considered fossils to be remains of organic creatures and suggested the mutability of species when fossils bear no resemblance to living creatures.

His work in orbital dynamics influenced Newton. Both corresponded with each other although there was a large degree of animosity between them. After the Great Fire of London he was appointed surveyor of London and designed many buildings including Montague House and Bethlehem Hospital.

Edmond Halley (1656-1742)

Edmund Halley was an astronomer (a comet is named after him) and mathematician. He was born in Shoreditch on the 8th November, 1656 and died in Greenwich on the 14th January, 1742.

In 1684 he met Sir Isaac Newton. He was one of Newton's major supporters. He funded and published Newton's 'Principia' in 1687. He was a Fellow of the Royal Society at the time of Hooke, Boyle and Wren.

In 1686 he published the first world map showing prevailing winds over the oceans. In 1701 he published the first magnetic charts of the Pacific and Atlantic oceans.

In 1690 he designed his first diving bell, which had an atmospheric air supply. He subsequently improved this design in 1716. The air supply was replenished by 2 thirty six gallon barrels lowered below the bell and connected to the bell by a hose. Divers used this bell to depths of 18 m and apparently stayed submerged for up to 1.5 hours with no recorded cases of decompression sickness.

He developed life expectancy charts in 1693 which were the first attempt to relate mortality and a population's age. These charts were used for insurance purposes (the first modern life insurance policy was issued in England in 1583) and are still the basic model used by Insurance companies today.

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DIVING BELLS THROUGH THE CENTURIES

John Bevan

Key Words

Bell diving, equipment, history.

Abstract

One of the oldest, successful and most enduring forms of diving involves the use of a diving bell. This paper traces the history of the applications and development of the diving bell over a period in excess of 2,000 years. Setting off in pre-Christian times in the Middle East, the story travels all over Europe, with occasional expeditions to the Americas, and closes with the appearance of the modern "transfer under pressure" bell, first introduced by the Royal Navy and now universally adopted.

Introduction

Alexander the Great is credited with the first recorded bell dive in 332 BC.[1] Legend has it that he descended in a bell called "Colimpha" at the Siege of Tyre. Aristotle described how his pupil, Alexander the Great, peered out of his bell to observe underwater sheep and dogs and even one gigantic creature that took three days to pass by! But before we credit Alexander the Great with being the first saturation diver as well, we have to consider that his bell was probably an atmospheric observation bell since it was referred to as a glass case, covered with asses skins and provided with a door made fast with chains. Another version describes the bell as constructed of wood, fitted with glass windows and a lid impregnated with resin, wax and other substances to make it water tight. Whilst the accuracy of any of the accounts is questionable, it may at least be reasonable to presume that Alexander the Great made some sort of a dive in some sort of a bell.

The 16th century

Surprisingly we have to wait nearly 2,000 years for the next and more reliable account of a bell dive.[2] An Italian by the name of Gulielmo di Lorena came up with a design for a bell in AD 1531. The diver had little freedom of movement because he was strapped into a frame inside the bell. The specially interesting aspect of this design is that it was a bottom-orientated bell which allowed diver to walk on the sea bed. So whilst the bell was raised and lowered by a lifting rope to the surface, it had the important ability to move laterally over the sea bed. In 1535 Francesco da Marchi dived in Lorena's bell and claimed to have remained underwater for one hour surveying Caligula's pleasure galleys sunk in lake Nemi near Rome but no mention is made of how the air was replenished within the bell. As with all these early diving bell designs, there was no facility to replenish the air inside the bell. In reality dive durations would therefore have been severely limited and the bell would have been raised periodically to provide a supply of fresh air at the surface. Interestingly this account also records the first time a diver used a red hat. Marchi stated after returning to the surface from one of his bell dives: *Moreover I had a hat of crimson silk, with a quantity of white feathers which were as dry as they had been when I went into the lake, and my companions each took one from me as a souvenir.*[2]

Today's diver's red hat may not be made of silk and the white feathers would be a little over the top, but a red hat seems to have become the enduring uniform of the diver.

The importance of the Mediterranean Sea as the field centre for the earliest diving experiments is confirmed by many subsequent accounts of underwater exploits.

Two Greek divers were reported by Taisner in AD 1538 to dive in a "large inverted kettle" and rise up again without getting wet.[3] The authenticity of this particular account is fairly reliable since the demonstration dive was carried out at Toledo, Spain, in the presence of King Charles V and several thousand spectators.

On 27 February 1582, the Spanish got into the news with a bell diving operation at Palermo, Sicily.[4] José Bono used an elaborate and magnificently cast, bronze bell to demonstrate his underwater prowess. The use of a heavy metallic construction is particularly well demonstrated in this design, the bell itself being sufficiently heavy to sink itself without the addition of extra weights. The disadvantage of this arrangement was that if the bell was lowered too far, or if it fell to the sea bed, the diver would be trapped inside.

