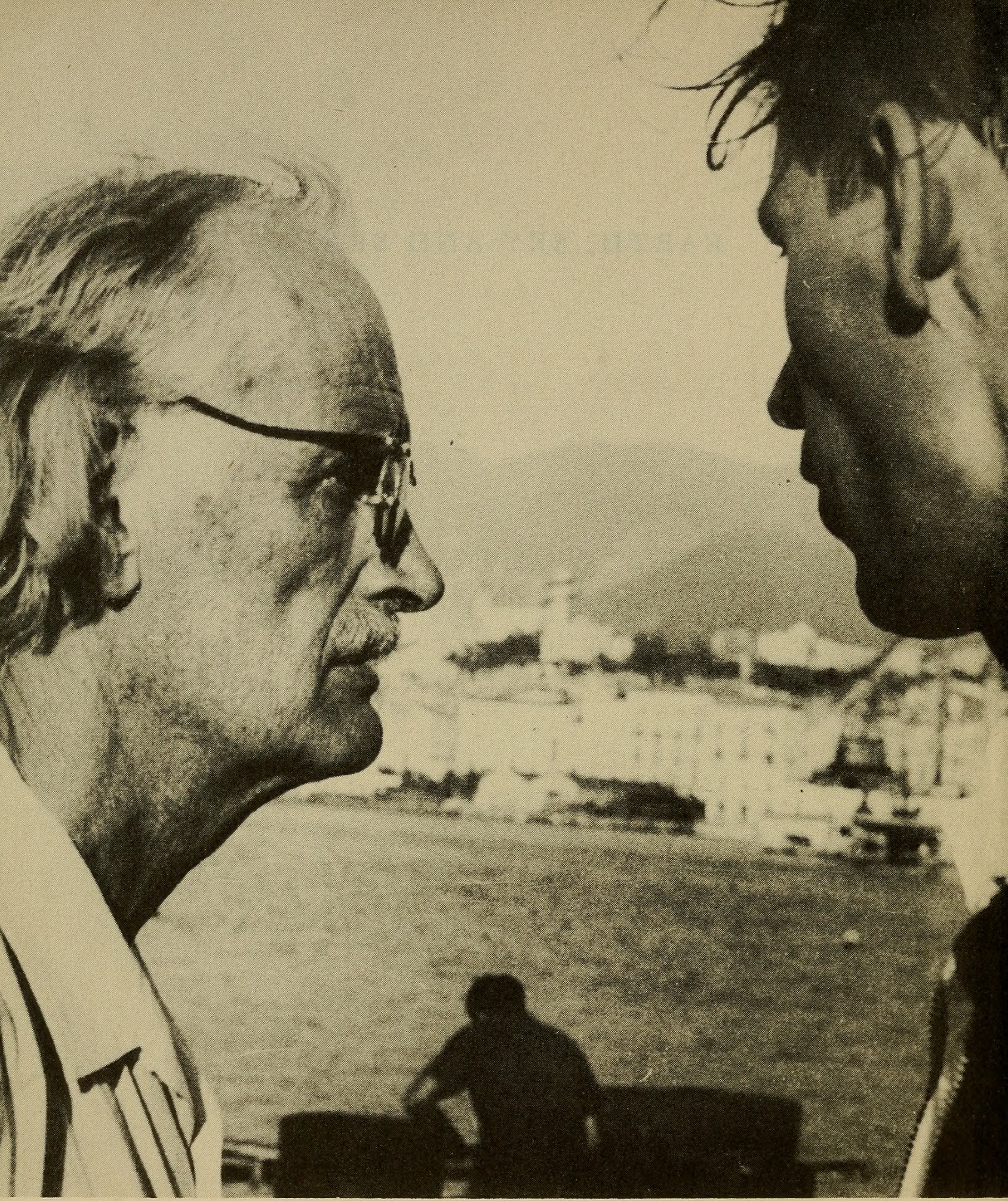
EARTH, SKY AND SEA



Professor Piccard and his son Jacques, the designers of the *Trieste*

EARTH, SKY AND SEA

by Auguste Piccard

translated by CHRISTINA STEAD

New York
OXFORD UNIVERSITY PRESS
1956

Library of Congress Catalogue Card Number: 56-9276

Published in April 1956, under the title *In Balloon and Bathyscaphe*, by Cassell & Company Ltd.

PRINTED IN THE UNITED STATES OF AMERICA

To my son

JACQUES PICCARD

Croix de Guerre

in recognition of his invaluable help which made possible the construction of the *Trieste* and its deep-sea diving.

'. . . replenish the earth, and subdue it: and have dominion over the fish of the sea, and over the fowl of the air, and over every living thing that moveth upon the earth.'

Genesis i. 28

The translator wishes to thank Mr. L. J. W. Hall who carefully read and annotated the manuscript in translation.

Contents

Part Four

TECHNICAL APPENDICES

List of Plates

Introduction

THIS book is not a manual: it is not my intention to explain to engineers how one must go about constructing a bathyscaphe. If that were my object, this work would contain many more technical details and the majority of its readers would find it trying: that is why I have avoided, as far as possible, formulæ and figures.[1]

This work likewise does not attempt to keep its readers breathless: the deep-sea dives effected with the *Trieste* conformed too closely to our forecasts to be dramatic. If, when we were on the sea-floor, we had had any trouble about releasing ballast and if we had barely managed to rise again after twenty-four hours, I could easily have dramatized this account. But, to me, a book of such a nature would have no reason for existence: on the contrary, I wish to show that the bathyscaphe is a dependable device, in which the father of a family may trust himself without anxiety.

The construction of an abyssal submarine is certainly not child's play: it requires the solution of an infinity of problems. But, in the end, there is no insurmountable difficulty: that is what I wanted to prove.

I have tried to express myself in such a way that anyone, even if he never had to deal with technical problems, may understand me. In particular, I have had in mind young people who do not yet possess the scientific equipment they will acquire later on, but who are already passionately interested in the achievements of science and modern industry.

But while getting a better grasp of the difficulties they will, I hope, share with me the joy felt in overcoming them.

People have often asked me why, after the stratospheric balloon, I wanted to build the bathyscaphe, a submarine designed for great depths. We will see in the next few chapters that the analogies between the two machines are striking, although they are intended for diametrically opposed purposes. It is probable that destiny wished to make these analogies fruitful by entrusting the same physicist with the working out of both types of apparatus. And how can we set ourselves against our destiny, especially when the end in view is so fine; when

[1] Certain technical details will be found in the Appendices at the end.

it is to play our part in one of the splendid tasks set for men, the conquest of our world? To discover new countries, to climb the highest peaks, to travel through new areas of celestial space, to turn our searchlights upon domains of eternal darkness, that is what makes life worth living.

However, the modern scientific seeker should not cast himself head foremost into these perils. The sport of the scientist consists in utilizing all that he knows, in foreseeing all the dangers, in studying every detail with profound attention, in always using the admirable instrument of mathematical analysis wherever it can shed its magic light upon his work. If he is convinced that in advance he has avoided all imaginable risks, and has neglected nothing in his plans, the scientist then has the serenity necessary to achieve success. Of what use is oceanographic research? This question has been asked me more than once. It is pointless. Two kinds of research exist. To begin with, the scientist works out of a love of research, without a determinate object, without always perceiving direct practical applications of his work. He discovers new facts, unknown relations. Even if this appears insignificant, a day will come when the results obtained will prove useful. It is then, but only then, that research turns towards the practical. Industry with its great resources then takes a hand. The most disparate discoveries are adjusted like pieces of a Meccano set, and what is missing is discovered in new researches. Then a new scientific edifice is built, something from which humanity will benefit.

We can make the following statement without risk of being contradicted by future events: each discovery, even the most apparently insignificant, will end by being of use to man. To support what we have just said, innumerable examples could be cited. Here are two: the Danish physicist Oersted (who discovered aluminium) observed that an electric current caused the compass to deviate. A fine discovery, of course, quite unexpected too. But of what use could it be? Then decade followed decade. The magnetic needle was made larger, the current stronger, Oersted's single loop was replaced by a coil. The result is the electro-magnet, the electric motor, the dynamo, the whole electrical industry, all those modern techniques of which we are so proud. In less than a century, the eight-hour day has replaced the fourteen-hour day. Was it really of so little importance for humanity, that, in a little laboratory, the needle in a compass turned a quarter of a circle? Here is another example, more recent. In this case the fundamental discovery and its practical utilization came close together. A British scientist, Alexander Fleming, took an interest in certain species of bacteria, keeping them alive on gelatine, taking care that no foreign spore entered his culture. Nevertheless, a spore of mould did enter. A green spot arose and developed. Fleming recognized it as the *Penicillium notatum*, in which he was in no way interested. This mould was even a nuisance, for all around it the cultures of bacteria ceased to develop.

Fleming could have thrown out the whole preparation and started another culture, taking still more care to avoid all contamination. But for what reason could the bacteria not live in the neighbourhood of the mould? A commonplace observation, perhaps. But in biology no fact is commonplace. Fleming studied the phenomenon at closer range. Other investigators followed him in this direction and much more rapidly than Oersted's discovery (we are in the twentieth century) Fleming's observation bore fruit. Everyone knows it. The *Penicillium notatum* secretes in minute quantity a new body, penicillin. It is toxic for the germs which cause certain maladies. Uncounted cures will be made presently, thanks to it and to other antibiotics which were discovered as an indirect result of the researches of one man.

The scientist, whether physicist, chemist or oceanographer, makes investigations then, first out of a taste for research; and if a new region of the earth, of the subsoil, of the atmosphere, or of the oceans opens up before him, if a new phenomenon or a new substance is discovered, he looks forward, thinking of the future. The work has not been done in vain.

By inventing an instrument able to navigate freely about the ocean-floor, I satisfied my taste for invention and, I trust, opened a door in oceanography.

EARTH, SKY AND SEA

PART ONE

FROM THE STRATOSPHERE TO THE SEA-BED

1: *In the Stratosphere*

THE technical means called upon for the exploration of the high atmosphere and the submarine depths present such striking analogies that my editor has asked me briefly to review the conquest of the stratosphere.[1] This work essentially aims at the description of my bathyscaphe and its voyages. Why did the achievement of the *FNRS*, for such was the name of my stratospheric balloon, precede that of the bathyscaphe? This is what I want to explain.

From the beginning of the last century it had been noticed that gases reputed to be perfect insulators for electricity could in reality, in certain conditions, conduct it. It had been observed, in particular, that the passage of electricity through the gases was possible when these gases were exposed to the radiation of radio-active bodies. But, what was surprising, these observations made in a balloon, for the atmosphere at altitudes of $2\frac{1}{2}$ miles to $5\frac{3}{5}$ miles,[2] revealed an increase of conductivity, while, as the distance from the earth and its radio-active bodies increased, it had been expected that a decrease would be observed. This led physicists to adduce the existence of another phenomenon, that of cosmic rays coming from outer space.

It was to enlarge our knowledge in this domain that I, a physicist, conceived the idea of ascending into the stratosphere.

Let us recall in a few lines what this word signifies. The higher we rise in our atmosphere, the lower are the temperatures we encounter. But, as Teisserenc de Bort discovered by means of his sounding-balloons, between $3\frac{3}{4}$ miles and 10 miles, according to the latitude and the season, we encounter a very marked limit beyond which the temperature ceases to fall, or even increases slightly, with the altitude. Here, from the meteorological point of view, begins the stratosphere, the region where the vertical displacements of air, which produce the

[1] On this subject see my book: 'Above the Clouds' (*Au-dessus des nuages*); Bernard Grasset, ed.

[2] These and all following calculations are suitable approximations to the figures in Professor Piccard's book. (Translator.)

condensation of water and the formation of the clouds, no longer exist. Thus the stratosphere is rightly termed the region of perpetual good weather. It is because it commences at $7\frac{1}{2}$ miles, as an average in our regions, that aviators in their everyday usage give this altitude as its lower limit.

It was to this high region, to be more precise to an altitude of 10 miles, that I wished to ascend to meet the cosmic rays in order to observe them in mass, where their initial properties would not yet have been too modified by collisions with the molecules of our atmosphere.

For a number of investigations, use had been made of sounding-balloons, the classic free balloon scarcely allowing man to do useful work beyond $3\frac{3}{4}$ to $7\frac{3}{8}$ miles. Beyond this range, in fact, the air is too rarefied for our organism, and even if the aeronauts have an equipment permitting them to breathe pure oxygen, they cannot stay for long above about $7\frac{1}{2}$ miles. The sounding-balloon was thus, for meteorologists, the sole means of exploring the high atmosphere. A generation had laboured to devise automatic instruments for recording pressure, temperature and humidity. But the measurement of cosmic rays was a delicate operation very different in nature, and could not be effected at the time with the necessary precision by these automatic instruments. That is why I decided to ascend myself to 10 miles. Luckily I was licensed as a free-balloon pilot and I had already made a dozen ascents. May I here relate how I became an aeronaut?

Like most young men of my time, I had a passion for everything related closely or remotely to this new science. It was the epoch when the heavier-than-air machine was making its first essays and when only optimists foresaw the future development of aviation: the lighter-than-air machine was still king of the sky. As a young physicist I naturally read all the aeronautical journals within reach. A question was being discussed in them by specialists: that of the distribution of the gas temperatures in the interior of spherical balloons. Now, I did not agree with the published results. These seemed to me to be in contradiction with theory, and this was explained by the fact that the method of measurement chosen was not suitable. It was necessary to take the measurements again in better conditions. I addressed myself to the Swiss Aero-Club (Aéro-Club Suisse) which, understanding the importance of the problem, permitted me to make several ascents with this scientific object. These were my first trips. I had in the interior of the balloon, along its vertical axis and also in the neighbourhood of its equator, a dozen electric thermometers, thermo-couples whose cold junctions were in the basket of the balloon. I myself constructed a simple and exact potentiometer and by means of an Einthoven galvanometer I could measure the temperatures of the gas within approximately a tenth of a degree. At the same time I could, by means of a rubber tube, take samples of gas from different parts of the balloon when it was at different heights and from them determine the density by means of a bunsen apparatus. This permitted me to follow the diffusion of the air coming in through the neck and being slowly mixed with the gas. All these measurements were made for daytime and for night-time at different altitudes, so as to show more clearly the influence of solar radiation.

These studies familiarized me with the balloon. I did not then think that later they would lead me into the stratosphere.

I have said that it was the study of cosmic rays which had led me into the stratosphere. As a matter of fact I had also another reason for going up there myself: I wanted to induce the air services to use the high atmosphere, to travel at high speeds at an altitude where the rarefied air offers less resistance. But since, in the stratosphere, the low pressures make human life impossible, I was going to have to make use of an airtight cabin permitting the maintenance of an almost normal atmosphere. The specialists of those days considered my suggestion as unrealizable. What today appears elementary to us, in those days seemed Utopian. But the single objection that they were able to make to me was that up till then no one had ever done it. How often have I heard reasoning of this sort! But it is just the function of the engineer to place his reliance upon theory when creating something new. If I had been an aviator I should perhaps have constructed, at the beginning, a stratospheric aeroplane. But being an aeronaut I plunged into the construction of a balloon. It was besides a relatively simple thing to suspend an airtight cabin to the free balloon.

The Belgian National Fund for Scientific Research (*Fonds National Belge de la Recherche Scientifique*), which had just been founded by King Albert I, supported my project and accorded me the necessary credits. In homage to the *Fonds National* the balloon was baptized the *FNRS*.

I wanted to ascend, as I have said, to meet the cosmic rays at a point where they would not yet have traversed more than a tenth of the atmospheric mass. Now at such an altitude the pressure is, naturally, no more than one-tenth of an atmosphere. In other words, at this height the pressure of the air is no more than a tenth of that we experience at sea-level. As the lifting force of a balloon is proportional to the density of the air displaced, as Archimedes would have already told us, I had thus to construct a particularly large and light balloon, so that it could carry observers, instruments and the airtight cabin.

I spare the reader the calculations I made: I had to have an envelope of 223,560 cu. ft., of 114 ft. in diameter, made of a material of the least possible weight. Here arises the principal difficulty in the construction of stratospheric balloons: a balloon of this volume, completely inflated with hydrogen, would have, at its take-off, a static lift of nearly 16 tons. To resist this force, material and net would have to be extraordinarily strong, and thus heavy—so heavy that the balloon would never reach 10 miles, where a cubic yard of hydrogen supports only one-tenth as much as it does down here. To permit the use of a light envelope, then, it was necessary to introduce into our balloon, at the moment of take-off, only a small part of the gas that it could contain, one-fifth of its maximum volume. During the ascent this gas would expand under the effect of the decrease of atmospheric pressure and only in the stratosphere would the envelope take its spherical form.

Which of my readers has been present at the rigging of a spherical balloon? The envelope is spread out on the ground, like a cast-net. Upon it the net is disposed. The gas is introduced. The envelope dilates and lifts up the net, which is held (and stretched) by bags of ballast. As the volume of the envelope increases, the bags are taken from mesh to mesh to be hooked on lower down. During this whole operation care must be taken that the folds in the expanding envelope open out completely, without being caught in the folds of the net. When the envelope has become spherical and has attained the desired height, the ropes attached to the net are affixed to the hoop and the balloon is prepared for the ascent. All this is accepted practice.

But our *FNRS* was to receive, at the beginning, only a small part of the gas which would later inflate it entirely. It was thus only the upper portion which would contain gas, the rest of the envelope remaining empty and hanging in great loose folds which would be progressively filled during the ascent. In these circumstances what was to be done to avoid the accidents arising from folds partially retained in the net? We could not count upon a procession of guardian angels to release the folds during the ascent; and as we could not give up the envelope, we were obliged instead to give up the net. It was therefore necessary to suspend the car directly to the envelope by means of a belt. (Fig. 1, Plates 1 and 2.) Here arose a difficulty of

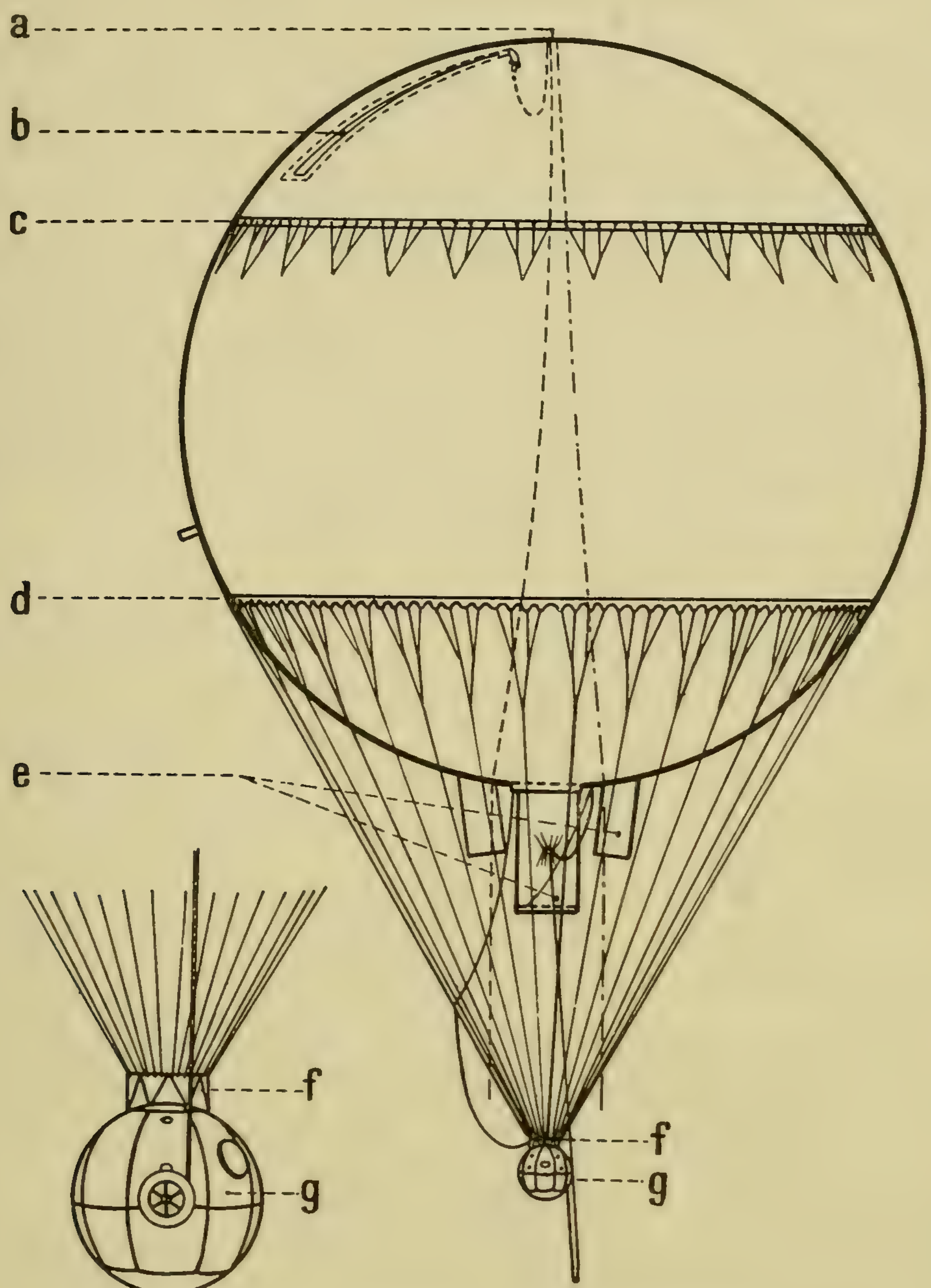


FIG. 1. The stratospheric balloon *FNRS*

a. Valve
b. Ripping panel
c. Ground-manœuvring band
d. Load-bearing band
e. Necks
f. Attachment of cabin to the envelope
g. Car

a new order. I had chosen Augsburg as the point of departure because it was there that the balloon had been constructed by Riedinger. Augsburg besides had the advantage of being distant from the sea in any direction. But a balloon, as well as a car, is subject to severe regulations. It must be constructed according to classic norms to obtain its certificate of airworthiness. Now my balloon varied from them in an intolerable manner, as much by the absence of a net as by the extreme lightness of the construction materials ($2\frac{3}{5}$ oz. to a square yard for the upper three quarters and only $1\frac{3}{5}$ oz. for the lower quarter, the whole covered by $2\frac{4}{5}$ oz. of rubber to the square yard).

An administration can make no exceptions, above all when a foreign professor is in question! The German permit was thus refused to me. Fortunately the international agreements allow a Swiss aeronaut to leave Germany with a Swiss certificate of airworthiness originating in Berne, and Berne, more liberal, gave me the authorization asked for.

Let us now look at the basket of our balloon, or rather at what it had instead of a basket. We must have a hermetically sealed cabin, carrying breathable air at ordinary pressure, and able to resist this internal pressure even when the outside pressure will be no more than one-tenth of an atmosphere. Our lives depend upon the airtightness and the strength of this cabin. Let us, then, have a spherical cabin in sheet aluminium of one-seventh of an inch (3·5 mm.) thick. The diameter will be 7 ft. (210 cm.). Two observers, surrounded by their instruments, will be perfectly comfortable here, surveying the outside world through eight round portholes of a convenient diameter, that of 3·15 in. (8 cm.). To avoid the danger of breakage caused by the difference between the pressures prevailing on the two faces, these windows are constructed of two sheets of glass, each 0·3 in. thick, separated by a thin layer of air which contributes to thermal insulation. We thus prevent the formation of rime on the windows, even in the stratosphere, where the external temperature is in the neighbourhood of −76° F. These windows offer no danger of breakage even when obliged to sustain a difference in pressures of nine-tenths of an atmosphere.

I did not imagine then that, nine years later, I should construct portholes to resist a pressure of 600 atmospheres.

How could we, from this sealed cabin, manage to drop ballast without air escaping? The principle of the air or water lock is well known. Here is how, when I was still a child, I observed its functioning for the first time. One day I was taken to visit a menagerie. In one of the cages was a lion and a lion-tamer. How would the tamer get out without the lion being able to follow him? It was a revelation for the little lad that I then was: the tamer went into a little adjoining cage through a door which he closed behind him: only after this did he open a second door which gave him access to the outside: at no time were the two doors open at once and the beast had not been able to get out. Forty years later I had not forgotten this scene. The tamer was now the ballast, which had to get out of the cabin without allowing the lion, that is, the air, to follow it.

It was sufficient to apply the principle of the air-chamber: let there be a container provided with two straight-through taps. By means of a funnel, we pour the ballast into the container through the upper cock, the ballast being composed, in our case, of lead-shot. Then, after this cock is closed, the lower cock is opened and through it the ballast pours directly towards the outside. So that the lead-shot in falling might not injure spectators, a very fine shot is needed. I made sure myself that there was no danger, by standing at the bottom of the big chimney of the University of Brussels under a rain of shot which was poured on my head from a height of 165 ft.

All would have been for the best if international regulations had permitted anything other than sand or water for ballast. What was to be done? To cut all discussion short, I declared that I had as ballast lead-sand. This explanation aroused no objection. However, by definition, sand is a non-metallic substance and nobody has ever seen lead-sand! I thus imitated the famous priest in the anecdote who was served with roast chicken on a Friday: he baptized it 'carp' and was thus able to enjoy it with a quiet conscience.

Let us note in passing that it was iron-shot which was used as ballast for the three bathyscaphes.

My brother, for his balloon, has found a graceful method of resolving the problem and satisfying the regulations in force: this time the ballast is of sand, real sand, and the sacks which contain it are arranged on the outside of the cabin: each one of them contains a detonator which electric conductors connect with a battery lodged in the cabin. A simple pressure on the switch button suffices: the sack rips open and empties itself. Afterwards this arrangement was adopted on the *Explorer II*, with which the American pilots reached $13\frac{2}{3}$ miles. The balloon had been inflated in a sheltered valley: the balloon commenced its ascent when, suddenly, the wind beat it down upon trees standing on a ridge. If the pilot had not immediately made use of his switchboard the *Explorer II* would have been destroyed. No other system of unballasting would have been speedy enough to save the balloon.

I cannot here give the whole story of the construction. However, I should like to describe one incident. It happened at the moment when the building of the car was nearly finished. The cabin possessed two manholes, closed by means of hatches to be put into place from inside: the pressure prevailing in the cabin forces the hatches against the joints. This principle is employed in all pressure chambers: the hatch naturally has a diameter greater than that of the opening. However, in order to be able to introduce the manhole cover usually the manhole is made oval: the cover is inserted by first putting in the small end and then by rotating it, bringing it into place. On the contrary, I had asked that the manholes in my cabin should be circular: for one thing, this system guaranteed better airtightness, and for another, the round shape better suited the spherical form of the cabin. In such a case, when the cabin is finished, there is no longer any possibility of getting in the hatches. I had therefore remarked that the covers should be placed in the cabin before they welded the last sheet of aluminium. When giving the order I had once more insisted upon it: of course, the directors of the factory were of my opinion, but not the worker responsible. Better than anyone else, he knew how to manage it: it was not the first pressure chamber that he had built and he had always seen the manhole cover put in last of all. (I even suspect him of never having understood why the manholes were oval.) For him, a man of action, only practical experience counted. He was wary of theory and was not going to let anyone impose upon him: still less a university professor whose reasonings were abstract. The car was welded then, but—without hatches.

I was invited to examine the finished effect. My first glance went to the inside of the cabin.

'But you've forgotten the hatches!'

'No, they're there.' And I was shown the hatches nearby.

'But you know that they should be inside. Now you won't be able to get them in.'

'But I don't see why not,' he replied, convinced that his experience was as good as that of ten university professors.

He took up a hatch and turned it about in every direction, like a child trying to push a saucepan lid into the saucepan. Then, when I returned to the factory, the two covers were inside the cabin. I paid tribute to the dexterity of the workers: and I am still wondering whether they had cut open the walls again or if they had cut through the hatches and rewelded them once they were inside. The repairs were, in any case, completely invisible.

Augsburg, September 1930. On the 14th September the balloon was inflated. Knowing that the wind would hinder the rigging of this large balloon and could even render departure impossible, we had waited several weeks for favourable weather forecasts. But to our great despair the weather changed abruptly, a violent wind took a hand and we had to empty the balloon and give up the idea of departure. A great disappointment, it goes without saying, for the public and the Press!

We waited once more for a more clement sky, but in vain. We had to wait until spring, winter not being a season favourable to an experiment of this sort. Finally, on the 26th May 1931, the weather forecasts were favourable. In the night of the 26th–27th May we got the balloon inflated: 100,000 cu. ft. of hydrogen. But on the morning of the 27th the wind rose once more and knocked the balloon about: the cabin was thrown out of the transporter and put slightly out of shape (later we were to notice the consequences of this). However, with my friend and collaborator, Paul Kipfer, I went into the cabin and we closed the manhole behind us. The wind increased. To hold the balloon, they attached, without my knowledge, a supplementary rope to the hoop. At 3·57 p.m. Kipfer, looking out of one of the portholes, said to me:

'A factory chimney is passing underneath us!'

They had let the balloon go and forgotten to give us the signal of departure that had been agreed upon!

We went up very quickly. Some moments afterwards I perceived that the insulator of an electric sounder going through the wall of the cabin was broken at the time it fell: the air—our precious air—was rushing out, whistling through the hole. Fortunately I had had prepared a mixture of tow and vaseline, expecting that this paste would be useful in case of a leak. I surrounded the insulator with insulating tape and with this paste. The work was not easy.

Soon Kipfer, who was observing the pressure gauges, said to me:

'We are at 2½ miles and there is still an equal pressure inside and outside the cabin!'

Well, why have I had this beautiful aluminium cabin built? Since it leaks like a basket, a simple wickerwork car would have been as serviceable! The situation was critical. I said to my companion:

'If we don't become airtight immediately, we must pull the valve and land, if we don't want to suffocate.' We didn't yet know that the rope of the valve was blocked. . . .

Both of us confident in this last resource, I went on with my work. But the hole was big! Bit by bit, however, the whistling grew feebler, then was silent. Never have I appreciated silence so much. The pressure already in our little home had gone down to less than two-thirds of normal. Happily we had a reserve of liquid oxygen. I poured some of it on the floor in small quantities[1] and the oxygen rapidly evaporating increased the pressure.

We still went up. The sky became darker.

Twenty-five past four! Twenty-eight minutes ago we were still in Augsburg, 1650 feet above sea-level.

'What altitude, Kipfer?'

'51,200 feet.'

In less than half an hour we had gone up over 9 miles. The balloon, whose shape at the moment of departure was rather that of a dried pear than of an apple, had now inflated following upon the expansion of the gas and had become perfectly spherical. The excess gas escaped by the neck and our aerostat reached its first position of equilibrium.

At last here we are in the stratosphere!

Around us the sky. The beauty of this sky is the most poignant thing we have seen: it is sombre, dark blue or violet, almost black. If the air were perfectly transparent, we should see the earth over a radius of 280 miles, and our visual field would cover 246,000 square miles of the planet (more than the surface of all France). But beneath the stratosphere there is the troposphere, whose upper limit on that day was about 7½ miles: it is much less transparent. At the horizon we perceive the confines of the two zones, as if drawn with a ruler. If one looks obliquely across the troposphere, the earth, so distant, is invisible: there is nothing to be seen but fog. But the more the glance is directed downwards, the more visible is the earth. Beneath us is the Bavarian plain. But, even if we look vertically down, the picture is blurred as in a bad photograph. There is, in fact, between us and the earth nine-tenths of the atmosphere, almost as much as if, at sea-level, we were looking at the moon. Alone, the mountains emerge from the foggiest regions of the troposphere. At first hidden by clouds, they

[1] If one pours out too much oxygen at a time, the sudden increase of pressure affects the ear.

reveal themselves bit by bit: a summit, then another: at last, all the snowy chains of the Bavarian Alps and the Tyrol, which we are approaching gradually.

In spite of the splendour of the spectacle, we took precautions. We threw out over a hundred pounds of ballast, which caused us to rise some hundreds of yards.

We soon made a very unpleasant discovery: the rope which controlled the valve was not working. It was tangled with the supplementary rope which was affixed at the moment of departure. Now, if we could not open the valve, we could not let the gas escape, to begin the descent. Instead of obeying us, the balloon would go down only when external conditions permitted it, that is to say, when it grew colder at sunset. Where should we be then? Over the land? Or above the Adriatic?

As it descended, the balloon would grow longer: the rope operating the stopped-up valve would therefore be stretched out, and would open the valve, accelerating our descent more than we wished.

However, to carry out our programme and reach that altitude where the pressure is only one-tenth of an atmosphere, we threw out more ballast and soon we saw a difference on our barometer between the two meniscuses of 2·992 in. exactly. Being used to seeing in the laboratory, on our barometers, columns of mercury of 29·92 in. we had a curious sensation when we read a barometric height reduced to one-tenth of what we call its normal value.

We should have been perfectly happy if it had not been for this incident of the valve. The future was uncertain. What were we to do? We decided not to throw out any more ballast, partly to shorten our trip, and partly, also, to be able to dispose of what remained at the moment of landing. Then we decided to pack up the instruments. If the balloon, as it drew out in length, itself pulled open the valve and thus occasioned too sudden a landing, we had to take precautions against being injured by loose objects.

We tried once more to open the valve by turning the windlass winch around which the cable was wound, by means of a crank placed inside the cabin. But the cable broke clean off, which definitely put at an end any hope of controlling the balloon.

There we were, prisoners of the stratosphere. Fortunately we had at our disposal a good reserve of oxygen, and of alkali, which is used to absorb the carbon dioxide produced by our breathing. Although our programme provided for a landing about midday, I had a reserve which should have let us remain shut up in our cabin until sunset. Provided, at least, that we could keep the cabin airtight. Having felt several times, in our ears, a sudden lowering of pressure, we perceived that we were once more losing air through the hole near the insulator; the vaseline had run out through the tow. So the struggle for life began again. The longer the trip took, the greater was the danger of reaching the Adriatic. We had a drift indicator which hung 50 yards below the car. As long as land was visible, it permitted us to determine our speed and the direction of our drift. The direction was, in fact, towards the Adriatic. Our speed was, luckily, very low: if it did not increase we were sure not to leave terra firma during the day. In the stratosphere the wind is often very violent. On certain days it would have borne us as far as above the Persian Gulf. If I had known the mountains which surrounded us, I could have found our position. But the view was too often obstructed by clouds to permit us to follow our course on a map. It would not have helped us much anyway. We could do nothing about it and all we could do was to await the turn of events.

As a last stroke of ill-luck, one of the large mercury barometers broke as the result of an awkward movement. The liquid metal flowed to the bottom of the cabin. Now, in certain cases, aluminium can be rapidly eaten away by mercury. Fortunately a good layer of paint protected the cabin. Nevertheless the presence of mercury was not reassuring. If only we had possessed a little pump with which we could have sucked it up! We had with us a rubber tube. If only, we thought, we had had a vacuum cleaner! As a matter of fact, never had a physicist at his disposal more vacuum than we had! The whole stratosphere was at our disposal. We connected our tube with a tap which led outside and we placed the other end on the cabin floor. The mercury was sucked up and thrown outside as well as the condensed water which had accumulated at the bottom of the sphere. But we hadn't come to the end of our difficulties.

We had departed before sunrise and we had traversed at high speed those zones where the temperature was between 50° and 75° C. below zero. The walls of the cabin were then very cold and its interior was rapidly covered by a good layer of frost. It was as if we were in a drop of crystal. If the situation had lasted, we should have suffered seriously from the cold. But soon the sun rose, the stratospheric sun.

Its radiance is twice as intense as at sea-level. The aluminium became heated and the frost dropped off. It began to snow in our cabin.

Bit by bit the temperature rose. 70° F. was very pleasant. 85° was bearable. But over 100° was too much! We sat down as low as possible in the sphere, as there it was coolest, but still we got very thirsty. I had asked that two big bottles of water should be put in our cabin: we found only one small one. Beneath the flooring with which the rounded bottom of our cabin was covered, the condensed water had collected: there would have been enough of it, but dust, oil and mercury made it into an undrinkable emulsion. Luckily Kipfer discovered a spring: fresh water, clean and distilled, flowed along the wall, on the shady side: there was not much of it, but it sufficed to wet our tongues from time to time. I found something even better: when we poured liquid oxygen into an aluminium goblet and waited for the oxygen to evaporate a thick layer of frost was formed outside. But it was so cold it burnt to the touch, for it was formed at – 350° F.: we had to wait a bit until its temperature was that of melting ice.

12.30 p.m., the sun at its zenith. At last the entire cabin came into the shadow of the balloon; and the temperature sank. One side of the cabin was painted black, the other being left bright. I had intended, by making the balloon turn round, to regulate the temperature, since black absorbs more heat than a bright metal: but the motor intended to bring about this rotation had been damaged at the time of departure: the whole morning it was the black side which had been exposed to the sun. During the afternoon the balloon turned round: and so we no longer had to suffer from the heat.

Towards two o'clock in the afternoon we began to descend very slightly. But a rapid calculation showed us that at this rate we should take fifteen days to get down! As a precaution, we decreased the outlet from our oxygen apparatus and we kept as still as possible so as not to turn too great a quantity of this precious gas into carbon dioxide.

3 p.m. The speed of descent is more marked. However, it would still take twenty-four hours at this rate to land. All the same the descent is getting faster: that is the essential thing.

4 p.m. 5 p.m. 6 p.m.! The hours are passing. We are crossing the Bavarian Alps. The sun is going down. The balloon, now colder, descends faster and faster.

8 p.m. Altitude 7½ miles. At last we had left the stratosphere. By the fog which suddenly covered the distant horizon we saw that we

were passing into the troposphere. Below us twilight flowed through the valley of the River Inn. On the ground, we found out later, people saw an unusual sight. The balloon, still in the sun's rays, appeared to the earth-people brilliantly illuminated against the dark sky. Until today, only the planets and the moon have been seen lighted up in this fashion. So they took us for another heavenly body. To the observers nearest at hand, the illuminated part of the balloon appeared in the form of a crescent. Had a little moon been born? Nothing was missing, it even had a halo. This was produced by the light reflected by the balloon and diffused in the fogs of the already obscured troposphere. (On the 18th August 1932 the reverse took place: our friends who were following us in a car were speeding in the direction of Venus, which they took for our balloon.)

The sun disappeared beneath the horizon. We descended more and more rapidly. Now it is known that if more ballast is thrown overboard than is necessary to stabilize a descending balloon, and the valve is not opened, the balloon will generally climb again to its earlier position of equilibrium. We had to be very careful then, when throwing out ballast, not to go back at one jump to 10 miles up. It was just unfortunate if the landing proved a little rough.

By means of the tap which communicated with the open air, we slowly decreased the pressure in the cabin, so that we could open our manholes as soon as possible.

Kipfer watched the barometers. At 15,000 ft. he announced equal pressures within and without. We opened the manholes immediately and put out our heads. After having been shut up seventeen hours, we were at last in the open air. Above us, the starry sky. Beneath, the high mountains, snow and rocks. The moonlight was magnificent. Two little clouds were lighted up from second to second by stormy discharges: but we saw no lightning nor heard any thunder. To be ready for anything, we prepared our parachutes, but the balloon very luckily left the stormy zone.

A glance towards the horizon: it still formed a straight line. But soon gloomy silhouettes emerged: mountains. We were already lower then than the highest peaks. Things were going to happen fast. We were in the high mountains near a pass covered with ice. On the south side it appeared to lead rapidly down towards the plain, but we were drifting northwards. Because of the danger of climbing again to 10 miles with the manholes open, we dared not cast out any ballast, and were obliged to manœuvre only by means of the ripping panel. We touched a very steep field of snow. In my hand I held the strap which allowed me to open the panel and to empty the balloon almost instantly. But I took good care not to do it: the site was not suitable for a landing. The balloon bounced and flew over a glacier. It was a maze of crevasses. One moment I could see the lights of a village, and I flashed a signal towards it with a torch. (The next day we learnt that this signal was seen perfectly from Gurgl.) But the village disappeared in the valley. At last we approached a flat place free of crevasses. Now was the moment! Kipfer pulled the strap of the ripping panel; the balloon quickly emptied; we touched the ice, the cabin rolled a little, then came to rest.

My manhole was on top, so I had an unrestricted view. The envelope was floating above us. The wind was so light that at every moment it threatened to fall on the cabin: then it leant over and lay down on the glacier: the opened ripping panel being underneath, it emptied only very slowly. A glance into the dark cabin showed me a heap of strange objects: 400 lb. of instruments, 750 bags of small shot, all scattered about upside down. And underneath, Kipfer, who was slowly picking his way out towards the top.

We had landed at an altitude of some 8700 ft. Switzerland? Austria? Italy? We bivouacked where we were. The place would have been fairyland if it had not been so cold! Wrapped up in the balloon material, I went to sleep, but I started from sleep from time to time, woken by the noise of a waterfall which in my dream I mistook for the whistling of our air leak! At dawn, from aeronauts we became alpinists: linked by a double rope, sounding the snow at every step with a bamboo stick found in the rigging of the balloon, we reached the edge of the glacier, and seeking out passages across the rocks, we went down slowly towards the valley. At midday a patrol of skiers came from Gurgl to our rescue, reached us and led us to the village. It is with gratitude that I think of the valuable help given to us as much by the mountaineers as by the authorities in the Tyrol. Forty men, twenty soldiers and twenty peasants carried the envelope of the *FNRS* on their shoulders from the Gurgl glacier to the village, without a path or on the worst trails and all this without one tear in the delicate material.

A few days later, at Zurich, where the Swiss Aero-Club welcomed us in triumph, its president, Colonel Messner, congratulated us, and expressed the hope that the world altitude record which we had just set up would not be beaten for many years. In my reply I had to contradict him.

'It will be a fine day for me,' I said, 'when other stratospheric balloons follow me and reach altitudes greater than mine. My aim is not to beat and above all not to maintain records, but to open a new domain to scientific research and to aerial navigation.'

In the months that followed, although we reached the altitude we aimed at, our enterprise was called foolhardy, partly because the valve rope became jammed: if we are safe and sound, it appears, it is a miracle. My spherical balloon had a bad press: I had no emulator, at least at the beginning. Meanwhile I kept myself occupied with work on cosmic rays. After a while I wanted to make a new ascent. This time it was my friends of the Aero-Club of Zurich and more especially Dr. E. Tilgenkamp, Colonel Garber and Dr. Bonomo who took it upon themselves to organize it.

In the early days of August, the weather forecast seeming favourable we decided to set forth the next day: the balloon was to be inflated during the night. In the afternoon, in radiant weather, the envelope arrived and was spread out. A little later, M. Jaumotte, director of the Belgian Meteorological Institute, rang me up from Brussels. He had heard that we were planning to take the air, but he warned me that thunderstorms were expected over central Europe during the night. Zurich confirmed this forecast, so I did not hesitate. Although the crew was already mobilized and everything ready for the business of filling the balloon, we cancelled the departure.

I still remember what the reporters thought of it: for was not the sky cloudless? Fortunately I stuck to my decision. And I smiled when later a violent storm burst over Zurich and Dubendorf. That night, I am sure, meteorology gained prestige in the eyes of the international press.

On the 17th August, finally, the forecast was good. In splendid weather, in the night, without a breath of wind, the *FNRS* was inflated: on the 18th, before sunrise, all was trim and at seven minutes past five in the morning, 'Let go!' rang out. What can I say about the ascent? Everything went smoothly according to our plan, like a laboratory experiment prepared with minute care. We found out that the particular gamma radiation, which according to a certain hypothesis should have been manifest above in an intense fashion, did not exist. Enjoying perfect visibility, we drifted slowly above the Lake of Wallenstadt, the Grisons, then the Lago di Garda, in the direction of Desenzano, where we arrived at 5 p.m.

Every landing in a free balloon has its surprises. It is one of the charms of the sport. At the moment when the guide-rope was about to touch the earth, I collected my best Italian to hail a crowd which gathered:

'*Prego, tenere la corda!*' (Please take the rope.)

And the answer, in German-Swiss:

'*Jo, Herr Professor, mir häbets dä scho.*' (Yes, Professor, we have it.)

It was my compatriot Zweifel, the engineer from Glaris. With his help, we made a perfect landing.

The geodetic surveyors of the Swiss topographic service, using the theodolite, calculated the greatest height attained to be 55,800 feet with a 'probable' margin of error of about ten feet. Calculated on the barograph, according to the rules established by the *Fédération aéronautique internationale pour l'homologation du record mondial* (International Aeronautical Federation for the Verification of World Records), it was no more than 53,400 ft: the difference—2400 ft.—is explained by the fact that the regulation takes account only of mean pressures at given heights, while the real pressures vary from day to day on account of meteorological conditions. We thus beat our preceding record, that of the 27th May 1931: Colonel Messner was satisfied: it stayed with Switzerland. As for me, I was satisfied too: this time we were able to bring our scientific programme to a satisfactory conclusion.

This ascent of the 18th August 1932 broke the ice: the airtight cabin acquired full civic rights in ballooning and aviation.

Work was begun on several stratospheric balloons: three in the United States, two in Russia, one in Poland, all larger than mine. Not for a second did I regret that the *Century of Progress* carried off the world record for the United States. No more than I regret that the French Navy, breaking my record of 3150 metres, dived to 13,287 ft. (4050 metres), off Dakar, with the *FNRS 3*, a bathyscaphe in the construction of which I took part.

What happened to the *FNRS* after that? Two years later, to the very day, on 18th August 1934, having on board M. Cosyns, pilot, and M. van der Elst as assistant, it rose once more into the stratosphere, to establish the connection between the Ardennes and the mountains of Jugo-Slavia. For other ascents money was lacking. When, because of age, the rubberized envelope began to split and the balloon was unusable as a gas aerostat, Cosyns and I tried to make a Montgolfier (hot-air balloon) out of it. The attempt was not devoid of interest: moving with the air, the spherical balloon would have escaped the cooling action of the wind, and the heat of the sun would have warmed it sufficiently to keep it in equilibrium without auxiliary heating. However, the neck was too small for a hot-air balloon: driven back by a sudden wind before the take-off, the envelope took fire and was destroyed in a few seconds by the flames.

The advent of electronic instruments might have sounded the knell of the era of the stratospheric balloon: in fact, equipped with automatic instruments, sounding-balloons today allow us to make meteorological and physical observations in better conditions and at less cost.

But the aerostat still has a task to fulfil: that of observing the spectrum of solar light reflected by the planets. If we can attain this, we shall know the composition of the atmosphere which surrounds these celestial bodies. We shall know then if there is oxygen in the atmosphere of the planet Mars, hence if, from this point of view, life is possible there. For that, a spectrograph must be directed upon Mars: but no mechanical device as yet allows us to direct a telescope automatically upon a heavenly body: the presence of an observer is indispensable. So that terrestrial oxygen may not falsify observations the astrophysicist should not have above him more than one-hundredth of the terrestrial atmospheric layer: or in other words, he should rise to over 18½ miles. At that height the lifting force of a metric cube of hydrogen (33·9 cu. ft.) is reduced to 10 grams ($\frac{3}{7}$ ounce): the balloon would have to be, at once, extra-light and of large volume. My brother's *Pléiade*, with its hundred rubber ballonets which support the cabin, would seem to be of particular interest: during a preliminary trial it attained the altitude aimed at of 9900 ft.

Nevertheless, to reach over 18½ miles of altitude it would be necessary to increase the volume and the number of ballonets of the *Pléiade* and, naturally, make use of an airtight cabin. The cost of such an experiment would rise in proportion: for the moment it cannot be attempted, money lacking: it is a pity. My friend Audouin Dollfus, astronomer and aeronaut, is making efforts at the present time towards this end. I hope he will bring them to a satisfactory conclusion.

