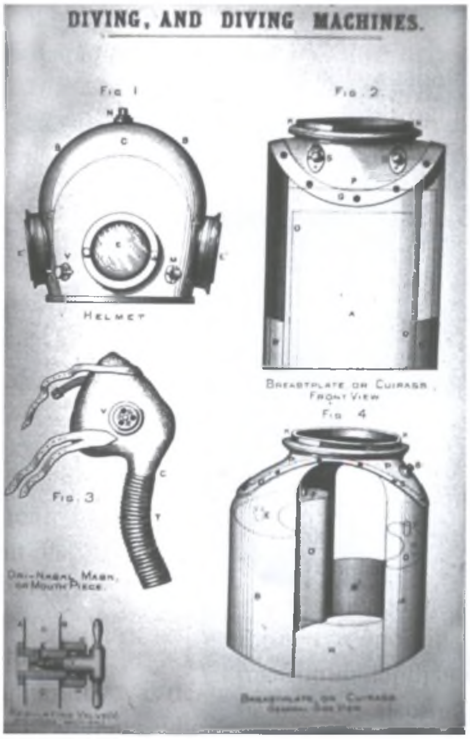
O_2 under H_2O
THE FLEUSS APPARATUS
A short history of the re-breather
By Peter Jackson

With the current new wave of interest in the re-breather, this seems an appropriate time to look back at the history of its development since 1879, when the principles were put into practice by Henry Fleuss.

Henry Fleuss

Fleuss was born in England in 1851 and planned to make a career in engineering but, at the age of sixteen, ran away to sea and joined the merchant marine, eventually becoming an officer with the P&O Company. In 1875, he watched diving operations being carried out in a harbor in Ceylon and became interested in the possibility of making the diver independent of his surface supply. A few weeks later, he was searching in a Calcutta book shop for information which would help him, and bought some books on physiology and chemistry, which he studied in his spare time.

From his studies Fleuss learned that in respiration, oxygen is consumed and carbon dioxide is produced. He reasoned that if the diver could carry with him a supply of oxygen and alkali, which would absorb the carbon dioxide, the diver could dispense with the supply of air from the surface.



First Diving Dress

Fleuss left the P&O Company in 1878 and set about putting his ideas into practice. He proved to be very resourceful, making much of the equipment himself, including his own means of producing and compressing oxygen. He was also young (27), energetic and confident, and he tested his apparatus on his own, underwater. In 1879, he tried out his new apparatus in the diving tank at the London Polytechnic, where he was observed by the eminent physiologist Benjamin Ward Richardson. Richardson took a keen interest in the invention and, with Fleuss' co-operation, conducted a number of tests to establish its effectiveness, both underwater and in poisonous atmospheres.

Richardson was clearly impressed by Fleuss and saw great potential in his invention. He wrote a number of papers on the subject and, in May 1880, gave a lecture to the Royal Society, at which Fleuss was present to demonstrate the apparatus in a chamber filled with poisonous gas.

The apparatus consisted of a standard diving dress with helmet, weights and lead soled boots. The copper helmet was made with a double wall, the space between forming a reservoir with a volume of about 1/4 cu. ft. This was charged with oxygen to a pressure of 16 atmospheres by means of a hand pump, and could thus hold about 4 cu. ft. of gas. A screw valve located at one side of the front window, allowed the diver to admit oxygen into the helmet and also facilitated charging the reservoir with oxygen. A screw plug in the crown allowed the reservoir to be purged of air. The double walled helmet was complicated in its construction and must have been very difficult to manufacture.

The jacket, as Fleuss called it, was also a complicated assembly. It was comprised of an ordinary breastplate to which were affixed two metal chambers. One at the front and one at the back. These were joined around the sides by two metal plates, one of which could be removed to allow the diver to get into it. Each chamber was fitted internally with a vertical division and a perforated false bottom, and also had a removable lid with two short pipes attached. The chambers were filled with small pieces of rubber sponge soaked in a very strong solution of caustic soda.

The diver wore a leather mask which covered the nose and mouth. It also had inlet valves in the sides and a flexible hose at the front which led to one of the pipes on the lid of the front chamber. He inhaled from the helmet and exhaled into the front chamber, where his breath passed down one side of the division, through the false bottom, and up the other side. A flexible tube, leading over the shoulder, connected the outlet of the front chamber to the inlet of the back chamber so the exhaled air passed through this. It finally returned to the helmet via a non-return valve. The diver's dress itself was flexible and acted as the counterlung.

First rescue apparatus

There were clearly deficiencies in Fleuss' apparatus, notably the lack of any control over the partial pressure of oxygen in the system. It was intended that the oxygen valve should be adjusted to give the correct flow and would then require little attention so there was, at least, a continuous supply.