The 17th century

Not to be out-done, the Italians, this time with military ambitions in mind, were back on the scene with a basic bell design provided by Buonaiuto Lorini in the year 1609.[5] Lorini's bell was built as a rectangular wooden chest, fitted with glass ports and reinforced with an iron frame. A large flat, stone counterweight fixed below the bell also doubled at a platform for the diver to stand on. This arrangement had the important advantage of the provision of a stand-off facility so that if the bell was lowered all the way to the sea bed, the diver could not be trapped within the bell. Provision was made for lifting the heavy bell by the use of a block and tackle arrangement. The military aspect is worth noting because many of these diving techniques were in fact quite secret at the time in view of their potential application during a war. Presumably their main use would have been to salvage sunken vessels and cargo.

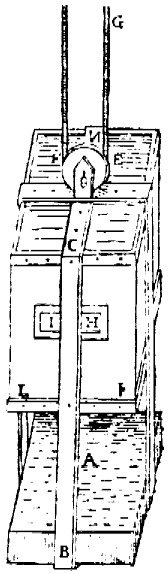

Figure 1. Lorini's bell redrawn from illustration 564 in Sir Robert Davis' book *Deep Diving and Submarine Operations* (7th Edition, reprinted 1969).

The French were next on the scene when a priest by the name of Gaspart Schott described another bottom-orientated or "portable" bell in 1664.[6] This bell was used in 1616 by Franz Kessler. It was constructed from a metal frame covered by leather and fitted with small ports. A metal counterweight was slung underneath and the diver was secured inside the bell by a leather harness. The buoyancy was arranged to be just a little on the negative side so the diver could lift the weight off the sea bed and walk about. In this respect it was similar in mode of operation to Lorena's bell of 1531 but different in that it did not appear to be provided with a hoisting facility. Perhaps it was therefore intended to be walked out to depth from shallow water. Apart

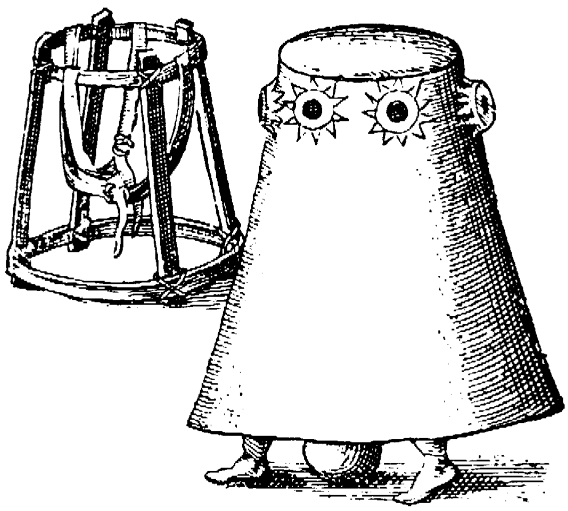

Figure 2. Kessler's bell redrawn from illustration 566 in Sir Robert Davis' book *Deep Diving and Submarine Operations* (7th Edition, reprinted 1969).

from the limited endurance of the system, it would seem that the design was operationally viable.

Sweden was the next country to learn the art of bell diving, necessity being the mother of plagiarism. There had been a naval incident of catastrophic proportion at Stockholm harbour when the magnificent man-of-war *Vasa* sailed out on her maiden voyage. The main problem was that she sank. Not surprisingly, this took everyone by surprise. The vessel was bristling with state-of-the-art cannon which were now doing no good whatsoever at the bottom of the harbour. This is when Hans Albrecht von Treileben and Andreas Peckell, both Swedes, appeared and offered to salvage the valuable cannon using their revolutionary diving bell. It was 1.25 m high and shaped like a church bell. Between 1663 and 1664, the two Swedes raised no less than 53 of the *Vasa*'s guns, each weighing 1.5 tons.[7]

Bell diving technology appears to have eventually reached Britain around 1665 when a gentleman from Greenock named Archibald Millar salvaged at least three cannon from a Spanish Armada ship wrecked at Tobermory in Scotland.[8-10] The bell, suspended in a chain bridle, was of cast metal weighing 260 lb (118 kg), beneath which a metal platform weighing 130 lb (59 kg) was suspended by more chains. It is likely that the weighting and buoyancy arrangements were such that if the bell's underslung platform landed on the sea bed, the bell would maintain its "stand-off" through being positively buoyant, and thus not trap the diver inside. Indeed it is likely that this was the normal mode of operation.

We now come to the most successful bell diving operation ever carried out, at least in financial terms. An ambitious carpenter, born to a blacksmith in Boston, USA, named William Phipps, had raised himself to the status of a ship's master. During his seagoing travels, he had heard incredible stories of Spanish shipwrecks which had carried untold quantities of gold and silver to the sea bed. He tried unsuccessfully on several occasions to recover such treasures, but mutinous crews had thwarted his efforts. He eventually ended up in London, seeking financial backing for yet another attempt. In 1667 he mounted his next expedition from England. His ship, manned by a reliable crew, sailed off down the Thames and this time it was carrying a diving bell consisting of a square wooden box bound round with iron bands and furnished with small windows. A stool was fixed inside for the convenience of the diver. To cut a long story short, the following year he sailed back up the Thames carrying treasure to the value of £300,000, recovered from a Spanish shipwreck off the island of Hispaniola.[11,12] The arrival of such wealth into the country, all in one go, shook the financial markets to their foundations. Phipps himself was paid £16,000. He was knighted by King James II. He was given the Governorship of New England and returned as Governor to Massachusetts.

