Trans IMarE, Vol 101, pp 161–170

The history of commercial, military and sport diving

Sir John Rawlins

SYNOPSIS

Probably man learned to dive soon after he learned to swim – in order to harvest food from shallow water. The recorded history of diving goes back some 5000 years. The earliest divers used the same breath holding techniques that are employed today by the Ama, the famous diving women of Korea and Japan, and the pearl divers of the Indian Ocean – and by innumerable spear fishermen the world over.

There was an obvious advantage in being able to prolong the stay underwater, and over the centuries many and various solutions to the problem were proposed. Alexander the Great is said to have gone down in a diving bell at the siege of Tyre in 328 BC, and much remarkably successful diving was done on the open bell principle from the 16th Century until the recent past, mainly for treasure recovery but also for underwater construction. But bell diving remained relatively static: what was needed was a means of allowing a diver to stay under water and walk or swim.

Early attempts to achieve this goal were frustrated by a lack of knowledge of physics and physiology. Nevertheless some weird and wonderful devices were proposed. During the 18th century successful solutions to the problem began to appear, based upon trial and error initially, but increasingly taking advantage of the growing understanding of science and engineering.

Military requirements and the prospects of immense rewards for salvage gave impetus to the development of diving techniques, and in the last 20 years the offshore oil and gas industry has resulted in diving to a depth which only 40 years ago would have been deemed impossible.

Now, perhaps, the wheel has turned full circle. Diving is becoming too difficult and too expensive. The future of seabed exploitation probably lies with remotely controlled devices and submarines.

Diving has an ancient history, for life evolved in the sea and in a comparatively short space of geological time animals had evolved that sought their living beneath the surface of the sea, while depending on the oxygen of the atmosphere for life support. Such creatures are divers in the definition to be used here; those that derive their oxygen directly from their watery environment are not.

I suppose the first true diving creatures were the marine dinosaurs and the archaic crocodiles and turtles, whose living descendants are the crocodiles, alligators and turtles and the marine iguanas of the Galapagos. And for those who choose to believe in the Loch Ness and other lake monsters, remember that they too have to come to the surface to breathe! Incidentally the archaic crocodiles and turtles were contemporaneous with the dinosaurs, yet the dinosaurs vanished while others persisted and very little changed. None of the palaeontologists seem to have considered this point. Of course today's marine mammals, a fascinating group, come in various shapes and sizes. Some are graceful in their environment, some distinctly less so, and the one we are specifically interested in – man – is often distinctly ungainly and liable to be brushed aside.

Probably man learned to dive as soon as he learned to swim – in order to harvest food from the shallow waters. The recorded history of diving goes back over 5000 years and in that time a mighty harvest of food and wealth has been reaped. In 3000 BC carved ornaments from Thebes incorporated mother-of-pearl, which could only have been obtained in quantity by diving. By 2500 BC Chinese divers were bringing up pearls for their Emperor. And Homer, writing about 1000 BC, refers to the extensive use of sponges. Greek sponge divers are still operating today.

Surgeon Vice-Admiral Rawlins joined the RNVR in 1947 and served for 2½ years on *HMS Triumph* in the Mediterranean, during which time he designed and built a diving apparatus and taught himself to dive. In 1951 he transferred to the RN and was appointed to the RAF Institute of Aviation Medicine where he was responsible for the development of the Anti-G suit, the Mk 1 Protective Helmet and the Flight Deck Communication System. In 1956 he commenced work on the problem of escape from sinking aircraft, which entailed underwater seat-ejections in 40 ft of water, achieving through-water velocities in excess of 34 ft/s and culminating in the introduction of an automatic underwater escape system for RN aircraft.

Following 3 years as PMO of *Ark Royal* he was seconded to the US Navy for work on thermal protection of divers in the Sealab 111 Program. After returning to the UK he commanded the Institute of Naval Medicine (1975) and in 1977 became Medical Director-General of the Navy. On retirement in 1980 he became President of the Society for Underwater Technology Inc and Chairman of Trident Underwater (Systems) Ltd, and General Offshore Corporation (UK) Ltd and a Director of Diving Unlimited International Ltd.

Honours and awards include the MBE (1955), OBE (1961), KBE (1979) and various national and international medals, prizes and Fellowships. In 1964 he was the Navy's 'Man of the Year'.

Those early divers took a deep breath and plummeted to the bottom, often weighed down by a stone. The same technique is used today by some of the Ama (the celebrated diving women of Korea and Japan) who have been plying their trade since at least the 4th Century. All they have by way of equipment is a pair of goggles, a bag to put their catch in and a knife to prise off abalone. They swim down to 20–30 feet and spend about 15 s on the bottom. When they surface they hang on to a float for about 30 s, then take a deep breath and dive again. Generally they average 60 dives an hour.

Other Ama, known as Funado, dive from a boat and go much deeper (60–100 feet) and spend 30 s on the bottom. In order to do this they use a weight to take them down, and a male assistant pulls them up with a rope at the end of the dive. The reason, of course, that the Funado can go deeper is that they are not swimming down and up, and so can make the oxygen in their lungs and tissues last longer. There are some 30 000 Ama still operating today.

The pearl divers of the Tuamoto Archipelago use a similar technique and make repetitive dives of 100–120 feet for a 6 h working day.

The desire to be able to prolong one's stay under water was prompted by both commercial and military goals, and many weird and wonderful devices have been proposed. Aristotle described a diving bell in which Alexander the Great is said to have gone down at the siege of Tyre. A delightful illustration in a 13th Century manuscript shows him in a glass barrel, brilliantly illuminated by two inverted candles, a very cheerful octopus, two sea-dogs, a marine sheep and Mr and Mrs Neptune!

Much successful diving was done on the bell principle, from the 16th Century until the recent past. The first detailed account was of a bell designed by Lorena in 1531 in which he conducted a survey of Caligula's treasure ships, sunk in Lake Nemi, and in which he claimed to be able to stay for 1 h under water. The bell was made of metal with a glass window, just large enough to contain the upper part of his body and supported partly from the surface and partly by a yoke resting on his shoulders. The bell enabled him to move across the bottom, and must obviously have been replenished with air. But the technique of design was kept secret.

Another successful bell, reminiscent of an hour-glass, was devised by Tartaglia in 1551 (Fig 1). A model was recently constructed and was successfully demonstrated off the Californian coast.

A bell, by Kessler in 1616, was ballasted by a metal ball, looking like the clapper of the bell. However, it is improbable that it was ever used, for if its negative buoyancy was so small that the operator could walk the bell around, it was obviously in great danger of capsizing and drowning the occupant.

However, a one-man bell used to salvage some of the guns of the Spanish galleon which sank in Tobermory Bay, Scotland, was of the type used successfully to salvage the guns of the *Wasa*, the pride of the Swedish Fleet, which sank near Stockholm in 130 feet of water in 1660. She was raised some years ago and can be seen, in all her glory, in Stockholm Harbour. A similar bell can be seen at St. Augustine, Florida, where it was used in salvage attempts on treasure ships driven onto Florida's treacherous reefs.

The diving bell is perfectly sound in principle (although some of the deeper operations must have been attended by decompression sickness) and most of the successful salvage operations over some 300 years were achieved with various versions of the bell. In England, one of the world's most famous treasure hunters, Sir William Phipps, contrived in 1680 a diving bell with which he recovered treasure to the value of £200 000.

The early bells generally relied upon the air which they took down from the surface to furnish a supply for the occupants. What was needed was a regular supply of fresh air – and a means of getting rid of the foul air.

