

## **The Sentinel Rebreather Concept Description**

I decided to put this together based on comments and observations at the last two dive shows.

### **Why did I design the Sentinel (S) and how does it differ from the Ouroboros (OR).**

The OR will always be our deep diving rebreather. It has very low breathing resistance (resistive), great electronics and manual backup systems and a virtually fail-safe gas plumbing system (Swagelok 316 stainless). All of these things add cost (especially the Swagelok!).

95% of divers will never take this rebreather anywhere near its' performance limits.

My view is that recreational diving now regularly takes a lot of people to 100m. This has led to the new design. Ten years ago 100m diving was heavy-duty expedition territory, now it is not. 100m as a bailout (with reasonable bottom times) is also not too difficult logistically.

So the challenge is to make a rebreather more cost effectively but still with an acceptable (and high) degree of performance.

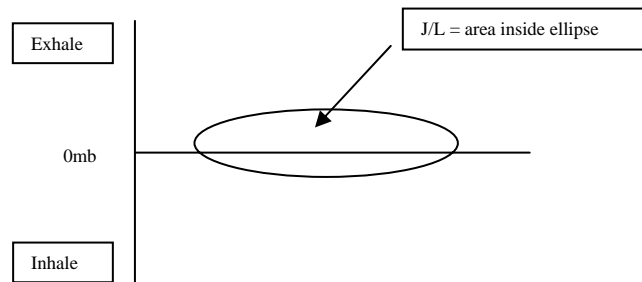
### **Breathing Performance**

Breathing performance should never be compromised in life-support equipment and it is continually a balance between low overall work of breathing and the size of the unit (in particular the mouthpiece).

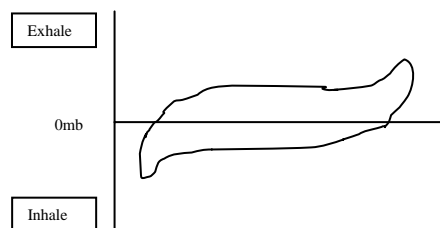
A unit that will always be used by very experienced divers, that never get stressed, can arguably have a lower breathing performance. A unit designed for a spectrum of the general diving market must assume stress will occur and when it does, if breathing performance is poor, the safety of the diver will be compromised.

The energy expended by a diver to push gas around a rebreather is a combination of three primary things.

1. The resistance to flow of all the bores within the unit (houses, mouthpiece etc.). At the surface as a diver breathes out and in again a breathing performance analyser will show a rise and then fall in pressure throughout the breathing cycle. This is known as the Pressure/Volume diagram or PV diagram. At the surface it is a sideways ellipse about zero pressure, much like the shape of your eye. The area within this ellipse is measured in Joules/liter and is known as the Resistive Effort (RE) required to push gas around the breathing circuit. At depth with increased gas density this ellipse will fatten, increasing the Joules/liter. An increase in breathing rate also increases the joules/liter.

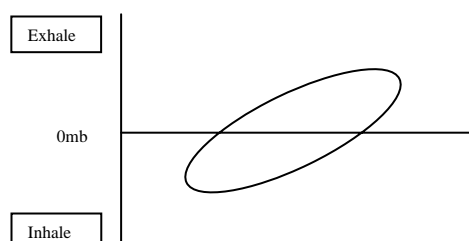


If the counterlung you are breathing into is too small for a standard breath, the two ends of the ellipse will turn up and down respectively. Further degrading the 'breathing feel' and increasing the peak to peak pressure felt by the diver.



A low RE is essential in any rebreather design as the effects of it cannot be compensated for by the diver, it is purely a function of the mechanics of the rebreather.

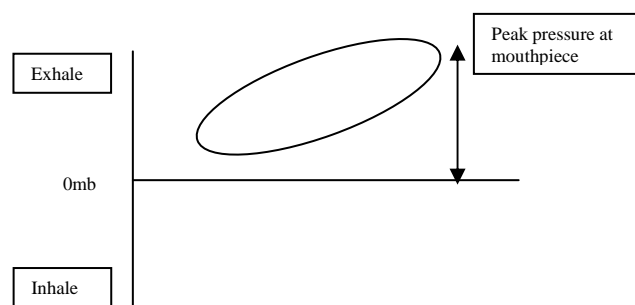
2. Once the unit is submerged, hydrostatic effect now plays a part. Depending on the test position (vertical or horizontal), the shape of the counterlungs (long/thin Vs doughnut etc.) and their position in the set will affect the angle of the ellipse. The ellipse, previously about zero, will tilt up to add a minimum and maximum peak pressure to the PV ellipse. These peak to peak pressures also affect 'breathing feel'. If the Counterlungs (CL) are long and this and the unit is anywhere other than horizontal the PV will start to angle up considerably, again degrading the 'breathing feel'.