Soon after testing his diving suit at the Polytechnic, Fleuss developed an apparatus for use in fires and mine rescue operations. It was of a much simpler and more practical design than his diving dress and was carried on the back like a knapsack. It consisted of a tinplate box, 12 inches square and 4 inches deep, which housed the alkali chamber. This was made from vulcanite with a perforated false bottom and three vertical divisions. A vulcanite lid, sealed with a rubber gasket, was clamped in place by metal rods which passed through holes in the outer box. The lid had connections for the breathing tubes and for the breathing bag which, in the first model, was mounted on the back of the metal box.

Two formed tubes led over the shoulders to a junction piece containing non-return valves, from which two short corrugated hoses led up to a full face mask. Attached to the bottom of the box, at waist level, was a copper cylinder, 12 inches long and 6-1/2 inches in diameter, containing 4 cu. ft. of oxygen at a pressure of 16 atmospheres. A valve at one end of the cylinder allowed for control of the oxygen and was connected, via a copper pipe, to the inhalation tube.

Fleuss soon modified the apparatus and moved the breathing bag from its exposed and vulnerable position on the back, putting it on the wearer's chest. The non-return valves were placed at the connections to the lid of the alkali chamber and he fitted two corrugated hoses over the shoulders and into the sides of the facemask, giving the wearer much greater freedom of movement. The new apparatus was demonstrated to several mining and engineering institutions, where it attracted a great deal of interest and support. At the recommendation of experienced mining men, Fleuss added a heavy copper cowling to protect the valves and hose connections at the top of the alkali chamber.

An opportunity to prove the worth of the new rescue apparatus came in June 1881, at the Seaham colliery, where an explosion in September of the previous year had killed 164 men and caused so much damage that the pit had remained closed ever since. Using Fleuss' apparatus, investigators were able to re-enter the mine and his equipment played a major part in its eventual reopening. In April 1882, the apparatus was used in the rescue of 10 men trapped after an explosion at Killingworth.

Fleuss was also still promoting his self-contained diving dress and was forced to make a second model when the original was lost in an accident in June 1880. The new model used his successful knapsack arrangement, adapted for use with a standard diving dress, and was altogether much simpler than the double helmet and metal jacket of the original. The alkali chamber was housed in a metal case with a heavy lid secured with screws and wing nuts. Two copper pipes with brass unions attached the case to connections on the breastplate. The copper cylinder, with its screw valve, was fixed to the bottom of the case and had loops attached, through which passed a leather belt. The diver wore a leather mask as before, with the exhalation tube connected to a short pipe extending into the helmet from one of the corselet (breastplate) connections. The helmet was of a standard pattern but had no air hose connection and, as far as is known, no exhaust valve. This was the apparatus used in the famous Severn Tunnel incident.

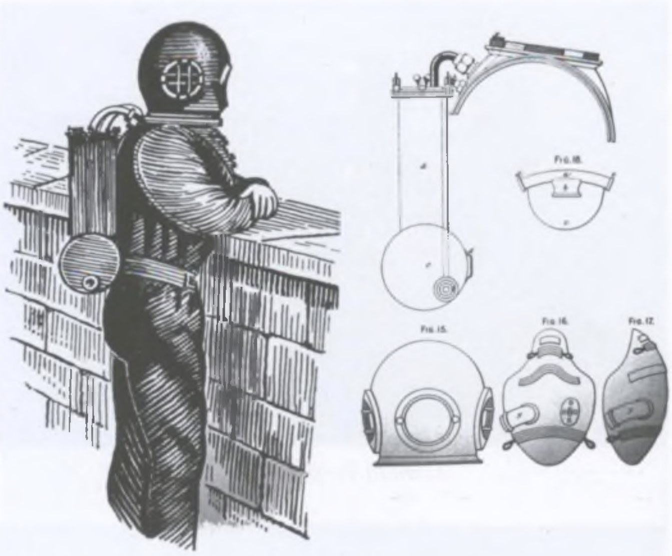
During the construction of a railway tunnel under the river Severn, a spring was struck and the tunnel began to flood. The escaping workmen failed to close a watertight door and the tunnel eventually filled up with water to a depth of about 40 feet. The open watertight door was 1020 feet along the tunnel and attempts to reach it by a diver in standard dress had failed due to the impossibility of dragging the necessary length of air hose behind him.

