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Dual rebreathers in practice: example experiences from the Wetmules and COBRA Divers

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Abstract

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Closed-circuit rebreathers have opened new frontiers in technical diving, but rebreathers are not invulnerable and therefore a 'bailout' gas supply is required. For extreme dives, open-circuit bailout is logistically impossible. This has led teams to adopt dual rebreather configurations, where a second rebreather serves as bailout. This article presents operational experiences from the Wetmules and COBRA Divers, who independently developed dual rebreather practices for extended range diving. The teams evolved contrasting approaches through extensive field testing. The Wetmules initially adopted partially integrated configurations, sharing components between rebreathers to reduce complexity for deep dives with straightforward access to dive sites. COBRA Divers used fully independent dual rebreathers, prioritising complete redundancy for remote locations with challenging logistics. Both developed techniques to ensure the operational status of the inactive rebreather including gas content variability, buoyancy control, and fault detection. Real-world experience validated theoretical benefits while revealing additional considerations. Both teams significantly reduced open-circuit bailout requirements, enabling extended penetrations and depths that were previously extremely difficult. Key operational insights included maintaining breathable gas mixtures in inactive loops, regular integrity checks, and managing variable buoyancy. The approach introduced new challenges: increased task loading, maintenance requirements, and novel failure modes specific to inactive rebreathers, showing that equipment redundancy does not automatically enhance safety. Dual rebreathers extend operational envelopes but introduce significant complexity. Benefits include eliminating gas switches during emergencies and maintaining optimal decompression profiles. However, inactive rebreathers remain vulnerable to undetected failures and demand higher operator proficiency. The contrasting approaches - integration versus full independence - reflect different operational priorities and mission parameters. This article contributes operational experience to support informed decision-making within the technical diving community.

Introduction

Closed-circuit rebreather (CCR) diving has opened new frontiers in technical diving in terms of depth and penetration range. Alongside these CCRs, open-circuit bailout serves as a gas supply backup to a failed CCR. However, for the most challenging dives, open-circuit bailout is not an option. For example, logistic difficulties may be encountered both underwater and topside. These challenges include issues with failing cylinders or regulators in addition to the sheer number of cylinders that need to be obtained, filled, and transported to the dive site before they are even carried or staged underwater. Staging cylinders for the duration of a project risks cylinder failure that may only be detected when bailout is needed.¹ Even if it is possible to carry all the open-

circuit bailout required, it may be very cumbersome on the dive. Planning for open-circuit bailout often does not account for breathing cold, dry gas; multiple gas changes during decompression; and difficulties locating and mounting staged cylinders. Divers who wish to complete major dives without relying on their CCR as a single point of failure are obliged to dive with multiple CCRs so that they can bail out to another CCR, should their primary unit fail.

The feasibility of this approach is driven by the increased availability of CCRs. The community's experience and trust in CCRs has grown, and their advantages for gas needs, decompression comfort, and efficiency are well known. Additionally, CCRs offer degraded operation modes (such as allowing the use of additional gas sources should the

Table 1
Glossary of technical diving and CCR terminology used in this article

Term	Definition
Closed-circuit rebreather (CCR)	Underwater breathing apparatus that recycles exhaled gas by removing carbon dioxide and adding oxygen, as opposed to open-circuit systems that exhaust all exhaled gas
Open-circuit bailout	Emergency breathing gas carried in conventional scuba cylinders as backup to a rebreather
Diluent	A gas mixture added to the breathing loop to maintain volume and reduce oxygen partial pressure by diluting the oxygen, typically by using helium or another inert gas
Breathing loop	The closed circuit through which gas circulates in a rebreather, consisting of the mouthpiece, hoses, counterlung, and scrubber
PPO ₂	Partial pressure of oxygen
Scrubber	The carbon dioxide absorbent material in a rebreather
Staging (cylinders)	Placing gas cylinders along the planned dive route for use as backup gas that the diver does not carry at all times
Setpoint	The target PPO ₂ that the rebreather attempts to maintain in the breathing loop
Automatic diluent valve (ADV)	Device that automatically adds diluent to the loop when ambient pressure increases, thus decreasing the volume of the breathing loop, during descent
Constant mass flow valve	Device that continuously adds oxygen at a fixed rate
Dive-surface valve (DSV)	Mouthpiece valve that can be sealed, isolating the breathing loop when removed from the diver’s mouth
Bailout valve (BOV)	Integrated mouthpiece that allows switching between rebreather and open-circuit bailout with a single action
eCCR (electronically controlled CCR)	Rebreather that uses oxygen sensors and electronically controlled solenoid valves to automatically maintain setpoint
Penetration range	The horizontal distance a diver travels from their entry point (particularly relevant in overhead environments)
Work of breathing	The respiratory effort required to breathe from a breathing apparatus
Gas density	A measure of the density the breathing gas attains at pressure, which increases respiratory effort and CO ₂ retention risk
Back-mount	Rebreather configuration worn on the diver’s back, similar to traditional scuba tanks
Side-mount	Rebreather configuration worn at the diver’s sides rather than on the back