After having journeyed through the stratosphere, let us now penetrate the oceanic deeps.

Plate I The *FNRS* takes off for its ascent to 10 miles, 18th August 1932

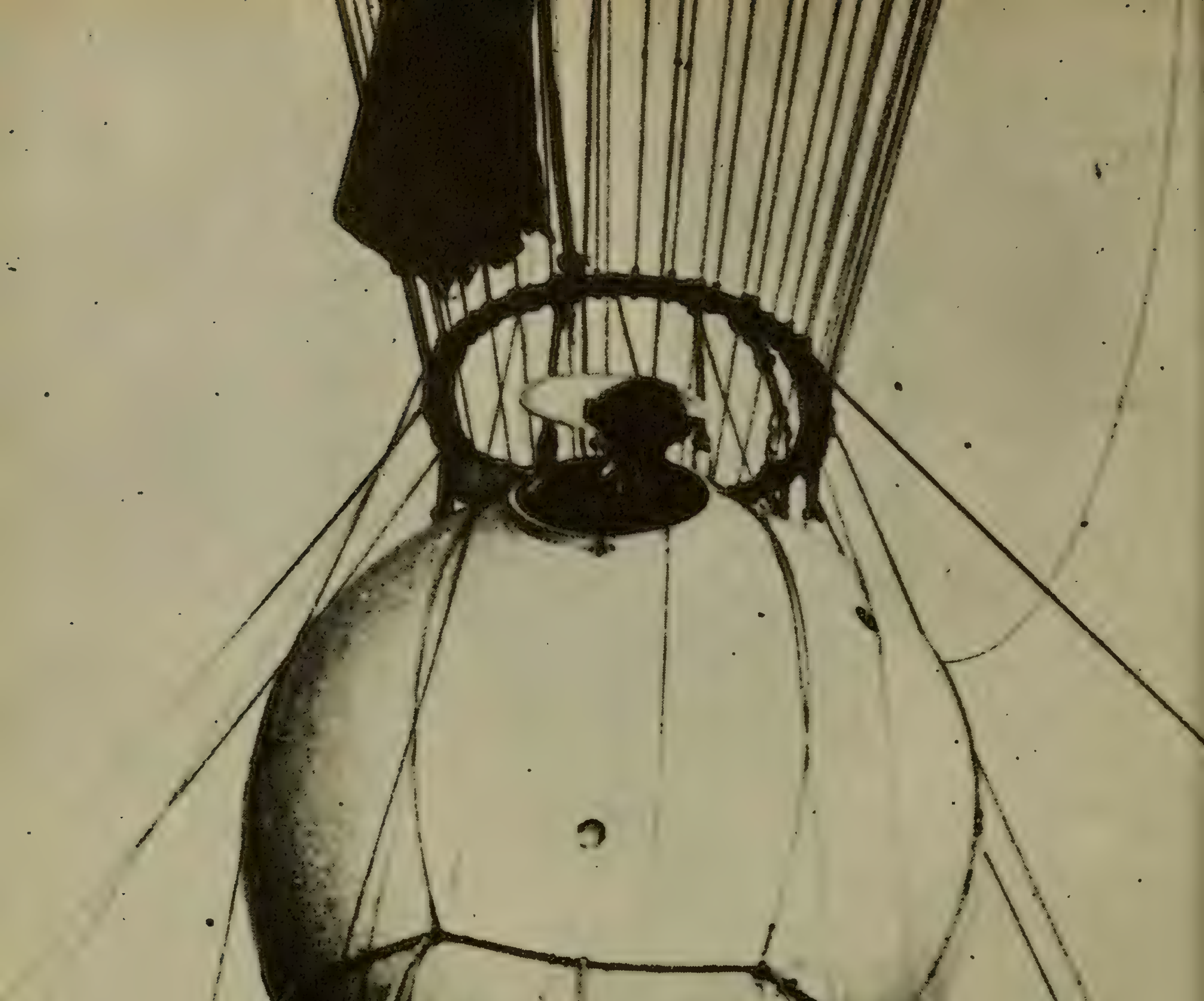


Plate II The cabin of the *FNRS*, with Professor Piccard at the manhole. The emergency parachute can be seen top left

2: *Man Beneath the Waters*

IN THE SHALLOWS

FROM the beginning of time man has been interested in the sea. He went fishing to find the complement of the food with which the land furnished him. He ranged along the rocky coasts in frail dugouts and reached neighbouring isles.

Later he began diving beneath the waves seeking sponges, corals and pearls, using a technique which has hardly changed for thousands of years. As man can live only brief moments on the reserve of air in his body, the diver would make a faster dive by carrying with him a heavy stone; then, holding on to a rope, he would have himself hauled up as quickly as possible by the men who remained in the boat. If he held a reed in his mouth, the other end of which emerged above water-level, he could of course breathe beneath the water and prolong his dive almost endlessly: but below a yard or two this method cannot be used, as the pressure of the water restricts the chest, very soon preventing all movement of the respiratory muscles.

It is told of Alexander the Great that he had himself shut into a crystal barrel and let down into the water by a rope held by his assistants on board a boat. What he is said to have seen is more than marvellous: in particular, a monster so long that, travelling along before Alexander's eyes upon the command of an angel, it took three days and three nights to pass. We have most eloquent engravings dating from the Middle Ages, showing the king in his barrel and the boat on the surface, with the boatmen. Obviously, here we have merely a legend, which arose no doubt quite late in the Middle Ages. Yet it is interesting, for the principle of the device used is that of the bathysphere of Beebe and Barton.

But let us come back to reality. When modern technique allowed of the construction of pumps, of air- and water-tight vessels and of flexible tubes, it was possible to work out the diving-suit with helmet (too well-known to need description here) of which the principle is derived from the diving bell.

Then, more recently, it has been possible to do without the air-supply tube, which has many inconvenient features and even serious dangers. Thus the diver has become free, autonomous: he carries with him a reserve of compressed air which permits him, according to the supply he has at his disposal, to breathe during fifteen, thirty and even forty-five minutes.[1]

At the same time the impediments of the 'diving-suit' and the heavy 'helmet' have been dispensed with. Thus instead of walking with difficulty on the sea-floor, the modern diver moves freely in three dimensions. His speed has been increased by rubber flippers affixed to his feet: thanks to this invention of Corlieu, the diver has become a 'frogman'. This sport, which arose before the war in France, is now spreading through the entire world. We know the role played by frogmen-divers at the time when the Allies landed in Normandy.

Readers interested in the history of diving will find a quantity of little-known details in the book of Pierre de Latil and Jean Rivoire, *A la recherche du monde marin* ('In Search of the Undersea World'), Plon (Paris), 1954. The authors, with extraordinary patience, have examined everything to be found in ancient documents on the subject of marine exploration.

What depths can man reach with these various methods? Whether he uses the classic diving-suit or the equipment of the frogman, the diver will still be subject to the pressure of the water, which adds 14·2 lb. per sq. in. to the atmospheric pressure each time he goes down another 33 ft. This pressure enters the thorax and the entire body. Contrary to what is often believed, it is not the mechanical effects of this pressure which limit the depths accessible to man. The serious or mortal accidents which occur are due to physico-chemical reaction in our bodies. Under heavy pressure, the nitrogen of the air breathed in is dissolved in the blood and even in the tissues, thus setting off various disturbances, of which the most dangerous is a feeling of sleepy well-being. In this state the diver, losing consciousness little by little, can be led to make false moves and even to remain beyond the safety limit, when a few minutes earlier he knew perfectly well that he was running a mortal danger in staying submerged any longer.

In rising to the surface, a new risk is incurred: the nitrogen, dissolved in the blood and in the tissues, is affected by the lower pressures and released just like carbon dioxide in a bottle of champagne or mineral water when it is opened. Thus the blood vessels may be obstructed by bubbles of nitrogen: this leads to 'gaseous embolism' and produces paralysis or death, either during the ascent, or even a

[1] For example, the Cousteau-Gagnan device.

few hours later. These dangers are lessened either by a very slow rise to the surface, the diver stopping to rest at different levels: or by diving only for very short periods and then rising very rapidly. They would be eliminated completely if it were possible not to breathe at all during the dive. In short, here is a dilemma: if the diver breathes, he is threatened with nitrogen intoxication, but if he is deprived of air, he suffocates.

From what we have just seen it is clear that the classic methods of diving cannot open the doors of the submarine abysses to man. Human limits are very restricted indeed. Down to 20 fathoms, it is admitted, there is no danger provided the diver ascends slowly, and sports amateurs are recommended not to go beyond this limit. Trained divers often go down to 30 fathoms. But lower than that the danger increases very rapidly. At 45 fathoms serious accidents are to be expected and rare are the cases where a diver has been able to return in good condition from the depth of 50 fathoms. For greater depths, nitrogen has been replaced, in the United States, by helium, which produces no chemical reaction and which is much less soluble in blood. Thus the diver risks neither intoxication nor embolism. This has permitted Bollard to endure a pressure of 100 fathoms of water. But what are these hundred or so fathoms of water in comparison with the miles which measure the ocean depths!

A minor difficulty, but nevertheless one which cannot be neglected, is known to many divers. At times they feel a sharp pain in the ears. The same pain can be felt in a free balloon or in an airplane. The explanation is known: the middle ear contains air separated from the external air by the tympanum. There can be too much pressure on this membrane if external pressure increases (or if it diminishes, as is the case when one goes up in a balloon) and the air within the ear fails to adapt itself to this pressure. Fortunately the middle ear is connected with the buccal cavity by the Eustachian tube. If this tube is quite open, the entire dive can take place without pain. But if the tube opens too late, a pain is then produced. By swallowing motions, skilfully executed, in general the canal can be opened. If a courageous diver keeps on with his work without the tube being open, a perforation of the tympanum many result with consequences that can be imagined. The susceptibility of the ear differs not only from man to man, but in the same diver, from day to day. The slightest cold can cause an obstruction of the Eustachian tube.

But, it will be said, if man meets so many difficulties in diving, how can the great cetaceans remain beneath the water during half an hour and even more? How can they reach depths of considerably over a hundred fathoms? How is it that they do not exhibit disturbances similar to those which in man are set up by a lack of oxygen or an excess of nitrogen in the blood? It must be understood to begin with that, the bigger an animal is, the less surface he offers in relation to his weight: if we have to make ten packets of 1 lb. we shall use, of course, more paper than if we have to make a single packet of 10 lb. Hence, the surface area of a large animal is relatively less than that of a small one. Another simile will make it quite clear: 10 quarts of hot water distributed in ten pots will get cold much quicker than if they were all in one pot.

It is then clear that the large cetaceans must produce relatively much less heat than us. Of course, they live in water, which carries off heat better than air: but this fact is more than compensated for by an enormous layer of fat, which is a remarkable insulator.

These sea giants must then have, in comparison with ourselves, a much slower metabolism: at the same time, with them, each unit of volume must consume less oxygen than with us. Thus they more slowly exhaust the oxygen stored in the red corpuscles of their blood and so carbon dioxide will accumulate more slowly. This is sufficient to explain the length of time they can remain under water.

Let us note, also, the reverse case: a small mammal like a mole eats every day the equivalent of its own weight. When two rival moles fight, the winner devours the loser without delay. A whale of this voracity is inconceivable. Now the quantity of oxygen absorbed by an animal is necessarily proportional to the quantity of food consumed. We can conclude that the small mammals cannot dive for very long.

Some other details concerning the cachalot or sperm whale: even if, before he dives, he fills his lungs with air, the volume of this air must diminish during the dive, for the body cannot resist the pressure: at 500 fathoms down, the volume of this air, even if it is not absorbed, is reduced to almost nothing: we must conclude that in the cachalot the bronchiae and trachea are not rigid.

The cetaceans have, moreover, the peculiarity of being able to adapt themselves to very irregular respiration: the mass of their blood is relatively large. As for explaining why they can go down so deep without feeling the disturbances which man feels, it is very simple:

they do not breathe at the bottom of the water. Hence they do not dissolve, under high pressures, nitrogen into their blood and are not prone to the accidents arising from this gas in excess.

Let us come back to man. There is no doubt at all that, to reach great depths, he must be completely protected from external pressure, that is, enclosed in a rigid apartment. Conventional submarines are constructed upon this principle.

The entire hull of the submarine is subjected to water pressure and, since it contains air at ordinary atmosphere pressure, the depth it can attain depends upon the strength of the hull. If the weight of the hull with all it contains, in machines, fuel, accumulators, arms and men, is equal to the weight of the water displaced, the submarine is in equilibrium, just as Archimedes could have told us.

Hence, the weight that the builder can give his hull and also its thickness, its resistance, and the depth the submarine can reach without the risk of being crushed, is limited. With our present structural materials this limit is between 50 and 150 fathoms. By forgoing all armament and decreasing the power of the engine, Pietro Vassena has been able to increase the range of depth with his pocket submarine C.3.

If a hull is to resist the pressures of the deep sea, it has to become thicker and therefore heavier than the displaced water. To sustain it, an external force must come into play. What is this force to be? There are two immediate solutions: either to suspend the cabin from a cable attached to the windlass of a surface vessel, or to have recourse to hydrostatic forces acting upon a bulky element, lighter than water, to which the watertight compartment is attached.

We meet the first of these solutions in the rigid diving-suits used for the recovery of treasure contained in ships sunk at depths inaccessible to ordinary divers: the diver is enclosed in a steel cylinder furnished with portholes and hung from a cable: by means of his telephone, he directs the manœuvres of the surface vessel which, with explosives, hooked tools and clamps, carries out the work: this, however, is not practicable beyond about 100 fathoms in depth. These rigid diving-suits can be considered as being the precursors of the bathysphere worked out by Professor William Beebe and Engineer Otis Barton. As for the second solution, I introduce it in the bathyscaphe.

The Beebe-Barton bathysphere is constructed of a cast-iron sphere of only 4 ft. 6 in. internal diameter and with a wall thickness of 1·26 in.: two windows in fused quartz serve to permit observation outside. It is borne by a steel cable and is lowered and raised by the windlass of the surface vessel.

By means of this first bathysphere, then, with a second of the same sort, built later by O. Barton, deep diving was carried out with complete success.

Here is the record:

		Metres	*Feet*	*Fathoms*	
1930	3rd June	600	1980	330	Empty
	6th	240	792	132	With Beebe and Barton
	11th	435	1410	235	With Beebe and Barton
1932	13th September	900	2970	495	Empty
	17th	900	2970	495	Empty
	17th	900	2970	495	Beebe and Barton
	22nd	655	2148	358	Empty
	22nd	670	2211	368	Beebe and Barton
1934	7th August	920	3036	596	Empty
	11th	750	2475	412	Beebe and Barton
	15th	223	735	122	Beebe and Barton
	15th	200	660	110	Beebe and John Tee-Van
1948	October	1360	4488	748	Barton

This is enough to show the great utility of the bathysphere, above all when it is desired to reach medium depths. Like all human works, it has some drawbacks, however, and the most serious is certainly the danger of the cable breaking: far beneath the surface, the observers would be condemned to a slow and terrible death.

We know, of course, that it is easy to give the cable a strength in every way sufficient to bear the cabin. But jarring must be taken into account. The surface vessel, rolling in the surge, rises and falls: it also suffers horizontal oscillations. Lateral waves and even longitudinal waves thus run down the cable, whence come interactions which cannot be calculated and also the danger of localized excess stresses.

Professor Beebe was several times shaken in a very unpleasant manner in his bathysphere and the crew of the surface vessel heard ominous noises resembling violent whip-cracks. Fortunately there was no break in the cable.

Oceanographic expeditions which lower nets to great depths always carry an ample reserve of these appliances. It is well known, in fact, that they run great risks of losing them by the cables breaking. All this demonstrates clearly, I believe, that the bathysphere, that is to say, the sphere suspended by a cable, is a very dangerous device if we wish to pursue our exploration of the oceans to their great deeps. The longer the cables the greater their weight. It is, of course, possible to use cables whose resistance to stress increases with the increase of the weight they must bear, but that is not sufficient to eliminate all risk of breakage. No doubt the safety of the bathyspheres could be increased by using nylon ropes. Nylon would have the advantage of having practically no weight in the water: besides, its considerable elasticity would absorb the effects of shocks. But are we certain that no spoilsport would take it into his head to sharpen his teeth on it? Apart from the danger of the cable breaking, the bathysphere has another disadvantage. The surface vessel being always more or less rocked by the billows, the sphere can never be completely motionless in the water. This motion is disagreeable to certain fish which prefer to move away and thus escape all observation. Finally, let us note that, according to the accounts of Professor Beebe, his bathysphere never approached the sea-bottom: he evidently considers that contact with the sea-bottom is dangerous for a cabin which shares the movement of a surface vessel. It is not to be forgotten, however, that immense credit is due to Professor Beebe for having built, with Engineer Barton, the first submarine cabin able to resist high pressures. It is no exaggeration to say that it is he who opened the doors of the abyss to man.

BATHYSPHERE AND BATHYSCAPHE

Briefly, the bathysphere shows many analogies with the captive balloon. Like the latter, the bathysphere is jarred if it moves in relation to the surrounding medium. In both cases there is the danger of the cable breaking, with the difference, however, that the aeronaut, rocked in his car by the tempest, cannot help wishing: 'If only this rope would break, what a fine trip in a free balloon we should have.' Very much to the contrary, the oceanographer, shut up in his tight cabin, is haunted by the terrifying idea that the cable may break.

But can we do without the cable? We now arrive at the idea of an appliance which would be to the bathysphere what the free balloon is to the captive balloon. No longer attached, it would be truly independent.

The submarine free balloon would have the advantages in the water that free balloons have in the air: at first it would go down, as the balloon rises, as soon as it is let go: then, it would be able to rise again as desired just as the balloon can descend whenever desired. That is what has been arrived at with the bathyscaphe, or deep-sea ship.[1]

The idea of such a ship is not new to me.

I was a first-year student at the Zurich Polytechnic School when by chance I read the fine book of Carl Chun recounting the oceanographic expedition of the *Valdivia.* Nets let down to considerably over a thousand fathoms brought back submarine fauna to the deck of the ship. They worked day and night. When a net was brought up in complete darkness, the oceanographers, leaning over the rails, were struck by the multitude of phosphorescent animals which the net contained in its seine. Certain fish were endowed with veritable headlights. But very quickly these lights grew pale and went out. The fish could no more endure the low pressure and the high temperature of the surface water than we could have endured the enormous weight of the masses of water beneath which they live.

To observe these fish in their natural setting, there is only one means, to go down ourselves to the deepest part of the ocean. It must be possible, I said to myself, to build a watertight cabin, resisting submarine pressure and furnished with portholes, to allow an observer to admire a new world. This cabin would be heavier than the water displaced. It would be necessary then, in complete analogy with the free balloon, to suspend it from a large vessel filled with a substance lighter than water.

The fundamental principle of the bathyscaphe was born.

The idea never occurred to me to use a suspension cable for my cabin. Even at this time the cable would not have seemed to me safe enough. However, at that time I should naturally have been incapable of resolving all the problems conjured up by the construction of such a device.

The student became an engineer, then also a physicist. The idea of submarine exploration in a free balloon never left him, although for a

[1] The name is composed from two Greek words: *bathos*, deep, and *scaphos*, ship.

long time he was not able to think seriously about the possibility of realizing his youthful dream.

I have already explained how the cosmic rays had given me the desire to rise to 10 miles. But a man cannot bear the low pressures which prevail at such an altitude, even if he breathes pure oxygen. 'No matter,' said I to myself, 'my submarine cabin, intended to resist external pressures of several hundred atmospheres, will give me the solution. It will suffice to build a much lighter cabin and to suspend it from a giant balloon capable of carrying it in the rarefied atmosphere of the altitude concerned.'

The evolution of my thought is clear. Far from having come to the idea of a submarine device by transforming the idea of the stratospheric balloon, as everyone thinks, it was, on the contrary, my original conception of a bathyscaphe which gave me the method of exploring the high altitudes. In short, it was a submarine which led me to the stratosphere.

Soon after, I retransformed in my mind the stratospheric balloon into a submarine balloon and I went and once more knocked at the door of the Belgian *Fonds National.* I asked for the credits necessary to bring the bathyscaphe into being. My request was accepted and I was first allocated the funds necessary for equipping a laboratory specialized in the study of high pressures. The question of the strength and watertightness of the future device was so important that I was obliged, in fact, to make numerous preliminary trials with different models. I had, in particular, to subject a scale model of the cabin, in special tanks, to pressures reaching as much as 1600 atmospheres: the weight of a column of water of 10 miles.

As my bathyscaphe, intended for the exploration of the sea, had to have portholes, their construction had to be studied with care. I also had to find safe methods of passing numerous electric and cable wires through the walls without allowing water to enter. The question of dropping ballast also had to be studied.

In all these labours I was seconded by my valued assistant, Jean Guillissen. The most important trials had been made, the construction of the bathyscaphe itself had begun, when the Second World War broke out. In it I lost my young friend, a victim of his patriotism.

At the end of 1945 I once more went to the *Fonds National* and asked for the credits necessary to take up the work again. The *Fonds National* gave me the credits, but with the stipulation that Max Cosyns, whom

I had chosen as my assistant, and who is a Belgian citizen (while I am of Swiss nationality), should share the supervision of the undertaking with me, with complete equality of rights and responsibility.

Such a division of command was no doubt necessary from the political point of view, but the formula hardly proved fortunate in practice. An achievement of this importance demands someone in absolute command: as this chief cannot physically perform the whole task himself, he must be surrounded by assistants over whom he has authority.

In the following chapters we are going to discuss, to begin with, some questions of a general nature relating to all bathyscaphes; then we shall begin on a detailed description of the building of the *FNRS 2*.

3: *The Principle of the Bathyscaphe*

STATIC LIFT

To understand how the bathyscaphe functions, it is sufficient to compare it to a free balloon.

In spite of the difference of surroundings in which they move and of the quite opposed ends in view, the principle in question is the same: that of Archimedes. If the weight of an immersed body is lighter than the weight of the ambient fluid corresponding to its volume, the body will rise: if it is greater, that is to say, if the body is heavier than the fluid which it displaces, it will descend. The balloon moves about in the air, where it must at first rise and then descend. The bathyscaphe moves about in the water. Leaving the surface, it must go down to the depths, then rise. The balloon rises because its envelope, inflated by a gas lighter than the ambient air (hot air, town gas, hydrogen or helium), is voluminous enough to support the weight of the car hanging from it. In the same way the bathyscaphe is, in its principle, lighter than water: a float filled with a light substance sustains a watertight sphere which is fastened to it.

What is the substance with a specific gravity less than that of water which is suitable for filling the float?

We must straightway exclude the use of gases: they are much too compressible. The pressures prevailing at great depths would reduce their volume and their supporting power in such proportions that it is not possible to consider their use, unless the effects of this compression can be avoided. To obtain this result it would be necessary to enclose the gas in a vessel with rigid walls, the more resistant and heavy the deeper the dives in prospect. It is the principle adopted for conventional submarines, the hull of which is filled with air: but we know that they cannot dive beyond 100 fathoms or so without the risk of their light hulls being crushed. But for the bathyscaphe which must be able to go down some thousands of fathoms, we must seek another solution, since this requires a considerable thickening of the walls, and hence a prohibitive weight.

I turned from gases and looked for a less compressible substance. A solid lighter than water would suit and would have the advantage of not flowing away if the float became damaged. Because of the fact that a solid is less compressible than a liquid, its lifting power does not decrease with the depth of immersion, as is the case with light liquids: on the contrary, at a depth, it would increase. One could contemplate the use of lithium or paraffin wax. Lithium would certainly be ideal. 35·3 cu. ft. (a cubic metre) weighs 1211 lb. (its specific gravity is only 0·55). In fresh water, 35·3 cu. ft. of lithium would suffice to carry a weight of 992 lb. Unfortunately the production of this metal is very limited. Before the last war, when I tried to procure some, one manufacturer offered me $\frac{1}{3}$ oz. and another $\frac{2}{3}$ oz! Since then the production of lithium has increased in the United States, but it is reserved for researches in nuclear physics.

In the end, the only solid which one could use was paraffin wax. Its specific gravity is 0·9. In fresh water 35·3 cu. ft. of paraffin would lift only a weight of 220 lb. and in sea water 264 to 287 lb. The bathyscaphe would thus require a very voluminous float: its cost and the difficulties of transport would be considerable.

Hence we must give up solids and look for a suitable liquid.

Petrol, a liquid of low specific gravity, fulfils the required conditions. But what quality of petrol should be chosen? The lighter it is, the more the size of the float can be reduced: but on the other hand, it must not be too light, or it will be too volatile and too compressible. The homogeneity of this petrol must be such that a partial evaporation would not too much modify the density. After studying the problem, the Esso Company furnished us (for the *Trieste*) with a quality which gave entire satisfaction. It boils at between 140° F. and 176° F., which proves a good homogeneity. At 32° F. its specific gravity is from 0·680 to 0·695: at this temperature 35·3 cu. ft. of this petrol carries on the surface in sea water a load of from 716 to 769 lb.

To an extent less than gases, but more than solids and water, the volume of petrol is a function of temperature and pressure. That is also a fact that must be taken into account when the problem is to build a bathyscaphe, by arranging, at the bottom of the float, a passage which allows the sea water to enter and to leave freely to compensate these variations: in this way the same pressure will always prevail inside and outside the float, which will allow the float to be built of relatively light metal sheeting. Let us here note the analogy with the small envelope of dirigible balloons.

The reader will perhaps wonder how we set about finding out how the volume of the petrol varied under the effects of compression and cooling. One can, of course, using printed data, calculate the contraction that a given hydrocarbon would sustain under the effect of pressure and cooling. But it would be exaggerated to add these two contractions: at high pressures the coefficient of thermal expansion is smaller than at ordinary pressure. Now on this subject the relevant literature is almost silent. We thought it wise to make direct experiments and with the engineers of the *Société Sécheron* at Geneva we perfected a new method at the time that I was working on the bathyscaphe for the French Navy.

Into an iron tube with thick walls (see Fig. 2) 7·87 in. long and 0·787 in. in diameter, containing a certain quantity of mercury *c*, there was introduced a glass tube, filled with petrol *b*, which had a small orifice at its lower end. The iron tube is closed at both extremities and by a flexible lateral tube *d* it is connected with a high-pressure pump. One begins by heating the whole apparatus to 86° F.: the petrol expands and the excess escapes by the orifice. Then the whole apparatus is cooled down to 32° F. and through the tube *d* oil is introduced under pressure. The petrol contracts and a corresponding quantity of mercury penetrates by the orifice into the glass tube. At the moment when, at the same time, the pressure reaches 400 atmospheres and the temperature is at 32° F. the apparatus is inverted and opened, and the volume of mercury which has entered the graduated part in the glass tube is measured. After a few small corrections necessitated by the contraction during and expansion after the experiment of the glass

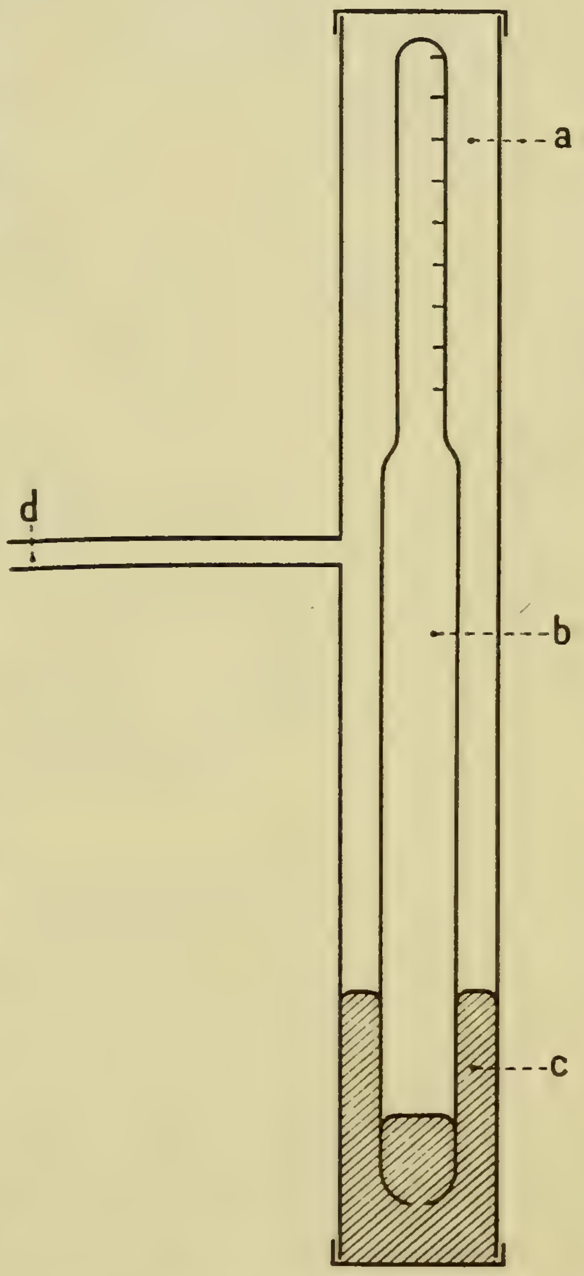


Fig. 2. Apparatus for measuring the variations of volume of the petrol according to temperature and pressure

and of the mercury (of which the coefficients are known) the volume of the mercury gives us the total contraction of the petrol; the problem being to determine it for an extreme case which might arise. Unfortunately the compressibility of petrol is greater than that of water. From this fact the lifting capacity of a given quantity of petrol necessarily diminishes proportionately as the bathyscaphe goes down: its vertical equilibrium is thus unstable. Hence the farther down the bathyscaphe goes, the heavier it becomes and the more it has a tendency to descend. Therefore it is nécessary for the pilot to be able to lighten the bathyscaphe by throwing out ballast.

The bathyscaphe can, however, in rare cases, recover its equilibrium, if in the course of its descent it encounters a layer of water that is much colder, and so denser. But this state of rest can only be temporary, because at the end of a few hours the temperature of the petrol will be equal to that of the surrounding water.

We observed this phenomenon of rest following upon a cooling of the water, on the 14th August 1953, when my son and I were making a trial descent in depths of 22 fathoms. At about 14 fathoms from the surface the *Trieste* reached equilibrium in a layer of cold water, where it came to a standstill (see pages 109–10).

THE BALLAST

The problem of ballast is vital for the bathyscaphe and from this point of view there is a fundamental difference between it and the free balloon. If the aeronaut has no more ballast to throw overboard he cannot rise any farther and he will perhaps have to land more quickly than he would have wanted to, and perhaps also make a rougher landing. But it is not a catastrophe. On the other hand, in the bathyscaphe, a breakdown in the unballasting apparatus would prevent it from ever returning to the surface. A method must be found thus, which in any circumstances will allow the pilot to unballast, and which will never be in danger of a breakdown. The ballast is outside the cabin: the pilot must then in some manner work through the wall of the cabin. How is it possible? One could imagine a mechanical system: a push rod or a shaft would pass through the wall and would start the unballasting: that would necessitate a stuffing-box. Now a stuffing-box, watertight at a pressure of some thousands of pounds per square inch and allowing free movement of the shaft, would be a very delicate and dangerous organ. If it is held too tightly, in fact, the shaft can be jammed and even may break. Moreover, the external pressure of the water jeopardizes the free play of the system. We must then give up the stuffing-box and any direct mechanical drive.

In these conditions I see no other solution than to use an electric control, but the very word electricity calls up the double spectre of short-circuit and bad connection. Let us put the problem the other way: the electric current will retain the ballast and when the current is switched off, whether intentionally or accidentally, the ballast will fall. It is the electro-magnet which fulfils these conditions: as long as the current runs through its coil, it will retain the burden: it will drop it as soon as the current is cut off.

The electro-magnet in its conventional form has, however, a disadvantage. Each magnet can hold and release only one mass, and that would only permit of unballasting in large portions, while it is essential that the pilot should be able, in some circumstances, to unballast in small amounts. I had used small shot when I was making my ascents into the stratosphere and now I used it here and stored it in two big tanks built into the float. Here is the arrangement we adopted and which proved to be to our entire satisfaction. The lower part of the storage tank is funnel-shaped: the orifice is encircled with an electric coil. If the electric current is running through it, the small shot is magnetized: it then forms a compact mass which plugs the orifice. If the current is cut, the shot flows like sand from a sand-box. If the current is switched on, the flow ceases instantly (see Figs. 9, 16 and 17).[1]

Besides the iron shot, the first bathyscaphe, the *FNRS 2*, carried three other sorts of ballast: tubs filled with scrap iron, held in place by electro-magnets and capable of being unballasted one by one; gravel stored in four big tanks closed at the bottom by flap-valves, also held shut by electro-magnets. If one switched off the current from one of these magnets, the valve opened and the contents of the tank flowed out at once. Last, in their turn, each of the two heavy storage batteries was suspended beneath the float to the armature of an electro-magnet: thus the batteries served as emergency ballast and could be sacrificed in case of necessity.[2]

[1] This is the device with which the *Trieste* is equipped. We shall see later that the storage tanks can be unballasted as well if necessary, for example, if the orifice becomes obstructed by a foreign body.

[2] This last mode of unballasting has also been adopted for the French bathyscaphe *FNRS 3*.

From the moment the bathyscaphe was begun it was necessary to know what quantity of ballast it must carry. An excess of ballast is useless and increases the cost of building and use of the submarine, since it necessitates an increase in the volume of the float. But if the quantity of ballast available is insufficient, woe to the pilot! Without going into details, we shall trace the principal elements of the problem.

If a float of roughly 22,000-gallons capacity, as that of the *Trieste* for example, is in equilibrium on the surface with the sea water at 86° F. and has this temperature itself, its lifting capacity diminishes, in round figures, by 8800 lb. (4000 kg.) if it goes down to $2\frac{1}{2}$ miles (4 km.) and reaches layers where the temperature is around 32° F. and if it stays long enough at this depth to reach this temperature itself. But if the descent is very rapid, the petrol, instead of getting cooler, is heated by the effect of the compression: this heating is in the order of 4·5° F. per 3300 feet, in difference of level.

This is the phenomenon called 'adiabatic heating'. We shall benefit by this heating when the bathyscaphe, steered by an automatic pilot, will descend rapidly to $3\frac{3}{4}$ miles. To compensate the decrease of buoyancy we must then dispose of a quantity of ballast of 8800 lb. To this ballast, which is obligatory, it is advisable to add what we shall call emergency ballast, which we fixed at an amount of 9460 lb., because if, during a test when empty, a joint breaks and the cabin is entirely flooded with water, it will suffer an overload cf 9460 lb.: and we want the bathyscaphe to rise again to the surface in spite of this overload.

The float of the *Trieste*, as a safety measure, was divided into compartments, the largest of which had a volume such that the loss of buoyancy would not exceed 9460 lb. if, following upon serious damage, all the petrol were replaced by water.

Other considerations likewise prescribe emergency ballast: in particular, the danger of being stuck in the bottom mud or in other obstacles such as seaweed. Likewise, in case of danger, we had to be able to unballast the bathyscaphe completely with the minimum delay to be able to go up at full speed. It is clear that these last considerations cannot be calculated in advance. But I estimated that 9460 lb. of emergency ballast would be sufficient.

The reader who is concerned for our safety will ask: 'What would happen if several of the mishaps mentioned occurred at the same time?

Plate III The launching of the *FNRS 2*, Dakar, 1948

Plate IV The float of the *FNRS 2* is filled with petrol, Dakar, 1948

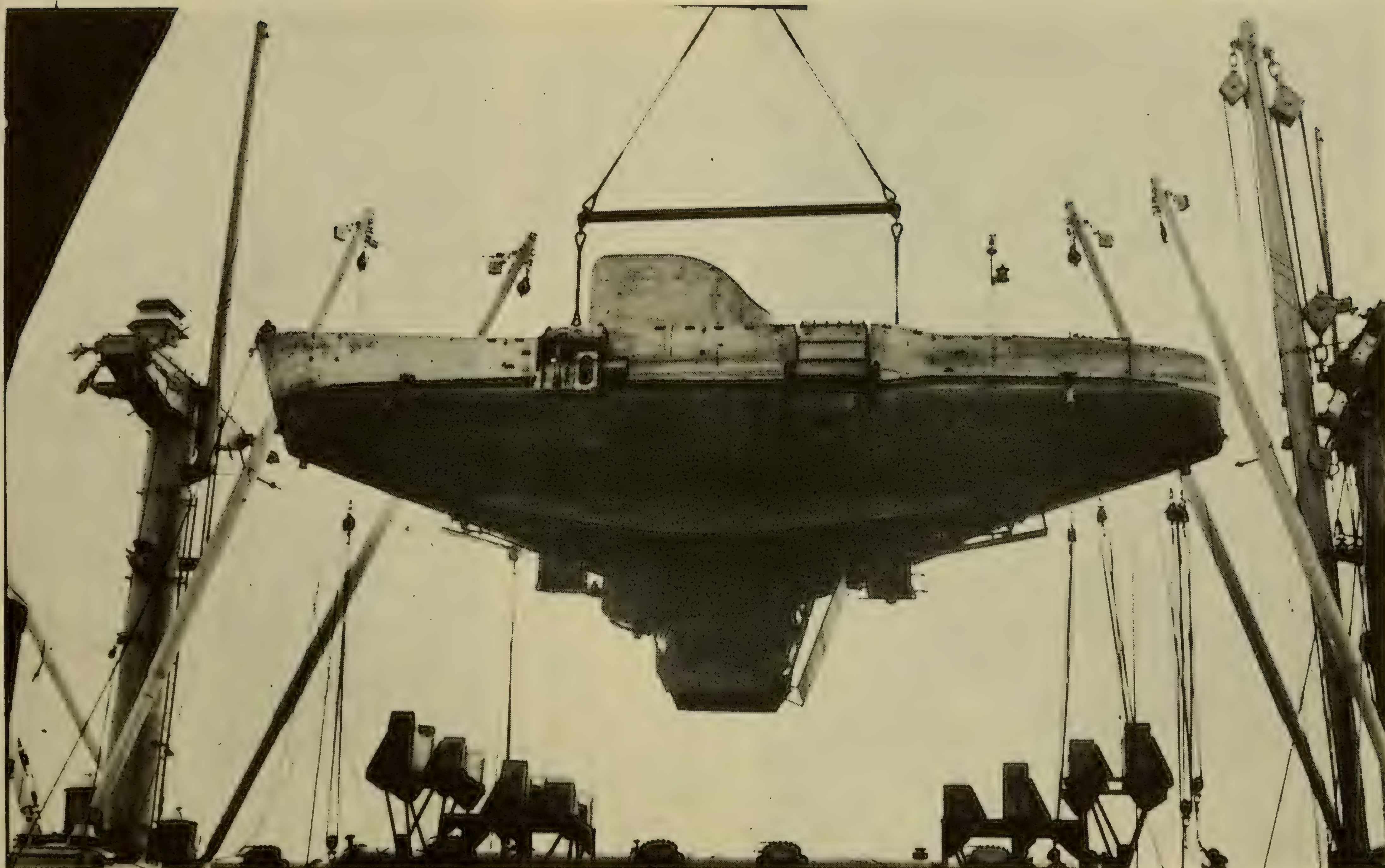


Plate V The *FNRS 3*

To provide for this, it would be necessary to double or treble the quantity of emergency ballast available.' It is true. But let us not forget that each of these occurrences is in itself very improbable. Supposing that there is a chance in a thousand for one of them to arise at a given moment, the probability of two simultaneous mishaps is one in a million: it is then less than the danger that each of us runs when we walk in a large city any day. Since we are not afraid to go about town, why should we fear to go down in a bathyscaphe? In fact, for reasons which we shall see later, the quantity of ballast available in the *Trieste* is several tons above the 18,260 lb., the sum of the two preceding figures.

TRAIL-ROPE AND PROPELLERS

Our bathyscaphe is then endowed with its essential property: it can move about vertically, it dives to the depths, then it rises to the surface and can even remain stable between the two. In that, it resembles the free balloon: but the analogy goes further still.

Each free balloon is furnished with a trail-rope, that is to say, a rope of a length between 33 and 55 yards and of a weight which varies between 44 and 176 lb., which hangs from the car. If the pilot is getting ready to land, he lets the balloon go down with some rapidity: it is important, however, that the balloon should be unballasted at the last moment to reduce the shock of contact with the earth. But if the pilot throws overboard only a trifle too much ballast, the balloon rises again. It is here that the trail-rope plays its part. Automatically, when the balloon approaches the earth, the trail-rope is thrown overboard; but it is taken on board, if the balloon shows any tendency to rise again. Also, if the balloon, in coming down, arrives at a place unsuitable for landing, the pilot can let it 'run on the trail-rope' until he finds a better place. During this last stage of the journey, it is the trail-rope which stabilizes the balloon at a short distance above the ground. In other cases again, even if it is not intended to land, the trail-rope is allowed to trail in order to observe the ground from close at hand. This procedure is above all entertaining, for it gives the passengers much more variety than a trip at a high altitude. I remember, for example, the delight that my passengers felt—they were Swiss aviators, among whom was Bieder, the conqueror of the Pyrenees and the Alps—when one winter day I dragged the trail-rope for many miles above a beech forest which enabled us to discern a multitude of hares and roe-deer which, caught unawares, ran off in all directions.

The trail-rope has another important function. At the moment of landing, it directs the balloon into a position suitable for operations.

The bathyscaphe, too, is provided with a trail-rope which plays the same part as with the free balloon: it unballasts the submarine at the moment when it approaches the bottom and thus decreases the landing shock. It maintains the submarine in stable equilibrium in the vicinity of the bottom and if a light current of water moves the ship, it allows the passengers to observe the bottom from close at hand, while the cabin moves about slowly at an altitude of a fathom or so following the folds of the ground. During this trip the trail-rope attached to the stern of the float also orientates the bathyscaphe in such a fashion as to place the observation window in front. That is why I equipped the *FNRS 2* and the *Trieste* with a trail-rope and why I have recommended its use to the French Navy.

The trail-rope of the free balloon is generally made of hemp: as ours had to be weighty, even under water, I used metallic cables; as it had to be more flexible than would be a single cable of the right weight, I employed a series of relatively thin cables which, combined, formed what I have called a 'horse-tail'. The *FNRS 3*, on the other hand, was provided with a heavy chain which offers the advantage of great flexibility. However, on a soft terrain, the friction of the chain is considerable: this can in certain cases bring the bathyscaphe to a complete standstill.

If, as is generally the case in the Atlantic, the water, even at great depths, is moving at a certain speed, the bathyscaphe will be able without any other aid to prospect a long strip of terrain. In many places, however, for example in the Mediterranean, the current is too weak to overcome the friction of the trail-rope: sometimes indeed there is no current at all. In such a case the observers, during the whole extent of the dive, could not observe more than a few square yards of the bottom: the scientific results from such a dive would be almost nil. To remedy this, the bathyscaphe should be endowed with its own power of movement. It must then, from being a free balloon, be transformed into a dirigible balloon. That is why we equipped each of the three bathyscaphes with two electrically driven propellers, one to port and one to starboard. The pilot operates each of these two propellers separately and can vary the direction and speed of rotation. Thus he controls the heading and the progress of the bathyscaphe. The propulsive groups of the *Trieste* were placed on the ship's deck, and consequently were easy of access when the bathyscaphe surfaced: the fact that here they become unusable is without importance, since one does not have to use them then. In the French bathyscaphe *FNRS 3* the propellers were placed lower down, beside the float: this is more in conformity with tradition: but in the position so chosen they were more exposed to damage by contact with boats or other obstacles.

What conditions were necessary for our propelling apparatus? To make observations, we did not need great speed; I thought a speed of 4 in. per second would amply suffice; or, in nautical language, about $\frac{1}{5}$ knot. But it must not be lost sight of that the propelling force developed by the screws had to be sufficient to overcome the friction produced by the trail-rope dragging along the ground. As the power of the motors was limited by the capacity of our accumulators, we had to have propellers of large diameter and of low rotational speed.

How were the motors to function under water? Three methods presented themselves.

One could consider using three-phase induction motors which have no brush. This was rejected; we should have had to install in the cabin a rotary converter, which would have been too cumbersome.

A motor could have been installed, in the air, within an airtight container resisting pressure. We rejected this idea as much on account of the weight and cost of the airtight container as on account of the construction problems that stuffing-boxes present.

The third solution, the one we chose for the *Trieste*, is ideal from every viewpoint. The motor turns in a vessel filled with trioline (an organic insulating liquid heavier than water): the shaft of the motor is vertical and it projects above the vessel. Because of the great density of the insulating liquid, we dispensed with a stuffing-box. At the top of the shaft a system of gears produced the desired reduction of speed for the rotation of the screw, and converted it without difficulty from rotation about a vertical axis to rotation about a horizontal axis. This arrangement served later as a model for the tachometer designed to measure our vertical speed in the course of dives: we shall speak of it again on page 97. The motors were designed and built by the Ercole Marelli Company of Milan: the reduction gears were built by the Navalmeccanica of Castellammare di Stabia. We gave up the idea of furnishing the bathyscaphe with a rudder which, in view of the low speed proper to the submarine, would have been very inefficient; our two screws were enough for its steering.

DIFFERENT TYPES OF BATHYSCAPHE

We now knew how we could carry out the different operations in diving, in rising again or in low-speed navigation at the bottom of the sea.

But how were we to get the bathyscaphe to the diving-place?

Several ways are possible.

The first consists in loading the bathyscaphe on a cargo-ship of large tonnage and transporting it to the place: this was the method used for the *FNRS 2*. From the hold of the cargo-ship itself the passengers went into the watertight cabin: the hatch was then closed upon them: then a crane lifted the submarine and deposited it upon the water. The dive could begin.

But this has one disadvantage: the weight of the submarine and of the float filled with petrol. Hence a very large ship was needed, for it alone would possess the hoisting installations necessary. But even such a ship as this would list dangerously while it held the bathyscaphe above the water and to counteract this tendency one would have to shift some other cargo in the ship to trim her. This in its turn would present other difficulties. A 'kangaroo' boat would have avoided all these difficulties: but we did not have one at our disposal.

As we could not choose the type of ship to carry us, we had to adapt the weight of the bathyscaphe to the tonnage of the cargo ship. Thus we were led to the idea of launching the submarine before filling the float with petrol and then pumping the petrol in, with the pilot and the observer already shut into the sphere. Once the dive was over the reverse operation had to be done: that is, empty the float of its petrol, then hoist the submarine on board: then only could the crew leave the cabin.

This was what we did with the *FNRS 2* in the Cape Verde Islands in 1948; we shall see that it was only possible in a very calm sea and that the crew was obliged to remain shut up in the cabin for too long.

The second solution seemed easier: fill the float at the home port and from there tow the bathyscaphe to the diving-place. It is there that the crew enters the cabin.

But this meant that the float had to be strong enough to stand up to towing, whatever the sea was like. Moreover, the shaft which permitted the crew to go down into the already submerged sphere was of frail construction. One thing was certain in any case: the second solution called for a much more expensive machine than the first. That is why, when building the *FNRS 2*, we gave up the idea from the outset. It will be shown later that we were able to adopt it in the case of the *Trieste*, thanks to the help that we received in Switzerland and Italy.

The third solution is a compromise: the bathyscaphe is built in such a way that it can be taken in tow: it is loaded, empty, on to a cargo-ship which transports it to the port nearest the diving-place, and there it is launched. It is filled with petrol: then, when the sea allows, it is towed to the place selected. That is the solution adopted for the *FNRS 3* which, as is known, was transported by cargo-ship from Toulon to Dakar, where it was filled with petrol before going down to 2200 fathoms.

There remains one question to resolve: should the bathyscaphe be loaded in one piece on the cargo-ship, or should the cabin and the float be shipped separately? This depends upon the cargo-ship itself.

