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**DIVE LAB XLDS RDC-3 AND INTERSPIRO DP2
AS CANDIDATES FOR AN
EXTREME LIGHTWEIGHT DIVING SYSTEM
(UNMANNED)**

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INTRODUCTION

The U.S. Navy seeks to identify a commercially available diving system to support limited-scope surface-supplied air diving operations. In general, the system should be lightweight, portable, and easily deployed and operated. To this end, the Navy Experimental Diving Unit (NEDU) has been tasked to test and evaluate commercially available lightweight diving systems as candidates for the Navy's Extreme Lightweight Diving System (XLDS).^{1,2,3} Resistive effort (RE) evaluations were performed for the Dive Lab model XLDS RDC-3 and the Interspiro model DP2 — both candidates for the XLDS — at the Experimental Diving Facility (EDF) of the NEDU. Because of the limited time available to schedule testing in the EDF, the Amron 8330H console (also a candidate for selection as an XLDS) was not performed. With the concurrence of Mr. Mike Leese (Naval Sea Systems Command 00C3 [NAVSEA 00C3]), its testing has been deferred to a date yet to be determined.⁴

METHODS

GENERAL

Unmanned RE testing was performed in accordance with NEDU test plan TP 05-35.⁵ Four Dive Lab three-diver XLDS RDC-3 systems and five Interspiro two-diver DP2 systems were evaluated. The Dive Lab system was evaluated with both MK 21 helmets and MK 20 full face masks (nonpositive pressure model [MKIIG]). The Interspiro DP2 system was evaluated with the Divator MKII full face mask (positive pressure model).

EXPERIMENTAL DESIGN AND ANALYSIS

Resistive Effort (RE)

Resistive effort was evaluated in 33-foot increments from 0 to 198 feet of seawater (fsw)/0 to 60.7 meters of seawater (msw) with air as the breathing medium. At each depth, 10 pressure-volume (P-V) loops were recorded. The RE — a volume-averaged pressure — was reported in kilopascals (kPa) for each ensemble average of the 10 P-V loops generated at each depth.

Diving console evaluations were conducted in EDF Alpha and Bravo hyperbaric chambers. Both the Dive Lab XLDS RDC-3 and the Interspiro DP2 diving systems were evaluated with lightweight umbilicals provided by the respective systems' manufacturers. The Alpha-Bravo hyperbaric complex was pressurized during tests, with divers' umbilicals inside Alpha chamber and the helmets/face masks inside Bravo chamber. Alpha and Bravo chambers were pressurized together as a single chamber during all tests.

Analysis was performed as detailed in NEDU *Technical Manual 01-94*.⁶ To meet the goals for Category 2 underwater breathing apparatus (UBA) — surface-supplied

demand UBA — the mean RE was not to exceed 1.76 kPa at a respiratory minute volume (RMV) of 62.5 liters per minute (L/min) at all depths.

Interface between the Dive Lab XLDS RDC-3 diving console and the Bravo chamber hull penetrator was accomplished by using NEDU-manufactured 25-foot lengths of $\frac{3}{8}$ -inch inside diameter (ID) standard diving umbilical.

Interface between the Interspiro DP2 console and the Bravo chamber hull penetrator was accomplished by using an approximately 30-foot length of $\frac{1}{4}$ -inch ID high-pressure (HP) hose.

EQUIPMENT AND INSTRUMENTATION

Facility Support Equipment

- a. EDF unmanned hyperbaric chambers with related services
- b. EDF bottle field for high-pressure diver quality air to pressurize chambers and supply breathing gas
- c. Water tank (Bravo ark) for submersing helmets/masks during RE testing
- d. Ark water-cooling system with chiller, heat transfer coils, circulation device, temperature control circuitry, and other support systems

Test Equipment and Instrumentation

- a. Mannequin heads for mounting helmets and full-face masks (EDF special equipment)
- b. Stand for supporting and orienting mannequin heads with attached remote controlled electric motor for manipulating helmet demand regulator adjustment knob (EDF special equipment)
- c. Breathing gas routing tees to attach helmets' and full-face masks' oral-nasal masks to breathing simulator loops (EDF special equipment)
- d. Oral pressure transducers (± 1 psi, differential, wet-wet, submersible; model PTX 317-9219; Druck Inc.; New Fairfield, CT)
- e. Depth pressure transducer (0–200 psi, differential, wet-wet, submersible; model PTX 317-9219; Druck Inc.; New Fairfield, CT)
- f. Linearized thermistor temperature sensors (700 series; Yellow Springs Instruments; Yellow Springs, OH)
- g. Two-channel thermilinear thermistor signal conditioner (DEI Model 1442; Deban Enterprises, Inc.; Yellow Springs, OH)
- h. Sinusoidal mechanical breathing simulators (model BM2B; Reimers Engineering; Springfield, VA)
- i. Workstation computer systems running Windows (XP Professional; Microsoft Corporation; Redmond, WA) operating system and LabVIEW (version 6.1i; National Instruments; Austin, TX) for data acquisition, instrument control, and data analysis

- j. NEDU-developed software for recording and analyzing parameters of P-V breathing loops
- k. Closed-circuit television systems to monitor UBA and in-chamber test equipment during testing
- l. Linearized thermistor temperature sensors (700 series; Yellow Springs Instruments; Yellow Springs, OH)
- m. Two-channel thermilinear thermistor signal conditioner (DEI Model 1442; Deban Enterprises, Inc.; Yellow Springs, OH)

PROCEDURES

Dive Lab XLDS RDC-3

Dive Lab XLDS RDC-3 testing of RE consisted of five scenarios.