onboard cylinders fail, or the operation of the CCR in semi-closed mode) allowing underwater problem correction, and issues can be resolved with less haste than with open-circuit diving, reducing time pressures.

This article presents the operational experiences of two teams who dive with dual CCRs: the Wetmules and COBRA Divers. It describes the mission parameters that have driven the design decisions that each team has made, the trade-offs involved, and the insights gained. Dual CCRs offer extended range and reduced reliance on open-circuit bailout. However, they introduce additional complexity and do not necessarily

improve safety. This article examines both the advantages and the challenges that dual configurations create.

The equipment setups and procedures described reflect team circumstances – diving locations, teamwork approach, and available support. Other teams using dual CCRs will likely reach different conclusions for valid reasons. This article serves as a starting point for discussions around dual CCR use in order to increase the level of safety in the community.

Key technical terms used throughout this article are defined in Table 1.

Two paths to redundancy

Bailout CCRs significantly extend operational range and improve safety margins – but these benefits come at a cost.¹ These costs include increased maintenance demands, procedural complexity, heightened task loading, and the cognitive effort involved in switching between systems during both normal and contingent operations.

A well-maintained, actively monitored single CCR in the hands of a competent diver is highly reliable. Minor problems on a CCR in active use may be detected and resolved in a timely manner. Introducing a second CCR brings new fault pathways that are harder to detect and resolve, including:

- » Variability in gas content across CCRs e.g., through the addition of diluent, oxygen, or the use of a constant mass flow valve.
- » Changes to the ambient pressure and thus the partial pressures of gases in the breathing loop.
- » Buoyancy variability caused by gas additions or venting of inactive loops.
- » Subtle faults that may go undetected if the unit is not actively breathed - e.g. a non-functioning automatic diluent valve (ADV) on descent, slow water ingress, or a situation where an electronic CCR attempts to raise PPO₂ on ascent by injecting oxygen into a loop where gas isn't circulating, so that the sensor's oxygen reading is inaccurate.
- » Additional maintenance and preparation requirements, including duplicate scrubber management, gas logistics, and functional checks.
- » Inconsistency between primary and redundant units, potentially causing challenges when diagnosing issues or executing emergency procedures because each unit behaves differently.

These considerations drove different design priorities. The Wetmules prioritised operational efficiency through integration and simplification, accepting certain single points of failure in exchange for reduced complexity and improved usability on deep dives with straightforward access from the surface. COBRA divers have complete redundancy, accepting increased complexity to eliminate shared failure points while maintaining flexibility for autonomous diving in environments with more challenging logistics. These contrasting requirements create different mission parameters and operational constraints that have shaped each team's equipment configuration. The following sections will describe each team's setup and how it was developed in greater detail.

WETMULES – INTEGRATED BAILOUT

The Wetmules use a mix of different configurations. Multiple twin Megalodon™ (InnerSpace Systems Corp., Centralia, Washington, USA) back-mounts and a twin JJ-CCR (JJ-

CCR ApS, Praestø, Denmark) are in use. These are not fully independent, as the CCRs share some single failure points – the mouthpiece, and in some cases oxygen and diluent are shared across both CCRs. Precise configuration varies among team members. Some team members use back-mount/side-mount combinations, utilising a KISS Sidekick rebreather (KISS CCRs LLC, Fort Smith, Arkansas, USA), and twin side-mount Liberty rebreathers (Divesoft s.r.o., Roudnice nad Labem, Czech Republic).

