratory work to the total respiratory work. Although studies were made by Patton and Sand, (1947), and Jarrett, (1965), on the position of the lung centroid, no previous investigation could be found for measurement of hydrostatic pressure values normally encountered by divers using open circuit demand UBA.

Ten SCUBA divers were photographed while swimming underwater in five approximate orientations, (horizontal, 45 degrees up and down, and 90 degrees up and down), and in an upright work position with head erect. Divers were photographed breathing from both mouth held single hose and back mounted two hose demand regulators. The heights and weights of the ten subjects including one female, (LW), are shown in Appendix C.

A marker was taped to the sternum of each subject immediately beneath the supra-sternal notch as a point of reference. The SCUBA equipment was adjusted comfortably by the diver. Markings on the SCUBA cylinders provided a reference scale for subsequent measurement of enlargements of the photographic slides, (Figures 5 and 6.) Lung centroid location, Lc, as defined by Jarrett was determined from body markings on the sternum, shoulder, and hip, and the distance, R, between lung centroid and the center of the demand regulator diaphragm, Hc, was measured for each position. A bar placed horizontally in the background established the diver orientation. Body angle, a, was defined as the angle between the horizontal reference bar and the hip-shoulder line. Angle ϕ between the hip-shoulder line and the lung centroid-demand regulator line was also measured. Values of the hydrostatic pressure, Hd, could thus be expressed as $Hd = R\sin(a+\phi)$.

Figure 5	Subject DM in a swimming orientation for hydrostatic pressure imbalance test using mouth-held regulator. Chest, tank, and horizontal reference markers are visible.
Figure 6	Subject DM in a vertical working position for hydrostatic pressure imbalance test using back-mounted regulator. Chest, tank, and horizontal reference markers are visible.





RESULTS

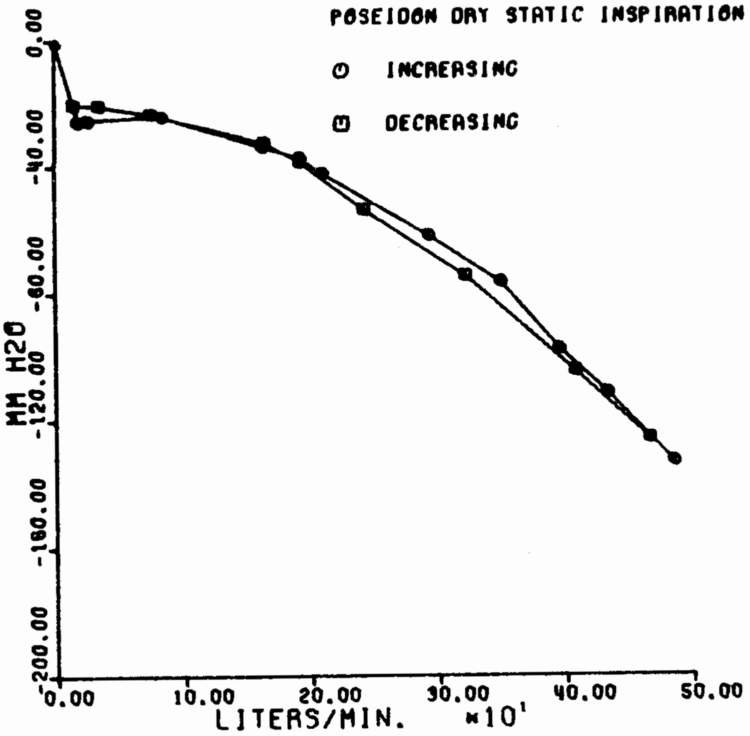
PART I: RESISTIVE WORK/STATIC TESTS Static

pressure-flow data were obtained for both dry and wet test conditions for Poseidon single hose and Trieste II two hose open circuit demand regulators. At 1 ATA plots of pressure, (mm H2O), as a function of of flow, (liters/min.), are shown in Figures 7 through 14. Pressure measurements were made for both increasing and decreasing steady-state flows in order to record possible hysteresis in the UBA under test. The greatest variation between increasing and decreasing ventilation for all tests up to 325 liters/min. was approximately 10 mm. H2O. The average of the increasing and decreasing pressure-flow values was used in subsequent computer simulations.

Resistances increased with ventilation for both regulators during expiration and for the Poseidon regulator during inhalation. The Trieste II two hose regulator, however, exhibited a nearly constant inspiratory resistance up to approximately 375 liters/min. in the dry test and 300 liters/min. in the wet test. The highest recorded expiratory flow for the Trieste II in the dry test was 151.5 liters/min. Greater exhaust flows in the dry condition caused exhaust

Figure 7 Poseidon dry static inspiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)

Figure 8 Poseidon dry static expiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)


POSEIDON DRY STATIC INSPIRATION
INCREASING
DECREASING
MM H2O
0.00
-40.00
-80.00
-120.00
-160.00
-200.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. ×10¹

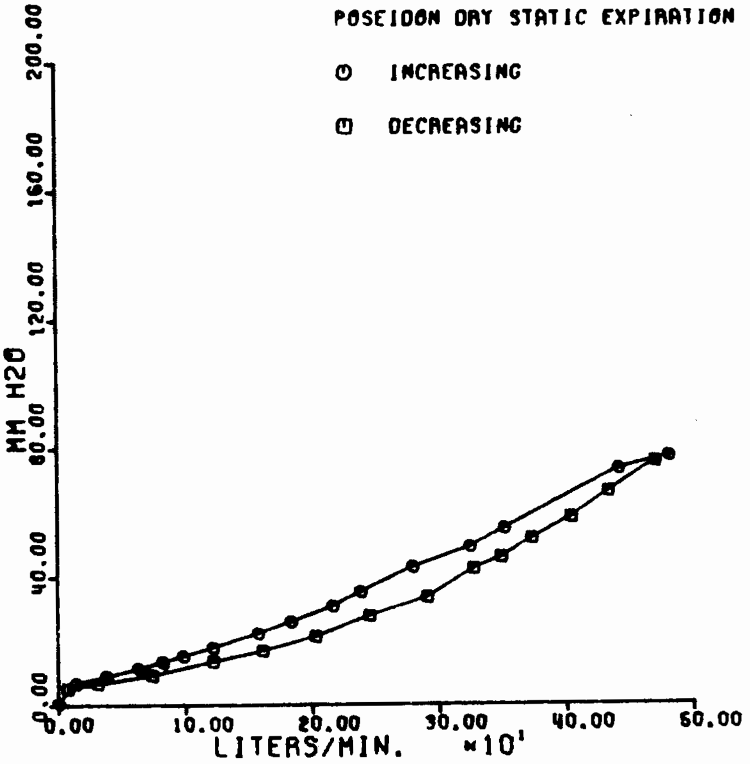
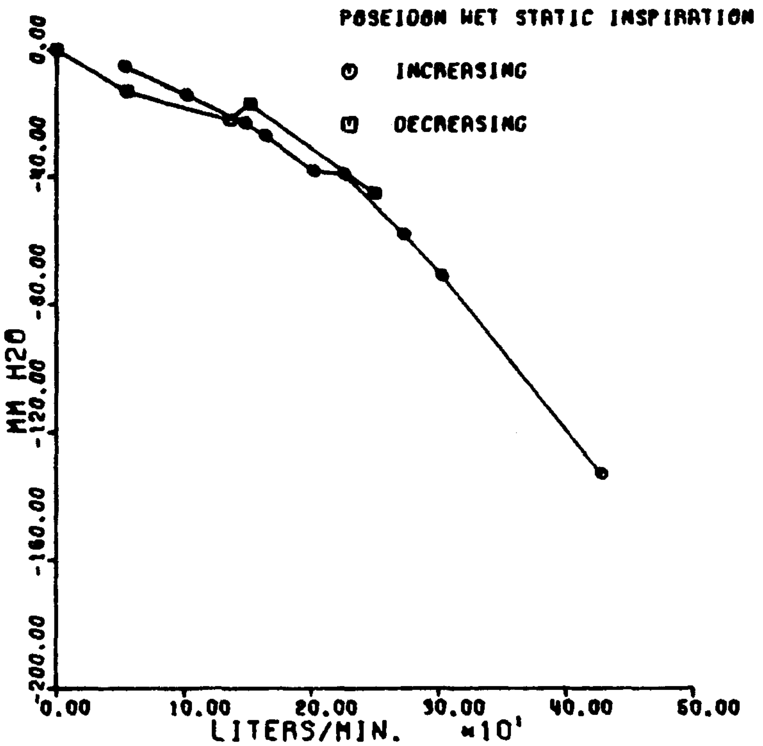

POSEIDON DRY STATIC EXPIRATION
INCREASING
DECREASING
MM H2O
200.00
160.00
120.00
80.00
40.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. ×10¹

Figure 9	Poseidon wet static inspiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)
Figure 10	Poseidon wet static expiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)


POSEIDON WET STATIC INSPIRATION
⊙ INCREASING
⊡ DECREASING
MM H2O
0.00
-40.00
-80.00
-120.00
-160.00
-200.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. ×10¹

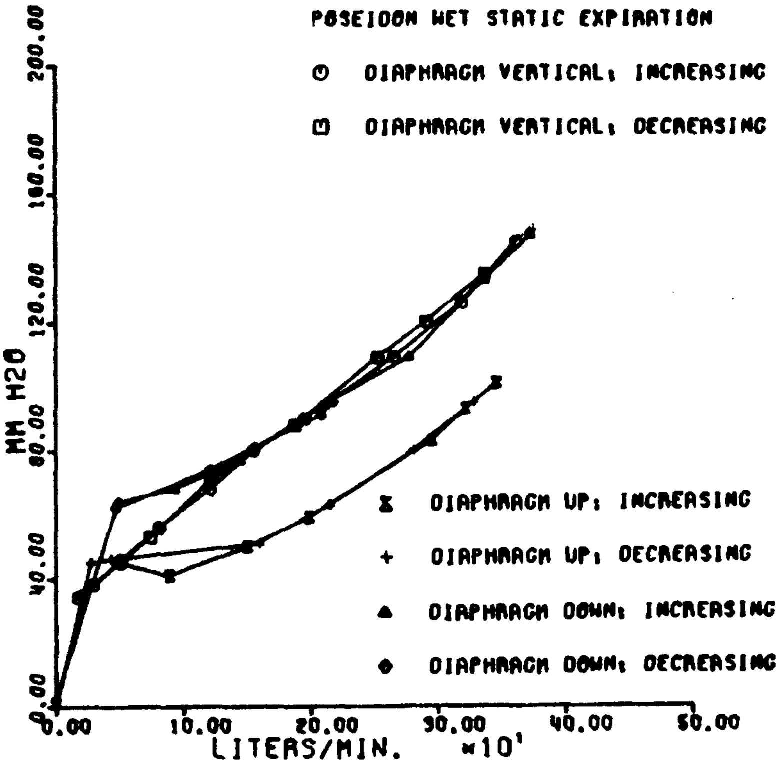
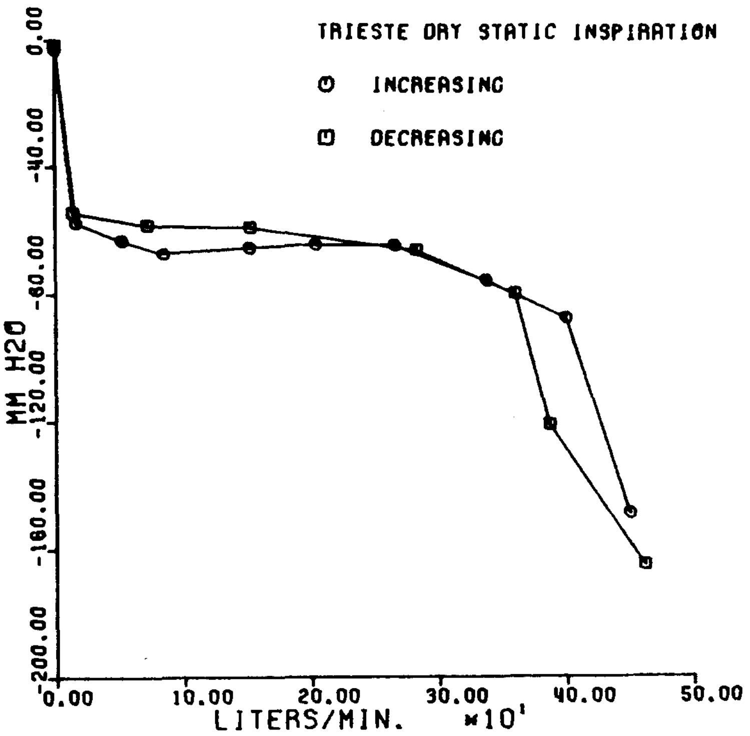

POSEIDON WET STATIC EXPIRATION
⊙ DIAPHRAGM VERTICAL; INCREASING
⊡ DIAPHRAGM VERTICAL; DECREASING
⧗ DIAPHRAGM UP; INCREASING
+ DIAPHRAGM UP; DECREASING
▲ DIAPHRAGM DOWN; INCREASING
◆ DIAPHRAGM DOWN; DECREASING
MM H2O
0.00
40.00
80.00
120.00
160.00
200.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. ×10¹

Figure 11	Trieste II dry static inspiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)
Figure 12	Trieste II dry static expiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)


TRIESTE DRY STATIC INSPIRATION
○ INCREASING
□ DECREASING
MM H2O
0.00
-40.00
-80.00
-120.00
-160.00
-200.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. ×10¹

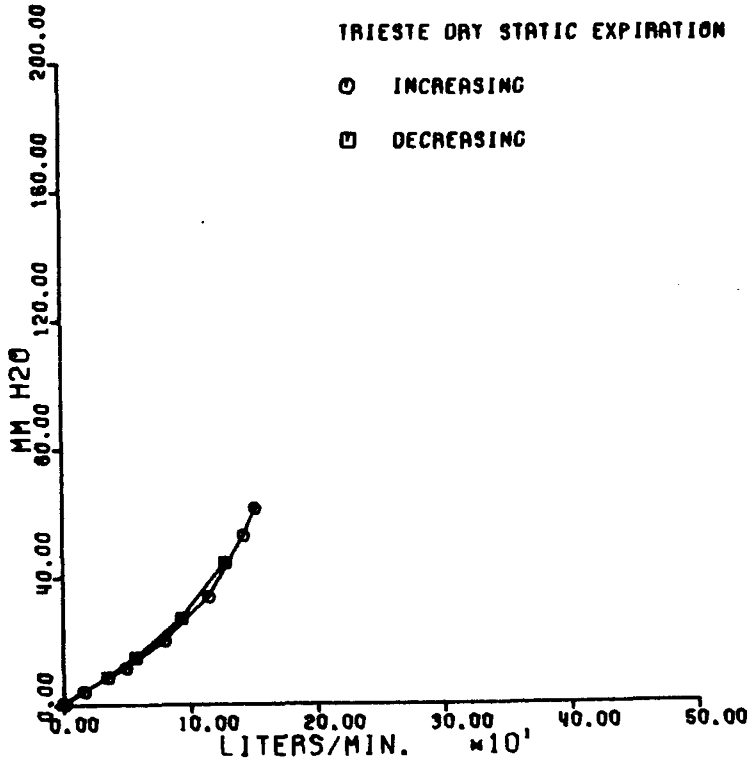
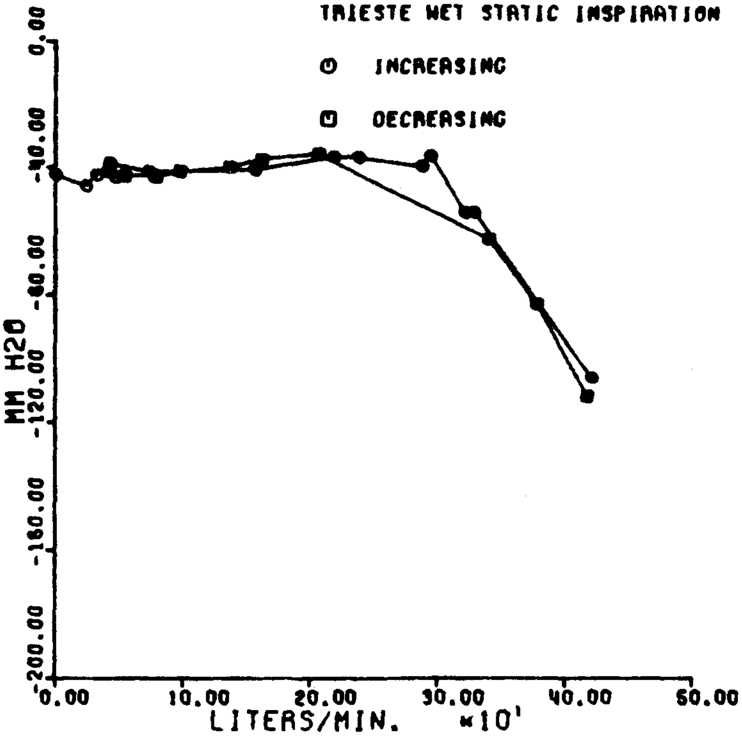
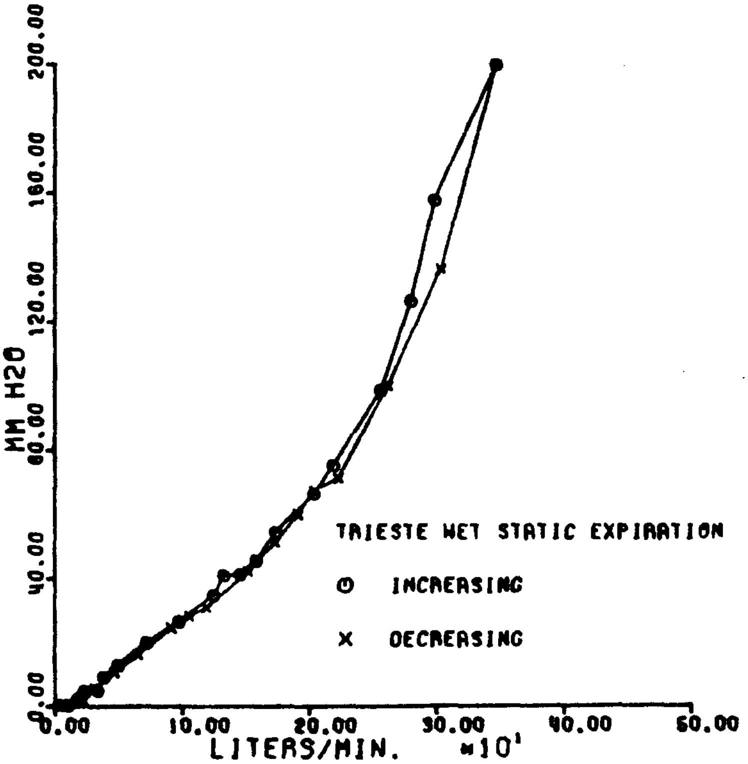

TRIESTE DRY STATIC EXPIRATION
○ INCREASING
□ DECREASING
MM H2O
200.00
160.00
120.00
80.00
40.00
0.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. ×10¹

Figure 13 Trieste II wet static inspiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)

Figure 14 Trieste II wet static expiratory resistance, (mm H2O), as a function of ventilation, (liters/min.)


TRIESTE WET STATIC INSPIRATION
○ INCREASING
□ DECREASING
MM H2O
0.00
-40.00
-80.00
-120.00
-160.00
-200.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. *10¹


TRIESTE WET STATIC EXPIRATION
○ INCREASING
× DECREASING
MM H2O
0.00
40.00
80.00
120.00
160.00
200.00
0.00
10.00
20.00
30.00
40.00
50.00
LITERS/MIN. *10¹

valve flutter with resultant considerable pressure fluctuations.

Expiratory pressure increases of approximately 30 mm H20 were noted with alteration in the orientation of the Poseidon regulator from the exhaust valve upwards to either exhaust valve vertical or exhaust valve downwards, (Figure 10.) The mouthpiece of the Poseidon is perpendicular to the exhaust valve which therefore remains vertical independent of the inclination of the diver to the horizontal. Expiratory resistance is thus independent of swimming angle. If the diver were to roll to one side, however, expiratory resistance, and consequently expiratory work of breathing would be affected accordingly.

Complete results of the work of breathing as estimated from the computer analysis of the steady state pressure flow data, together with inspiratory and expiratory work values and percentages of total work, are contained in Appendix D. Simulated work of breathing, (kg.m./min.), as a function of sinusoidal ventilation, (liters/min.), are shown in comparison to dynamic test results for the Poseidon in Figure 21 and for the Trieste II in Figure 22. Also shown are Cooper's, (1960a), maximum and recommended standards for respiratory protective devices.