Scenario 1:

- Four Dive Lab XLDS RDC-3 consoles were evaluated.
- Breathing was via one MK 21 helmet submerged in fresh water.
- Water temperature was maintained at 38 ± 2 °F (3.3 ± 1.1 °C).
- Air was the breathing medium.
- Depths were increased in 33 fsw increments from 0 to 198 fsw.
- The demand regulator adjustment knob was adjusted at each depth.
- RE was evaluated at 22.5, 40.0, 62.5, 75.0, and 90.0 L/min RMV.
- The steady flow valve was closed on the helmet during RE evaluation.
- Console supply pressures were 500 and 1500 psig and were supplied through a scuba cylinder.
- Manifold (console outlet to umbilical) pressure was 350 psig.
- Intermediate compensating system (ICS) regulator set pressure was verified to be 150–165 psig.

Scenario 2:

- Procedures were the same as in Scenario 1, except that one MK 20 full face mask (nonpositive pressure model [MKIIIG]) was used.

Scenario 3:

- Procedures were generally the same as in Scenario 1, except that only one console was evaluated.
- Two MK 21 helmets supplied from one regulator were used, and evaluations were made only at 62.5 L/min RMV with 1500 psig supply pressure.
- Helmets were breathed out of phase (but at an unspecified phase differential).

Scenario 4:

- Procedures were generally the same as in Scenario 1, except that only one console was evaluated.
- Two MK 20 full face masks (nonpositive pressure model [MKIIG]) supplied from one regulator were used, and evaluations were made only at 62.5 L/min RMV with 1500 psig supply pressure.
- The MK 20 masks were breathed out of phase (but at an unspecified phase differential).

Scenario 5:

- Procedures were generally the same as in Scenario 1, except that only one console was evaluated.
- Two MK 21 helmets supplied from one regulator were used.
- One helmet was breathed at 62.5 L/min RMV at 66 fsw; the second helmet was at depth with the steady flow valve wide open but was not breathed.

Interspiro DP2

Interspiro DP2 was set up in accordance with the Interspiro *Surface Supply Divator DP1 User Manual*. Five Interspiro DP2 consoles — which are in fact DP1 consoles with “tee” adapters attached to their breathing gas outlets — were evaluated. The tee allows two umbilicals to be attached to the console outlet. During unmanned RE evaluations, the tee adapter was installed on the inside of the EDF Bravo chamber hull penetrator. Two divers’ umbilicals were then connected at the tee inside the Bravo chamber.

- Two Divator MKII (positive pressure) face masks were used during the evaluation.
- Water temperature was maintained at 38 ± 2 °F (3.3 ± 1.1 °C).
- Air was the breathing medium.
- Depths were increased in 33 fsw increments from 0 to 198 fsw.
- Evaluations were made at 22.5, 40.0, 62.5, 75.0, and 90.0 L/min RMV.
- DP2 console supply pressure was 1500 psig.

The DP2 was not tested with a 500 psig breathing gas supply: the breathing gas low-pressure acoustic alarm activates when the pressure decreases to 55 bars (798 psig). HP breathing air was supplied to one of the two DP2 console inlet hoses from the EDF bottle field through the Bravo chamber console breathing air regulator. The other DP2 console inlet hose was attached to a Divator HP cylinder assembly, which was not a source of diver’s breathing gas but was used to blank the second console HP inlet hose. Using EDF bottle field breathing gas allowed testing to be performed at a constant breathing gas supply pressure and precluded needs for multiple changes of charged Divator cylinders to support the large gas quantities consumed during unmanned testing.

RESULTS

Dive Lab XLDS RDC-3

Results of RE determinations for Dive Lab XLDS RDC-3 testing Scenarios 1 and 2 are shown in Figures 1 through 4. The goal of 1.76 kPa at 62.5 L/min RMV⁶ was met to a depth of 165 fsw for the MK 21 helmet and to a depth of 132 fsw for the MK 20 (nonpositive pressure) full face mask when the RDC-3 console was used to supply breathing gas to the helmet. The difference in the RE results for 1500 and 500 psig console supply pressures was not significant (sample size: $n = 4$).