According to a Doctor Panthon of Lyons, France, writing in 1678, a French diver named Jean Baptiste was, around 1677, successfully salvaging money lost in two wrecks near Cadaques, Spain.[13] Baptiste's diving bell was a departure from conventional bell design thinking, in that it was a massive structure. Most, if not all previous bell designs had been intended for single occupancy. But Baptiste's multi-occupancy bell was 13 ft (3.9 m) high and 9 ft (2.7 m) in diameter at its base. It was made of wood and was strengthened with iron hoops. Iron ballast weights, each weighing between 60 to 80 lb, were suspended all the way around the base. Several divers could operate from the bell at the same time and the large volume of enclosed air would have provided a higher than usual endurance capability. Endurances of 1 to 2 hours were claimed. The handling of such a huge diving bell would have presented novel engineering problems and Baptiste's illustration helpfully includes details of how the bell was operated from a robust crane arrangement fixed between two surface vessels. The divers collected coins from the wrecks and their method of remuneration was novel to say the least. Each diver was allowed to keep as much of the money he salvaged as he could hold in both his hands and mouth!

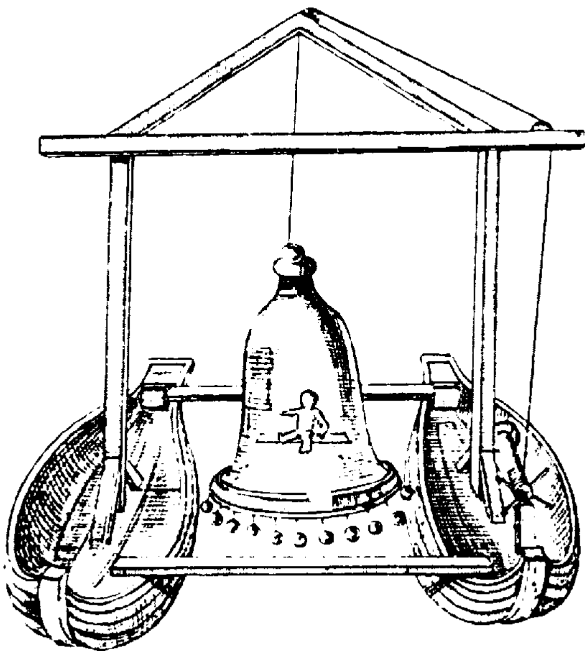

Figure 3. The Cadaques bell redrawn from illustration 568 in Sir Robert Davis' book *Deep Diving and Submarine Operations* (7th Edition, reprinted 1969).

Remaining in France, a most important proposal was made by Dr Denis Papin in a letter he wrote to Colonel du Rossy in 1689:[14,15] *Fresh air could be injected constantly into the diving bell by means of a strong leather bellows furnished with valves, by a tube passing under the bell and opening into its upper part. And so, since the bell would always remain empty and rest entirely on the ground, the bottom in this place would be almost dry and one could* *work there just as if he were out of the water, and I have no doubt that it would save much expense when construction must be carried on under water. Moreover, in case the leather bellows were not strong enough to compress the air as much as would be necessary at great depths, one could always meet this difficulty by using pumps to compress the air.*

This is a remarkable statement that was way ahead of its time. The suggested technique would not see the light of day until 89 years later when John Smeaton first applied a pump to a diving bell in England.

The Phipps experience had the effect of concentrating many minds on get-rich-quick-schemes. One of these minds was that of Sir Edmund Halley who was at the time suffering from a singular lack of success in making comet-watching pay.