PART II: RESISTIVE WORK/DYNAMIC TESTS

One ATA pressure characteristics of a Poseidon mouth held and a Trieste II back mounted regulator were measured during sinusoidal ventilations using a respiration simulator connected to the immersed UBA. Test conditions had tidal volumes of 1, 2, and 3 liters and ventilatory rates of up to 95.9 liters/min. for the Poseidon and 80.1 liters/min. for the Trieste II.

Pressure and flow data obtained from the dynamic tests at a tidal volume of 2 liters are plotted in Figures 16 and 17 for the Poseidon regulator, and in Figures 19 and 20 for the Trieste II regulator as a function of sample number, (60/sec.)

Piston displacements from which these pressure and flow curves are generated are depicted in Figures 15 and 18 for Poseidon and Trieste II regulators respectively. Data is shown in cm. as a function of sample number for both uncorrected and compression corrected displacements.

Complete results of the dynamic work of breathing computer calculations are contained in Appendix E for the Poseidon regulator and in Appendix F for the Trieste II

Figure 15 Uncorrected and compression corrected piston displacement, (cm.), for Poseidon regulator. 1 ATA wet dynamic test at 2.0 liters tidal volume and 17.7 breaths/min. respiratory frequency.

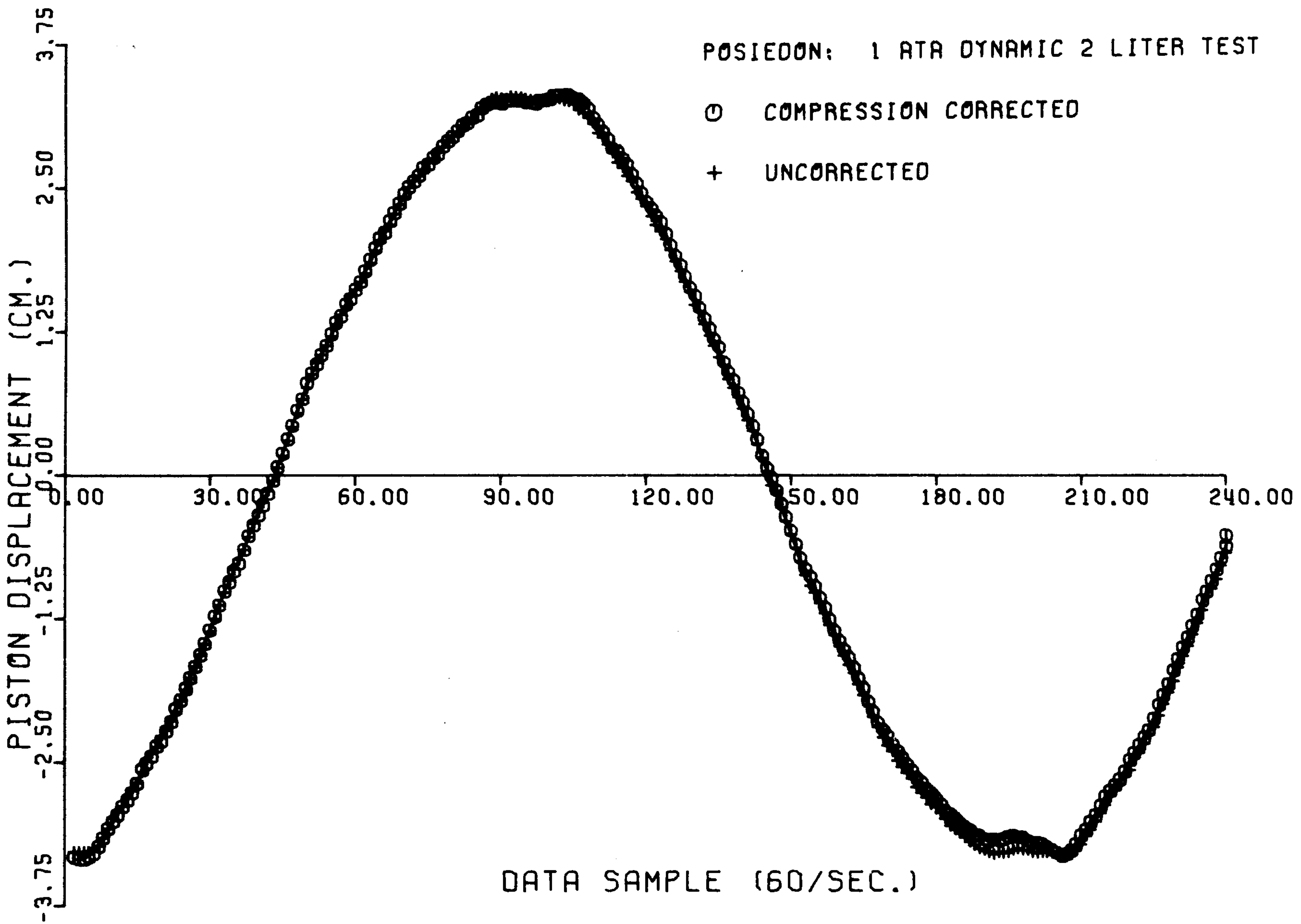

POSIEDON: 1 ATA DYNAMIC 2 LITER TEST
⊖ COMPRESSION CORRECTED
+ UNCORRECTED
PISTON DISPLACEMENT (CM.)
3.75
2.50
1.25
0.00
-1.25
-2.50
-3.75
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
DATA SAMPLE (60/SEC.)

Figure 16 Flow, (liters), as a function of time, (seconds), for Poseidon regulator. 1 ATA wet dynamic test at 2.0 liters tidal volume and 17.7 breaths/min.

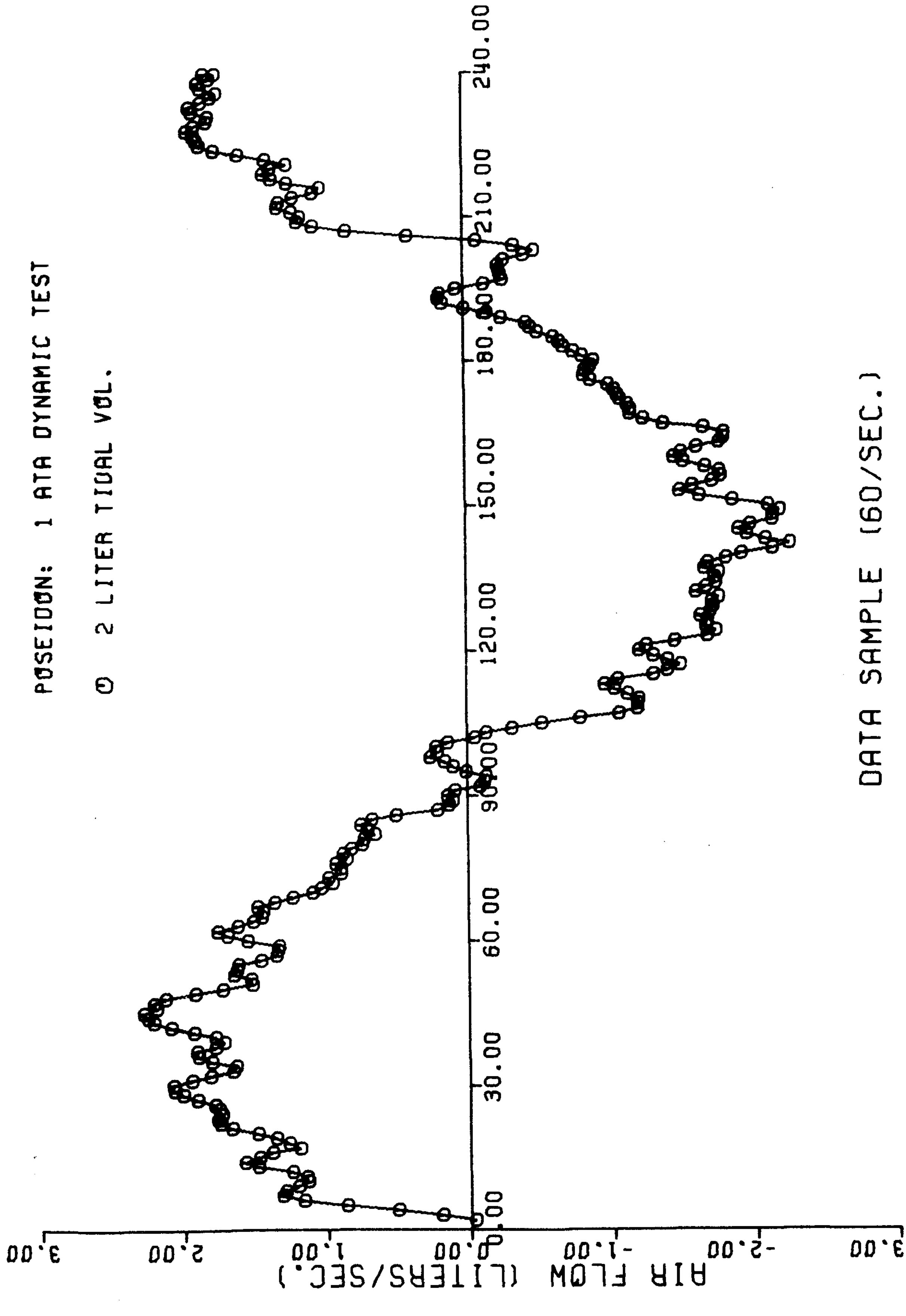

POSEIDON: 1 ATA DYNAMIC TEST
○ 2 LITER TIDAL VOL.
DATA SAMPLE (60/SEC.)
AIR FLOW (LITERS/SEC.)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00

Figure 17 Pressure, (mm H2O), as a function of time, (seconds), for Poseidon single hose regulator. 1 ATA wet dynamic test at 2.0 liters tidal volume and 17.7 breaths/min.

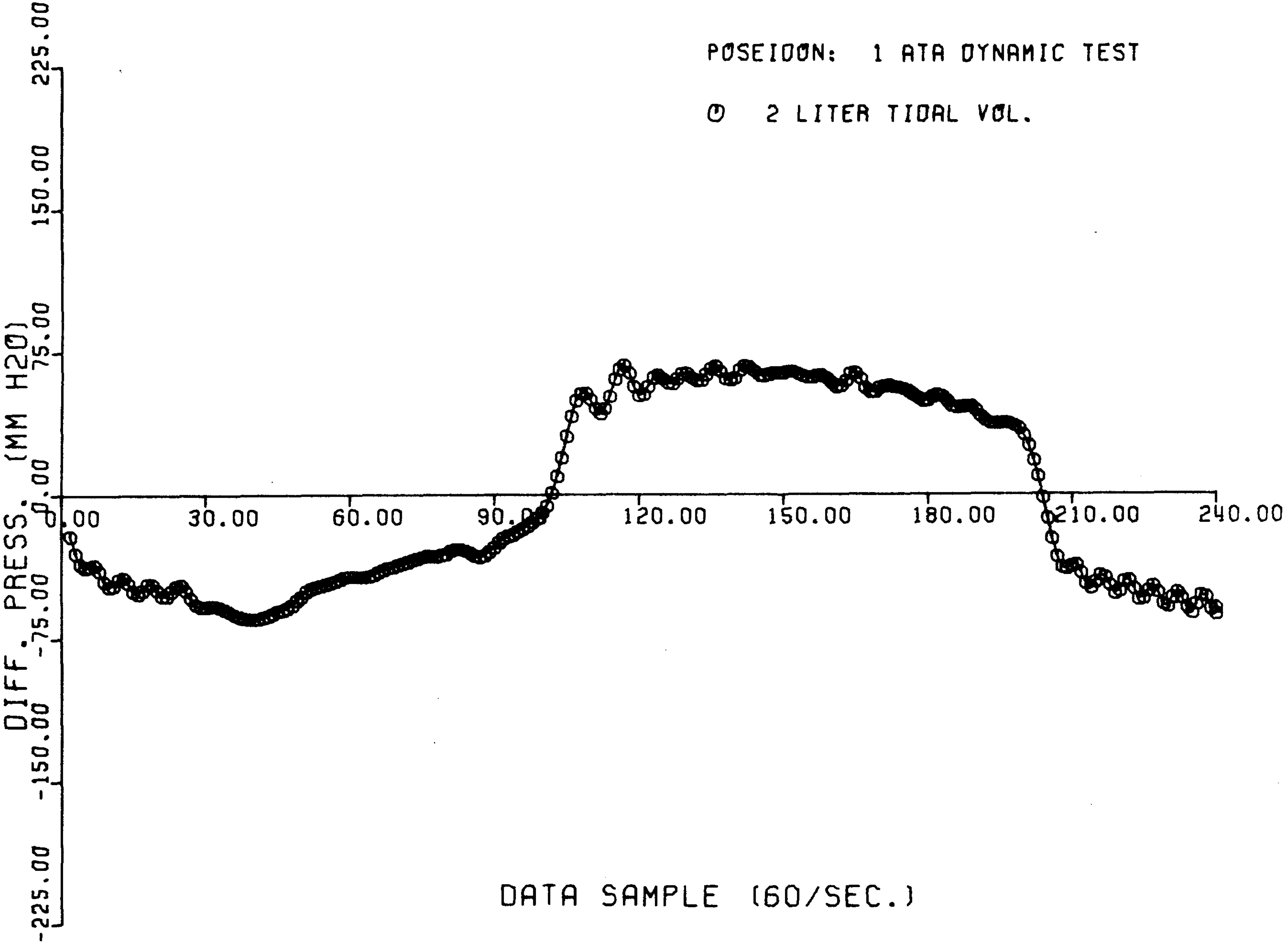

POSEIDON: 1 ATA DYNAMIC TEST
⊙ 2 LITER TIDAL VOL.
DIFF. PRESS. (MM H2O)
225.00
150.00
75.00
0.00
-75.00
-150.00
-225.00
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
DATA SAMPLE (60/SEC.)

Figure 18 Uncorrected and compression corrected piston displacement, (cm.), for Trieste II regulator 1 ATA wet dynamic test at 2.0 liters tidal volume and 20.8 breaths/min. respiratory frequency.

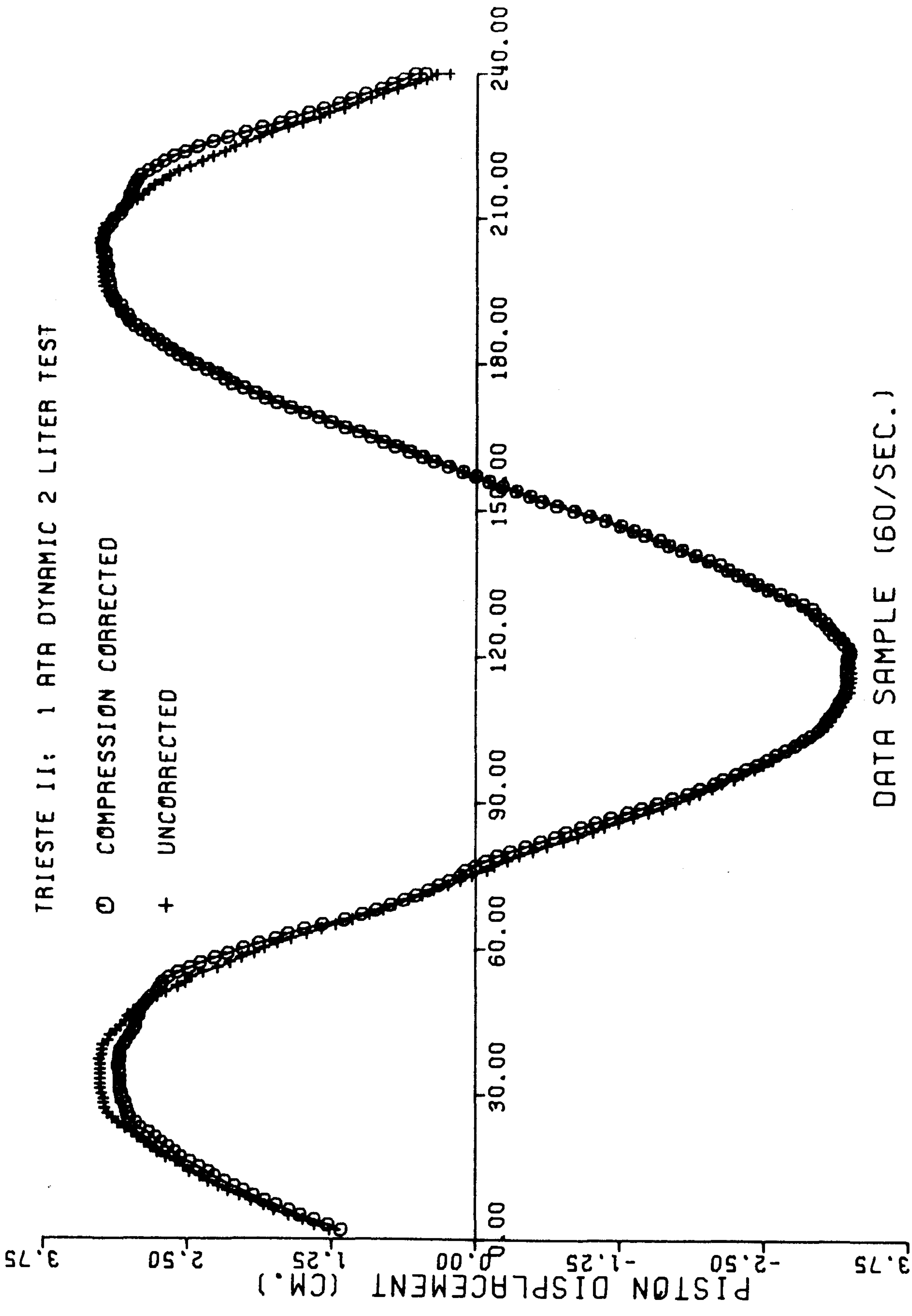

TRIESTE II: 1 ATA DYNAMIC 2 LITER TEST
ʘ COMPRESSION CORRECTED
+ UNCORRECTED
DATA SAMPLE (60/SEC.)
PISTON DISPLACEMENT (CM.)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
3.75
2.50
1.25
0.00
-1.25
-2.50
-3.75

Figure 19 Flow, (liters), as a function of time, (seconds), for Trieste II regulator 1 ATA wet dynamic test at 2.0 liters tidal volume and 20.8 breaths/min. respiratory frequency.