With 1500 psig breathing gas supply to the console and with two MK 21 helmets supplied from a single RDC-3 regulator, the RE goal of 1.76 kPa at an RMV of 62.5 L/min was still met to 165 fsw (Figure 5 [Scenario 3, sample size: $n = 1$]). When two MK 20 full face masks were similarly supplied from one RDC-3 regulator (Figure 6 [Scenario 4, sample size: $n = 1$]), the RE goal was met to a depth of 132 fsw.

During Scenario 5 tests at a simulated depth of 66 fsw, two MK 21 helmets were supplied from a single RDC-3 console regulator. One helmet was not breathed but had the steady flow valve wide open, while the other helmet was breathed at 62.5 L/min RMV. Resistive effort for the breathed helmet was determined to be 0.96 kPa (sample size: $n = 1$).

Interspiro DP2

Results of RE determinations for the Interspiro DP2 are shown in Figure 7. With a 1500 psig breathing gas supply through the console, the Interspiro DP2 met the goal of 1.76 kPa at a 62.5 L/min RMV⁶ to a depth of 198 fsw while breathing two MKII (positive pressure) full face masks.

DISCUSSION

Dive Lab XLDS RDC-3

No functional deficiencies were noted during the unmanned testing of the Dive Lab XLDS RDC-3. The "XLDS RDC-3 Operations and Maintenance Manual" was under development during the time NEDU was performing unmanned RE evaluations. Mr. Michael Ward (Dive Lab, Inc.; Panama City Beach, FL) provided a working draft of that manual for use during the unmanned evaluation.

Historically, unmanned RE evaluations have used a minimum sample size of five ($n = 5$). Since only four Dive Lab XLDS RDC-3 systems were available during this unmanned evaluation, results are therefore based upon a sample size of four ($n = 4$).

Interspiro DP2

The *Interspiro Surface Supply Divator DP1 User Manual* provided with the DP2 system was minimally useful. While it provided descriptive information on the system, it provided only cursory operational and maintenance guidance. The manual does not provide any equipment schematics, technical drawings, parts breakdowns, or a bill of materials. Detailed maintenance requirements and procedures are not addressed.

Unmanned testing logistics and interface with EDF testing facilities were complicated because the Interspiro DP2 system uses DIN fittings. Even the most basic function — such as charging the DIN-equipped, 300 bar (4350 psig) working pressure HP cylinders — requires adapters to interface with the existing NEDU system fittings that are non-DIN. This is not an Interspiro DP2 system deficiency, but it may be a deployment logistics complication requiring attention.

During initial setup of unmanned testing to evaluate the RE of the DP2 system, one of the two MKII full face masks free-flowed when submerged in the ark. Both masks were provided with the DP2 system and were new. NEDU technicians verified mask regulator adjustments to be within manufacturer specifications, but the free flow persisted. When this problem was discussed with the manufacturer, Mr. Ola Lindh of Interspiro stated that the springs in the demand regulator were too weak.⁷ Although NEDU technicians tried different MKII mask regulators from another DP2 system, the free flowing persisted until the umbilical was changed. Since the technical documentation provided with the Interspiro DP2 system does not provide troubleshooting details, NEDU technicians were unable to verify that the regulator on the umbilical that was changed had been functioning properly. When Interspiro representatives were contacted about the free-flow problem, they were both interested and responsive.

CONCLUSIONS

Unmanned testing results indicate that RE for the MK 20 full face mask, when supplied with breathing gas from the Dive Lab XLDS RDC-3 system, is acceptable to permit manned evaluation at NEDU to 132 fsw. Unmanned testing results also indicate that RE for the MK 21 helmet, when supplied breathing gas from the Dive Lab XLDS RDC-3, is acceptable to permit manned evaluation at NEDU to 165 fsw.

Results from RE effort evaluation of the MKII (positive pressure) full face mask, when supplied breathing gas from the Interspiro DP2, are satisfactory to permit controlled manned dives to a depth of 198 fsw.