Use of twin CCRs in the Wetmules started in 2006 when a dual back-mount CCR was constructed for experimental purposes. The setup was initially composed of two fully redundant CCRs but there followed a process of simplification over several years to make the apparatus lighter and more user-friendly. This was achieved at the cost of introducing single points of failure. These changes are considered acceptable due to the low probability of these failure points actually causing a catastrophic failure.

These changes are:

1. The use of a combination twin dive-surface valve (DSV) and open-circuit bailout valve (BOV). This integrates both breathing loops and open-circuit bailout into a single switchable valve that allows switching between breathing loops and open-circuit with a single one-handed operation. It is therefore quick and easy to test the integrity of both CCRs during the dive with minimal interruption to other tasks. It is recognised however, that failure of the mouthpiece or structural failure of the combined valve would present a very serious problem as this would compromise both units simultaneously.
2. Simplification of oxygen supply: use of one oxygen cylinder for both CCRs, with a Y- or H valve and two first stage regulators, to reduce weight and bulk.
3. Simplification of diluent supply: use of one diluent cylinder for both CCRs. This is only suitable where there is a continuous ascent to the surface - if multiple ascents in a 'saw-tooth' profile are required there should be redundancy in the diluent supply.
4. Reducing the number of displays (handsets and head-up displays). These may be reduced as far as one handset and head-up display for the primary loop and one handset for the secondary loop, to reduce clutter and confusion and simplify equipment donning.

The twin back-mount configuration is optimised for deep dives with easy access to the water (i.e., the equipment does not have to be carried far or over difficult terrain). This configuration does not have the capacity to divide the two CCRs into individual units that can be transported or dived separately. When these features are required (e.g., a long-range multi-sump cave dive), alternative configurations are used: either back-mount/side-mount or twin side-mount combinations. Figures 1 and 2 show the dual-back-mount setup from the front and back, respectively.

Figure 1

View of the front of a Wetmules setup showing the integrated BOV



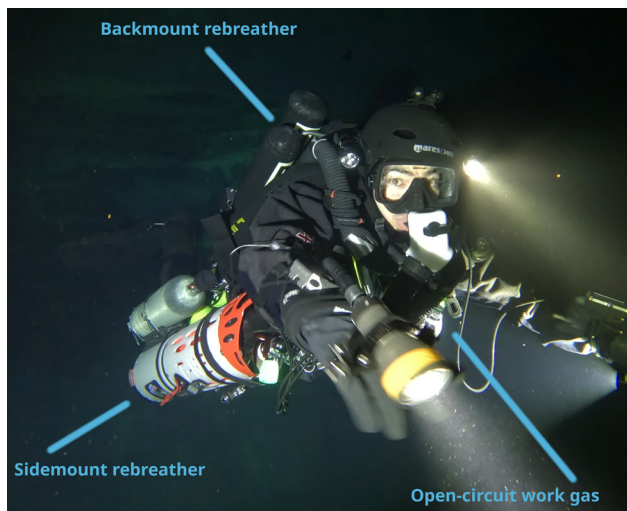
Figure 2

Rear view of the Wetmules setup showing the scrubbers and gas supply



Figure 3

Example of a COBRA setup; on this dive the side-mount CCR, mounted on the diver's right, is being used as the primary, with the breathing loop of the back-mount CCR stowed under the diver's chin. Open-circuit gas used for work purposes and as an emergency gas to transition between CCR loops is mounted on the diver's left



The Wetmules have a less integrated approach than COBRA, it being left to individual divers to determine the configuration that fits their individual requirements and those of the mission at hand, although with plentiful discussion and mutual review. However, in many cases an innovation made by one team member has been adopted generally by others.

COBRA DIVERS – FULL INDEPENDENCE

The COBRA divers use a mixture of platforms, including SF2 (ScubaForce, Mönchengladbach, Germany), JJ, rEvo® (rEvo BVBA, Brugge, Belgium), and side-mounted Liberty, T-Reb® (Other Gravity, Piaseczno, Poland), KISS Sidekick, and a custom build. An example of a typical setup is shown in Figure 3.