Seaham Collery 1881

Fleuss was called to the scene with his diving dress in November 1880 and made a number of attempts, in total darkness, to reach the door. He had never been underground before and was not familiar with his surroundings or with the obstacles he encountered, and failed to go much further than about three hundred feet into the tunnel. Siebe Gorman's famous diver Alexander Lambert made another attempt, using Fleuss' apparatus, and succeeded in reaching the door, closing a sluice and uprooting one of the tram rails passing over the sill of the door. He was gone for an hour and a half. On a second excursion, he succeeded in closing the door and the tunnel was eventually pumped out and construction resumed.

In spite of the publicity that Fleuss gained from this incident, little more progress was made with his diving dress, perhaps because much of his time was taken up with the rescue apparatus, which was attracting so much interest. This, however, also failed to become a commercial success for him and Fleuss eventually moved into other fields of interest. It was not until 1902, when Robert Davis invited Fleuss to collaborate with Siebe, Gorman in developing his rescue apparatus commercially, that success for his invention was finally on the way.

The Fleuss-Davis Apparatus had a chest mounted breathing bag, divided internally into front and rear sections by a vertical partition reaching to within an inch or so of the bottom, which was filled with sticks of caustic



Second diving apparatus

soda to about 5 inches deep. Two non-return valves at the top corners of the bag led one to each compartment, such that the wearer's exhaled breath passed into one compartment and filtered through the bed of caustic soda into the other compartment, from which it was inhaled. A steel cylinder, fitted with a screw valve, contained 6 cu. ft. of oxygen at a pressure of 120 atmospheres, and was slung across the small of the wearer's back.

Fleuss-Davis apparatus

The whole apparatus was robust, simple and reliable and was well suited to use in the mines. Further improvements were made, including the addition of a pressure gauge and a regulator which supplied a constant flow of oxygen to the breathing bag. Later, when soda lime took the place of caustic soda, a chemical cooler was added. Davis named the apparatus "Proto" and it was a successful and enduring product, adopted by mining and tunneling companies and fire brigades all over the world. It was in widespread use before the First World War and is still used in mines today.

Proto

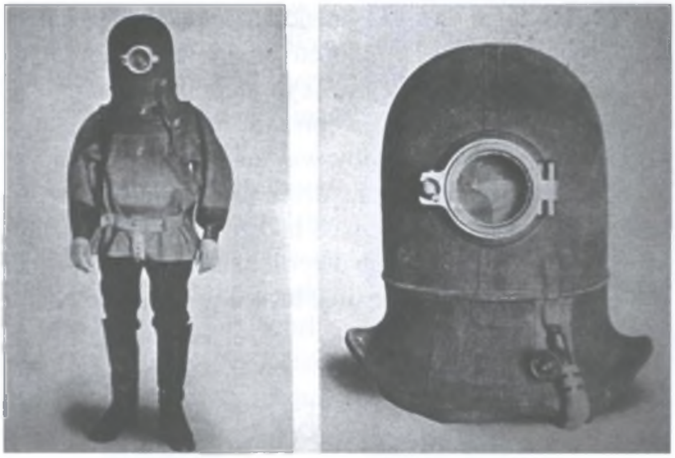
The Fleuss diving dress made a re-appearance in about 1906, modified to a semi-closed circuit with a mixture of air and oxygen stored in two cylinders below the alkali chamber and supplied at a constant rate by a regulator. The surplus gas escaped by way of a conventional exhaust valve, which gave the diver some control over his buoyancy. The old leather mask had given way to a mouthpiece and nose clip and the diver inhaled from the helmet and exhaled through a flexible tube into the alkali chamber, as before. A later development of the apparatus incorporated an injector to induce a continuous circulation of air around the breathing circuit, thus freeing the diver from the mouthpiece and nose clip.

Self-contained Diving Apparatus

The benefits of a self-contained dress, with the diver cut off from any surface support and his whereabouts uncertain, were limited to situations like that in the Severn Tunnel, where the much safer option of using standard dress was not possible. Either way, the diver was still a clumsy figure underwater, struggling on the bottom in his lead soled boots.

In the early 1900's, the increasing use of submarines and the increasing number of accidents which befell them, led to a pressing need for a simple escape apparatus which would allow a man wearing ordinary clothes to breathe underwater. One of the first of these was the Hall-Rees apparatus of 1906, which was, however, still very much a diving suit, complete with metal helmet and, with the addition of weights and lead soled boots, was used as such for shallow work. The Williamson brothers equipped the divers of the Nautilus with this apparatus in their 1916 film version of Jules Verne's classic story *Twenty Thousand Leagues Under the Sea.*

The Hall-Rees apparatus was very simple and used a canister containing granules of potassium peroxide, which liberates oxygen on contact with the moisture in the wearer's exhaled breath. The by-product of this reaction is alkaline which thus absorbs carbon dioxide. This



Hall-Rees escape apparatus

Human Torpedo

simple system works well and is still used in miners' escape apparatus. The use of potassium peroxide underwater, however, wasn't without problems, as it could catch fire if too much water got into the canister. It would also burn your fingers if you handled it.