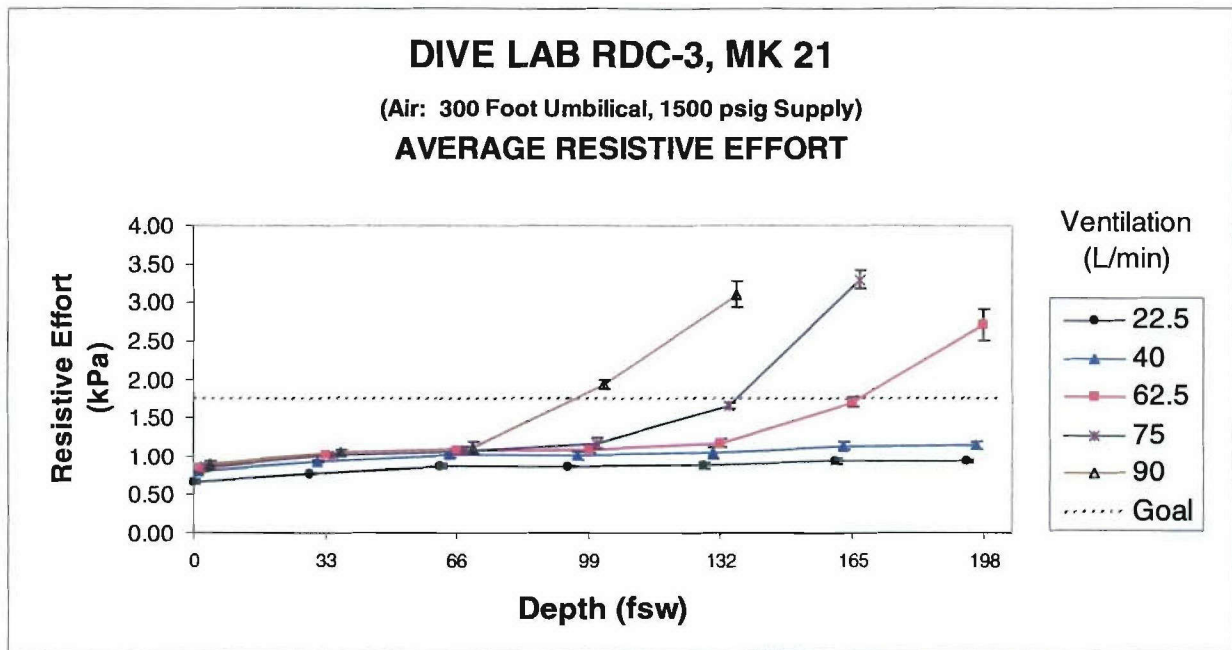


Figure 1. Resistive effort plotted against depth with a 1500 psig supply pressure to the console (Scenario 1). Console outlet pressure to the diver's umbilical is 350 psig. Each line shows the average of four consoles. Error bars show the standard deviations. To improve readability, the symbols are slightly offset horizontally. The interrupted line shows the goal (1.76 kPa) for resistive effort.

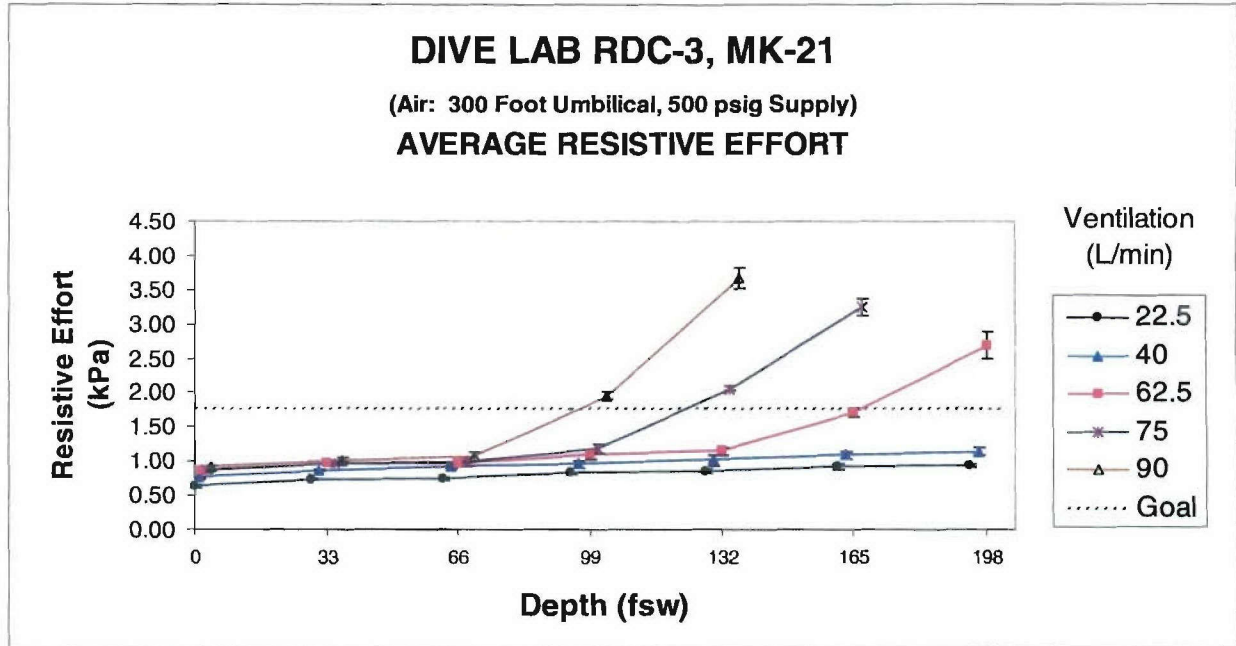


Figure 2. Resistive effort plotted against depth with 500 psig supply pressure to the console (scenario 1). Console outlet pressure to diver's umbilical is 350 psig. Each line shows the average of four consoles. Error bars show the standard deviation. To improve readability, the symbols are slightly offset horizontally. The interrupted lines show the goal (1.76 kPa) for resistive effort.