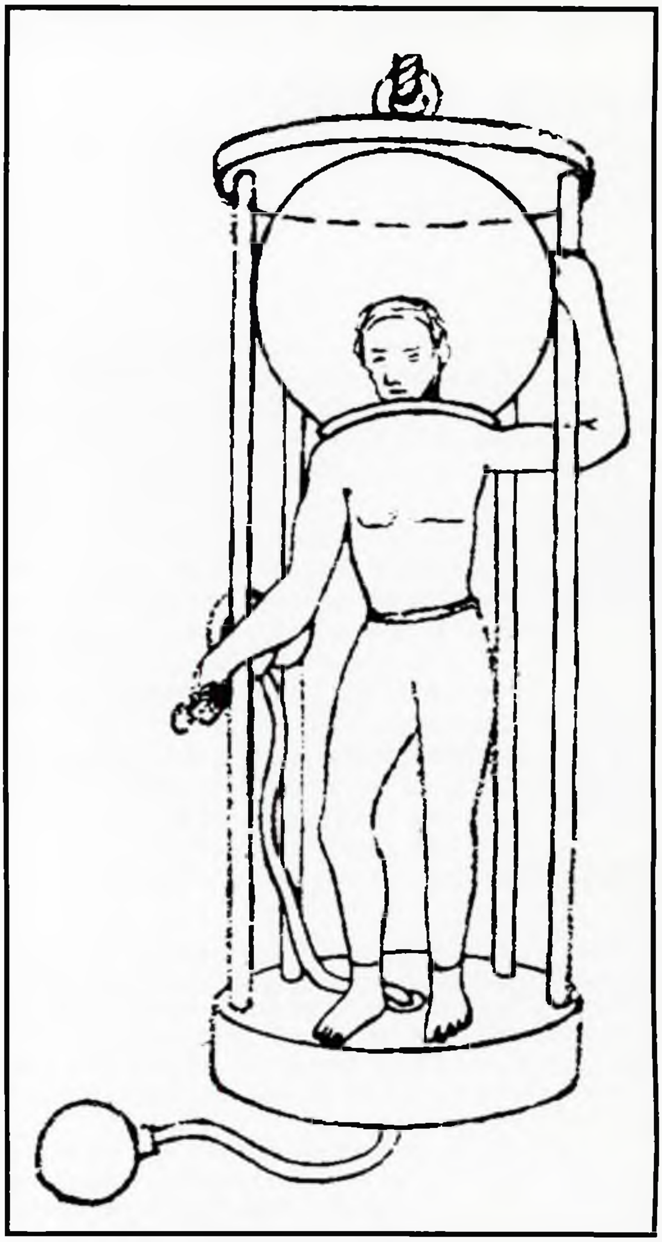

Fig 1: Tartaglia (1551)

In a bell designed by Halley – he of the famous Comet – air was sent down in a lead-lined barrel which had two bung-holes, one at the bottom which was open to the sea, and another at the top connected to a leather hose which was weighted so that it always hung below the level of the barrel, so that no air could escape. On arrival at the bottom, the occupants of the bell hooked the hose up inside – whereupon the water pressure, acting via the bottom hole, forced the air up into the bell. The foul air could be released by a tap in the top of the bell. Halley recounts that he and four others were able to stay for 1.5 h at a depth of 60 feet without discomfort.

Later bells were supplied by an air pump at the surface – as was the bell which was designed by my great-great-grandfather, John Rennie, in 1812 (Fig 2). Sir Robert Davis, whose classic work 'Deep Diving and Submarine Operations'[1] has been reprinted, comments: "Subsequent improvements have not involved any alteration of consequence in the design of the ordinary pattern of the bell".

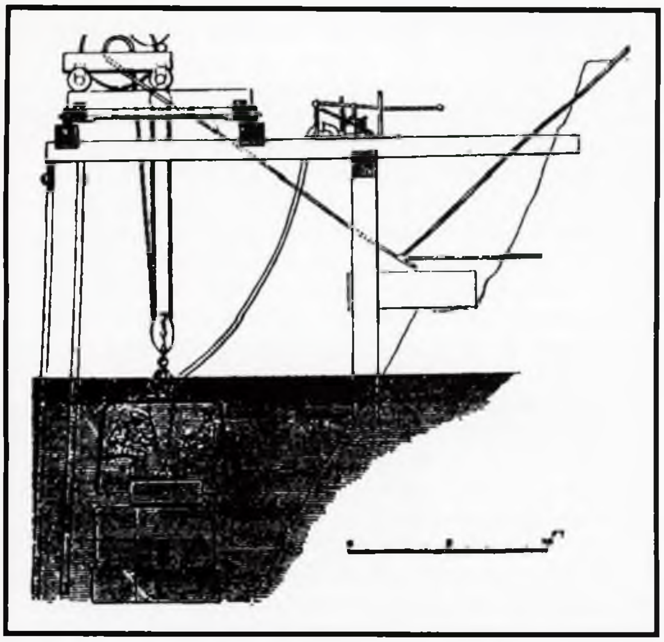

Fig 2: Rennie's bell (1812)

Of course the disadvantage of the bell is its lack of mobility, even though Rennie's bell was capable of some degree of movement through being suspended from a travelling hoist on an overhead frame. But what was needed was a means of allowing a diver to stay underwater and walk or swim.

The notion of a simple pipe to the surface probably had its origin in a military stratagem. Herodotus, writing about 460 BC, refers to the famous Greek diver Scyllias, who was employed by the Persian King Xerxes to bring up sunken treasure. Xerxes refused to let him return to Greece but he escaped and on his return taught his daughter Cyana to swim under water using a breathing tube.

There are many references to the use of tubes, usually cut reeds, being used to enable people to elude their enemy by hiding under the water. According to Mauricino the Slav, people of 1000 years ago resorted to such a device, lying on their backs in shallow water and breathing through a long reed.

Since the principle of water pressure was not appreciated, it is obvious that early designs of diving equipment would merely involve lengthening the tube to the surface. There is a typical illustration in an anonymous manuscript of 1430: Leonardo da Vinci (ca 1500) speculated along similar lines but kept his tubes pretty short. Actually, the maximum length of the tube by which one can breathe from the surface is about 15 inches.

A design taken from an illustrated book of 1511, which purported to be a reprint of a military treatise of AD 375 by a Roman known as Vegetius, shows a diver wearing a leather hood and pipe to the surface, and carrying a most un-Roman halberd in one hand and a fish in the other – an achievement which Sir Robert Davis describes in deathless prose as, "Bordering on the miraculous, since the leather helmet is entirely devoid of eye-glasses so that the unfortunate wearer must have depended entirely for guidance – during the short interval which would elapse between his descent and asphyxiation – upon instructions shouted down to him through the tube!"

Lorini – not to be confused with Lorena – in 1597 was at it again with a leather suit and a metal helmet which was continuous with a large-bore leather pipe to the surface. The whole thing looked like an elaborate device for demonstrating the effect of squeeze!