With treasure-hunting foremost in his mind, Halley designed and built an improved diving bell incorporating for the very first time a brilliantly simple means of supplying air to the bell whilst it remained at work on the sea bed. His bell was constructed of wood coated with lead. It was 3 ft (0.9 m) in diameter at the top and 5 ft (1.5 m) in diameter at the bottom. There was a glass window at the top to admit some light coming down from the surface. Three weights, of 1 hundredweight (51 kg) each, were suspended 3 ft (0.9 m) below the bottom edge of the bell. The bell had an internal volume of 60 cubic feet (1,699 litres or 1.699 m^3) and would have accommodated two men in reasonable comfort. Surface communications was provided by a lead plate onto which appropriate messages could be scratched using an iron nail and the plate would then be sent up or down as required. A lump hammer served the function of an eraser. But the really novel feature was in the extra 36-gallon (162 litre) barrels, heavily weighted, which could be lowered down, air-filled, to the bell and the air allowed to escape into the bell via a short leather hose. The "used" warmer air inside the bell, which collected at the top of the bell, was vented through a valve at the top of the bell. This represented a quantum leap forward in bell diving technology. The bell could now work for extended periods without the need for frequent excursions back to the surface. Halley's first diving expedition was to Pagham harbour on the Sussex coast, England, in July 1691, where he demonstrated the ability to remain 1 hour and 15 minutes at a depth of 10 fathoms (60 feet or 18 m).[16] These numbers should start to ring bells in the minds of those with a hyperbaric medicine bent (there is an unintentional clue hidden in the pun). On 7 October 1691 Halley together with wealthy colleagues Sir Steven Evance, Francis Tyssen and John Holland, who undoubtedly shared Halley's treasure hunting ambitions, took out a patent for the ingenious life support system.[17] Halley formed a salvage company in 1692, which ran at least until 1696, the shares of which were available on the market. The stated maximum operating depth of the company was 10 fathoms (60 feet or 18 m).. Perhaps for tax reasons, little more is known about the success or otherwise of Halley's salvage company.

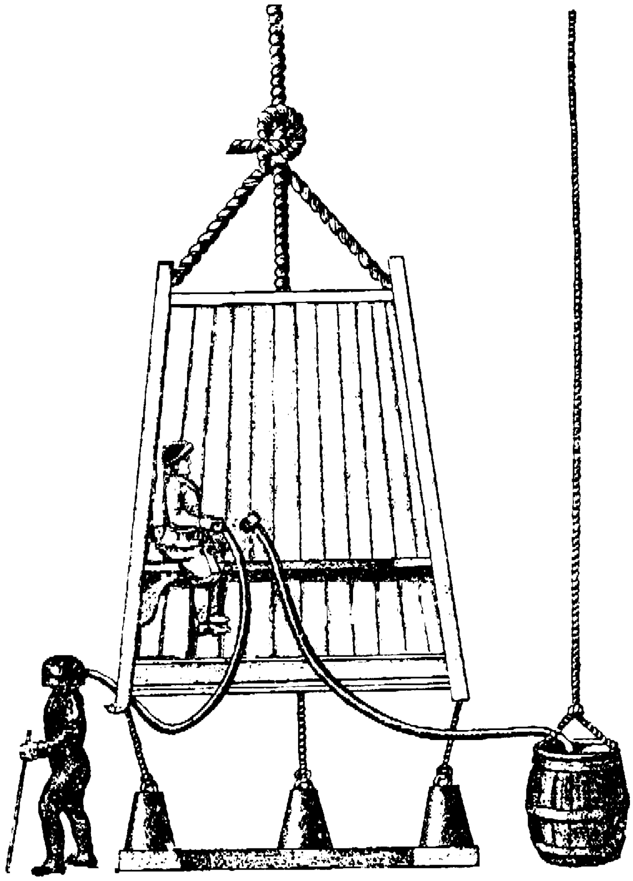

Figure 4. Halley's bell redrawn from illustration 570 in Sir Robert Davis' book *Deep Diving and Submarine Operations* (7th Edition, reprinted 1969).

The 18th century

The military reappear on the scene in 1728 when Marten Treiwald, Captain of Mechanics and Military Architect to King Frederick of Sweden, proposed a new twist in bell life support systems.[18] Treiwald's bell was made of copper loaded with lead weights at the rim and had a heavy iron plate suspended by chains beneath. The bell was for a single diver and supplied with air according to Halley's system. But Treiwald's improvement was a spiral tube that wound its way around the inside of the bell. His idea was that when the air in the bell was becoming exhausted, the diver, whose head would be near the top of the bell (where the warmer, exhaled air collected) could inhale through the tube and thereby use the fresher, cooler air at the bottom of the bell. The importance of this will be better appreciated when one remembers that the water temperature around the Baltic could be uncomfortably low so the diver would be keeping as much of his body out of the water, and as high in the bell, as possible. Treiwald referred to his bell as a

"Campana Urinatoria". Roughly translated this means a bell for hunting gold. Bell divers were referred to as Urinatores, meaning gold hunters though other interpretations have been proposed.

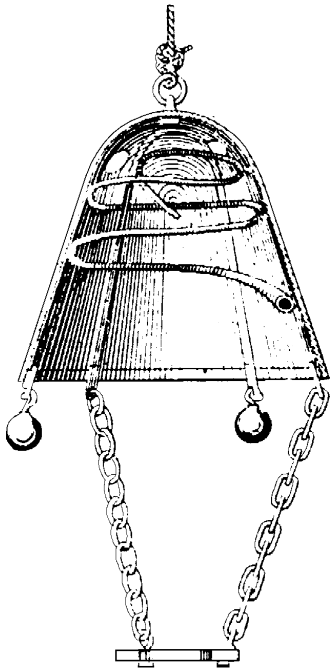

Figure 5. Treiwald's bell redrawn from illustration 571 in Sir Robert Davis' book *Deep Diving and Submarine Operations* (7th Edition, reprinted 1969).