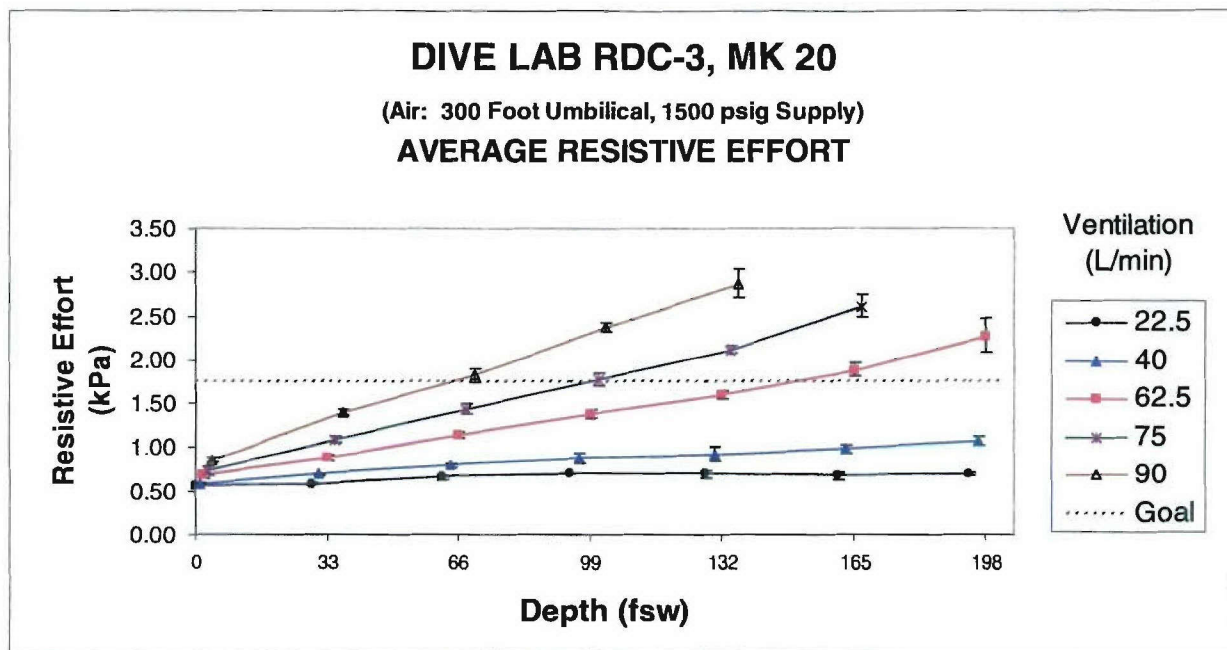


Figure 3. Resistive effort plotted against depth with a 1500 psig supply pressure to the console (Scenario 2). Console outlet pressure to the diver's umbilical is 350 psig. Each line shows the average of four consoles. Error bars show the standard deviations. To improve readability, the symbols are slightly offset horizontally. The interrupted line shows the goal (1.76 kPa) for resistive effort.