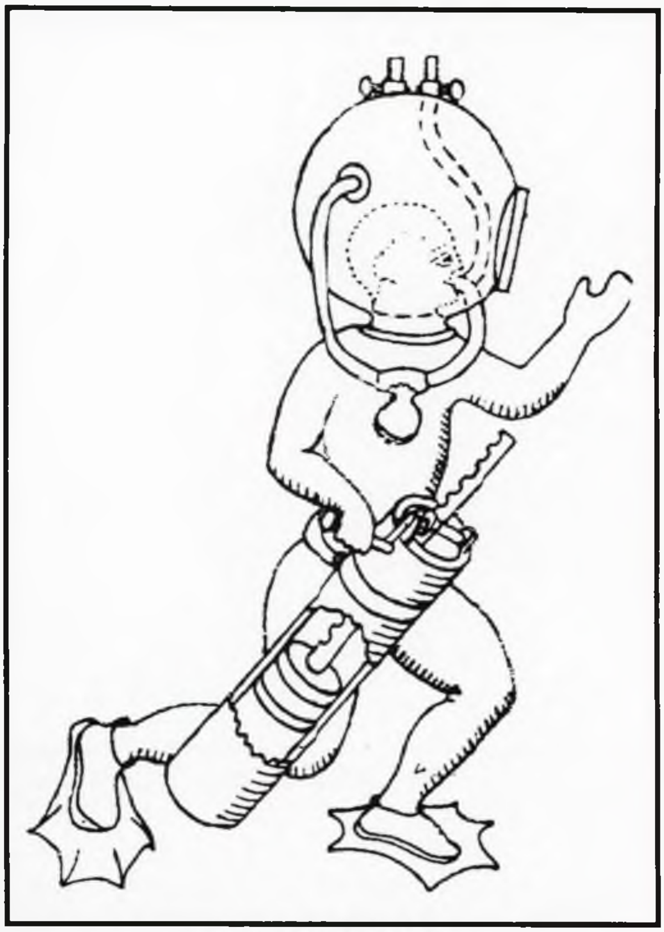

Fig 3: Borelli (1680)

One wonders how many intrepid adventurers perished or suffered lung injury before the impracticality of breathing air at atmospheric pressure when diving naked or clad in a flexible suit became borne in upon them. Borelli, an Italian mathematician, published a carefully worked-out proposal for a self-contained diving apparatus in 1680, which was equally impractical although, if he had known a little more of physics and physiology, and had done a few experiments, it might have had the makings of a diving apparatus that was years ahead of it's time (Fig 3). The large brass helmet, 2 feet across, was fitted with a circular glass window. The neck of the helmet fitted closely around that of the diver, and was laced to a water-tight suit of goatskin. The helmet was filled with air at atmospheric pressure and the diver inhaled this through his nose, exhaling through his mouth into a curved tube, at the most dependent point of which was a leather pouch to catch the condensed moisture. The air, which Borelli believed to have been purified thereby, returned through the pipe to the upper part of the helmet. Attached to the diver's waist was a cylinder fitted with a closely fitting piston operated by a rack and pinion. By racking the piston inwards he was able to reduce its volume and thus its buoyancy: conversely by racking it out he could increase its volume and therefore its buoyancy – and so ascend. It is a useful study to enumerate all the practical and theoretical faults in this design, which was never tested.

Of course a flexible reservoir, even though filled with air at atmospheric pressure, would permit a diver to breathe in and out under water for a few breaths, until the carbon dioxide (CO_2) partial pressure became too high so that the rebreathing bag illustrated in a 15th Century manuscript, had actually more

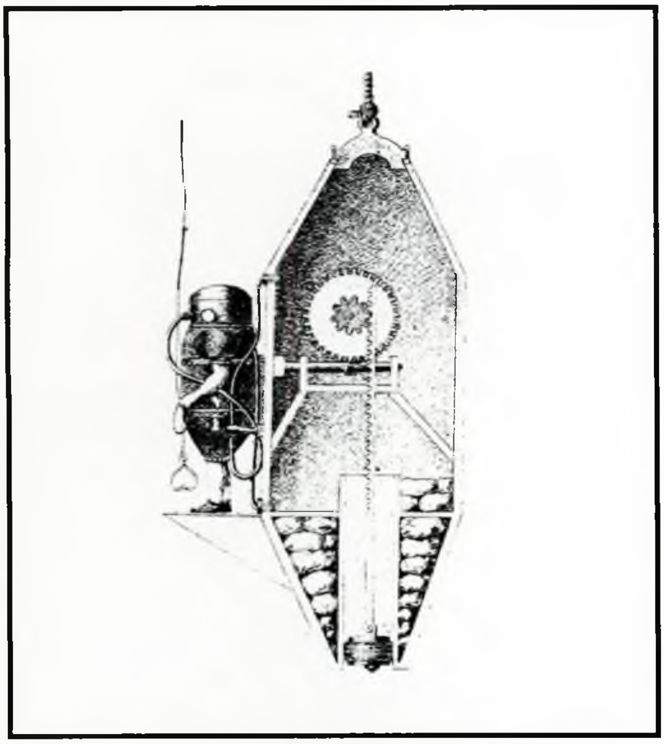

Fig 4: Klingert (1797)

to recommend it than the other half-baked designs considered so far – provided the problem of buoyancy could be overcome.

There is a well known picture from an Assyrian frieze, which is often reproduced in diving textbooks as an example of the earliest self-contained diving apparatus. In fact they are using inflated goat skins to swim across a river, and it would have needed a 50 lb weight belt to sink them! On 13th January 1980 the London Times published a photograph of anti-Soviet Afghan tribesmen, carrying modern rifles, crossing a river by exactly the same technique.

Tradition dies hard, and nowhere more so than in the diving world. Undeterred by years of failure in the atmospheric air/flexible diving dress mode, the engineering ingenuity of the 17th Century continued to perpetuate the age-old myth with fantastic elaboration. Many and various were the devices they contrived. As late as 1797 Klingert in Germany came up with an interesting design. It consisted of a very large helmet and an equally large metal body belt, connected by a leather jacket with short sleeves which were strapped around the upper arm and a pair of breeches strapped above the knees (Fig 4). All joints were watertight and, according to Sir Robert Davis, the driver obtained air by a twin air pipe, supported by a float on the surface.

Once again one feels that he was within reach of success if only he had realised that a supply of compressed air at the pressure of the ambient water, plus a simple relief valve on the helmet, was all he needed. It is said that the apparatus was tested in the River Oder, when a man sawed through the trunk of a tree under water. If you have ever had to use a handsaw under water you will know what an exhausting task it is, and I would have thought it impossible while submerged and breathing atmospheric air. But on the other hand, if there was a pumped supply and Klingert had got it right, why did he not go further? The age of practical diving was just around the corner and he could have been first in the field.

John Fullarton in 1805, who, I confess, was a Royal Navy medical officer, came up with a remarkable contraption consisting of a leather dress surmounted by a copper helmet. The dress was stiffened over the chest by a brass hoop, to relieve the pressure of water on the lungs, and was to be inflated with compressed air prior to descent. Sir Robert Davis comments: "The chief novelty was the method of supplying the diver with air. This presents an unrivalled collection of disadvantages! The diver stood inside a large annular reservoir, made of tinned copper, resembling a tub with the bottom knocked out. This was to contain air at atmospheric pressure. The diver breathed in and out of this reservoir, and occasionally worked a double-acting force pump mounted on the side of it, which was supposed to suck down fresh air and expel the foul air through the same pipe. The advantage of combining an air pump and an air pipe with so huge a reservoir is not clear. Nor is the use of connecting a dress inflated with compressed air, to a reservoir at atmospheric pressure!"

The last of these extravaganzas was Drieberg's Triton of 1811. The original drawing of this depicts the diver as being stark naked. To make up for this he wears a highly decorative crown which has three lugs on it by which it is connected to radius rods, pivoted on the shoulder pieces and linked to the boards of the bellows carried on the back. The idea was that the diver, by continuously nodding his head, should provide himself with a supply of air from the surface, and also for the candle in his lantern!