So far we have seen diving bells being used principally for salvage operations, more or less on an opportunistic basis. The time was fast approaching when a more "professional" and perhaps respectable application was established. No less a person than the "father of civil engineering" was responsible for turning the diving bell into an engineering tool. John Smeaton, often referred to as the first true civil engineer, was founder of the Smeatonian Club for civil engineers which later evolved into the Institution of Civil Engineers in 1818. Smeaton is probably best remembered for his brilliant and enduring design for the Eddystone Lighthouse (1759-1882), all previous designs having fallen prey to the elements. Less well known are his efforts to underpin the bridge at Hexham, in the north of England in 1778. But it was here that he was the first to use a diving bell in a civil engineering construction function. Not only that but it was at Hexham that he also employed the force pump to deliver air into the bell for the first time (as first suggested by D Papin in 1689). This bell was a strong chest, 3 ft 6 ins (1.05 m) long, about 4 ft 6 ins (1.35 m) depth and about two feet (0.6 m) wide. The air pump was actually fixed to the top which protruded above water level.[19] Perhaps the reason Smeaton kept this project at a low profile was because the bridge fell down three years later. Undeterred, Smeaton went on to greater things and on 6 July 1779 he first used a new, cast iron bell which he had designed and built to carry out much of the underwater preparatory work at Ramsgate harbour which he was responsible for building. This bell weighed 50 cwt (2,545 kg). It was 4.5 ft (1,35 m) high, 4.5 ft (1,35 m) long, 3 ft (0.9 m) wide and had room for 2 men though they must have been a little cramped. Because the bell was to be used fully immersed the air was supplied by force pump through an umbilical air hose, the first time this technique for supplying air was used. The bell was intended to be lowered all the way to the sea bed and pumped dry so the divers could observe and work on the sea bed in relatively dry conditions. The main application of the bell was to remove stones from the sea bed before construction work commenced. About 100 tons (101,818 kg) of stones were removed by Smeaton in this way.

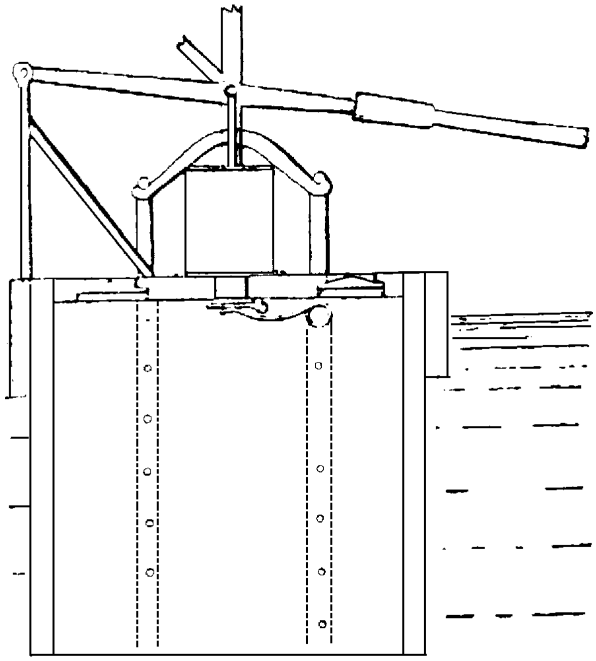

Figure 6. Smeaton's bell redrawn from illustration 573 in Sir Robert Davis' book *Deep Diving and Submarine Operations* (7th Edition, reprinted 1969).

Our next unlikely hero is a confectioner from Edinburgh in Scotland. Charles Spalding suffered a financial blow when a consignment of raw materials he had bought was lost, along with other valuable merchandise, in a wreck on the Farne Islands off the east coast of England. Being a bit of an unstoppable character, he was commissioned by his colleagues who had interests in the lost cargo to go and get the cargo back. So Spalding set about designing a diving bell to do the job. This he built and in 1775 off he went to recover his cargo. This was when he discovered the difficulties of operating a diving bell off a small boat and he returned empty-handed. He went back to the drawing board and redesigned his bell. This time he introduced some revolutionary improvements. His new bell had an air chamber at its top which could be either filled with air from the bell or flooded with water from outside the bell. In addition, he incorporated a weight slung inside the bell which could be raised or lowered at will. By this means, Spalding was able to control the degree of negative buoyancy of the bell and the height of the bell off the sea bed. The bell was 200 English gallons (900 litres) capacity. The top compartment was of 25 wine gallons. The bell required 16-20 cwt (815 to 1,018 kg) to sink it. The air was supplied using Halley's plan and air vessels of 40 wine gallons each. For normal operations the bell would be used in its heavy mode. The internal weight could be lowered a few feet below the bell to provide a useable stand-off distance from the sea bed. Alternatively the bell could be made less negatively buoyant, the internal weight adjusted to just below the edge of the bell and in this configuration, Spalding could stand on the sea bed, lift the weight (and bell) and move the whole bell laterally over the sea bed.[20-23]