Whilst the Hall-Rees apparatus was enjoying its brief adoption by the British submarine service, Draeger was working on a more compact apparatus, the Tauchretter, which was in service in German submarines by 1913. It was not unlike the Fleuss rescue apparatus, but reversed, with the breathing bag on the back and the cylinder and alkali canister on the front. It was also complicated in its construction.

Tauchretter

The Davis Submarine Escape Apparatus (DSEA) was introduced in the 1920's and adopted by the submarine services in many countries. It was a neat and simple development of the Fleuss apparatus, with a breathing bag mounted on the chest and a small cylinder of oxygen slung below it. A soda lime canister, housed inside the bag, was connected by a single breathing tube to a mouthpiece, which was fitted with a tap to close off the tube and preserve the soda lime.

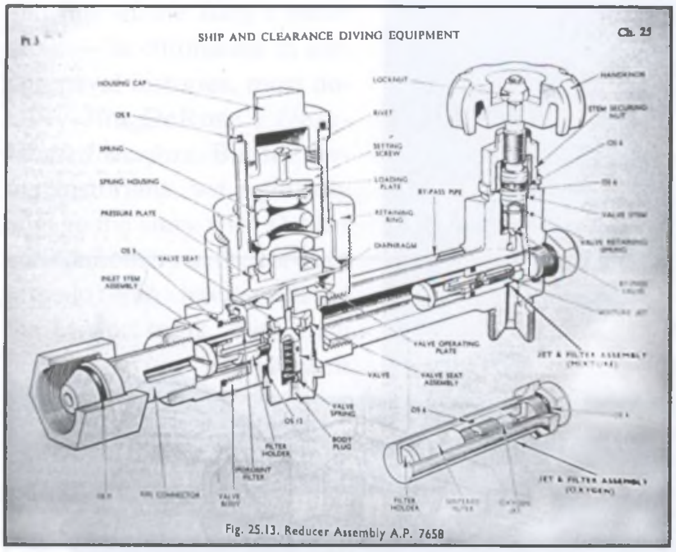
The Davis apparatus allowed the wearer to move about freely, not only inside the submarine but also under the water, and this was to lead to an unexpected turn of events. The life-saving apparatus was about to become the means of waging a new kind of submarine warfare.

The military potential of the Davis apparatus was developed during the Second World War by the Italians, who adapted it for use with manned torpedoes. The British, smarting from the success of this new Italian weapon, soon followed with their own developments and, among all the activity, the frogman was born and diving changed forever. Equipped with fins, streamlined and neutrally buoyant, the new diver was silent, swift and free but, breathing pure oxygen, he couldn't go deep.

Frogmen in Davis Submarine Escape Apparatus

A great deal was learned during the war about oxygen poisoning, shallow-water blackout and other problems attendant on oxygen diving, resulting in new and improved apparatus being developed. Some utilized the semi-closed circuit principle, where an oxy-nitrogen mixture is fed into the breathing circuit by a constant mass flow regulator, the small surplus of gas escaping continuously through a relief valve. This arrangement, whilst simple and reliable, also had its limitations. The gas mixture and flow rate had both to be pre-selected according to the maximum depth of the dive and the wastage of gas limits duration and prohibited economic use with helium, thus restricting the maximum depth at which the apparatus could practicably be used. It also made bubbles which limited its military applications.

It was the new science and technology of solid-state



CDBA Regulator

electronics which made possible the fully automatic closed-circuit diving apparatus, in which the partial pressure of oxygen in a diluent gas, such as helium, could be constantly monitored and corrected according to consumption and depth. The re-breather finally grew up when diving entered the electronic age.

The Author. Peter Jackson is a self-employed engineer specializing in the design and manufacture of diving, fire-fighting and industrial breathing apparatus. He has been continuously engaged in this field since joining Siebe Gorman's experimental department over 30 years ago. His research into the history of Sir Robert H. Davis' Deep Diving and Submarine Operations was published in issue No. 6 and he is the editor of the "Do It Yourself Diver" column that frequently appears in **Historical Diver**. He presented a paper on his research into the Fleuss Mask at the 1996 Tek Conference in New Orleans and was the recipient of the HDS-USA's 1996 E.R. Cross Award, which he received from Hans Hass. Peter is the UK Representative for HDS-USA.

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