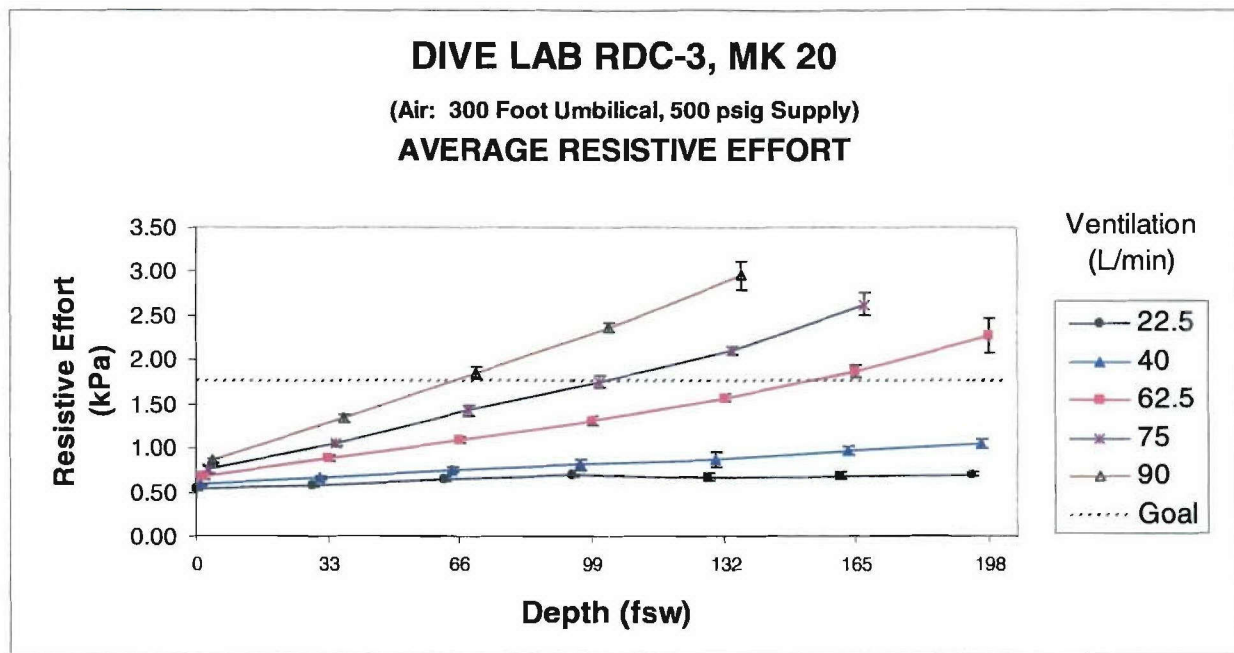


Figure 4. Resistive effort plotted against depth with a 500 psig supply pressure to the console (Scenario 2). Console outlet pressure to the diver's umbilical is 350 psig. Each line shows the average of four consoles. Error bars show the standard deviations. To improve readability, the symbols are slightly offset horizontally. The interrupted line shows the goal (1.76 kPa) for resistive effort.

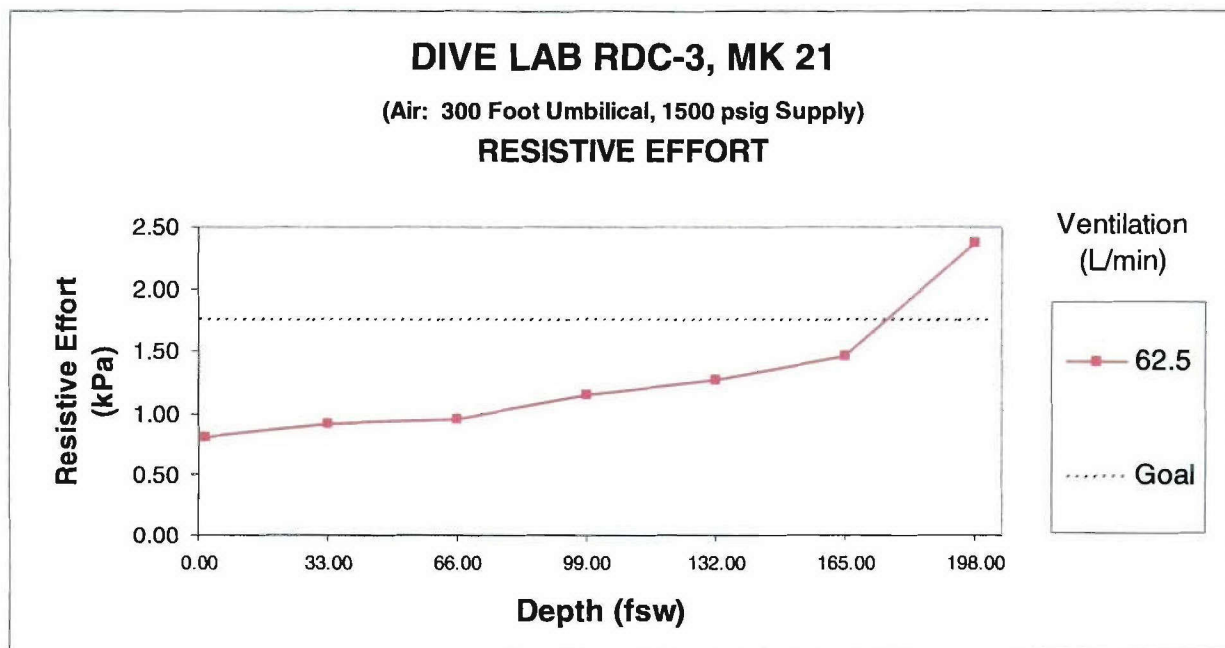


Figure 5. Resistive effort plotted against depth with a 1500 psig supply pressure to the console (Scenario 3). Data represents the resistive effort from one of two helmets when both helmets are supplied from one console regulator and breathed simultaneously. Console outlet pressure to the diver's umbilical is 350 psig. The data line represents a console sample size of $n = 1$. The interrupted line shows the goal (1.76 kPa) for resistive effort.