One account of Spalding's successful bell diving operations stated "Mr Spalding, impelled by curiosity and intrepidity of spirit, and a genius for mechanics, made several attempts to remain for a considerable time in deep water under the bell which was always crowned with success. He at length became such a proficient in the aquatic art, that he could remain if necessary for a whole day in water of 12 or 14 fathoms deep" (72 to 84 ft or 22 to 25.5 m)![24] We are looking here at no less than the first saturation dives. And yet another first for the Spaldings was related in the same journal *His (Charles Spalding's) acquaintances having so many proofs of the trifling danger with which this wonderful visitation of the deep was attended, many of them ventured at different times to accompany; nay, an Amazonian lady, belonging to Edinburgh went down with him, where she remained upwards of half an hour.*

This must be the first account of a lady bell diver and it surely has to be the very first ever Amazonian bell diver!

Spalding's most successful diving operation was in September and October of 1782 when he raised 9 brass and 6 iron guns from the wreck of HMS ROYAL GEORGE sunk at Spithead, near Portsmouth, England. The following year he was employed to salvage the cargo from the East Indiaman *Count Belgioso* sunk just outside Dublin harbour, Ireland. Here he achieved yet another first which sadly has to be covered in the Diving Accidents paper.

The next bell diver appeared the following year on the same wreck where Spalding came to grief. This was Adam Walker of Manchester, England, a lecturer on natural philosophy.[25] He too had been commissioned to design a bell to recover the rich cargo of the *Count Belgioso*. Walker described his bell as follows:[26] "I recommended a conical tub of wood, three feet diameter at bottom, two and a half at top, and three feet high; so loaded with lead, at bottom, as just to sink itself; with a small seat for the diver; a small metal tube was attached to the in and out-side of the bell, as a, b, c, with a stop cock at a; and a flexible leathern tube or hose to the other end at c; this tube terminated in a forcing air-pump, fastened to the side of the ship; a solid piston actuated by a lever ... With this bell on his head, he can walk about several yards in a perpendicular posture." Walker's bell was perhaps the first time that a diving bell involved in an offshore salvage operation had been supplied by air by a force pump. The only previous example of this arrangement for the air supply had been Smeaton's application in harbour construction.

The 19th century

The use of diving bells in marine civil engineering took a major step forward in the early 1800s. John Rennie took over the improvements to Ramsgate harbour in 1807, some 15 years after the death of John Smeaton. He made further improvements to the use of the diving bell in actual construction activities including an overhead gantry bell handling system and the ability to hoist large building blocks under the bell and then into position underwater.[27] The cast iron bell was 5 tons (5,091 kg) in weight, 6 ft (1.6 m) high, 6 ft (1.6 m) long and 4.5 ft (1.35 m) wide. There were solid glass, cast "bull's eyes" on the top to admit light. The technique was later exploited in harbour construction works all over the world. His son Sir John Rennie, who later took over the business along with his brother George, became the principal manufacturer of diving bells in Britain. By the 1840s their bells had been supplied to all of the Royal Navy's dockyards around the world as well as to most of the major harbours and dockyards around Great Britain.

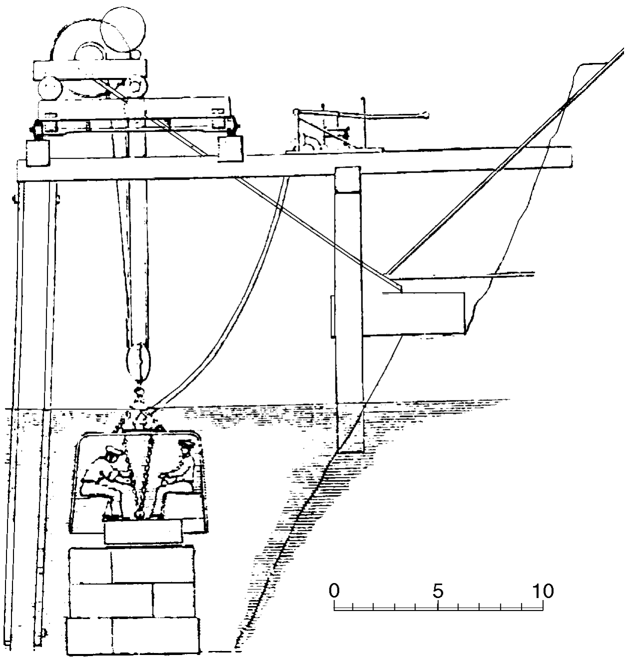

Figure 7. Rennie's bell redrawn from illustration 574 in Sir Robert Davis' book *Deep Diving and Submarine Operations* (7th Edition, reprinted 1969).

