THE FRENCH BATHYSCAPH PROGRAM

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INTRODUCTION

The purpose of the third symposium on naval hydrodynamics is to study the latest technical developments concerning the means of navigation available to all men. Therefore it seemed reasonable to include, among other topics, the survey of a very new achievement which enables man to reach the greatest depths actually known, namely, the bathyscaph. But it was perhaps less logical to ask France to deal with this subject, since the diving record is now held by the U.S. Navy with the bathyscaph TRIESTE, manned by CDR Don Walsh and Mr. Jacques Piccard, who reached 11,000 metres in January 1960. I wish to express my thanks to the organizers of this symposium who asked me to read this paper, thus emphasizing the part taken by France in the development of this system of underwater navigation.

In the short historical account with which I shall begin this paper, I intend to give more details about this French participation, and to sum up the different types of bathyscaphs actually known.

In the second part, I will recall the principles involved in this new kind of navigation as well as the operational sequence of bathyscaph diving.

In the third part, I will briefly describe the first French achievement, the FNRS-3, then, in the fourth part, the new type now under construction, the Bathyscaph 11,000.

I will conclude by mentioning a few scientific results obtained during the 80 dives made by the FNRS-3 since it was built.

I regret to have no exceptional announcement to disclose to this honorable assembly as regards hydrodynamics: the only new fact concerning propulsion is the essential part played by the weight and by the Archimedean principle of buoyancy in vertical movements of the craft. All movement in other directions is achieved by means of conventional propellers which are entirely satisfactory in every respect.

HISTORY

The first attempts at very deep diving were made by two Americans, Professors William Beebe and Otis Barton, who in 1934 succeeded in diving to 908 metres, a remarkable depth at that time. But the 1.45-metre diameter and 45-mm thick cast steel sphere in which they

were enclosed hung at the end of a steel cable. Far from being a safe device, this permanent link with the surface was a source of real dangers; to say nothing of a possible breaking of the cable, which would have resulted in the total loss of the sphere (which was heavier than the upward pressure exerted on it), the motion of the surface ship, in a heavy swell, was amplified by the cable, so that the Bathysphere (as its designers called it) was very uncomfortable, and it was quite impossible to approach the bottom.

The inventor of the first self-contained deep-diving craft was Professor Auguste Piccard, a Swiss scientist. He applied to underwater navigation the operating principles of the free balloon. The observation sphere, which was much heavier than the volume of water which it displaced, was attached under a thin sheet-metal tank, filled with petrol lighter than sea water. This petrol was directly exposed to external pressure. Vertical movement was effected by jettisoning ballast: steel shot for rising and petrol for sinking. Professor Piccard, of the University of Brussels, submitted his design to the Belgian "Fonds National de la Recherche Scientifique" (FNRS) which eventually granted the necessary funds (1939). The construction, delayed by war, was resumed in 1945 under the joint direction of Professors Piccard and Cosyns.

The craft had been called FNRS-2 (FNRS-1 had been Piccard's and Cosyns stratopheric balloon) and it was shipped in September 1948 to Dakar, where the first trials took place with the assistance of the French Navy. Unfortunately, many defects in this first construction were revealed during these trials. However, the FNRS-2 succeeded in reaching a depth of 1380 metres without passengers, but all hope of performing this feat a second time had to be given up.

However, this semifailure had established the soundness of the general principles, and it was decided to undertake the construction of a new craft on the same lines. The job was entrusted to the French Navy by the Belgian "Recherche Scientifique." An agreement was signed in October 1950 between the Belgian FNRS, the French CNRS, and the French Navy concerning the design and construction of the new craft. Ingénieur Principal du Génie Maritime Gempp , who was in charge of this work, retained only the sphere of the first bathyscaph and succeeded in building a vehicle capable of being towed in a moderate sea and accessible to a crew when afloat, which was not the case with the FNRS-2, where the passengers had to shut themselves in the sphere before the bathyscaph was lowered and the float was filled with petrol, so that the prediving operations were so complicated as to be unacceptable.

Professor Auguste Piccard remained technical adviser to the French Navy for this work. He paid several visits to Toulon to join in discussions of the project. But in the beginning of 1952, he ceased to collaborate, in order to have another bathyscaph built in Italy, the TRIESTE. This Italian bathyscaph was constructed at Castellamare di Stabia, near Naples, and in August 1953, it dived to 3000 metres, manned by the famous Professor and his son, Jacques.

Meanwhile, the FNRS-3, as the French bathyscaph was called in tribute to the Belgian scientists who financed part of its construction, was planned and laid down in July 1952 by Toulon Naval Dockyard. It was launched on June 3, 1953 and made its first dives to 2000 metres off Toulon in August 1953. It was then taken to Dakar (French West Africa) and successfully achieved its first two dives to the maximum depth for which it had been designed, reaching 4200 metres on January 31, 1954, without passengers, and 4050 metres on February 15,1954 with passengers. I took part in this record dive as the engineer responsible for the construction, together with Capitaine de Corvette Houot, appointed commanding officer of the bathyscaph.