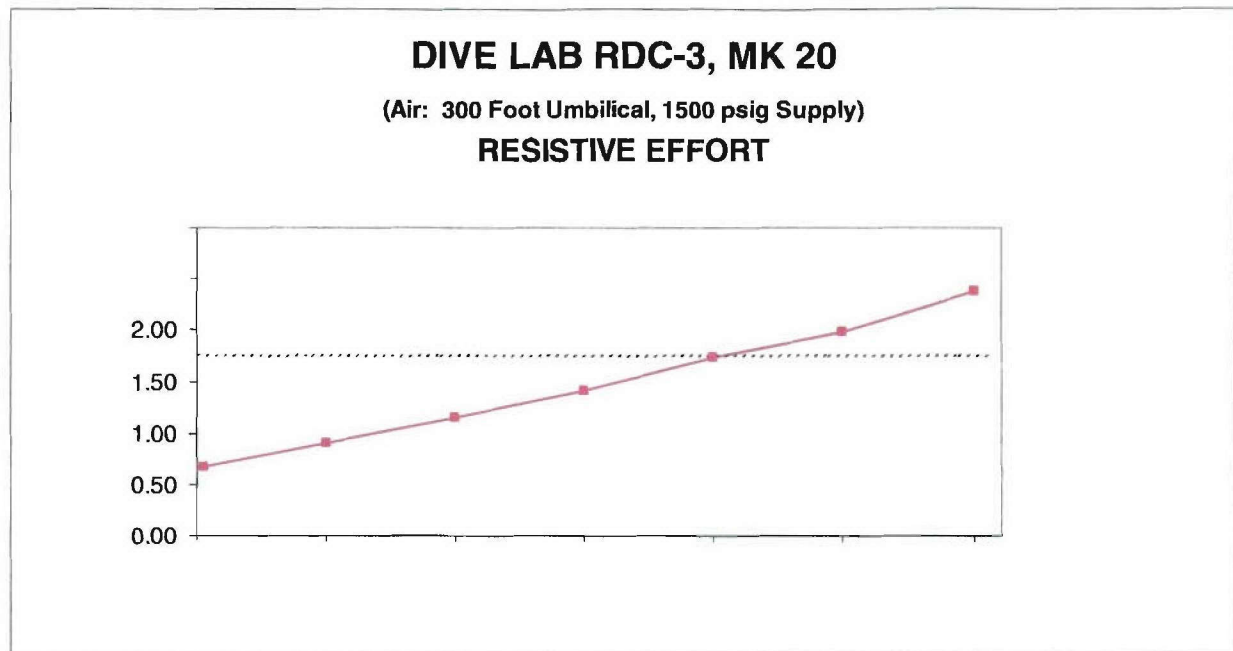


Figure 6. Resistive effort plotted against depth with a 1500 psig supply pressure to the console (Scenario 4). Data represents the resistive effort from one of two full face masks when both masks are supplied from one console regulator and breathed simultaneously. Console outlet pressure to the diver's umbilical is 350 psig. The data line represents a console sample size of $n = 1$. The interrupted line shows the goal (1.76 kPa) for resistive effort.

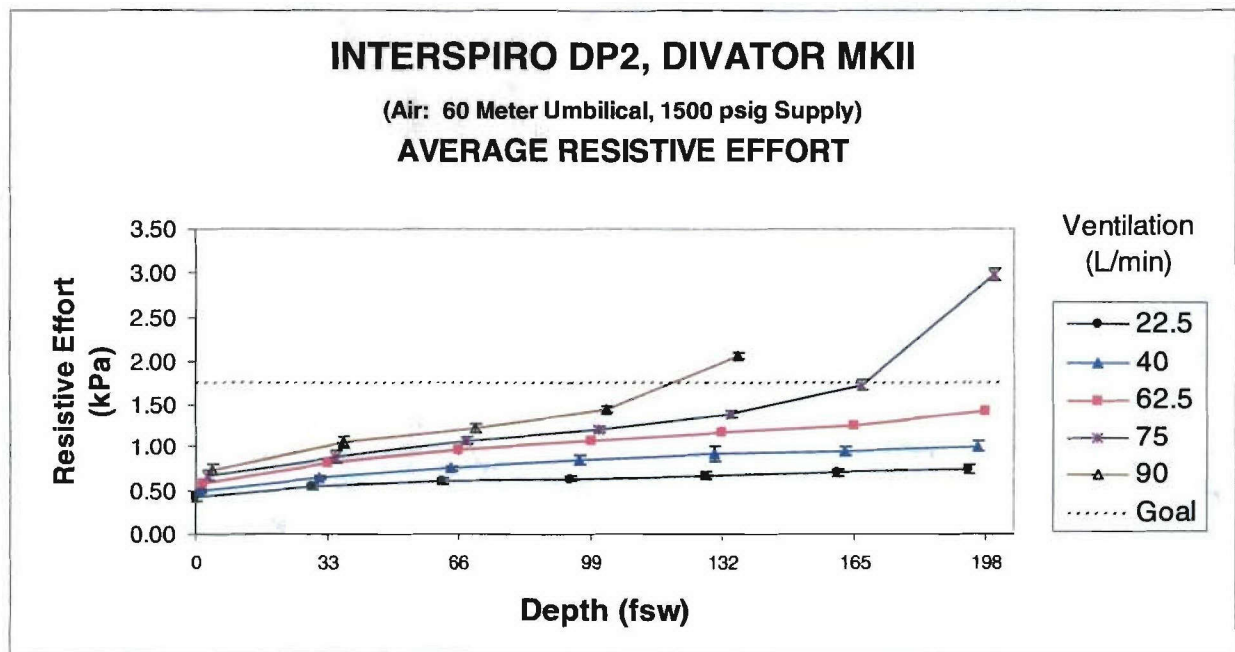


Figure 7. Resistive effort plotted against depth with a 1500 psig supply pressure to the console. Console outlet pressure to the diver's umbilical is 1500 psig. Each line shows the average of five consoles. Error bars show the standard deviations. To improve readability, the symbols are slightly offset horizontally. The interrupted line shows the goal (1.76 kPa) for resistive effort. Data presented in this figure represent the resistive effort for one of the two MKII full face masks evaluated.