COBRA divers began using dual CCRs when it became clear that open-circuit bailout was becoming logistically impossible for their diving objectives. This was driven by the remoteness of many dive locations where sufficient gases for open-circuit bailout are unavailable, and the impracticality of carrying sufficient bailout to complete decompression obligations on extended range dives. Unlike some teams with dedicated support, COBRA divers operate autonomously - carrying, staging, and donning all equipment themselves, often setting up from vehicles or improvised staging areas near dive sites. This setup allows staging CCRs individually and donning the side-mount CCR in water unassisted.

The team prioritises complete independence between CCRs. Each unit maintains fully separate gas supplies, loops, and electronics, with no shared components that could introduce single points of failure.

The evolution of COBRA's dual CCR practices occurred through systematic experimentation. Initially, the team explored side-mount CCRs as bailout units, some of which lacked onboard diluent supplies and required gas from bailout cylinders. Operational experience showed this to be impractical because it required time-consuming steps between entering the water and descent. Consequently, the team transitioned to fully independent CCRs, each with integrated diluent and oxygen supplies.

When diving with dual CCRs, the team uses a combination of back-mount and side-mount. With few exceptions, both units are eCCRs. During a typical dive, the same diluent gas mixture is used in both CCRs, and decompression is tracked via an independent computer rather than relying on the decompression calculated by one of the CCR controllers.

Equipment selection has been optimised for work of breathing and operational requirements. Where necessary, CCRs needed modification. Constant mass flow valves were removed from some units to prevent oxygen accumulation in inactive loops. The team standardised offboard gas connectors across all platforms to ensure compatibility. This makes it possible to connect any cylinder used on the dive with any of the CCRs used. On a given dive, one of the CCRs will be primary, but the primary varies between dives as the team maintains equal proficiency with both units. Each CCR has its own handset and heads-up display, ensuring independent monitoring and control of both systems. For COBRA divers, dual CCRs have become standard practice for dives requiring more than one bailout cylinder, as a second CCR provides comparable mounting complexity to a stage cylinder but superior performance underwater.

Design decisions undergo team review and testing. Often members adopt improvements that have proven effective through in-water evaluation, creating a process of convergence without an explicit desire for standardisation. Pre-dive briefings review equipment configurations when changes have been made, ensuring the team is familiar with each other's setups.

Pre-dive procedures require additional steps compared to integrated systems. Following community guidance,² COBRA divers employ challenge-and-response checklists to verify readiness of both units before entering the water. Final gear configuration is typically completed in water. This costs time and procedures must be adapted to the environment, for example to tight cave or mine entrances. The full independence of the units adds steps to in-water procedures; for example, switching loops requires closing the active mouthpiece, switching to the backup loop, and

purging and opening its mouthpiece – a sequence requiring multiple seconds and careful execution. It is essential that this can be performed with high workloads, such as when managing other equipment such as diver propulsion vehicles.

Unlike stage tanks with fixed gas mixture and buoyancy, CCRs have variable gas content and volume that shift throughout the dive. While functionally advantageous, this variability is procedurally hazardous as the system could add gas unsupervised or contain unbreathable mixtures. COBRA divers designed procedures to maintain bailout CCRs in a known, safe state throughout the dive. The objective is maintaining the setpoint in a breathable range (0.5–1.3 bar) by flushing the loop with diluent during descent once the diluent's PPO₂ exceeds the low setpoint. This prevents electronic oxygen injection, avoids buoyancy fluctuations and maintains stable loop composition. Only diluent addition is needed to maintain loop volume. During ascent, the team switches to the bailout CCR when its PPO₂ approaches the low setpoint and manually raises the PPO₂ to the high setpoint, preventing the addition of oxygen while gas isn't circulating. These practices restore the predictability of open-circuit systems without sacrificing the CCR's performance advantages.

The secondary CCR can become unusable without detection. The COBRAs mitigate this risk by maintaining a breathable gas mixture by regularly monitoring the PPO₂ of both CCRs with equal vigilance and verifying loop integrity at critical points during the dive. These integrity checks are performed by briefly switching onto the secondary unit and breathing it to circulate the gas. This is done when the PPO₂ approaches the edge of the acceptable range, and prior to work to ensure periodic validation at a static depth. This leads to a minimum of the interaction points shown in the example in Figure 4, which is a controller output from a shallow cave dive.