So far we have looked at successful breath-holding divers, successful bell divers, and several hundred years of unsuccessful endeavours to supply men with air at atmospheric pressure. The practical alternative to supplying a diver with air at the ambient pressure (whatever that might be) is to isolate him from the pressure of the water.

Probably the first successful exponent of this principle was John Lethbridge who designed and operated what he called his 'Diving Engine'. It was made of wood, reinforced inside and out with iron hoops, with two arm holes fitted with short sleeves, and a glass port, 4 inches in diameter and 1.25 inches thick. There were two air holes at the top, through one of which air was introduced with a bellows, and then both were stoppered with wooden plugs prior to the descent. It required 550 lb of ballast and, in an account dated 1749, he says, "I was able to move about 12 ft square at the bottom, where I have many times been for more than 6 h, being very frequently refreshed upon the surface by a pair of bellows. I have been 10 fathoms deep many times, and have been 12 fathoms with great difficulty". The difficulty was of course ischaemic pain in the arms and physiologically it seems remarkable that he could work for considerable periods at 60 feet. Nevertheless Lethbridge conducted a great deal of successful salvage work over the years.

Note that in comparison with JIM, today's most widely used armoured diving dress, it has two advantages, one of which it shares with WASP; it can move over a soft sea bed without disturbing the sediment. In fact, had he provided it with a glass dome and some form of propulsion, he would have had a shallow water WASP – and superior in the exquisite control and capability of the manipulators with their incomparable feed-back systems. And why bother going deep when there was plenty to salvage within the design range of the system – and with virtually no competition?

So far we have traced the history of diving more or less chronologically, and I intend to do that, returning to 1 atmosphere suits in due course.

In 1820 the Deane brothers, in England, devised a system which provided the diver with air at the ambient pressure. It

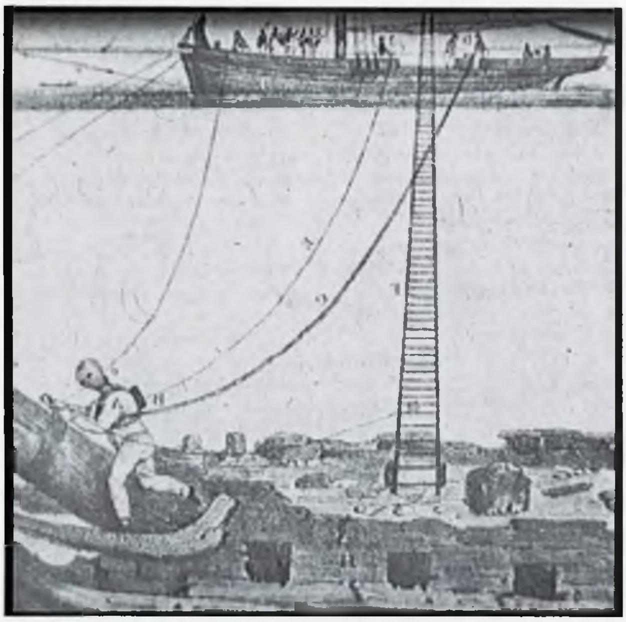

Fig 5: John and Charles Deane working on the *Royal George*, Spithead (1834)

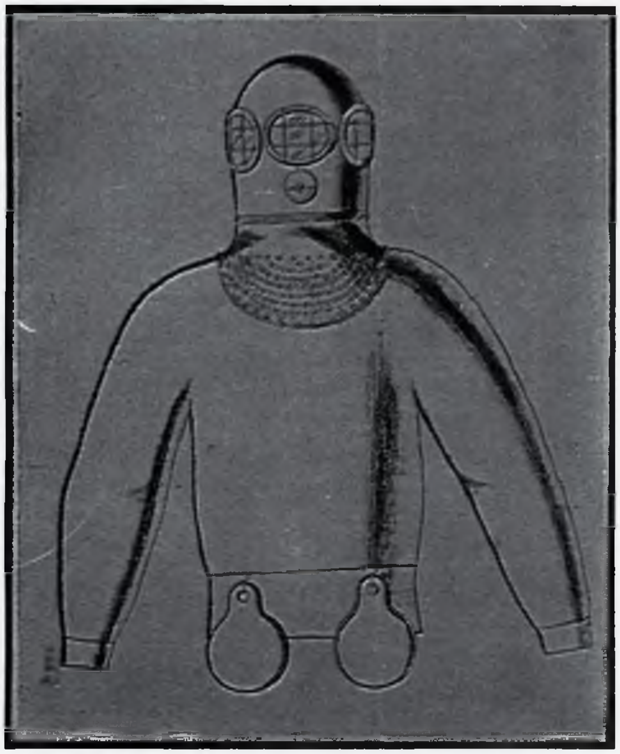

Fig 6: Siebe's 'open' diving dress (1819)

consisted of a copper helmet attached to a leather suit. Air was supplied to the helmet via a flexible hose and a pump on the diving boat and escaped beneath the rim of the helmet. The diver, of course, had to remain upright. By 1828 they had, according to a handbook produced by Deane, "After vast study and labour, brought it to fruition".

Much good work was done with this apparatus, notably salvage of the guns of the *Royal George* which had capsized and sunk in 65 feet of water in 1782 with "Admiral Kempenfeldt and twice 400 men" (Fig 5). They also dived on the *Mary Rose*, Henry VIII's flagship which was finally brought to the surface on 11 October 1982. John Deane, by the way, was still diving in 1856, under the ice in Crimea, salvaging sunken Russian warships.

Fig 7: Siebe's first 'open ' diving helmet (1819)

There is much controversy regarding the originator of the 'closed suit' which was to develop into the standard diving suit that is still in use today. In 1819 Augustus Siebe, who had come to England 5 years earlier, following discussions with John Deane introduced his 'open dress' (Figs 6 and 7) in which the helmet was attached to a jacket reaching to the waist and supplied by a pump at the surface, with the excess gas escaping below the jacket. This seemed an obvious improvement on the open helmet design although the diver still had to be circumspect in his movements. It seems probable that the Deanes cooperated with Siebe, who subsequently made a number of improvements to both suit and air pump. In 1837 Siebe introduced his 'closed suit' with a relief valve at the side of the helmet, which marks the beginning of the era of standard diving.

For the record, two other Englishmen, Fraser and Bethell, also took out patents for closed suits 2 years earlier, but for one reason or another they faded out of the picture.

It will already have been apparent that the histories of military and commercial diving are inextricably interwoven – which is really not surprising. The same is true of the history of military and commercial aviation.

One of the first to exploit Siebe's improved suit was Colonel Pasley of the Royal Engineers, who undertook final dispersal of the wreck of the *Royal George*. There are detailed records of this operation, and the chief credit goes to two intrepid divers, Sergeant Harris and Corporal Jones.

It is not generally realised, even by Royal Navy divers, that it was the army that taught the navy to dive. Colonel Pasley stated the first naval diving course, with 13 petty officers and ratings from the Navy Gunnery School, under the tutelage of the redoubtable Corporal Jones.

It is fitting to record that the Royal Engineers have continued to maintain an interest in diving, although usually on a rather small scale, and in October 1982 it was Colonel Chitty and his men from the Royal Engineers' Diving School who had responsibility for designing and constructing the massive frame by which the *Mary Rose* was lifted from her watery grave after 437 years.

Pursuing the path of chronology, I want to turn now to the self-contained diving apparatus – which was to become so important, first in military and then in sport diving, as to outsell in volume all other forms of diving apparatus.