Staying briefly in Ireland, we next meet Thomas Steele, a rich land owner from County Clare. Steele was a colourful character who became politically obsessed, losing most of his family's fortune in a bungled attempt to send armaments to the revolutionaries in the civil war in Spain. He took out a patent for a unique diving bell in 1825.[28] The novelty lay in the inclusion in a cast iron bell of a separate compartment which remained at atmospheric pressure.[29-31] Whilst technically feasible, it was never a practical option. Steele later became a friend of the Deane brothers who invented the diving helmet and after a tempestuous political career associated with Daniel O'Connell, sadly took his own life in 1848 by throwing himself into the Thames from Waterloo Bridge.

By the early 1840s, the Rennie cast iron diving bell was the standard. When Colonel Charles Pasley of the Royal Engineers decided to move into the diving business he logically chose such a bell. In 1838 he attempted to use a Rennie bell, borrowed from the local dockyard, to clear the wreck of the brig *William* which was obstructing navigation of the Thames at Gravesend. It was not successful because the water current played havoc with the bell handling requirements. The job had to be completed by helmet divers. The following year Pasley began work on clearing the wreck of the ROYAL GEORGE at Spithead, Portsmouth. This time he decided to modify the diving bell to overcome the problem of tides causing the bell to be thrown violently about. His idea was to give the bell a hydrodynamic profile by the addition of "boat-ends". His prototype was built at great expense but the resulting structure was so large, heavy and unwieldy that it took over 40 men to operate it. Following the abortive trial on 14 May 1839 from HMS ANSON in the Medway, just off the Thames, Pasley was forced once again to revert to helmet divers and that was the end of his bell diving episode.[31]

Still with the military, the Crimean War (1854-1856) became the theatre for some firsts for underwater activities. The main underwater interest lay in the problem posed by the Russians when they sank a line of battle ships at the entrance to Sebastopol harbour to block access to the allied British and French fleets. John Deane was commissioned to blast a channel through these ships but that story belongs in another paper. Back in England, another brilliant mind applied himself to the problem. This was Charles Babbage, famous for inventing the computer, who proposed a unique diving bell design which could approach the sunken ships underwater and allow lock-out divers to place explosive charges against the hulls of the block-ships.[32] Fortunately the idea was never taken up so Babbage was spared to do more important work.

The Crimean War did however spawn one new diving bell design which at least made it into the water. This was the Nautilus Bell first patented by J H Tuck in 1855. The bell was ultimately built by Rottermund & Hallett for the newly-formed Nautilus Submarine Company and funded by the British government. A whole variety of top engineers were involved in its final design and construction. Amongst these were John Scott Russell, Major H B Sears and a Wilhelm Bauer of Austria. Even Augustus Siebe appears to have been helping on the sidelines, quite possibly with the plumbing, pumps, pressure gauges and valves. The bell was quite ahead of its day in concept and incorporated several unique advances, notably the ability to adjust its own buoyancy and move itself around the sea bed.[33] Sadly for the developers, the Crimean War ended before they had finished their project so they had to look elsewhere for a customer. In 1857 the rusting bell was spotted in Victoria Docks, London. The following year a desperate attempt was made to commercialise the project when the bell was demonstrated in the river Seine at Port Royal, France. But the absence of any further news on the subject suggests that it had joined the growing pile of failed diving bell designs.

The late 1800s and early 1900s saw a huge increase in harbour-building projects in and around Britain. One of these was a major harbour development which started in Dublin, Ireland in 1870. Yet another clever new concept was introduced to the diving bell for this operation. The engineer responsible had the colourful name of Bindon Blood Stoney. His diving bell was no less than 20 ft (6 m) square at roof level and 6.5 ft (1.95 m) high. But the innovative aspect was a vertical pipe, 3 ft (0.9 m) in diameter and 37.5 ft (11.4 m) long which was connected to the top of the bell. At the top of this pipe was built an air lock, 6 ft 6 ins (1.95 m) high. The total height of the system was 44 ft (13.3 m) and it weighed 80.5 tons (81,9 tonne). The brilliance of the idea was that the bell no longer needed to be raised to the surface every time the workers within needed to be changed and consequently slow down the operation. By the use of the air lock, the workers could commute in and out freely, at will. Surprisingly, one of the major problems encountered within the bell by the workers was that it became oppressively hot inside, despite being surrounded by water at about 10°C. At times, the men could not work more than 30 minutes without rest.[34] Bell buffs can still have guided tours around this bell which stubbornly refuses to rust away on the quayside at Dublin harbour.

The 20th century

Meanwhile on the south coast of England the harbours at Dover and Folkestone were being expanded. At these the Rennie system of placing large building blocks on the sea bed with great precision with the use of diving bells was heavily exploited. The expanding Siebe Gorman company grew even more successful through their design and manufacture of the large diving bells required for the works. In 1904 the Admiralty extended their pier at Dover harbour and Siebe Gorman built the diving bells for Messrs Pearson & Son Ltd. The bells were 17 ft (5.15 m) long, 10 ft 6 ins (3.2 m) wide and 6 ft 6 ins (1.95 m) high inside.