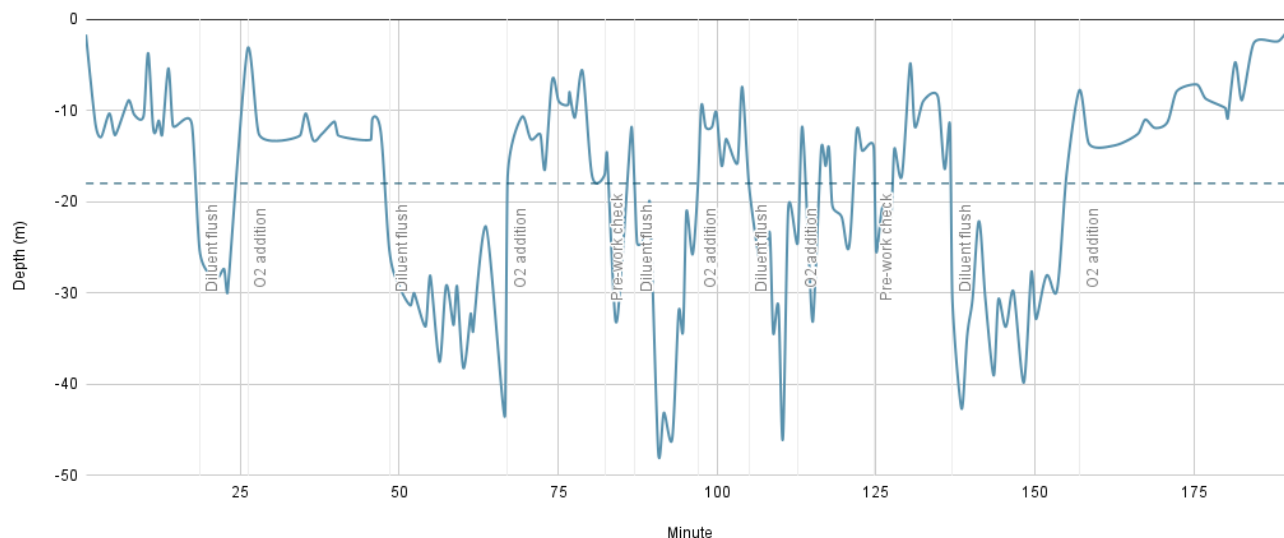
Operational experience

Both teams have developed sufficient confidence in their dual CCR systems to significantly reduce open-circuit bailout requirements. Where previously four or more bailout cylinders were carried – which may still be insufficient for complete decompression – current practice involves carrying only one or two open-circuit bailout cylinders.

The approach has proven effective in actual contingency conditions. During one incident on a dive several kilometres into a cave, it was necessary to bailout from the primary CCR at a depth of 60 m. The procedures had maintained a breathable gas mixture in the secondary unit, and the switching procedure functioned correctly despite the stress of an unplanned problem. This real-world test confirmed that the procedures function effectively under actual emergency conditions.

Figure 4

Example log showing minimal interaction points with secondary CCR; these occur on descents and ascents, and before critical points, e.g., before working or traversing restrictions. Dashed line depicts depth where PPO₂ of diluent gas exceeds low setpoint. The primary CCR is using its high setpoint except for the descents and the last decompression stops, where the PPO₂ is controlled manually



Lessons learned

This article describes techniques adopted by two teams using dual CCRs for challenging dives. While both teams solved similar problems, their solutions reflect different operational priorities - the Wetmules optimised for deep diving efficiency through integration, while COBRA prioritised redundancy and portability. There are advantages and disadvantages to each setup. These experiences are shared to make it easier for other teams to decide if and how they should adopt the use of multiple CCRs in their dives. To that end, this section examines what makes the use of multiple CCRs unattractive – what problems multiple CCRs do not solve, and what problems they create.