As we have seen, various impractical proposals were made for breathing air from a reservoir – but hitherto always with the stored gas at atmospheric pressure. When technology made it possible to store compressed gas there was another spate of designs, but in those early days of diving endeavour the proposals came from mathematicians and engineers, whereas what was needed was the services of an experimental physiologist.

The basic requirement for a self-contained breathing system is a store of oxygen which can be delivered to the diver at a pressure and flow determined by his depth, his activity, and his physiological parameters. In terms of engineering there are several ways in which this can be done. Pure oxygen, or air, or some mixture of oxygen with a suitable diluent gas, can be supplied at the required pressure and rate for the diver to take what he needs and exhale the CO_2 and unused oxygen into the water. This is the principle of the self-contained compressed air system, generally known as scuba, which, while enjoying the advantage of simplicity, is very wasteful of gas. It would be sheer extravagance in the case of pure oxygen or a special oxygen mixture. An obvious alternative is to use a store of pure oxygen, remove the CO_2, and recirculate the unused gas.

But because of the limiting partial pressure of oxygen a diluent gas is essential in order to be able to dive deeper than 30 feet. Ways of conserving the diluent gas will be considered later.

Fortunately, in historical terms, there was one apparatus which neatly bridged the gap between the surface-supplied system and the self-contained system. This was the apparatus designed by Rouquarol and Denayrouze in 1872. Air was supplied to the diver via a 'regulator' carried on his back and connected to a surface supply. This regulator consisted of a box interposed between the air supply and the breathing hose, closed by a membrane or diaphragm which is subject to the pressure of the water on one side and of the air breathed by the diver on the other. When the diver breathes in, he lowers the pressure in the box, which causes the membrane to bulge inwards and open, by means of a system of levers, a valve which admits more air from the supply (Fig 8).

Thus we have here the first example of a surface-supplied demand system, which would have been pleasant to use because of the awareness of an infinite supply of air. But what is more important from the point of view of our history is the fact that there was an alternative mode; the surface connection could be dispensed with and the diver could breathe from a reservoir of compressed air carried on his back.

Technology had not yet permitted the construction of high pressure cylinders and the next successful diving apparatus, that set the pattern for many years to come, was that of Henry Fleuss.

In 1878 he designed a self-contained oxygen apparatus with a CO_2 absorber for use under water and in irrespirable atmospheres, which produced some spectacular successes. The oxygen was stored in a copper cylinder at a pressure of 40 atmospheres and CO_2 was absorbed in tow impregnated with caustic soda.

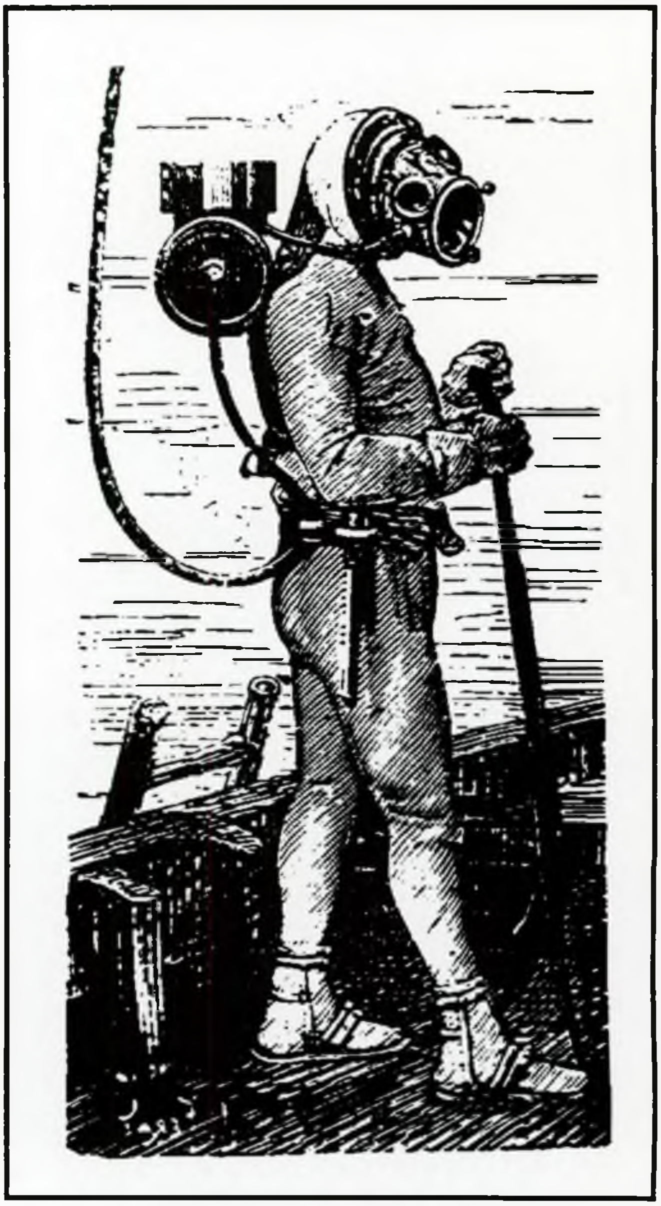

Fig 8: Rouquarol and Denayrouze (1872)

Wearing this apparatus the great diver Alexander Lambert in 1882 managed to close a door in a flooded railway tunnel under the Severn River in south-west England. He had to go down a 200 foot vertical shaft, with 50 feet of water at the bottom, then along a tunnel 1000 feet long, and all in pitch darkness.

He found the door wedged by two rails running over the sill. He ripped one up with his bare hands, found the other would not move and so plodded back, went up for a crow bar, returned, levered up the rail and forced the door shut. A remarkable feat on pure oxygen at that depth.

The tunnel flooded again 3 years later and Lambert went down once more with the Fleuss oxygen equipment. This time he collapsed and very nearly lost his life. The reason, of course, was oxygen poisoning. But undeterred, he went down the next day in his standard suit with two divers who descended the shaft with him and tended his life-line and air hose. And this time he slammed the door shut.

Largely thanks to the First Admiralty Deep Diving Committee, by the start of World War I standard air diving was well understood. In 1914 250 000 dollars worth of silver was