During this last dive, the bathyscaph descended to the greatest depth ever reached by man until the beginning of 1960, when the deepest sea floors known to this day (about 11,000 metres off the Philippines) were reached by the TRIESTE bought by the United States of America.

The U.S. Navy had acquired the TRIESTE with a view to using this powerful underwater research tool for oceanographic purposes. After the apparatus had undergone important changes: lengthening of the float, replacing the original sphere by a new one, forged by Krupp steelworks, in Germany, and enlarging the shot silos, it was an American bathyscaph which landed for the first time on the bottom of the Pacific Ocean, at the depth of 11,000 metres.

So, there are now two bathyscaphs in operation: one, the FNRS-3, is French, and the other, the TRIESTE, is American. Their research programs are quite similar: physical and biological oceanography, study of the propagation of supersonics and of electromagnetic radiations in sea water, and the geology of ocean bottoms. A second French bathyscaph is under construction in the Toulon Naval Dockyard; I shall mention it briefly at the end of this paper.

As to the existence of other deep-water oceanographic vessels, we can only guess, as these would be Russian. The USSR has stated several times that it was building bathyscaphs, but we have no information on this subject.

PRINCIPLES

To descend to great depths beneath the sea, man must enclose himself in a pressure hull that is watertight and capable of withstanding the pressure exerted upon it. To withstand a uniform external pressure, the best shape is a sphere; that is why the hulls of bathyscaphs have, up to now, taken the form of a sphere. Allowing for the safety factor selected and for the inside diameter necessary to meet the accommodation requirements, this sphere must have a certain thickness, which is determined by the strength calculation of materials. Owing to this thickness, the sphere is much heavier than the volume of water which it displaces. It would immediately sink to the bottom if it were not suspended underneath a float filled with extra-light petrol, which gives it the necessary buoyancy.

This is the main difference between a submarine and the bathyscaph: in the case of a submarine, the weight of the pressure hull plus the weight of all the hull fittings and inside equipment must be equal to the displacement. We shall apply the term bathyscaph to the machine for which the weight of the pressure hull, including that of internal and external fittings, is greater than its displacement. Therefore, the float is necessary to ensure the trim.

Vertical movement is effected by increasing or decreasing the machine's weight. The increase in weight is produced by jettisoning petrol (which is replaced by sea water); the dischargeable petrol is contained in a special tank, which is isolated from the float itself whose buoyancy must not be impaired; this attitude is absolutely necessary to the lift of the craft. The decrease of weight is produced by shedding ballast; this consists of small steel shot contained in vertical silos in the center of the float. This shot is held in at the base of the silos by the electromagnetic field of an electromagnet called an electrochute, which lets the shot fall when the current is cut. In addition, there is a safety device, called an electrorapid-release, which enables the opening of the silo to be freed completely

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if the electrochute is blocked. In any case, the ballast is automatically released in the event of a power failure.

External pressure acts freely on the petrol through a stabilizing hole, in the bottom of the float. Unfortunately, this petrol has an important drawback: it is very compressible. When the bathyscaph sinks, the petrol is compressed and sea water enters the float.

The resulting increase in weight is markedly greater than the apparent decrease in weight due only to the increasing density of sea water. Therefore, once the bathyscaph has started to sink, it descends quicker and quicker. It is necessary to discharge shot during the descent, in order to slow down this movement and to avoid sinking into the soft muddy bottom from which it would perhaps be difficult to break loose. On the other hand, once the bathyscaph starts going up, its speed increases progressively and it is impossible to stop it. The maximum speed under such conditions is approximately 1 metre per second.

Sphere and float are joined by a metal frame. The float is surmounted by a narrow deck running from stem to stern, with a conning tower in the center, in order to protect from heavy seas, during the towing of the bathyscaph to the diving site, the various external fittings that have to be placed there and the upper hatch of the entry shaft to the sphere. This entry shaft runs vertically through the float and enables passengers to enter or leave the sphere while the bathyscaph is afloat. It also acts as the submersible's water-ballast; that is to say, being normally empty on the surface, it fills with water during diving. The increase in weight when it is flooded with water is enough to make the machine submerge.

Added to this, there are also devices enabling one to tow the bathyscaph on the surface, to fill the entry shaft (by a flooding valve in the bottom) and to empty it (by means of compressed air), to land on the bottom with the aid of a guide chain, and to drive it horizontally while under water. There is exterior lighting, for detection of the sea floor and of obstacles ahead, and means of communication with the outside world while under water or on the surface, various measuring instruments, and so on. I shall give a fuller description of these accessories in the next section concerning the FNRS-3.