A CL of a safe minimum size (so as not to affect 1 above), shaped around the centroid position of the divers lungs will produce lower peak to peak pressures. Both this and the RE are tested at depth with high ventilation rates, as again the diver can do nothing to correct these issues in set design except breathe slower.

Hence the results from 1 and 2 are additive and go towards the total 'breathing feel' of the unit.

3. A final function is important and that is the Rotational Hydrostatic Effect ((HE). This simulates the diver moving into different positions. It is function of 1 and 2 above and the counterlung position (and shape) with reference to lung centroid in these varying positions. It is currently conducted with a fixed loop volume so that comparisons can be drawn. The rotation has the effect of moving the angled PV diagram up and down about the zero point (and in some cases modifying the angle) and in effect creating an offset (addition/subtraction) in peak pressure.



So for the total 'breathing feel' of a set, 1,2 and 3 are all added together at this stage. Test 3 gives the only result where the diver has the ability to compensate for the pressures seen at the mouthpiece as they can vent or inject manually in the different positions or change position, thus improving the 'feel' somewhat.

Units with over-shoulder counterlungs generally have a lower HE. But if counterlung volumes are excessive or are not constrained, the HE results can be compromised significantly.

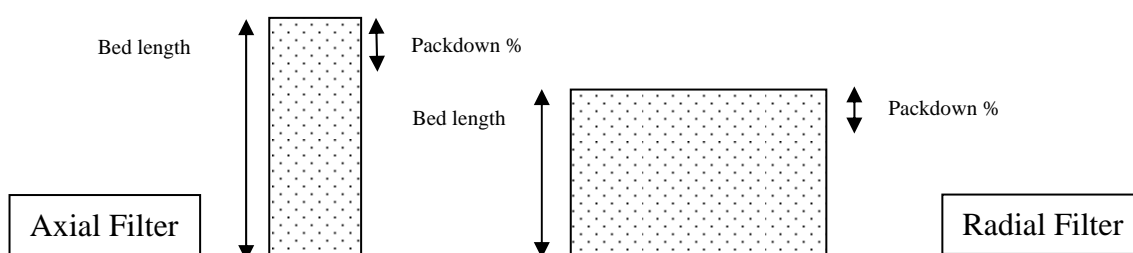
Backmounted counterlungs traditionally show high HE when the diver is swimming on their back.

So given that the total breathing feel of a set is a function of all three of the above, almost any CL concept can be made to generate a good overall work of breathing. Over-shoulder counterlungs traditionally solve the HE problem quite well but designs often compromise items 1 and 2 as a result, which remain un-adjustable by the diver.

Over-shoulder CL's have their own issues such as 'harness clutter' and large buoyancy shifts, which can in-turn affect the sets ability to track PO2 setpoint accurately.

### Absorbent Filters

Traditionally we have been led to believe that axial designs are a low-duration performer and radial is high. This is not always the case. What can be said is that radial designs have a lower breathing resistance due to the bed length and are often less prone to packing errors due to the bed height versus the pack down % (at least in doughnut radials).



Axial canisters can be just as efficient.

The Sentinel can use three different absorbent systems in the same mechanics. Each can interface with our Canister Duration Meter (CDM) which is a licensed United States Navy product we have rights to. The CDM is a thermal system which predicts the 5mb CO2 point on a duration curve.

Version 1 is a user-packed granular system. The absorbent canister is located over the CDM and filled. Being a user-packed axial design you are required to tap the sides of the canister and then refill it to the top again (as per the instructions) before replacing the lid. The CDM assembly is spring loaded into the canister base and the base fitted back into the rebreathers' centre section. This process disengages the spring plate and forces the canister up into a seal in the canister head. Both auto-aligning the filter and continuously re-packing it during use.

Version 2 uses a pre-packed, disposable granular cartridge which is 'snow storm filled' to remove packing errors. It in turn fits onto the CDM and locates in the same way.