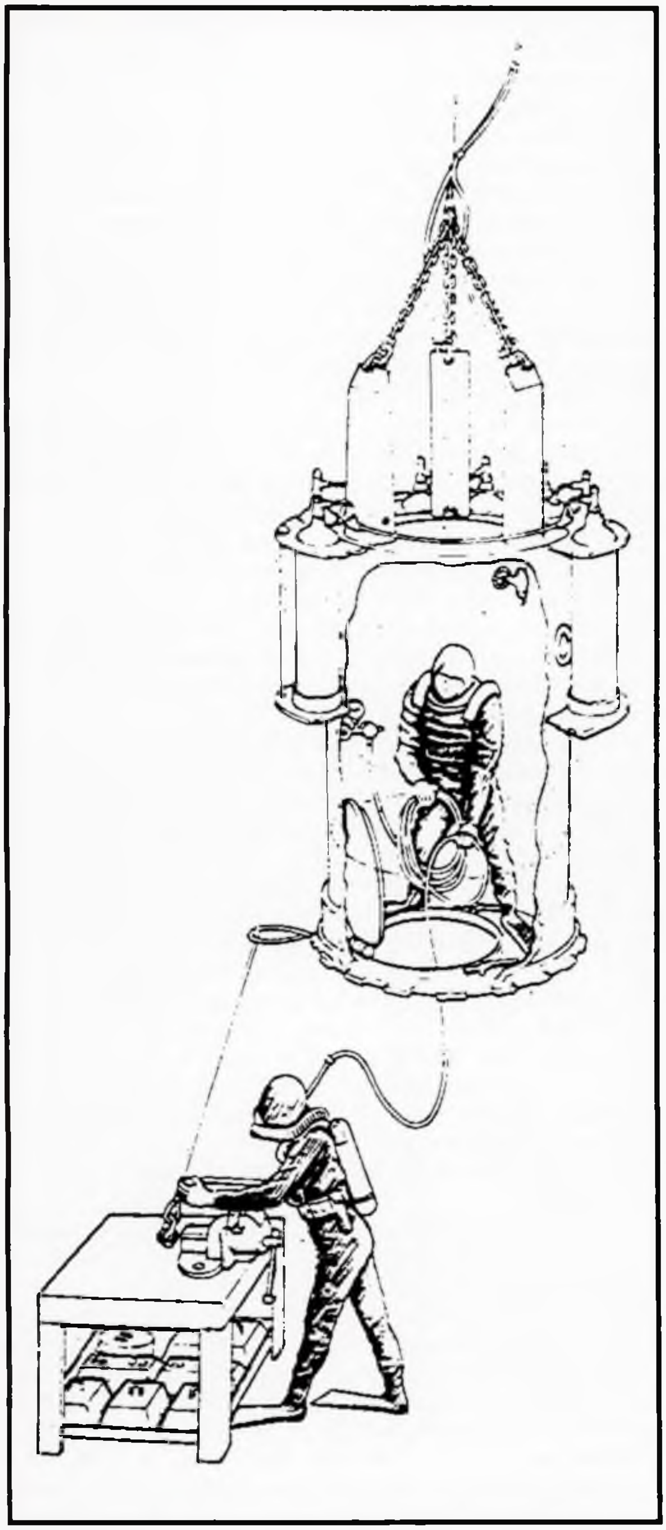

Fig 9: Royal Navy submersible decompression chamber (SDC)

recovered from the *Empress of Ireland*, sunk in 180 feet of water and for the first time there was mention of surface decompression, that is, bringing the diver straight to the surface and into a decompression chamber in which he is taken rapidly to the depth of the dive and then decompressed according to a regular schedule.

In 1915 Gunner Stillson of the US Navy made a number of air dives to 304 feet in standard dress off Honolulu; an impressive achievement in the light of today's knowledge of nitrogen narcosis and oxygen toxicity.

But in the main, World War I divers were occupied in ship repair work, salvage, and harbour clearance and there was little improvement in diving technology.

After the war there were some impressive salvage operations. Over a period of time most of the German battleships scuttled in Scapa Flow were patched and raised.

In 1924 the US Navy started experiments with oxygen–helium mixtures (oxy-helium) to overcome nitrogen narcosis, in retrospect an advance comparable with that of the introduction of Siebe's flexible dress. And in 1931 the Royal Navy set a final world record for an air dive with an open sea dive to 344 feet, using a helmet with an injector–Venturi system to improve gas flow and reduce the level of the CO_2 in the helmet, together with a submersible decompression chamber fitted with an oxygen breathing system to shorten the time for decompression (Fig 9). Using this equipment nearly £5 M in gold bullion was recovered from the *Laurentic* which had been torpedoed in 132 feet of water in 1917.

In 1922 the *Egypt* was sunk in a collision in 402 feet of water with £1.05 M worth of gold on board. She was too deep for the diving equipment and tables of that time. Hence it was the first deep diving operation to employ a 1 atmosphere armoured suit.

At this point, we need to turn the clock back a little to look at the first attempts at employing 1 atmosphere suits. A suit made by Lafayette in 1875 was anthropomorphic in shape but no attempt was made to articulate the limbs. It was supplied from the surface at atmospheric pressure so that it amounted to an elaboration of Lethbridge's diving engine of a century earlier.

Another, of around 1895, was made of waterproof fabric stiffened with spirals of brass wire. The designer's confidence in the flexibility of the limbs when the suit was under pressure was hopelessly optimistic.

In the United States a suit designed by MacDuffie in 1914, made of aluminium with cylindrical joints supported on ball races, was tested to 200 feet in Long Island Sound (Fig 10). Neufeldt and Kunkhe constructed a light alloy suit with a buoyancy ring round the helmet with which divers from the ill-fated *Artiglio* in 1930 identified the *Egypt* after a 2 year search and succeeded in recovering the Captain's safe (Fig 11).

Shortly afterwards the *Artiglio* was blown up while dispersing a wreck and the chief divers and most of the crew were killed. However the second *Artiglio*, using an observation chamber and a grab, successfully completed the operation over the next 2 years, recovering three-quarters of the bullion on board – perhaps the first example of a successful remote-control diving operation.

Of special interest was a suit by Joseph Peress of England in 1930 which was tested in Loch Ness at 447 feet – at which point the liquid-sealed joints (a great advance) were found to move quite freely. In 1935 the same diver, Jim Jarrett, after whom today's JIM suits are named, went down on the *Lusitania*, torpedoed off Ireland during World War I and alleged to be the reason for the United States entering the war. As you may know, there has been speculation over the years as to whether she was armed and carrying munitions, and within recent years another diving operation was mounted using JIM, sponsored by a group which I believe were more interested in the news value of evidence of armaments than in the jewellery said to be in the Captain's safe. In spite of all sorts of wild rumours – for example of previous clandestine dives to remove the evidence – no further revelations followed the recent operations.

During the interim period there were two very different advances in diving technology that were to have immensely far-reaching effects. In 1933 a Frenchman called Le Prieur produced a simple self-contained apparatus consisting of a low pressure cylinder slung from the waist which supplied air via

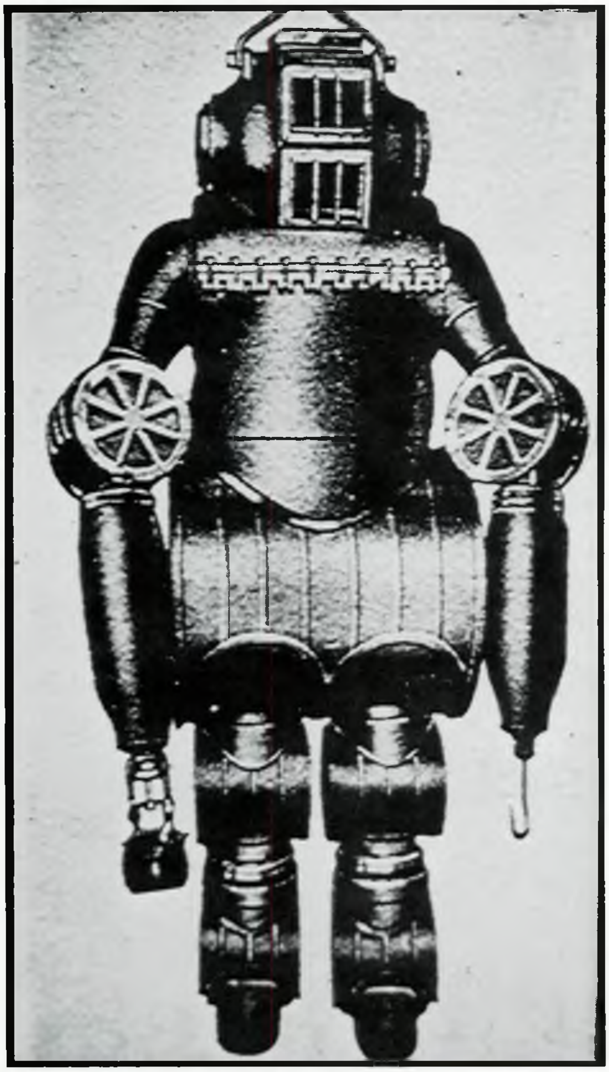

Fig 10: MacDuffie (1914)