4: *The Construction of the FNRS 2*

AFTER these general considerations, let us return to our first bathyscaphe. We gave it the name of *FNRS 2* in memory of the first stratospheric balloon, the *FNRS*, and to record once more our gratitude to the *Fonds National*, that magnificent institution to which Belgian science owes so much and which one can say without exaggeration has stimulated the creation of similar institutes in other countries.

Taking into consideration the limited credits at our disposal, we chose for this bathyscaphe the non-towable form: this decision was not taken without ripe reflection nor without having discussed with the specialists the possibilities of operating on the high seas by employing the cranes of a cargo-boat.

Here is the construction in detail.

THE CABIN

The spherical cabin is naturally one of the main portions of the bathyscaphe. It must conform to the following requirements:

It must resist the enormous pressures which it will sustain at great depths and that with all desirable safety;

It must be perfectly watertight; and be fitted with an equally strong and watertight hatch;

It must have portholes which will allow the occupants to observe and to photograph the external world; these windows naturally must also be strong, watertight and perfectly transparent;

The cabin must be spacious enough for the crew—a pilot and an observer—to be able to remain there without being too restricted in their movement, in spite of the presence of numerous instruments necessary for piloting, for renewing the air and for observation.

For the stratospheric balloon I had fixed the diameter of the cabin at 6·90 ft. (2·10 m.). This cabin was constructed of a light aluminium sheeting of only 0·1375 in. (3·5 mm.) thick: we were able to allow ourselves this luxury. But the cabin of the submarine represents, in itself, the main source of weight, the problem being to maintain it in equilibrium in the water: all the dimensions of the bathyscaphe and consequently its cost depend thus in large measure upon the weight of this cabin. We had to be modest.

But, on the other hand, if two passengers are to be shut up for a long time in this submarine cabin, it is important that they should have some comfort relatively. The bathysphere of Professor Beebe had an internal diameter of $4\frac{1}{2}$ ft. Beebe and Barton have shown that two men can live for long hours in such a space: but they themselves found that it was very uncomfortable. I spent a few minutes in it myself, in Beebe's laboratory of course, not in the open sea. Although I was alone in the sphere and my height is not much greater than that of Beebe, I found the situation rather painful.

After some trials made with mock-ups we settled for an internal diameter of $6\frac{3}{5}$ ft. (2 m.).

When the *Trieste* was being built I adopted the same dimensions for the new cabin—a proof that I have not regretted my initial decision.

Let us note in passing that if I had held to the diameter of 6·9 ft., the weight of a cabin with the same safety would have increased in the proportion of 100 to 116, that is to say, in our case, by 3520 lb., which would have resulted in a considerable increase in the dimensions of the float.

In what material should we make the cabin and what should be the thickness of the walls?

To calculate precisely the stresses to which the wall of a sphere will be subjected, if the thickness is the same throughout and the pressures which it bears are uniform, presents no difficulty. But it was otherwise in our case. Several openings were cut in the cabin: portholes, hatch, passages for electric cables and some tubes; this decreases its solidity. It is clear that the thickness of the wall must be increased around these holes, and it is here, particularly when we pass from simple thickness to reinforced thickness, that calculation falls short. We were forced to make tests with models which alone could give us the necessary data. Scale models rigorously conforming to plan and, of course, constructed in the same material as the real thing, were placed in the laboratory in a steel tank filled with oil in which the pressure was increased progressively by means of a pump until a violent explosion announced that the little sphere had been crushed. The pressure at which this took place was that at which the full-size cabin would also probably be crushed.

The pressure to which it could be subjected in safety would naturally be less. What is called the factor of safety is the relation between these two pressures. In the majority of technical structures a safety factor of 4 is insisted upon. If the designer can call upon very great experience in the matter, and above all if the failure of the structure would not be fatal to the crew, a safety factor of 3 or even 2 would be permissible. But in our case I thought that it would be better not to go lower than a safety factor of 4.

Although it immediately appeared probable to us that we should fix our choice of material upon steel, we first of all made some trials with plexiglas and with a magnesium alloy. These materials, lighter than steel, would have allowed us to have a greater wall thickness for the same weight. The magnesium alloy did not satisfy us. As for the plexiglas, it is not strong enough for great depths: on the other hand it would probably do very well for the mesoscaphe, which is not intended to go down beyond some 500 fathoms (see page 142).

We therefore chose a steel of the best quality, in this instance the cast-steel called 'indefatigable' from the Henricot Steel Mills (*Aciéries Henricot*) of Court-Saint-Etienne, Belgium. In consequence of our calculations and trials with models, we gave the walls a thickness of 3·54 in. (9 cm.), increased to 5·91 in. (15 cm.) in the neighbourhood of the openings. Thus conceived, the cabin would probably be crushed at a pressure of 10 miles of water: at 2½ miles deep we should then have what we want, a safety factor of 4.

However, it can happen, above all when pieces of cast metal are used, that bubbles and flaws form and remain in the interior of the metal without there having been any fault on the part of the foundryman. When mills proceed to mass production they make preliminary trials in order to determine the casting conditions which will give them an absolute guarantee of the homogeneity of the metal. In our case this was not possible. Therefore we subjected the finished cabin to radiographic examination.[1] The *Union Minière du Haut-Katanga* (Union of Mines of Upper Katanga) lent us a gram of radium, which we placed in the centre of the sphere. Photographic films, in the aggregate 18 square yards, were laid around the external surface of the cabin. After being exposed for twenty-four hours, the developed film showed that the steel was homogeneous almost throughout. In certain spots, however, we discerned lacunae in the material. To discover their nature, we then proceeded, with the help of a sort of boring-chisel, to take a sample of the defective part: the material thus removed

[1] With the assistance of the *Établissements Gevaert.*

had to be replaced by a pin in the shape of a truncated cone in 'indefatigable' steel, having the apex of the cone coinciding with the centre of the sphere. The stresses being everywhere perpendicular to this conic surface, the strength of the sphere was in no way affected.

The sample taken out showed bubbles with diameters rising to $\frac{1}{5}$ in., but which, in the opinion of specialists in steel, would not too

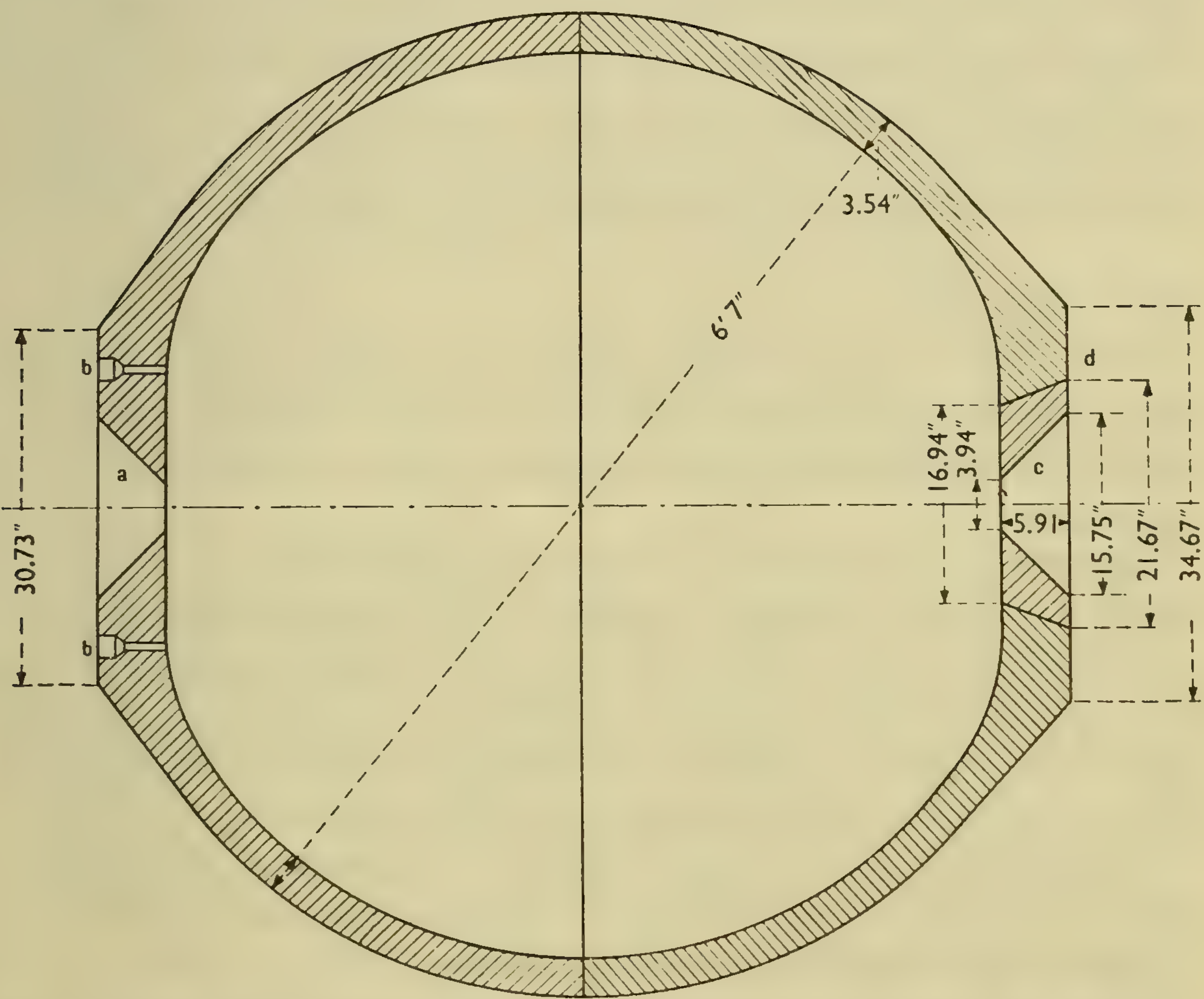


FIG. 3. Cabin of the *FNRS 2*, the *FNRS 3* and the *Trieste*, without the clamping device

a. Forward porthole *b.* Passages for electric cables *c.* Door porthole

greatly impair the strength of the cabin. I agreed with this, while still making up my mind to have the bathyscaphe make dives while empty, down to a depth which would exceed by 50% that to which we intended to descend ourselves. I considered this an elementary precaution.[1]

Fig. 3 shows the cabin in section. The casting as well as the machining would have been impossible if the cabin had had to be in a single

[1] I wish here to express my gratitude to the *Établissements Henricot* and thank them for the trouble they have taken.

piece. Therefore we designed it in two hemispheres, separated by an equatorial joint: this division in no way diminished the strength of the whole thing, the stresses along the joint being everywhere perpendicular to its surface. It was naturally essential that the two surfaces to be joined should be perfectly flat, so that the stresses should be distributed uniformly over the whole contact surface. The two hemispheres were finished on a lathe, internally and externally, so that their thickness might be uniform. At the moment of casting, each hemisphere had a weight of 10 tons, a weight that machining reduced to 5 tons. The object of this process is to eliminate doubtful parts of the casting which are found, generally, on the surface and upper parts of a casting.

THE WINDOWS

From a bathyscaphe, it goes without saying, there must be a wide view of the submarine world. The cabin must be furnished with good windows, without which the bathyscaphe itself would have no reason for existence.

Here we encountered a new and exciting problem. As theory is completely lacking, we had to depend entirely upon experiments with models. The concern with which we watched these experiments can be imagined and likewise the joy we felt as we saw the ideal solution appear little by little: it was only after having found it that I was able to decide to go on to the construction of my submarine.

Professor Beebe and Engineer Barton had equipped their bathysphere with windows in fused quartz. But even with small differences in pressure the results had not been satisfactory.

In the laboratories specializing in the study of high pressures, we had recourse to very tiny peepholes made of a cone in diamond. At the highest pressures even these diamonds cracked regularly: it is true that they were subjected to enormous pressures, about a hundred times as great as those to which the windows would be subjected in the sea.

But why not simply take glass, as I had done for the stratospheric balloon? It is because the pressures we had to resist were infinitely greater.

If a cylindrical hole bored in a plane sheet of steel is covered over externally by a sheet of flat glass, a porthole is obtained which will quite well resist all the pressures we were thinking of; but the diameter of the opening would be too small, so that the visual field would be too restricted. We then considered cutting in the wall of the cabin a conical hole to which would be fitted a block of glass in the shape of a truncated cone. The visual field would then be much larger. On this subject I consulted Professor Michels in his celebrated laboratory for high pressures at Amsterdam: he advised me against it, predicting cracks when the bathyscaphe rose again to the surface, that is to say, when the pressure was diminishing. I then made other experiments interposing between glass and steel a diversity of softer substances. One day we thought we had won: the glass appeared to have resisted perfectly. But we suffered a great disappointment when two days later there appeared in our block of glass, near the smaller end, a series of scarcely perceptible cracks. It was clear that we could not use glass.

Then, in May 1939, Professor Guillisen, my young assistant's father, drew my attention to plexiglas, a perfectly transparent organic substance well known today, which had then just appeared on the market. Plexiglas is much less hard than glass: therefore I thought that, to have the slightest chance of success, we should have to reduce the internal diameter of the new porthole to minute proportions. But we discovered during model trials that this was quite unnecessary and that all things considered a porthole with an internal diameter of 3·94 in. (10 cm.), an external diameter of 15·75 in. (40 cm.) and 5·91 in. (15 cm.) thick was amply strong. By extrapolation from the results of our observations, I felt able to conclude that such a porthole would only be deformed permanently at a pressure corresponding to $18\frac{3}{5}$ miles of water, and that failure (which would, of course, be fatal for the occupants of the cabin) would only threaten them at much greater pressures. This result, so surprising at first glance, is explained by the fact that plexiglas is somewhat plastic: if a small part of the substance is overloaded beyond its limit of elasticity, it goes slightly out of shape and passes the excess load to adjacent parts: thus the stresses are distributed in a more uniform fashion throughout the entire piece, while glass, which does not possess this plasticity, can only yield to an overload by cracking.

These windows are perhaps the finest feature of the bathyscaphe. Let the reader picture to himself an observer stooping to one of these portholes and contemplating with his own eyes the world of the ocean depths which, for the first time, are revealed to man. On one side an interior, of reduced dimensions it is true, but comfortable enough. Here a normal atmospheric pressure prevails. On the other side the ocean, which is weighing on the external surface of the plexiglas with a force of some 500 tons. Our confidence in these windows was so complete that during all our dives we never thought for an instant of the consequences of our plexiglas cracking. The production of such items is not in the normal programme of industrial manufacture. Therefore we owe our suppliers [1] special gratitude for the care they took in furnishing us with these beautiful objects, whose transparency is that of pure crystal.

It should be added that observation can be improved and the visual field of one of these portholes can be greatly increased by applying a prism of plexiglas to the internal surface: the total reflection that the thin layer of air separating the two parts would produce may be prevented by introducing a drop of glycerine.[2]

THE JOINTS

It is not enough that the cabin should be solid: it is also necessary that the different joints and particularly the great joint between the two hemispheres should be perfectly tight.

There are many methods in use to make sure that the joint between two rigid parts does not leak. When there is low pressure, of the order of one atmosphere, for example, it is enough to place a layer of rubber between the two parts. Because of its flexibility, the rubber adheres perfectly to the two parts, even if these are not perfectly flat: this is the sealing commonly used in preserving jars. At higher pressures the rubber ring is in danger of being forced out of its position. The rubber must then be replaced by a harder substance, leather, lead, or even pure copper, and the parts of the vessel must be clamped strongly together by means of powerful bolts. However, even for very high pressures one can, in certain cases, use a rubber ring embedded in a groove.

In the case of our two hemispheres the interposition of any more or less flexible or plastic washer would offer great dangers. One cannot in fact prevent two hemispheres forced against each other by the

[1] When the *Trieste* was building, it was the *Société Vétrocoke* at Porto-Marghera (Venice) which was kind enough to supply us with three new portholes in plexiglas.

[2] The reader wanting more precise details will find in the appendices a résumé of the pressure tests that we made in 1938 with plexiglas models in different shapes.

enormous pressure of the water from squeezing out, however slightly, the edges of the washer, while the middle portion of the washer would remain in place. The pressure between the two hemispheres will then be decreased towards the edge of the joint and increased towards the middle. This non-uniformity of stress would impair the strength of the whole construction. So we had to give up the idea of an interposed

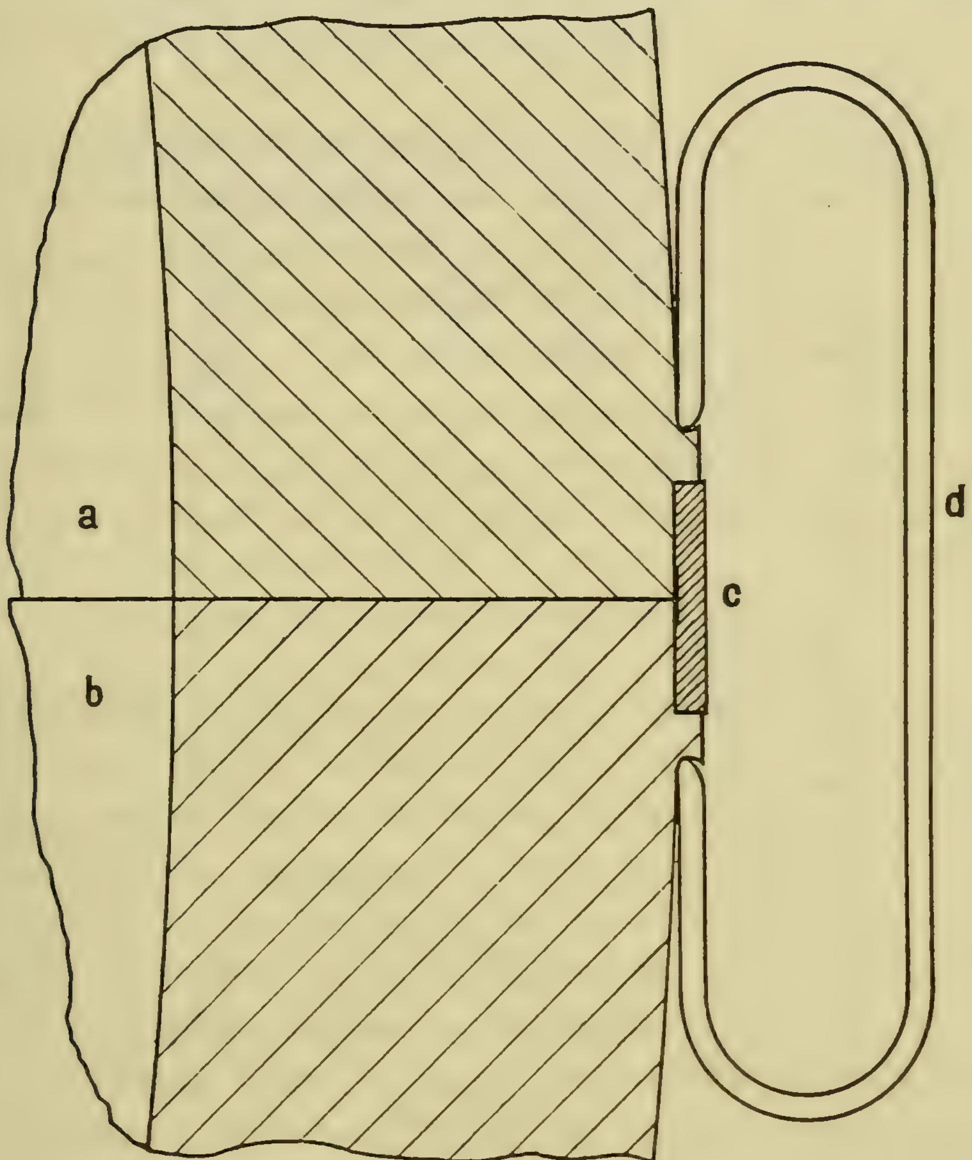


FIG. 4. *FNRS 2–FNRS 3*. Clamp for the two hemispheres

a. } Hemispheres
b.

c. Rubber
d. Steel clamp

layer and make use of the autoclave joint. The principle is very simple: the two hemispheres are placed directly one against the other, and on the exterior of the cabin the joint is surrounded by a band of rubber. The pressure of the water forces this rubber against the metal and it is perfectly leak-proof provided that the two hemispheres are fitted against each other exactly, in other words, on condition that the machining is faultless. If anything should penetrate the fissure, it would be the rubber. Let us add, to be exact, that this sort of joint, however, should not be used under pressure much greater than those in question in our case, for then the rubber would become hard and brittle.

While the *Trieste* was resting on the bottom of the Tyrrhenian Sea under a pressure of 325 atmospheres, I carefully examined the great joint of the cabin: I did not find a single drop of water in it.

THE FLOAT

It is the petrol contained in the float which must carry the whole weight of the bathyscaphe. The cabin with its contents has a weight of 11 tons: but it only displaces 5·5 tons of water. Its apparent weight is then only 5·5 tons—the weight that the float must carry. If, in round figures, the density of the petrol is 0·65 tons per cubic metre, and that of the water at the surface of the sea is 1·02 tons per cubic metre, each cubic metre of petrol will carry 0·370 of a ton. The volume of petrol necessary to carry the cabin and its contents should then be

$$\frac{5{\cdot}5\text{t}}{0{\cdot}37\text{t/m}^3} = 14{\cdot}8 \text{ cu. m.} = 522{\cdot}7 \text{ cu. ft.}$$

One must also take into account the weight of the metallic parts of the float, of the heavy storage batteries and of other loads, and lastly of the contraction of the petrol due to the low temperatures and to the pressures of the great deeps. On the other hand we had to have a reserve of petrol to take care of a possible leak, or to free us if we were caught in floating seaweed, the mud at the bottom or any other obstacle, or again to compensate a possible difference of density between the petrol allowed for and the petrol supplied. All these considerations reckoned in, we were led to fix the volume of the float at 1059 cu. ft. (30 cu. m.).[1]

All this petrol was contained in six upright cylindrical tanks, as is shown in Fig. 5. Between these cylinders was placed the small vessel containing the driving petrol and the ballast tanks. All this was surrounded by a casing of iron sheeting 0·04 in. thick which should in a certain measure protect the petrol tanks, decrease the hydraulic resistance opposing the movements of the bathyscaphe and retain any petrol which might leak from a reservoir: finally, one could by

[1] For the *Trieste* the volume was increased to 3742 cu. ft., this last bathyscaphe being stronger and therefore heavier.

introducing air increase the buoyancy of the bathyscaphe on the surface. It is clear that if we had had unlimited funds we should have improved the float right at the beginning: it would have been a simple matter to reinforce the casing and to give it a more hydrodynamic form. But if we had at this moment presented the plan of a more marine construction, we should have been told, 'It's very pretty, but it's too dear.' However that may be, if we had not brought the *FNRS 2* into being with the means and in the conditions that I have recorded

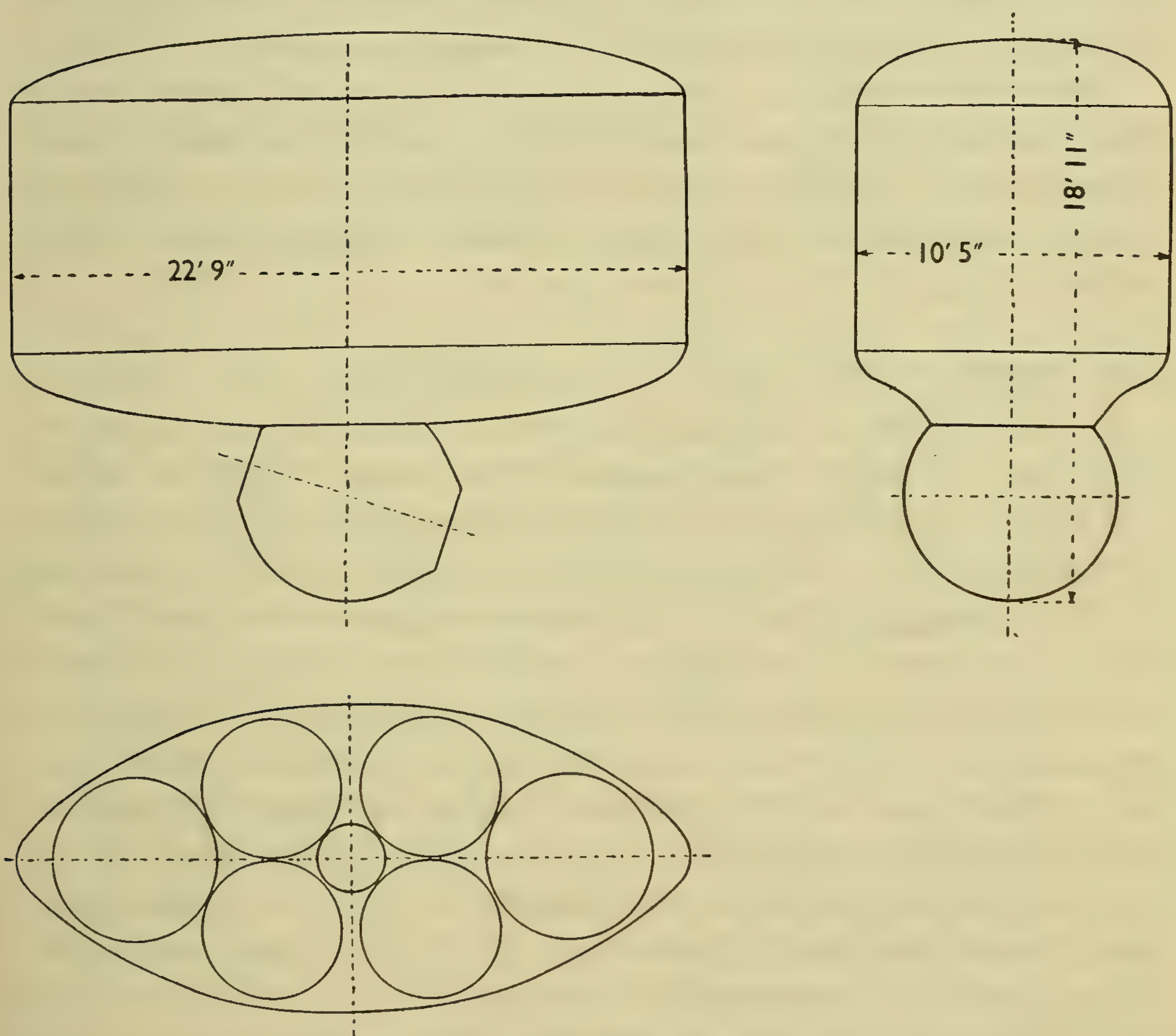


FIG. 5. *FNRS 2*. Float and cabin

here, the *FNRS 3* would certainly not have seen the light and probably not the *Trieste* either.

These reservoirs had to be made in aluminium sheeting of a thickness of 0·1375 in. After the dimensions had been fixed, M. Cosyns discovered in the second-hand metals market aluminium tanks which were of dimensions corresponding exactly to our plan. They had originally been intended to contain the fuel for V2 rockets, but the rapid advance of the Allies across Belgium had prevented their use. It would have been a curious trick of fate if these vessels, instead of helping to propel engines of death and destruction through the stratosphere, had been used for the scientific exploration of the submarine deeps. One can see here another example of the analogy between aeronautics and submarine navigation. (These remains of the V2s unfortunately were lost to us at the last moment.)

A fresh analogy: the tanks were supplied to us in the end by the *Établissements Georges L'Hoir* of Liège, who had previously constructed the aluminium cabins for the stratospheric balloon *FNRS*.

The seven aluminium tanks were placed vertically upon a steel framework which supports the cabin (Fig. 5). The Mercantile Marine Engineering Company, of Antwerp, generously took upon itself to supply the envelope and arrange the whole rigging of the bathyscaphe.[1]

THE SOURCES OF THE ELECTRIC CURRENT

To supply the current needed for the lighting and propulsive equipment we had to have a considerable source of power: a lead acid battery of 14 cells and 900 ampere-hours as well as a small reserve battery of 12 cells. The large battery, arranged in two iron caissons, was held beneath the float by two electro-magnets, as we have already said. The caissons were filled with oil and were connected with the sea: this oil was consequently at the same pressure as the water. The pressure could have no influence on the electro-chemical reactions of the batteries because the volumetric variations which accompanied them were slight: for the rest, the tests which we had made in our pressure chamber had proved it. There is no point in spending any more time on the special details of the *FNRS 2*. All the principles of its construction were repeated in that of the *Trieste* and above all in the *FNRS 3*. Profiting by experience we naturally introduced improvements into the two latter, which we shall mention later.

[1] We take this opportunity of thanking them cordially, as well as their director and chief engineer, M. de Bièvre.

5: *En Route for Dakar*

At Tamise, on the Scheldt, above Antwerp, a cargo-ship is being built. Two professors from Brussels visit it frequently. The fact is that the Belgian Government has put the *Scaldis* at their disposal to take the *FNRS 2* to its diving site and the ship must, consequently, be prepared for its work. It is a ship of 3500 tons, powered by steam, which is superior to Diesel, in that its speed can be varied rapidly, and it can go into reverse as often as is desired: it is thus very manœuvrable, which is important in our venture.

To say that this ship was conceived under a lucky star and that good luck always accompanied her would be an exaggeration. Before being used by us she made her maiden voyage to the Baltic: ill-luck pursued her, for the electric motor which actuated the rudder broke down: that could happen to any ship, and an emergency device is provided which, operated by hand, allows the crew to navigate. But, as luck would have it, the *Scaldis* was in shoal water: the men rushed forward but, before they could intervene, the ship struck a shoal. The crew just managed to avoid shipwreck, but the *Scaldis* had to be put into dry dock. Later, while we were on board, she stopped in the middle of the Channel because of damage to an engine. A few days later there were fresh alarms: this time it was our own engineer who, with the help of the lathe from our little workshop, repaired a defective valve. Another time, with our oxy-acetylene welding apparatus, he repaired a damaged steampipe. At Dakar the single screw of the *Scaldis* was found to have two blades instead of three and she had to go once more into dry dock. After returning from our expedition she was sold to Bulgaria.

Such is the ship, then, with which we had to work. The master, Captain Laforce, a crew of fifty, and the members of our expedition, made up her complement. Madame Cosyns accompanied her husband, as chemist: among other tasks, she had to maintain in good order the apparatus, which, during the dives, measured the amount of carbon dioxide in the air inside the sphere. My son Jacques was also one of the party, as well as two young biologists from the University of Brussels, Georges Marlier and Van den Eeckhoudt, who were joined at Dunkirk by Theodore Monod, Professor at the Museum of Natural History at Paris and Director of the *Institut Français d'Afrique Noire* at Dakar, the oceanographer Claude Francis-Boeuf, whose tragic end in a plane accident in Abyssinia we had to deplore not very long after that, and Dr. Daniel Bouchet, the physician of our expedition. There were with us also an engineer from the University of Brussels, Louis Ockum, whose assistance was valuable to us for the adjustment of certain pieces of apparatus, and for all sorts of repairs, and a photographer, Raphael Algoet, who was to develop the stills on board and also some of the films that we intended to take. Lastly, the Belgian Government sent us, as publicity officer attached to the expedition, Henri Ghysels, who carried out the not always easy tasks with which he was entrusted with a tact and delicacy that it gives me pleasure to stress. It may seem excessive, looking back on it, to have four observers with us, but if all the dives projected had been accomplished, each of them would have been able to go down at least once.

The cabin and instruments having arrived safely from Court-Saint-Etienne and from Brussels, the bathyscaphe was set up in the workshops of the 'Mercantile . . . .' Then, by means of a powerful crane, it was stowed in the large hold of the *Scaldis*, which was entirely reserved for us. In the free space round this hold we installed a workshop where we were to work during the voyage. The plan was to put in at Dunkirk, where the *Scaldis* would take on freight intended for West Africa, the freight to be stowed in the unoccupied holds: on the return trip it was to bring back colonial produce.

On the 15th September 1948 the *Scaldis* weighed anchor at Antwerp and moved towards the Scheldt. She moved so slowly along the docks of the port that our friends had time to reach the Kruisschans Lock by car and wait for us there. We leant over the railings and waved farewell, while the *Scaldis* was let down to the lower level. So we set sail for the open sea.

The weather was threatening, with drizzling rain, and the ship had to drop anchor near Flushing, not being able to risk a night passage in a storm through the difficult channels which lead to the North Sea. But when we reached the headland of Brittany, off Ushant, the weather turned fine. The Bay of Biscay belied its reputation and all the way to Dakar we were to enjoy magnificent weather.

Now that we speak of it, why Dakar? What region had we then chosen for our experiments? Several considerations dictated our choice. We could not go too far from Europe, or our costs of transport would have risen out of all proportion: we had to avoid localities where storms are too frequent: finally, an essential point, if we wanted to go down $2\frac{1}{2}$ miles after having subjected our apparatus to a test while empty, with an 'overload' of 50%, we should have to be able to use depths of $3\frac{3}{4}$ miles. Now the North Sea and the Channel have no such depths; besides, there is too much traffic on these seas. The Bay of Biscay and the North Atlantic are too often racked by storms. Then we had thought of the Gulf of Guinea, and, in particular, of the point where the geographical co-ordinates are the simplest in the world, longitude and latitude 0°. But having in mind the limited time during which we had the *Scaldis* at our disposal, we gave up this plan and finally decided on the vicinity of Cape Verde.

During the first part of the trip, in the Channel, we met many ships and passed fairly close to a submarine. It sent us light signals in Morse code, but at such speed that none of us could make them out. Was it an order? A message of goodwill? Did it suspect that our ship was carrying a new submersible capable of diving twenty times deeper than itself? In the Atlantic the ships became less frequent. Several times we saw sharks. More remarkable, we saw butterflies at hundreds of miles from the coast. How many hours had they had to persevere in their solitary flight to reach that point? Doubtless they had been carried by rising currents of air like gliders. One of them, after having followed the *Scaldis* for an instant, was snapped up under our eyes by a bird. This sight pained us!

Off the coast of Africa we made the acquaintance of flying fish. We saw them abruptly rise out of the water in great numbers and fly off in all directions. It was not, as is often said, gliding: the speed with which they emerged from the water would not be sufficient to carry them to the distances which we observed: we distinctly saw their flying fins vibrate in the air like the wings of dragonflies. After fifty or a hundred yards the fish drops into the water. Its alighting, considered from the aeronautical point of view, is quite a failure. It dives no matter how into a wave, without making the least attempt to reduce the impact, as any bird would do, by flaring out before landing. If it doesn't fly a great distance, it is because flight with such small wing-fins must be exhausting. Besides, a prolonged flight would have no purpose, for it is clear that it only leaves the water to escape an enemy: to tell the truth we never saw their pursuer, but by noticing the place from which the flying fish emerged we could guess the path of the hunter.

6: *Diving at Cape Verde*

OFF Dakar a sloop of the French Navy came to meet us, the *Élie-Monnier*; she had on board Captains Tailliez and Cousteau. A warship, or more exactly a military vessel fitted out for oceanographical research, it serves as a home base for the famous divers of the French Navy who, equipped with the light Cousteau-Gagnan diving-suits, have specialized in submarine exploration in the shallows and have already given us films of great beauty. Algoet, our photographer, did not know that sometimes they fish for cameras as well. A few days later, in fact, while getting into a longboat with both hands on the ladder, he took the strap of his camera between his teeth, but imitating the crow in the fable, he let it drop into twenty fathoms of water. He was most upset, but Dumas, one of the divers, consoled him: 'Take it easy! It will be all right when it's dry.' And putting on his equipment, he jumped into the water, dived and came back with the camera, just as coolly as if he had picked a pencil up from the ground.

DAKAR

At Dakar the authorities gave us a triumphant reception as if we had already succeeded in our attempt. It seemed premature to me, and I thought about counting unhatched chickens. Several details of the bathyscaphe had yet to be verified and adjusted. I was realizing the drawbacks of the expedition's being under a divided command, and I was regretting that I was not in sole charge. Happily the French Navy gave us all the help we wanted. It was invaluable to us.

We had to find the bathyscaphe as quickly as possible when it came up after a deep dive. A considerable drift was to be expected, while it was under the water, and a single ship would not be enough to find it again: above all not the *Scaldis*. Admiral Sol, commanding officer at the Dakar base, decided to give us an escort of two frigates, *Croix-de-Lorraine* and *Le-Verrier*, and to attach two hydroplanes to them. May I be permitted here to thank Admiral Sol most cordially, as well as the officers of the French Navy, and the engineers and personnel of the arsenal, for their generous help and for the cordial reception. It is a pleasant memory.

Our departure for the Island of Bao-Vista, one of the Cape Verde Islands, in the vicinity of which our first dives were to take place, was delayed by M. Cosyns falling ill. This waiting period at least allowed us to proceed to some practice in the matter of launching the bathyscaphe. The operation, though a little too complicated, was spectacular. The submarine lay in the hold of the *Scaldis*: two hooks were raised above its float. On the cable of the crane hung a big hook with a beam attached to it. At its extremities hung two other hooks which were attached to the first hooks. The steam engine of the winch begins to work. Slowly the *FNRS 2* is lifted out of the hold. Its cabin is above decks: the crane turns. The *Scaldis* lists. The winch turns in the opposite direction, unrolls the cable and for the first time the *FNRS 2* makes contact with its element. The cabin enters the water: the float in turn is immersed to a third of its height. At this moment the cable slackens: the *FNRS 2* is afloat. It is light, for it has not yet been filled with petrol. As a precaution the float had been filled with carbon dioxide in order to avoid all danger of explosion at the moment of pumping in the petrol. Two hoses connect the *Scaldis* with the bathyscaphe. By one hose a pump sends the petrol from the reservoirs into the cylinders of the float. The other is used to evacuate the gas: driven out by the petrol, the gas flows back towards the reservoirs of the *Scaldis*, where it occupies the space which has become free. Slowly the bathyscaphe sinks, until the moment when the 7040 gallons have been pumped in. Our calculations are shown to be correct, the float still shows a little above the surface. When the two passengers are in the cabin and the ballast is in place, the bathyscaphe will be in proper equilibrium, ready for the dive. After having taken the petrol on board the *Scaldis*, we replace the *FNRS 2* in the boat's hold.

On the 19th October we at last left Dakar for Bao-Vista: the Portuguese Government had authorized the French Navy to enter its territorial waters, and the *Élie-Monnier* with its echo sounder took soundings at a great number of points. It marked out a zone in the neighbourhood of Bao-Vista where the bottom descends in a gentle regular slope: this was the place which seemed most suitable for the first tests. We dropped anchor here on the 21st October 1948.

Although we did not come out to explore the archipelago, binoculars and telescopes were much in evidence. The climate here is extremely arid, almost a desert. We were told that it had not rained for three years! This was perhaps a little exaggerated, since vegetation was not totally absent. The inhabitants appear to live from fishing. Of mixed race for the most part, descendants of Portuguese and Negroes, they lead a wretched existence. Since we didn't land, some of them came off in a small boat to offer us eggs, even a chicken, in exchange for cigarettes. The first day we thought we saw a large lake on the island, at sea-level. The breeze was light; but strangely enough large waves seemed to wrinkle its surface. From hour to hour, more extraordinary still, the lake changed its shape: it spread out, and then shrank. The next day it had disappeared. It was a mirage.

The first descent was to be made at a depth of 14 fathoms: I wanted the divers to be able to come with us, to survey operations, particularly to check our unballasting. Although I was persuaded that there was nothing to fear on this score, it seemed prudent to be able to call upon them for help in any case.

As our submarine had to be able to make tests without a crew, we had equipped it with an automatic pilot: it had to cut off the current to the electro-magnets by means of a servo-mechanism manufactured by Sprecher u. Schuh (Aarau, Switzerland) and thus release the ballast as soon as the Haenni pressure gauge recorded arrival at the prescribed depth. But it could have happened that, either through a mistake in the level, or as a result of drifting, the bathyscaphe came to rest on the ground without having reached the depth intended: to arrange that in this case the pilot would not remain inactive, it had been equipped with a Longines time-switch which, at the end of a set time, should set off the unballasting and the ascent. Besides this, a special installation was to start off the same operation in the case of water leaking into the cabin. For this first descent in shallow water, where there were to be two of us in the cabin, the automatic pilot was not needed. It had been understood that it would not be connected up. However, without mentioning it to me M. Cosyns had connected it, merely being satisfied with not rewinding the time switch. For my part I had wound up the time switch to see if it was working well.

What had to happen, did happen. At H-hour, while the bathyscaphe was still in the bottom of the hold and we were preparing to transfer it to the water, the current to the electro-magnets was cut automatically and one of the big batteries was detached and damaged. This accident held up our operations for one day, a delay at first sight without importance, but annoying when one must work within a very limited time. However, this made it evident that our robot was behaving itself.

On the 26th October, finally, all was ready for the first dive.

Normally, M. Cosyns should have gone with me. But he preferred to stay on the *Scaldis*, from where he kept an eye on the working out of operations. I regret for his sake that he did not participate in this first of all tests that I had waited for for so long, and that I was rejoicing to be able to carry out at last. Since this left a place free, one of the biologists was able to go down with me. Volunteers were not hard to find, and we drew lots to decide who was to come down with me. Professor Monod drew the lucky number. To console themselves the others persuaded themselves that they would go deeper when their turn came.

For me it was the great moment. It was not a matter of a dive of 14 fathoms, but that all the details of the bathyscaphe must now be put to the test. Whether one is at 14 fathoms or $2\frac{1}{2}$ miles the unballasting and the renewal of the air in the cabin, the headlights and the propellers, all must function in the same way. We went down into the hold and by the manhole, with its diameter of 17 in., we slid into the cabin. It was three o'clock in the afternoon. The heavy door suspended from a trolley rolling on two rails installed at deck-level on the *Scaldis* was brought up, put into place and bolted. There we were, cut off from the outside world. The telephone should have allowed us to keep in touch with our friends, but it was not working; one result of the divided command. Five years later the telephone in the *Trieste* was to give us complete satisfaction: my son could direct the last operations from the cabin before the dive. While at a depth of 22 fathoms we were to drift along before Castellammare di Stabia, the communication with the surface continuing uninterrupted.

But we are still at Cape Verde. Shut in the cabin, Professor Monod and I looked out of the portholes: we felt nothing at first, but all at once we noticed that the bottom of the hold was moving away from us: the winch had taken us in charge: here we were now above the deck of the *Scaldis*. Are we starting out for the stratosphere? No, after 30 ft. we stopped rising, and the crane turned. The deck of the ship seemed to slip along beneath us, then the rails and the blue sea: then the hull of the ship appeared to rise. We went slowly down towards the water, till at last the portholes were immersed. The blue light penetrated the cabin. The sight was most beautiful.

But then something happened, for the windows came out of the water again while we were impatient to go down: prisoners, we could do nothing. If only we had known what was happening! But the telephone, alas, was silent. I had, however, had the operations thoroughly rehearsed in the port of Dakar: hadn't the crew had enough training? As I had no way of communicating with the surface, it was impossible for me to intervene. If only I could have been two men; without losing my place in the cabin, have been present on the deck of the *Scaldis*!

At last we heard the noise of the steam engine driving the winch. We went down again. A fathom lower we came to a standstill. As the float was not filled with petrol, it was too light and sank no deeper in the water than to a third of its height. They seemed to be connecting the hoses for the petrol and the carbon dioxide. The only thing that we could hear was the murmur of our Draeger apparatus. But at last a new noise was added: the murmur of the pump motor which was sucking up the petrol in the fuel-bunkers of the *Scaldis* and sending it down into the tanks of the bathyscaphe. Loaded thus, we went slowly down. We watched the sea. In front of our portholes a swimmer passed. Is it Nicolas, the friend of Captain Nemo? A picture illustrating *Twenty Thousand Leagues under the Sea* has remained engraved on my memory: half a century has not effaced it: Aronnax, Professor in the Museum at Paris, and Captain Nemo in the semi-darkness of the saloon of the *Nautilus*: outside, in full light, the diver. Today it is I who am in the submarine. At my side there is indeed a professor of a Museum in Paris, but it is not Aronnax, it is Dr. Monod. We are not in the *Nautilus* but in the *FNRS 2*. And we are in 1948.

This cannot be, then, the pearl-fisher of Cape Matapan. But in spite of all this, the analogy amused us. It was a diver from the *Élie-Monnier*. He had in front of his eyes the big goggles divers wear, between his lips the mouthpiece by which they breathe, and on his feet Corlieu palms. He came close to our porthole: I lit up my face so that he could see me.

The whirring of the pump ceased: the float was full of petrol. Now why didn't we go down? The daylight decreased. Have they forgotten us on top there? The tropical night falls rapidly. The lights of the *Scaldis* lit up the sea around us. We plugged in our lamps.

Once more a diver paid us a visit; he found us playing chess. Why not? We had nothing else to do, unfortunately. As neither Monod nor I saw him, he attracted our attention by knocking several times on the wall of the cabin. On a little board, which he held in front of the window, we read: 'You are going down. Don't stay down there too long.

Don't start anything working.' At last some news! But why did he say 'don't stay down too long'? No doubt he meant not longer than is usual during bathyscaphe dives, but as our descent was the first ever done in a bathyscaphe, the order lacked clarity to some extent. And why weren't we to start up the motor? When we came up, no one could give us an explanation. It was a disappointment for me not to see our propellers function. We concluded from the message that they were in the process of putting the ballast aboard. Suddenly Monod cried: 'We're at the bottom.' Without a jolt, without a jar, the *FNRS 2* had grounded at 14 fathoms: the projectors of the *Scaldis* illuminated a vast area.

As the echo sounder and the frogman had led us to expect, the bottom was flat. But if we had hoped to find anemones, corals or pearl oysters here we should have been disappointed: the sea was empty. Everywhere there was a grey sediment, ridged like a ploughed field, where the surge had rolled it into furrows. Here and there, there were a few dark patches, which Dr. Monod could not explain. A luminous fish passed. Dr. Monod told me that it was not the fish which was phosphorescent, but the algae with which it was covered.

We started the apparatus to measure the cosmic rays, and the meter crackled loudly. Without even checking the recorder, we could hear that it was slower than on the surface. Fourteen fathoms of water, then, absorb an appreciable part of cosmic radiation. At the end of a quarter of an hour, having nothing to do since we were not to move about, we decided that the limit between 'not long enough' and 'too long' had been reached, so we set about throwing the ballast overboard. Twelve large tubs of iron scrap were held to the float by electro-magnets: I had my hand on a switch; all I had to do was press with one finger for one of the electro-magnets to let go. In short, it's as simple as a modern lift. In fact, after a light pressure on the button, I could see through the porthole that one of the ballast tubs had loosened itself and fallen. I repeated this operation several times: and the ground moved away from us. At ten o'clock at night we came once more to the surface.

Hours passed, interminably. We heard the pump functioning and, at last, the winch going into action. My porthole came out of the water: we were rising. I could see the *Scaldis*, with the whole crew at the rails: I recognized my son, who is a head taller than the others: he would very much have liked to come with me. If one could have told him that night that five years later he would go down too, but to 1680 fathoms, in a perfected bathyscaphe, the building of which he had himself directed!

We went on rising till we came to the level of the deck. The crane swung round; under us the hold was open: on all sides the sailors held the machine by ropes so that it would not knock the sides of the hold. The final phase: we were lowered into the hold. I saw our comrades, who were eager to join us as soon as possible. At last the *FNRS 2* came to rest on its cradle. It was three in the morning when the door was opened. All went well, but with an incomprehensible slowness. We had been shut up twelve hours. The same Draeger apparatus, which on the 27th May 1931 allowed us to live for seventeen hours in the stratosphere, had furnished us with breathable air during all this time.