THE BATHYSCAPH FNRS-3

The sphere of the FNRS-3 is made of cast steel containing nickel, chromium, and molybdenum, with a yield point of 95 kg/mm^2 after heat treatment. It was built by the Emile Henricot steel works, at Court St Etienne, in Belgium. Its inside diameter is 2 metres, and its thickness 9 centimetres, reinforced to 15 centimetres around the hatch and porthole. It is composed of two hemispheres separated by the equatorial plane normal to the porthole-hatch axis. The joint consists of the two metal faces bearing one upon the other. The hemispherical parts are held together, with an initial force of 24 tons, by 400 steel clamps gripping two flanges machined on both sides of the joint.

Water tightness at low depth is ensured by a synthetic rubber ring which is fitted on the sphere before setting up the clamps. The viewing portholes, made of Plexiglas, 150 millimetres thick, are shaped in a frustum of a cone, with two parallel planes and forming an angle of 90 degrees at the apex. The internal and external planes have a diameter of 100 and 400 millimetres, respectively. At great depths, the watertightness of the joint between porthole and sphere is ensured by the plasticity of the Plexiglas. The hatch is made up of a steel frustum of a cone with two parallel planes and an angle of 45 degrees at the apex. At the center, it has a porthole which is similar to the viewing port. This hatch, weighing about 140 kilograms, is hinged about an axis and balanced in all positions, like a

submarine hatch, so that it is comparatively easy to handle. Around the porthole ten transit holes have been made in the sphere to link the inside with the outside, as follows: electric cables (Pyrotenax cables with copper sheathing and insulated with pressure injected magnesia) and pipes for hydraulic fluid and compressed air.

The float which contains the lifting petrol is made of steel plating 4 to 6 millimetres thick. It is divided into a certain number of tanks which only communicate at the bottom (to limit the loss of petrol in case of damage). The shot silos and the entry shaft to the sphere run vertically through the float. This float has a length of 16 metres and a width of 3.35 metres. The center part is cylindrical and the ends are in the shape of a truncated cone; two stabilizing keels are fitted on each side of the float to improve the dynamic stability during vertical movements and in particular in the course of an overrapid ascent. Trials on models, undertaken at the trial tank of the Service Technique des Constructions et Armes Navales had revealed the existence of oscillations in the course of ascents in a state of slightly excessive positive buoyancy (all ballast jettisoned), which might have been dangerous to the equipment and uncomfortable for the crew.

To conclude this description of the FNRS-3, it is necessary to mention the outside storage batteries housed in two baths filled with oil and exposed to external pressure. These batteries are used to run the propelling motors and the searchlights and supply about 1000 ampere-hours at 28 volts. The two motors are one-horsepower each. They drive two horizontal shaft propellers which enable the bathyscaph to be steered and moved horizontally over an approximate range of 50 metres. There are six searchlights of 1000-watt each. The incandescent bulbs which equip them are enclosed in steel cylinders which are designed to withstand external pressure.

All the remote controls of this external equipment are housed inside the sphere. Contact is maintained with the surface by an ultrasonic transmitting-receiving set, during the diving (radio transmission only works while the bathyscaph is on the surface). An echo sounder gives the distance from the bottom, a log the vertical speed, and a compass indicates the bearing of the craft during the descent. Moreover, an air-regeneration plant enables two men to live for 48 hours in this confined space; the carbon dioxide is absorbed by soda lime; the oxygen consumed is replaced by a fresh supply contained in cylinders of compressed oxygen.

THE BATHYSCAPH 11,000

The Bathyscaph 11,000 is the name we have temporarily given to the new French craft under construction, to indicate the maximum depth for which it has been designed, that is to say, eleven-thousand metres.

The sphere of the Bathyscaph 11,000 is made of forged steel, alloyed with nickel, chrome, and molybdenum, with a yield point of 105 kg/mm^2 after heat treatment. It was built by the Compagnie des Ateliers et Forges de la Loire in its works of St. Chamond and St. Etienne (France).

Its internal diameter is 2.10 metres (2 metres in the case of the FNRS-3) and its thickness is 15 centimetres (9 centimetres in the case of the FNRS-3).

The hatch, in the shape of a truncated cone, has an opening diameter of 45 centimetres and is located at the upper part, to facilitate the inner arrangement of the sphere. Three

viewing portholes are provided; one looks forward and the other two are side portholes disposed in vertical planes forming an angle of 50 degrees with the fore and aft symmetry planes of the bathyscaph. The axes of the three portholes point downward forming an angle of 20 degrees with the horizontal plane.

To avoid all change in thickness which would impair the aplexism of the sphere, no stiffening has been provided in the area of the hatch and portholes. Each of these is equipped with an optical system mounted in a 21-millimetre-diameter hole, which is plugged by Plexiglas shaped in a frustrum of a cone, forming an angle of 90 degrees at the apex, and only 45 millimetres thick.