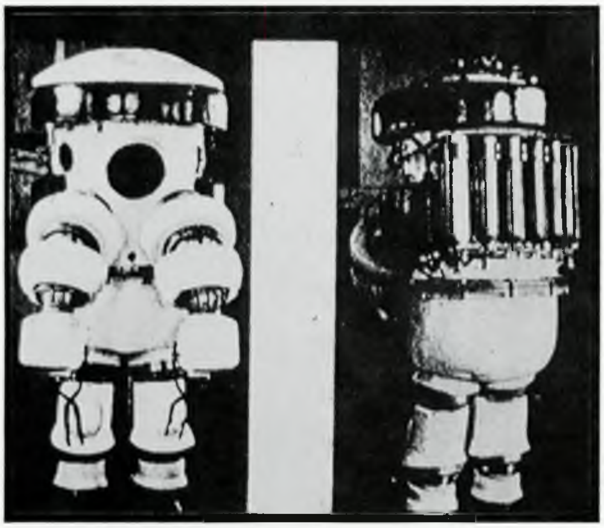

Fig 11: Neufeldt and Kuhnke (1920)

a hand valve into a full face mask, escaping around the sides of the mask. It was intended as an aid to spear fishing, a sport which had been initiated by Guy Gilpatric, an ex-patriot American flyer living on the Mediterranean coast. Gilpatric, who was later joined by such well-known spear fishermen as Dumas, Taillez and Kramerenko, never wore fins although they also originated in France (the invention of M. de Corlieu) and came on the market in 1935 – the same year that Kramerenko, the inventor of the spring harpoon, introduced pressure-compensated goggles, based on those worn by the Ama.

Le Prieur's system was obviously inefficient, but another young spear fisherman, George Commeinhes, came up with the answer – a cylinder worn on the back with a demand valve, based on exactly the same principle as Rouquayrol's, worn between the shoulder blades. It had a full face mask with an air inlet and an expiratory valve placed opposite the inlet. It was approved by the French Navy in 1937 and subsequently the inventor did a demonstration dive to 190 feet. His model GC 47 was manufactured but unfortunately he was killed in the battle for Strasbourg in World War II.

Le Prieur, by the way, formed the world's first club for 'Divers and Underwater Life'. Further clubs proliferated in the Mediterranean countries in the 1930s and led to the Italians becoming the world's first underwater saboteurs.

During World War II Cousteau and Gagnan, in occupied France, patented their famous 'Aqualung' which was similar in principle to Commeinhes' but had separate inspiratory and expiratory hoses, with the expiratory valve located with the demand valve on the back. It was of course this device that opened up the sea to tens of thousands who would otherwise never have dived.

The other highly important advance of the inter-war years was the introduction of helium–oxygen diving in the USA, without which the extraction of wealth from the sea bed today – which is of such vast importance – could scarcely have been accomplished.

I say 'scarcely' because there could be another way. There are, of course, other suitable diluent gases such as hydrogen. The problem is that in certain proportions hydrogen and oxygen form an explosive mixture, which means that mixing the compressed gases can be highly dangerous. Nevertheless Arne Zetterstrom, a Swede, constructed a viable oxygen–hydrogen diving apparatus in 1944, with which he made a world record dive to 525 feet. Unfortunately he died during the ascent owing to actions on the part of his attendant.

Meanwhile, in the combatant countries during the 1940s an entirely new class of diver was emerging, popularly known as the frogman.

On 19 September 1941 a Royal Navy tanker, the *Derbydale*, in Gibraltar harbour, shook as 500 lbs of explosive went off, shattering her hull. It was the result of 5 years work by two Italian Naval architects, Tesci and Toschi, who developed a torpedo with a detachable warhead which was driven by two men wearing self-contained oxygen sets and dry-suits at a maximum speed of 3 knots. They approached the target with their face masks awash, then dived under the ship, clamped a line from the warhead to the keel, attached it, and withdrew.

Further attacks followed and Tesci and several others were captured. As a result, two Royal Navy Lieutenants, Bailey and Crabb, formed the nucleus of attack parties known as 'P' parties, to try to repel the Italians and remove or defuse the charges. Crabb was a Bomb and Mine Disposal Officer and a poor swimmer who never took exercise if he could avoid it. Nevertheless, he rapidly learned to dive with a Davis Submarine Escape Apparatus and after the war achieved international notoriety following the Ordzhonikidze affair.

In the following year the Italians operated an individual attack system. Underwater swimmers lodged 5 lb mines against the bottoms of ships in Gibraltar harbour with inflated balloons. One exploded prematurely and the P parties went in, found the mines, and punctured the balloons.

During that summer, while carrying out a ship's bottom search, Lieutenant Bailey saw an enemy frogman approaching.

He drew his knife and slashed the other's suit. The Italian, who wore flippers, retreated but it is not known whether he got back to base.

The following year three large British ships were sunk in the harbour as a result of a most ingenious operation. At the outbreak of war, an Italian tanker lying in Algeciras harbour was scuttled. In 1942 Lieutenant Vinsintini had the brilliant idea of turning it into a secret underwater base for two-man torpedo attacks on Gibraltar.

A so-called 'repair crew' was sent on board and converted the hold into a workshop for assembling the torpedoes, partially flooded the bow compartment, and cut a hole in the bows of the ship below water level. The assembled torpedoes were then lifted into the compartment and their crews took them out under water across the bay to Gibraltar.

The peak of the Italian success came with the crippling of the battleships *Queen Elizabeth* and *Valiant* in Alexandra harbour. Six men, with three tiny craft, crippled two of the most powerful warships in the world.

The leader, Count de la Penne, was captured and interrogated by the British Admiral. He refused to speak and was therefore taken into the bowels of the ship to think it over. After some time he asked to be taken to see the Captain and told him that to avoid loss of life the order should be given to clear lower decks. He still refused to say what the threat was but his advice was taken and he was taken below again to persuade him to change his mind. Shortly afterwards there was a violent explosion and the ship settled at the bottom. He was unhurt and when later Italy changed sides it was Admiral Cunningham who pinned the highest Italian decoration for valour on his chest.

In Alexandretta, a Turkish port used by the Allies to load chromium, another intrepid Italian was at work. Sub Lieutenant Ferraro operated single-handed by swimming out to ships and attaching mines which were armed by a small propeller device. When the ships left harbour and had travelled a few miles the mine exploded – and the ships were naturally assumed to have been torpedoed. In a single month Ferraro sank two ships and severely damaged a third. After the war he continued his interest in diving and became President of the World Underwater Federation Sports Committee (CMAS) and of one of the largest Italian diving equipment companies.

By now the Royal Navy had set up its own two-man torpedo group, or 'charioteers' as they became known (Fig 12). They also used closed-circuit oxygen and part of their training was to crawl under an anti-torpedo net on the bottom at 90 feet. Not surprisingly there were many cases of unconsciousness and convulsions, and it is said that a Commander who reported for training at 0800 hours was on the mortuary slab by 1100 hours!