The *FNRS 2* itself behaved very well. There was no reason then for not going on with our programme.

For the first serious dive I had contemplated going down with one of our biologists, or, if M. Cosyns wanted it, with him, to 550 fathoms. From the beginning it had been laid down that the bathyscaphe would not go down with a crew to more than two-thirds of the greatest depth previously reached without a crew. In other words, we were applying here the classic rule of the engineer who requires an overload of 50% before any mechanism is accepted. (With the cabin of the *Trieste* made of forged steel, this precaution was unnecessary in 1953 when it was only a question of going down to 1650 fathoms.) That implied then an empty descent of the bathyscaphe to 825 fathoms.

FOGO

The *Élie-Monnier* had picked out a place suitable for the tests, behind the Island of Fogo, which is another one of the Cape Verde group. In Portuguese, *fogo* means fire. In fact a volcano dominates this little island. It is a cone of remarkable symmetry which rises to nearly 9900 ft. For me and for several of my comrades who had never seen a volcano from near at hand, to approach this was something of an event. At the moment of our arrival the volcano was dormant: it was almost the sleep of the Sleeping Beauty, for the last eruption had taken place in 1857. Great lava-beds transformed into grey rock reached down to the sea and showed the route which the destructive fire had taken during the past centuries. It was clear that an eruption would be very serious, for all along the coast there were dwellings. Two years after our visit, the newspapers announced that an eruption had ravaged the island. I was sorry that our little fleet, the *Croix-de-Lorraine*, the *Le-Verrier*, the *Élie-Monnier* and the *Scaldis*, were not present then to give assistance.

On the 31st October the *FNRS 2* had to be sent down alone to a depth of 825 fathoms. So that it would not strike the bottom too violently if it happened to be at a point with less depth than supposed, we had installed, as well as our automatic pilot already described, a sort of antenna hanging below the bathyscaphe and which, upon arriving upon the ground, would have released the ballast. During the launching of the bathyscaphe, the antenna was still tucked up. At the moment when the bathyscaphe crossed the railings, Cosyns and I, who were watching operations from the bridge of the *Scaldis*, noticed that a rope was coming dangerously near to our machine. Before we could intervene, it touched the sensitive point. The robot functioned well, but as a robot without sense: and tons of ballast fell into the water. It was the rolling of the *Scaldis* which had caused the accident. Again an annoying delay.

The sea was too rough to start operations again, so the *Élie-Monnier* went off on a reconnaissance trip to the Island of Sao-Thiago. Upon its return, its officers announced that conditions were ideal in the Bay of Santa-Clara and that we should find the depths needed near the coast: if the wind did not change, we should have a glassy sea. The *Scaldis* therefore set sail for this island.

DOWN TO 770 FATHOMS WITH THE AUTOMATIC PILOT

When the morning was well advanced on 3rd November 1948 we began preparations once more. The contact gauge was set for a depth of 770 fathoms. Like most alarm-clocks, the time switch which, at the hour fixed, would set off the unballasting in a situation where the gauge had not been able to work, was not intended for dormice: it cannot be set for a time beyond twelve hours, because its little contact wheel turns round twice in twenty-four hours. At the moment when the hatch was closed on the manhole, we gave it a maximum delay by fixing it to go off at 4.40 p.m. It seemed that this would give us an ample margin of time. The series of operations to be carried out, however, is rather long. It was one o'clock in the afternoon before our submarine could at last be launched. That left us three hours and forty minutes until H-hour. The *Élie-Monnier* took new soundings. Was our navigation at fault? Had the current carried us away from the island? In short, we now had only 495 fathoms under us, so we had to tow the machine to a deeper spot. Since the cabin was underwater, we naturally could no longer adjust the clockwork. We had a very short time before us. Scarcely had we begun to move than one of the two towing-lines of the *Scaldis* broke: a new cable had to be brought from the reserve; and we had to catch the *FNRS 2*, which was adrift. At last we started out again. By now the time at our disposal was extremely short. The submarine was still a little light. Very hurriedly we gave it the extra ballast. At last, at four o'clock, the bathyscaphe went down.

We knew that at 4.40 p.m. it would unballast itself. Nothing could prevent that. It had then only forty minutes to reach the prescribed depth. We did not know exactly its speed of descent. The moment was dramatic. We had equipped our bathyscaphe with a radar antenna so that the frigates could find it again in case of fog. At the moment when this antenna disappeared below the surface, Captain Laforce, who was sceptical, said to me:

'During the war I saw several ships go down exactly as your *FNRS 2* is going down now. Not one came to the surface again.'

It was not encouraging. But our *FNRS 2* was not a ship like the others; it was a bathyscaphe! I had entire confidence in my automatic pilot. But I was afraid that forty minutes was not enough for the machine to reach the desired depth. Crew and passengers scrutinized the sea: clusters of observers crowded the masts and spars of the two frigates. I myself watched the horizon from the bridge of the *Scaldis*. Everyone was afraid that the bathyscaphe would not come up. As for me, I was sure it would come up again, but I was afraid it would come up too soon.

Slowly I turned my telescope. Several of our launches and boats were scattered about. But what was that little boat that I could see in the distance? None of ours had been sent over there. It could not be the *FNRS 2*, since it had no antenna. However, I recognized its orange colour, and that's what it was! It was 4·29 p.m. The time switch could not have gone into action, then. But had the submarine really been able to cover in twenty-nine minutes a vertical route of $1\frac{3}{5}$ miles? In that case everything would be in order. But what if water had penetrated the cabin, if it was a leak which caused the alarm apparatus to function? The answers to these questions would have to wait until we could open the cabin and read the recording pressure gauge.

Meanwhile the frogmen of the *Élie-Monnier* examined the cabin. What they told us was not very reassuring. Drops of water could be seen inside one of the portholes, which proved that a joint was not tight. It is true that a few drops would have been enough to dampen a porthole, and I refused to give up all hope.

The submarine was brought alongside. Meanwhile the wind rose; night came on suddenly, as it does in the tropics. After dark, operations were more difficult. We connected the hose without difficulty which should conduct the carbon dioxide into the float, but we could not manage to join up the big tube which would bring back the petrol to the *Scaldis*. The sea was too rough and the hose too heavy: all our efforts were in vain. The waves swept the deck of the bathyscaphe and the two men working on it stood in great danger of being washed overboard. A shark turned slowly around the submarine. Although sharks rarely attack man, so they say, this made us anxious, for fear, perhaps, that at night they might be less pacific. At this moment I learnt that one of the men could barely swim. That made up my mind, and we took them back on board.

Since there was no possibility of raising the bathyscaphe with its petrol in it, we decided to tow it to shelter inside the Bay of Santa-Clara. But we could only go very slowly: the *FNRS 2* was not intended for this sort of transport: the waves beat on its sides: the metal plates creaked under their blows. Also, I had the impression that the float was slowly going down: if that was the case, it meant there was a leak in one of the reservoirs, and the water, entering by one of the lower orifices, was driving out the petrol and taking its place: at night and in such weather it was difficult to tell. In fact this was a mistake, but I was not to know it till later. If the bathyscaphe got any heavier it would end by sinking. We therefore had to take a quick decision: the petrol had to be replaced not by water but by carbon dioxide. We had to force this gas into the reservoir by means of the narrow tube, but since the big hose could not be connected, we had to sacrifice the petrol and let it run out into the sea. That would put an end to our diving and to the whole expedition, but we reckoned it better to sacrifice the petrol than to risk the loss of the bathyscaphe itself.

6600 gallons of petrol in the open sea caused a considerable danger of fire, so we had to prohibit smoking. I sent this decision by radio to the *Élie-Monnier*, and we opened the cock of the carbon dioxide: the petrol from the bathyscaphe spurted out like a geyser. At this moment the *Élie-Monnier* drew near; and its funnel sent out a shower of sparks. My communiqué had not been transmitted in time. Fortunately they heard our shouts and the dispatch-vessel moved away.

Little by little the float was emptied: the *FNRS 2* rose higher in the water. We now tried to attach the hooks hanging from the cross-beam to the hooks on the bathyscaphe, but all our efforts were vain: the *Scaldis* and the *FNRS 2* were rolling much too much. Fearing that the sailors would be injured by the hooks, we had to give up this operation and once more take the sailors on board. Their courage and loyalty were admirable. The *Scaldis* set course for the Bay of Santa-Clara from which the wind and the drift had carried us far: the water would be calm there. Meanwhile the bathyscaphe battled desperately with the waves. Its plates groaned all night long. At midnight I asked the captain where we were.

'We are still in the same place,' he said. 'We are only just holding our own against the current.'

We dared not go faster: the bathyscaphe would not have stood it. At last, as the night wore on, the situation slowly improved. We gained on the drift and the closer we got to the island, the less drift there was. The waves grew less as well: and we moved faster.

When dawn came we were in the bay: and there, without any difficulty, the *FNRS 2* was brought aboard the *Scaldis*.

With feverish anxiety we opened the hatch. A first glance showed us that there was very little water in the cabin, not enough, in any case, to have caused the automatic pilot to unballast. There was therefore some ground for hope that the desired depth had been reached. I slid first into the sphere and to my great joy I could announce a depth of 759 fathoms. The difference of 11 fathoms between the depth for which the contact pressure gauge was set and that marked by the index of the recording pressure gauge was of no importance: the automatic pilot had fulfilled its mission.

Unquestionably then in twenty-nine minutes the bathyscaphe had covered 1518 fathoms, which represents a mean speed of 5 ft. per second. It was clear that the unballasting had been too substantial: the bathyscape must have risen to the surface at a speed of more than 6 ft. 6 in. per second. At this rate the critical velocity had been exceeded. A marked rocking had resulted and it was this motion which had caused the antenna to break (see page 62).

But how did the water get into the cabin? The direction of the splashes led us to the faulty part: it was the union of the tube bringing water under pressure to the pressure gauge which had become partly unscrewed. If the automatic pilot had had two hands and a pipe wrench it could without difficulty have tightened this joint. On the *Trieste* the same unions did not allow the passage of a single drop of water, even at a depth of 1650 fathoms. It was a pity, in short, that this dive had been done empty: if one of us had gone with the bathyscaphe, the Press could have spoken of a great success: at this moment it was still Professor Beebe who, with his 508 fathoms, held the world record for depth. Nevertheless, we had not set out to hunt records, and the fact that a habitable cabin had indeed come back from 759 fathoms had exactly the same value, from the technical point of view, as if a man or a guinea-pig had been shut up in it. Perhaps even a little more, since the construction of the robot constituted quite a presentable technical achievement.

It should be noted here that two French officers of the *Élie-Monnier*, full of enthusiasm for the bathyscaphe and confident of its success, had offered themselves as volunteers for this dive. This courageous offer could not be accepted for the reasons given above, our submarine having first to make a dive without a crew.

This dive to 759 fathoms put an end to our tests for 1948.

A few days later Mr. Barton dived in his captive bathysphere to 748 fathoms.

We now set sail for Dakar, arriving there on the 6th November. The end of the expedition came almost without incident. The *Scaldis* had to go to collect freight in French Equatorial Africa, so as not to go home empty: the budget at our disposal did not allow us to pay for the passages of twelve persons in a passenger boat or a plane. Once more the French authorities made a generous gesture; and on the 12th November at ten o'clock in the evening we left Dakar all together on board an Air France plane. We flew over the Sahara on a moonless night: in the darkness we could scarcely distinguish the dunes. A little before dawn we landed at Casablanca. In the east Mercury was visible, standing out against a still dark sky; in Europe one can never see this planet so clearly. Then the plane left for Paris, passing in a straight line over Cadiz, Toledo, Madrid, the Bay of Biscay, Arcachon. As we flew over, we could see to the east the Straits of Gibraltar and its rock, Morocco and the Atlas Mountains, and beyond the Mediterranean. It all looked exactly as on the map. It is true, then! And yet the map was drawn long before any human eye was able to see all these places as a group.

At Paris we changed planes, and at four o'clock in the afternoon we arrived in Brussels.

What is the verdict on our expedition to the Cape Verde Islands? There we had, without doubt, plenty of disappointments: but, and I should like to emphasize this, the expedition was far from being a failure.

It is not the first time that a scientific experiment has had to be done over and over again until it can take place in perfect conditions. And what of technique? What is the number of planes which have run over the field without ever having been able to get into the air? I still remember the time when we lay down flat in order to make sure that the wheels had left the ground: we were struck with admiration every time we saw a few inches between the tyres and the ground. Is it then serious that our first expedition did not have a spectacular success, since it provided proof that the principle of the bathyscaphe was correct? Henceforth, for this study we could call upon much greater resources, financial and otherwise; resources such as one would not have dared to risk for a first trial. Without the *FNRS 2*, neither the *FNRS 3* nor the *Trieste* would have been born. And if in 1953 and 1954 it was possible to dive successively to 1100, 1650 and 2200 fathoms, it is indeed to the *FNRS 2* that it was due.

The French officers of the *Élie-Monnier*, who so brilliantly and so spontaneously collaborated in this expedition, immediately saw the value of the bathyscaphe; and it is they who, by making strong representations to the French Navy, which was hesitant, caused it to decide to take it over.

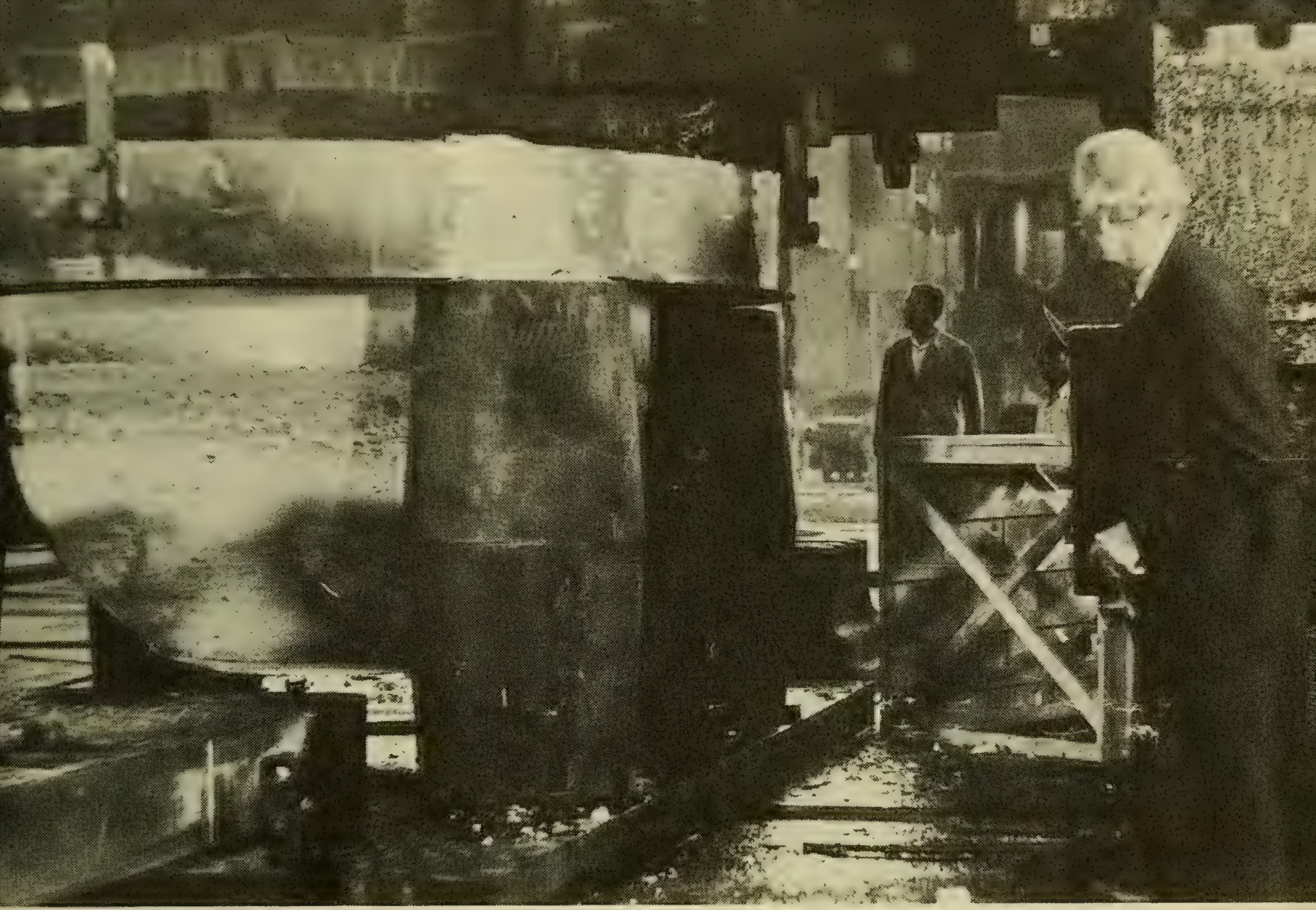


Plate VI Completing the formation of one of the hemispheres

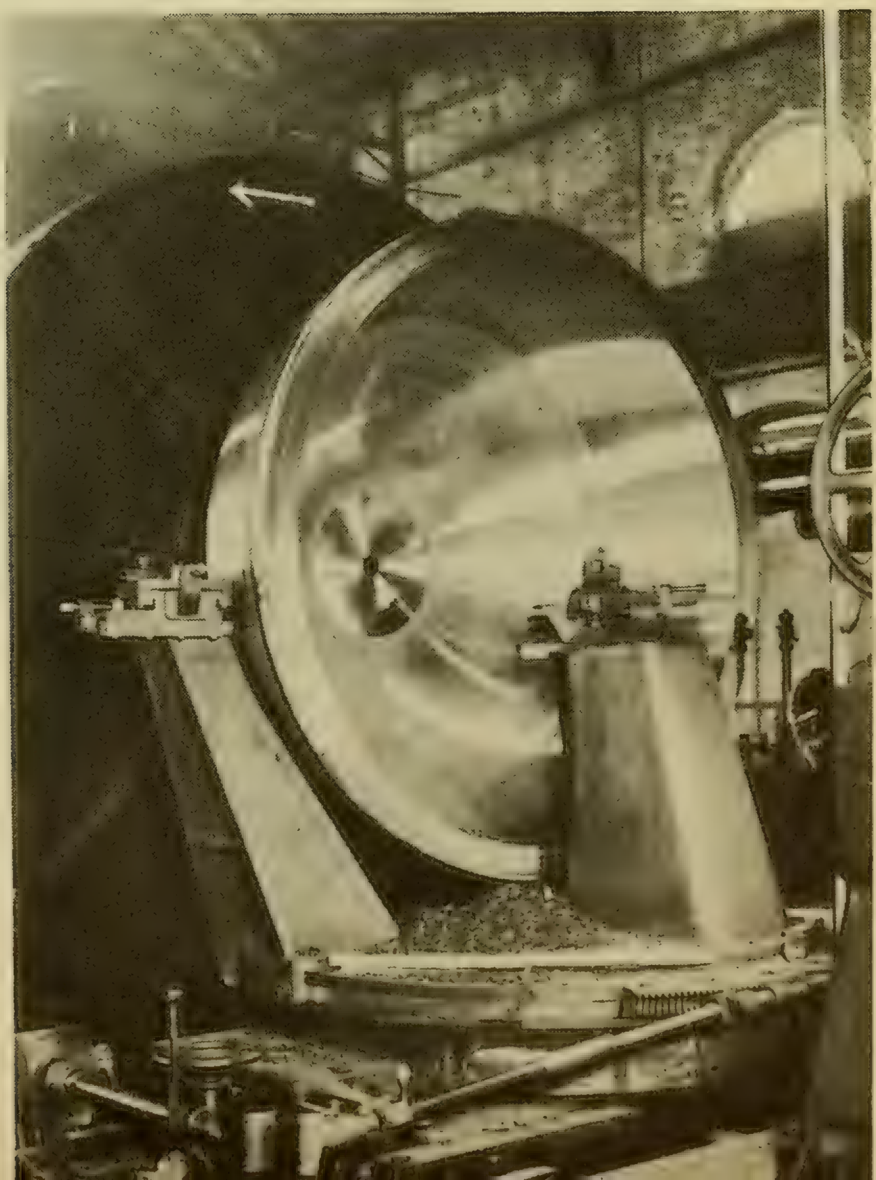


Plate VII One of the hemispheres on the lathe after stamping

Plate VIII The float under construction. Notice the corrugated-steel bulkheads

7: The FNRS 3

We have seen that the French authorities and French Navy lent us valuable aid in 1948. From Dakar to the Cape Verde Islands, and during the tests, the dispatch-vessel *Élie-Monnier* and the frigates *Croix-de-Lorraine* and *Le-Verrier* never left our sides. I still feel a great gratitude to all of them.

With the French officers we naturally discussed the results obtained and the difficulties encountered. We were all agreed that it was necessary to modify the structure of the *FNRS 2* in certain of its parts. In particular, taking it on board had proved difficult. Therefore it was advisable to go back to the former plan, studied by me in 1938, which had been abandoned for reasons of economy, the towing of the bathyscaphe to the diving-place with its float already full of petrol. Apart from the cost, this solution offered no extra difficulties in particular. It was enough to follow the lines of the hull of a vessel: however, it implied that on the high seas the crew would have to enter the cabin by a shaft and operate the door while the cabin was submerged.

Upon my return to Brussels I studied this problem in detail. But the *Fonds National* had to take into account public opinion and the reactions of the Press. They were reproached with having invested funds in an undertaking doomed from the first: they had to pay the more attention to these opinions because I was of Swiss nationality and I was not a sailor. Discussions followed; in 1950 the *Fonds National* signed an agreement with the French *Centre National de la Recherche Scientifique* (National Centre of Scientific Research) and with the French Navy, by the terms of which the French Navy took upon itself to transform the bathyscaphe by utilizing the cabin of the *FNRS 2*. The Belgian institute granted large credits for the new undertaking. M. Cosyns and I were nominated 'scientific advisers'. The bathyscaphe remained the property of the *Fonds National* until three dives to great depths had taken place: then it would belong to the French Navy. It was to be called the *FNRS 3*.

In the beginning, in my capacity as adviser, I went to Toulon on several occasions: my suggestions were of use, I believe, since the arsenal did not possess an experimental physicist. I may say that I began this work with enthusiasm. But the conditions under which I collaborated with them gradually became too painful for me: the work showed no progress: I had no rank: my situation was not easy.

This is where I stood when an unforeseen event took place in the beginning of 1952. A message came to me from Trieste asking me if I would direct the construction of a new bathyscaphe, as physicist-engineer in chief, should their plans come to a head.

The prospect of working out plans and overseeing the building of this second machine, myself being solely responsible, was tempting, there is no doubt. It would be like before the war, when the *Fonds National* had granted funds to me alone. Moreover, if, instead of one bathyscaphe, two were constructed at the same time, the explorations of the great depths could only profit.

Anyway, now that I had communicated my ideas to the French arsenal, I had not much more to do at Toulon. They could henceforth get along without my help. Without delay I let the French naval authorities know about the proposal that had been made to me.

The arsenal at Toulon remained in possession of the cabin of the *FNRS* 2, which it could use just as it was, without making any changes, and it had my instruments.

From this time on, with my son Jacques, I devoted myself to the building of the new bathyscaphe, the *Trieste*.

I regret to have to refer here to a discussion which arose when the *Trieste* was completed. In truth the reproaches made to me are not worthy of being mentioned here: but if I were silent it might be misinterpreted. I was much criticized for leaving Toulon, and for having, according to some, 'secretly' undertaken the building of the *Trieste*. On this point I must make it clear: on the 23rd January 1952, before going to Trieste, and long before anything had been decided in Italy, I made the *Direction Générale des Constructions et Armes Navales* at Paris conversant with the new situation. Following this, I had asked the *Fonds National* to communicate to the French Navy that I was withdrawing from Toulon, unless the French Navy asked me to do further work.

Certain newspapers wished to give the impression that the bathyscaphe was a French invention and that I had profited by my visits to the arsenal at Toulon to copy the plans of the *FNRS* 3; according to these newspapers, I had used them afterwards to build the *Trieste*. The truth is much simpler: taking into account all the experience we had acquired, we had one way and another thought it well to build a

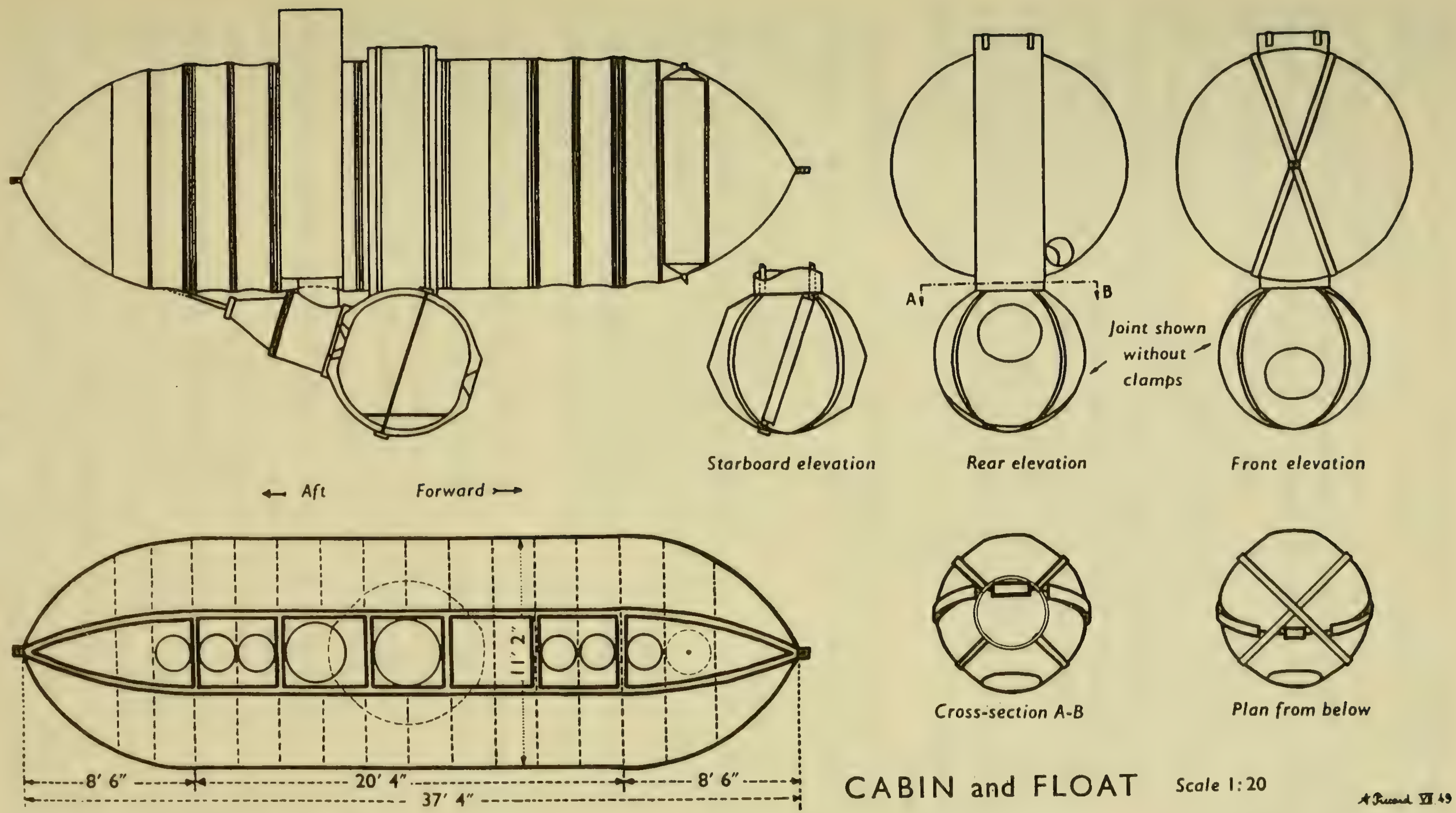


FIG. 6. Design of bathyscaphe from the drawings by Professor Piccard made in July 1949

towable bathyscaphe. In other words, we had come back to the concept I had had in mind in 1938 and which I had given up, as I have said above, because it was much too expensive. Immediately upon my return from Dakar I had worked over the details and I have in my possession a project representing a bathyscaphe of this type which I drew up in Brussels in July 1949, that is to say, long before I had entered the arsenal at Toulon (see Fig. 6).

The characteristics of the *Trieste* will be seen immediately from this plan: cylindrical float tapering at back and front, entrance chamber, cabin attached to the float by four steel clamps, etc.; the mechanism allowing the cabin hatchway to be set in place was modified later. I had, besides, given a photostat of this plan to Captain Cousteau and to M. Francis-Boeuf. From the moment it has been decided to design the bathyscaphe so that it can be towed, its general form is *ipso facto* determined.

On my suggestion the French Navy adopted numerous devices installed on the *FNRS 2*: release of the ballast-shot by magnetic valve, control valve, trail-rope, screws, lateral lighting of the field of vision by projectors, and many other things. The fact that we left with the French Navy the Draeger apparatus and the Haenni (Swiss) pressure gauges, etc., is secondary; but I insist on one point: the cabin of the *FNRS 2* constitutes the main part of the *FNRS 3*. Now it is I who first drew the plans: I had then a perfect right to reproduce this sphere and incorporate it in the *Trieste*. Its weight fixes the dimensions to be given to a bathyscaphe.

This is enough, it seems to me, to explain the similarities between the *FNRS 3* and the *Trieste*. Constructed on the same initial principle, neither of them is a copy of the other. Just as is shown by the published photographs (for example, Plate V of this book) the float of the *FNRS 3* very much resembles the hull of a real ship, while I retained the float of cylindrical form as in the plan of 1949, it being more solid, lighter and less costly. In spite of that, and on account of the internal bilge keel, it behaved very well on the high seas. Certain details will be found, naturally, in both machines, as, for example, the tower, or the upper hatch of the entrance chamber. They are normal practice in submarines and, the two bathyscaphes having been constructed with the collaboration of submarine engineers, these similiarities in no way prove that one of the two machines was copied from the other. A biologist could say here that a cat's eye was not copied from a dog's eye, although the two animals descended from the same ancestor.

In conclusion here are the first performances of the *FNRS 3*, manned by Captain Georges Houot and Marine Engineer Pierre Willm, as I read of them in the Press:

1953	17th June	13 metres	(7 fathoms)
	19th June	30 ,,	(16½ fathoms)
	25th July	70 ,,	(38½ fathoms)
	29th July	500 ,,	(270 fathoms) (without crew)
	5th August	1500 ,,	(820 fathoms) (without crew)
	6th August	750 ,,	(410 fathoms)
	12th August	1500 ,,	(820 fathoms)
	14th August	2100 ,,	(1150 fathoms)
1954	27th January	4100 ,,	(2250 fathoms) (without crew)
	15th February	4050 ,,	(2210 fathoms)
	22nd April	1600 ,,	(880 fathoms) (Captain Houot and Professor Monod)

PART TWO

THE *TRIESTE*

In the spring of 1952 my son Jacques and I accepted the proposal received from Trieste to build a new bathyscaphe: it was to bear the name of that city.

We are fundamentally indebted to Swiss and Italian generosity for being able to bring off our first series of experiments: therefore the Trieste *wore the flags of those two countries together. Italian industry granted us industrial and technical aid and Switzerland gave us large funds. The Fiat company accorded us generous grants and by its gift of a car facilitated our work. The Esso Company put at our disposal* 22,000 *gallons of extra-light petrol distilled specially for us. The Terni Company, the Cantieri Riuniti dell'Adriatico (United Adriatic Shipyards) and those of Castellammare di Stabia, and many other firms and institutions, in Switzerland as well as in Italy, generously shared in the undertaking. I shall speak of them later. I thank them all. In the appendix will be found the list of friends, patrons and donors.*

What did our new machine look like?

The general principle of the FNRS 2 *was naturally kept: a watertight cabin sustained by a float containing petrol. But there was an essential difference: the machine was intended to be towed, as we have already said: the result was that the crew had to be able to enter and leave the cabin on the open sea, by a shaft which went down through the float. This involved considerable modifications. The cabin, however, was almost identical with that of the* FNRS 2.

1: The Float

THE float of the *Trieste* was built at one of the dockyards belonging to the *Cantieri Riuniti dell'Adriatico* Company of Trieste at Monfalcone, a pretty little industrial town lying between the Karst hills and the sea.

As is often the case in technical problems, different requirements suggested mutually incompatible solutions, and the answer was sometimes a compromise based more on judgment than on mathematical formulae. We were lucky to be able to profit by the long experience of M. Loser, the engineer at the dockyard. I have special gratitude for him: he spared neither time nor trouble in seeking with me the best solutions of a great number of problems set by the construction of our ship, which varied, it must be said, in a marked way from established practice in conventional naval architecture.

Fig. 7 shows the structure in its main lines: the float, in plates of mild steel, fusiform or more correctly cylindrical, tapering equally at both ends. Total length 49 ft. 6 in.; diameter of the cylinder 11 ft. 6 in. (3·5 m). Inside there are twelve compartments for petrol of a total volume of 3736 cu. ft.: at each end an air tank of 212 cu. ft. The central compartment of a capacity of 153 cu. ft. contains stabilizing petrol. It is built in the form of a vertical cylinder. Each of the other compartments and the two tanks which occupy the entire width of the float are separated from each other by twelve transverse partitions, or bulkheads, of corrugated iron. The thickness of the metal sheets forming the bulkheads and the air tanks is 0·118 in. (3 mm.); that of the metal sheets on the outside of the compartments for petrol is 0·1973 in. (5 mm.). The weight of the float when empty is 15 tons: this float enjoys the luxury of having its bilge-keels inside: immersed in the petrol, they damp out rolling movements considerably by their friction with the liquid.

The reader will see from Plate XI the dark lines painted on the hull of the *Trieste*: their purpose is not to imitate a zebra but to indicate clearly the position of the partitions, for, during the operations on land, it is important to support the bathyscaphe where the float is stronger, that is to say, at the bulkheads. Moreover it is important that, in case of damage, it can be immediately ascertained which compartment has been affected. All the parts, outside and in, have been painted, but it was difficult to find for the interior a paint which would resist sea water as well as petrol.

If I had it to do again, and if I had at my disposal sufficient funds, I should construct the entire float in stainless steel. The increase in

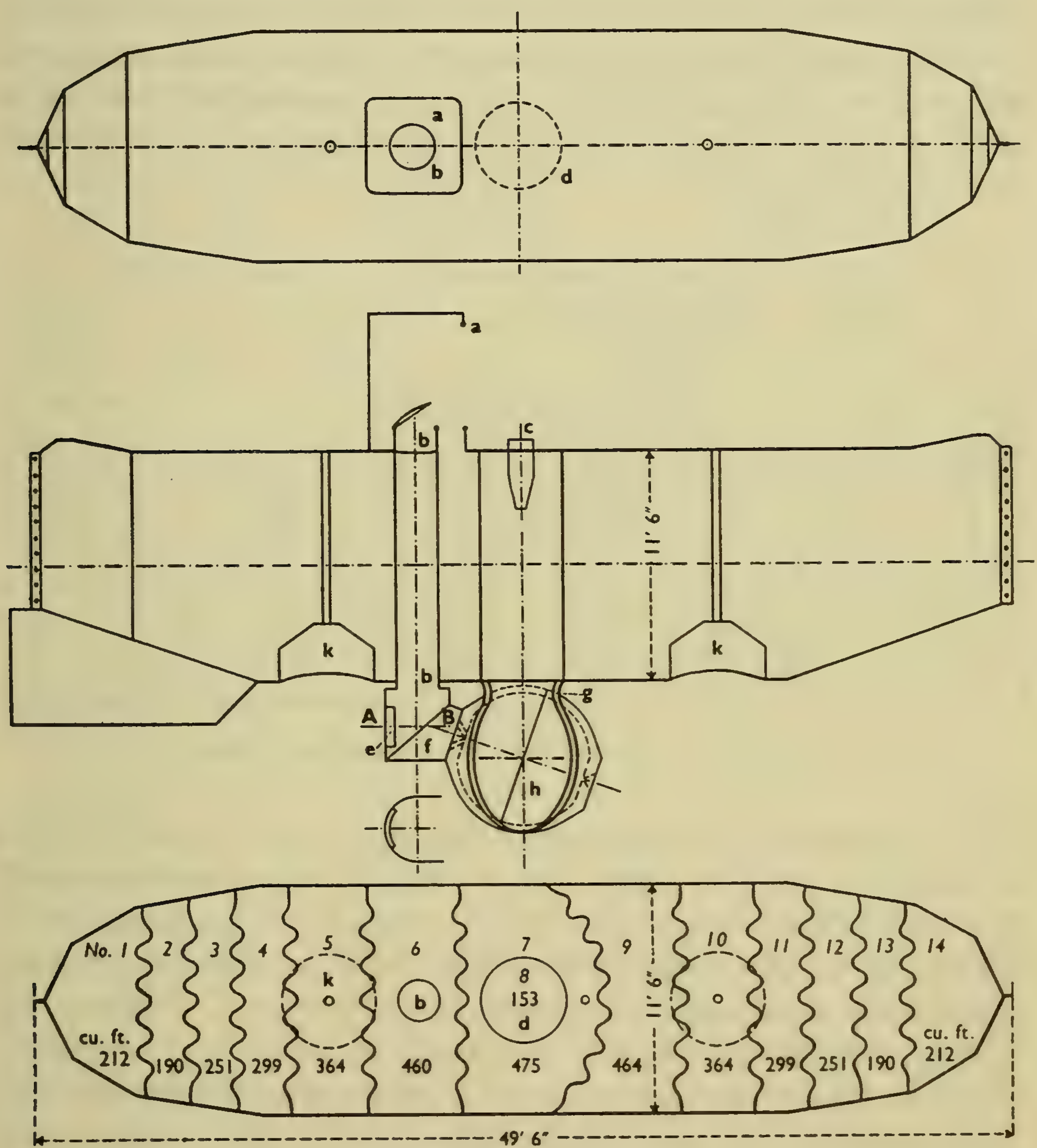


FIG. 7. The *Trieste*

cost, in the end, would not be as great as one might think at first sight, for one would save on the cost of painting which has to be done periodically. Moreover, with stainless steel, which is stronger and not liable to decrease in thickness by corrosion, the plates could be made thinner; the decrease in weight which would result would permit a decrease in all the dimensions of the float.

Directly or indirectly all the compartments of the float must be in communication with the sea. Thus the water will partially take the place of the petrol when this diminishes in volume, either as a result of the increased pressure due to the descent, or following upon a decrease of temperature. The water will be driven out when the petrol expands. The pressure will then always be about the same inside and outside the float, with the consequence that the walls will not be acted upon by the enormous pressures of great depths. Fig. 8 shows the arrangement used.

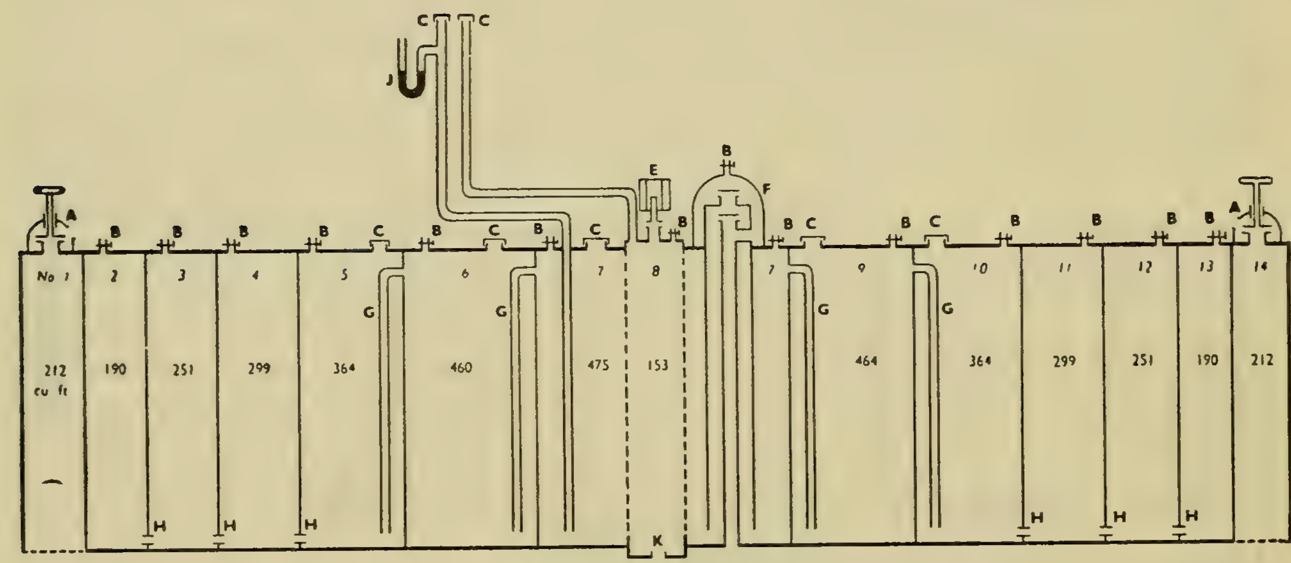


FIG. 8. Compartments in the float of the *Trieste*

Let us imagine the bathyscaphe floating on the water. The float is still full of air. The caps of the openings C are unscrewed and the drain-cocks B are opened. In order to avoid a loss due to expansion, the float is not completely filled with petrol. First, therefore, a certain quantity of water is poured into reservoirs 6, 7 and 9. This quantity of water has been calculated in advance, in terms of the density of the petrol and its temperature, as well as of the total weight which the bathyscaphe is to support. (At the time of the first filling of the *Trieste*, it was a matter of 510 cu. ft. of water.) For the rest, the float has been calculated rather generously, for, as we have seen, at the moment when the plans were drawn up, neither the weight of the metal plates nor the specific gravity of the petrol were known with precision.

Through the openings C we introduce nearly all the petrol required to fill the float completely. All the filling-holes are closed except the one which is on top of the tower, on the left in the diagram. Then, through this last opening, we continue to introduce the petrol. During this filling operation the air in the compartments goes out by the drain-cocks B. (These consist of two straight-through cocks with a bore of 0·49 in.) As each compartment becomes full the petrol is seen to rise through the drain-cock, and this must then be closed. When all the drain-cocks are closed, we know that there is no more air in the float. This is very important because, in the deep sea, any air in the float would be compressed to a very small volume and an equivalent quantity of water would enter the float. From this there would result an overload of about 10 lb. per gallon.

It is thus essential to make sure that all air is excluded before each dive; but we must also be able to determine the quantity of water present in each compartment. For this purpose we constructed a very simple instrument: a metallic tube 13·2 ft. long and 0·394 in. in external diameter, which is traversed from end to end by an insulated copper wire which projects 0·394 in. beyond the lower end, this last part being bare. The top of the tube and the wire are cemented to a dry battery and a little bulb. If it is in contact with the base of the tube, the sea water (a conductor) closes the electric circuit, and the lamp lights up. The drain-cocks, in the open position, give free passage to the tube; it is thus easy to sound each compartment and to determine the quantity of water present in it.

Compartments 2, 3, 4 and 5 as well as 10, 11, 12 and 13 are intercommunicating at their lower ends by the openings H, while the compartments 5, 6, 7, 9 and 10 communicate by the tubes G. The purpose of these tubes is always to conduct the water towards the central reservoir 7. This prevents losses of petrol by way of the reciprocating valve and also improves the longitudinal stability of the bathyscaphe. The reservoir 8 contains the stabilizing petrol. It is equipped with a valve E operated electro-magnetically and with a hole K by which the water enters to replace petrol that has been jettisoned.

When, after the filling, all the openings B and C are closed, the float breathes through the double valve F to compensate the variations of volume of the petrol. The U-shaped tube J should avert catastrope if by some accident the double valve F becomes blocked. It contains mercury, and its dimensions are such that it allows water to pass in either direction if a difference of pressure of 0·15 atmospheres occurs.

(The details of the construction of the double valve F and of the control valve E are given in the Appendices.)

Another danger, namely, the stopping up of all this piping by ice, is also guarded against. If the bathyscaphe stays a certain time at the bottom, the petrol gradually takes on the temperature of the ambient water, which in the Atlantic, even in the tropics, can be close to freezing point. Let us suppose that now it begins a rapid rise: on account of the adiabatic expansion, the temperature of the petrol will go still lower, falling to 15° or even 5° F. As a result the water contained in the pipes will freeze along the walls. The cross-section of these pipes must then be of a size such that in no case can the ice formed prevent the free circulation of water, otherwise the float could burst. Taking into account the thermal conductivity of the ice, and of the time during which the low temperature of the petrol could continue, we calculated the cross-section that these tubes must have and, as a measure of precaution, these calculations were verified by tests carried out at the *Glacières de Bruxelles* (Brussels Refrigerating Works) and at the ice-works of E. Burgin of Basle.

Finally, the drain-cocks B are covered with caps which protect them against all damage. These caps also prevent a loss of petrol in case the straight-through taps should leak. To avoid the caps, which naturally contain air, being crushed under great pressure, they are connected to rubber vessels filled with water, placed in the float: in the depths the petrol compresses the rubber sacks and causes the water to pass into the caps, to replace the air, the volume of which will have been reduced to almost nothing.

THE AIR TANKS

The extremities of the float are air-tanks (Nos. 1 and 14, Fig. 8). Their purpose is to give buoyancy to the bathyscaphe during all the surface operations. When full of air, they increase the lifting force of the float by 12 tons. Before the dive is begun, the valves A are opened, and sea water enters at the bottom of the tanks. After the dive, compressed air, supplied from the towing vessels by means of a flexible tube, is used to expel the water in these tanks: the deck can then be seen to emerge more and more above the level of the sea. If necessary, the float can also be trimmed by filling the two tanks unequally. They also assure a certain protection in case of collision: being built in metal sheeting of 0·118 in.

thickness only, they would meet the impact first and their damage would not result in any loss of petrol.

THE CONTROL VALVE

The bathyscaphe, derived from the free balloon, is, like the balloon, equipped with a control valve: by 'pulling' the valve the aeronaut allows gas to escape, thus diminishing the speed of ascent or beginning the descent. In the same way the pilot of the bathyscaphe must be able, by opening the control valve, to sacrifice the petrol to check the rate of ascent, to stabilize his machine or even to make it go down.

The valve of the balloon is placed at the top of the single gas envelope. If it remains jammed in its open position, the pilot cannot avoid a return to earth. This happened when the first American stratospheric balloon, the *Century of Progress*, took off; instead of going up into the stratosphere, the balloon, after having reached a height of only a few hundred feet, landed in the middle of Chicago railway station. Some weeks later, the valve having been modified, it went up again, and this time brought the altitude record from Europe to America. To eliminate dangers of this type, obviously more serious for a bathyscaphe than for a balloon, it is sufficient to place the valve on the top of a small, independent reservoir. I chose the central tube of our hull (from which the cabin was to be suspended) to store the stabilizing petrol. Its small volume of 153·5 cu. ft. represents a static lift of the order of 3300 lb.

The manipulation of the valve, very simple in the conventional free balloon, more complex in the stratospheric balloon, here became a difficult problem. It is described in the Appendix.

UNBALLASTING

It is difficult to say which is the most important part of the bathyscaphe: just as the strength of a chain depends upon that of each link, each of the components of our submarine was of vital importance: numerous problems had to be resolved before it was possible to plunge into the construction of the whole.

The problem of unballasting, however, is among the most interesting: it is one of those which occupied our thought from the beginning.

In describing the *FNRS 2* we mentioned different systems of unballasting, all based upon the utilization of a magnetic field whose action ceases as soon as the current which feeds it is cut off.