Version 3 uses the polymer bonded Extendair cartridges which again locate on the CDM in the same way. When using versions 2 and 3, an additional sealing O ring at the base of the CDM comes into play and like the top seal should be kept clean and greased.

The Extendair cartridges give several advantages over granules such as a lower breathing resistance and easier flood recovery.

## **Counterlung**

The unit comes as standard with one back-mounted counterlung (CL). This CL is teed off of the inhale side of the loop at the output of the canister head, hence the inhale breathing hose is not actually connected to it, it just provides an expandable volume. In a head-down position water will preferentially drain into the CL. When the diver goes head-up again, water drains back to the canister base where the water/gas dump is positioned.

The single back-mounted CL has several advantages;

1. More protection
2. Less heat loss
3. Simpler flood recovery
4. Reduction of failure points

Mid 2008 a second option will be available. The set will be available without its' hard case. Cylinders will attach to the canister centre section as will a harness/BCD support and a single, cordura covered CL will plug into the existing CL position and be attached over the shoulders to the harness.

This configuration will allow the diver to travel with a small/lighter set.

## **Gas systems**

The set has no high-pressure (HP) hoses. It uses digital HP sensors fitted directly into the first stage. The digital HP provides content and usage/leak alarms.

The set uses the same oxygen solenoid as the Ouroboros. It is rated to over 15 bar as an interstage pressure. The regulator first stages are Poseidon Extremes with a 12 bar (approx.) over pressure valve (OPV), primarily to protect the solenoid and low pressure (LP) piping.

The LP circuit does not use conventional hoses. It uses super-flexible LP tubing with a woven protective cover with a burst pressure of 200 bar. The tubing is more resilient to UV and saltwater in long-term use than rubber. It is also lighter and more flexible.

A Level 1 system does not have any manual gas addition (bypass) valves. Levels 2 and 3 have gas injection blocks mounted on the shoulders of the harness (one each side). The block can manually inject gas into the loop. On a level 3 unit each block also has an isolating slider for the oxygen solenoid and the automatic diluent valve (ADV) should they fail in an open position.

A level 3 unit can also have an off-board gas connector (Swagelok) fitted to each block. This system is unique in that it not only allows off-board gas to be injected manually but it also routes it through the automation (ADV, solenoid). The diluent off-board is even available at the Bailout Valve (BOV).

The BOV is integrated into the mouthpiece (which is neutral in-water). The second stage is a Poseidon Extreme. Rotating the switch selects open or closed circuit.

With a level 1 system. A 'red' alarm on the HUD will trigger a response to switch to open circuit and ascend.

With level 2 and 3 systems. The BOV is used as a 'sanity' breath system. This is especially useful in hypercapnic incidents where there is a strong desire NOT to switch off the set to an alternative bailout regulator. The 'sanity breath' allows you to assess the situation and then take the correct action.

The BOV and breathing hoses are counterweighted to offset buoyancy.

The breathing hoses are fitted to the canister head via a dual lock quick-release system, comprising a quarter-turn and a push button. The hose ends are double radial O-ring sealed. The complete mouthpiece and hose assembly can be quickly removed for cleaning as can the CL.

The diluent LP circuit is fed from the first stage through a multi-port manifold to allow connection of BCD/suit feeds etc.

The HP sensors use a 'dynamic reserve' system. On the diluent side, dependant on depth and an assumption of open-circuit breathing rate, the reserve alarm will vary. Hence in shallow water the alarm will trigger later compared to deep water, still allowing a safe ascent to the surface.

Oxygen setpoint control is also dynamic. The set can be put in 'auto-setpoint' mode (only levels 2 & 3 are selectable, level 1 is auto only). Level 1's maximum PO<sub>2</sub> is set to 1.2 other levels are selectable upto 2 bar PO<sub>2</sub>.

Upon submersion the unit will slowly increase the setpoint to the preset during the descent. Once at a stable depth the diver can select the high setpoint themselves or wait until the set automatically switches.

Upon ascent the set will remain at the high setpoint until the safety or required decompression is complete and then decrement towards the surface (reducing to 0.7) to avoid unnecessary buoyancy shifts.

The loop over-pressure valve is located in the canister base. It is also the water drain. It is unique in that it can be set on the surface for a given pressure and then irrespective of the position of the diver in the water, it will always dump at approximately the same pressure.