The first successful attack was on Palermo harbour in Sicily, five chariots having been launched from submarines a few miles from the port. Only two got into the harbour where, having negotiated a series of anti-torpedo nets, they successfully attacked their allotted targets. The biggest prize was the cruiser *Ulpio Traiano* which was sunk by Lieutenant Greenland and Leading Seaman Ferrier. They also attached limpet mines to three submarine chasers and a merchant ship, all of which exploded as planned.

In 1958 Ferrier was my scientific assistant at the Royal Naval Physiological Laboratory and I only became aware of his exploits, and his subsequent extraordinary activities in Italy and Germany, when I saw him on the television programme 'This is your Life'.

Chariot attacks were made on a number of targets in the European Theatre, the best-known being the unsuccessful attack on the battleship *Tirpitz* in a Norwegian fjord and the successful attack on La Spezia harbour, Italy, by a joint team of British charioteers and Italian frogmen under the command of none other than the Count de la Penne, which penetrated the harbour defences and sank the cruiser *Bolzano* which had been taken over by Germans.

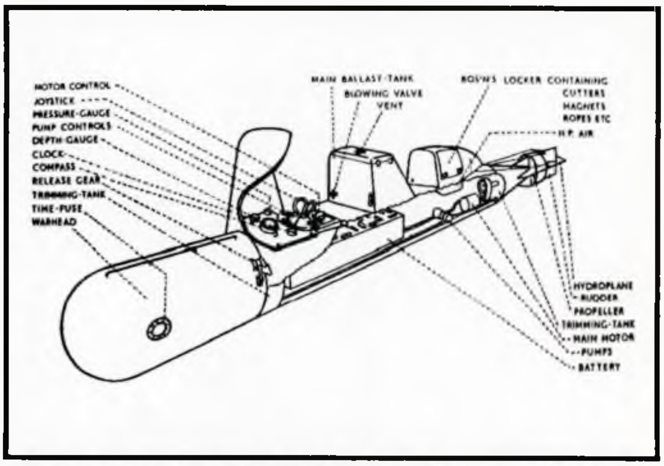

Fig 12: Diagrammatic sketch of mark I human torpedo

Meanwhile the Royal Marine Commandos were developing their Special Boat Section which employed tiny submersible one-man canoes powered by a $^1/_2$ hp electric motor. They were used for beach reconnaissance, underwater demolition of beach defences, and as a means of taking small raiding parties ashore. They had their equivalent in the US Navy UDT (underwater demolition teams) and SEAL teams, and using modern equipment played an important part in the recent operations in the Falkland Isles.

Much more elaborate, and more effective in many respects, were the midget submarines or X-craft which carried a crew of four and had a diver lock-out compartment. They were powered under water by batteries and on the surface by a London bus engine! They had a range of 300 miles, could submerge to 300 feet and had 36 h endurance. They carried detachable 2 ton charges of explosives on each side of the hull and the diver could cut a way through torpedo nets.

X-craft made successful attacks on the *Tirpitz*, the charges from two boats lifting her 5 feet out of the water and crippling her. And in the Far East they immobilised the Japanese heavy cruiser *Takao*, and cut the Saigon–Singapore and Saigon–Hong Kong cables.

Of course the first midget submarine was the *USS Turtle*, designed by Bushnell in 1775 during the War of Independence. It never sank a ship but the first submarine to do so was the Confederate submarine *Hunley* which, in 1864, attacked the *Housatonic* with a spar torpedo and sank with her.

By and large, despite all the underwater activities during World War II, little was added to the technology of diving. After the war, the main naval interest was in detecting and disarming mines, and in England the Navy developed the Clearance Diving Breathing Apparatus which is a semi-closed-circuit system, using a pre-mix of nitrogen and oxygen carried in two cylinders on the back, with a continuous flow into a rebreathing bag via a reducing valve and a canister filled with CO_2 absorbent. A relief valve on the bag allowed excess gas to escape. The mixture and gas flow were pre-set according to the depth. Thus for a swimming diver at 60 feet the mixture would be 60% oxygen/40% nitrogen and the flow 6 litres/min. This would provide for an oxygen consumption of 3 litres/min (Fig 13).

The advantages of the system are its greater economy – hence greater duration than a compressed air set (110 min with a 6 litres/min flow), its silence, its thin stream of bubbles from

Fig 13: Royal Navy clearance diving breathing apparatus (1960)

the relief valve which are hard to detect from the surface, and its virtually constant buoyancy and trim. Also, because the percentage of nitrogen is about half that of air, the decompression times for the set are halved as compared with an air set.

All navies have developed semi-closed-circuit sets of various complexities. The Royal Navy set has the advantage of simplicity.

The complete answer to gas wastage is of course a fully closed-circuit system whereby the oxygen partial pressure is continually monitored by electronic means and automatically kept at the optimum. The CO_2 is scrubbed, and the diluent gas added as required and simply recirculated – no noise, no bubbles and maximum duration, but very expensive and requiring expert maintenance.

Progress in deep diving since the war is mainly attributable to the physiologists but now that the mechanism of the various diving illnesses is so much better understood, military and commercial diving technology is directed towards improving existing techniques and easing the work of the diver.

To trace the record briefly: in 1948 Petty Officer Bollard, RN dived to 540 feet on oxy-helium, stayed 5 min on the bottom and spent 8.5 h decompressing. In 1958 Lieutenant George Wookey, RN extended the world depth record to 600 feet and worked on the bottom for 4.5 min, subsequently decompressing over a period of 6.5 h. The dive was extremely costly and the diver suffered severely from cold, in spite of the use of the SDC and transfer under pressure into the deck chamber of the diving ship. It looked as though 600 feet represented the limit for diving operations.

Meanwhile George Bond, in the United States, had started his saturation diving programme which was to have far-reaching results – but in 1960 a giant stride in diving progress was taken in a most unexpected quarter, a country which had neither a Navy nor access to the sea. This was when Keller electrified the diving world by carrying out a chamber dive to a pressure equivalent of 1000 feet, decompressing in 31 min.

Experimental dives in hyperbaric chambers have reached a depth of 2012 feet and exceptional open-sea dives have reached 1680 feet. The substitution of hydrogen and various exotic gases for helium may make it possible for divers to perform useful work as deep as 3000 feet. The increasing use of closed-circuit self-contained systems will extend the depth range and duration of future untethered diving operations. But there are certain imponderables, biological, technological and financial, which will militate strongly against extending the depth range beyond the present limits.

These are summarised as follows.

1. The known and postulated physiological limitations, including the direct effects of hydrostatic pressure on tissue cells and the deterioration in some types of psychological performance which seems to be associated with deep saturation diving appear to involve very fundamental biological processes.
2. The knowledge required to overcome or avoid these effects will be increasingly hard and expensive to obtain.
3. Considerations of the cost of manned diving systems and supporting equipment, liability insurance, divers' wages, and the need for increased experience to cope with the increasing depth and risks will make economics a very large influence on the future of deep diving.

Of course all the physiological limitations can be overcome by the use of 1 atmosphere armoured suits, but the performance of such systems as JIM and WASP are severely limited by their clumsiness and by the inefficiency of muscle power when operating inside armoured sleeves.

More and more oil companies are insisting upon diverless operations, which implies an increasing demand for technologically advanced robotic systems. But cameras, however sophisticated, cannot match the human eye for depth perception, nor computers for pattern recognition. Modern concepts of manned underwater vehicles have a great potential for underwater search and identification, as well as for on-site direction of remotely controlled operations.

Thus the techniques employed in the salvage of the *Egypt*'s gold 65 years ago may have set the pattern for the deep diving operation of the future.

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