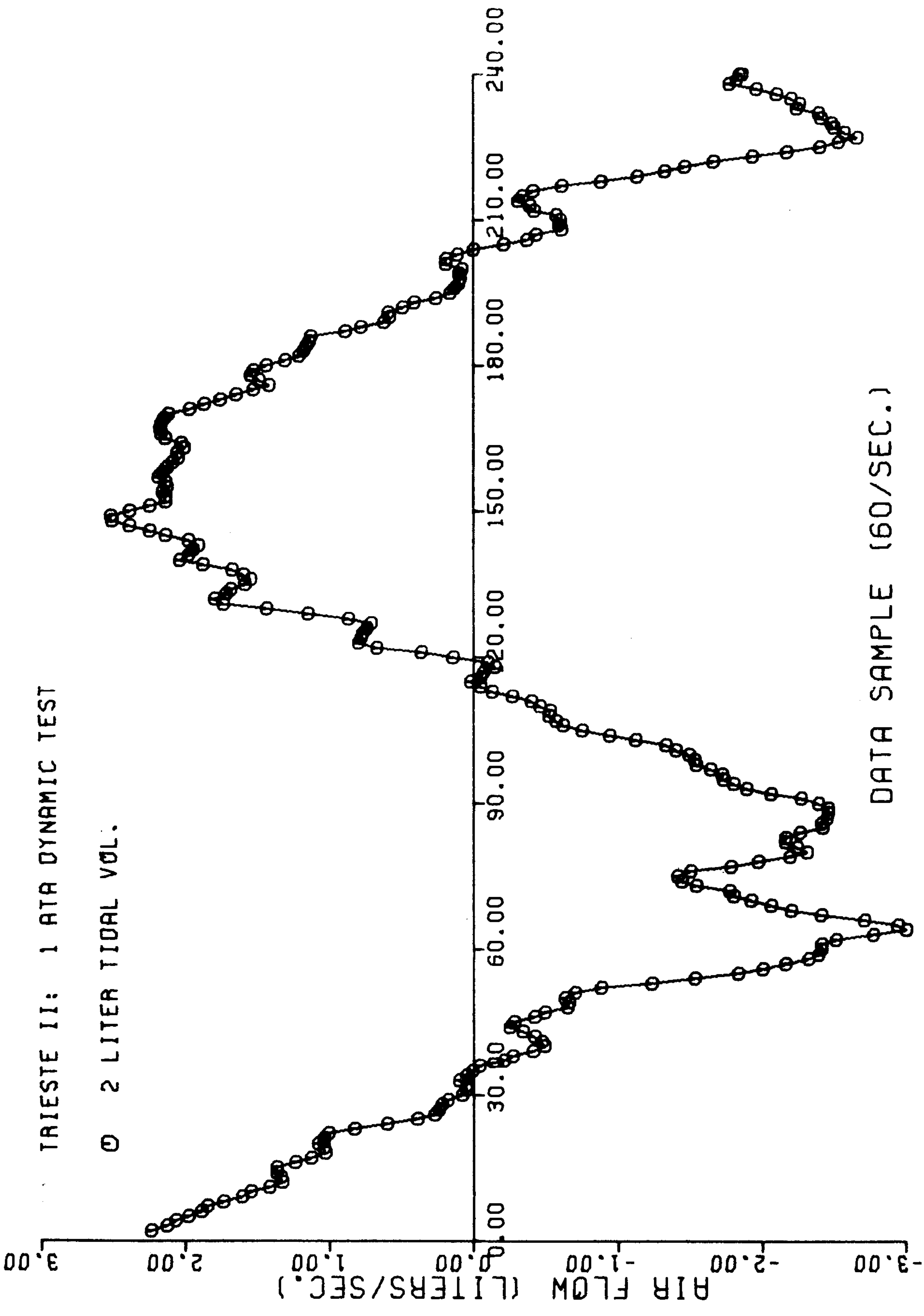
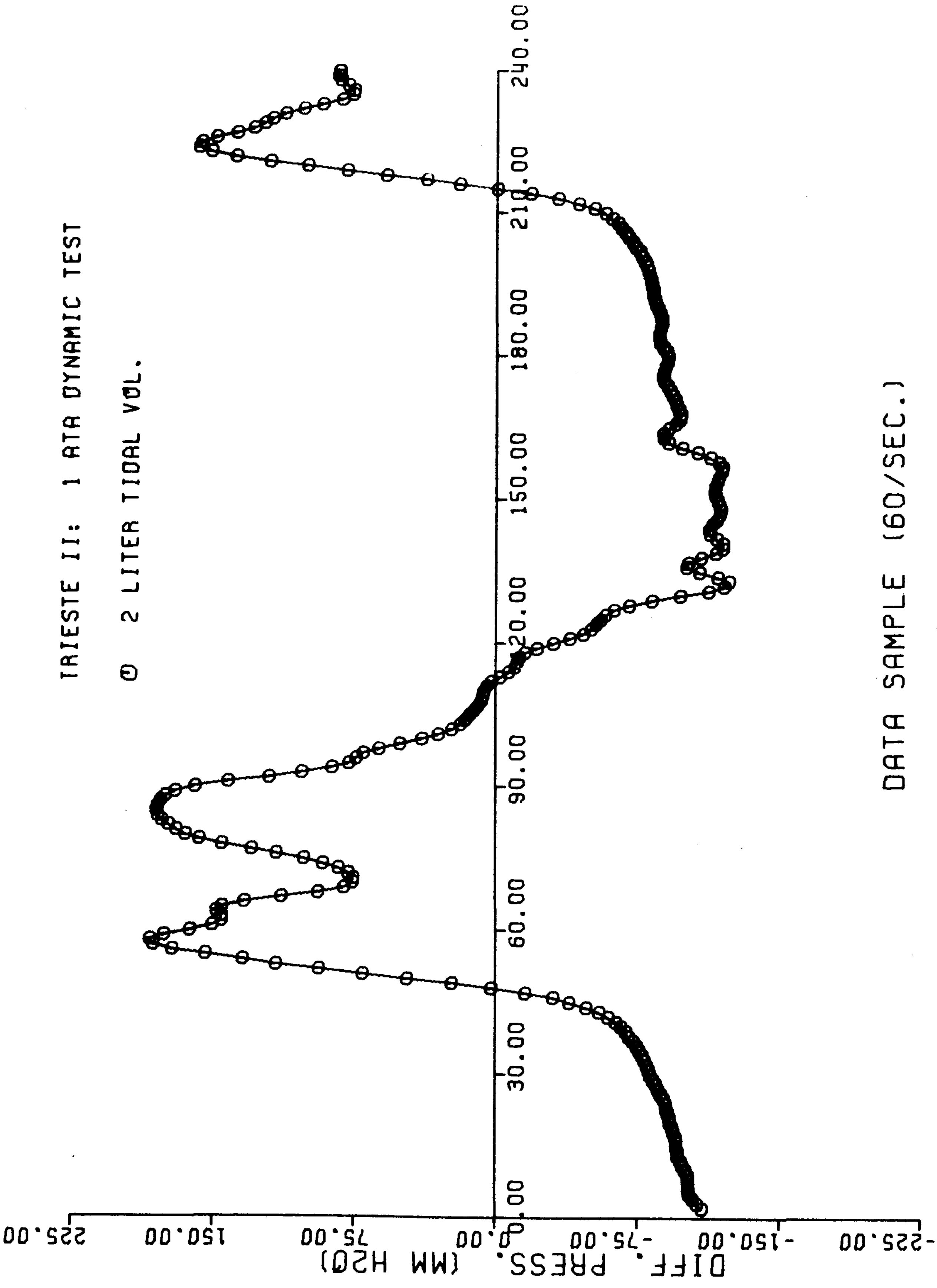

TRIESTE II: 1 ATA DYNAMIC TEST
⊖ 2 LITER TIDAL VOL.
DATA SAMPLE (60/SEC.)
AIR FLOW (LITERS/SEC.)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
3.00
2.00
1.00
0.00
-1.00
-2.00
-3.00

Figure 20 Pressure, (mm H2O), as a function of time, (seconds), for Trieste II two hose regulator 1 ATA wet dynamic test at 2.0 liters tidal volume and 20.8 breaths/min. respiratory frequency.


TRIESTE II: 1 ATA DYNAMIC TEST
⊖ 2 LITER TIDAL VOL.
DATA SAMPLE (60/SEC.)
DIFF. PRESS. (MM H2O)
0.00
30.00
60.00
90.00
120.00
150.00
180.00
210.00
240.00
225.00
150.00
75.00
0.00
-75.00
-150.00
-225.00

regulator. Total work of breathing, (kg.m./min.),, as a function of sinusoidal flow, (liters/min.), is plotted in Figures 21 and 22 respectively. Inspiratory and expiratory work components of the total work of breathing for the two regulators are similarly shown as a function of ventilation in Figures 23 and 24.

The work of breathing was calculated manually for one test run from the pressure-time and flow-time plots, (Figures 16 and 17, and 19 and 20), as a check on the results of the computer calculations. The computer program based calculations used an equal time interval for work of breathing approximations according to the expression:

$$W = \int P * (dV/dt) * dt$$

Where W = Work of Breathing

P = Pressure

V = Volume

t = Time

Manual calculations for the work of breathing, however, were derived from the summation of an equal volume increment times the differential pressure at each increment interval throughout the breathing half-cycles according to the expression:

$$W = \int P * dV$$

The difference between the two methods was 4.8% and was within the estimated accuracy of the manual calculation.

Figure 21 Resistive work of breathing, (kg.m./min.), as a function of ventilation, (liters/min.), for Poseidon mouth-held open circuit underwater breathing apparatus. Dynamic testing of apparatus immersed in water. Maximum and recommended standards by Cooper, (1960a), are also shown.

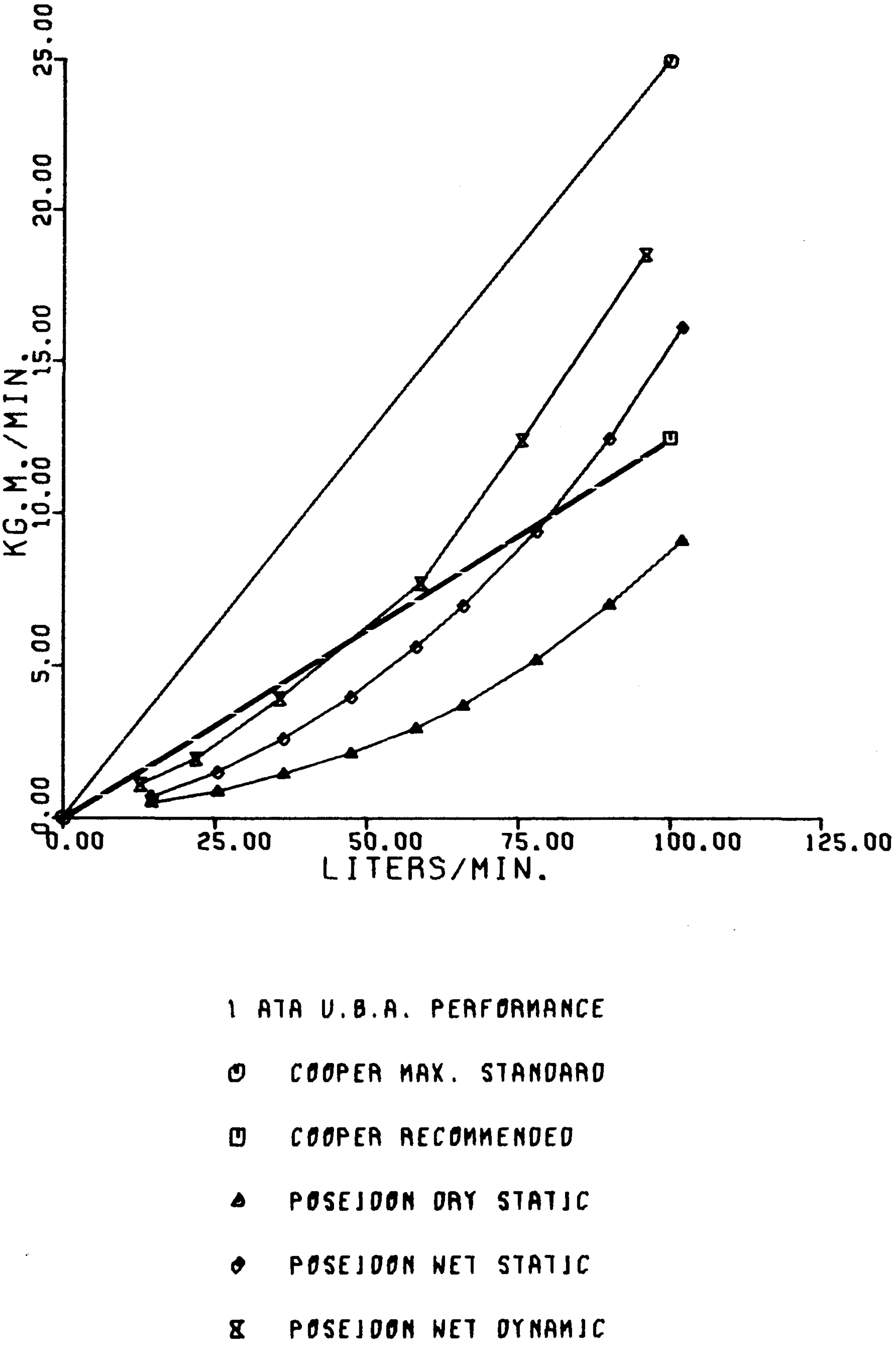

KG.M./MIN.
0.00
5.00
10.00
15.00
20.00
25.00
0.00
25.00
50.00
75.00
100.00
125.00
LITERS/MIN.
1 ATA U.B.A. PERFORMANCE
COOPER MAX. STANDARD
COOPER RECOMMENDED
POSEIDON DRY STATIC
POSEIDON WET STATIC
POSEIDON WET DYNAMIC

Figure 22 Resistive work of breathing, (kg.m./min.), as a function of ventilation, (liters/min.), for Trieste II back-mounted open circuit underwater breathing apparatus. Dynamic testing of apparatus immersed in water. Maximum and recommended standards by Cooper, (1960a), are also shown.

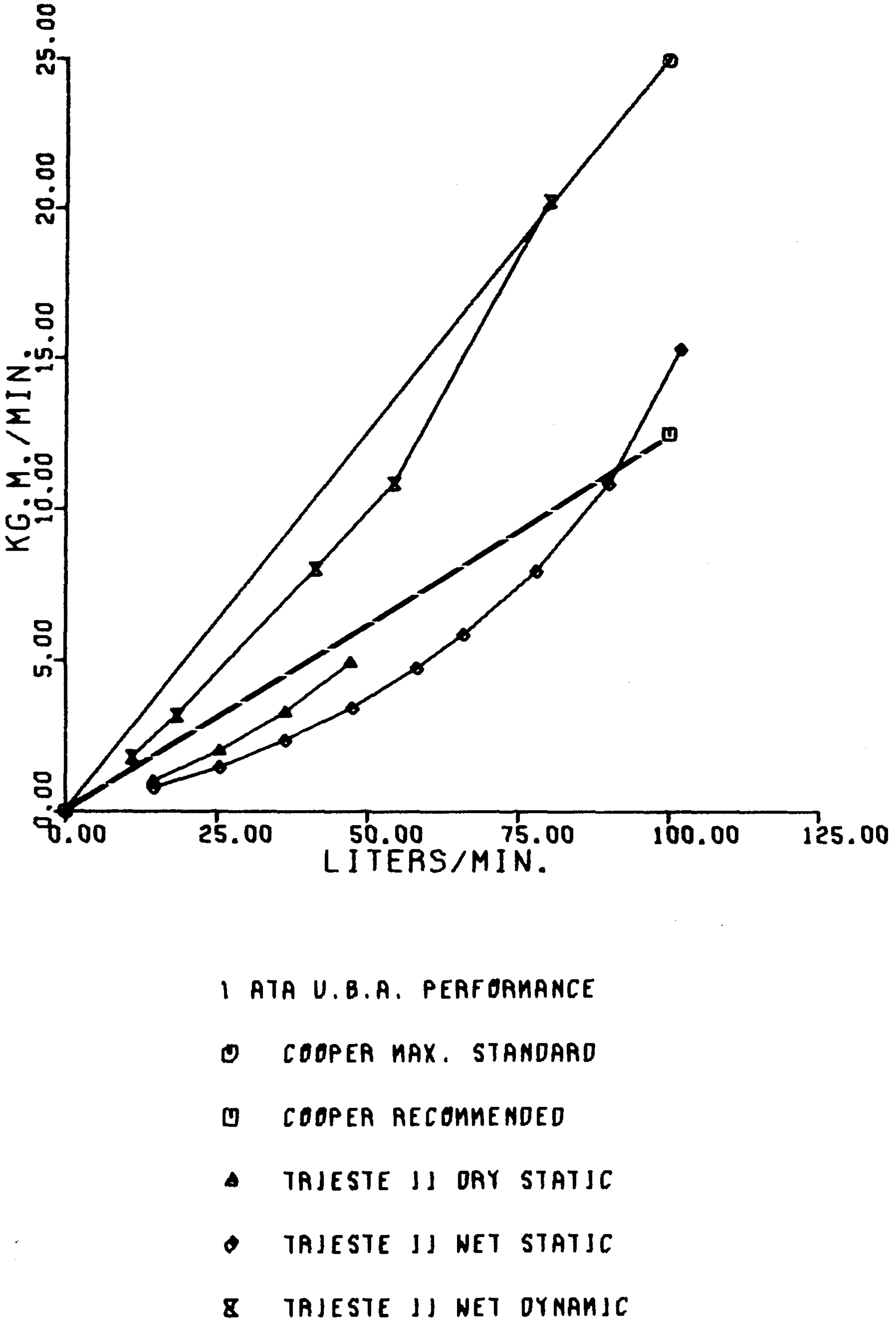
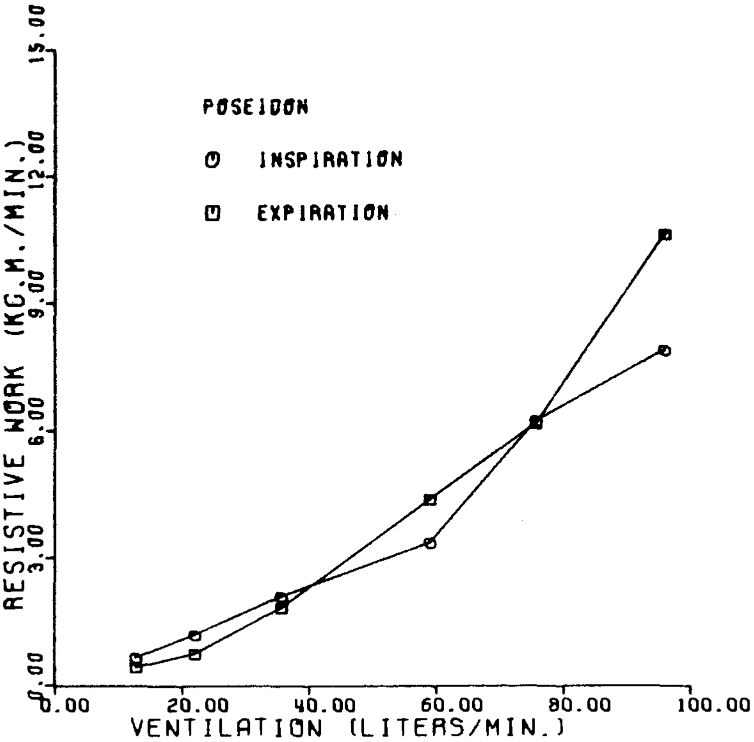
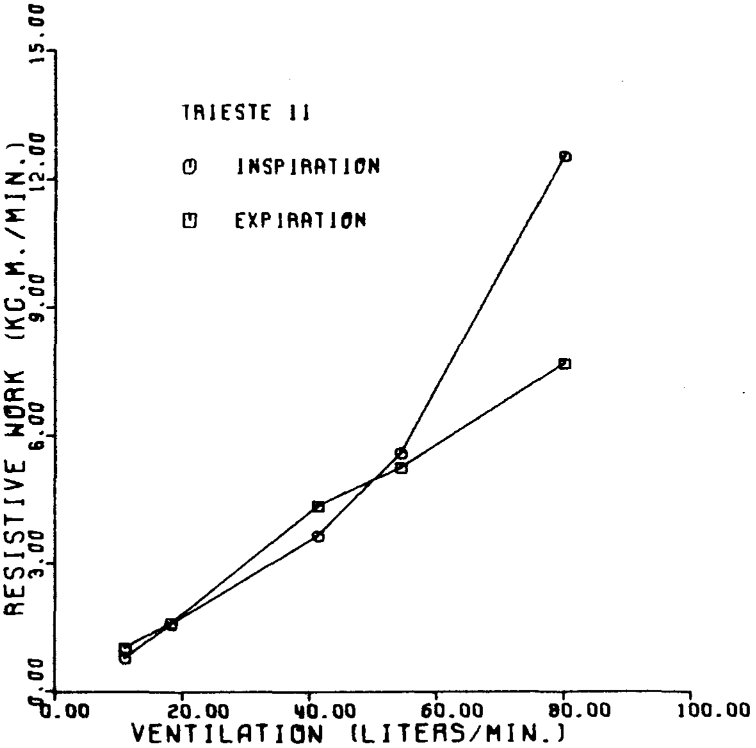

KG.M./MIN.
0.00
5.00
10.00
15.00
20.00
25.00
0.00
25.00
50.00
75.00
100.00
125.00
LITERS/MIN.
1 ATA U.B.A. PERFORMANCE
COOPER MAX. STANDARD
COOPER RECOMMENDED
TRIESTE II DRY STATIC
TRIESTE II WET STATIC
TRIESTE II WET DYNAMIC

Figure 23	Poseidon inspiratory and expiratory resistive work of breathing, (kg.m./min.), as a function of ventilation, (liters/min.) Dynamic testing of apparatus immersed in water.
Figure 24	Trieste II inspiratory and expiratory resistive work of breathing, (kg.m./min.), as a function of ventilation, (liters/min.) Dynamic testing of apparatus immersed in water.


POSEIDON
INSPIRATION
EXPIRATION
RESISTIVE WORK (KG.M./MIN.)
0.00
3.00
6.00
9.00
12.00
15.00
0.00
20.00
40.00
60.00
80.00
100.00
VENTILATION (LITERS/MIN.)


TRIESTE II
INSPIRATION
EXPIRATION
RESISTIVE WORK (KG.M./MIN.)
0.00
3.00
6.00
9.00
12.00
15.00
0.00
20.00
40.00
60.00
80.00
100.00
VENTILATION (LITERS/MIN.)