In the construction of the *Trieste* we simplified the system and rendered it more flexible by making use of only one of the means worked out for the *FNRS 2*. The ballast consists of 9 tons of iron pellets contained in two metal tubs together weighing 2 tons. (See Fig. 9.) At the base of each of these tubs is placed a magnetic valve permitting the ballast to be released. Moreover, each tub is suspended from an electro-magnet: thus the ballast can be released in small portions by means of the magnetic valves: the two tons weight of the tubs constitutes an emergency ballast which can be dropped by cutting off the current to the electro-magnets. Besides, if necessary, such as would be the case if the valves were stopped up, the pilot could always

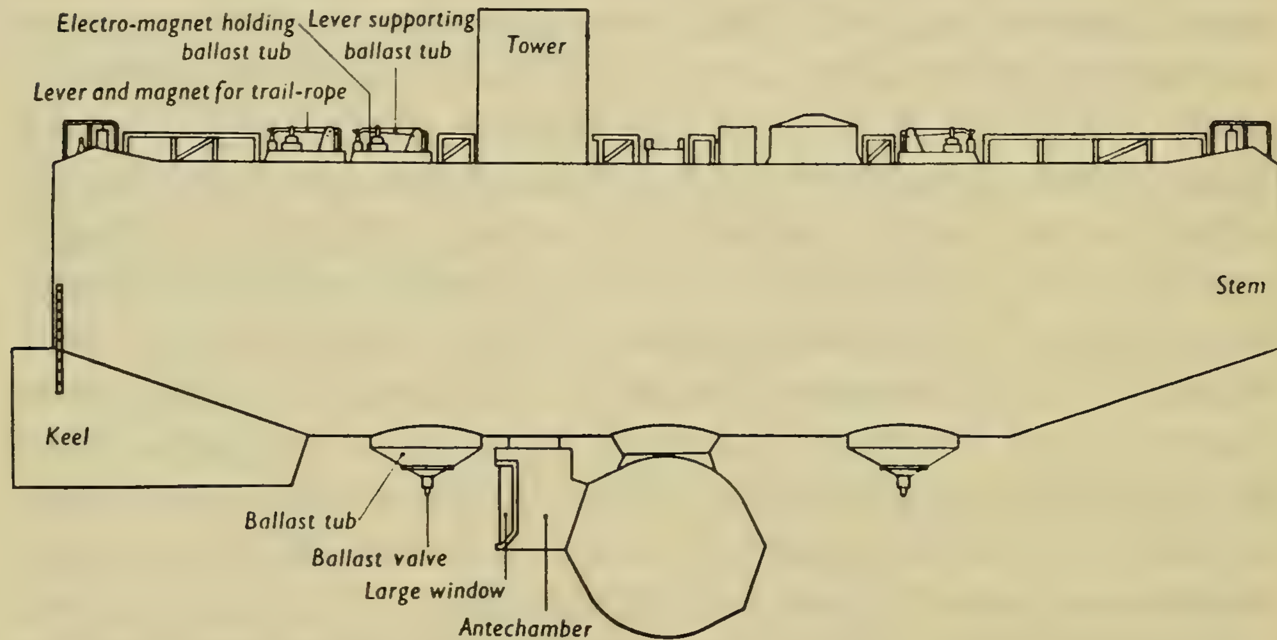


FIG. 9. Side elevation of the *Trieste*

drop at one blow all the iron pellets with the tubs. (The detail of the valves and the electro-magnets will be found described in the Appendix.)

Suffice it to say that the iron in the valve, when magnetized, forms into a solid block, and stops up the outflow pipe at the point where its cross-section decreases. Figs. 16 and 17 explain the working.

CHAMBER LEADING TO THE CABIN

The passengers of the *FNRS 2* entered the cabin while the bathyscaphe was still in the hold of the parent ship. As the *Trieste* had to be launched in the port, it was necessary to arrange that the crew should not have to remain shut up in the cabin during the whole journey to the diving site. From this arose the need to reach our cabin in the open sea, when this cabin would be 13 ft. below the surface of the water. This was how we did it. A tube *b b* of a diameter of 25 in. (Fig. 7) traverses the entire float from top to bottom and ends beside the cabin in a little space which we called the antechamber (see Fig. 7, Fig. 9 and Plate XI). The top of the tube can be closed by the normal circular hatch seen in submarines and ends in the conning-tower on deck. On the surface this shaft is generally empty: it is entered by a ladder and one gets into the cabin by sliding through the door, shaped like a truncated cone, which gives access to it. This door is closed and, by means of a pump on the towing vessel, the shaft is filled with water. Then the upper hatch is closed. The bathyscaphe is then ready for the descent: it will suffice to open the air tanks for it to dive.

After the dive the shaft must be emptied. For this purpose the occupants of the cabin have ready bottles of compressed air which they direct into the shaft by means of a small steel tube. Thus the water in the shaft is driven out through a large tube which leads from the bottom of the antechamber to above the deck.

One can also make use of compressed air from the towing vessel to empty the water-lock without action on the part of the passengers. This is necessary during empty dives and is useful when one wants to economize with the bottles of compressed air in the cabin.

The use of the pump to fill the shaft with water could have been avoided, for example, by placing a sluice gate at the base of the shaft or by equipping the bathyscaphe with its own pump, but after study the system chosen appeared the most suitable, at least for the first dives.

The door of the cabin has a porthole in plexiglas which allows one to see into the antechamber: the wall of the antechamber facing this porthole has a large window in plexiglas 1·18 in. thick, 33·5 in. high and 23·6 in. across. This window never has to sustain a difference of pressure of more than a few fathoms of water, since in a dive the shaft is in communication with the outside water through the large tube we have mentioned. Hence the thickness of 1·18 in. for the plexiglas is quite enough. This plate of glass is a beautiful industrial achievement that we owe to *Vétrocoke*. Through the porthole of the cabin and the large window the observers enjoy very good visibility in this direction, always provided that the water introduced into the shaft is perfectly clean. The *Trieste* thus possesses two portholes giving broad fields of outside vision, while the *FNRS 3* has only one that is really of use.

THE CENTRAL TUBE OF THE FLOAT AND TRIM OF THE SPHERE

There is a vertical steel tube 47·3 in. in diameter, with a wall thickness of 0·394 in. in the centre of the float, which goes right through it. It is welded to the two extremities of the hull. It has three separate functions:

The interior of this tube serves as a reservoir for the stabilizing petrol. At the top of the tube a big hook is affixed which allows the crane to lift the entire bathyscaphe: thus the load is well distributed over the top and the bottom of the hull. The bottom of the tube projects slightly below the float: the cabin is suspended from it. The cabin is carried by two bands of mild steel 3·94 in. wide and 0·394 in. thick which run round it and cross each other at its base and of which the four extremities are connected by means of four straining-screws at four points of the central tube. Between these steel bands and the cabin there is a thick layer of rubber, as well as between the cabin and the base of the central tube. By means of the straining-screws the cabin is held tightly against the tube.

At the base of the cabin an iron cross prevents the steel bands from getting out of place and assures them a certain protection.

According to calculations the safety-factor of this suspension is very great. Even so we tested it and this was done in the following manner:

While the float was at the dock and rested on its cradle, we alternately loosened one and then the other of the steel bands. The load on each band was thus doubled in turn. But as the cabin is roughly twice as heavy in the air as in the water, the suspension was thus tested with a load four times the normal.

As a precaution we also surrounded the cabin with four large cables which would suffice by themselves to carry it.

If this construction is compared with that adopted for the *FNRS 3*, it will be seen that our old cabin of the *FNRS 2* is resting now in a veritable basket of steel framework: the factor of safety of this suspension seems very much greater than for ours. However, I should not like to make an exchange of the two systems of fixing. I consider that a measure of safety corresponding generously with technical norms is enough: moreover, it is obvious that the basket of the *FNRS 3* runs the risk of becoming caught in submarine obstacles.

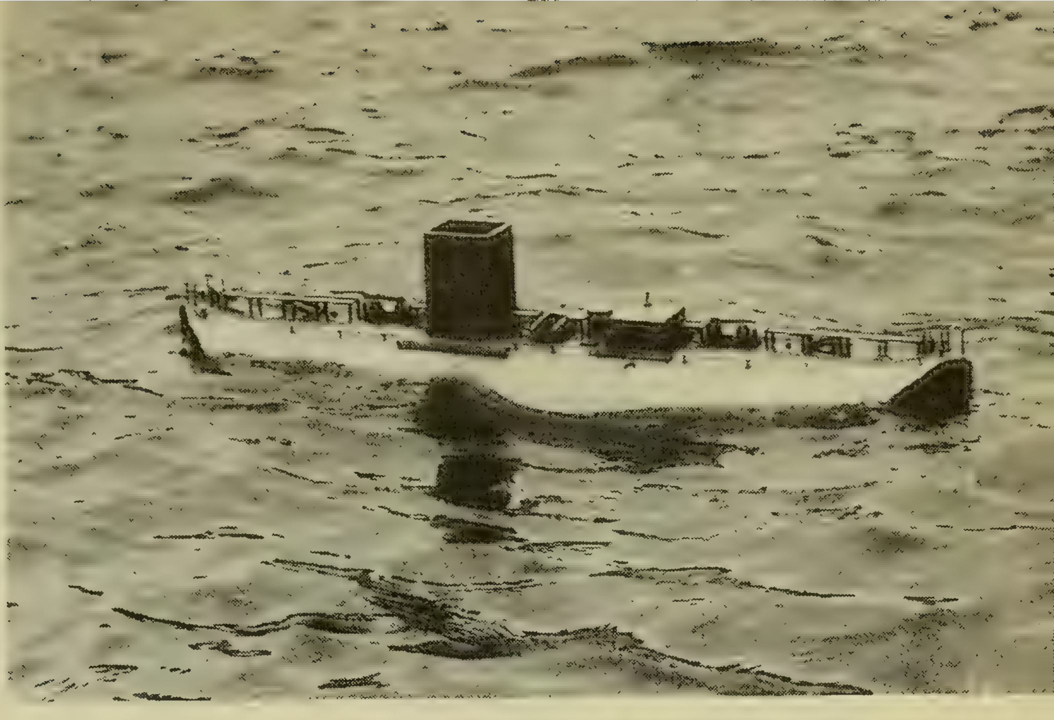


Plate IX A model of the *Trieste* undergoing hydrodynamic tests

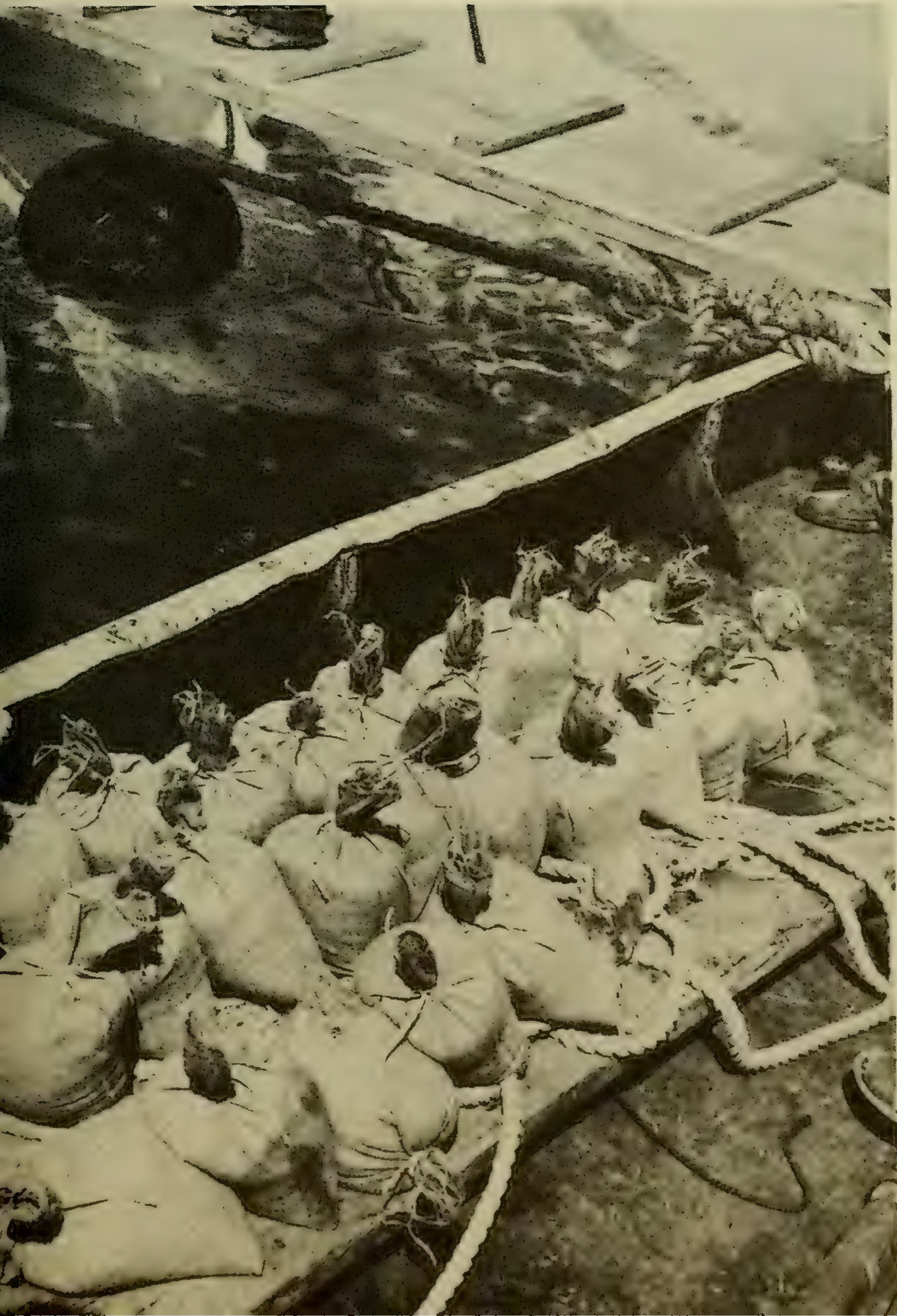


Plate X The iron shot used for ballast

Plate XI The *Trieste* is launched at Castellammare

2: *The Cabin*

AFTER the cabin of the *FNRS 2* had been handed over by the Belgian *Fonds National* to the French Navy, we went to Terni to build a new bathyscaphe.

Terni, about 60 miles north of Rome, is an industrial centre on the banks of the Marmora, a tributary of the Tiber. In the beginning, before the era of electricity, the falls of the Marmora supplied power to a forge. This developed and became one of the greatest industrial enterprises of Italy, the *Società per l'Industria e l'Elettricità* (Industrial and Electrical Company), which now operates in its original centre vast steel-mills of a very modern type.

This company bent all its energies to the building of a really faultless cabin.[1]

The first, that of the *FNRS 2* and the *FNRS 3*, was in cast steel. For the *Trieste*, however, it was decided to make it in forged steel, which is stronger and more malleable.

As a matter of fact every solid that is subjected to stress is deformed. If the stress has not exceeded the elastic limit the part takes its original form again as soon as the load is removed. If this limit has been exceeded, the part, after the unloading, retains a certain deformation, called 'permanent deformation'. A still greater stress produces breakage. For certain materials, like glass, this ultimate stress is almost identical with the elastic limit: glass does not sustain permanent deformation, without breaking. Other materials sustain a very great deformation before breaking: they are malleable. Among the ordinary metals, lead presents the greatest malleability. When by accident a component breaks, it is not generally because the load has exceeded that which the broken section should be able to bear: the cause of it is more often that the stresses were not uniformly distributed over the whole section. When an overloaded part breaks, its load passes entirely to the neighbouring parts: these, overloaded in their turn, break. Thus step by step a whole part can yield, although rough reckoning has led one to believe that it was strong enough. If, however, the material shows a sufficient malleability, the overloaded part

[1] Here I should like to express my great gratitude to this company and especially to the engineer, Mr. Flagiello, Director of the Professional School of Terni, who devoted his energy and his art to the manufacture of this component.

can stretch out beyond its elastic limit without breaking; it thus continues to contribute to the strength of the whole.

In general, forged metals will take a greater permanent deformation than cast metals: they are more malleable. This is the case with steel. We were very happy when they told us at Terni that they possessed a press powerful enough to forge the two hemispheres of our cabin. Over and above the superiority of the material itself, this process of manufacture had other advantages.

In a casting the upper part is apt to be of lesser quality. It is there that one most often encounters flaws and pockets arising from gaseous discharges. The raw material for each hemisphere formed an ingot cast in a vertical position, 12·70 ft. high and of a mean diameter of 3·5 ft.: this ingot weighed 24 tons. One could thus sacrifice all the upper part of the cylinder before beginning to forge the material in order to utilize only the lower part, which would be of much better quality. This part would then be flattened by means of a press, so as to give it the shape of a disc. This disc would then be pressed into the shape of a hemisphere. Thus each pocket would be flattened and would finally form a thin vein which would run perpendicular to the radial line of the sphere. The elementary theory of strength of materials shows that in these conditions a small initial defect would hardly decrease the strength of the sphere at all.

AT THE FORGE

Here we are in the immense forging shop at Terni. The door of one of the greatest furnaces rises. It is so dazzling at first that nothing can be seen inside. If a smoked glass is used, however, an incandescent block can be distinguished. A giant tool, suspended from a travelling crane, transports this radiant mass across the hall and places it upright on the bed of the press. Now imagine this press exerting 12,000 tons, probably the most powerful in Europe, if not in the world, while its ram, actuated by three hydraulic cylinders, is lowered slowly: under its pressure the block is compressed and broadens out. Upon contact with the air, a layer of oxide is formed on the block of metal: less hot than the interior of the ingot, it crumbles under the action of the press and the dazzling steel appears before oxidizing once more.

The work is not done in one operation. The block returns to the furnace several times and stays there for several hours each time before the operation is continued. At one time it is as broad as it is tall, then broader, so broad that the power of the press would not be enough to flatten it over all its surface. Other measures are resorted to: the action of a great horizontal steel bar, attached to the face of the ram, which rises and descends, pressing the block at each descent, while this turns during each rise of the ram. The whole surface is thus crushed bit by bit and the piece takes the shape of a ship's biscuit 10 ft. in diameter. Its thickness, passing from the centre to the rims, goes from about 11·80 in. to 4·70 in.

The spectacle is impressive. All this work does not seem to require any human effort. We scarcely see even the foreman, who, without saying a word, with a few gestures of his hand, or even with a finger, directs his gang: every man is always in the right place at the right time carrying out the action required. Of a blinding white, the block gives out an intense heat and the men have to have masks for their faces.

This flat biscuit must now be given a hemispherical form. Under the press they place upon four blocks a steel ring of an internal diameter of 7 ft. 5 in. The incandescent disc is placed upon it. A massive hemispherical die of a diameter of 6 ft. 2·8 in., carried by the ram, comes down slowly, touches the middle of the disc and, continuing on its way, forces it through the ring: from being a saucer it becomes a bowl. At the same time, by means of a stream of water, the bowl is cooled, so that the effect of deformation is concentrated on the other parts. Once the whole disc has passed through the ring, the entire piece falls upon the bed of the press.

This last phase represents the most delicate and most impressive operation of the whole manufacture. The directors of the mills, the engineers and the workmen who are momentarily free have come to watch; it isn't every day, even at Terni, that a piece of work as large and at the same time as delicate is to be seen.

The work of the forging shop is finished. Each hemisphere has a weight of 10·8 tons, of which more than half will be removed by machining on the lathe. But it will first undergo a heat treatment which will give it the degree of hardness required and the necessary homogeneity and which will above all eliminate the internal stresses induced by forging.

The piece then goes back to the furnace, where it reaches a certain fixed temperature, its colour ranging through the dull reds and uniformly distributed. It is then slowly immersed in a bath of hot oil, after which it is put back into a furnace in which the temperature is allowed to decrease gradually according to a well-established plan. This operation must give the steel not its final *hardness* but a degree of malleability which will facilitate machining on the lathe, for the lathe will take off five tons of material from each hemisphere in the form of shavings. It is not till just before the last machining and the last polishing on the lathe that a new heat treatment with a new tempering will give the steel exactly the degree of hardness demanded for its purpose. (Plate VI illustrates the work in the forging shop.)

CHECKING THE MATERIAL

Although the metal used and its method of manufacture would lead us to expect a perfect quality, prudence still insists that we should make sure of the quality by very minute checks. Thus during the machining we took little specimens which were afterwards examined in the laboratory. All the results were very satisfactory. The cabin when finished, trimmed and polished shone like a silver ball. The slightest surface defect would have been glaring. On this point there was no cause for anxiety. But did the heat treatment impart the desired hardness *throughout* the hemisphere? This is where the Brinell test comes in. Before the very last machining operation a small area of the piece is polished, and on it is placed a ball of tempered steel which is made to penetrate the metal slightly with a well-determined pressure. The ball is taken out and, under the microscope, the diameter of the imprint the ball has left is measured: if it is too big, the steel lacks hardness; if it is too small, it is because the steel is too hard; if the edges are irregular, the metal is brittle. The check is made in a great number of places distributed over the whole surface of the cabin. It is conclusive. We know henceforth that the internal and external surfaces of our cabin are made of a steel which meets our requirements. But is the same true of the interior of the mass? From this point of view we are to be reassured by radiographic and ultrasonic checks, which we shall discuss in detail below. (See Part 4, page 166.)

THE LIMIT OF DEPTH

What depth will our cabin stand without danger? From calculations and tests with a model the results showed that it would probably be crushed around 9 or 10 miles. That did not, naturally, mean that it would stand up to a depth of 8 miles, if such a depth could be found.

We know, in fact, that any piece of metal can always, because of lack of homogeneity or because of some internal tension, yield to stresses less than the calculated ultimate strength. It is the province of the engineer, and his alone, to work out the load which may be sustained without abnormal risks. For my own part, I considered that depths up to $2\frac{1}{2}$ miles could be reached practically without any danger by our cabin, seeing it had been made of finest quality forged steel. I should have been much less categorical if we had been dealing with a cabin in cast steel.

To go down deeper it would be necessary first to carry out trials with the bathyscaphe empty, that is to say, to install an automatic pilot in the *Trieste* as we had done for the *FNRS 2*. We already had the necessary instruments. At the moment when the bathyscaphe reached the depth intended, two pressure gauges, independently of each other, would cut the current feeding the magnetic valves and would thus automatically start the ascent. If for any reason the bathyscaphe rested on the bottom before reaching the depth intended, two pieces of mechanism, independently of each other, would cut the current to the magnetic valves, after a certain set time. Finally, if a leak occurred and salt water entered the cabin, it would close an electric circuit and by means of a servo-mechanism would cut the current to the magnetic valves.

These empty trials would greatly increase the safety. Modern industry, which makes great use of this method, generally carries them out with overloads of 50%. I know only one case where the empty trial is impracticable: it is that of dams for hydro-electric systems. Even if it were possible it would call for the evacuation of hundreds of thousands and in certain cases of millions of inhabitants. Military submarines indeed are not generally subjected to empty trials. It would, however, be easy to fix under the hull ballast to be dropped automatically for the trial dive.

What is the depth that the *Trieste* could reach after having been successfully through empty dives? It is impossible to say precisely: it depends on the aim of the dive and above all on the risk that the crew has agreed to take. As for me, I was willing to go down as far as $3\frac{3}{4}$ miles without any fear, not to beat a record, but to make observations, the scientific value of which would be recognized beforehand.

If it were desired systematically to explore the very great deeps it would be necessary to build a still stronger cabin, that is to say, heavier (and in consequence with a bigger float), or one of a smaller diameter.

THE COMPLETED CABIN

Our cabin has the same dimensions as that of the *FNRS 2* and the *FNRS 3*: internal diameter, 6 ft. 6¾ in. (2 m.); thickness of the wall, 3·543 in. (9 cm.), increased to 5·9 in. (15 cm.) around the porthole and the door; diameter of the porthole seating, 3·94 in. (10 cm.) on the inside and 15·75 in. (40 cm.) on the outside. The window is a cone of plexiglas of the exact dimensions of this aperture. The manhole has a diameter of 16·9 in. (43 cm.) on the inside and gradually increases to 21·65 in. (55 cm.) on the outside, where it is tightly closed by a steel door in the form of a truncated cone. In the centre of this door is placed the second porthole in plexiglas, identical with the other.[1]

Fig. 3 shows a section of the cabin (without the joints). Here are seen two hemispheres; in the centre of one is placed the chief observation porthole, in the centre of the other the door with the second porthole. The axis of symmetry passing through the centre of these two openings makes an angle of 18° with the horizontal. The door opens obliquely towards the top in the antechamber and the principal porthole thus looks obliquely downwards. Twelve holes bored in the wall around the main porthole permit the passage of the cables and tubes, which will be described in due course.

THE DOOR

The door, the dimensions of which are given above, weighs 352 lb. and its operation presents something of a problem. In the beginning I had envisaged a sliding system with hydraulic control, rather like a London tube door. This system was rather too complicated for us. Afterwards the engineer, Mr. Flagiello, suggested a hinge with a horizontal axis allowing the door to be opened downwards. As I was still not altogether satisfied with this idea, I decided to place the hinge laterally, its axis making an angle of 18° with the vertical. With this arrangement the door opens to the side, obstructs the passage less than if it opens downwards and is operated more easily. I had been afraid at the beginning that the hinge would prevent the door when closed from settling with the necessary precision into its conic seating, but

[1] These portholes are identical with those of the *FNRS 2* and the *FNRS 3*. In the Appendix details will be found of the working out of the design.

a slight manipulation of the hinge overcame this difficulty. The resistance that the door offers to manipulation is nil in an open position. It reaches its maximum when closed and this maximum is one-third of the maximum which would be required for a door with a horizontal axis (sine $18° = 0{\cdot}30902$). Even reduced to one-third, this resistance would still be too great to allow the door to be opened with one hand. That is why we also placed a torsion-spring around the hinge. The principle of this spring is explained in the Appendix and, in fact, permits the door to be opened and shut very easily with one hand.

A rubber ring which is pressed automatically against the joint of the door, as soon as it is closed, ensures watertightness.

So that the door may remain well closed, even if the external pressure of the water is slight, a small screw placed opposite the hinge keeps it in position.

This method of closing gave us complete satisfaction. It allowed very rapid opening and closing and did not require the great effort which was necessary to close the door of the *FNRS 3*. Moreover one could, to go through the manhole, use the entire width of the opening, of which the diameter was 16·9 in., whilst in the cabin of the *FNRS 2* and the *FNRS 3* it was generally necessary to leave in place the closing ring, which is only 14·56 in. in internal diameter and which, for certain people, made getting in and out much more difficult.

After the dive it can happen that the door adheres to the greasy walls. It was easily unstuck by means of another little screw placed beside the first one.

JOINING THE HEMISPHERES

Fig. 10 shows how the two hemispheres *a* and *b* are joined together. To the edge of each of them is joined a sort of flange: the two flanges are clamped together by means of two rings *g* and *h* which are themselves riveted and welded to each other. The exact centring is ensured by a circular pin *f* which enters into two grooves machined into the flanges. A rubber band *c* thermally insulated by a layer of asbestos *d* placed over the joint and stretched lightly around the two hemispheres, functioning as an autoclave, ensures a perfect seal.[1] As a precaution,

[1] From many points of view it would have been simpler to give enough breadth to the flanges to allow them to be fixed directly by bolts and rivets. However, for reasons of manufacture we gave up this solution which, as well, would have necessitated an accumulation of material prejudicial to uniform distribution of the stresses.

on the inside of the rings, the crevice between the ring and the spherical surface of the cabin was packed with lead. As it turned out, the joint never leaked.

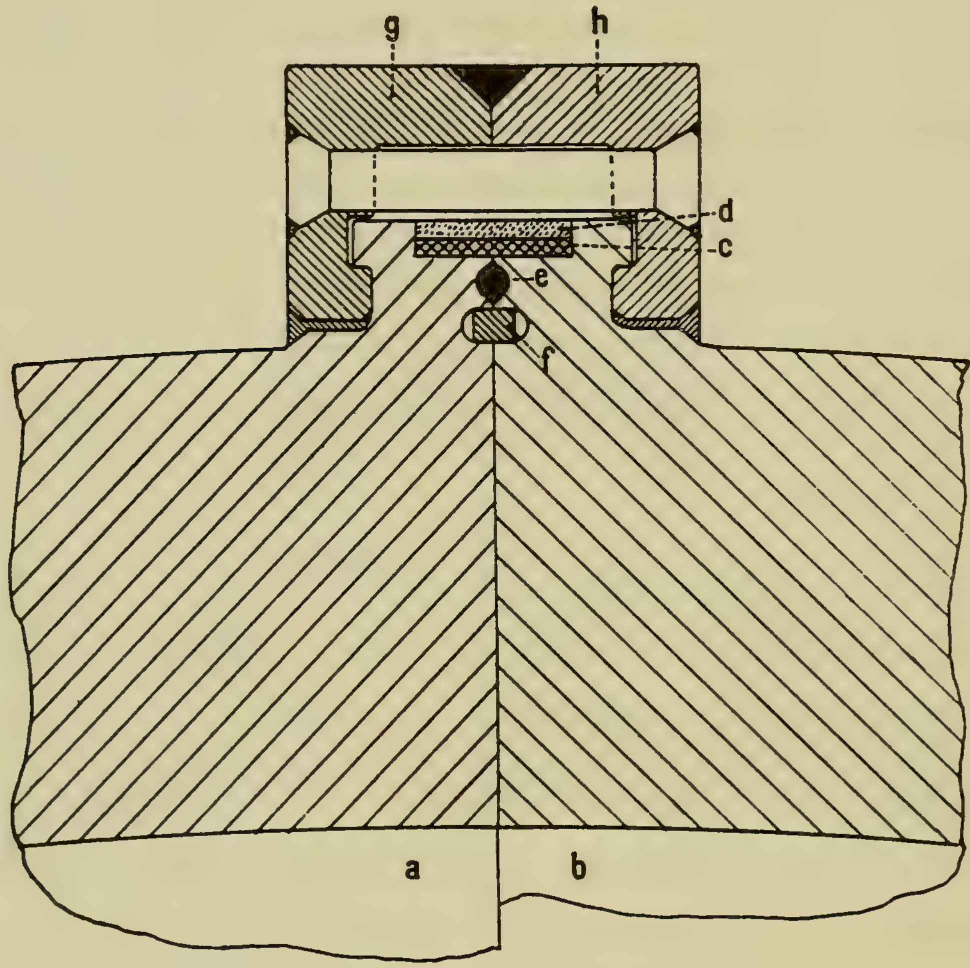


FIG. 10. The *Trieste*. Joining the two hemispheres of the cabin

OPENINGS FOR CABLES AND TUBES THROUGH THE WALL

The passage of the cables and tubes through the wall of the cabin raised difficult problems. A number of thin copper wires had to conduct the electric current to various instruments placed outside the cabin: magnetic valve and electro-magnet for the ballast; telephone, radio, tachometers and some small electric bulbs. The projectors, the motors and, as originally planned, the accumulators required conductors of rather large cross-section. Furthermore, a tube was needed to connect the pressure gauge with the external water-pressure; and another for the compressed air which was to drive the water out of the entrance shaft. Last, two schnorkel tubes, with cross-section sufficiently large to provide ventilation for the cabin when the bathyscaphe was on the surface. These openings had to comply with two conditions. First, the pressure had in no case to be able to drive the conduit into the interior of the sphere. At a depth of $2\frac{1}{2}$ miles the water would gush in at a speed of 92 ft. per second with a flow of 26 gallons per second. The crew, even if not stunned by the spouting water, would succumb to the pressure in less than seventy seconds. Then the conduits had to be perfectly watertight, above all where we had electric cables, all short circuits having to be absolutely avoided: this was a particular danger because, under pressure, sea water always tends to enter the insulators.

All these problems were still more complicated by the fact that the number and diameter of the holes going through the wall were limited by considerations concerning the strength of the cabin. We were able to pierce a dozen holes around the porthole, just where the thickness of the wall was 5·9 in.: as is shown in Fig. 3, the diameter of an opening *b*, beginning at the outer surface of the sphere, was 1·97 in. over a length of 1·57 in. and then tapered to a diameter of 0·79 in. as it went inwards, the junction of the two diameters being effected by a conical piece. For each of the different openings a separate piece of construction with laboratory tests, with a model, was necessary.

Complementary technical details are given at the end of this book.

This new design of the openings allowed us to bring directly into the cabin itself the large pyrotenax cables, with an external diameter of 0·63 in. of which the core had a diameter of 0·45 in. carrying the heaviest currents. Thus we were able to do without the relays which, placed outside the cabin in containers filled with oil, caused certain difficulties in the *FNRS 2* and *FNRS 3*.

3: *Equipment of the Cabin*

RESTORING THE AIR

The problem arose how to prevent the air from becoming fouled in the restricted space in which we were to have to live for many hours. We had to have an installation which purified the air and replaced the oxygen consumed.

The human organism consumes oxygen and gives out carbon dioxide and water vapour: this is the principal action of our breathing. (At the same time the human body releases, by means of the lungs, small quantities of organic matter called anthropotoxins, upon the importance of which opinions differ. They can be absorbed by means of active carbon.)

The quantity of oxygen necessary for a man depends on many circumstances: while resting, the consumption is about 0·35 pints (0·2 l.) a minute. If our nutriment contained carbohydrates exclusively, the volume of carbon dioxide given off would be equal to the volume of oxygen absorbed, following the equation $C+O_2=CO_2$. Fatty substances, however, contain almost twice the number of atoms of hydrogen as of carbon and the combustion of the hydrogen absorbs the oxygen by producing not carbon dioxide but water vapour. The result is that, for 0·35 pints of oxygen consumed per minute, a man only gives off about 0·317 pints (0·18 l.) of carbon dioxide. I owe these details to the specialists of the 'Draegerwerk' establishment of Lubeck which built the aeration apparatus of the stratospheric balloon, an apparatus which I afterwards installed in the *FNRS 2*: it was handed over to the French Navy at the same time as the cabin. For the *Trieste* the same supplier presented me with a new apparatus. Here is the principle of it:

Oxygen contained under pressure in a gas-bottle is released through an injector, draws up the ambient air and drives it back through cartridges containing soda-lime which absorbs all the carbon dioxide; the air, thus regenerated and enriched with oxygen, returns into the cabin: this is what is called a closed-circuit apparatus. If the intake of oxygen is regulated to 2·64 pints (1·5 l.) a minute, the apparatus purifies 12·77 gallons (58 l.) of air at the same time. If the two occupants of the cabin give off 0·63 pints (0·36 l.) of carbon dioxide a minute, the concentration of this gas will gradually reach 0·62%. Now we know that

1% of this gas is quite innocuous; a person would only begin to be affected at 2%. Our apparatus was thus more than satisfactory for the two occupants planned for from the beginning: it would allow the presence of three persons without difficulty.

We could also, if needed, reduce the intake of oxygen. With 1·76 pints (1 l.) a minute, for example, the quantity of air regenerated would be nearly 9 gallons a minute and the concentration of the carbon dioxide would rise by degrees to 0·85%.

In any case, the apparatus would furnish more oxygen than two men consume and the concentration of this gas would rise bit by bit. In the stratospheric balloon that was of no importance since the excess air could always be allowed to escape and in the cabin there could even be established a pressure less than one atmosphere. In the bathyscaphe the excess of oxygen must be remedied in another way. This was very simple: as soon as the oxygen became in excess, we closed the bottle of this gas and the air was sent through the alkaline cartridges by means of an electric fan. Its rate of feed being 52·8 gallons a minute, it had only to operate a quarter of the time during which the bottle of oxygen was closed.

In passing, it may be noted that, contrary to an opinion commonly held, it is much more important to absorb the carbon dioxide from the air than to add oxygen to it.

What about the water vapour? A man expels from his lungs in twenty-four hours about 2 lb. of water: the quantity of water given out by perspiration depends much upon the circumstances, but it can easily reach from 2 to over 4 lb. a day. The crew of the bathyscaphe might then give off over 12 lb. of water vapour in twenty-four hours, which represents 10 pints of water vapour a minute! As the wall of the cabin of the stratospheric balloon became extremely cold on the side opposed to the sun, the water vapour condensed sufficiently there. In the bathyscaphe, however, it would be worth while to absorb the humidity by means of a hygroscopic substance, in the present case, silicagel: this substance has the great advantage over sulphuric acid, phosphoric acid and calcium chloride, which are usually employed in the circumstances, that it never liberates a corrosive liquid.[1]

Unforeseen circumstances could result in the crew remaining shut

[1] During the expedition to the Cape Verde Islands, I used silicagel manufactured by the Uetikon factory (Switzerland). For the *Trieste* it was the Baslini Company (Milan) which furnished us with this absorbent.

up in the cabin for longer than the apparatus is capable of maintaining life, for example, if serious damage prevented the emptying of the entrance-shaft. In such a case the bathyscaphe would have to be towed to the port, the petrol would have to be emptied out, and the submarine lifted out on to the quay by a powerful crane. And all this before the occupants could be freed. That could last several days. The imprisonment would doubtless be very painful, but disaster would be avoided if the cabin could be ventilated by communication with the outside air. With this in view, we furnished the cabin with two schnorkel tubes by which we could ourselves, by using the electric ventilator, set up a good ventilation of the cabin. The passing of the schnorkels through the wall of the cabin and their closing during dives presented quite a pretty problem for solution. (See Appendix.)

On the other hand it was important to be able to control the condition of *our* atmosphere. From the point of view of humidity, it was very simple: a hair hygrometer was a sufficient indicator. The amount of carbon dioxide was indicated by a Siemens electric apparatus which did not employ any reagent. It was based upon the variations in the thermal conductivity of the air as a function of its carbon dioxide content; a small needle galvanometer indicated the percentage of this gas.

As for controlling the oxygen, this is in general rather a complicated affair. In order to avoid the use of corrosive liquids, of white phosphorous or copper filings heated red-hot, I invented a very simple apparatus. It was based upon the following reasoning: since we can neither produce nor absorb nitrogen, the quantity of this gas contained in the cabin is constant. Since the relation of oxygen to nitrogen should not vary, the quantity of oxygen contained in the cabin must also be constant. If we, for the moment, leave aside the carbon dioxide, we must require that the total weight of air enclosed in the cabin should remain constant. As the temperature is variable, a barometer measuring the pressure would not suffice, and to it must be added a thermometer and a slide rule. Here is the apparatus which replaces these three instruments (Fig. 11): a U-shaped glass tube placed halfway up the cabin contains in its base a certain quantity of mercury; one branch is always open, the other is provided with a cock which is closed at the same time as the cabin door. Thus enclosed between the cock and the mercury is a constant quantity of air of which the temperature is pretty much that of the average temperature of the air in the cabin.

Thus if the temperature varies, the pressure alters on each side of the mercury to the same extent without influencing its position; but if the quantity of oxygen in the cabin increases or diminishes, the pressure in the cabin varies and the mercury indicates it.

Thus the control of the apparatus for the regeneration of the air is very simple. It is set going as soon as the Siemens apparatus indicates 1% of carbon dioxide and this is done either by the oxygen injector or by the ventilator, so as to maintain the two columns of mercury at the same level. If the mercury rises in the closed side of the U-shaped tube, the ventilator is set going: in the inverse case, the oxygen injector is put into operation.

It would be easy to take into account the concentration of carbon dioxide to make corrections. But such precision is superfluous.

FIG. 11. Apparatus controlling the density of air in the cabin

PRESSURE GAUGES

Although the pressure gauges were not vitally important to us, it was essential, nevertheless, for them to be in good working order, since they indicate and record our depth. In the balloon we also had pressure gauges, but while these had to measure variations in pressure which never reached one atmosphere, those in the bathyscaphe had graduations reaching up to 600 atmospheres, which corresponds to a depth of 3¾ miles in fresh water, and slightly less in sea water.[1]

The principle of the high-pressure gauge is very simple: the interior of a steel tube, bent into a semi-circle, the Bourdon tube, is subjected to the pressure that is to be measured, in our case the pressure of sea water. If the pressure increases, the tube straightens slightly, and this movement is transmitted to the needle of the gauge.

The *Trieste* has four pressure gauges installed: a large one recording

[1] At the time of the construction of the *FNRS 2* our pressure gauges were supplied by the firm of Haenni (Jegenstorf, Switzerland) and after these had been handed over to the French Navy (where they were used on the *FNRS 3*) the same firm constructed a set of improved apparatus for us.

in orthogonal co-ordinates (a simple indicator system), and a small one, the needle of which moves round an arc of a circle: then two pressure gauges, each with a needle and suitable electric contacts, which actuate apparatus designed to release the ballast, during dives in which the bathyscaphe is not manned but is operated by an automatic device. The two graphs (Figs. 13 and 14) show the differences between the recording apparatus. For the first pressure-gauge mentioned, the time reads from bottom to top; but while the point of the recording needle in the small one describes the arc of a circle, that of the large one moves in a straight line from left to right when the pressure increases. If the speed is constant the little gauge traces a curved line: the large one, on the contrary, traces a straight line the slope of which depends upon the vertical speed of the bathyscaphe. It is inclined at 45° when this speed is 31·4 in. per second. This greatly facilitates the piloting of the bathyscaphe and the making of observations.

These pieces of apparatus must naturally be in communication with sea water; but the sea water must not come in, for it could cause corrosion. In the antechamber is found a vessel full of oil which has a pressure equal to that of the sea water. A steel tube of 0·25 in. (6·35 mm.) external diameter and 0·072 in. (1·82 mm.) internal diameter passes from this vessel to the interior of the cabin, where it ends in a distributor which by means of four tubes is connected with the four pressure gauges.

At the mouth of the distributor there is a high-pressure cock. If one of the pressure gauges happened to leak (which, in fact, never happened) the crew would have to close this cock, disconnect the tube of the defective gauge, screw a stopper in its place, and re-open the cock: this whole operation could be completed in less than a minute. It was the Fiat Company which installed all the tubing in the cabin, employing tubes and unions standardized in the automobile industry, where they are used for the injection of fuel in Diesel engines. It is true that the normal injection pressure of the Diesels is less than that which is found here. But if one compares the operating conditions of lorry engines (the variation in pressure running at each second revolution of the engine from zero to the maximum and vice versa, whence inevitable vibrations are set up) with those of the bathyscaphe where the maximum pressure is only reached gradually and, in practice, only a limited number of times, it is clear that all this tubing would function without failure in the bathyscaphe.

These pressure gauges, graduated to record from 0 to $3\frac{3}{4}$ miles in depth, naturally cannot possess great sensitivity. Now, in certain cases, above all if the bathyscaphe is near to the surface, a much greater sensitivity would be desirable. Thus for the *FNRS 2* I invented and had built a pressure gauge in which the height of a column of mercury varies by 3 ft. for depths changing from 0 to $3\frac{3}{4}$ miles. It was thus delicate enough to render perceptible variations in depth of 3 ft., the displacement of the mercury being proportional to the pressure. This pressure gauge was given with the *FNRS 2* to the French Navy by the Belgian National Fund.[1] As the construction of this gauge is very costly and would have demanded a good deal of my time, I gave up the idea of reproducing it. Instead I designed a small gauge, very simple and quite sensitive, graduated from 0 to 330 ft. depth. The description of this is given in the Appendix.

THE TACHOMETER

The pressure gauges certainly showed us the depth that we had reached, but that was not enough. For piloting purposes it is important to be able to determine at any moment what is our vertical speed. According to the circumstances, this speed determines the need to drop ballast or petrol. It is true that the slope of the line drawn by the recording gauge allowed us to determine this speed, but only after a considerable delay, since the graduated paper moves only at the rate of $\frac{1}{25}$ in. a minute. Several minutes are then necessary for the slope of the recorded line to be observed. This is too long.

Exactly the same problem occurs with the free balloon and two instruments have been constructed to measure its vertical speed—the variometer and the vane anemometer or wind gauge.