Photo 1. Dive Lab XLDS RDC-3 console with one 300-foot umbilical. The diver-worn harness includes two cylinders. The larger cylinder is the emergency gas system (EGS). The smaller cylinder is the intermediate compensating system (ICS). The high-pressure whip assembly used to supply HP breathing gas from scuba cylinders is not shown.

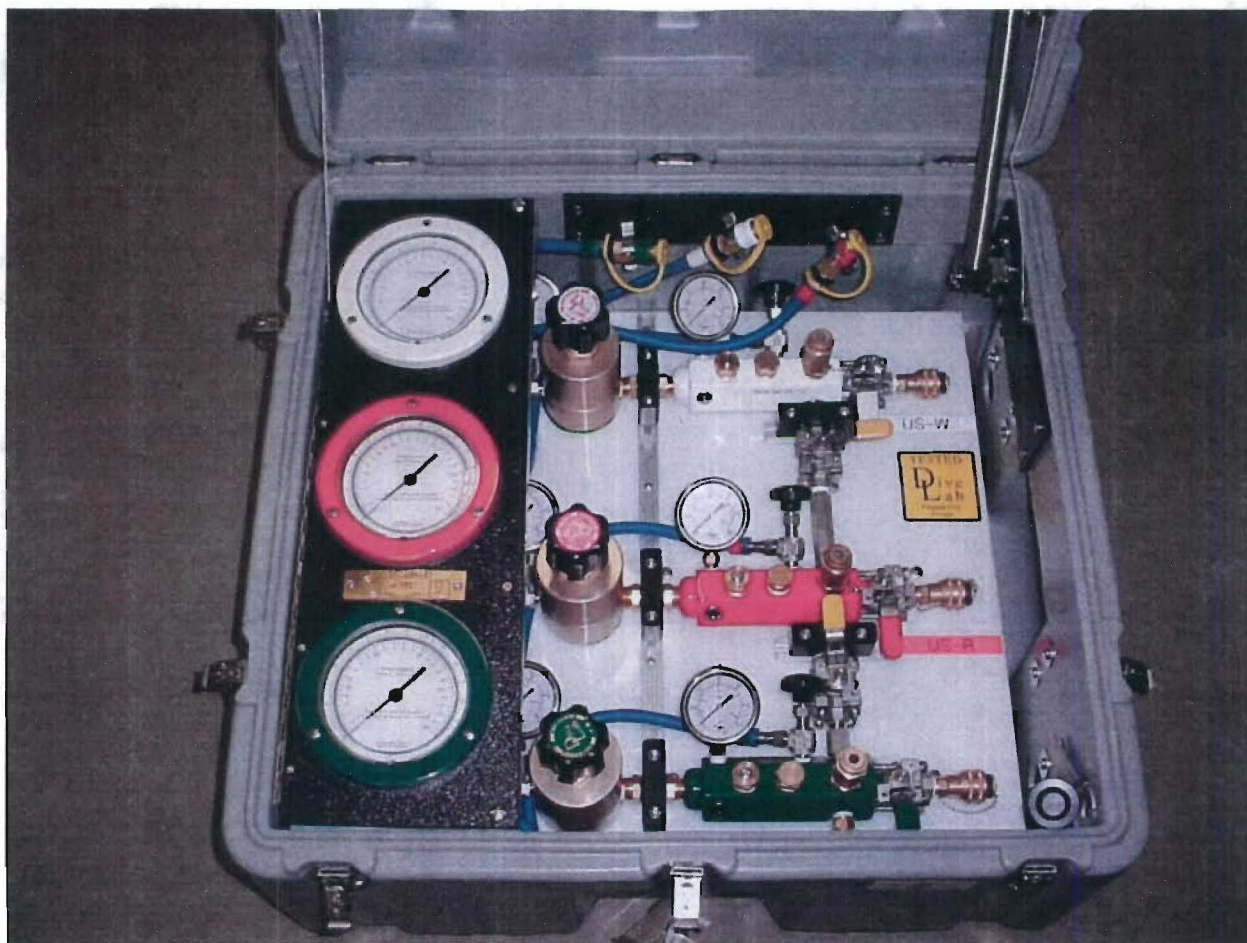


Photo 2. Dive Lab XLDS RDC-3 console showing three diver stations.



Photo 3. Interspiro DP2 system with 60 m umbilicals.

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