PART III: HYDROSTATIC PRESSURE IMBALANCE

The hydrostatic pressure difference between the diver's lung centroid and the demand regulator diaphragm of his open circuit UBA was measured directly from the slides for ten divers and are shown plotted relative to swimming angle in degrees for mouth held, (Figure 25), and back mounted, (Figure 26), regulators respectively. The mean values of R and were first determined for each subject in the swimming position in order to obtain a mean curve, $Hd = R\sin(a+\ )$, representative of the group. R and values measured in each position were slightly different. With the two hose regulator this was due to small movements of the equipment relative to the diver, but with the single hose regulator variations resulted from movements of the mouth and head. The mean R and for all ten subjects were then determined from individual mean values. Standard deviations were calculated using the differences, $(Hd - Hd\ )$, between the mean curve and the individual data points measured from the slides. The mean value of Hd when swimming was defined by the equation:

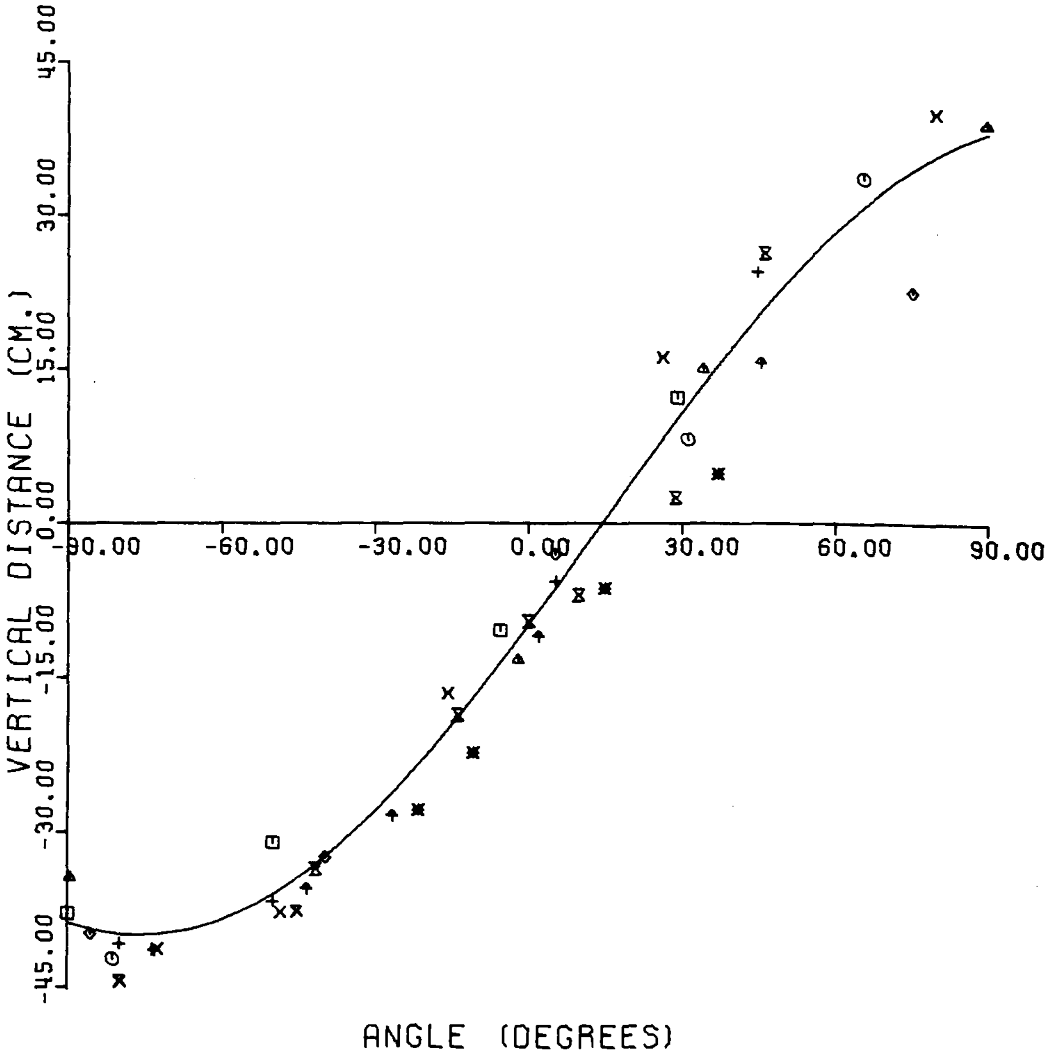
$$Hd = 40.0 \sin(a-14.5\ ) + 4.3 \text{ cm. } H_2O$$

for mouth held regulators, and

$$Hd = 27.9 \sin(a+33.8\ ) + 2.9 \text{ cm. } H_2O$$

for back mounted regulators. These equations apply over the range of diver orientations $-90. < a < 90.$ with respect to the horizontal.

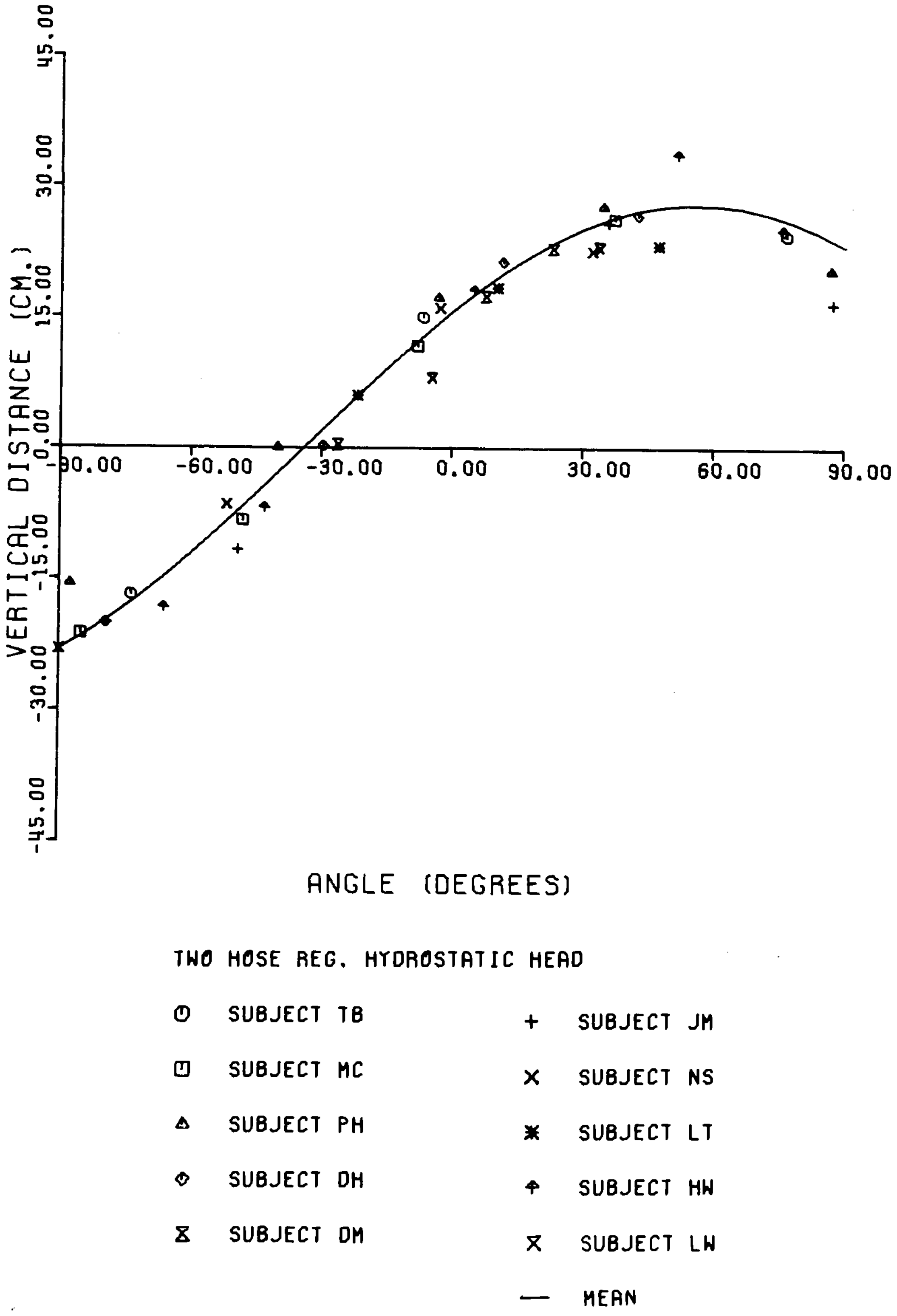
Figure 25 Variation in vertical distance between lung centroid and demand valve, (cm.), as a function of diver orientation with respect to the horizontal for mouth-held demand regulator.



SINGLE HOSE REG. HYDROSTATIC HEAD

⊙	SUBJECT TB	+	SUBJECT JM
⊡	SUBJECT MC	×	SUBJECT NS
△	SUBJECT PH	✱	SUBJECT LT
◇	SUBJECT DH	♠	SUBJECT HW
⧖	SUBJECT DM	⯰	SUBJECT LW
		—	MEAN

Figure 26 Variation in vertical distance between lung centroid and demand valve, (cm.), as a function of diver orientation with respect to the horizontal for back-mounted demand regulator.



TWO HOSE REG. HYDROSTATIC HEAD

Mean hydrostatic pressure was calculated from the data for each subject in an upright working position with head erect. A working position mean value of:

$$Hd = 24.1 \pm 3.7 \text{ cm. } H_2O$$

was calculated for a mouth held regulator, and

$$Hd = 24.7 \pm 2.6 \text{ cm. } H_2O$$

with a back mounted regulator.

Nearly all open circuit UBA presently available are similar in the placement of the demand diaphragm relative to either mouthpiece for mouth held or cylinder mounting for back mounted. These results are therefore considered to be representative of open circuit scuba irrespective of apparatus manufacturer or model.

DISCUSSION

Static test calculations of the work of breathing were greater for the Poseidon regulator during immersion than during dry testing. Steady state pressure-flow data, (Figures 7 through 10), showed this to be the result of an increase in exhalation resistance at all ventilations. Large changes in Poseidon exhalation resistance were noted with variation in exhaust valve orientation, (Figure 10.) It is suggested that during immersion, the formation of bubbles and their subsequent release from the area of the exhaust ports caused increased expiratory pressure for a given flow rate compared to the non-immersed condition. Cooper recommended that the work of breathing for respiratory devices, (kg.m./min.), not exceed one-eighth of the ventilation, (liters/min.), (1960a.) Steady state immersed work of breathing at 1 ATA exceeded this at approximately 81 liters/min. for the Poseidon, (Figure 21.)

Trieste II regulator static tests found inspiratory and expiratory resistances, (Figures 11 through 14), and work of breathing, (Figure 22), to be greater in the dry condition than when immersed. Differences in expiratory resistance may have been largely a result of the same exhaust valve difficulty which abbreviated the dry steady state testing.

Steady state work of breathing under wet conditions at 1 ATA for the Trieste II regulator exceeded Cooper's recommended standards at approximately 92 liters/min., (Figure 22.)

Dynamic work of breathing at 1 ATA for the Poseidon UBA exceeded Cooper's recommendations at approximately 51 liters/min. ventilation, plotted in Figure 21. The Trieste II UBA under the same conditions exceeded these values at all ventilations. Further, at the highest flow rate tested, (3 liters tidal volume and 26.7 breaths/min.), the Trieste II reached Cooper's maximum limit of the work of breathing equal to one-fourth of the ventilation, as shown in Figure 22.

The steady state testing of both regulators was carried out in conjunction with the dynamic testing in order to investigate the validity of static determinations of UBA work of breathing. The obtainment of similar results would indicate that UBA performance measurements could be made without the need for a respiration simulator. However, static work of breathing values were as much as 23.2% less than dynamic at 95.9 liters/min. for the Poseidon and 58.2% less at 80.1 liters/min. for the Trieste II. Of this difference, Poseidon static inspiratory work was 42.2% less than dynamic inspiratory work, while static expiratory work was only 9.1% less than dynamic expiratory work. For the

Trieste II values were 75.9% less and 29.4% less respectively.

The dynamic testing, simulating typical diver employment of the UBA, cycled the regulators through inspiratory and expiratory breathing phases with sinusoidal variation in flow rate. Hysteresis losses due to damping during opening and and closing of the tilt valve inspiratory mechanism and water flow resistance with movement of the demand diaphragm probably caused increases in work of breathing compared with static testing estimations. Exhausting of water influx into the exhaust ports during the first stages of exhalation, and non-steady state exhaust bubble formation may also have affected the work of breathing.

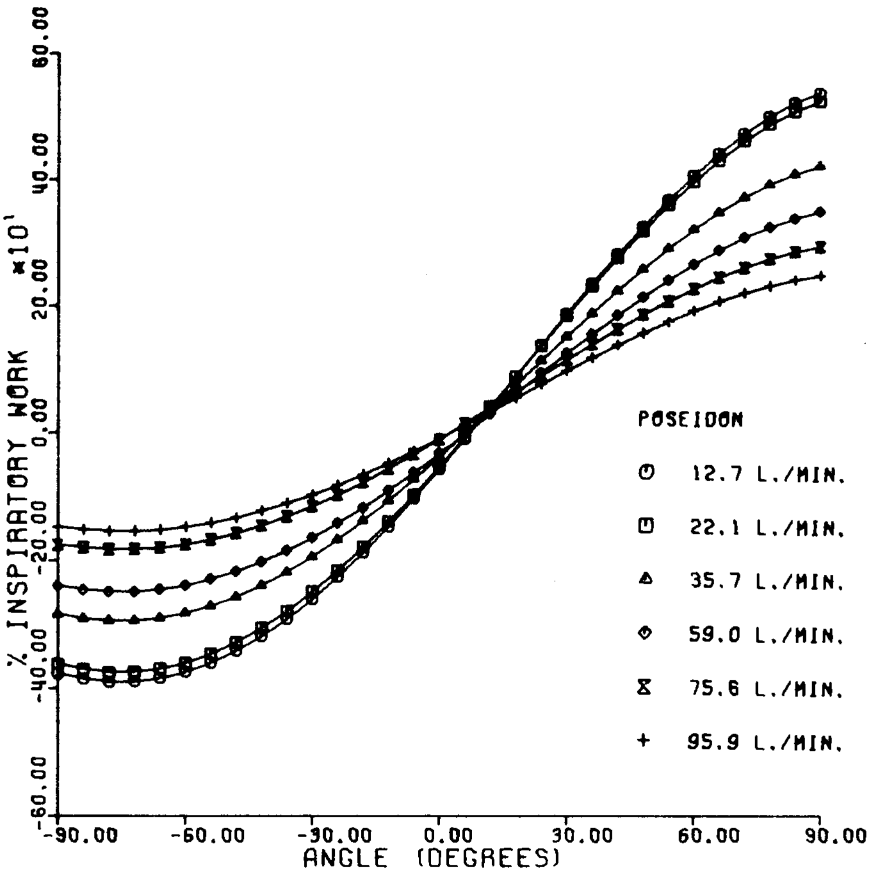
Because the differences between static and dynamic test results are both large and difficult to correct, it is concluded that steady state testing is not a valid method for work of breathing evaluation of UBA.

Hydrostatic pressure imbalance, as shown in Figures 23 and 24, varied with swimming orientation by approximately ± 40 cm. H20 when using mouth held regulators and ± 28 cm. H20 with back mounted regulators. In addition, hydrostatic pressure imbalance with mouth held regulators is also affected by head position, the amount of possible variation increasing as the swimming angle deviates from the horizontal. This is reflected in the difference between hydrostatic pressure imbalance measured when the diver was swimming upward, (+40 cm. H_2O), and the upright working position where the diver was looking horizontally, (+24 cm. H_2O.)

Hydrostatic pressure imbalance has a significant effect upon inspiratory and expiratory work. Figures 29 and 30 illustrate inspiratory and expiratory work as percentages of the total respiratory work for a mouth held and a back mounted regulator at 1 ATA at high ventilations plotted with respect to swimming angle. The percentages shown without hydrostatic imbalance indicate the external respiratory load that would result if the demand valve were placed in the ideal position at the lung centroid. Percentages of total work were determined from the pressure-flow measurements made during the wet dynamic tests.

Negative external expiratory work may result in a reduction in the total expiratory work and hence a lesser involvement of the respiratory muscles. Negative hydrostatic work exceeding the combined internal and external resistive work, will result in braked expiration, and thus cause a

Figure 27	The inspiratory work percentage of the total work of breathing as a function of diver orientation with respect to the horizontal. Based on 1 ATA dynamic testing of a mouth-held open circuit regulator immersed in water.
Figure 28	The inspiratory work percentage of the total work of breathing as a function of diver orientation with respect to the horizontal. Based on 1 ATA dynamic testing of a back-mounted open circuit regulator immersed in water.


% INSPIRATORY WORK ×10¹
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-90.00
-60.00
-30.00
0.00
30.00
60.00
90.00
ANGLE (DEGREES)
POSEIDON
12.7 L./MIN.
22.1 L./MIN.
35.7 L./MIN.
59.0 L./MIN.
75.6 L./MIN.
95.9 L./MIN.