The variometer cannot be utilized in a bathyscaphe. But the vane anemometer can be employed almost as it stands (Fig. 12). It consists of a bladed fan *b* mounted with its vertical axis of rotation. The vertical wind produced by the motion of the balloon starts it rotating and this speed of rotation is proportional to the speed of the balloon. In the case of the bathyscaphe a slight difficulty arises: if one wishes to observe the vanes directly, the anemometer must be placed beneath the float, in the neighbourhood of the porthole; but in this position

[1] I am not sure that it is still used, the principle varying too much from the norm.

the water is so agitated by the wash that when we are rising at a speed of 3 ft. per second we see, floating in the water, small particles which move up and down without our being able to distinguish whether the bathyscaphe is rising or descending. To avoid these eddies, we mounted our anemometer at the top of the tower and 3 ft. away from

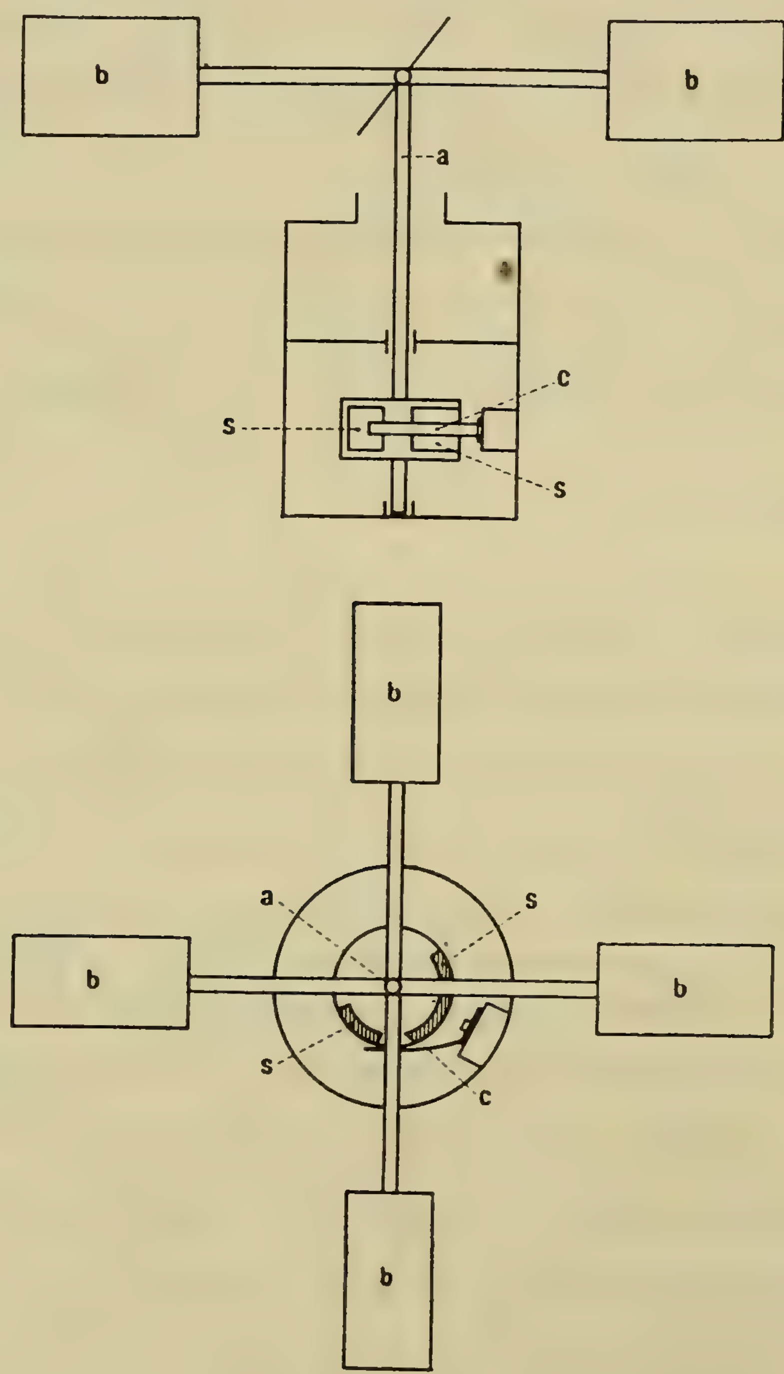


FIG. 12. Vane anemometer for measuring the vertical speed of the bathyscaphe

the side. In these circumstances it was impossible to observe the vane anemometer directly, and so it had to transmit its signal electrically. This was quite simple: at the base of the anemometer shaft (see Fig. 12) we fitted a cylinder of insulating material upon which were placed two metallic segments *s s* (one short and one long) so that a

Plate XII The *Trieste* off Capri

Plate XIII Capri. The *Trieste* at the start of its dive to 594 fathoms

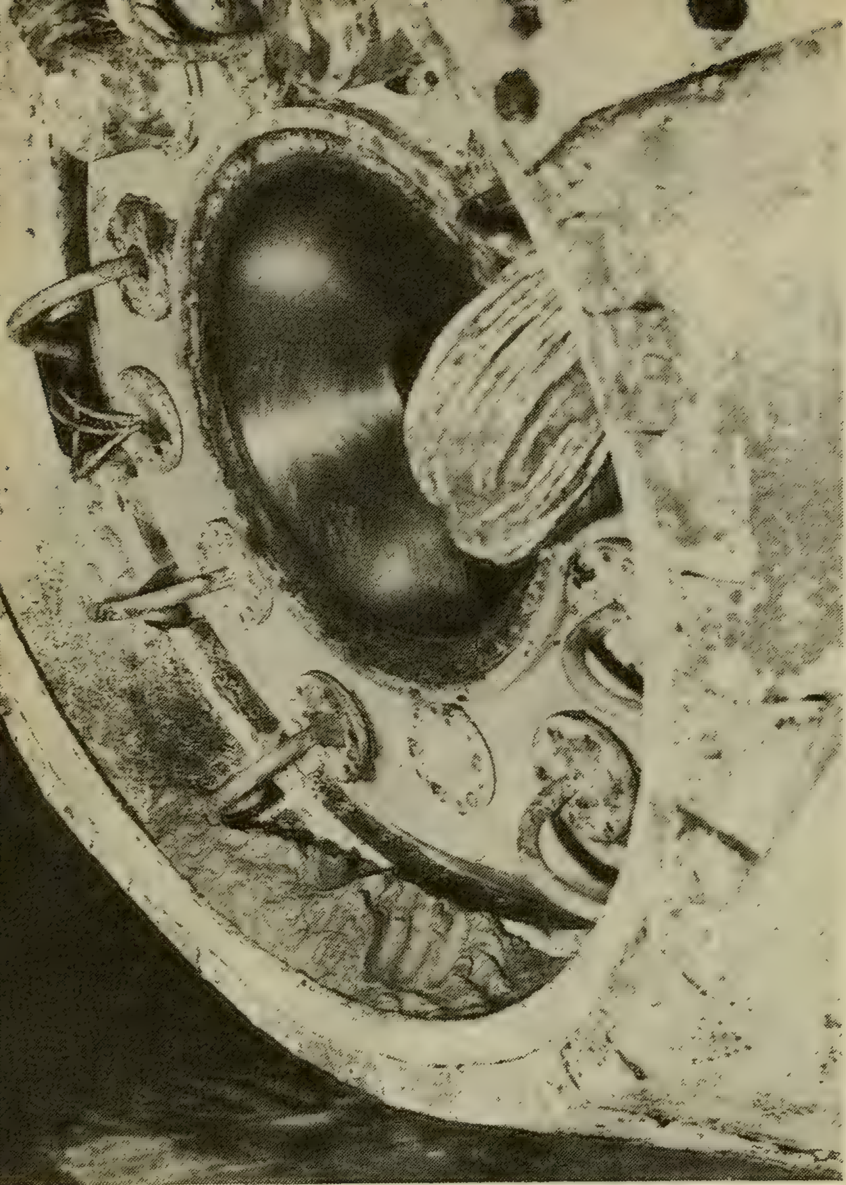


Plate XIV Some sediment from the sea-bed deposited in a metal fairing under the porthole after the dive off Capri

Plate XV Sample of the sediment shown in Plate XIV, greatly magnified. The diameter of the particles varies from 0·1 to 0·2 mm.

brush *c* rubbing against the cylinder gave in Morse code the signal *a* (· — · — · —) when the bathyscaphe was rising and *n* (— · — · — ·) when it was going down. These signals were transmitted to the cabin and a luminous sparking indicated to us the direction and speed of our movement, each revolution of the anemometer corresponding to a determined height. We had thus a true tachometer (a time-speed indicator). So that it would not be disturbed by the conductivity of the sea water, the base of our shaft with its segment-bearing cylinder was placed in a small vessel containing trioline.

THE INTERIOR LIGHTING OF THE CABIN

The lighting installation is more important than would be thought at first sight: at all costs we had to prevent the observer from being dazzled.

I remember an excursion during which, on a day of brilliant sunlight—it was in 1916—I penetrated into a grotto of the Jura Mountains in Vaud, Switzerland. I had indeed a compass with a luminous needle; but without shining my flash lamp on it I could not observe it: my retina retained a 'memory' of the daylight. I recalled this episode when I installed the internal lighting of the cabin: the majority of phosphorescent animals are scarcely brighter than a luminous compass-needle.

I distributed in the top of the cabin six small incandescent bulbs, thus lighting up only the white-painted ceiling, and achieving a system of indirect lighting that looked quite up-to-date. Each bulb had its own switch. One of the bulbs was of thirty watts: the five others of 5 watts. In our little cabin, where almost all the instruments were painted white, a 5-watt bulb would be quite enough for the occupants to see by clearly. To carry out a delicate operation, the six bulbs would have to be alight at the same time. For observation of the exterior, they would generally all have to be out.

We also had large independent flash lamps with which to throw a bright light on a small area. They would be valuable in case of a breakdown of the electric current—which, however, never took place.

During the Capri dive, at one moment I put out my flash lamp, and finding myself in complete darkness placed it on a little shelf within reach. As ill-luck would have it, this happened to be the battery of accumulators controlling the ballast! Immediately a shower of little sparks appeared, and we heard the crackling of a short-circuit. It is easy to imagine how quickly I picked my torch up again! Fortunately the metallic case of my pocket torch had only short-circuited one or two of the twenty-four cells in the battery. But it was an anxious moment. If the battery had been entirely short-circuited, our ballast would have been released and we should have risen to the surface without having reached the desired depth.

EXTERNAL LIGHTING

We wanted to observe the submarine world. We had therefore to be able to make use of an external system of lighting as powerful as possible, particularly so when we wanted to take photographs. How should we arrange the projector?

We must not forget that sea water is never perfectly transparent. We speak of water being 'perfectly transparent' when visibility extends to 60 yards.

Let us leave the sea for a moment, and imagine ourselves in a car in a thick fog. In the daytime we can just distinguish the outline of a house 60 yards away. Then night comes on, and when we switch on the headlamps, the range of visibility is reduced to a few yards. We then come into a town. Here the street lamps are placed on each side of the street. If we put out our headlamps our range of visibility increases at once and we can see the street a good distance ahead. We can draw an important conclusion: the floodlights of our bathyscaphe must not be placed inside the cabin: they must be suspended from the float in such a way that the flood of light will cross our visual field in a narrow cone making an angle with our sight-line that as nearly as possible approaches 90°. Thus all objects entering the lighted zone will appear to us to be shining against a dark background. We thus have on a large scale what in the laboratory is called ultra-microscopic lighting.

Our arrangement presents another advantage which is not negligible: if an object appears in the lighted zone, we know at once at about what distance it is and this allows us to estimate its real dimensions.

Each projector is equipped with a 1000-watt bulb which, very much overloaded, can in a short time develop a lighting intensity of nearly 60,000 lumens.

I shall not spend much time explaining in detail the construction of the projectors. Suffice it to say that they were furnished with incandescent bulbs specially made by Philips and protected from external pressure by strong steel cases. In order not to reach prohibitive dimensions as well as weight, we had to use special bulbs much smaller than those normally needed by a filament of 1000 watts. This obliged us to fill the cases with water to obtain a sufficient cooling of the bulb. The case was provided with a little plexiglas window and an ellipsoidal reflector concentrated the light on this window. Then, a second reflector, parabolic, concentrated the light in a small conical beam.

Finally, as well as the projectors, we arranged on the outside of the cabin some small incandescent lamps of 35 watts.

THE ELECTRICITY SUPPLY

We had to have a source of electrical energy for operating our equipment such as the ventilator, the small lamps, the tachometer, the unballasting apparatus and particularly the driving gear and floodlamps. In the beginning we had intended to have a lead-acid battery of 14 cells and 900 ampere-hours, given to us by Hensemberger. It weighed 2640 lb. and was consequently too cumbersome to be placed in the cabin. Therefore we put it on the deck of the bathyscaphe, in a large vessel filled with petrol.

As we had cause to regret, the sun of Italy is not an unmixed blessing. Lying in the port of Castellammare, the battery was overheated to such a point that its polythene cell jars were affected. As there was insufficient time to make new polythene cell jars, we temporarily replaced this large battery by a smaller battery placed in the cabin. It was powerful enough to operate all our lighting apparatus, but the time during which we could operate the motors and projectors, which take a great deal of current, was reduced.

For our next undertaking Hensemberger furnished us with new cells in silver-zinc. Providing the same energy, they take a quarter of the space and are only a quarter the weight. We could therefore carry in the cabin batteries of the same capacity as at the beginning had had to be placed outside. This made it a lot easier. These cells could be charged in the cabin, since they give out very little gas, and are not corrosive, being free from sulphuric acid. They are not affected if they are completely run down and one does not have to recharge them as soon as they are discharged. This was a great asset to us. We had also a small lead-acid battery placed in the cabin to supply the unballasting apparatus: this was necessary to prevent the loss of ballast and tubs even if the principal battery became completely discharged, as it might during observations if the floodlights and motors were operated for many hours.

INTERNAL LAY-OUT OF THE CABIN

The cabin of the *Trieste* was laid out in much the same way as that of the balloon *FNRS* and also of the *FNRS 2*.

At the bottom of the cabin an aluminium ring of 47 in. diameter served as a base. On this ring were six aluminium uprights of 1·18 in. square section and 23·6 in. apart: they supported a second ring of the same diameter as the first, which came quite close to the top of the cabin. The whole formed a rigid cage. To hold this in place, the top part had to be jammed against the top of the cabin. But an important detail of construction enters into one's calculations at this point.

If the cabin goes down to 2½ miles, the external pressure causes all its dimensions to decrease. The diameter decreases by 0·065 in. and the two rings, which are 5 ft. 3 in. apart, would be brought closer by 0·0475 in., if both were touching the cabin. Moreover, at the bottom of the sea, the temperature of the body of the sphere will be lower than when it was fitted up, while the temperature inside will not drop so much. If, for example, the difference in temperature between the cabin and the uprights were 45°F., the uprights would be cramped to the extent of 0·176 in. In short, the effect would be that the sphere forced down the uprights 0·065 in. The consequence of this would not be that they broke, but they would buckle or bend sideways. It is quite simple to calculate how much they would bend; the lateral deflection, in fact, would amount to 1·1 in. halfway up the uprights. To avoid this, I put strong steel springs in a housing bored in the upper part of each upright, to force pieces of metal against the cabin with a force of 110 lb. for each upright. Strips of rubber placed between these pieces of metal and the cabin, as well as a rubber ring lodged between the lower ring and the base of the cabin, produced such friction that the whole centre cage, while remaining free to expand or contract, was nevertheless held rigid.

On the lower ring a piece of sheet aluminium formed the floor. The free space between this floor and the spherical bottom of the cabin was 7·87 in. high at the centre: we called it the cellar. A trapdoor gave access to it. This space was not wasted, as we used it to store the reserve containers of alkali and the bottles of compressed air, which were needed to empty the entrance shaft after each dive. The observer watching through the porthole was also glad of this space, as it made his position a little more comfortable: it increased the relative height of his seat. Also, after being shut up in the cabin for many hours, the crew were glad to be able to straighten up completely: the total diameter of the cabin was just enough to allow my son to stand upright.

All the space above the floor was available for the crew. Like the supports of library shelves, the uprights had holes spaced an inch apart: into these were fixed brackets standing out towards the walls of the cabin and supporting aluminium shelves upon which the different instruments were fixed. By this means the height of the shelves could be varied to suit the differing heights of the apparatus. This whole installation was carried out by the Volta Institute at Trieste, in aluminium alloys presented by the 'Lavorazione Leghe Leggerre,' Porto Marghera (Venice).

4: Off to Castellammare di Stabia

It is not enough simply to construct a bathyscaphe. There must still be found a base suitable for submarine expeditions, and one supplied with workshops, with, of course, their directors and their engineers. The North Adriatic was ruled out: it lacks the necessary depth. The Italian Navy suggested the dockyards of the 'Navalmeccanica' at Castellammare di Stabia—a little port situated in the southern part of the Gulf of Naples, facing Vesuvius, at the foot of the Monte Faïto. There are found together the activity of Northern Italy and the well-known charm of Southern Italy.

It was there then that the cabin and float had to be taken. How was the latter to be transported from Trieste to the Gulf of Naples? If the freight charges, calculated on the 4238 cu. ft. (120 cu. m.) of the float, had not been exorbitant, and if we had found a cargo-boat making the trip at the right moment, we should have chosen the maritime route. Second possibility: to launch the float and have it towed by a small motor-boat, to double the peninsula by standing offshore from Corcyrus, then between Scylla and Charybdis, to reach the Gulf of Naples, the native haunt of Polyphemus. But Ulysses had already made the experiment: the sea can be unfriendly in these latitudes.

We gave up the idea of maritime transport.

The dimensions of the float made the use of the railway out of the question. There remained the road.

We looked some time for a company which had the means at its disposal and would give the desired guarantees. One day, driving about the streets of Milan in our car, my son and I suddenly saw in front of us a giant transformer on a trailer, being towed by a powerful lorry. We passed it, we let it pass us; we did this several times. Stowage and packing of the transformer, everything inspired us with confidence. We took note of the name of the firm, 'Pejrani, Turin'. An exchange of letters followed, then a trip to Turin: however expensive and difficult the job, Pejrani said they would not treat this as a business transaction, since it was a question of scientific research. If we paid for the petrol and the police tax, Pejrani would charge it to overhead expenses. We here wish to thank this firm for their very valuable assistance.

Between Monfalcone and Castellammare di Stabia the roads go through cuttings with bridges which limit the height of a load to 13 ft. 2 in. On the underslung trailer the hull with its diameter of 11 ft. 6 in. would just clear. But on the upper part of the float there was the superstructure to which we fixed the electro-magnets, the conning-tower, as well as the device that the crane grasps each time the bathyscaphe is launched; while beneath the float there were the metal sheets to which the cabin was to be attached. All this increased the total height. If the float could be turned through an angle of 90° to rest on its side, there would be no difficulties with height: but then it would be too wide for the roads.

Fig. 7 shows that we limited the dimensions of all these parts so that if the float is inclined 45° they are all contained roughly in an $11\frac{1}{2}$-ft. square. Thus placed on the trailer, it did not exceed 13 ft. 2 in. in height, nor 11 ft. 6 in. in width.

So it was that at the beginning of January 1953 the float began its long trip. It went round the Adriatic shore and round Venice, turned south, crossed the passes of the snowy Apennines, came down the west coast, and arrived safe and sound at Castellammare. The entire journey was done at a speed of 9·3 miles an hour, escorted by the traditional motor-cycle police who watched over its safety and that of other road users. The whole trip lasted eleven days. On the way it met another cumbersome consignment: the fuselage of a plane, also inclined at 45°.

In the alleys of Castellammare the population watched this mysterious engine go by with interest. Some guessed at once that it was a new submarine.

We then had to transport the cabin. Its dimensions were such that it could be loaded on to a truck. From Terni on, at a low speed, also preceded and followed by a motor-cycle escort, it crossed the Roman campagna by the ancient ways. It passed under the shadow of the Colosseum. Man's interests have changed! Across the ancient Pontine Marshes, by Naples and the outskirts of Pompeii, along a road cut out of the lava, it reached the workshops of the 'Navalmeccanica'. This time there was no more mystery and everyone was waiting impatiently for it. By a curious coincidence, the transportation was done by the Danzas firm at Basle, which had already carried the cabin of the balloon *FNRS* from Desenzano in Switzerland. On this occasion, as on that one, we have yet to be charged.

It is thus at Castellammare that we began the assembly of the numerous parts which together formed the *Trieste*.

My son, who from the beginning had organized all the operations, at Monfalcone as well as at Terni, more than ever held the reins in his hands. The study of economics had developed his feeling for synthesis. In short, whether you convert tons of wheat into pounds sterling or divide hundredweights by square inches, the principle is always the same. First in the yards and last to leave, always there when wanted, Jacques knew how to maintain contact with the workman as with the engineer. Not a detail escaped him. Not an instrument but had passed through his hands; nothing that had not been subject to his personal control. He knows the apparatus better than I do. It was he who inspired all the enthusiasm which is indispensable in the carrying out of such an undertaking. What a privilege for me to have this time such an assistant and to be able to place my whole confidence in his intelligence as well as in his overflowing energy.

5: *The First Dives of the Trieste*

On 1st August 1953—the Swiss national holiday, a coincidence of happy augury—the colours were hoisted on the *Trieste*: the tricoloured flag of the Italian Navy and the white cross on a red background of Switzerland. The bathyscaphe is still at the dock on her cradle. The giant crane of the 'Navalmeccanica.' yards approaches and its powerful hook grasps the suspension-ring of the bathyscaphe.

It is customary for a ship to be baptized before it first makes contact with its element. In general, a bottle of champagne is broken on its prow. Never having understood the relation existing between bits of broken glass and a ship to which we wish a happy future, I left out this part of the ceremony. On the other hand the priest was welcome who, asperging the *Trieste* with holy water, according to a pious Italian custom, put it under the divine protection without which all human labour is vain.

Then the crane lifted the bathyscaphe and, rolling along its railway, carried it towards a sheltered place in the port. At this moment a cloud of pigeons flew from the top of the crane and hovered beneath the *Trieste*. This unexpected and charming tribute had been prepared for us by the crane driver, who had wanted to play his part in the solemnity of the moment. The crane stopped, swung round and placed the bathyscaphe in the sea. As its hull as yet contained nothing but air, it floated high on the water.

The following day the 'Esso' tankers arrived from Naples. A hose was placed between the dock and our submarine and 18,920 gallons of petrol passed into our reservoirs. Why, it will be asked, 18,920 gallons when the float could contain 22,660 gallons? Because at the time that we drew up the plans of the *Trieste* it was necessary to leave a margin of safety, for at that time we were quite unaware of what would be the exact thickness of the metal sheets and their weight. There can, in fact, be differences between the metal sheeting ordered and that which is turned out by the rolling mills. Moreover, we had to take into account the possibility that we might later install heavier apparatus. Again, we had provided for the event where the bathyscaphe might make dives in tropical waters: in warm seas the petrol would expand and the possibility of the formation of vapour was not to be overlooked. Finally, we had to be able, on occasion, to employ a heavier petrol, which for the same lifting force would have a greater volume. For all these reasons it was better to have a good margin at our disposal than to have a float that was too small, even by 250 gallons.

Now, having all the factors in our calculation well in hand, we saw that 18,920 gallons of petrol sufficed to carry the bathyscaphe. We began then by introducing 3740 gallons of water into the float: that, with the 18,920 gallons of petrol, just filled it.

If we had filled the tanks entirely with petrol, it would have been necessary to take on board, as well as the ballast reckoned on, 4 or 5 tons of emergency ballast. It is true that thus we could have given more stability to the bathyscaphe; but, in fact, there was no need for this.

On 11th August 1953 the *Trieste* could at last be submerged. It was not, properly speaking, a dive. The bathyscaphe remained fast to its moorings and, the depth of the water being only 5 fathoms, the tip of its flagpole remained in sight. This test enabled us to check certain parts and to have exact data on the loading. On the 13th August, as a new test, we had ourselves towed out a little farther towards the middle of the harbour where the depth reaches a little over 9 fathoms. There, too, the experiment proved satisfactory.

During these tests, including those conducted during the dive at Capri, we had the pleasure of seeing with us once more Engineer Loser, whom the management of the Trieste dockyards had kindly lent, so that he might once more give us his valuable assistance.

On the 14th the *Tenace* heavy-duty tugboat belonging to the Italian Navy took the *Trieste* in tow and towed it out to sea to a point where the depth is 22 fathoms. We had chosen this depth so that, in case of need, the divers could keep in contact with us. I have such pleasant memories of this first dive that I should like to tell of it in more detail.

The weather was splendid, the sea calm: a rowing boat took me to the *Trieste*, which my son Jacques had not left during the brief tow. We opened the upper hatch of the entrance shaft, and went down the ladder which leads to what we call the antechamber. We were barely 16½ ft. from the surface: through the big pane of plexiglas the water appeared marvellously clear. The light was quite blue, as in the celebrated grotto of Capri. We slid through the manhole and closed the heavy door behind us: Jacques picked up the telephone receiver, connected by a cable 297 ft. long with a rubber boat on the surface, and gave the necessary instructions.

In the cabin reception was so good that I could hear Engineer Salvio not only speaking into his telephone, but also retransmitting the orders:

'The door is closed, begin to fill the shaft.'

The hydrant of the *Tenace* went into action: water poured into the lock, and soon the window was submerged. At the end of a few minutes the people on the surface told us:

'Shaft full.'

On deck they closed the upper hatchway: 'Open the valves of the two air tanks.'

The air escaped, replaced by 400 cu. ft. of water.

'You are going down. The deck is almost entirely submerged. Wait, you've stopped going down.'

The bathyscaphe was still too light. Jacques spoke on the telephone again:

'Pump air into the two tanks. Bring twenty bags of ballast.'

Up we went again.

'Twenty sacks are aboard.'

'Expel the air again. Open the sluices a half-turn. Another quarter-turn.'

'You are going down. The deck is submerged. The tower is half under. It has disappeared. Now, the flagpole.'

This time the *Trieste* dived and the light from outside decreased in a very marked way. In a few minutes we should touch bottom.

We looked out of the porthole, but we could see nothing. And then we caught sight of the bottom, very indistinct, perhaps 8 fathoms away; but we had stopped moving. The explanation was simple: in this fine, calm weather the Italian sun had considerably heated the upper layer of the water, which became lighter. Now the *Trieste* was floating on a colder, and hence heavier, layer. We had begun the dive with an insufficient overall weight and the bathyscaphe was not heavy enough to penetrate the layer of cold water which increased the buoyancy of the petrol. Through the porthole we saw our friend, Engineer de Sanctis, who had dived down to pay us a visit. When we came up he told us that, in fact, at the depth where we stopped, he had run into a layer of icy water; the cold had forced him to go up again.

This reminded me of the ascent of the stratospheric balloon on 18th August 1932: my friend Tilgenkamp had carefully 'weighed' us but, after a magnificent start, we had been held up, at a low altitude, by an inversion layer. The warm air had decreased our buoyancy. It was not till after we had thrown over quite a lot of ballast that the balloon was able to continue its ascent into the stratosphere.

This time it was the cold water that was to blame. Three courses of action were open to us. We could wait for the petrol in the float to be sufficiently cooled for the bathyscaphe to start going down again, but that would take too long. We could open the control valve and let out the petrol, but that would be a useless sacrifice of it. We chose the third solution, namely, to go up again, take extra ballast on board, and then go down once more.

By telephone we told the surface:

'Get ballast ready. We are coming up to get it.'

My son turned the unballasting switch: the iron pellets poured out in a dark trail from the orifice of the tanks, forming all around a great cloud of rust. Soon we were on top and the usual operations took place: then the *Trieste* was suitably laden. We dived slowly. Around us the daylight decreased a little. We looked downwards—the bottom became distinct, the water was clear. Even without artificial lighting, we could distinguish all the details. But the sea here was particularly bare; all we could see was mud and here and there small mounds representing indefinable objects. In a state of equilibrium with the water, the bathyscaphe drifted slowly along near the bottom: from time to time it struck it gently, each time raising a cloud of mud. The drift continued.

What ideal conditions for observation! But of what use in such a desert! Years ago the wind had brought a large palm tree here: there it was, covered by mud, so that one could hardly guess at its shape.

By telephone we announced:

'All's well. We're at the bottom.'

'What can you see?'

'Some sand—an empty shell . . .'

What animal did it belong to? I was unable to say. If we had been in fresh water I should have guessed at a *Limnea ovata* or a young *Limnea stagnalis* (freshwater gastropods) but here I was out of my element. At last we saw an object worthy of interest: we brushed against a large sea-anemone. Its tentacles were waving gently in search of prey: I reckoned them 16 in. long; the creature a lemon-yellow colour and standing out against a blue-green background. At a depth of 22 fathoms, then, the water lets in yellow light, and we admired the beautiful anemone; but drawn along on our course, we soon lost sight of it. Finding nothing more that interested us, we told the surface that we were going up. The electric current which held the iron pellets in the tanks was cut, and the pellets escaped and fell on the bottom, raising a large circular cloud. We seemed to be in a lift. We heard a curious noise, and asked by telephone what it was.

'You can hear the screws of the *Tenace*: it is coming near.'

A few moments later the *Trieste* surfaced and the *Tenace* pumped out the water from the shaft with compressed air. We could see the level going down in the antechamber. When it was clear we opened the door and went up to the deck.

Some people were surprised that a bathyscaphe designed to go down to $2\frac{1}{2}$ miles should spend its time paddling in the shallows along the coast where any amateur diver equipped with self-contained diving equipment could easily dive. Naturally, ironic remarks were heard. People forgot simply that as yet there was no handbook for the use of bathyscaphe pilots, and that, in spite of our theory, a number of parts had yet to be tested before the submarine could fulfil the role expected of it. On this occasion we certainly broke no records, but we became used to steering the *Trieste* and we learned a good deal. We could also have proceeded to the first trials in the open seas, but here we had obtained the same results with less difficulty. The dockyards which had built the bathyscaphe, and we ourselves, know now that our confidence was justified. The members of the crew also had received training in the various operations: transport of ballast, filling the lock, radio, telephone, etc.

As described above, the cabin was provided with two portholes: one in front, which looks obliquely down on to the sea, and the other behind, which looks towards the antechamber and its large window; normally, we should thus be able to utilize the back porthole to observe the sea across the antechamber. But the water which filled the antechamber was so dirty that day that it was quite impossible to see anything through it. Thereafter, before each dive, we had the lock and the antechamber cleaned out. Moreover we arranged that the pumps on the *Tenace* should run for a while till it was delivering clear water, before filling the antechamber. Finally, a bucket and a brush were placed in the tower and all those going down into the lock were asked to clean their shoes before setting foot on the ladder. It was almost like entering a Hindu sanctuary. Thus, during the subsequent dives, we were always able to observe the sea by the front and back portholes.

The most valuable lesson learned on this day was that we should not begin a dive with insufficient ballast. On the calm sea of the Bay of Naples it had been easy to take on the ballast we lacked. But on 30th September, off Ponza when the waves swept over and submerged the deck of the *Trieste*, we were very glad not to have to repeat this operation.

6: Diving to 594 fathoms off Capri

FOLLOWING upon these preliminary dives, we had no essential change to make in the *Trieste*: all the parts, whatever they might be, had functioned perfectly. Containers of alkali and bottles of oxygen were changed and then we were ready to undertake a real dive.

We had such confidence in the solidity of the cabin, the porthole and the passages of the conductors through the walls that we felt it was unnecessary to send the *Trieste* down empty. Jacques and I dived right away.

What depth should be chosen? South of Capri there is a submarine hollow of 605 fathoms. To find greater depths we should have to go farther off, towards Ponza: there the depth reaches 1980 fathoms. For the moment, 550 fathoms would be enough; even if a descent to 1650 did not offer any serious risk, I preferred to confine myself to this to begin with.

The weather had been set fair during the first fortnight of August, as is usually the case in Southern Italy: however, on the 15th it changed just when we were ready. There were storms and the sea was very rough. At last, on 25th August, the weather forecasts were more favourable. We telephoned to Naples and to the Admiralty, and the same day, in the afternoon, the tugboat *Tenace* crossed the bay and dropped anchor before Castellammare. Everything had been prepared in advance, and at 6 p.m. the *Trieste* left harbour. The speed was low because, as had been shown by tests with models, the *Trieste* had a tendency to diverge from a straight line if it was towed too quickly: it advanced in a zigzag, veering 45° now to port, now to starboard. To steady it I provisionally fixed a deep-sea anchor to the stern. This resulted in a noticeable improvement, but it was only when we added a drop-keel to the float that the *Trieste* had good sea-manners. In bright moonlight we moved onwards, leaving Capri on our right, and at early dawn on the 26th we arrived at the place chosen for the dive (Lat. 40° 30′ 03″ N.; long. 14° 12′ 30″ E.). A launch belonging to the 'Navalmeccanica', with engineers and sailors of the naval dockyard aboard, came with us. Coming from Naples, the *Fenice*, a fast corvette of the Italian Navy, joined us: she was a great help to us in keeping watch over the diving zone. In fact it was essential that when we rose to the surface no boat was moving about in the neighbourhood. No one knew the exact spot at which the bathyscaphe would break surface. The *Fenice* tirelessly quartered the sea and asked ships to keep two or three miles away. With two exceptions, all the ships fell in with our demands. However, one large steamer insisted on keeping on its course. A threat of force was necessary before it would give in. The other spoilsport was a speedboat from Capri: it carried a celebrated film star. When the *Trieste* rose to the surface, the speedboat circled round us. As we had to have a certain freedom of movement, and soft words proving vain, the *Fenice's* hoses went into action: they had the desired effect.

The *Fenice* also fulfilled another purpose. The Italian Admiralty had invited reporters and journalists to be present for the dive. Although the time between the announcement of departure and our getting under way was short, fifty or sixty journalists were on board the corvette.

In the grey light of early morning, under the command of my son and Engineers Salvio and Traetta, we got ready to set out.

Like her model, the free balloon, the bathyscaphe is, as we have seen, provided with a trail-rope which facilitates navigation at the sea-bottom. But this cable might possibly get caught in something. So that it can be released, the trail-rope is fastened by a catch which is held shut by an electro-magnet. It is necessary only to cut the current which feeds it to release the cable. We had noticed, in fact, that the catch opened a little too easily: it happened that at the moment when the cable was unrolled a shock released it. Weighing 770 lb. it sank straight to the bottom. We had other cables in reserve on board the *Tenace*, but as it is difficult to repair the catch when at sea, we decided to dive without a trail-rope.

To economize on current before our departure, we closed the outflow tubes from the tanks with screw caps and blocked the armatures of the electro-magnets with pins. We then had to switch the current on to the solenoids, which stop the iron pellets from flowing away by magnetic action. Then a diver, equipped with a Salvas diving equipment, went under the float, unscrewed the screw-caps and handed them to my son. All that had to be done now was to turn a switch in the cabin to start the unballasting: we could at the last moment take out the pins blocking the magnets.

The operations were carried our normally: my son and I went down

Plate XVI The *Trieste* off Ponza, 29th September 1953

Plate XVII Before the dive off Ponza, Salvio cleans the large window of the antechamber. Note the door on the left, and (above) the magnetic ballast valve

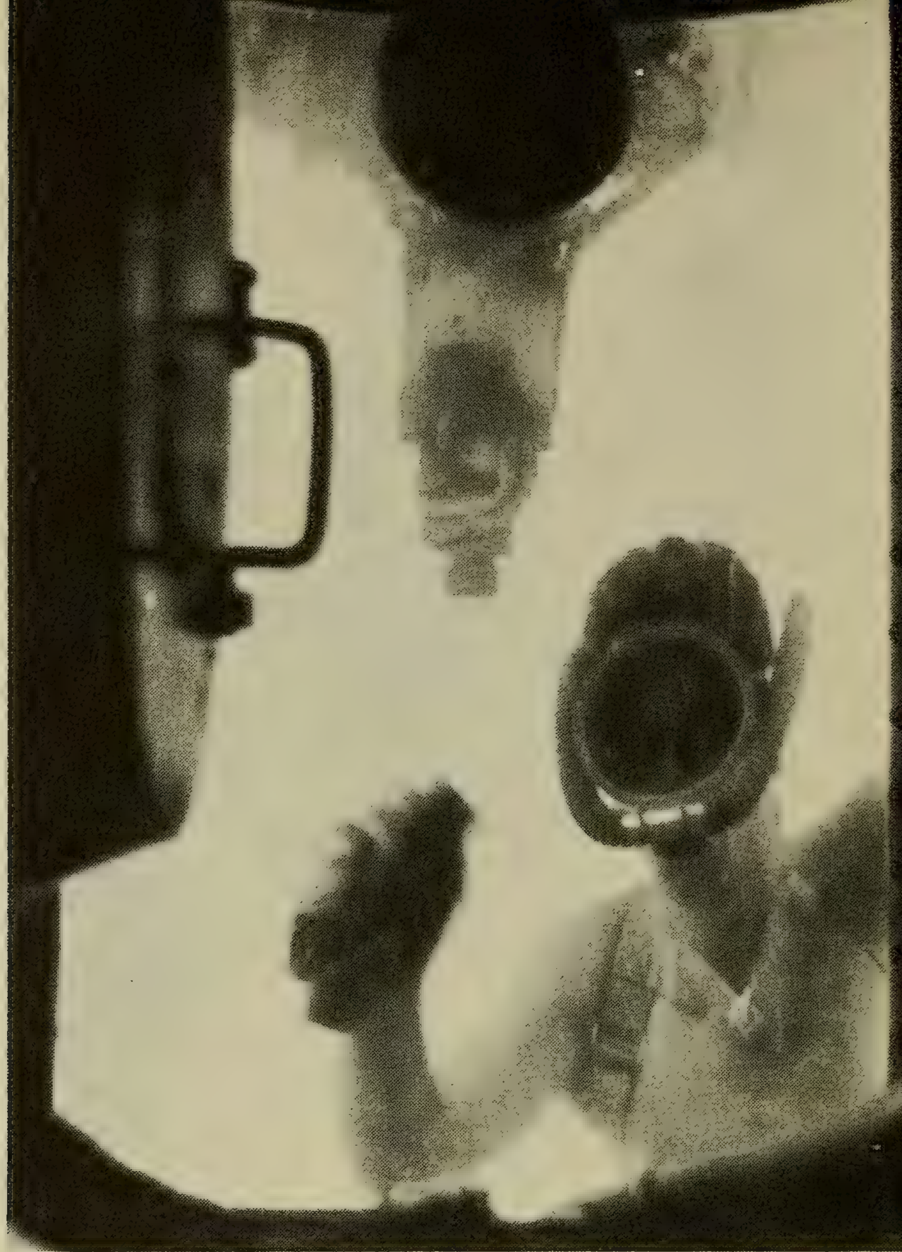
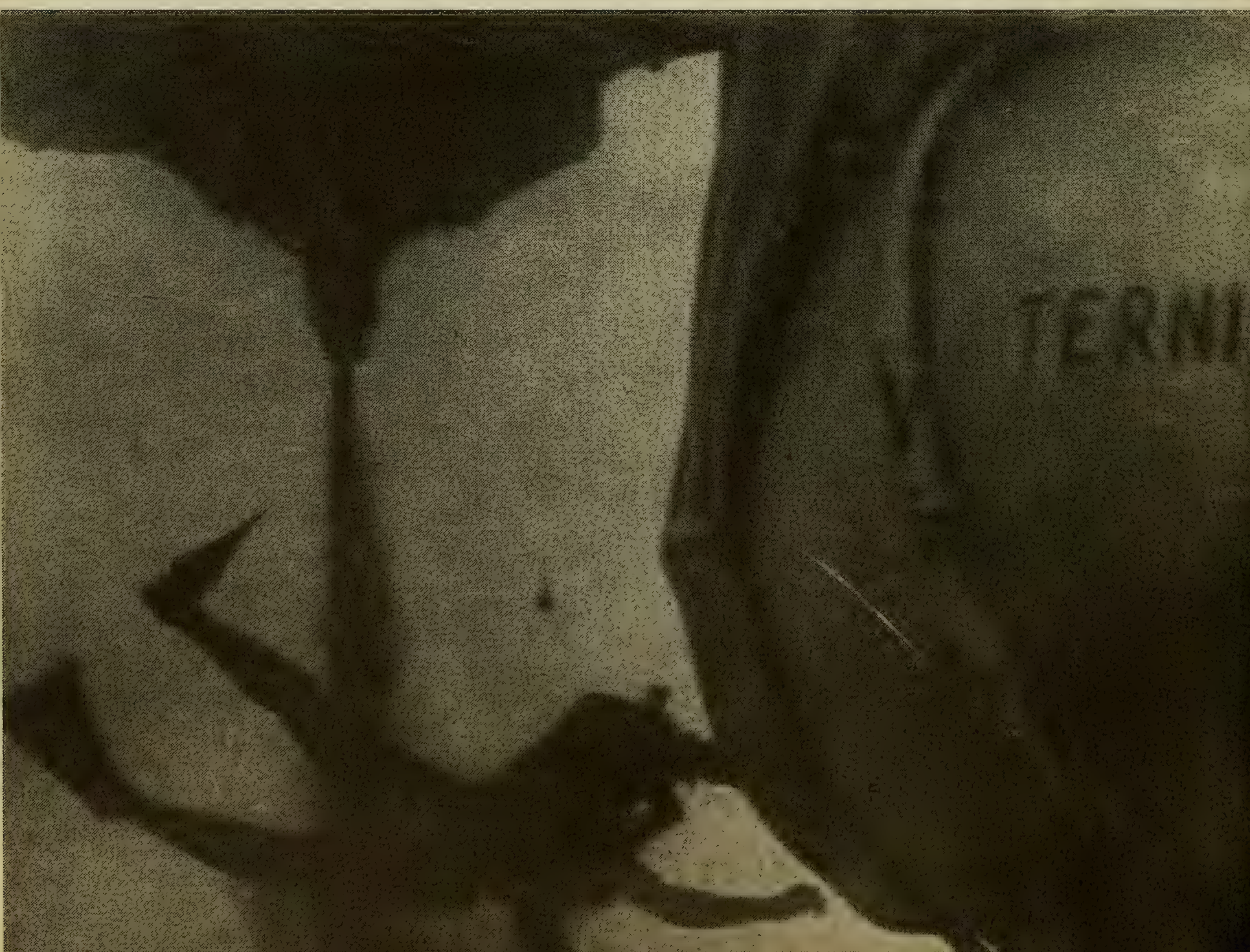


Plate XVIII Checking the unballasting device



into the cabin and closed the door. The orders were transmitted by telephone: 'Fill the lock. Close the hatch. Take out the pins.'

'Pins out.'

'Did you yourself see that they were taken out?' (An error could prove fatal.)

'I saw it with my own eyes.'

'Open the sluices in the air tanks.'

We heard the boatswain retransmitting the order: the water rushed into the tanks and weighed down the bathyscaphe.

Then the message came through from the surface:

'You are going down . . . the deck is under water. The tower is half-under . . . we are disconnecting the telephone cable.'

A sharp noise told us that from now on we were isolated and left to ourselves. The descent began.

Suddenly we noticed that the iron pellets were running out from the front tank: we connected the ammeter on the solenoid circuit, or, more correctly, the millivolt-meter on the shunt of the circuit corresponding to it: the index remained at zero, a proof that the circuit was cut. A few minutes later we were on the surface again. Between two and three tons of iron pellets had escaped.

The film which was taken underwater during the preparation showed me later the probable reason of the breakdown: the cable supplying the solenoid must be relatively weak at a certain point so that it can break, if circumstances force us to sacrifice an entire tank of ballast: at the critical moment, a diver came near the solenoid: inadvertently he must have pulled on the cable with his breathing apparatus and broken it at its weak point.

What was to be done? To repair the cable underwater was quite impossible. Were we to go back to Castellammare, empty the petrol tanks, hoist the bathyscaphe on to the dock, and then, after repairs, start all over again? It would have taken a week at least, and we could not spare the time, as the season was already well advanced. Leaving the *Trieste*, we went aboard the *Tenace* to study the situation. It was a difficult situation. Suddenly my son had an idea.

'Supposing we seal the opening of the faulty tank? We could then replace the tons of ballast which have been lost by the emergency ballast that we have on the *Tenace*. So we could go down again this afternoon.'

At first sight, to go down with a single tank working seemed like taking an unjustified risk: but the depth was only 550 fathoms and the unballasting of a single tank would be enough to assure the return of the bathyscaphe to the surface. In case of necessity we should still be able to jettison the entire tank with its contents. Instead of fourfold security—two solenoids and two electro-magnets—we should have it threefold; that was enough.

The morning had been lost, but in the afternoon we were ready again. The usual operations were gone through once again; this time everything went forward without a hitch. At last the telephone was disconnected from its socket and the bathyscaphe went down; slowly the light grew less.

I have often been asked what were my thoughts at these moments. There was nothing to cause us anxiety. Neither my son nor I could believe in the possibility of any fatal accident. However, it must be admitted, seeing the light decrease while the gauge indicated increasing pressures has something impressive in it. We knew, of course, that in the course of nature day must always follow night; it is a spectacle which men have seen hundreds of millions of times. But, until now, those who have come back from the kingdom of shadows can be counted on the fingers of one hand. And yet we had confidence in the laws of nature: we had only to turn such and such a switch to cut the supply of electricity to the solenoids and start the unballasting. Less heavy than water, we should necessarily rise: Archimedes knew it centuries ago!

My preoccupations were of another order and I feared only one thing: to have to go up again to the surface too soon if ill-luck had it that some circuit was broken. This time everything went well and the light grew less: in the beginning the light which filtered in through the portholes was still sufficient for us to distinguish objects in the cabin; then, little by little, the shadows grew thicker; the portholes alone were still visible: grey-blue discs 4 inches in diameter; slowly the colours blurred. All became grey, then dark grey, then black.

DAYLIGHT UNDER WATER

To what depth is light visible and what is the colour of the last ray one can see? It is hard to say. Coming out of the full daylight, the eye is considerably less sensitive than after it has been an hour in darkness. It follows that, when going down, the frontier between day and night seems to be closer to the surface than when rising. The perception of colours disappears more quickly than that of light. There are in the retina two sorts of sensitive cells: the first, the cones, distinguish colours, but are less sensitive to light; the others, the rods, are more sensitive to light, but do not perceive colours.

A very simple experiment will demonstrate this. Let us go into a dark room lighted only by a feeble blue lamp: the bulb appears blue, but if we glance aside, the rest of the room does not have any appearance of colour. The same phenomenon is observed in photography: the black and white films are more sensitive than the colour films. This explains why I cannot say what is, in fact, the colour of the last luminous ray. The proverb 'every cat in the twilight's grey' applies literally in such a case: the last glimmer seems grey. However, Schiller's diver speaks of a purple darkness and Beebe of a violet light. Only a photograph of the spectrum would permit an answer to this question. One thing is certain in any case: 18 inches of water already absorbs a great part of the red light and a few yards intercepts it altogether. To prove this, just look at the water in a white-enamelled bath-tub: it appears bluish because, already, the water in it absorbs a part of the red light.

Let us not forget that the permeability of sea water to light rays is not constant: it varies according to the place and from one day to the next. One cannot be exact; all that can be said is that below some hundreds of yards the darkness is complete.

COLOURS OF SUBMARINE VEGETATION AND FAUNA

I hope I may be permitted to digress into the domain of biology.

On land we admire the colours of plants and animals. But why is the finery of the peacock so beautiful? Simply to arouse the interest of the pea-hen. Butterflies, too, recognize their kind by their colours and the designs that adorn their wings. Lastly, what of the flowers, which unfurl chromatic marvels to attract the insects which fertilize them?

What is the origin of these colours? Darwin provided an answer: from generation to generation the handsomest peacock has had the greatest success, or in other words, has had the most descendants. He it is who has had the greatest number of opportunities of transmitting his colours to posterity. It has always been so: from century to century selection has enriched his characteristics. Among the butterflies the handsomest, too, are those most certain to be reproduced. In the same way the most beautiful flowers have necessarily produced the greatest number of seeds.

If, at a few yards below the surface, one observes the rocky bottom of the sea, one is seized with admiration at the richness of tone. But, strangely enough, the anemones and the other stationary animals often display magnificent colours, just as much as the fish. Yet, fixed to the rock, they do not set out on nuptial journeys. What good then are these colours? Is it to attract their prey or, on the contrary, to frighten off their enemies? If the diver goes deeper, down where the red light does not reach, and detaches a grey-coloured animal from the rock, very often this creature will appear bright red in the daylight. The nets of the oceanographic vessel *Valdivia* brought up from several thousand fathoms, depths where perpetual night reigns, lobsters of the finest red. How can this colouring be explained? We are far from knowing this. Darwin's theory has certainly something to do with the matter; but the last word has not yet been said: let us then continue to observe and seek.

THE DIVE GOES ON

We turned on the lights in the cabin, and glanced at the pressure gauges: the pressure was 45 atmospheres, showing that we were almost 250 fathoms down. We put out the light, and were in absolute darkness. I looked through the porthole: like a shooting star, a luminous dot crossed my visual field. A living thing! Animal or vegetable? In this darkness true plants cannot live. We saw several of these phosphorescent animals, sometimes solitary, sometimes in a group, then once more, the opaque shadows round us. Lower down I noticed a creature more brilliant than the others, more distant, surrounded by a halo of light: it looked like a planet in misty weather. It was too far off for me to be able to make out the shape. A single fish showed itself, about 4–8 in. long, and also slightly phosphorescent. When we lit the 5000-candlepower projector—its beam was directed downwards—a quantity of small bodies appeared, luminous dots standing out against a dark background. A more perfect demonstration of ultra-microscopic lighting could not be imagined! The water was admirably limpid: when no animalcule was within range the light-beam was practically invisible.

The recording gauges describe their regular curves: 200, 250, 300 fathoms. As expected, the petrol contracted and the bathyscaphe became heavier. Its speed increased progressively: it had now reached 3·3 ft. a second and even a little more. In these conditions there was nothing surprising in our not seeing any fish. If we wanted to proceed to zoological observations, it would be necessary to brake the descent, so as not to frighten them away, or better still, to hold the bathyscaphe in equilibrium. Perhaps, too, by hanging a bait in front of the porthole we could attract towards us representatives of the fauna of the abyss.

All life in the sea is dependent upon the upper layers illuminated by the solar rays: by virtue of chlorophyll organic substances are produced here. Small fish and crustaceans feed on living or dead algae, or on diatoms; then, in their turn, they become the prey of larger creatures. At all levels, animals lie in wait for dead bodies going downwards. They also eat each other. Each depth possesses its particular fauna. Right at the bottom there is a world apart: flat fish, crustaceans, spider-crabs, shells, filtering the water to get out of it anything that is edible.

We waived the idea of stabilizing the bathyscaphe since this time our object was not to make zoological observations, but to test the *Trieste* and to demonstrate that it was able to dive to 550 fathoms. If we threw overboard too much ballast we should go up to the surface again without having reached the bottom. It is true that, even so, we could have opened the valve to let out a certain quantity of petrol. However, if the ascent took place at high speed, we should not have been able to let enough out to compensate for the decrease in weight induced by the expansion of the petrol. Before being able to adjust the amount of ballast and petrol, something else was needed: to know at each moment the exact speed of the bathyscaphe. Certainly we had depth gauges, but as has been said, they were not sufficient and we had not yet got our tachometer.[1]

This time we let the *Trieste* go straight towards the bottom. Afraid to throw out too much ballast, in the event we did not throw out enough: 400, 500 fathoms. Soon we ought to be able to see the bottom.