The cylinders in a level 1 unit are a 3l (diluent) and a 2l (oxygen). Level 2 & 3 sets come with dual 2l cylinders. As the base foot of the case is extendable (or removable) longer cylinders of a similar diameter can be fitted. As the 1st stages are free to move, almost any style of cylinder valve can be fitted. The standard valve supplied is an AP Diving cylinder valve.

### **Electronics**

The unit comes with electronics similar to the Ouroboros with a different human-computer interface (HCI).

There are two HUD's, one front and one rear. A Primary display and a Backup display (levels 2 & 3 only). There will be an option mid 2008 for an intelligent Backup display which will double as a data logger and dive computer.

All the electronics, solenoid and batteries are outside of the breathing loop.

The Primary display connects to the Core Life-Support Module in the canister head via a cable. The Primary does not contain any system control electronics and is just a display. The Core Module provides life-support and decompression status.

The HUD's, Backup display and HP sensors also connect into the Core Module.

Electronic failure of any display will not affect life-support functionality.

The HUD on a level one unit has 3 states.

Green - All OK

Amber - Your consumables are running low, slowly ascend towards the surface on closed circuit (often this alarm will go away on ascent).

Red - Perform open circuit bailout now. You will then be prompted to switch the Primary to open circuit decompression.

The HUD on a level 2 & 3 follows the Ouroboros logic and gives additional information on decompression, PO<sub>2</sub>, solenoid status and general alarms.

All HUD's have visual and tactile alarms. The tactile alarm only sounds at extreme alarm levels to reduce 'alarm blindness'.

To activate the unit the user can do so in three ways.

1. By switch on the Primary (the pre-dive sequence check-list will then automatically start)

2. By entering the water and getting to depth (1.3m approx.). A pre-dive abort alarm sound and be logged.
3. By breathing the unit on land or in the water. This final 'auto-breathe' function is the primary fail-safe. The unit will turn on when it senses breathing and provide a minimum life-support (irrespective of setpoint) of 0.4 PO<sub>2</sub>.

The Primary comes with a colour screen and the Backup display is a 3 x PO<sub>2</sub> LCD panel. Both with backlights. The VPM decompression algorithm is available as an option.

### **Pre-Dive Check-list**

The unit has a pre-dive check-list on-screen which is activated at every power up. While (in an emergency) it is possible to abort the check-list and start diving. A Pre-dive abort alarm will sound for a period and the abort will be logged in the dive log.

The pre-dive sequence is intelligent in that it knows when the filter has been removed (hence the unit has been apart) and how long it has been at the surface between dives and will adjust its' pre-dive sequence accordingly, prompting for more or less checks.

### **Oxygen Sensor Calibration and Filter in/out Detector**

The set has oxygen sensor logging (alarming when it is time for a change-out), Voting logic (with manual override on levels 2 & 3) and the ability to calibrate the cells during a filter change when exposed to air.

Positioned on the CDM there is also a filter in/out sensor. This triggers when a filter is changed or removed temporarily. This sensor alarms if no filter is present and will force an automatic air calibration of the oxygen cells in the background whenever the filter is refitted or oxygen sensors are re-connected. Exposure to ambient air must be ensured during this procedure and altitude calibration is automatic.

Calibrating on air is applicable given sensor failure modes and sensor characteristic modelling.

### **Battery Systems**

Primary power is supplied via triple-redundant Lithium-Ion rechargeable batteries. The backup display has its' own battery, charged with the main system.

Chargers are available for a range of AC and DC voltage sources (mains/car etc.) as well as emergency charge capability via a stand-alone plug in charger pack with its' own batteries (available mid 2008).

### **Canister Duration Monitoring (CDM)**

The CDM is under license from the United States Navy, who have completed hundreds of research dives to correlate the thermal wavefront within a filter and compare it with when a given millibar of CO<sub>2</sub> breaks through the filter. Further enhancements have been completed by Closed Circuit Research to show filter duration remaining as a bar graph in 5% increments. The CDM can work with all three filter mediums by simply selecting the correct filter during the pre-dive sequence.

Backup oxygen metabolism predictor software provides additional fail-safes which operate in parallel with the CDM.

### **Data-logging**

All sets are configured with full 'black box' datalogging capability of all key parameters. An optional PC link system is available.

### **Maintenance**

The set logs usage hours and will prompt for factory service. It is possible to strip the complete breathing loop down to its component parts without any tools.

As the hoses and counterlung are quickly removable, cleaning routines are simplified.