The watertight lead-throughs into the sphere for cables and pipes have been designed similarly to those of the FNRS-3.

The float is approximately twice the size of the former. It has been designed to reduce to a minimum the power required for towing and to increase the towing speeds. That is why the sphere is no longer suspended below the float but it is now integrated to it, and the only area which is now visible is that of the three portholes. It will be 21 metres long and 5 metres high and its extreme width will be 4 metres.

As in the case of the FNRS-3, the new bathyscaph will have steel shot in silos running vertically through the float and held in by electromagnets placed at the base.

The outside batteries will be much more powerful than those of the FNRS-3. They will be located on the after-part of the float and will be accessible, when the bathyscaph is afloat, through an after-shaft similar to the forward one leading to the sphere. These batteries will supply the necessary power to a 30-horsepower propulsion motor driving a propeller with a horizontal shaft lying in the fore and aft symmetry plane of the bathyscaph. In addition, a steering propeller with an axis normal to the fore and aft symmetry plane and a lifting propeller with a vertical axis will each be driven by a 5-horsepower motor.

The 1000-watt pressure-resisting searchlights are still under design. All the measuring, navigational, and communicating equipment now existing on the FNRS-3 will of course be fitted on the new bathyscaph. The construction of this craft is financed by the French "Centre National de la Recherche Scientifique." It was begun in 1959 and will be completed during 1961. After trial dives to the maximum designed depths, the Bathyscaph 11,000 will, like its predecessor, be placed at the disposal of the Recherche Scientifique.

CONCLUSION

Although the main purpose of this Symposium is to investigate the characteristics of high-performance ships, I think it may be of interest to conclude this paper with the scientific results obtained during the first five years of the FNRS-3's operational activities.

During this period, the French bathyscaph made more than 80 dives, in the course of which it was possible for scientists interested in various scientific activities to undertake their respective researches. Thus, biologists have had the opportunity of studying the behaviour of abyssal fauna and the distribution of plankton versus depth and physical characteristics of sea water. Geologists and sedimentologists have been able to observe the various aspects of the sea bottom, to confirm or refute certain of their hypotheses concerning the formation of underwater canyons in particular. Physicists have installed on the bathyscaph precision recorders for measuring temperature, pressure, the pH value, the

speed of ultrasonics and their absorption, and so on. The physicist oceanographers also intend to measure the speed of deep underwater currents, the existence of which was not even suspected before the first dives.

I feel that now is the time to state that it is definitely out of the question to carry out oceanographic research from oceanographic surface ships. Man must penetrate into the medium he wants to investigate, since he now has the means of doing so. The oceanographic ship of the future will have to be submersible and in order to dive below one-thousand metres, which is the actual limit for conventional submarines, it will also have to be a bathyscaph. But, on the other hand, the study of the sea will only prove a poor investment if each country works on its own, without close cooperation with its neighbor. Oceanography is an international science calling for an international organization. The recent International Geophysical Year has already pooled the efforts of a great number of nations towards this specific purpose. This effort must be pursued in the future. I sincerely wish that the present and future bathyscaphs be designed and operated jointly by all the research workers who are interested in oceanography. As a matter of fact this symposium is striking proof that any real progress in the matter should spring from international cooperation. That is why I wish to thank once more the organizers of this symposium for inviting France to present her program concerning bathyscaph.

DISCUSSION

M. St. Denis (Institute for Defense Analysis, Washington)

Man will always try to excel himself and, having gone high, he will try to go higher, or, having gone deep, he will try to go deeper; but fortunately in this case there is a bottom to things. This idea of breaking records may be sufficient justification for building a bathyscaph, but if one tries to give a scientific reason for going deep, one must ask himself what he is to gain thereby. When man goes deep, all he can do at great depths is to look and to collect, and it would seem to me that he can see and collect with a lot less complication than a bathyscaph by using instruments remotely controlled from the surface. But be that as it may, and accepting the author's viewpoint that it is advantageous to have a bathyscaph to go deep to do certain things, it becomes evident that a manned vehicle is going to grow in size because one will want to carry more and more instruments or more and more people. And with a growth in size of the bathyscaph there follows a growth in size of the float and eventually the vehicle is going to become bigger and bigger and costlier and costlier. So one must ask oneself if this trend in size and in cost cannot be reversed or at least retarded. It seems that this can, to a large extent, be done, and it can be done by the proper choice of materials. Steel, even high-tensile steel, has not the same strength-to-weight ratio of, say, aluminum which is slightly superior to it; and titanium is superior to aluminum in this respect and fiberglass is superior to both. I have just a simple question and that is this: In constructing the bathyscaph, was any thought given to the use of these alternate materials, and if so, why were they discarded?

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