The projector was turned on and suddenly a circular surface appeared in the cone of light. My son, who was at the porthole, called: 'Steady on!' like an aeronaut who expects a rough landing. We were already on the bottom: we touched so gently that we were not aware of it. 594 fathoms.

An oceanographer told me that the sedimentary deposit increased not more than $\frac{1}{25}$ in. a year and that, at the end of several centuries,

[1] We had it made after our return from Capri.

the mud solidifies, and becomes rock in a thousand years. The soft layer should not be more than about a yard thick. Other scientists estimate that the thickness of the yearly sedimentary deposit is not even as great. Down where we were, south of Capri, far from a river mouth, I expected only a very slight deposit. Now what did we see? Nothing! The cabin was stuck in the mud up to the porthole. (Upon our return, examining it, my son worked out that it had gone 4 ft. 6 in. deep into the mud.)

During the descent we had been rejoiced to think of the discoveries that we should make, once on the bottom. And we saw nothing. The light from the projectors did not reach us: when we turned on the interior lighting we saw that a sandy mass was obstructing the window. In fact the samples of soil which remained stuck to the cabin showed that it was not sand but a substance of very fine composition, almost dusty, which to the naked eye appeared homogeneous: this explained why we entered it so easily. The Institute of Applied Geology at Milan asked us for a sample, so we sent them some. The macrophotograph of it showed its composition. It is in masses of this formation that, in the course of millions of years, oil is formed.

This time no observations were possible. During the dive on the 14th August, 22 fathoms down, we had seen the bottom perfectly: the descent had been slow and the *Trieste* had not driven into the mud. The same thing had to be achieved also at great depths. (A balloonist must make six ascents before he obtains his pilot's licence and on several occasions the instructor goes with him; the pupil aeroplane pilot must fly as an onlooker with his teacher before being allowed to fly in dual control, then to be at the controls alone, and lastly to be left to himself. It was quite otherwise for the pilot of the bathyscaphe.)

The aim of today's dive was to prove the strength of the bathyscaphe, and the objective had been attained. But even in these conditions the cabin could already render great services as a laboratory, particularly for the measurement of gravitation. The geophysicists have installed a network of stations over the globe. In these they proceed to the measurement of ground acceleration: the data gathered allows the geological structure of our planet to be studied. For this the observatory has to be safe from any vibration or movement: ships therefore cannot be used. Now, to know the gravitation between the continents would be of the highest importance: the information gathered would permit us to determine the structure of the part of the earth's crust which is covered by the sea. Up till now the only means at our disposal had been those installed on board a Dutch submarine by Professor Vening Meiners: for this the submarine had to remain stationary for hours at a constant depth, the members of the crew being condemned to absolute immobility. The data would be at once more exact and easier to obtain if the gravimetric pendulum were placed in the cabin of our bathyscaphe, stationary as it is in the mud. One would still have to study the problem of the transmission of hourly signals by ultrasonic methods. But the difficulties are not so great that a solution cannot be found.

UP TO THE SUNLIGHT

At the end of a quarter of an hour, thinking it useless to prolong our sojourn at the bottom, we decided to go up. The machine had to be lightened. The opening of one of the ballast tanks was blocked up by a plug: the other was free and allowed four tons of iron pellets to be thrown overboard, that is to say, more than is necessary to compensate the overload that we had on touching bottom and to drag the cabin out of the mud. Jacques turned the switch, and in theory the ballast should have flowed away, but it was impossible in this mud to make sure of it. The silence was total, a real silence of the tomb. However, the situation was in no way alarming: a single tank was available; the iron pellets thus could not flow out faster than a rate of 110 lb. a minute. And even after this tank was emptied, we could still throw the other overboard, in other words, 8800 lb. of supplementary iron pellets and 4400 lb. more, the weight of two ballast tanks when empty. Suddenly the bathyscaphe leant forward and the mud ran along before the porthole. I rushed to it in the hope of perceiving the bottom at last. But, in dragging itself out of the mud, the cabin stirred it up; a cloud formed and, when it had cleared away, the bottom was already out of sight.

The dive entered upon its last phase: as we did not open the control valve and as, following upon the decrease in pressure, the petrol expanded, the bathyscape became more buoyant and the speed of its ascent increased: it reached about 3·3 ft. a second. In the glimmer of the projector innumerable dots of light showed themselves: the particles of mud stuck to the cabin were loosened and were outlined pale against the black background. During the greater part of the ascent we turned out the projectors: the phosphorescent animals interested me more than the illuminated particles of mud. A glance at the gauge was sufficient to assure me that the ascent was continuing: it went on without rolling, without jarring.

A child's balloon goes up in zigzags. It is not the buffetings of the wind that induce these changes in direction: if one repeats the experiment in a large hall sheltered from all wind, the ascent will take place in the same manner. It is the eddies produced by the balloon itself which are the cause of its behaviour. One has only to give it a light load, so as to decrease the speed, to establish that there is a critical speed: below this speed, the trajectory is strictly vertical, and above it, the eddies make the balloon zigzag. In the same way, if a tennis ball is released at the bottom of a bathing pool, it ascends in a zigzag. If the bathyscaphe rose too fast, it would behave in the same manner. It is impossible to determine in advance by calculation the critical speed beyond which the eddies would be formed: I had therefore made provision for coping with too great oscillations by using a parachute: attached beneath the cabin, it would open and would brake the ascent. Once more this is an analogy between the aerostat and the bathyscaphe. However, trusting to remain below the critical speed, I calculated that we could do without it. My optimism was justified: more smoothly than in the best of lifts we rose without the slightest oscillation.[1]

We were still in darkness. But for the instruments we could still have believed ourselves at the bottom. It is a thrilling moment when the first gleams filter through the portholes! Little by little the illumination grows. From then on there were no more phosphorescent animals. Soon it was light enough for us to recognize objects in the cabin, with all the lights out. The daylight increased and the portholes were resplendent with a bluish light. The cabin began to sway, a slight rocking: we had reached the surface. Above us the rays of the sun played in the waves: spots of light danced in the antechamber. Suddenly the ringing of the telephone made us jump. After forty-five minutes there we were again in contact with the external world and its civilization.

When the *Trieste* dived, the escort units moved out to avoid any danger of collision. The pneumatic dinghy manned by Mr. Salvio and a sailor alone remained in the neighbourhood. When the *Trieste* surfaced, 500 yards separated the dinghy from the bathyscaphe: rowing, the two men tried to race the *Tenace* to the scene and the *Tenace*,

[1] This was not always to be the case (see page 134).

from 2 miles off, came up at full speed. The dinghy won. Salvio connected the telephone and established contact:

'Hallo! Everything all right? How far down?'

'More than 550 fathoms.'

The compressed-air hose on board the *Tenace* was connected to the tubing of the tower and the air entering the shaft drove out the water. We could see the level going down outside the rear porthole. When the lock was empty, they opened the hatches, and we climbed up the ladder and got out on to the deck. A longboat came alongside and took us to the *Tenace*. In its turn the *Fenice* came up, bringing the journalists: in the calm sea it could come almost side by side with the *Tenace*.

One sceptical spirit demanded proof of our depth, but if our word was not enough, the recording indicators came to our aid as reliable witnesses, as a naval officer had sealed them with a lead seal when we set off. Twenty-one years ago, at Dubendorf, the meteorologist Berger, steward for the Swiss Aero-Club, had sealed the two barographs in the stratospheric balloon in the same way.

Did they want us to go and get the recording instruments from the *Trieste* so that the reporters could themselves verify the depth reached? I very much wanted to suggest that they should go down themselves to see the imprint that our cabin had left in the mud. At that moment Bucher, one of the divers, hailed us. He was holding out a handful of grey-blue clay.

'I picked it off the cabin!'

At the spot where we were, the marine chart showed the depth to be from 550 to 605 fathoms: there it was, the proof they wanted!

At the beginning of this chapter I told why we had closed the outflow opening of the front ballast tank: the back tank alone was working. The bathyscaphe had thus been thrown slightly out of equilibrium and, now that it was on the surface, it was lying slightly low by the bow. We did not think of pointing it out to the journalists. A few days later, opening the newspapers, I learned with some astonishment that we had been next door to catastrophe! It appears that a compartment of petrol had leaked and that we had just managed to come up again by throwing overboard all our ballast. I ought by rights to be trembling to think of the perils which, it seems, we had just escaped from!

With its complement of journalists, the *Fenice* went back to Naples: the launch from the 'Navalmeccanica' yards took the engineers back to Castellammare and the *Tenace* took the *Trieste* once more in tow: slowly we passed by Capri, and reached port after nightfall; where the bathyscaphe was made fast alongside.

We went back to work to make preparations for the big test.

7: Diving to 1700 fathoms

TWENTY-FIFTH September 1953. Once more the *Tenace* proceeds towards Castellammare. We are about to set out for the *Trieste*'s big test. In the yards, workers and engineers carry out the final preparations. The *Trieste*, motionless, is at the dock. Rejuvenated by a coat of fresh paint, fitted with several new pieces of apparatus, it seems to be waiting, just as impatient as ourselves, again to take up its service on the high seas.

What had we been doing since the dive off Capri?

We made many small improvements: each dive is only a prelude to the following dive and serves as a lesson for future experiments. The towing speed was too low. We added a keel beneath the stern of the float: perhaps it slightly decreased the remarkable stability of the *Trieste*, but not enough to be noticeable. We did this, not to prevent rolling, but to increase the speed of the float on the surface. Actually this keel permitted the towing speed to be trebled.

A wire to a solenoid had been broken. This was put right, and a new system was evolved to increase the efficiency of this component.

We had been hindered by not knowing our vertical speed with precision, so we built the tachometer which was described earlier.

Light had been lacking towards the rear of the bathyscaphe, and to remedy this a third projector was constructed identical with the first and placed on the stern.

A number of busybodies criticized what they thought was calculated delay, but in fact we did not waste a moment, and all the time was spent providing the *Trieste* with improvements. It was not enough for us to dive deeper: what we wanted was to develop the scientific possibilities of the *Trieste*.

Where were we to dive this time?

We had marked out on the map, south of the Island of Ponza, at some sixty miles to the north-west of Castellammare, a vast sandy submarine plateau, whose depth varied between about 1650 and 1760 fathoms. It was an ideal spot for landing a submarine balloon. However, it would mean a whole night's towing; but the sea was calm, and we could set out without anxiety.

At 4 p.m. we weighed anchor. Two sailors came aboard the *Trieste*, while I stayed aboard the *Tenace*. We ran along the coast of the Sorrento peninsula; close to Ischia and Capri. The corvette *Fenice*, engaged in manœuvres, was in the region and we exchanged military salutes. The following morning, at dawn, she was to join us at the place selected for the dive. As night fell, the searchlights were lit, and by the light of their beams we could watch the *Trieste* gliding smoothly along in our wake.

After a while the wind began to rise. By radio we were told that the weather forecast had changed and was less and less favourable. The *Tenace* was pitching. The *Trieste* behaved very well, however, in spite of the waves which began to sweep her deck. The journey continued, but all night long we were worried that heavy weather was going to spoil our plans. Towards midnight the wind blew stronger and stronger. The last stars hid behind big low clouds. By the light of the floodlamps, we could see the waves breaking, sometimes covering the *Trieste* to halfway up the tower. We could make no decisions at that hour; whatever happened we had to wait for daybreak.

In the greyness of early morning, gathered on the quarter-deck of the *Tenace*, our faces roughened by the wind and spray, we had to make a decision.

Jacques had himself taken on board the *Trieste* by the little rubber dinghy. He rapidly inspected the bathyscaphe, and found everything in order. Tossed by the waves and pitching in the swell, the *Trieste* behaved remarkably well. But it was clear that the operations which precede a dive would have been almost impossible in that weather. How were we to put into the water the trail-rope still rolled up on the deck of the bathyscaphe? The men who were to put it in place at the last moment would have all their time taken in hanging on to the 'Tientibene' (the hand-rail) let alone fixing it. How were we to check the air space of the electro-magnets?[1] Or make sure that they still had the $\frac{1}{125}$ in. required? How could one ask the men, after the 'Let go!', to get back to the boats by swimming, with waves several feet high?

However, a last endeavour had to be made: the *Fenice* poured out oil to calm the waves and the *Tenace* stood broadside on to protect the *Trieste*. But all these measures proved useless, and we finally had to give up for the day.

We did not, however, think of going back to Castellammare. We

[1] See Appendix 2.

had been on our way for more than fifteen hours, and the little port of Ponza, only a few hours away, offered us an ample refuge from the weather. So we set sail for Ponza.

In the bright intervals we could see more and more clearly the contours of Ponza. Bit by bit the waves subsided, as we came under the lee of the island. The cliffs dropped perpendicularly to the sea. The 'Faraglioni' rocks stood out starkly.

Running along the coast, the *Tenace* rounded a headland, then entered a bay. The commandant of the port came out in a launch to meet us, and then went off with the officers of the *Tenace* and my son to look for a berth in the port where the *Trieste* could be moored. Although its displacement was only 3861 cu. ft., its draught was 19 ft. 10 in., so it had to be moored away from the quay.

Ponza is a strange island, full of the unexpected: the climate is extremely dry and springs are rare. The water has to be brought from the mainland in tankers. One of the chief crops is the Agave or sisal-hemp, the dried leaves of which are used for fuel. The houses of the little town are grouped around the port and on the slopes surrounding it: their neat, clean look makes an agreeable impression.

We asked the mayor who welcomed us what the inhabitants lived on. Crayfish-fishing—the Ponza crayfish is renowned throughout Europe—provides for their needs in great part. Secondly, there is the tourist trade. Little hospitable restaurants face the quays and visitors lodge with the inhabitants: you are as well off as in a good hotel. Another source of wealth is emigration. Of the 15,000 native-born, 8000 live in New York. Very much attached to their little country, hardworking and intelligent, they send their savings to their families left behind in Ponza. As far as is possible, they spend their holidays in the island: when their working life is done, they come back to live there.

We were the guests of the municipality.

The weather got better and we hoped to be able to undertake a dive on the 30th September. On the 29th my son and Mr. Traetta of the 'Navalmeccanica' yards went down to a depth of 50 ft. in the lee of the island to inspect the bathyscaphe and make sure that the heavy weather had not caused any damage. In the evening the corvette *Fenice* went to the place where we intended to make the dive and told us over the radio that there was a medium swell.

At midnight, once more, we weighed anchor: at first, as long as we were near the island, all went well. But gradually the waves began to make themselves felt. We were all somewhat anxious. We kept looking towards the *Trieste*, but those who were mounting guard on board made signs to us that all was well.

From low clouds a fine rain was falling at six o'clock in the morning, when Captain Zanchi, military head of the expedition, came to inform us that we were at the spot selected. 'Medium' swell. We could see now what that meant. Certainly, for a battleship or for an aircraft-carrier, the sea was not really bad: it was better than two days earlier. But we all had the same thought just the same: should we be able to make the final checks? Would the operation be possible?

It was possible, because all the dockyard workers who were with us—electricians, mechanics, fitters, engineers—metamorphosed themselves suddenly into wonderful sailors. All together we were a united crew; we had only one thought: to succeed.

Jacques gave the signal, and everything went forward with strict precision. The boats were launched. On the order of Captain Zanchi, no one was allowed to leave the *Tenace* without putting on a life-jacket. After putting on mine, I went down the little port ladder and I had to wait until the up-and-down motion of the waves was good enough to let me get a footing to get into the launch.

When I reached the bathyscaphe there was the further difficulty of getting up on deck. Fortunately Jacques was there already: he stretched out his hand, and made it possible for me to get aboard. On the *Trieste*, Salvio and Traetta made sure that all was in order. We went down into the lock: before entering the cabin there was no time to make last farewells—they would have been pointless anyway, as we should see each other again soon. The work in common continued. While the navy and our friends mounted guard on the surface we could go off in complete confidence towards the abysses. Everything went well: the rolling ceased. The bathyscaphe entered its element: entering the kingdom of eternal calm, it descended. The tachometer's little light winked: dash, dot; dash, dot: we were going down. Beyond the portholes the light got less, the last bluish gleams disappeared. Lower, the first phosphorescent animals appeared. 508 fathoms, the depth reached by Beebe and Barton on the 15th August 1934. 594 fathoms, the depth we reached five weeks ago off Capri. The tachometer's red bulb winks faster and faster: our speed was increasing; and this was shown also by the contour of the line traced on the barograph. Was this the moment to unballast? Once again, if the object of our dive had been to observe the fauna, we should not have hesitated to do it: motionless in the water, the conditions would be ideal for observation. The fish would certainly not be suspicious of an inert body: we should take them off guard with the light of our projector, and be able to photograph them. But today we wanted to prove above all that our bathyscaphe was a veritable *abyssal* submarine. What was more, we hadn't a minute to lose: if the meteorologist gave us a reliable forecast, in a few hours conditions on the surface would have become worse. In that absolute calm it was difficult to imagine a wave, but we did not forget the violence of those which had almost prevented us, a few moments before, from reaching the deck of the *Trieste*.

The red bulb blinked on; the barograph continued to trace its curved line. 748 fathoms, the depth reached by Barton in 1948 in his bathysphere. 759 fathoms, the depth reached by the *FNRS 3* in the same year during its dive without crew off the Cape Verde Islands.

When Sven Hedin, exploring Tibet, wanted to continue his journey to Lhasa the natives tried to forbid him the road: the prohibition was strict: no foreigner was admitted to the holy city. Sven Hedin was not impressed by this and replied: 'Our law at home forbids us to retrace our steps before we have reached our end, therefore we must carry on.' And the Tibetans, overcome with wonder, gave way.

We too went on our way: time passed rapidly. Sometimes I watched at the porthole while my son watched the instruments, sometimes we changed places. The containers of soda-lime belonging to the apparatus renewing the air, by means of which we could breathe, become warmer in the natural course as they absorb the carbon dioxide. The heat reaches the opening first, then the centre, then the end of the container, while the other end has already become cold again, saturated with carbonic gas. Soon we should have to change them. We had an ample reserve at our disposal in our 'cellar', in the bunker fitted out under the flooring.

1150 fathoms! It was from this depth that, on the 14th August 1953, the *FNRS 3*, manned by Captain Houot and Engineer Willm, came back without having seen the bottom.

At this moment we still had more than 550 fathoms of water beneath us. I suddenly remembered the device of Santos-Dumont: 'Through seas never yet furrowed' (*Por mares nunca d'antes navegados*).

We too were entering a virgin sea. My feelings were like those that I felt on the 27th May 1931 when, with Kipfer, I entered the stratosphere. But the analogy stops there: here there was neither sun nor moon nor stars, nothing but opaque shades.

The descent continued. We slowed it down somewhat by throwing out a little ballast. 1375 fathoms. We were diving at a rate of over a yard a second. A glance at the gauges: more than 1680 fathoms. Now it was time to throw out the ballast: opening both tanks, we let it flow out at a rate of over 4 lb. a second.

A slight rocking: that was the bottom, and the gauges, in perfect accord, indicated a pressure of 325 atmospheres, corresponding to a depth of some 1732 fathoms. Just as off Capri, we were on mud, but the big window was not obstructed this time. Through the porthole set in the door we could see the outflow mouth of the rear ballast tank: nevertheless, we had still waited a bit too late to unballast. But how could we have known exactly at what distance we were from the ground? We should have had to have an echo sounder, which our financial means did not at that time let us have.

I have been asked why we limited ourselves to a depth of 1732 fathoms. In reply, let me recall the phrase uttered by Akleh-ben-Nafy, successor of Mahomet. After having brought his horsemen all along the coast of North Africa, and passed the Pillars of Hercules, perceiving the ocean, which stretched forever in the direction of the setting sun, Akleh-ben-Nafy drove his horse into the water, brandished his scimitar and cried: 'Allah is my witness that the sea alone prevents me from continuing on my road and converting yet other peoples by fire and the sword to the faith of the prophet.'

I could, in my turn, have pulled out my slide rule and cried: 'Neptune is my witness that the ground alone stops me from opening up the deepest oceans to scientific exploration.'[1]

Once more we threw out ballast. For a few minutes the bathyscaphe did not react: through the porthole we watched the iron pellets flow from the rear tank. Were we too heavy, or was the mud really as sticky as it seemed? It was, really, quite natural that a certain time should be required to discharge the ballast that we had to get rid of, but this immobility in the submarine desert was a little unnerving.

All at once, water swirled before the porthole: this time we were

[1] The *Trieste* could without danger reach the greatest depths: the whole point is to have a base of operations close enough to the diving site.

Plate XIX Professor Piccard at the top of the lock

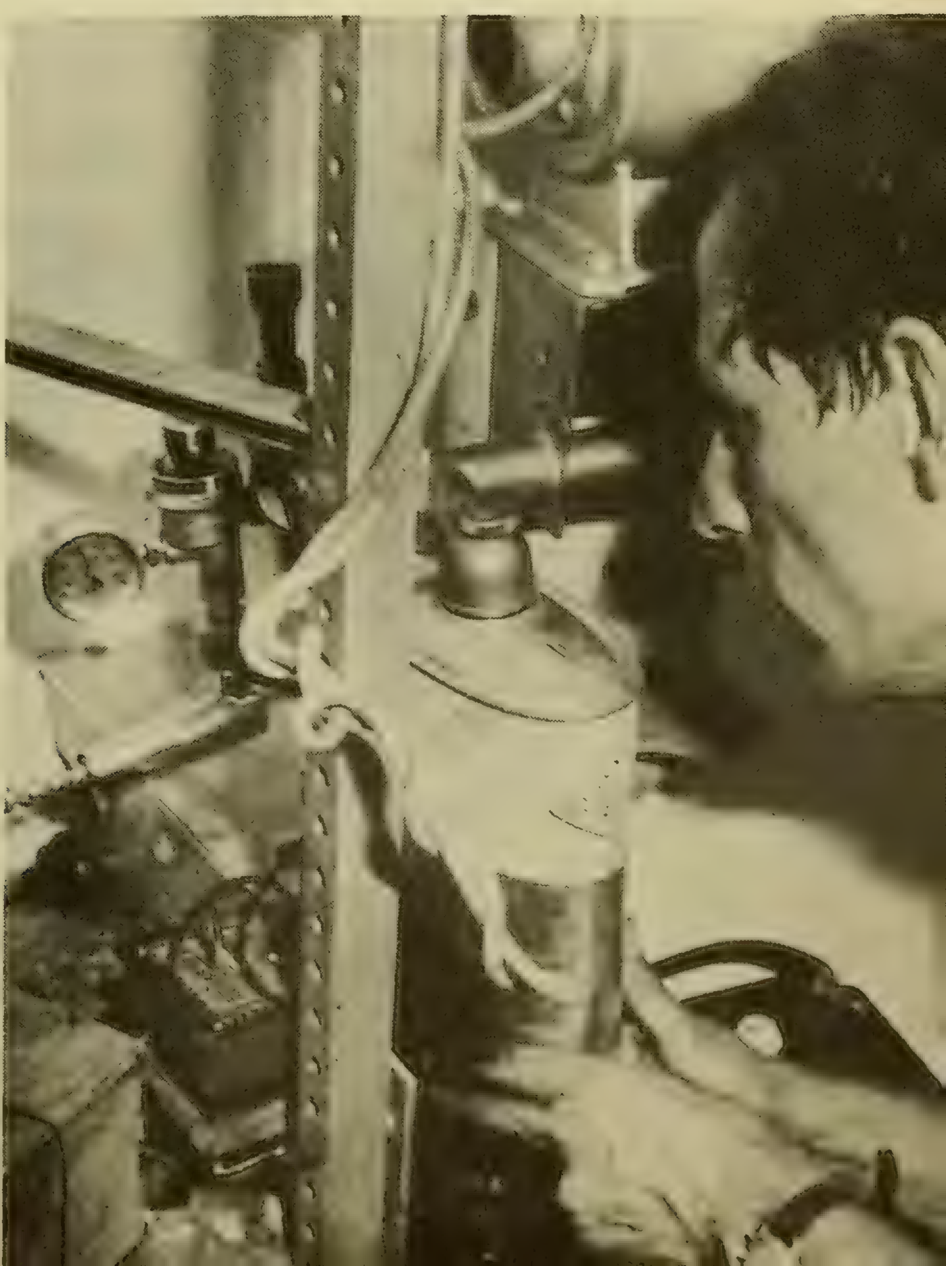


Plate XX Inside the cabin. Jacques Piccard checks the Draeger apparatus for purifying the air

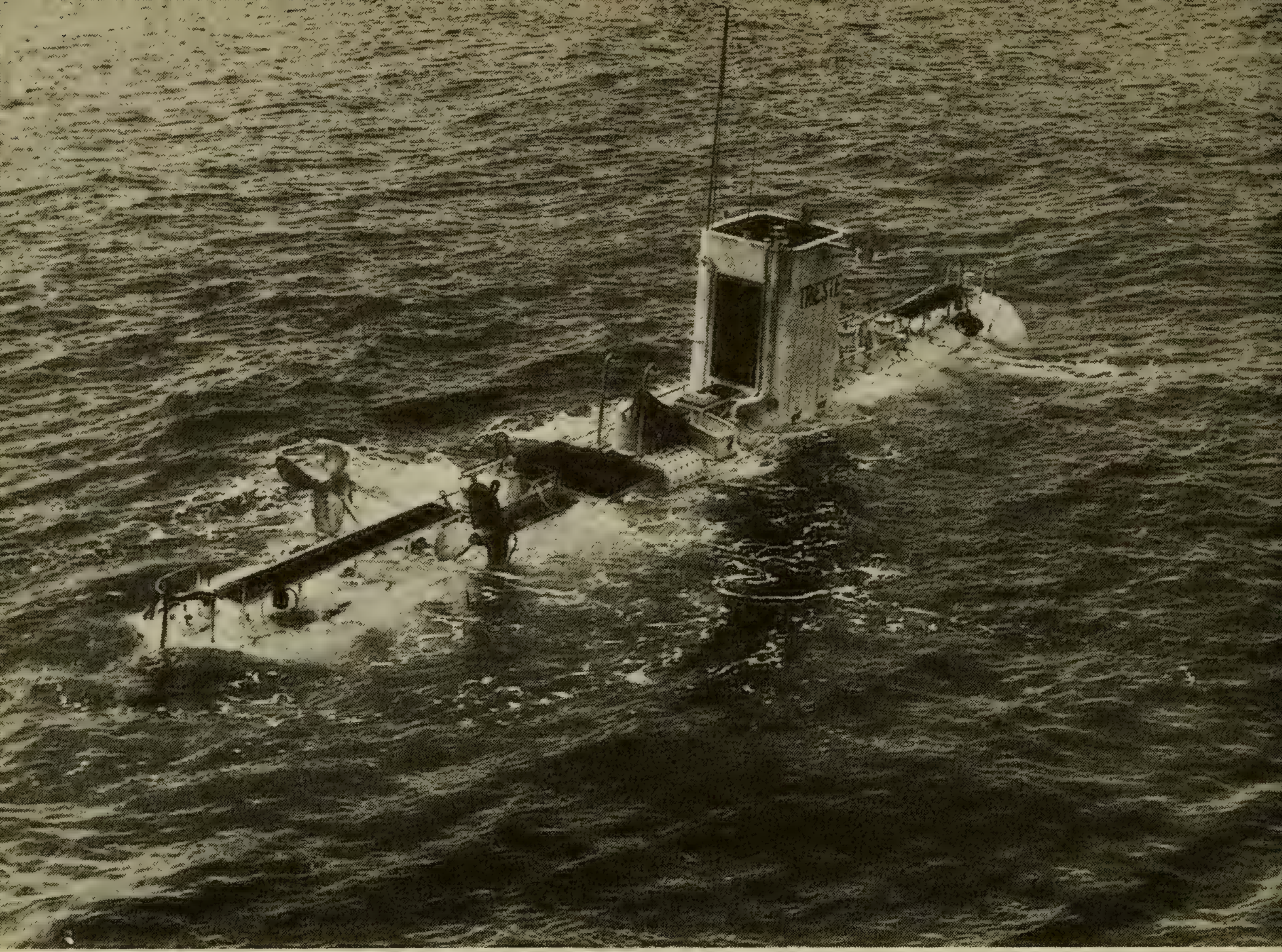


Plate XXI The *Trieste* breaks surface after diving to 1732 fathoms

Plate XXII Returning to Castellammare after the last dive

rising, and very quickly. The ascent took place normally: phosphorescent animals appeared and the speed increased progressively as we approached the surface. The first rays of light pierced the liquid layer: daylight became apparent, clearer and clearer. Suddenly we were being tossed on the waves, for we had reached the surface. The sea, just as the meteorologist had predicted, had become worse.

Until then we had not yet used the device which allowed us to empty our entrance shaft ourselves: in order to economize our compressed air, we had waited each time for the *Tenace* to connect its compressed-air hose to the coupling on the tower. This time we wanted to test our facilities for emptying the bathyscaphe's lock. As soon as we were on the surface, we opened the compressed-air cock. The water rose through the discharge pipe and flowed out in a great jet. If the rubber dinghy belonging to the *Tenace* was around it would see us blow like a whale. Hardly was the lock emptied when we heard three knocks on the deck. The dinghy had reached us, but why was the telephone not ringing? We went up through the shaft and opened the hatch; and were surprised to find a shower of shot lying about practically everywhere on deck. Salvio was just in the act of cleaning out the telephone plug. What had happened? Evidently before reaching bottom, at the moment when the bathyscaphe was still going down rapidly, we threw out ballast, and saw it escaping from the ballast tank. Issuing in a compact stream, it went down faster than we did: but once spread about in a wide cloud, the isolated grains, slowed down by the water, fell more slowly. We overtook them. It was only when the bathyscaphe reached bottom that the ballast caught up with us. A shower of iron-shot then fell on the deck and some of it rolled from there to the ground. But the uneven surfaces remained covered with it. The electro-magnets had drawn a good part to them: and the telephone socket was full of them.

That is exactly what happens in a balloon. If, while the balloon is descending, a sack of ballast is emptied all at once, the sand at first remains massed, then spreads out and forms a cloud: due to its momentum, the balloon continues its descent and goes through the cloud, but as soon as the unballasting has produced its effect, the balloon stops, or goes up again; at that moment a rain of sand falls upon its envelope. On account of the eddies produced by the displacement of the balloon, the car usually receives a goodly part of it.

Standing upright in the tower of the *Trieste*, with its deck swept by the waves, my son and I waited for a longboat to come and fetch us. There was a heavy swell and it was difficult to get aboard the boat. But at last we managed it and approached the *Fenice*. The question was now how to grasp the ship's ladder and to jump on it without getting our feet caught between it and the edge of the longboat. It was not easy: the boat rolled in the waves, going up and down and in and out, striking the ship and then swinging away. For my part I found this crossing from vessel to vessel much more difficult and dangerous than a dive down to 1732 fathoms in the *Trieste*.

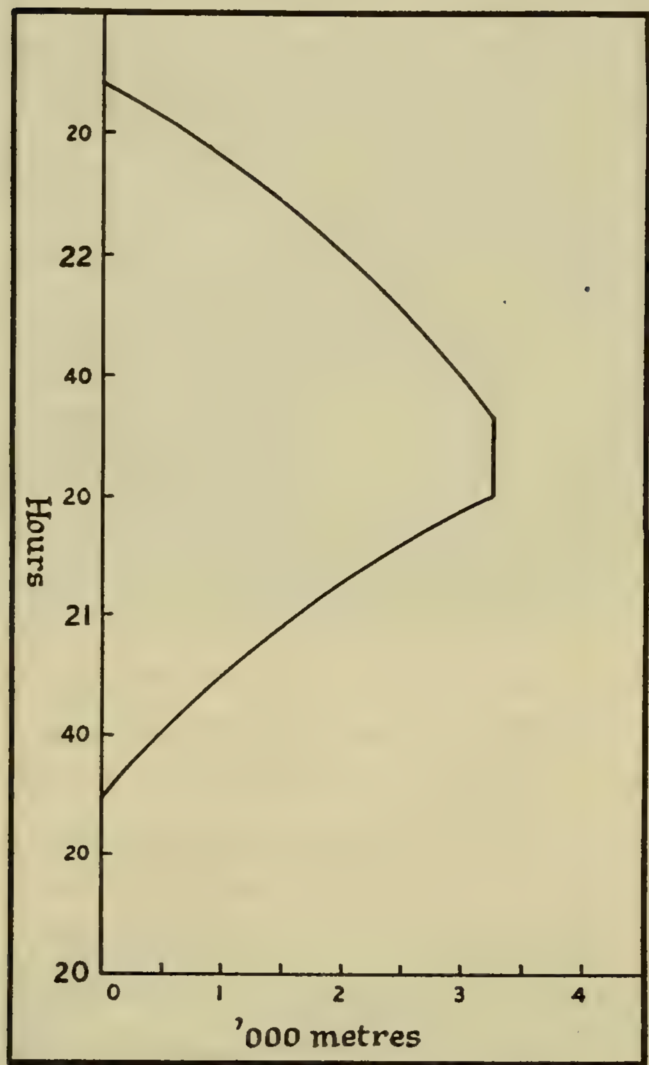


FIG. 13. Record of the Ponza dive to 1732 fathoms (large pressure gauge). To read off the time, subtract 12 from the figures on the left

Admiral Girosi and the journalists greeted us enthusiastically and at once asked how far down we had been. We told them we had reached 1732 fathoms.

From the entire world we received congratulations upon our *record*. However, that was not what I was after: the fact that the bathyscaphe had at last shown what it could do was enough for me.

While we are speaking of depth, may I be allowed to mention certain details. The precision recording gauge, in agreement with the two index gauges, indicated a maximum pressure of 4620 lb. per sq. in. (see Figs. 13 and 14). In fresh water at 39·2° F. this pressure corresponds to a depth of 1787 fathoms. However, sea water is denser. The small gauge indicated 4590 lb. per sq. in. To determine the depth precisely, we must know, as well as the pressure, the temperature of the water and its salinity at different depths and be able to calculate its mean density: expressed in atmospheres, the pressure multiplied by 5·66 and divided by the relative density would give the exact depth in fathoms. Without these data, we had to be satisfied with an approximation which gave 1732 fathoms.

THE RETURN

We could have gone back directly to Castellammare di Stabia, but my son planned to make a dive at a lesser depth with Engineer de Sanctis: he wanted to see if the light from the projectors was sufficient to make films. We therefore asked Captain Zanchi to take us to Ponza and to have the *Trieste* towed there by the *Tenace*. The mayor of the island was aboard the *Fenice*. He informed the citizens of his island by radio of the success of the dive, and invited them to come to the port to welcome us. The farewells that the frigate gave us were a witness to the interest that Italy has in scientific research. As is well known, the salutes given by ships of a navy correspond with the rank of the persons leaving the ship. At the moment when my son and I approached the gangway, the crew was drawn up on deck: Admiral Girosi said something to an officer on board. The latter was surprised:

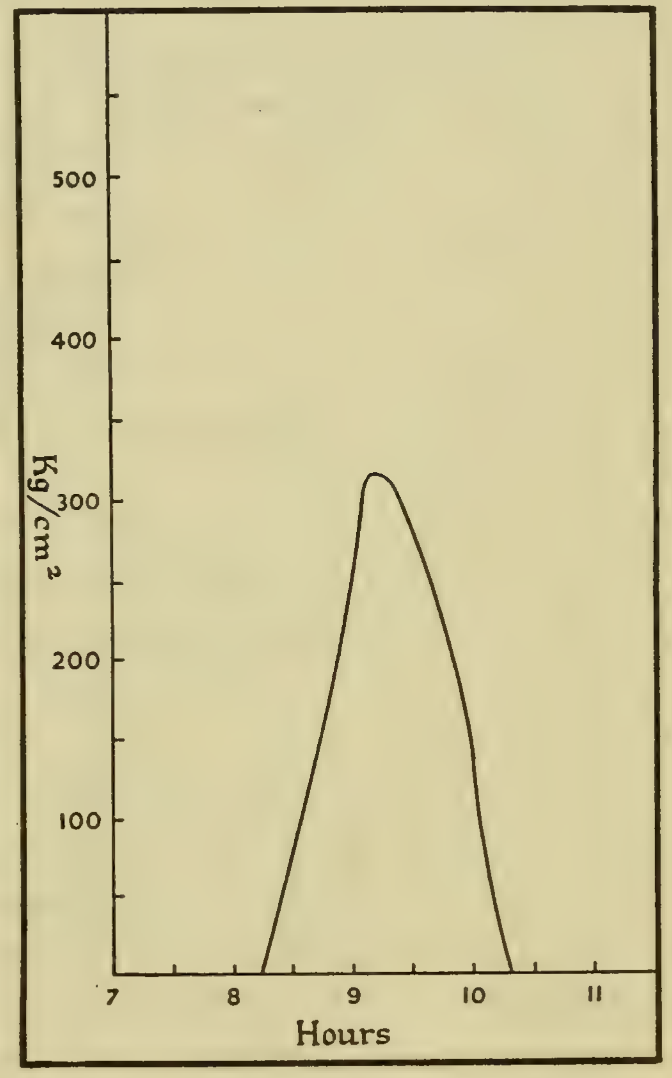


Fig. 14. Record of the Ponza dive (small pressure gauge)

'Those are the honours given to an admiral!'

And I heard the answer:

'Admirals of the abyss, they deserve it!'

Thus then, saluted by six sharp whistles, it was that two Swiss land-lubbers left the *Fenice*. The authorities of the island and the inhabitants were celebrating: we reached our lodgings under a rain of flowers thrown from the windows. The same evening we were invited to a dinner by the municipality: crayfish occupied an honoured position on the table. At the end of the meal, the notables left: they said they had to attend a meeting to make important decisions. Result: two new honorary freemen of Ponza that evening take a well-earned rest.

The following day, on board the *Tenace*, we left the island. The municipality presented us with the sword of a swordfish as a souvenir: this trophy worthy of a museum of natural history had been brought back from the Red Sea by a Ponza fisherman.

The *Tenace* was now running along the Island of Ischia: there it was that my son, with de Sanctis, carried out the intended dive to 357 fathoms. 'So as not to lose the habit!' he said. This trial made a much greater impression upon me than the descents in which I myself took part. For this once I had to give up my place in the bathyscaphe, as the cabin would be very small for three people plus a 35-mm. cine-camera. I was present at the series of preparatory operations: up till then I had known them only by having heard the orders given through the telephone.

When everything was ready, the sluices of the air tanks were opened, and the bathyscaphe sank. The tower was halfway in when the two last sailors who had been handling her plunged into the water and swam back to the tug. The aerial, then the two flags which float at the masthead, sank in their turn. The *Tenace* and the *Fenice* moved away.

The place chosen, situated to the south of Ischia, is off the sea routes: but the wind and the currents carried us away towards the island. Scarcely had the *Trieste* disappeared, when vessels appeared on both sides. At full speed, the *Fenice* went to meet them to ask them to withdraw.

At last, in the distance, the *Trieste* emerged. But why was the flagstaff bent? Why did the deck rise higher than usual? When they emerged, my son and de Sanctis told us what had happened. During the descent all had gone forward according to programme and the bathyscaphe landed gently on the bottom at 357 fathoms. But during the ascent, a suffocating gas had invaded the cabin.

Jacques knew what had to be done. If sea water enters one of the cases containing the accumulators, chlorine is released. Several submarine crews have been victims of this toxic gas. Although he could not detect any leak of water, he decided to ascend as quickly as possible. He grasped the handle of the switch: all the ballast fell out and the *Trieste* rose at full speed: her rate of ascent exceeded the critical speed of which we have spoken (page 122). Without a parachute, the bathyscaphe was violently shaken: the amplitude of the oscillations reached 45°.

In 1948, near the Cape Verde Islands, when the automatic pilot started off the general unballasting at 789 fathoms, the same thing happened to the *FNRS 2*, and the radar aerial was broken. Today the *Trieste*'s flagstaff was bent, a proof of the violence of the oscillations. Fortunately, being made of soft aluminium, it did not break, otherwise we should have lost the two flags. Up to now they had accompanied us in all our dives, folded and put away in the cabin. But today, for the last descent of the year, we had hoisted them to the masthead.

A minute inspection of the cabin did not explain the release of the gas. We supposed that the camera was responsible for it. Its electric motor functioned badly. It is probable that, following upon a short-circuit, one of its insulating materials was overheated and the decomposition of the synthetic resin gave off the suffocating gas. In the restricted space of the cabin, a very little thing is enough to poison the air. At the moment of the accident, a tape recorder was functioning. We could hear on it, distinctly, the panting breaths of my son and de Sanctis.

All's well that ends well!

Taken in tow by the *Tenace*, the *Trieste* came back to Castellammare: the sea was calm, and as it was the last tow, we put on speed. At 6 knots the *Trieste* behaved magnificently, thanks to the new keel. Night had already fallen when we arrived at Castellammare: illuminated boats came to meet us and fireworks lit up the sky. A great part of the personnel of the 'Navalmeccanica' was there to welcome us. The little town was *en fête*: the bathyscaphe, in whose construction the population took so large a part, had come back to its home port.

During the following days the municipality organized a reception, presented us with a diploma as honorary freemen, and then gave a procession in the streets of the town.

Soon we returned to Switzerland and our village of Chexbres, above the Lake of Geneva, on the verge of the Vaudois vineyards. There too a warm welcome awaited us, and we were surprised to see our syndic, our pastor and the whole council of the commune, with a gendarme and a horticulturist in their company, assemble before our villa and present me with a beautiful blue cedar. We planted the tree. It bears a plaque in memory of the 30th September 1953, a touching mark of esteem from our friends of Chexbres.

Here we are now in the spring of 1954. The *Trieste* slept all the winter in the yards of Castellammare di Stabia. It is not that she lacked the will to travel. But to take in hand the improvements which alone would justify new dives, the money contributed was still insufficient. Our wish, that of my son as well as my own, was to go back to our work again as soon as possible and to put our bathyscaphe at the disposal of oceanographers and all scientists who were interested in it.*

* In Autumn 1954 my son made some dives with various scientists.

PART THREE

IN THE FUTURE

1: *What the dolphin taught us*

ALL those who sail the Atlantic have seen schools of dolphins frolicking near their ship. They dive and emerge: you would think they were at play. Then, disappearing, they swim towards the ship. From high on the bow, one can see them shooting along just under the surface. Before the stempost, leading the ship by only a few yards, they glide along, side by side, far enough away for the water not to be churned by the ship. One thing struck us immediately: to swim at the speed of the *Scaldis* they did not seem to make the slightest effort. Now we were moving at 10 knots. Even if the speed were double or treble that, the sailors told me, the dolphins would still escort us without difficulty. Their movements were barely perceptible: although they were swimming near the surface, they did not produce any waves. This proves that the energy developed by them is very slight: they therefore must have a very efficient hydrodynamic shape.

We know that every body which moves in water must overcome a certain resistance. The energy necessary, in general, increases with the square of the speed. Most of the energy expended is lost in the waves produced.

An experiment is called for: if one makes a model, in paraffin wax for example, having exactly the shape of the dolphin, and it is towed through water by means of a thread, one might expect that this model too would move without resistance and without causing waves. But this is not the case. The resistance met is considerable, and waves are produced. The waves and the eddies show us where the energy transmitted by our thread goes and is lost. Have we not copied our living model with enough care, the slim body ending in a fish-tail? That is not the trouble. All attempts made to copy the best swimmers, as for example the trout, have given the same result: but the trout has the same skill and can move near the surface without producing a furrow. But the phenomenon is easier to observe in the dolphin, which has the curious habit of going ahead of a ship. What then is the secret and the exact mechanism of the displacement of these swimmers?

Let us observe a little more closely what happens when any body is moved through the water. It is not certain that eddies should form at any given instant or specified place. But the smallest of them, still in an embryonic state, has the ability to develop and to grow. The water alongside the ship is thus in an unstable condition. In order to understand what we mean by that, let us study a little more closely an experiment that everyone is familiar with.

Let us place a long cane vertically on its point. We know that necessarily it will not be long before it falls: and it will fall in that direction in which it was originally leaning. If we had been able to place its centre of gravity exactly above the point of rest it would remain upright indefinitely. We know that it is impossible to reach this perfect position of equilibrium. The slightest initial eccentricity increases rapidly, like an avalanche rushing down a mountain.

Nevertheless, we can see in any circus a juggler maintaining in perfect immobility a long cane at the end of his finger. Perfect immobility? If we look closely we shall observe that his hand is continually making little movements. It is evident that these motions compensate all the while the slightest defects of equilibrium. Each of us could, with some training, repeat the experiment with more or less success.

What the juggler does with his cane the dolphin does with the water. An eddy is forming and tends to develop and grow, but the dolphin intervenes. A very slight movement on his part is sufficient to arrange things. A fraction of a second later this would be impossible: the eddy would have grown and would have become unmanageable. The analogy is perfect: if the juggler had waited till the rod leaned too far in one direction, he could not have brought it back to equilibrium.

We begin to see the dolphin's secret. He must have under the skin nerves of an extreme sensitivity, which act like pressure gauges, and by means of which he perceives the slightest sign of a developing eddy. Then, with a well-timed movement of his skin, he neutralizes the scarcely-formed eddy. Thin currents of water glide along his body and collect again behind him. The pressure which, necessarily, is exerted upon his head is compensated by that produced by the thin currents of water produced at his tail. Porpoises, dolphins and trout do not know the theory that we have just explained. Reflexes and instinct with them take the place of higher mathematics.

Can the naval designer draw any practical conclusions from the teachings of the dolphin? I am tempted to reply in the affirmative.

A transatlantic steamer when moving expends a force of some tens of thousands of horse-power which is pure waste: we can easily see where this energy is going. Indeed, if at the bow the currents of water separate in reasonably good order to allow the hull to pass, they are joined together again behind in great disorder and the course of the ship is marked across miles of ocean by the swirling of waters it has produced.

Are these eddies inevitable? The water currents could, however, if they really wanted to, join up again behind the ship according to the same laws that they observed when separating. Here is a magnificent field for research for the naval engineer. To copy the dolphin, there is a problem which is simple to propound. The solution is perhaps difficult to find, but it is probably not impossible.

I could imagine, for example, a ship, the hull of which would be covered with a rubber membrane, under which a great number of pressure gauges would be disposed. The slightest eddy at its origin would affect these instruments. This perception is transformed into electric current and transmitted to a central station, the electronic brain of the ship which analyses all these impulses and determines the movement which the 'skin' of the ship must be made to execute in order to cancel the slightest eddy at its origin. To determine what is to be done is the most delicate part of the problem. For, once this is solved, the electronic brain will be able, without difficulty, to send out electric currents of suitable force to little electro-magnets disposed in great numbers between the pressure gauges, in such a way as to produce well-organized reactions in the 'skin' of the ship.

In practice should we begin our trials with a surface ship or a submarine? I should choose the submarine without hesitation. In fact the surface-frontier between air and water presents great difficulties, difficulties that even the dolphin has not been able to surmount. We see the dolphin moving majestically along in front of our ship just below the surface. We observe the slow movements of his flippers and the delicate wrinklings, apparently unsystematic, of his skin: we know that it is these last which prevent the eddies. But the dolphin is a mammal: from time to time he must put his nostrils out of the water to breathe. Immediately something goes wrong: the system is disordered; there are showers of spray; the water swirls round the animal. What energy is dissipated! But an instant later the dolphin masters the situation, and once more we see him glide through the water in perfect calm. It is therefore the submarine that we should choose for our first attempts.

For the moment, let us give our imagination free rein. This is what Captain Nemo will invent tomorrow.