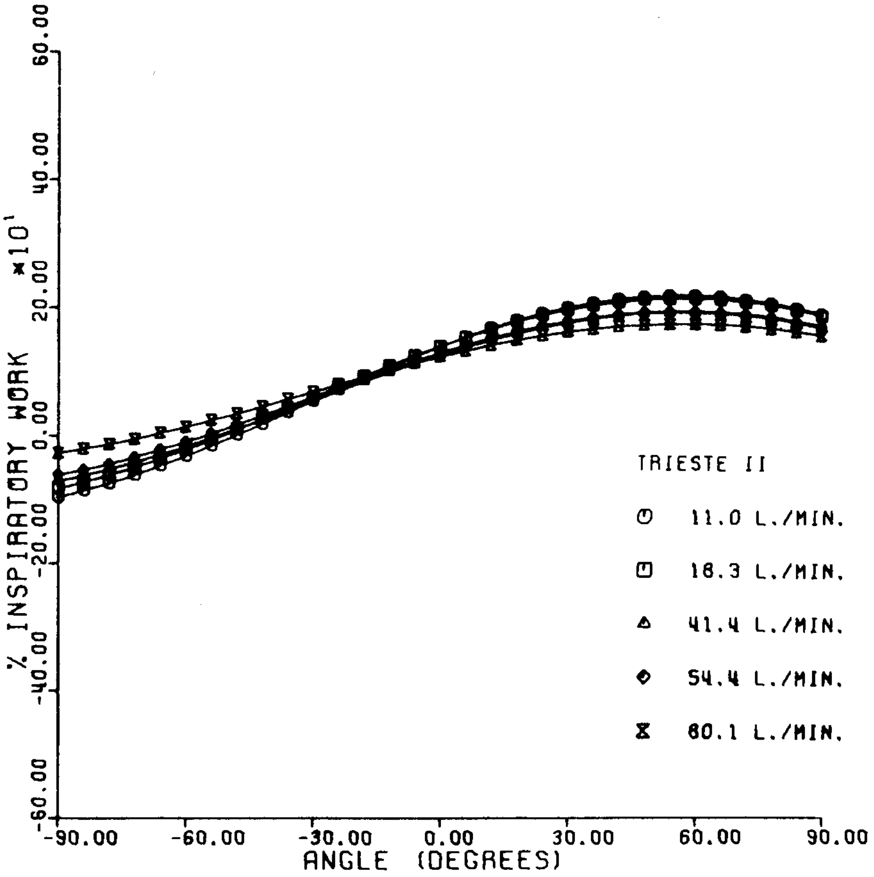
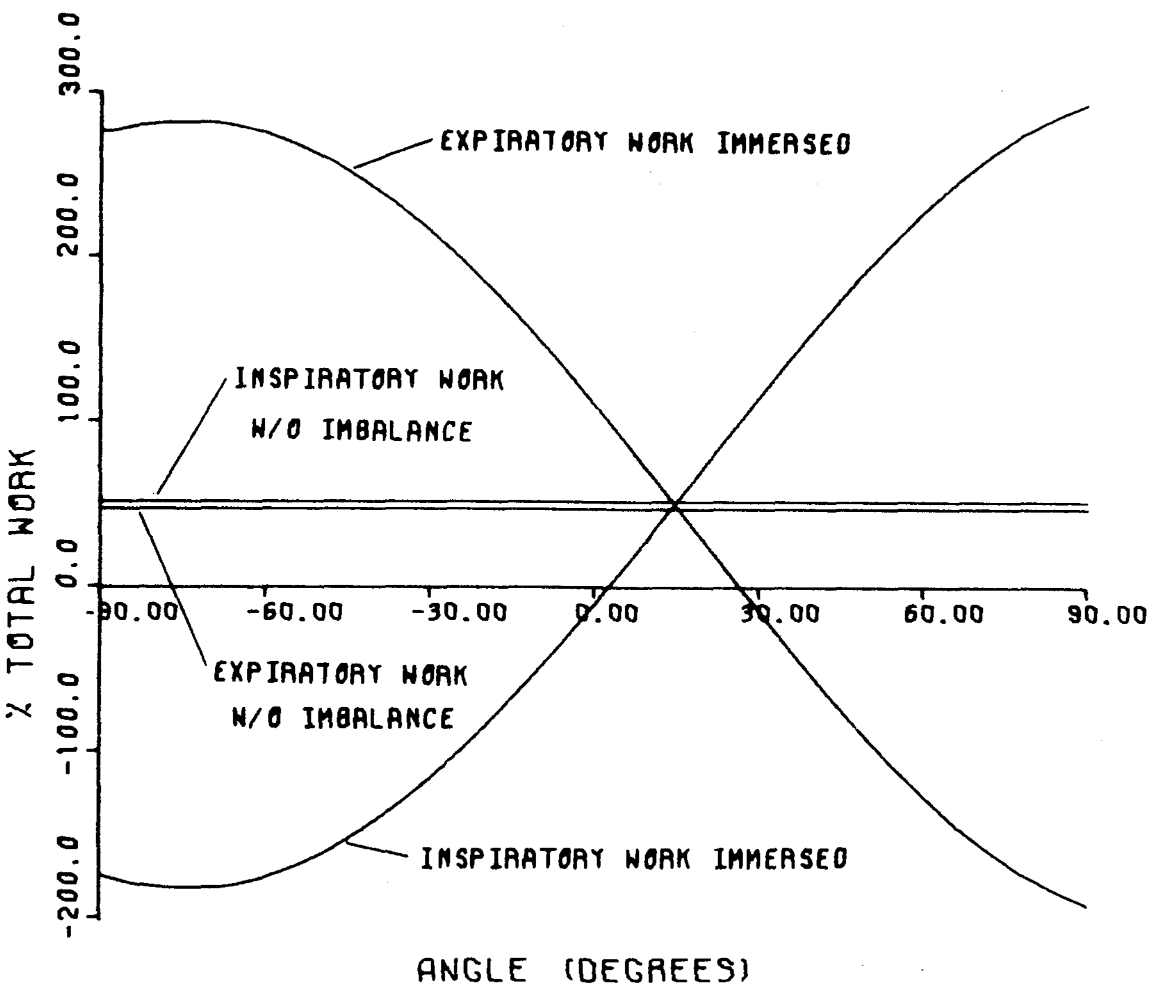
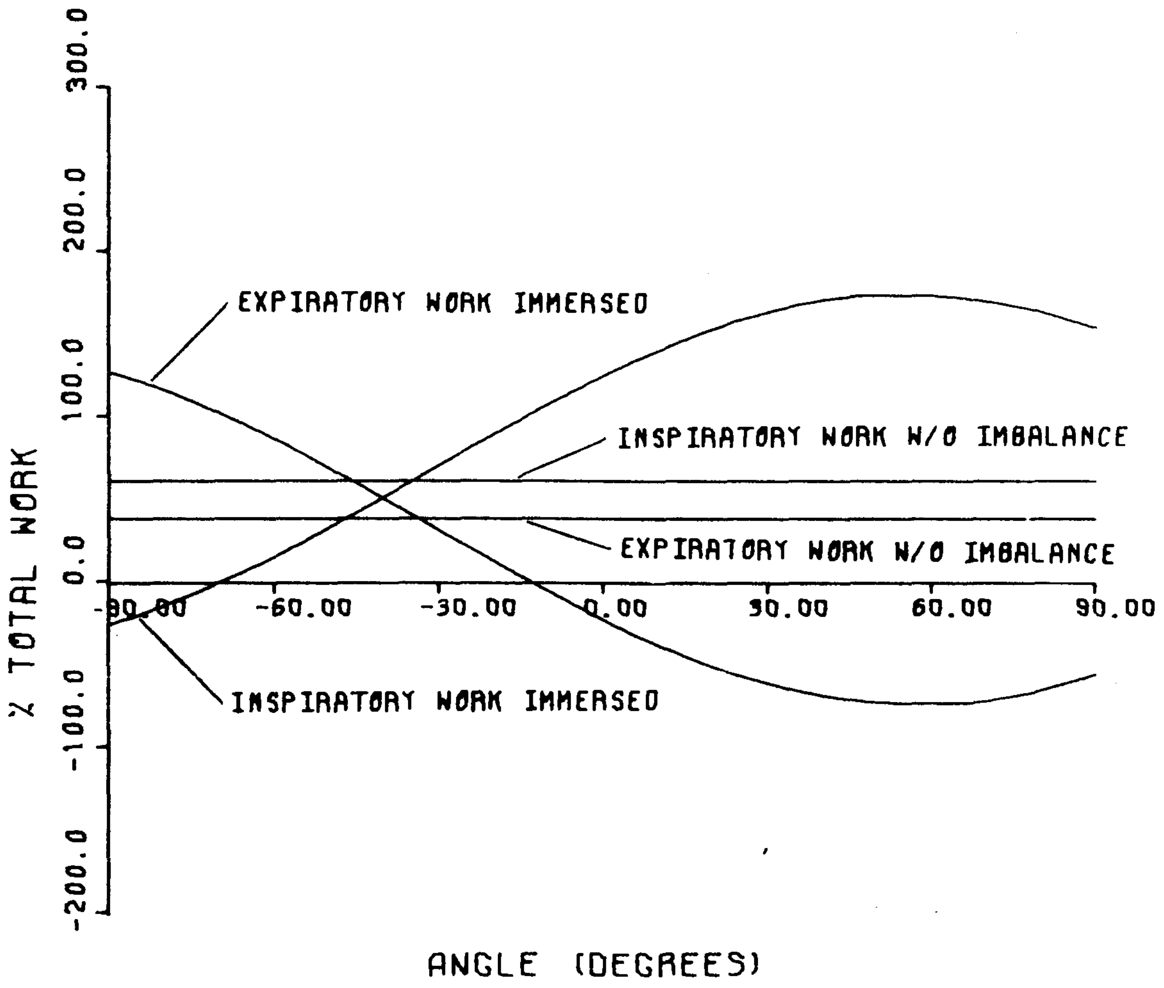

% INSPIRATORY WORK ×10¹
60.00
40.00
20.00
0.00
-20.00
-40.00
-60.00
-90.00
-60.00
-30.00
0.00
30.00
60.00
90.00
ANGLE (DEGREES)
TRIESTE II
11.0 L./MIN.
18.3 L./MIN.
41.4 L./MIN.
54.4 L./MIN.
80.1 L./MIN.

Figure 29 Inspiratory and expiratory work expressed as a percentage of the total work of breathing. The figure shows work both with and without hydrostatic imbalance. Based on 1 ATA dynamic testing of a mouth-held open circuit regulator at 75.6 liters/min. ventilation immersed in water.



1 ATA SINGLE HOSE: 75.6 L./MIN.

Figure 30 Inspiratory and expiratory work expressed as a percentage of the total work of breathing. The figure shows work both with and without hydrostatic imbalance. Based on 1 ATA dynamic testing of a back-mounted open circuit regulator at 80.1 liters/min. ventilation immersed in water.



1 ATA TWO HOSE: 80.1 L./MIN.

greater involvement of the inspiratory muscles. This latter condition imposes an unnecessary respiratory load upon the diver.

Cooper's suggested standards for respiratory protective devices, (1960a), included the recommendation that at high ventilation rates the fraction of work done in expiration should not be more than 50%. The effect of hydrostatic imbalance on inspiratory and expiratory work decreases with the increase in UBA resistive work with either increasing ventilation and or increasing depth, (Figures 27 and 28.) Comparisons of Figures 29 and 30 show that at 1 ATA the back mounted two hose regulator provides a greater range of diver orientations having expiratory work less than 50% of total work of breathing. In terms of balancing the work of breathing between inspiration and expiration the back mounted regulator may thus be preferable especially if the diver's body inclination is predominately in other than a horizontal swimming position during the dive.

Whether the diver should breathe against a positive or negative pressure depends to an extent upon the magnitude of the inspiratory and expiratory resistive work of the particular demand regulator in use. Thus if expiratory resistive work is larger it is best to breathe against negative pressure in order to shift part of the load to inspiration, thereby making use of hydrostatic pressure imbalance to obtain the best ratio of inspiratory and expiratory work. Considering Cooper's recommendations for limiting expiratory work, and the comfort indicated pressures found by Paton and Sand, (1947), and Thompson and McCally, (1967), it is probably best to incorporate negative pressure breathing provided levels are not excessive.

CONCLUSIONS

The respiration simulator with sinusoidal ventilation used in this investigation enables the determination of the work of breathing for open circuit demand underwater breathing apparatus under immersed dynamic conditions. Test results thus give estimations of apparatus performance in terms of physiologically acceptable respiratory work loads and permit direct comparison between different underwater breathing apparatus.

Steady state bench testing was found to be not a valid method for underwater breathing apparatus evaluation as a result of non-replication of dynamic inspiratory and expiratory resistances.

Hydrostatic pressure imbalance as determined for various diver orientations using both mouth held and back mounted demand regulators was a significant factor in inspiratory and expiratory work percentages of the total work of breathing.

Respiration simulator measurements of the work of breathing for the underwater breathing apparatus tested exceeded earlier recommended standards even at 1 ATA at ventilations within the physiological range of working divers.

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Appendix A Computer Program for Resistive Work/Static Tests

APPENDIX A: Computer Program for Resistive Work/Static Tests

```
//    EXEC    WATFIV
$JOB 0447/BENCH,KP=29,TIME=2,RUN=FREE
C       Set up data arrays for flow rate and diff. press.
       DIMENSION A(30), B(30), C(30), D(30), E(9), F(9)
C       First 3 lines:  Dry inspiration flow rate
C       Second 3 lines:  Dry inspiration pressure
C       Third 3 lines:  Dry expiration flow rate
C       Fourth 3 lines:  Dry expiration pressure
C       Last 2 lines: Tidal volume and Respiratory frequency
 11   OREAD(5,12) (A(J),J=1,30),(B(K),K=1,30),(C(L),L=1,30),
      1(D(M),M=1,30),(E(I),I=1,9),(F(N),N=1,9)
 12    FORMAT (10F7.0)
C       Set flow surface area in sq. cm.
       SA = 3.14 * (2.54/2.00) ** 2
C       Set acumulator equal to zero
       W = 0.
C       Set work of inspiration equal to zero
       WI = 0.
C       Set work of expiration equal to zero
       WE = 0.
 21    WRITE(6,22)
 22   OFORMAT ('0',8X,'VT',4X,'RESPHZ',3X,'VENTM',4X,'WI',5X,
      1'WIM',6X,'WE',5X,'WEM',5X,'WTM',4X,'PEREX',3X,'PERIN')
C       Set tidal volume and respiratory frequency
       DO 1 J = 1,9
       VT = E(J)
       RESPHZ = F(J)
C       Establish time increment
       DT = 1.00/(RESPHZ*30.0)
C       Maximum velocity
       VMAX = 3.14 * RESPHZ * VT
C       Sample flow rate every 12 degrees
       DO 2 I = 1, 30
C       Set bench data counter
       N = 2
C       Convert degrees to radians
       Z = (3.14/15.0) * I
C       Flow rate
```

APPENDIX A: (continued)

```
      RP = SIN(Z) * VMAX
 35   IF (I-15) 40,40,45
C      Establish expiratory phase values
 40   VI = C(N)
      VO = C(N-1)
      PI = D(N)
      PO = D(N-1)
      IF (RP - VI) 50,55,60
C      Establish inspiratory phase values
 45   VI = A(N)
      VO = A(N-1)
      PI = B(N)
      PO = B(N-1)
      IF (RP - VI) 60,55,50
C      If flow rate less than bench flow rate, interpolate
 50   W = W + RP * (((RP - VO)/(VI - VO)) * (PI - PO) + PO) * DT
      GO TO 70
C      If flow rate equal to bench flow rate, calculate W
 55   W = W + RP * PI * DT
      GO TO 70
C      If flow rate greater than bench flow rate, increment bench
 60   IF (N-30) 65,23,23
 65   N = N + 1
      GO TO 35
 23   WRITE(6,24)
 24   FORMAT ('0','Flow rate exceeds approximation')
      GO TO 2
 70   IF (I-15) 2,75,2
 75   WE = W/1000.
      W = 0.
 2    CONTINUE
      WI = W/1000.
      VENTM = RESPHZ * VT
      WIM = WI ● RESPHZ
      WEM = WE * RESPHZ
      WTM = WIM + WEM
      PEREX = (WEM/WTM) * 100.0
      PERIN = 100.0 - PEREX
```

APPENDIX A: (continued)

```
 25    WRITE(6,26)VT,RESPHZ,VENTM,WI,WIM,WE,WEM,WTM,PEREX,PERIN
 26    FORMAT (5X, 10F8.4)
       W = 0.
 1     CONTINUE
       STOP
       END
$ENTRY
-   0.00-  19.28-  38.55-  57.83-  77.10-  96.38-115.66-134.93-154.21-173.4
-192.76-212.04-231.31-250.59-269.86-289.14-308.42-327.69-346.97-366.2
-385.52-404.80-424.07-443.35-462.62-481.90-501.18-520.45-539.73-559.0
  -1.50  -57.27  -59.39  -59.39  -63.63  -63.63  -63.63  -63.63  -63.63  -63.6
 -63.63  -63.63  -63.63  -64.48  -65.75  -68.72  -72.11  -74.24  -78.48  -89.0
-101.81-114.53-131.50-144.23-161.20-174.77-190.89-207.86-222.71-239.6
   0.00    5.05   10.10   15.15   20.20   25.25   30.30   35.35   40.40   45.4
  50.50   55.55   60.60   65.65   70.70   75.75   80.80   85.85   90.90   95.9
 101.00  106.05  111.10  116.15  121.20  126.25  131.30  136.35  141.40  151.5
   0.30    1.32    2.84    3.85    5.17    6.39    7.41    8.93    9.94   11.4
  12.99   14.21   15.53   17.35   19.08   20.60   22.63   24.15   26.49   27.9
  29.94   32.27   34.61   36.84   39.59   42.93   45.98   49.02   53.08   61.2
   1.00    1.50    2.00    2.50    3.00    3.00    3.00    3.00    3.00   14.6
  17.00   18.20   18.90   19.40   22.00   26.00   30.00   34.00
```

Appendix B Computer Program for Resistive Work/Dynamic Tests

APPENDIX B: Computer Program for Resistive Work/Dynamic Tests

```
/*JOBPARM  PSWD=MAD,PRTY=5
//   EXEC   FORTGCLG,REGION.GO=240K
//FORT.SYSIN  DD  *
C      Set up data arrays for displacement, diff. press.,
C      ventilation, total, resistive and hydrostatic work of
C      inspiration, and total, resistive and hydrostatic work
C      of expiration
     0DIMENSION A(2000),B(2000),VENT(50),H(50),WI(50),
     1WIR(50),WIH(50),WE(50),WER(50),WEH(50),JKI(50),JKE(50),D(2000)
C      Read Hydrostatic Head Data in cm. H20
      H(1) = 0.0
      READ(5,11)(H(I),I=2,32)
 11   FORMAT(8F6.2)
C      Read digitized displacement and diff. prass. data
      DO 2 I = 1,1502
      READ(5,12)A(I),B(I),C
 12   FORMAT(3F8.0)
 2    CONTINUE
C      Establish time increment
      DT = 1.00/60.00
C      Surface area of piston in sq. cm.
      SA = 3.14 * (19.79/2.0) ** 2
C      Displacement transducer cm. conversion factor
      CALA = 0.0040
C      Differential pressure transducer mmH20 conversion factor
      CALG = 0.209
C      Zero Offset Corrected to MMH20
      OFFSET = -210.0
C      Establish demand valve water head in mm H20
      HD = 187.0
C      Center Volume of Cylinder in Milliliters
      L=5710.
C      Equivalent Center Line Voltage
      E1 = L/(SA * CALA)
C      Actual Center Line Voltage:  (MAX + MIN)/2
      E2 = 619.0
C      Voltage Correction
      E3 = E1 - E2
```

```
C      Corrected Displacement
      D(1) = 2 * E2 - A(1) + E3
      PRINT 30
 30  0FORMAT (6X,'TIDVOL',2X,'RESPHZ',2X,'VENTM',4X,'WIM',
     15X,'WIRM',4X,'WIHM',4X,'WEM',5X,'WERM',4X,'WEHM',4X,
     2'WTM',4X,'PEREX',3X,'PERIN',4X,'HC')
C      Establish lung centroid water head in mm H20
      DO 3 N = 1,32
      HC = H(N)
C      Set expiration counter equal to zero
      KE = 0
C      Set inspiration counter equal to zero
      KI = 0
C      Set resistive work of inspiration equal to zero
      WKIR = 0.0
C      Set resistive work of expiration equal to zero
      WKER = 0.0
C      Set hydrostatic work of inspiration to zero
      WKIH = 0.0
C      Set hydrostatic work of expiration to zero
      WKEH = 0.0
C      Set complete inspiration cycle internal data count to zero
      NKI = 0
C      Set complete expiration cycle internal data count to zero
      NKE = 0
C      Set total data count for even inspirations and expirations
C      equal to zero
      ISUM = 0
C      Set uncorrected minute work of inspiration equal to zero
      PWIM = 0.
C      Set uncorrected minute resistive work of inspiration
C      equal to zero
      PWIRM = 0.0
C      Set uncorrected minute hydrostatic work of inspiration
C      equal to zero
      PWIHM = 0.0
C      Set uncorrected minute resistive work of expiration
C      equal to zero
```

APPENDIX B: (continued)

```
      PWERM = 0.0
C      Set uncorrected minute hydrostatic work of expiration
C      equal to zero
      PWEHM = 0.0
C      Set uncorrected minute work of expiration equal to zero
      PWEM = 0.
C      Set ventilation equal to zero
      VEN = 0.
      PVENT = 0.
      DO 4 I = 2,1402
     0D(I) = D(I-1) - ((2*E2 - A(I-1)+E3) * (B(I-1) * CALG+10330. + H
     1/(B(I) * CALG + 10330. + HD) - (2*E2 - A(I) + E3))
 4    CONTINUE
      DO 5 I = 1, 1396
C      Five point smoothing curve variables for velocity
      AA = D(I)
      BB = D(I + 1)
      CC = D(I + 2)
      DD = D(I + 3)
      EE = D(I + 4)
C      Velocity in cm./sec. using five point smoothing
      VI = ( (-2.0 * AA - BB + DD + 2.0 * EE) * CALA )/(10 * DT)
      IF (I-1)35,35,40
C      Initial velocity in cm./sec. using five point smoothing
 35   VO=VI
      GO TO 5
C      Corrected flow rate in liters/sec.
 40   RF = SA * VI/1000.
C      Corrected differential pressure in mmH20
      PC = B(I) * CALG - HD - OFFSET
C      Incomplete first cycle rejection
      IF (KE) 45,45,65
 45   IF (KI) 50,50,65
 50   IF (VO) 60,5,55
 55   IF (VI) 85,5,5
 60   IF (VI) 5,5,100
 65   IF(VO) 70,70,75
 70   IF(VI) 90,90,95
```