The bells came complete with lights, signalling gear and a "loud-sounding telephone apparatus". The latter was one of the first attempts at an electric telephone for underwater use. The bells were specifically designed to have flush sides so they could be placed very close to the quay walls. To permit this, the ballast weights were fitted inside the bell.[35] Siebe Gorman built more bells like these for harbour works in Devonport and Folkestone, England, and for Gibraltar. The Folkestone development which started in 1905 and was carried out by Messrs Coode, Son & Co, used two of Siebe Gorman's bells. Each bell was 12 ft 9 ins (3,9 m) long, 10 ft (3 m) wide and 6 ft 6 ins (1.95 m) high and weighed 26 tons (26,473 kg).[36]

The Royal Navy's interest in underwater operations grew in the 1900s, not least as the result of two world wars. Surface orientated helmet diving had been the mainstay of the navy's diving operations for generations but the technique was found to be severely limited when deeper diving was needed. The penalty of protracted decompression times demanded a new approach to deep diving. The next step in diving bell development is inextricably interlaced with decompression table development and I have to be careful not to stray too far into Dr David Elliott's territory. Suffice it to say that special diving bells were needed to provide the operational capability for divers to carry out hitherto undreamt of lengthy decompressions. The first step was a bell which could be sealed at depth and the divers brought to the relative safety of the ship's deck inside the bell, there to carry out the remainder of their decompression schedule. This was christened the Submersible Decompression Chamber (SDC) by its inventor, Sir Robert Davis. The Royal Navy first used a bell of this type, designed and built by Siebe Gorman, in 1931 when they reached over 300 ft (90 m) depth in Loch Lyne, Scotland. The system was stretched to its limit when the diver was surfaced from a pressure equivalent to 30 ft (9 m) inside the bell and he walked to a waiting deck compression chamber, there to be recompressed and again slowly decompressed (a sort of surface decompression procedure). This was the procedure adopted when Bollard reached a depth of 535 ft (162 m) from HMS RECLAIM in 1948, when he was able to find time to have a cigarette on his way from the SDC to the deck chamber. It was used again when Lt George Wookey reached 600 ft (182 m) from HMS RECLAIM in a Norwegian fjord on 12 October 1956. This time however both the diver and his attendant (R Clucus) were suffering from pain bends as they made their way over to the deck chamber.

This procedure was acceptable for the initial increase in diver depth capability, but the bell was too small for very long decompressions and the surface decompression procedure was often accompanied with unacceptably high bends incidence. So somehow the divers had to be transferred from the diving bell into larger pressure chambers on board the surface support vessel. Sir Robert Davis, the then managing director of Siebe Gorman & Co Ltd, had patented the solution in 1931[37] and illustrated the application in subsequent editions of his acclaimed book, Deep Diving and Submarine Operations.[38] The Navy, true to its traditional reputation for conservatism and scepticism, took a quarter of a century to acknowledge the merit of Davis's transfer-under-pressure (TUP) chamber. A TUP diving system was eventually commissioned on board HMS RECLAIM in 1957 immediately following the embarrassment at the bends suffered on the 600 ft (182 m) dive.

Davis's TUP bell was an immediate and unqualified success. It heralded the birth of deep diving on a world wide scale.

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SCUBA DIVING AND THE MENSTRUAL CYCLE: INTERIM DATA FROM THE SECOND YEAR OF A FOUR YEAR PROSPECTIVE STUDY OF DIVING WOMEN

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Key Words

Physiology, recreational diving, women.

Background

The majority of medical recommendations concerning females in recreational scuba diving are based on data from fit young men and animals and not from females who may be menstruating, menopausal or pregnant. The effects of increased pressure, resulting from scuba diving, on the menstrual cycle, or the effect of the menstrual cycle on a woman's ability to dive safely are not well documented.

Aerospace studies have attempted to evaluate any relationship between the menstrual cycle and altitude decompression illness (DCI).[1,2]

Studies of changes in the menstrual cycle in airline stewardesses have been carried out and have shown changes in menstruation, though some of these effects may be attributed to time zone changes.[3,4] In addition, separate studies of Chinese and South American non-diving female populations, living at various altitudes, have demonstrated changes.[5,6] Differences in abdominal pain, length of menstrual phase and hormone profiles were observed.

Only one formal preliminary study has so far attempted to address the issue of whether scuba diving affects the menstrual cycle.[7] This study acknowledged that more precise information and more subjects were necessary to expand on the results which showed that the dives, carried out in the hyperbaric chamber on two women, had no gross effect on the menstrual cycle.

Recently Doyle found that data from the Divers Alert Network (DAN) data base showed women taking the oral contraceptive pill were more likely to experience DCI if they dived whilst menstruating.[8]

Comparative studies, between males and females,[9-12] have attempted to assess the relative risk of diving DCI. The most recent is the "Men and Women in Diving" (MWD) study carried out by the Diving Diseases Research Centre (DDRC).[13] Studies have differed in their findings. Zwingelburg and later both Fife studies found no difference between males and females in the incidence of DCI. Bangasser's study showed that there was a 3.3 fold increase in the incidence of DCI amongst women compared