The practices described in this article represent highly specialised techniques developed by experienced teams and should not be interpreted as instructional material. Dual CCR diving demands the highest level of CCR competency. Divers must demonstrate absolute mastery of each individual CCR unit before attempting dual configurations, all foreseeable failures should be manageable in-water under high task load, without requiring extensive conscious thought. This capability must be second nature. Environmental challenges such as cave or wreck penetration add substantial task loading and should be mastered separately before being combined with dual CCR complexity. The absence of formal training pathways or mentorship for these techniques reflects their pioneering nature; divers considering dual CCR configurations must recognise they are developing expertise in an area where established standards do not yet exist.

The Wetmules and COBRAs dive with multiple CCRs while acknowledging that a second CCR itself brings its own risks.

These include:

- » Variability of the state of the CCR and breathing loop, producing additional workload and possibly breathing inappropriate gas mixtures.
- » Rendering the CCR inoperable due to user error.
- » The CCR failing in an undetected and unrecoverable manner.

In addition to the task loading demands that bailout CCRs place on their users, bailout CCRs are often used in contexts with a high workload. This means that high proficiency is needed for all tasks necessary for both safe and successful completion of the mission. Certain practices that have proven useful in addressing these aspects of dual CCR use are set forth in Table 2.

With the use of bailout CCRs, other challenges have a higher impact due to the greater depth and range achieved by the dive team, such as navigation, temperature, and oxygen toxicity. Also, a second CCR does not mitigate hypercapnia due to respiratory insufficiency endogenous to the diver.³ This risk of respiratory insufficiency must be mitigated by lowering gas density. In this area, the limitations of helium have led to experiments of using hydrogen in diluent.⁴ In short, pushing the boundaries using a second CCR quickly reveals new boundaries that must be overcome in different ways if divers wish to continue diving deeper or farther.

In the cases of the Wetmules and COBRA divers, the use of dual CCRs has provided vast benefits without causing adverse outcomes. However, it must be acknowledged that the absence of adverse events does not mean that these practices are ‘safe’. Nevertheless, it is the hope of the authors that sharing these experiences will help divers

Table 2

Risks that arise when using multiple CCRs above and beyond the risks associated with deep and extended range diving, and practices that have proven useful for both teams to mitigate these risks

Status	Risk	Mitigation
Mitigation in place	Non-active rebreather condition deteriorates unnoticed	Check rebreather frequently during logical activity points. Event-rather than time-based triggers are more preferred.
	Unbreathable gas mix in non-active unit	Use procedures to keep the mix in the second unit breathable, checking regularly, at a minimum at critical points in the dive.
	Decompression calculation errors due to different setpoints in each rebreather	Use an independent computer for decompression with a fixed setpoint matching what is breathed.
	User error renders non-active rebreather inoperable	Practice and drill with critical feedback to reduce operator error in nominal and contingency operations.
Risk tolerated	Failure of both rebreathers	As in open-circuit bailout, failure of both the primary and secondary rebreather is catastrophic. The likelihood of this risk materialising is considered sufficiently low that the risk is tolerated.
	High procedural complexity in bailout scenarios	A second rebreather does not help - bailing out is a complex activity, independent of what type of bailout system is used
	Issues arising from gas density and work of breathing	A second rebreather does not help and may be inferior to open-circuit due to the additional work of breathing imposed by the closed-circuit breathing system.

who are considering closed-circuit bailout to make more informed decisions.

Conclusions

The use of dual CCRs in technical diving is becoming increasingly common as the community pushes operational boundaries beyond what would be possible with open-circuit bailout. This evolution opens new frontiers in underwater exploration but simultaneously introduces new challenges.

It is valuable to anticipate problems arising from introducing significant changes to the dive system, and test these systems under low-risk conditions. This methodology surfaces issues emerging from the integration of equipment, team, and the real environment, allowing for adaptation before use in exploration. An iterative approach, combined with extensive practice, has proven effective. The cycle of diving, learning, adapting, and repeating should be constant - perfection is neither expected nor achievable.

Looking forward, CCRs will likely become increasingly accessible, providing scope for these techniques to become more widespread. As dual CCR use increases within the technical diving community, the development of training frameworks and standardised procedures remains an unfilled gap for the broader CCR training ecosystem. Dual CCR adoption should proceed thoughtfully and cautiously, with appropriate recognition of the additional complexity and risk factors involved.

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