APPENDIX B: (continued)

```
 75    IF(VI) 80,105,105
C       Positive to negative, (VO positive and VI negative)
C       Finalize work of expiration for that breath,
C       reset work of expiration, finalize expiration cycle internal
C       data count, and increment expiration counter
 80    IF(NKE-40)105,105,82
 82    WER(KE) = WKER
       WKER = 0.0
       WEH(KE) = WKEH
       WE(KE) = WER(KE) + WEH(KE)
       WKEH = 0.0
       MKE = KE
       JKE(MKE) = NKE
       VENT(KE) = VEN
       NKE = 0
       VEN = 0
 85    VO = VI
       KI = KI + 1
C       Negative no change, (both VO and VI negative)
C       Add work segment to work of inspiration for that breath, keep
C       counter the same, and increment inspiration cycle internal
C       data count
 90    WKIR = WKIR - RF * PC * DT
       WKIH = WKIH - HC * RF * DT * 10.0
       NKI = NKI + 1
       GO TO 5
C       Negative to positive, (VO negative and VI positive)
C       Finalize work of inspiration for that breath,
C       reset work of inspiration, finalize inspiration cycle internal
C       data count, and increment inspiration counter
 95    IF(NKI-40)90,90,97
 97    WIR(KI) = WKIR
       WKIR = 0.0
       WIH(KI) = WKIH
       WI(KI) = WIR(KI) + WIH(KI)
       WKIH = 0.0
       MKI = KI
       JKI(MKI) = NKI
```

```
      NKI = 0
 100  VO = VI
      KE = KE + 1
C      Positive no change, (both VO and VI positive)
C      Add work segment to work of expiration for that breath, keep
C      counter the same and increment inspiration cycle internal
C      data count
 105  WKER = WKER - RF * PC * DT
      WKEH = WKEH - HC * RF * DT * 10.0
      NKE = NKE + 1
      VEN = VEN + RF * DT
 5    CONTINUE
C      Calculate smallest number of even complete half cycles
      IF (NKE-NKI) 110,115,115
 110  J = NKE
      GO TO 120
 115  J = NKI
 120  DO 6 I = 1, J
      ISUM = ISUM + JKI(I) + JKE(I)
C      Time uncorrected minute work of inspiration
      PWIM = PWIM + WI(I)
C      Time uncorrected minute resistive work of inspiration
      PWIRM = PWIRM + WIR(I)
C      Time uncorrected minute hydrostatic work of inspiration
      PWIHM = PWIHM + WIH(I)
C      Time uncorrected minute work of expiration
      PWEM = PWEM + WE(I)
C      Time uncorrected minute resistive work of expiration
      PWERM = PWERM + WER(I)
C      Time uncorrected minute hydrostatic work of expiration
      PWEHM = PWEHM + WEH(I)
      PVENT = PVENT + VENT(I)
 6    CONTINUE
C      Minute work of inspiration in kg.m./min.
      WIM = PWIM * 0.06/(ISUM*DT)
C      Minute work of resistive inspiration in kg.m./min.
      WIRM = PWIRM * 0.06/(ISUM*DT)
C      Minute work of hydrostatic inspiration in kg.m./min.
```

```
      WIHM = PWIHM * 0.06/(ISUM*DT)
C      Minute work of expiration in kg.m./min.
      WEM = PWEM * 0.06/(ISUM*DT)
C      Minute work of resistive expiration in kg.m./min.
      WERM = PWERM * 0.06/(ISUM*DT)
C      Minute work of hydrostatic expiration in kg.m./min.
      WEHM = PWEHM * 0.06/(ISUM*DT)
C      Minute Ventilation in liters
      VENTM = PVENT * 60.0/(ISUM*DT)
C      Respiratory frequency in cycles per minute
      RESPHZ = J * 60.0/(ISUM*DT)
C      Tidal Volume in liters
      TIDVOL = VENTM/RESPHZ
C      Total Minute Work in kg.m./min.
      WTM = WIM + WEM
C      Expiratory Work Percentage of Total Work
      PEREX = ((WERM + WEHM)/WTM) * 100.0
C      Inspiratory Work Percentage of Total Work
      PERIN = 100.0 - PEREX
     OPRINT 32, TIDVOL,RESPHZ,VENTM,WIM,WIRM,WIHM,WEM,WERM,WEHM,
     1WTM,PEREX,PERIN,HC
 32   FORMAT (3X, 13F8.2)
 3    CONTINUE
      STOP
      END
//GO.SYSIN DD *
-23.18-21.43-19.45-17.25-14.86-12.32 -9.63 -6.84
 -3.98 -1.07  1.85  4.75  7.60 10.36 13.01 15.52
 17.86 20.00 21.92 23.61 25.03 26.18 27.05 27.61
 27.88 27.84 27.49 26.85 25.91 24.68 23.19
```

Appendix C Hydrostatic Pressure Imbalance Subject Data

APPENDIX C: Hydrostatic Pressure Imbalance Subject Data

HYDROSTATIC PRESSURE IMBALANCE SUBJECT DATA

Subject	Height (cm.)	Weight (kg.)
TB	182.9	84.1
MC	172.7	63.6
PH	186.1	84.1
DH	162.6	69.1
DM	179.1	72.5
JM	182.9	71.4
NS	181.6	79.5
LT	177.8	74.8
HW	179.7	90.0
LW	165.1	54.8
MEAN	177.1 ± 7.8	74.4 ± 10.5

Appendix D

Steady State Estimations of the Work of Breathing for Single Hose and Two Hose Regulators, where:

VT = Tidal Volume in liters
RESPHZ = Respiratory Frequency in breaths/min.
VENTM = Minute Ventilation in liters/min.
WI = Work of Inspiration in kg.m./breath
WIM = Minute Work of Inspiration in kg.m./min.
WE = Work of Expiration in kg.m./breath
WEM = Minute Work of Expiration in kg.m./min.
WTM = Total Minute Work of Breathing in kg.m./min.
PEREX = Expiratory Work Percentage of Total Work of Breathing
PERIN = Inspiratory Work Percentage of Total Work of Breathing

```
POSEIDON DRY STATIC TEST DATA WORK OF BREATHING ESTIMATIONS

 VT RESPHZ VENTM    WI    WIM     WE     WEM     WTM  PEREX PERIN
1.00 14.60 14.60  0.02   0.35   0.01    0.11    0.47 24.34 75.66
1.50 17.00 25.50  0.04   0.60   0.02    0.26    0.85 29.98 70.02
2.00 18.20 36.40  0.05   0.95   0.03    0.47    1.42 33.00 67.00
2.50 18.90 47.25  0.07   1.35   0.04    0.73    2.09 35.22 64.78
3.00 19.40 58.20  0.10   1.85   0.06    1.08    2.93 36.88 63.12
3.00 22.00 66.00  0.10   2.30   0.06    1.38    3.67 37.49 62.51
3.00 26.00 78.00  0.12   3.23   0.07    1.94    5.17 37.54 62.46
3.00 30.00 90.00  0.15   4.37   0.09    2.63    7.00 37.55 62.45
3.00 34.00102.00  0.17   5.66   0.10    3.45    9.11 37.92 62.08

POSEIDON WET STATIC DATA WORK OF BREATHING ESTIMATIONS

 VT RESPHZ VENTM    WI    WIM     WE     WEM     WTM  PEREX PERIN
1.00 14.60 14.60  0.01   0.07   0.04    0.59    0.67 89.00 11.00
1.50 17.00 25.50  0.01   0.21   0.08    1.28    1.48 86.06 13.94
2.00 18.20 36.40  0.02   0.43   0.12    2.15    2.58 83.34 16.66
2.50 18.90 47.25  0.04   0.75   0.17    3.20    3.95 80.94 19.06
3.00 19.40 58.20  0.06   1.21   0.23    4.39    5.59 78.45 21.55
3.00 22.00 66.00  0.07   1.65   0.24    5.30    6.95 76.28 23.72
3.00 26.00 78.00  0.10   2.51   0.26    6.89    9.39 73.32 26.68
3.00 30.00 90.00  0.13   3.76   0.29    8.69   12.45 69.79 30.21
3.00 34.00102.00  0.16   5.41   0.32   10.71   16.12 66.46 33.54
```

```
TRIESTE II DRY STATIC DATA WORK OF BREATHING ESTIMATIONS

 VT  RESPHZ VENTM    WI    WIM    WE    WEM    WTM  PEREX PERIN
1.00 14.60 14.60  0.06  0.84  0.01  0.13  0.97 13.62 86.38
1.50 17.00 25.50  0.09  1.55  0.03  0.43  1.98 21.67 78.33
2.00 18.20 36.40  0.13  2.28  0.05  0.97  3.24 29.84 70.16
2.50 18.90 47.25  0.16  2.97  0.10  1.92  4.89 39.28 60.72
3.00 19.40 58.20  Flow rate exceeds approximation

TRIESTE II WET STATIC DATA WORK OF BREATHING ESTIMATIONS

 VT  RESPHZ VENTM    WI    WIM    WE    WEM    WTM  PEREX PERIN
1.00 14.60 14.60  0.04  0.62  0.01  0.12  0.74 15.90 84.10
1.50 17.00 25.50  0.06  1.05  0.02  0.38  1.43 26.53 73.47
2.00 18.20 36.40  0.08  1.48  0.05  0.85  2.33 36.55 63.45
2.50 18.90 47.25  0.10  1.87  0.08  1.52  3.39 44.77 55.23
3.00 19.40 58.20  0.12  2.26  0.13  2.47  4.73 52.17 47.83
3.00 22.00 66.00  0.11  2.52  0.15  3.31  5.83 56.73 43.27
3.00 26.00 78.00  0.11  2.93  0.19  5.00  7.93 63.04 36.96
3.00 30.00 90.00  0.11  3.43  0.25  7.40 10.83 68.34 31.66
3.00 34.00102.00  0.13  4.31  0.32 10.99 15.29 71.84 28.16
```

Appendix E Poseidon Single Hose Dynamic Work of Breathing Calculations including Inspiratory and Expiratory Work Variations with Changes in Diver Orientation, where:

TIDVOL = Tidal Volume in liters
RESPHZ = Respiratory Frequency in breaths/min.
VENTM = Minute Ventilation in liters/min.
WIM = Minute Work of Inspiration in kg.m./min.
WIRM = Minute Inspiratory Resistive Work in kg.m./min.
WIHM = Minute Inspiratory Hydrostatic Work in kg.m./min.
WEM = Minute Work of Expiration in kg.m./min.
WERM = Minute Expiratory Resistive Work in kg.m./min.
WEHM = Minute Expiratory Hydrostatic Work in kg.m./min.
WTM = Total Minute Work of Breathing in kg.m./min.
PEREX = Expiratory Work Percentage of Total Work of Breathing
PERIN = Inspiratory Work Percentage of Total Work of Breathing
HC = Hydrostatic Pressure Imbalance in cm.

```
PILIO RUN CALA=0.0106 CAL6=0.174 OFFSET=-75.7 HO=200.0 E2=628.0

  TIDVOL  RESPHZ   VENTM     WIN     WIRM    WIHM     VEM    VERM    VEMM   WTM    PEREX    PERIN      HC
   1.43    8.90    12.73    0.65    0.65    0.0     0.42    0.42    0.0    1.08    39.45    60.55     0.0
   1.43    8.90    12.73   -4.23    0.65   -4.88    5.35    0.42    4.93   1.12   476.50  -376.50   -38.73
   1.43    8.90    12.73   -4.34    0.65   -4.99    5.46    0.42    5.04   1.12   485.47  -385.47   -39.86
   1.43    8.90    12.73   -4.39    0.65   -5.04    5.51    0.42    5.09   1.13   489.78  -389.78   -39.98
   1.43    8.90    12.73   -4.38    0.65   -5.03    5.51    0.42    5.08   1.13   489.34  -389.34   -39.82
   1.43    8.90    12.73   -4.32    0.65   -4.97    5.45    0.42    5.02   1.12   484.28  -384.28   -39.45
   1.43    8.90    12.73   -4.21    0.65   -4.86    5.33    0.42    4.91   1.12   474.45  -374.45   -38.54
   1.43    8.90    12.73   -4.04    0.65   -4.69    5.16    0.42    4.74   1.12   460.06  -360.06   -37.24
   1.43    8.90    12.73   -3.82    0.65   -4.47    4.94    0.42    4.52   1.12   441.27  -341.27   -35.58
   1.43    8.90    12.73   -3.55    0.65   -4.20    4.67    0.42    4.25   1.12   418.04  -318.04   -33.35
   1.43    8.90    12.73   -3.24    0.65   -3.89    4.35    0.42    3.93   1.11   390.74  -290.74   -30.86
   1.43    8.90    12.73   -2.88    0.65   -3.53    3.99    0.42    3.57   1.11   359.53  -259.53   -28.03
   1.43    8.90    12.73   -2.49    0.65   -3.14    3.59    0.42    3.17   1.11   324.78  -224.78   -24.99
   1.43    8.90    12.73   -2.06    0.65   -2.71    3.16    0.42    2.74   1.10   286.65  -186.65   -21.49
   1.43    8.90    12.73   -1.60    0.65   -2.25    2.70    0.42    2.27   1.10   245.51  -145.51   -17.84
   1.43    8.90    12.73   -1.11    0.65   -1.77    2.21    0.42    1.78   1.09   201.97  -101.97   -14.01
   1.43    8.90    12.73   -0.61    0.65   -1.26    1.70    0.42    1.27   1.09   156.10   -56.10   -10.01
   1.43    8.90    12.73   -0.09    0.65   -0.74    1.18    0.42    0.75   1.08   108.64    -8.64    -5.91
   1.43    8.90    12.73    0.43    0.65   -0.22    0.65    0.42    0.22   1.08    59.92    40.08    -1.74
   1.43    8.90    12.73    0.96    0.65    0.31    0.11    0.42   -0.31   1.07    10.61    89.39     2.44
   1.43    8.90    12.73    1.48    0.65    0.83   -0.42    0.42   -0.84   1.07   -38.94   138.94     6.60
   1.43    8.90    12.73    2.00    0.65    1.35   -0.94    0.42   -1.36   1.06   -88.12   188.12    10.69
   1.43    8.90    12.73    2.50    0.65    1.85   -1.44    0.42   -1.87   1.06  -136.31   236.31    14.66
   1.43    8.90    12.73    2.98    0.65    2.33   -1.93    0.42   -2.35   1.05  -182.98   282.98    18.47
   1.43    8.90    12.73    3.43    0.65    2.78   -2.38    0.42   -2.81   1.05  -227.46   327.46    22.07
   1.43    8.90    12.73    3.86    0.65    3.21   -2.81    0.42   -3.24   1.04  -269.44   369.44    25.44
   1.43    8.90    12.73    4.25    0.65    3.60   -3.21    0.42   -3.63   1.04  -308.24   408.24    28.53
   1.43    8.90    12.73    4.60    0.65    3.95   -3.56    0.42   -3.98   1.04  -343.25   443.25    31.30
   1.43    8.90    12.73    4.90    0.65    4.25   -3.87    0.42   -4.29   1.03  -374.17   474.17    33.73
   1.43    8.90    12.73    5.16    0.65    4.51   -4.13    0.42   -4.56   1.03  -400.51   500.51    35.79
   1.43    8.90    12.73    5.37    0.65    4.72   -4.34    0.42   -4.77   1.03  -421.96   521.96    37.46
   1.43    8.90    12.73    5.53    0.65    4.88   -4.50    0.42   -4.93   1.03  -438.20   538.20    38.72
```

```
PILIS RUN CALA=0.0106 CALG=0.174 OFFSET=-75.7 HD=200.0 E2=627.0

 TIDVOL  RESPHZ   VENTM     WIM      WIRM     WIMM     WEM     WERM     WEMM     WTM    PEREX    PERIN     HC
  1.49   14.79    22.05     1.18     1.18     0.0      0.74    0.74     0.0      1.92    38.56    61.44     0.0
  1.49   14.79    22.05    -7.27     1.18    -8.45     9.28    0.74     8.54     2.01   461.66  -361.66   -38.73
  1.49   14.79    22.05    -7.45     1.18    -8.54     9.47    0.74     8.72     2.01   470.32  -370.32   -39.56
  1.49   14.79    22.05    -7.54     1.18    -8.72     9.55    0.74     8.81     2.01   474.50  -374.50   -39.96
  1.49   14.79    22.05    -7.53     1.18    -8.71     9.54    0.74     8.80     2.01   474.08  -374.08   -39.92
  1.49   14.79    22.05    -7.43     1.18    -8.61     9.44    0.74     8.70     2.01   469.18  -369.18   -39.45
  1.49   14.79    22.05    -7.23     1.18    -8.41     9.24    0.74     8.50     2.01   459.67  -359.67   -38.54
  1.49   14.79    22.05    -6.94     1.18    -8.12     8.95    0.74     8.21     2.01   445.74  -345.74   -37.21
  1.49   14.79    22.05    -6.56     1.18    -7.74     8.57    0.74     7.82     2.00   427.56  -327.56   -35.48
  1.49   14.79    22.05    -6.10     1.18    -7.28     8.10    0.74     7.35     2.00   405.07  -305.07   -33.35
  1.49   14.79    22.05    -5.55     1.18    -6.74     7.55    0.74     6.81     1.99   378.66  -278.66   -30.86
  1.49   14.79    22.05    -4.94     1.18    -6.12     6.92    0.74     6.18     1.99   348.45  -248.45   -28.03
  1.49   14.79    22.05    -4.25     1.18    -5.44     6.23    0.74     5.49     1.98   314.82  -214.82   -24.90
  1.49   14.79    22.05    -3.51     1.18    -4.69     5.48    0.74     4.74     1.97   277.91  -177.91   -21.49
  1.49   14.79    22.05    -2.71     1.18    -3.89     4.68    0.74     3.93     1.96   238.08  -138.08   -17.84
  1.49   14.79    22.05    -1.88     1.18    -3.06     3.83    0.74     3.09     1.96   195.93   -95.93   -14.01
  1.49   14.79    22.05    -1.00     1.18    -2.19     2.95    0.74     2.21     1.95   151.52   -51.52   -10.01
  1.49   14.79    22.05    -0.11     1.18    -1.29     2.05    0.74     1.30     1.94   105.57    -5.57    -5.91
  1.49   14.79    22.05     0.80     1.18    -0.38     1.13    0.74     0.38     1.93    58.39    41.61    -1.74
  1.49   14.79    22.05     1.71     1.18     0.53     0.20    0.74    -0.54     1.92    10.63    89.37     2.44
  1.49   14.79    22.05     2.62     1.18     1.44    -0.71    0.74    -1.46     1.91   -37.36   137.36     6.60
  1.49   14.79    22.05     3.52     1.18     2.33    -1.62    0.74    -2.36     1.90   -85.00   185.00    10.60
  1.49   14.79    22.05     4.38     1.18     3.20    -2.49    0.74    -3.23     1.89  -131.68   231.68    14.66
  1.49   14.79    22.05     5.21     1.18     4.03    -3.33    0.74    -4.07     1.88  -176.89   276.89    18.47
  1.49   14.79    22.05     6.00     1.18     4.82    -4.12    0.74    -4.87     1.87  -219.99   319.99    22.07
  1.49   14.79    22.05     6.74     1.18     5.55    -4.87    0.74    -5.61     1.87  -260.67   360.67    25.44
  1.49   14.79    22.05     7.41     1.18     6.23    -5.55    0.74    -6.29     1.86  -298.27   398.27    28.53
  1.49   14.79    22.05     8.01     1.18     6.83    -6.16    0.74    -6.90     1.85  -332.20   432.20    31.30
  1.49   14.79    22.05     8.54     1.18     7.36    -6.70    0.74    -7.44     1.85  -362.16   462.16    33.73
  1.49   14.79    22.05     8.99     1.18     7.81    -7.15    0.74    -7.89     1.84  -387.69   487.69    35.79
  1.49   14.79    22.05     9.36     1.18     8.18    -7.52    0.74    -8.26     1.84  -408.49   508.49    37.46
  1.49   14.79    22.05     9.63     1.18     8.45    -7.80    0.74    -8.54     1.84  -424.23   524.23    38.72
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F2L16 RUN CALA=0.0106 CAL6=0.174 OFFSET=-75.7 HD=200.0 E2=627.0
    TIDVOL  RESPHZ  VENTH     WIN    WIRM     WIHM      WEN    WERM     WEHM    WTM    PEREX    PERIN      MC
      2.02   17.68  35.69    2.08    2.08      0.0     1.82    1.82      0.0   3.90    46.68    53.32     0.0
      2.02   17.68  35.69  -11.37    2.08   -13.65    15.64    1.82    13.82   4.07   383.96  -283.96  -38.73
      2.02   17.68  35.69  -11.86    2.08   -13.94    15.94    1.82    14.12   4.08   390.87  -290.87  -39.56
      2.02   17.68  35.69  -12.00    2.08   -14.08    16.08    1.82    14.26   4.08   394.20  -294.20  -39.96
      2.02   17.68  35.69  -11.99    2.08   -14.07    16.07    1.82    14.25   4.08   393.87  -293.87  -39.92
      2.02   17.68  35.69  -11.82    2.08   -13.90    15.90    1.82    14.08   4.08   389.96  -289.96  -39.45
      2.02   17.68  35.69  -11.50    2.08   -13.58    15.58    1.82    13.76   4.07   382.38  -282.38  -38.54
      2.02   17.68  35.69  -11.03    2.08   -13.11    15.10    1.82    13.28   4.07   371.27  -271.27  -37.21
      2.02   17.68  35.69  -10.42    2.08   -12.50    14.48    1.82    12.66   4.06   356.77  -256.77  -35.48
      2.02   17.68  35.69   -9.67    2.08   -11.75    13.72    1.82    11.90   4.05   338.84  -238.84  -33.35
      2.02   17.68  35.69   -8.80    2.08   -10.88    12.84    1.82    11.01   4.04   317.77  -217.77  -30.86
      2.02   17.66  35.69   -7.80    2.08    -9.88    11.83    1.82    10.00   4.03   293.69  -193.69  -28.03
      2.02   17.68  35.69   -6.70    2.08    -8.78    10.71    1.82     8.89   4.01   266.88  -166.88  -24.90
      2.02   17.68  35.69   -5.49    2.08    -7.57     9.49    1.82     7.67   4.00   237.45  -137.45  -21.49
      2.02   17.68  35.69   -4.21    2.08    -6.29     8.19    1.82     6.37   3.98   205.70  -105.70  -17.84
      2.02   17.68  35.69   -2.86    2.08    -4.94     6.82    1.82     5.00   3.96   172.10   -72.10  -14.01
      2.02   17.68  35.69   -1.45    2.08    -3.53     5.39    1.82     3.57   3.95   136.70   -36.70  -10.01
      2.02   17.68  35.69   -0.00    2.08    -2.08     3.93    1.82     2.11   3.93   100.08    -0.08   -5.91
      2.02   17.68  35.69    1.47    2.08    -0.61     2.44    1.82     0.62   3.91    62.48    37.52   -1.74
      2.02   17.68  35.69    2.94    2.08     0.86     0.95    1.82    -0.87   3.89    24.43    75.57    2.44
      2.02   17.68  35.69    4.41    2.08     2.33    -0.53    1.82    -2.36   3.87   -13.81   113.81    6.60
      2.02   17.68  35.69    5.85    2.08     3.77    -1.99    1.82    -3.82   3.85   -51.77   151.77   10.69
      2.02   17.68  35.69    7.25    2.08     5.17    -3.41    1.82    -5.23   3.83   -88.95   188.95   14.66
      2.02   17.68  35.69    8.59    2.08     6.51    -4.77    1.82    -6.59   3.82  -124.97   224.97   18.47
      2.02   17.68  35.69    9.86    2.08     7.78    -6.06    1.82    -7.88   3.80  -159.30   259.30   22.07
      2.02   17.68  35.69   11.05    2.08     8.97    -7.26    1.82    -9.08   3.79  -191.70   291.70   25.44
      2.02   17.68  35.69   12.13    2.08    10.05    -8.36    1.82   -10.18   3.77  -221.64   321.64   28.53
      2.02   17.68  35.69   13.11    2.08    11.03    -9.35    1.82   -11.17   3.76  -248.66   348.66   31.30
      2.02   17.68  35.69   13.97    2.08    11.89   -10.22    1.82   -12.04   3.75  -272.52   372.52   33.73
      2.02   17.68  35.69   14.69    2.08    12.61   -10.95    1.82   -12.77   3.74  -292.85   392.85   35.79
      2.02   17.68  35.69   15.28    2.08    13.20   -11.55    1.82   -13.37   3.73  -309.41   409.41   37.46
      2.02   17.68  35.69   15.73    2.08    13.65   -12.00    1.82   -13.82   3.73  -321.94   421.94   38.72
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P3L20 RUN CALA=0.0106 CALG=0.174 OFFSET=-75.7 HO=200.0 E2=637.0

   TIDVOL  RESPHZ   VENTH     WIN     WIRN     WIHN     WEN    WERN     WEHN    VTH    PEREX    PERIN      HC
    3.08   19.18   59.02     3.34     3.34      0.0     4.36    4.36      0.0   7.71    56.63    43.37      0.0
    3.08   19.18   59.02   -19.22     3.34   -22.56    27.22    4.36    22.86   8.00   340.23  -240.23   -38.73
    3.08   19.18   59.02   -19.70     3.34   -23.05    27.71    4.36    23.35   8.01   346.08  -246.08   -39.84
    3.08   19.18   59.02   -19.94     3.34   -23.28    27.95    4.36    23.58   8.01   348.89  -248.89   -39.98
    3.08   19.18   59.02   -19.91     3.34   -23.26    27.92    4.36    23.56   8.01   348.61  -248.61   -39.92
    3.08   19.18   59.02   -19.64     3.34   -22.98    27.65    4.36    23.28   8.01   345.30  -245.30   -39.48
    3.08   19.18   59.02   -19.11     3.34   -22.45    27.11    4.36    22.75   8.00   338.89  -238.89   -38.64
    3.08   19.18   59.02   -18.33     3.34   -21.68    26.32    4.36    21.96   7.99   328.49  -228.49   -37.21
    3.08   19.18   59.02   -17.33     3.34   -20.67    25.30    4.36    20.94   7.98   317.24  -217.24   -35.44
    3.08   19.18   59.02   -16.09     3.34   -19.43    24.05    4.36    19.68   7.96   302.09  -202.09   -33.35
    3.08   19.18   59.02   -14.64     3.34   -17.98    22.58    4.36    18.21   7.94   284.31  -184.31   -30.86
    3.08   19.18   59.02   -12.99     3.34   -16.33    20.91    4.36    16.54   7.92   263.99  -163.99   -28.03
    3.08   19.18   59.02   -11.16     3.34   -14.51    19.06    4.36    14.70   7.90   241.39  -141.39   -24.90
    3.08   19.18   59.02    -9.18     3.34   -12.52    17.05    4.36    12.68   7.87   216.62  -116.62   -21.49
    3.08   19.18   59.02    -7.05     3.34   -10.39    14.89    4.36    10.53   7.84   189.91   -89.91   -17.84
    3.08   19.18   59.02    -4.82     3.34    -8.16    12.63    4.36     8.27   7.81   161.69   -61.69   -14.01
    3.08   19.18   59.02    -2.49     3.34    -5.83    10.27    4.36     5.91   7.78   131.99   -31.99   -10.01
    3.08   19.18   59.02    -0.10     3.34    -3.44     7.85    4.36     3.49   7.75   101.30    -1.30    -5.91
    3.08   19.18   59.02     2.33     3.34    -1.01     5.39    4.36     1.03   7.72    69.83    30.17    -1.74
    3.08   19.18   59.02     4.76     3.34     1.42     2.92    4.36    -1.44   7.69    38.03    61.97     2.44
    3.08   19.18   59.02     7.19     3.34     3.84     0.47    4.36    -3.90   7.65     6.11    93.89     6.60
    3.08   19.18   59.02     9.57     3.34     6.23    -1.95    4.36    -6.31   7.62   -25.52   125.52    10.69
    3.08   19.18   59.02    11.88     3.34     8.54    -4.29    4.36    -8.65   7.59   -56.48   156.48    14.65
    3.08   19.18   59.02    14.10     3.34    10.76    -6.54    4.36   -10.90   7.56   -86.43   186.43    18.47
    3.08   19.18   59.02    16.20     3.34    12.86    -8.66    4.36   -13.03   7.54  -114.93   214.93    22.07
    3.08   19.18   59.02    18.16     3.34    14.82   -10.65    4.36   -15.01   7.51  -141.80   241.80    25.44
    3.08   19.18   59.02    19.96     3.34    16.62   -12.47    4.36   -16.84   7.49  -166.61   266.61    28.53
    3.08   19.18   59.02    21.58     3.34    18.23   -14.11    4.36   -18.47   7.47  -188.97   288.97    31.30
    3.08   19.18   59.02    22.99     3.34    19.65   -15.54    4.36   -19.91   7.45  -208.70   308.70    33.73
    3.08   19.18   59.02    24.19     3.34    20.85   -16.76    4.36   -21.12   7.43  -225.80   325.80    35.79
    3.08   19.18   59.02    25.16     3.34    21.82   -17.75    4.36   -22.11   7.42  -239.17   339.17    37.46
    3.08   19.18   59.02    25.90     3.34    22.56   -18.49    4.36   -22.85   7.41  -249.52   349.52    38.72
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P3L25 RUN CALA=0.0106 CAL6=0.174 OFFSET=-75.7 HD=200.0 E2=627.0

   TIDVOL  RESPRT   VENTM     VIN      VIRM     VINM     VEN     VERM     VENM     VTR    PEREX    PERIN      HC
    3.07   24.64    75.61     6.23     6.23     0.0      6.16    6.16     0.0     12.39    49.72    50.28     0.0
    3.07   24.64    75.61   -22.58     6.23   -28.81    35.44    6.16    29.28    12.86   275.61  -175.61   -38.75
    3.07   24.64    75.61   -23.20     6.23   -29.43    36.07    6.16    29.91    12.87   280.27  -180.27   -39.86
    3.07   24.64    75.61   -23.50     6.23   -29.73    36.37    6.16    30.21    12.87   282.51  -182.51   -39.96
    3.07   24.64    75.61   -23.47     6.23   -29.70    36.34    6.16    30.18    12.87   282.29  -182.29   -39.92
    3.07   24.64    75.61   -23.12     6.23   -29.35    35.99    6.16    29.83    12.87   279.65  -179.65   -39.48
    3.07   24.64    75.61   -22.44     6.23   -28.67    35.30    6.16    29.14    12.86   274.54  -174.54   -38.54
    3.07   24.64    75.61   -21.45     6.23   -27.68    34.29    6.16    28.13    12.84   267.05  -167.05   -37.21
    3.07   24.64    75.61   -20.16     6.23   -26.39    32.99    6.16    26.83    12.82   257.29  -157.29   -35.48
    3.07   24.64    75.61   -18.58     6.23   -24.81    31.37    6.16    25.21    12.79   245.22  -145.22   -33.35
    3.07   24.64    75.61   -16.73     6.23   -22.96    29.49    6.16    23.33    12.76   231.05  -131.05   -30.86
    3.07   24.64    75.61   -14.62     6.23   -20.85    27.35    6.16    21.19    12.73   214.87  -114.87   -28.03
    3.07   24.64    75.61   -12.29     6.23   -18.52    24.99    6.16    18.83    12.69   196.87   -96.87   -24.90
    3.07   24.64    75.61    -9.76     6.23   -15.99    22.41    6.16    16.25    12.65   177.13   -77.13   -21.49
    3.07   24.64    75.61    -7.04     6.23   -13.27    19.65    6.16    13.49    12.61   155.86   -55.86   -17.84
    3.07   24.64    75.61    -4.19     6.23   -10.42    16.75    6.16    10.59    12.56   133.38   -33.38   -14.01
    3.07   24.64    75.61    -1.22     6.23    -7.45    13.73    6.16     7.57    12.51   109.73    -9.73   -10.01
    3.07   24.64    75.61     1.83     6.23    -4.40    10.63    6.16     4.47    12.46    85.29    14.71    -5.81
    3.07   24.64    75.61     4.94     6.23    -1.29     7.48    6.16     1.32    12.41    60.23    39.77    -1.74
    3.07   24.64    75.61     8.05     6.23     1.82     4.31    6.16    -1.84    12.36    34.91    65.09     2.44
    3.07   24.64    75.61    11.14     6.23     4.91     1.17    6.16    -4.99    12.31     9.50    90.50     6.80
    3.07   24.64    75.61    14.18     6.23     7.95    -1.92    6.16    -8.08    12.26   -15.68   115.68    10.69
    3.07   24.64    75.61    17.14     6.23    10.91    -4.92    6.16   -11.08    12.21   -40.32   140.32    14.66
    3.07   24.64    75.61    19.97     6.23    13.74    -7.80    6.16   -13.96    12.17   -64.15   164.15    18.47
    3.07   24.64    75.61    22.65     6.23    16.42   -10.53    6.16   -16.69    12.12   -86.84   186.84    22.07
    3.07   24.64    75.61    25.16     6.23    18.93   -13.07    6.16   -19.23    12.08  -108.22   208.22    25.44
    3.07   24.64    75.61    27.45     6.23    21.22   -15.41    6.16   -21.57    12.04  -127.96   227.96    28.53
    3.07   24.64    75.61    29.52     6.23    23.29   -17.51    6.16   -23.67    12.01  -145.75   245.75    31.38
    3.07   24.64    75.61    31.32     6.23    25.09   -19.34    6.16   -25.50    11.98  -161.45   261.45    33.73
    3.07   24.64    75.61    32.86     6.23    26.63   -20.90    6.16   -27.06    11.96  -174.81   274.81    35.79
    3.07   24.64    75.61    34.10     6.23    27.87   -22.16    6.16   -28.32    11.94  -185.69   285.69    37.46
    3.07   24.64    75.61    35.04     6.23    28.81   -23.12    6.16   -29.28    11.92  -193.92   293.92    38.72
```

```
P3L30 RUN CALA=0.0106 CAL6=0.174 OFFSET=-75.7 HD=200.0 E2=637.0

  TIDVOL   RESPNE   VENTN    VIN     VIRN    VIHN     VEN     VERN    WENH     VTN    PEREX    PERIN      HC
   3.09    31.08    95.90    7.91    7.91     0.0    10.65   10.65     0.0   18.56    57.39    42.61     0.0
   3.09    31.08    95.90  -28.53    7.91  -36.44   47.79   10.65   37.14   19.26   248.09  -148.09  -38.73
   3.09    31.08    95.90  -29.31    7.91  -37.22   48.59   10.65   37.94   19.28   252.02  -152.02  -39.56
   3.09    31.08    95.90  -29.69    7.91  -37.59   48.97   10.65   38.32   19.29   253.92  -153.92  -39.96
   3.09    31.08    95.90  -29.65    7.91  -37.56   48.93   10.65   38.28   19.29   253.73  -153.73  -39.92
   3.09    31.08    95.90  -29.21    7.91  -37.11   48.48   10.65   37.83   19.28   251.50  -151.50  -39.45
   3.09    31.08    95.90  -28.35    7.91  -36.26   47.61   10.65   36.96   19.26   247.19  -147.19  -38.54
   3.09    31.08    95.90  -27.10    7.91  -35.01   46.33   10.65   35.69   19.24   240.87  -140.87  -37.21
   3.09    31.08    95.90  -25.47    7.91  -33.38   44.68   10.65   34.03   19.20   232.63  -132.63  -35.48
   3.09    31.08    95.90  -23.47    7.91  -31.37   42.63   10.65   31.98   19.17   222.44  -122.44  -33.35
   3.09    31.08    95.90  -21.12    7.91  -29.03   40.25   10.65   29.60   19.12   210.48  -110.48  -30.86
   3.09    31.08    95.90  -18.46    7.91  -26.37   37.53   10.65   26.88   19.07   196.82   -96.82  -28.03
   3.09    31.08    95.90  -15.52    7.91  -23.43   34.53   10.65   23.88   19.01   181.62   -81.62  -24.90
   3.09    31.08    95.90  -12.31    7.91  -20.22   31.26   10.65   20.61   18.95   164.96   -64.96  -21.49
   3.09    31.08    95.90   -8.88    7.91  -16.78   27.76   10.65   17.11   18.86   147.00   -47.00  -17.84
   3.09    31.08    95.90   -5.27    7.91  -13.18   24.09   10.65   13.44   18.81   128.03   -28.03  -14.01
   3.09    31.08    95.90   -1.51    7.91   -9.42   20.25   10.65    9.60   18.74   108.08    -8.08  -10.01
   3.09    31.08    95.90    2.35    7.91   -5.56   16.32   10.65    5.67   18.67    87.42    12.58   -5.91
   3.09    31.08    95.90    6.27    7.91   -1.64   12.32   10.65    1.67   18.59    66.27    33.73   -1.74
   3.09    31.08    95.90   10.20    7.91    2.30    8.31   10.65   -2.34   18.51    44.89    55.11    2.44
   3.09    31.08    95.90   14.12    7.91    6.21    4.32   10.65   -6.33   18.44    23.43    76.57    6.60
   3.09    31.08    95.90   17.96    7.91   10.05    0.40   10.65  -10.25   18.36     2.17    97.83   10.69
   3.09    31.08    95.90   21.70    7.91   13.79   -3.41   10.65  -14.06   18.29   -18.64   118.64   14.66
   3.09    31.08    95.90   25.28    7.91   17.38   -7.06   10.65  -17.71   18.22   -38.77   138.77   18.47
   3.09    31.08    95.90   28.67    7.91   20.76  -10.52   10.65  -21.17   18.15   -57.92   157.92   22.07
   3.09    31.08    95.90   31.84    7.91   23.93  -13.75   10.65  -24.40   18.09   -75.98   175.98   25.44
   3.09    31.08    95.90   34.75    7.91   26.84  -16.71   10.65  -27.36   18.04   -92.68   192.68   28.53
   3.09    31.08    95.90   37.35    7.91   29.45  -19.37   10.65  -30.02   17.99  -107.68   207.68   31.30
   3.09    31.08    95.90   39.64    7.91   31.73  -21.70   10.65  -32.35   17.94  -120.93   220.93   33.73
   3.09    31.08    95.90   41.58    7.91   33.67  -23.67   10.65  -34.32   17.90  -132.22   232.22   35.79
   3.09    31.08    95.90   43.15    7.91   35.24  -25.28   10.65  -35.93   17.87  -141.41   241.41   37.46
   3.09    31.08    95.90   44.33    7.91   36.43  -26.48   10.65  -37.13   17.85  -148.36   248.36   38.72
```

Appendix F

Trieste II Two Hose Dynamic Work of Breathing Calculations including Inspiratory and Expiratory Work Variations with Changes in Diver Orientation, where:

TIDVOL = Tidal Volume in liters
RESPHZ = Respiratory Frequency in breaths/min.
VENTM = Minute Ventilation in liters/min.
WIM = Minute Work of Inspiration in kg.m./min.
WIRM = Minute Inspiratory Resistive Work in kg.m./min.
WIHM = Minute Inspiratory Hydrostatic Work in kg.m./min.
WEM = Minute Work of Expiration in kg.m./min.
WERM = Minute Expiratory Resistive Work in kg.m./min.
WEHM = Minute Expiratory Hydrostatic Work in kg.m./min.
WTM = Total Minute Work of Breathing in kg.m./min.
PEREX = Expiratory Work Percentage of Total Work of Breathing
PERIN = Inspiratory Work Percentage of Total Work of Breathing
HC = Hydrostatic Pressure Imbalance in cm.

```
TIL10 RUN CALA=0.0041 CAL6=0.209  OFFSET=-210.0 HD=187.0 E2=530.0 BOUNCE=80

    TIDVOL  RESPHZ   VENTM     WIM     WIRM    WIMM     WEM     WERM    WEMM     WTM    PEREX    PERIN      HC
     0.96    11.46   10.96    0.77     0.77    0.0      1.00    1.00    0.0      1.77    56.46    43.54     0.0
     0.96    11.46   10.96   -1.73     C.77   -2.50     3.54    1.00    2.54     1.81   195.59   -95.59   -23.18
     0.96    11.46   10.96   -1.54     0.77   -2.31     3.35    1.00    2.35     1.81   185.29   -85.29   -21.43
     0.96    11.46   10.96   -1.33     0.77   -2.10     3.13    1.00    2.13     1.80   173.60   -73.60   -19.45
     0.96    11.46   10.96   -1.09     0.77   -1.86     2.89    1.00    1.89     1.60   160.56   -60.56   -17.25
     0.96    11.46   10.96   -0.83     0.77   -1.50     2.63    1.00    1.63     1.80   146.34   -46.34   -14.86
     0.96    11.46   10.96   -0.56     0.77   -1.33     2.35    1.00    1.35     1.79   131.15   -31.15   -12.32
     0.96    11.46   10.96   -0.27     0.77   -1.04     2.06    1.00    1.06     1.79   114.99   -14.99    -9.63
     0.96    11.46   10.96    0.03     0.77   -0.74     1.75    1.00    0.75     1.78    98.14     1.86    -6.84
     0.96    11.46   10.96    0.34     0.77   -0.43     1.44    1.00    0.44     1.78    80.78    19.22    -3.98
     0.96    11.46   10.96    0.66     0.77   -0.12     1.12    1.00    0.12     1.77    63.02    36.98    -1.07
     0.96    11.46   10.96    0.97     0.77    0.20     0.80    1.00   -0.20     1.77    45.10    54.90     1.85
     0.96    11.46   10.96    1.28     0.77    0.51     0.48    1.00   -0.52     1.76    27.20    72.80     4.75
     0.96    11.46   10.96    1.59     0.77    0.82     0.17    1.00   -0.83     1.76     9.52    90.48     7.60
     0.96    11.46   10.96    1.89     0.77    1.12    -0.14    1.00   -1.14     1.75    -7.69   107.69    10.36
     0.96    11.46   10.96    2.18     0.77    1.40    -0.43    1.00   -1.43     1.75   -24.31   124.31    13.01
     0.96    11.46   10.96    2.45     0.77    1.58    -0.70    1.00   -1.70     1.75   -40.12   140.12    15.52
     0.96    11.46.  10.96    2.70     0.77    1.93    -0.96    1.00   -1.96     1.74   -54.93   154.93    17.86
     0.96    11.46   10.96    2.93     0.77    2.16    -1.19    1.00   -2.19     1.74   -68.53   168.53    20.00
     0.96    11.46   10.96    3.14     0.77    2.37    -1.40    1.00   -2.40     1.74   -80.79   180.79    21.92
     0.96    11.46   10.96    3.32     0.77    2.55    -1.59    1.00   -2.59     1.73   -91.61   191.61    23.61
     0.96    11.46   10.96    3.47     0.77    2.70    -1.74    1.00   -2.74     1.73  -100.73   200.73    25.03
     0.96    11.46   10.96    3.60     0.77    2.83    -1.87    1.00   -2.87     1.73  -108.13   208.13    26.18
     0.96    11.46   10.96    3.69     0.77    2.92    -1.96    1.00   -2.96     1.73  -113.74   213.74    27.05
     0.96    11.46   10.96    3.75     0.77    2.98    -2.03    1.00   -3.03     1.73  -117.36   217.36    27.61
     0.96    11.46   10.96    3.78     0.77    3.01    -2.06    1.00   -3.06     1.73  -119.10   219.10    27.88
     0.96    11.46   10.96    3.76     0.77    3.00    -2.05    1.00   -3.05     1.73  -118.85   218.85    27.84
     0.96    11.46   10.96    3.74     0.77    2.97    -2.01    1.00   -3.01     1.73  -116.58   216.58    27.49
     0.96    11.46   10.96    3.67     0.77    2.90    -1.94    1.00   -2.94     1.73  -112.45   212.45    26.85
     0.96    11.46   10.96    3.57     0.77    2.80    -1.84    1.00   -2.84     1.73  -106.39   206.39    25.91
     0.96    11.46   10.96    3.44     0.77    2.66    -1.70    1.00   -2.70     1.73   -98.48   198.48    24.68
     0.96    11.46   10.96    3.27     0.77    2.50    -1.54    1.00   -2.54     1.73   -88.91   188.91    23.19
```

```
TILIS RUN CALA=0.0040 CALB=0.209 OFFSET=-210.0 HD=187.0 E2=619.0

     TIDVOL   RESPHZ   VENTM      WIM      WIRM     WIHM     WEM      WERM     WEHM     WTM     PEREX    PERIN     MC
      0.98    18.65    18.32     1.56     1.56     0.0      1.59     1.59     0.0      3.15     50.45    49.55    0.0
      0.98    18.65    18.32    -2.62     1.56    -4.18     5.83     1.59     4.25     3.21    181.69   -81.69  -23.18
      0.98    18.65    18.32    -2.31     1.56    -3.87     5.51     1.59     3.93     3.21    171.96   -71.96  -21.43
      0.98    18.65    18.32    -1.95     1.56    -3.51     5.15     1.59     3.56     3.20    160.91   -60.91  -19.45
      0.98    18.65    18.32    -1.55     1.56    -3.11     4.75     1.59     3.16     3.20    148.60   -48.60  -17.25
      0.98    18.65    18.32    -1.12     1.56    -2.68     4.31     1.59     2.72     3.19    135.17   -35.17  -14.86
      0.98    18.65    18.32    -0.66     1.56    -2.22     3.85     1.59     2.26     3.18    120.84   -20.84  -12.32
      0.98    18.65    18.32    -0.18     1.56    -1.74     3.35     1.59     1.76     3.17    105.60    -5.60   -9.63
      0.98    18.65    18.32     0.33     1.56    -1.23     2.84     1.59     1.25     3.17     89.71    10.29   -6.84
      0.98    18.65    18.32     0.84     1.56    -0.72     2.32     1.59     0.73     3.16     73.35    26.65   -3.98
      0.98    18.65    18.32     1.37     1.56    -0.19     1.78     1.59     0.20     3.15     56.62    43.38   -1.07
      0.98    18.65    18.32     1.89     1.56     0.33     1.25     1.59    -0.34     3.14     39.75    60.25    1.85
      0.98    18.65    18.32     2.42     1.56     0.86     0.72     1.59    -0.87     3.14     22.91    77.09    4.75
      0.98    18.65    18.32     2.93     1.56     1.37     0.20     1.59    -1.39     3.13      6.28    93.72    7.60
      0.98    18.65    18.32     3.43     1.56     1.87    -0.31     1.59    -1.90     3.12     -9.90   109.90   10.36
      0.98    18.65    18.32     3.91     1.56     2.35    -0.79     1.59    -2.38     3.11    -25.51   125.51   13.01
      0.98    18.65    18.32     4.36     1.56     2.80    -1.25     1.59    -2.84     3.11    -40.36   140.36   15.52
      0.98    18.65    18.32     4.78     1.56     3.22    -1.68     1.59    -3.27     3.10    -54.27   154.27   17.86
      0.98    18.65    18.32     5.17     1.56     3.61    -2.07     1.59    -3.66     3.10    -67.03   167.03   20.00
      0.98    18.65    18.32     5.52     1.56     3.96    -2.43     1.59    -4.01     3.09    -78.53   178.53   21.92
      0.98    18.65    18.32     5.82     1.56     4.26    -2.74     1.59    -4.32     3.09    -88.67   188.67   23.61
      0.98    18.65    18.32     6.08     1.56     4.52    -3.00     1.59    -4.58     3.08    -97.22   197.22   25.03
      0.98    18.65    18.32     6.29     1.56     4.72    -3.21     1.59    -4.80     3.08   -104.16   204.16   26.18
      0.98    18.65    18.32     6.44     1.56     4.88    -3.37     1.59    -4.95     3.08   -109.42   209.42   27.08
      0.98    18.65    18.32     6.54     1.56     4.98    -3.47     1.59    -5.06     3.07   -112.81   212.81   27.61
      0.98    18.65    18.32     6.59     1.56     5.03    -3.52     1.59    -5.11     3.07   -114.45   214.45   27.88
      0.98    18.65    18.32     6.58     1.56     5.02    -3.51     1.59    -5.10     3.07   -114.20   214.20   27.84
      0.98    18.65    18.32     6.52     1.56     4.96    -3.45     1.59    -5.04     3.08   -112.08   212.08   27.49
      0.98    18.65    18.32     6.41     1.56     4.85    -3.33     1.59    -4.92     3.08   -108.21   208.21   26.85
      0.98    18.65    18.32     6.24     1.56     4.68    -3.16     1.59    -4.75     3.08   -102.53   202.53   25.91
      0.98    18.65    18.32     6.01     1.56     4.45    -2.93     1.59    -4.52     3.08    -95.11   195.11   24.68
      0.98    18.65    18.32     5.75     1.56     4.19    -2.66     1.59    -4.25     3.09    -86.15   186.15   23.19
```

```
T2L18 RUN CALA=0.0106 CALG=0.209 OFFSET=-210.0 HO=187.0 E2=504.5
   TIDVOL   RESPMZ   VENTM     WIM     WIRM    WIMM     WEM     WERM     WEMM     WTM    PEREX    PERIN      HC
    1.99    20.77    41.39     3.65    3.65     0.0     4.35    4.35      0.0    8.00    54.35    45.65     0.0
    1.99    20.77    41.39    -5.76    3.65   -9.42    13.94    4.35     9.59    8.18   170.51   -70.51   -23.18
    1.99    20.77    41.39    -5.05    3.65   -8.70    13.22    4.35     8.87    8.16   161.92   -61.92   -21.43
    1.99    20.77    41.39    -4.25    3.65   -7.90    12.42    4.35     8.05    8.15   152.16   -52.16   -19.48
    1.99    20.77    41.39    -3.36    3.65   -7.01    11.49    4.35     7.14    8.13   141.28   -41.28   -17.28
    1.99    20.77    41.39    -2.39    3.65   -6.04    10.50    4.35     6.15    8.11   129.41   -29.41   -14.86
    1.99    20.77    41.39    -1.35    3.65   -5.00     9.45    4.35     5.10    8.09   116.73   -16.73   -12.32
    1.99    20.77    41.39    -0.26    3.65   -3.91     8.33    4.35     3.99    8.07   103.23    -3.23    -9.63
    1.99    20.77    41.39     0.87    3.65   -2.78     7.18    4.35     2.83    8.05    89.16    10.84    -6.84
    1.99    20.77    41.39     2.03    3.65   -1.52     5.99    4.35     1.65    8.03    74.66    25.34    -3.98
    1.99    20.77    41.39     3.22    3.65   -0.43     4.79    4.35     0.44    8.01    59.82    40.18    -1.07
    1.99    20.77    41.39     4.40    3.65    0.75     3.58    4.35    -0.77    7.98    44.85    55.15     1.86
    1.99    20.77    41.39     5.58    3.65    1.93     2.38    4.35    -1.97    7.96    29.90    70.10     4.75
    1.99    20.77    41.39     6.74    3.65    3.09     1.20    4.35    -3.15    7.94    15.12    84.88     7.60
    1.99    20.77    41.39     7.86    3.65    4.21     0.06    4.35    -4.29    7.92     0.74    99.26    10.36
    1.99    20.77    41.39     8.94    3.65    5.28    -1.04    4.35    -5.38    7.90   -13.15   113.15    13.01
    1.99    20.77    41.39     9.95    3.65    6.30    -2.06    4.35    -6.42    7.88   -26.37   126.37    15.52
    1.99    20.77    41.39    10.91    3.65    7.25    -3.05    4.35    -7.39    7.86   -38.75   138.75    17.86
    1.99    20.77    41.39    11.77    3.65    8.12    -3.93    4.35    -8.28    7.84   -50.13   150.13    20.00
    1.99    20.77    41.39    12.55    3.65    8.90    -4.73    4.35    -9.07    7.83   -60.37   160.37    21.82
    1.99    20.77    41.39    13.24    3.65    9.59    -5.43    4.35    -9.77    7.82   -69.42   169.42    23.41
    1.99    20.77    41.39    13.82    3.65   10.17    -6.01    4.35   -10.36    7.80   -77.05   177.05    25.03
    1.99    20.77    41.39    14.28    3.65   10.63    -6.49    4.35   -10.84    7.80   -83.24   183.24    26.18
    1.99    20.77    41.39    14.64    3.65   10.99    -6.85    4.35   -11.20    7.79   -87.94   187.94    27.08
    1.99    20.77    41.39    14.87    3.65   11.21    -7.08    4.35   -11.43    7.78   -90.97   190.97    27.61
    1.99    20.77    41.39    14.98    3.65   11.32    -7.19    4.35   -11.54    7.78   -92.43   192.43    27.88
    1.99    20.77    41.39    14.96    3.65   11.31    -7.18    4.35   -11.52    7.78   -92.21   192.21    27.84
    1.99    20.77    41.39    14.82    3.65   11.17    -7.03    4.35   -11.38    7.79   -90.32   190.32    27.49
    1.99    20.77    41.39    14.56    3.65   10.91    -6.77    4.35   -11.11    7.79   -86.86   186.86    26.85
    1.99    20.77    41.39    14.18    3.65   10.52    -6.38    4.35   -10.72    7.80   -81.79   181.79    25.91
    1.99    20.77    41.39    13.68    3.65   10.02    -5.87    4.35   -10.21    7.81   -75.17   175.17    24.68
    1.99    20.77    41.39    13.07    3.65    9.42    -5.25    4.35    -9.60    7.82   -67.17   167.17    23.19
```

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T3L20 RUN CALA=0.0107 CALG=0.209 OFFSET=-210.0 HD=187.0 E2=506.0

      TIDVOL   RESPHZ   VENTM     WIM     WIRM     WIHM      WEM     WEPM     WEHM      WTM    PEREX    PERIN       MC
        3.02    18.02   54.39    5.58     5.58      0.0     5.24     5.24      0.0    10.82    48.42    51.58      0.0
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39   -6.79     5.58   -12.37    17.85     5.24    12.61    11.06   161.36   -61.36   -23.[illegible]
        3.02    18.02   54.39   -5.85     5.58   -11.43    16.89     5.24    11.66    11.04   153.00   -53.00   -21.43
        3.02    18.02   54.39   -4.80     5.58   -10.38    15.82     5.24    10.58    11.02   143.51   -43.51   -19.46
        3.02    18.02   54.39   -3.62     5.58    -9.20    14.62     5.24     9.38    11.00   132.93   -32.93   -17.23
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39   -2.35     5.58    -7.93    13.32     5.24     8.08    10.97   121.38   -21.38   -14.86
        3.02    18.02   54.39   -0.99     5.58    -6.57    11.94     5.24     6.70    10.95   109.06    -9.06   -12.32
        3.02    18.02   54.39    0.44     5.58    -5.14    10.48     5.24     5.24    10.92    95.94     4.06    -9.63
        3.02    18.02   54.39    1.93     5.58    -3.65     8.96     5.24     3.72    10.89    82.26    17.74    -6.84
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39    3.46     5.58    -2.12     7.40     5.24     2.16    10.86    68.16    31.84    -3.98
        3.02    18.02   54.39    5.01     5.58    -0.57     5.82     5.24     0.58    10.83    53.74    46.26    -1.07
        3.02    18.02   54.39    6.57     5.58     0.99     4.23     5.24    -1.01    10.80    39.19    60.81     1.85
        3.02    18.02   54.39    8.12     5.58     2.53     2.66     5.24    -2.58    10.77    24.66    75.34     4.75
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39    9.64     5.58     4.06     1.11     5.24    -4.13    10.74    10.29    89.71     7.60
        3.02    18.02   54.39   11.11     5.58     5.53    -0.39     5.24    -5.63    10.72    -3.69   103.69    10.36
        3.02    18.02   54.39   12.52     5.58     6.94    -1.84     5.24    -7.08    10.69   -17.18   117.18    13.01
        3.02    18.02   54.39   13.86     5.58     8.28    -3.20     5.24    -8.44    10.66   -30.03   130.03    15.52
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39   15.11     5.58     9.53    -4.47     5.24    -9.71    10.64   -42.06   142.06    17.86
        3.02    18.02   54.39   16.25     5.58    10.57    -5.64     5.24   -10.88    10.62   -53.11   153.11    20.00
        3.02    18.02   54.39   17.28     5.58    11.70    -6.68     5.24   -11.92    10.60   -63.06   163.06    21.92
        3.02    18.02   54.39   18.16     5.58    12.60    -7.60     5.24   -12.84    10.58   -71.85   171.85    23.61
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39   18.94     5.58    13.36    -8.37     5.24   -13.61    10.56   -79.26   179.26    25.03
        3.02    18.02   54.39   19.55     5.58    13.97    -9.00     5.24   -14.24    10.55   -85.28   185.28    26.18
        3.02    18.02   54.39   20.02     5.58    14.43    -9.47     5.24   -14.71    10.54   -89.84   189.84    27.03
        3.02    18.02   54.39   20.31     5.58    14.73    -9.78     5.24   -15.02    10.54   -92.78   192.78    27.61
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39   20.46     5.58    14.88    -9.92     5.24   -15.16    10.54   -94.20   194.20    27.[illegible]
        3.02    18.02   54.39   20.44     5.58    14.86    -9.90     5.24   -15.14    10.54   -93.99   193.99    27.84
        3.02    18.02   54.39   20.25     5.58    14.67    -9.71     5.24   -14.95    10.54   -92.15   192.15    27.49
        3.02    18.02   54.39   19.91     5.58    14.33    -9.36     5.24   -14.60    10.55   -88.79   188.79    26.85
-------------------------------------------------------------------------------------------------------------------------
        3.02    18.02   54.39   19.41     5.58    13.83    -8.85     5.24   -14.09    10.56   -83.86   183.86    25.81
        3.02    18.02   54.39   18.75     5.58    13.17    -8.18     5.24   -13.42    10.57   -77.43   177.43    24.48
        3.02    18.02   54.39   17.96     5.58    12.37    -7.37     5.24   -12.61    10.58   -69.66   169.66    23.19
```

```
T3L25 RUN CALA=0.0040 CALG=0.209 OFFSET=-210.0 HD=187.0 E2=1383.5

  TBDVEL  RESPHZ   VENTH    VIN     VIRM    VIHM     VEN     VERM    VEHM     VTN    PEREX   PERIN     NC
   2.98   26.85   80.12   12.54   12.54    0.0     7.68    7.68    0.0    20.22   37.97   62.03    0.0
   2.98   26.85   80.12   -5.58   12.54  -18.12   26.25    7.68   18.57   20.67  126.99  -26.99  -23.14
   2.98   26.85   80.12   -4.21   12.54  -16.76   24.85    7.68   17.17   20.64  120.41  -20.41  -21.43
   2.98   26.85   80.12   -2.66   12.54  -15.21   23.26    7.68   15.58   20.60  112.93  -12.93  -19.46
   2.98   26.85   80.12   -0.94   12.54  -13.49   21.50    7.68   13.82   20.56  104.59   -4.59  -17.23
   2.98   26.85   80.12    0.93   12.54  -11.62   19.59    7.68   11.91   20.51   95.49    4.51  -14.84
   2.98   26.85   80.12    2.91   12.54   -9.63   17.55    7.68    9.87   20.46   85.77   14.23  -12.38
   2.98   26.85   80.12    5.01   12.54   -7.53   15.40    7.68    7.72   20.41   75.43   24.57   -9.43
   2.98   26.85   80.12    7.20   12.54   -5.33   13.16    7.68    5.48   20.36   64.65   35.35   -6.89
   2.98   26.85   80.12    9.43   12.54   -3.11   10.87    7.68    3.19   20.30   53.54   46.46   -3.98
   2.98   26.85   80.12   11.71   12.54   -0.84    8.54    7.68    0.86   20.24   42.17   57.83   -1.07
   2.98   26.85   80.12   13.99   12.54    1.45    6.20    7.68   -1.48   20.19   30.70   69.30    1.85
   2.98   26.85   80.12   16.26   12.54    3.71    3.87    7.68   -3.81   20.13   19.24   80.76    4.75
   2.98   26.85   80.12   18.49   12.54    5.94    1.59    7.68   -6.09   20.08    7.92   92.08    7.60
   2.98   26.85   80.12   20.64   12.54    8.10   -0.62    7.68   -8.30   20.02   -3.10  103.10   10.36
   2.98   26.85   80.12   22.72   12.54   10.17   -2.74    7.68  -10.42   19.97  -13.74  113.74   13.01
   2.98   26.85   80.12   24.68   12.54   12.13   -4.75    7.68  -12.43   19.92  -23.86  123.86   15.52
   2.98   26.85   80.12   26.51   12.54   13.96   -6.63    7.68  -14.31   19.88  -33.35  133.35   17.88
   2.98   26.85   80.12   28.18   12.54   15.64   -8.34    7.68  -16.02   19.84  -42.06  142.06   20.00
   2.98   26.85   80.12   29.68   12.54   17.14   -9.88    7.68  -17.56   19.80  -49.91  149.91   21.92
   2.98   26.85   80.12   31.00   12.54   18.46  -11.24    7.68  -18.92   19.77  -56.84  156.84   23.61
   2.98   26.85   80.12   32.11   12.54   19.57  -12.37    7.68  -20.05   19.74  -62.68  162.68   25.03
   2.98   26.85   80.12   33.01   12.54   20.47  -13.29    7.68  -20.97   19.72  -67.42  167.42   26.18
   2.98   26.85   80.12   33.69   12.54   21.15  -13.99    7.68  -21.67   19.70  -71.02  171.02   27.08
   2.98   26.85   80.12   34.13   12.54   21.59  -14.44    7.68  -22.12   19.69  -73.33  173.33   27.61
   2.98   26.85   80.12   34.34   12.54   21.80  -14.66    7.68  -22.34   19.69  -74.45  174.45   27.88
   2.98   26.85   80.12   34.31   12.54   21.77  -14.62    7.68  -22.30   19.69  -74.29  174.29   27.84
   2.98   26.85   80.12   34.04   12.54   21.49  -14.34    7.68  -22.02   19.69  -72.84  172.84   27.40
   2.98   26.85   80.12   33.54   12.54   20.99  -13.83    7.68  -21.51   19.71  -70.19  170.19   26.88
   2.98   26.85   80.12   32.80   12.54   20.26  -13.08    7.68  -20.76   19.72  -66.31  166.31   25.91
   2.98   26.85   80.12   31.84   12.54   19.30  -12.09    7.68  -19.77   19.75  -61.24  161.24   24.68
   2.98   26.85   80.12   30.68   12.54   18.13  -10.90    7.68  -18.58   19.78  -55.11  155.11   23.19
```