We are at Le Havre. The *Dolphin*, the first submersible passenger-ship, is at the wharf, ready to get under way for her inaugural voyage. She is going to cross the Atlantic. The passengers are moving about in the saloons and cabins. We cast off: a slight rolling is felt. The weather forecast is not very reassuring. A timid passenger is wondering how he is going to stand the pitching and swell on the high seas. The steward guesses how he is feeling.

'Don't worry, you'll feel absolutely nothing. At the moment we are being towed out of port . . . we are diving now. Look at this pressure gauge: we are already 27 fathoms down. Do you feel the slightest movement?'

'No, indeed, it's absolutely calm.'

'This calm will last until we reach the roads outside New York. Here is the tachometer. You can see that we are going along at 60 knots.'

'How is it possible? To get up such a speed you would need an engine of enormous power. Your rates are lower than those of ordinary steamers.'

'It's natural that we can give you rates lower than those of our competitors. The *Dolphin* has a low-powered engine and besides it can make two crossings while the others are making only one. And finally, since our trip does not even last two days, our passengers do not require so much comfort as on a *de luxe* steamer. We have neither a solarium nor a bathing pool.'

'But this crossing must be very dangerous. We might run into a naval submarine whose time-table is unknown to you.'

'Do you see this luminous screen?'

'Is it a television screen?'

'No, it is an echo sounder. You know that radar cannot be used under water. But because of the ultrasonic waves which we emit, each ship—by reflecting them—here shows itself by a white spot, and that happens as soon as it is less than 3 miles from us. We can determine its exact situation by the position of the white spot on the screen. And here, you see, the distance that separates us from the bottom of the sea is continuously indicated. Thus you need have no fear of any unpleasant encounters.'

'It's really marvellous. But one word more about the engine. You told me that it was quite small, and yet you mentioned a speed of 60 knots.'

The two move to the other side of the control-room.

'Here it is.'

'But it's a toy! And what is in this locker?'

'It is our electronic brain. It neutralizes, at the very moment of their origin, all the eddies which may arise all along the hull, so that the resistance we produce is almost nil. And so this little engine is more than able to maintain our 60 knots.'

'All that is impressive, really superhuman. Who invented this miracle?'

'In the grand saloon you have no doubt noticed a marine painting showing a dolphin cutting through the waves. It was under his direction that our engineers designed this new submarine which bears his name.'

2: *The Mesoscaphe, the Submarine Helicopter*

It is very natural that oceanographers should want to extend their investigations to yet greater marine depths. There is no question here of a 'records psychosis': they simply want to know *all* about the sea. The bathyscaphes *FNRS 3* and *Trieste*, when they gave access to depths of two or three miles, gave the oceanographers means of exploration unknown up to this day. With relatively simple changes, it would be possible even to build bathyscaphes which would be able to go down to six miles or more, thus to reach the bottom of the deepest trenches known.

But as an old proverb says, why shoot sparrows with cannon? There is still much to be discovered in the first two miles of the ocean depths. If we do not want to go any deeper, is it really necessary to build a bathyscaphe endowed with a heavy cabin and with a float which must be filled with petrol, or even a bathysphere sustained by a cable?

We are obliged to have the cabin if we wish to go down deeper than the several tens of yards accessible to the free diver: that's clear. But if the object of our researches is limited to the first 1000 fathoms of sea depth, the pressures ruling in this zone can be borne by a less strong, and therefore a lighter, cabin than those of the *FNRS 2*, the *FNRS 3* or the *Trieste*. And if the cabin with all its contents is made lighter than water, our apparatus can sustain itself without using the float of the bathyscaphe or the cable of the bathysphere: it will even be necessary to provide it with an arrangement so that it can sink in the water.

To a machine of this sort, suitable for medium depths, I should like to give the name of mesoscaphe.[1]

In its own kingdom the mesoscaphe should be as mobile as possible. It must above all be capable of going up and down a great number of times under its own power. One could, obviously, give it a small tank of petrol and of releasable ballast, in this imitating the old free balloon and the bathyscaphe. But we can do better: let us give up the petrol entirely. Let us poise or equilibrate the mesoscaphe in such a way as to make it a little lighter than the water displaced and provide it with a large propeller with a vertical axis of rotation corresponding

[1] From the Greek *mesos*: middle; *scaphos*: ship.

to the main rotor of a helicopter, which will communicate to it a vertical force directed downwards. Thus our mesoscaphe will be a *true helicopter* in reverse. It will go down under the power of its propeller. It will reach equilibrium somewhere near the bottom by decreasing the speed of rotation of its propeller and, so as to rise slowly, it will be enough for it to stop its motor.

To avoid the situation where the reaction of the propeller would make the mesoscaphe turn round on its own axis, we could provide it with two helicopter propellers turning in opposite directions in the style of the large aerial helicopters. I think, however, that it would be better to give it, like the bathyscaphes, two small lateral propellers with horizontal axes, turning normally in opposite directions and balancing the torque of the large propeller. By regulating the speed of rotation of the two small screws, the pilot will be able to steer his ship and move it in all horizontal directions.

Since the large propeller does not support the apparatus but gives it the power of sinking, a breakdown of the motor would be without serious consequences: it would automatically bring the mesoscaphe back to the surface.

However, if the particular aim is to explore the sea-bottom, there is nothing to prevent us economizing our electrical energy during the descent and even going down much faster than the propeller is capable of. For this purpose we shall put aboard our little submarine some releasable ballast, just as is done for its big brothers the bathyscaphes.

As the cabin by itself shows much less resistance to the water than the float of the bathyscaphe, it will be enough to have at our disposal a relatively small quantity of ballast. As it approaches the bottom, the pilot will throw overboard only a portion of the ballast, so as to stabilize his machine as exactly as possible. The vertical manœuvres during observations could then be conducted with a very small consumption of electrical power by the large propeller. For the return journey it will be possible to throw all the ballast overboard, in order to go up very quickly.

The entire mesoscaphe, fully equipped, would weigh about 5 tons. Any little cargo-steamer would then be able to transport it easily, to launch it and take it back on board, which would very much reduce the cost of operation in comparison with the expenses of an expedition with the bathyscaphe.

As for the cabin, it could be made of steel like that of the bathyscaphes, perhaps also in a light alloy of aluminium magnesium. This would be easy to calculate. But it would be very much better to build it entirely in transparent plexiglas. This material is less strong than steel, and we should thus have to give a greater thickness to the walls. But plexiglas is lighter than steel: its specific gravity is only 1·19. 100 cu. in. of plexiglas in sea water weighs only ·607 lb., while that amount of steel weighs 24·59 lb.

Such a cabin, built to go down to 1100 fathoms, would have greater static lift than a steel cabin of the same strength and the same internal diameter. It would be able to carry a more powerful engine and battery of accumulators than the metallic cabin.

But—and this is the most important thing—being as transparent as the best glass, it would present a wonderful panoramic view to the observers. The observer would no longer be obliged to fix his eye to a little porthole from which he can see only a small part of his environment. He would live in the middle of the sea, and be able to let his glance rove in all directions like the free diver, the frogman. The mere thought of such a dive stimulates the imagination. What will the realization be like?

Here a few technical questions arise. Would not our vision be distorted by the refraction of the water and the plexiglas? The answer is simple: the water would become like a concave lens, and the eye applied to the wall of the cabin would become slightly long-sighted. An eyeglass of a dioptric third would be enough to make the necessary correction. If one moved away from the wall, certain distortions of vision would be produced. But these would not be disagreeable. In the antechamber of the *Trieste* we looked out (at shallow depths) through the large round window in plexiglas, the curvature of this window being double that of the cabin. Objects naturally appeared shrunken in the horizontal direction, but this deformation was practically unnoticeable.

To calculate the strength of a plexiglas cabin is not easy, as this material safely sustains slight deformations beyond its elastic limit (which is, moreover, a great advantage in our case). It would be necessary, before having the real cabin built, to proceed to numerous tests with models subjected to high pressures. It is only after these laboratory researches that we should be able definitely to settle the depth possible to be reached and the thickness required for the walls of the cabin.

Finally, the question of the possibility of its construction would have to be examined closely. It would probably be impossible to run it off in two large hemispheres, as I had done for the cabin which is in use at the moment in the *FNRS 3*. In this case the cabin would be subdivided into a larger number of pieces. It would be possible, for example, to replace the two hemispheres by twelve-twelfths of a sphere, all exactly equal and glued or welded together. Their contours would be the central projection on the sphere of the twelve pentagons of a regular dodecahedron. The thirty joints would be flat surfaces.

In these conditions the joints between the twelve spherical pentagons would in no way decrease the strength of the cabin. The manhole would be conical, cut in one of these twelve pieces. It would be closed by a door likewise in the form of a truncated cone: this door, being in plexiglas, would in no way decrease the strength of the cabin.

Another solution should also be considered: to construct the sphere of a great number of rings stuck together. This construction would naturally be simpler. However, the joints between the rings, this time subjected to shearing, would have to be perfect in quality.

All things considered, the mesoscaphe, like the bathyscaphe, would be entirely safe. Its scientific operation would be less expensive than that of the bathyscaphes, and would give better results down to those depths to which the strength of the plexiglas would allow it to descend.

If circumstances, financial and otherwise, do not permit me to construct this new apparatus myself, I hope that some day someone will be found to take my project in hand and bring it to a happy conclusion.

3: The Oceanography of Tomorrow

It was the stratospheric balloon which first of all made possible the study of cosmic rays at a great altitude. The progress of automatic apparatus, however, in particular those in the electronic sphere, is such today that sounding-balloons replace direct observations in the high atmosphere.

Some realms of observation of which we have spoken are, however, reserved to the manned balloon, especially when it is a question of astronomical observations where an instrument must be pointed towards a heavenly body.

We note the same evolution in connection with the observation of great depths. Cameras, automatically operated, are sent down which take, at random, thousands of photographs in the course of a single dive. The waste of film is enormous, but if, all things considered, one photograph in a thousand is usable, it costs less than if one had taken it in a bathyscaphe.

There is also submarine television: the observer, installed in a boat, then follows upon an electronic screen the scenes which the apparatus, suspended to a cable, transmits from the bottom: when an interesting scene appears, the simple release of a catch, worked on the boat, is enough to set the cine-camera going.

The realm to be studied is so vast and so thrilling that these instruments promise us a fascinating harvest. But no automaton will replace the bathyscaphe when it is important to study carefully a particular object. It alone can move about in such a way as to photograph whatever the navigator may have discovered from the best angle and in the most favourable conditions.

There is also a group of observations which completely escapes the photographic eye: that is the study of the faint lights produced by the phosphorescent animals and vegetation. Astronomers well know that the heavenly bodies producing the least light are visible only to the camera and then only during very long exposures of the film. Very often the photographic telescope must follow a region of the sky for hours, and even for nights, for the feeble light rays from a distant star to be added together upon the photographic plate. Our retina, on the contrary, has a short memory: if it adds up luminous impressions, it is only during fractions of a second. If a phenomenon lasts only a short time, the eye is thus much more sensitive than the film. Let us give as an example the shooting stars, which must be studied entirely by the eye. Only the brightest can be photographed.

The same thing is true of the phosphorescent submarine animals. We have to see them ourselves: to take instantaneous exposures they are not luminous enough, and for time exposures they are too mobile.

Why are these animals phosphorescent? Why have some of them veritable headlights? Is it to see their prey? Is it to frighten off their enemies? To blind them? Is it to recognize each other, as our glow-worms do? It is possible, too, that a part of these phosphorescences are of no use at all, that they are simple consequences of chemical reactions which accompany certain vital processes. If we take a walk, after rain on a warm summer night, in our forests we sometimes find pieces of rotten wood which emit a faint light, engendered by the mycelium of certain fungi: no one would think that these bits of wood or their guests have any purpose in this.

So many questions, so many mysteries. It is only by going down ourselves to the depths of the sea that we can hope to clear them up.

Let no one say that these observations are purposeless. No one can foresee the resources that future generations will find in the ocean. Let us remember, for example, that nature took millions of years to decompose the organic matter of the marine sediments and make petrol of it: did high pressures play a part in these reactions? Will industry ever come to speed them up to such a point that, instead of looking for petrol, we shall be able to make it?

The organic matter formed annually in the seas is doubtless a multiple of what agriculture produces over the entire earth. It is not impossible that one day we shall find in the sea the food that the fields can no longer furnish us with. Already today entire populations live from fishing. But perhaps by using the plankton more directly—algæ, diatoms and minute crustaceans—humanity will find enormous resources in the seas, which cover three-quarters of the globe.

Throughout this field of exploration it is oceanography which will guide humanity. How is that to be? I cannot say. But the fact has been proved many times already: all scientific research sooner or later bears fruit.

PART FOUR

TECHNICAL APPENDICES

Appendix 1

Strength Tests made on Model Portholes

OUR portholes are made of pieces of plexiglas in the form of truncated cones, of which the apex angle is 90°, as is shown in the section represented in Fig. 15. The conic surface rests in a socket of the same form, machined for one of the portholes in the wall of the cabin and for the other in the circular hatch of the manhole (see sketch of the cabin, page 43). The pressure of the sea acts upon the large end of the piece formed as a truncated cone and pushes it towards its seating. The watertightness thus produced is perfect, as has been demonstrated in all our tests with the model. As a measure of precaution, we have also added to the portholes of the bathyscaphes rubber rings, placed on the outside upon the joint, according to the principle of the autoclave.

The mathematical analysis of the distribution of stresses of such a component would perhaps be possible, if its material were perfectly elastic, but I think it would still be very difficult. But it is probable that the plexiglas will be loaded in places beyond its limit of elasticity: a deformation not proportional to the stress, that is, the plastic deformation of the material, will then play an important part in its behaviour under stress. This is, in my opinion, the reason the portholes in plexiglas have given much better results than glass portholes. In these conditions we cannot think of approaching the problem by theory. Here we are in the presence of one of those instances where only laboratory experiment will be able to inform us.

Let d be the diameter of the interior face of the porthole (therefore the small face) and h the thickness of the porthole. We know that the resistance of such a piece to the pressure of a liquid depends solely upon the proportion $\frac{d}{h}$, and that it is independent of the absolute size of the piece. We can therefore proceed to strength tests on small models, which is important in view of the considerable expense which would be involved in tests made on full-size pieces.

The graph in Fig. 15 gives a general idea of our tests. From left to right there is recorded the relation $\frac{d}{h}$ of different models. The bigger it is, the greater the stress it will experience for a given pressure. From bottom to top are recorded the pressures applied during each of the tests. Each of these tests is shown by a cross. Underneath the lower curve is to be found the zone within which all the models resisted the pressures applied without sustaining permanent deformation. Cross No. 2 represents a test lasting eight hours, cross No. 3 one lasting

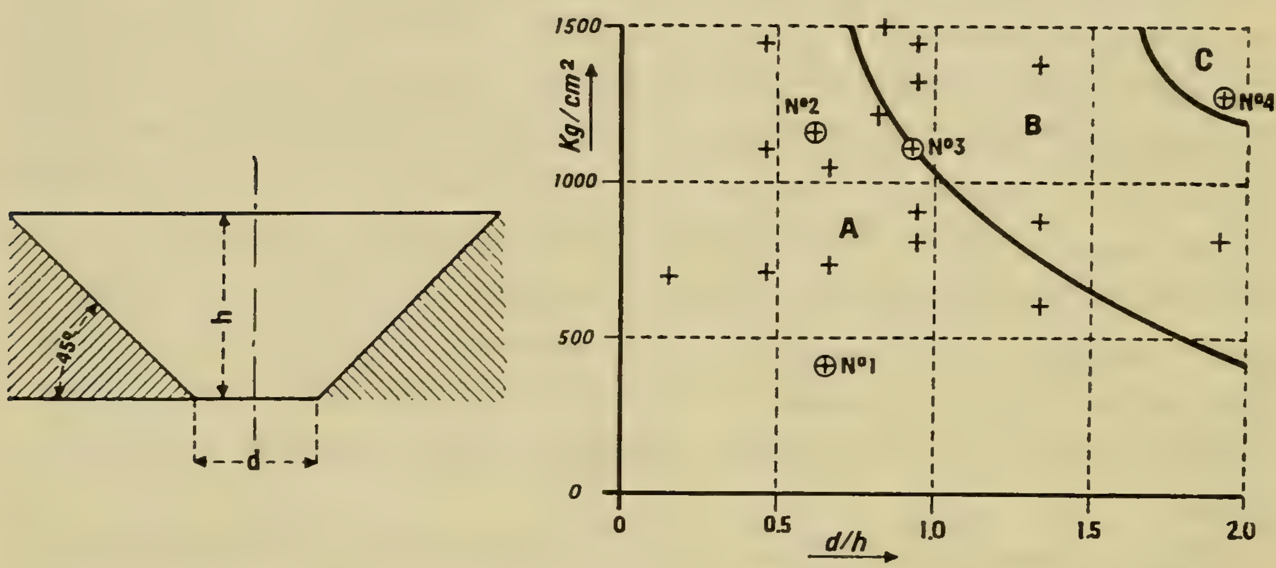


FIG. 15. Diagram of strength tests made on model portholes

eighteen hours. The other tests made were of shorter duration. Between the two curves is to be found the zone where the plexiglas sustained permanent deformations more or less considerable, but without ever having been broken, thus without ever having let a drop of liquid pass through. Experiment No. 4 alone, recorded above the second curve, resulted in the destruction of the model. There is no question in this case of the plexiglas having been defective. It was the conical hole in the steel plate which splayed on the side where there was low pressure and in these conditions it is clear that the plexiglas could no longer resist. The conical socket had been machined in a plate of mild steel much softer than the special steel of our cabins. As this breakage took place under a load of 1270 atmospheres (corresponding to a depth in the sea of more than 7·4 miles), this test was very reassuring. The interior diameter of this model was twice as great as its thickness. For the portholes of the bathyscaphe *FNRS 2* I chose an interior diameter which was only two-thirds of the thickness. Cross No. 1 is the record of one of these portholes under a load of 2·5 miles of water. It may be concluded from these tests, and from a glance at our diagram, that the portholes of the *Trieste* and of the *FNRS 3* offer complete safety at the depths for which our bathyscaphes have been designed. It would be interesting to know the pressure at which our portholes would be driven in. As long as tests have not been made for pressures much greater than 1600 atmospheres, an exact answer cannot be given to this question. By roughly extrapolating the results shown by our diagram I think that it would be only at depths exceeding 12 miles that our plexiglas would show a permanent deformation. Breakage would only occur at much greater depths, and there is no part of the ocean depths known to exceed about 7 miles.

It goes without saying that our tests with models are only conclusive upon condition that the material of the real portholes has the same mechanical properties as that of the models. Now the models were cast in one piece. For the fabrication of the portholes it was necessary, in order to avoid excessive heating at the moment of the polymerization of the methacrylate, successively to cast several layers of the raw material one upon the other. We made sure that this procedure was equivalent to that of casting a single piece by cutting small test pieces out of the material removed during the machining of the large portholes by the Vetrocoke Company. The tensile tests effected, for example, with test pieces whose direction of loading was at an angle of 45° with the layers, have shown that the bonding between these layers was perfect.

To conclude this survey, let us mention one more interesting fact: if a piece of plexiglas is overloaded, its whole mass becomes cloudy; if the overload has not been too great, this cloudiness will disappear with the load. If, on the contrary, the piece has been greatly overloaded, the cloudiness will persist, even after the load has been released. It is unnecessary to say that in our real portholes we have never observed the formation of the faintest cloudiness. This is one more reason for our confidence.

Appendix 2

Magnetic Valves and Electro-magnets

The ballast of the *Trieste* is composed of cast-iron pellets. It has the appearance of small, rather regular balls of a diameter of $\frac{1}{10}$ in., and is obtained, in the same way as bird-shot, by the cooling of a shower of molten metal (see Plate X). It is contained in two sheet-metal tubs with funnel-shaped bases. The piping of this funnel is narrower at one place and the lower tube is surrounded by a coil. Fig. 16 gives a diagrammatic view of the valve, where the coil is represented simply by three turns of a cable. Fig. 17 gives a cross-section of the valve in more

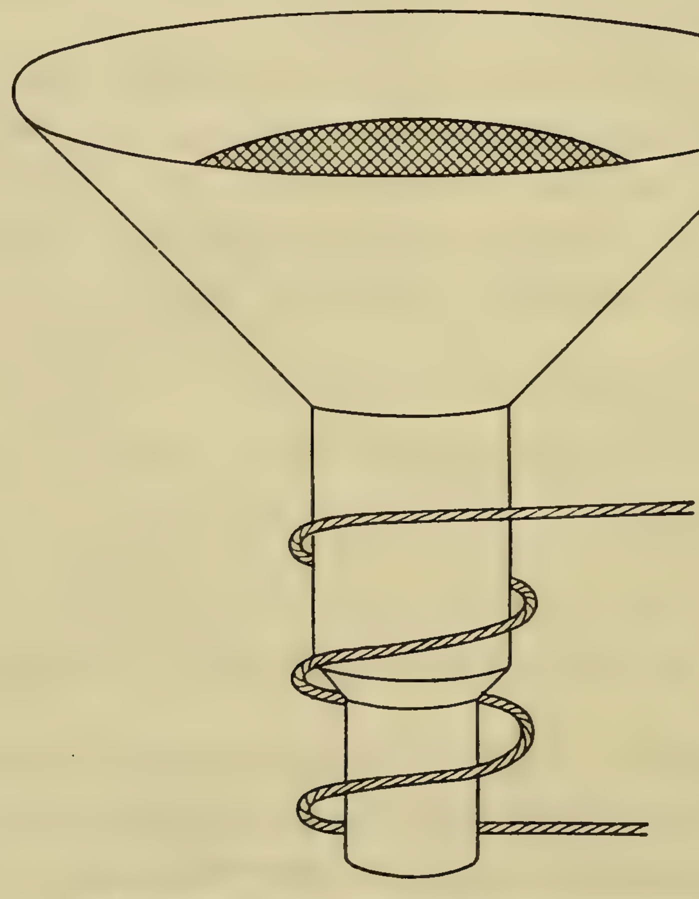


FIG. 16. Diagram of the magnetic valve

detail. As long as an electric current runs through the coil *d*, the iron-shot is magnetized just where the tube narrows. In this way it is transformed into a more or less rigid mass which acts as a plug. Thus the pellets cannot flow away. As soon as the current is cut, the pellets are demagnetized and flow like sand in an egg-timer. It is enough to switch on the current to stop the flow at once. It is clear that the principle is very simple.

There is always the danger of the current being cut off, by either a short-circuit or a poor contact, but in our case this would not have catastrophic consequences. The ballast would fall out and the bathyscaphe would reach the surface sooner and more rapidly than its occupants would like, but that is all.

To economize the ampere-turns necessary to produce the magnetization, thus to economize the energy in our accumulators, we arranged along the lines of magnetic force of the mild steel *a*, *a*, *a*, in the form of a central tube, two annular plates and an external cylinder. At the point where the central tube narrows, the iron is replaced by a non-magnetic substance *c*, plexiglas or stainless steel. Thus the lines of force, not finding any more solid iron on their route, are obliged to go through the iron pellets, this having a much greater magnetic permeability than the non-magnetic substance, even though less than that of solid iron.

The construction of the coils *d* sets a delicate problem, by the fact that they will be in sea water at high pressure and that all danger of a short-circuit must be avoided. We gave up the idea of protecting the coils by strong steel containers, thus preserving them from external pressure. To give an adequate protection, this construction would have been too expensive, too heavy and too complicated. The whole coil could be placed in an insulating liquid (as we did for the electric motors and for the tachometer, pages 37 and 99). However, we preferred a still simpler construction. The winding is composed of copper wire insulated in polythene. It was naturally necessary that this insulation should not present the slightest defect through the whole extent of the wire. Thanks to the assistance of the Marelli Company of Milan, this condition was completely fulfilled. Thus the sea water could penetrate between the wires of the coil without damage. It is even necessary that it should be able to enter everywhere, because if air remained caught between the turns without the water being able to get to it, the pressure of the water would produce deformations in the winding which, in their turn, would jeopardize the continuity of the insulation. To avoid all danger, while the wire was being wound, we interposed little sheets of celluloid between the layers and upon the side of the coil. Along these pieces of celluloid there remains a little free space through which the water has access to the whole coil.

The whole assembly at no time gave us trouble. It is true that the insulation, to be perfectly safe, must be rather thick, which decreases the area that the copper may occupy. It results in a greater consumption of electrical energy than would have been needed with simple cotton insulation.

This valve requires, it is easy to see, a greater number of ampere-turns to stop the flowing out of the ballast once it has started than to hold it in position. In order to economize the energy of our accumulators, we can carry on with a retaining current which is only half the current employed to stop the outflow. With this in view, the

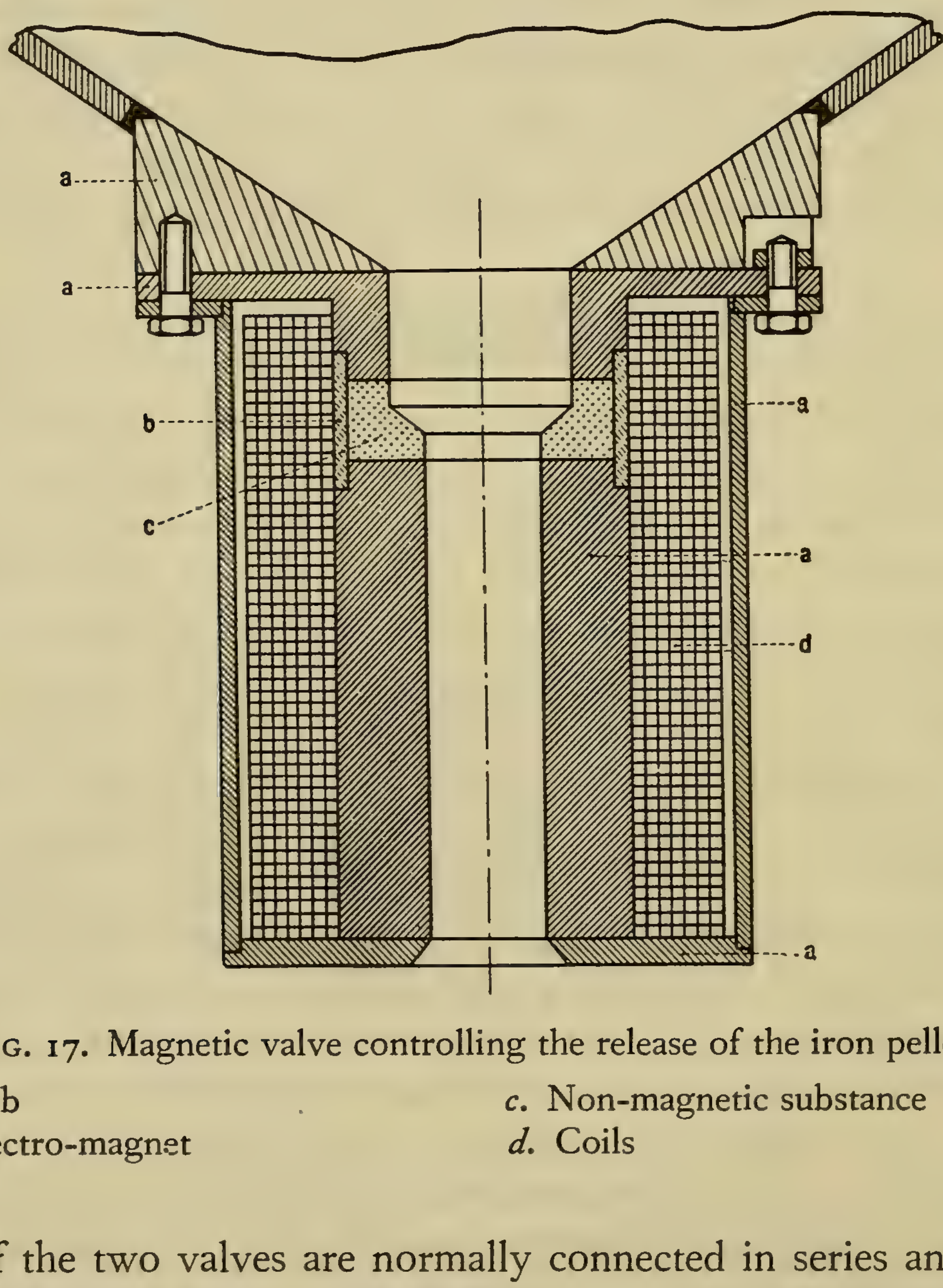


FIG. 17. Magnetic valve controlling the release of the iron pellets

a. Tub
b. Electro-magnet
c. Non-magnetic substance
d. Coils

coils of the two valves are normally connected in series and only in parallel during a few seconds at the moment when the pilot wants to stop the outflow of ballast.

We give here some numerical data concerning the unballasting of the *Trieste*. Two ballast tubs, each of which weighs a ton when empty. Contents of each tub: 4·5 tons of iron pellets. Diameter of the outlet pipe below the narrowing: 1·57 in. Rate of outflow: almost 110 lb. per minute for each valve (in Plate XVIII the outflowing can be seen). Power consumed by the coil: 3·6 watts when idle and 14·4 watts at the moment when the outflow is stopped. In the cabin a rotary switch is arranged in such a way that one can, at will, cause one or other of the two valves to open.

While the bathyscaphe is on the surface we do not want to use up the electrical energy unnecessarily. A diver therefore goes down to close the mouths of the valve mechanically, by means of a plug. Removal of this plug, however, is achieved from the deck before each dive, by releasing the retaining cable. Later an arrangement was worked out which permitted the closing and opening of the tubing with more ease and without the services of a diver.

These valves function very well. Elementary prudence, however, demands that we should envisage the possibility of an obstruction. There are indeed different possible causes of a stoppage. If the pellets rust, they can be transformed into a compact mass, which will prevent all outflow. Very fortunately iron pellets practically do not rust under water. Even after having remained for months in sea water, they are perfectly fluid. If a little oxide is formed, it does not induce caking. But it is quite otherwise if wet iron pellets are exposed to the air, because then they are capable of solidifying within a few hours.

The danger of rust does not appear very serious, but as the phenomena we observe are, in spite of everything, a little mysterious, this danger must not be considered as non-existent. Another sort of stoppage could occur, naturally, if by accident a foreign body, a bit of sacking, for example, were introduced into the ballast tub. Finally, if the bathyscaphe drove very deeply into the mud, the outlet mouth could be obstructed.

Although all these causes of stoppage may be rather unlikely, we must find a way to save the bathyscaphe, even if the two valves should become blocked. That is why we installed a device which allows us to throw overboard both tubs together with their contents. Here is how this operation could be done reliably.

Each tub is suspended by a chain under the float in a seating of the latter (see Plate VI). This chain passes up through a tube which traverses the entire float and reaches the deck of the bathyscaphe, where it is attached to a hook and lever system. The lever is held by an electro-magnet, in such a way that the hook releases the chain as soon as the current to the electro-magnet is cut. Here, once more, a failure of electric current would not be catastrophic, although it would lead to the loss of the tubs and the magnetic valves. The bathyscaphe would go up again at full speed, but without the occupants being exposed to the slightest risk.

Fig. 18 explains the apparatus which, on deck, holds the chain: its last link, of a special form, is hooked to the extremity E of the small arm of the lever EACD. It cannot slide towards the left and release itself because the fixed hook J stops it from escaping. The lever is held

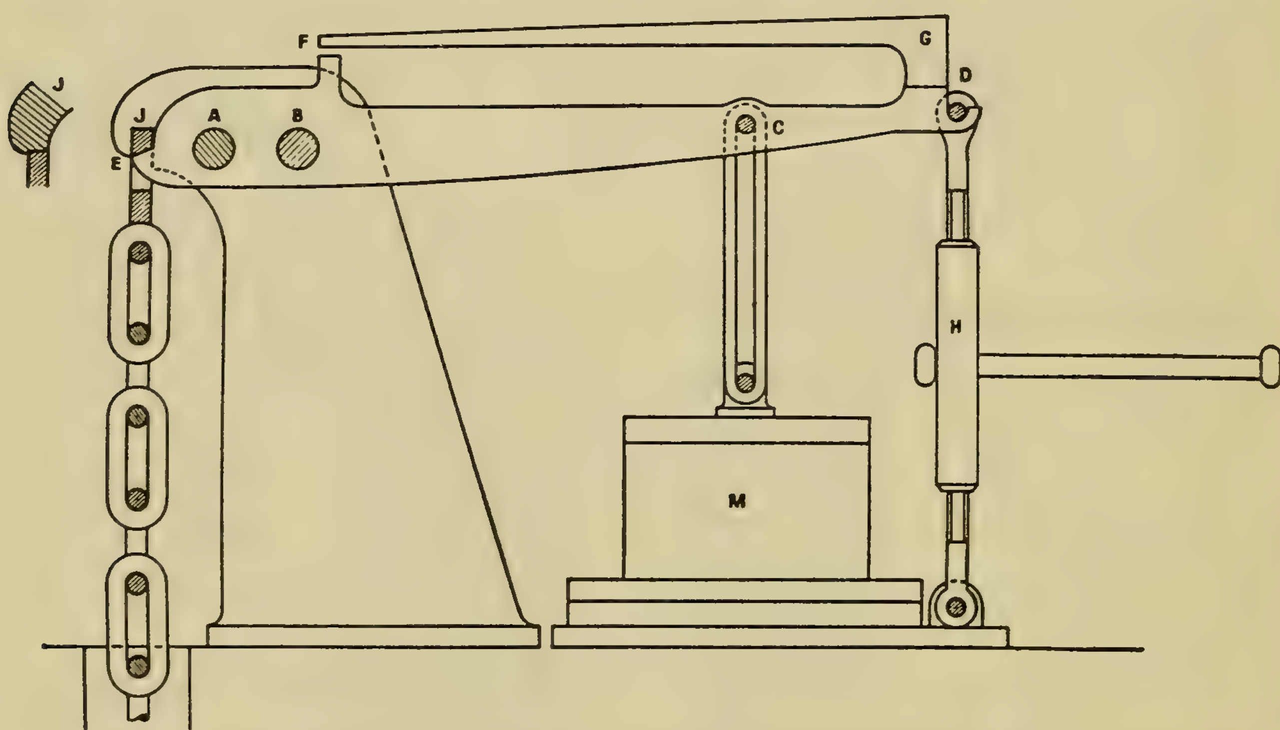


FIG. 18. Diagram of lever supporting the ballast tub

by the electro-magnet M. As soon as this magnet lets go, the lever pivots around its axis A and the chain is released.

Upon the surface we can, in order to economize the electric current, lock the lever either by means of a pin B or by means of the turnbuckle H. The reason for this double locking is that if it is the pin which retains the lever and if the electro-magnet does not work, the whole right arm of the lever is entirely unloaded.

On the other hand, if the turnbuckle is brought into action and the pin is removed, then the lever is subjected to the effect of the load and deflects slightly. The left extremity of the arm FG then moves away slightly from the lever. This movement can be easily measured by means of a little graduated wedge. Since the elastic deformation of the lever is proportionate to its load, our lever plays the part of a dynamometer. It thus permits us to measure the quantity of ballast which is within the tub. The precision of this measurement is not great, a ton inducing a variation of only $\frac{1}{25}$ in. But that is sufficient, because if, after a dive, an error of ± 100 lb. were made in our estimate of the ballast, it would be unimportant. The essential thing is to know, more or less, whether the tubs are full of pellets or not. Let us suppose, indeed, that through a small leak we have lost little by little a large quantity of petrol and that the loss of static lift so produced has been compensated, without our observing it, by our losing bit by bit all the ballast. After a deep dive in these conditions we should not be able to surface again, because we should not have at our disposal sufficient ballast. It is true that the loss of petrol ought to have been perceptible by verifying the level of water in the float, by means of the electric sounder, but a double control is valuable just the same.

May I be permitted here to say a few words on the subject of a system of ballast control by a magnetic sounder such as I had proposed for the *FNRS 3*. A small electro-magnet with a laminated iron case and with an open magnetic circuit shows a certain self-induction. If this magnet were to be plunged into the iron pellets, the magnetic circuit would be closed and its self-induction would considerably increase. If several magnets were disposed through the ballast tank we could easily, by means of a suitable electric instrument mounted in the cabin, determine in the course of a dive the level of the ballast and thus calculate the reserve still at our disposal. This could be very useful.

At the time the *Trieste* was building, I had to do without this measure for the following reason: I wanted it to be possible, in case of the outlet being blocked, for the ballast tubs to be thrown overboard altogether. If we had kept these tubs the shape of a high narrow tank, lodged in the float, the risk would have been, in the case of the bathyscaphe listing heavily, that the tub would have become blocked in its housing as it emerged, due to the leverage exerted by its length. As the necessity for throwing overboard the whole tub occurs above all in case of accident, we had to reckon with the possibility of the bathyscaphe listing heavily. To prevent all possibility of the tubs being stuck in their housings, we had to construct large shallow tubs, having such clearance that, even if inclined at 45° in relation to the float, they could not be jammed. But with this shape the height of the level at any single point would not give the necessary information. We should have had to have a great number of magnetic sounders.

The ideal apparatus for determining the ballast reserve would be a modern electric strain-gauge. The principle of this apparatus is embodied in a constantan wire fixed along a piece of steel. If the steel, when under load, lengthens, the constantan wire is stretched and becomes thinner and its electrical resistance increases. Constantan wires would be affixed along a part of the tub supports. The effect of the thermal expansion of the steel could even be eliminated by using two wires, one placed on the upper part of the lever and the other on the lower part. It would then be necessary to measure the difference between the two resistances. The occupants of the cabin could thus always, by means of a Wheatstone's bridge, determine the weight of the tubs, and therefore the ballast reserve.

Although there are certain difficulties to be overcome, I hope to have the opportunity of working out this apparatus.

The electro-magnet which retains the lever is of conventional form: it is a bell-shaped magnet with its axis vertical. Fig. 19 gives a cross-section of it. One of the two poles is constituted by the central core, the other by a cylinder which surrounds it. Here are the principal dimensions of one of these magnets: diameter of core, 5·25 in.; internal diameter of cylinder, 7·98 in.; external diameter, 9·6 in.; height of core, 5·44 in. The coil *d* is placed between these two pieces. On the lower side, the magnetic circuit is closed by the base plate *f*, to which are attached core and cylinder. The disc-shaped armature is placed upon the magnet. It is upon the ring of this armature that the tractive force operates. We know that if the armature touched the poles of the magnet directly, a great part of the magnetic pull would persist after the current was cut off. The magnet would 'stick' as they say. There must then be maintained between the magnet and the armature a gap called the air-space or air-gap. This air-space yields a 'demagnetizing field' which demagnetizes the iron as soon as the current is cut off from the coil. The weaker the coercive field of the iron, that is to say, the milder it is magnetically, the more the air-space can be decreased without the risk of the magnet sticking.

Also the number of ampere-turns necessary to maintain a certain magnetization in the iron is the greater the larger the air-space, since it is this air-space which produces a field of demagnetization which must be compensated by the field of the coil. It results from what we have just said, that to economize electrical energy the iron of the magnet must be as soft as possible. We were fortunate in that the Falck

Company of Milan furnished us with a remarkably soft iron, the 'Armco' iron of the Armco Company (Genoa). The permanent field of this iron is so weak that an air-space of $\frac{1}{250}$ in. would have sufficed for the permanent magnetism of our magnet to be diminished to an insignificant value, after the current was interrupted. However, as minor deformations are always to be feared, we chose a distance between armature and magnet of $\frac{1}{125}$ in., which makes a total air-space of $\frac{1}{62}$ in.

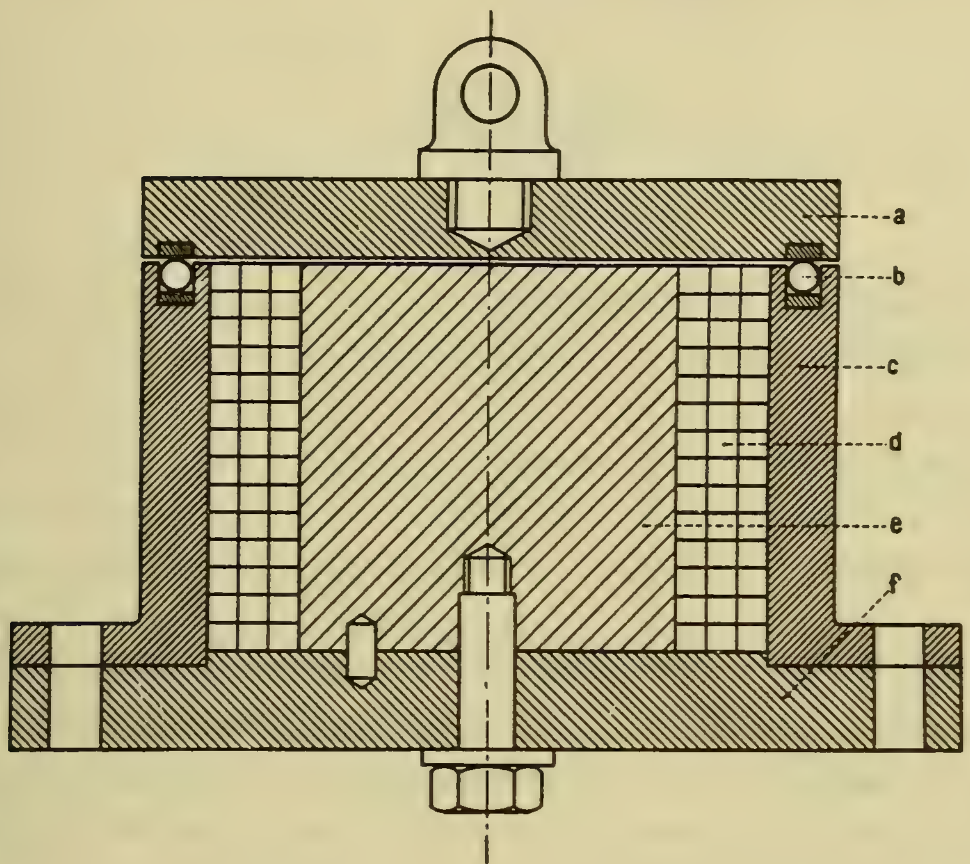


FIG. 19. Electro-magnet holding a ballast tub

To obtain this air-space we placed in sockets made in the upper part of the cylinder six steel balls *b* of $\frac{1}{2}$ in. diameter, which stand out exactly $\frac{1}{125}$ in. When the magnet is energized with the lever disconnected from the tubs each of these balls has a load of 726 lb. So that they will not penetrate the mild steel, small washers of hardened steel are placed above and below the balls. Thus the contact between the armature and the magnet only occurs on six areas of very reduced dimensions. This was necessary to avoid all danger from suction. Before each dive, one checks, by means of a feeler gauge, whether the air-space is still large enough.

Each magnet consumes 36 watts. The attractive force which it exercises upon the armature is 4400 lb. As the mechanical advantage of the lever is in the relation of 1 to 7, it produces a force of 30,800 lb. at the hook. As the tubs full of ballast weigh only 12,100 lb., this force is sufficient to retain them even if the swell produces a certain amount of jarring. Let us here recall that during the towing, when somewhat violent shocks could occur, the position of the levers is assured by the pins (B in the preceding diagram).

The windings of these magnets are insulated according to the same principle as that of the magnetic valves.

Appendix 3

Form of the Float

The naval engineer will be surprised perhaps at the cylindrical form of our float. He would have selected a shape approaching that of the hull of a real ship. Let us observe, however, that the centre of gravity of a ship is generally above the centre of gravity of the water displaced. The stability of the vessel must be obtained by the shape of the hull. This is what is called stability of form, such as we find, for example, if a sheet of cork floats on the water: although the centre of gravity of this sheet of cork is above the level of the water, its stability is perfect. A cylinder, on the other hand, completely submerged, does not possess any stability of form. But if its centre of gravity is considerably below its axis, therefore below the centre of gravity of the displaced water, it is perfectly stable. This is the type of stability which our bathyscaphe makes use of. The heavy cabin will place the centre of gravity of the whole below the axis of the float. In order that the vessel should behave properly when it is on the surface and at sea, the stability thus acquired must naturally not be sacrificed pointlessly by placing too many heavy objects on the deck. Along with other reasons, this is why the ballast receptacles were housed at the bottom of the float.

The cylindrical form has considerable advantages over all others. For a given volume, weight and length, the resistance of a cylinder to buckling is greater than that of a ship's hull. The smaller the radius of curvature of a metal sheet, the more resistant this sheet is to external pressure, and if at any point the radius is large, the rigidity of the whole will be affected: now the cross-section of a cylinder has a smaller radius than the largest radius of the cross-section of any other form of the same capacity. Therefore the cylindrical form is the strongest.

Again, the construction of a hydrodynamic ship's hull costs more than that of a simple cylinder. The plates which are to form the bottom of a ship must be designed individually, and each of them has a different curvature. In our cylindrical hull the sheets, with the exception of the foremost and aftermost, are all of the same form and same curvature.

Appendix 4

Transverse Partitions of the Float

These must meet several requirements:

1. They contribute to the solidity of the hull. Without them, the hull, lifted up at both ends by two waves, could fold like a rubber tube, by flattening in the centre.

2. They must be strong enough to resist variations in pressure if, accidentally, during the decanting of the petrol into the float, one of the compartments were completely filled while its neighbour still held only air.

3. To permit changes of volume of the petrol due to variations of temperature and pressure, without any loss of the precious liquid, the float must contain in its lower part a certain quantity of water. The stability of the bathyscaphe would be poor if this water, heavier than the petrol, could move about freely in the float and accumulate at one of its extremities, thus accentuating any initial disturbance of equilibrium in the machine, however slight.

4. It must be arranged so that if one of the compartments is flooded by water, following a leak, the change of trim which results must not be too great. That is why we have progressively decreased the volume of the compartments situated closer to the extremities.

5. If by ill-luck a leak occurs and one of the compartments is entirely flooded, the loss of the sustaining liquid must be able to be compensated by the unballasting of emergency ballast. Also the minimum quantity of this emergency ballast can be determined if we require that, during an empty test, the bathyscaphe is able to rise even if the cabin has been flooded. If we do not want to exceed this minimum ballast, the maximum volume of a compartment is limited by the condition that this same ballast must be sufficient to save the

bathyscaphe if one of the compartments is entirely flooded by water. These considerations limit the maximum volume of the big compartment to about 460–486 cu. ft.

6. In the tropics the sea can have a surface temperature of 86° F.: at the bottom it may have cooled down to the vicinity of 32° F., on account of currents coming from the arctic regions. If the bathyscaphe descends rapidly to $2\frac{1}{2}$ miles, the petrol, which at the beginning had a temperature of 86° F., will be heated by adiabatic compression by another 18° F.: its temperature will then be in the neighbourhood of 104° F. The hull, on the contrary, will take on, approximately, the temperature of the water outside, because the heat-transfer coefficient between moving water and iron is much greater than the heat-transfer coefficient between motionless hydrocarbon and iron. The partitions, on the contrary, surrounded in all parts by petrol, will take on its temperature. We must then envisage the possibility of a difference in temperature between hull and partitions of 72°. If hull and partitions are rigid, because of this considerable stress would result.

If the hull itself cannot be deformed, the specific pressure in the partitions may be calculated by the formula:

$$\sigma = K \Delta T E$$

where K equals $1{\cdot}1 \times 10^{-5}$/C.°, ΔT equals 40°C. and E equals $31{\cdot}3 \times 10^{6}$lb. per sq. in. which gives

$$\sigma = 13{,}800 \text{ lb. per sq. in.}$$

Although decreased by the elasticity of its hull, this stress would not be negligible, because it is added to other stresses whose absolute value we do not know, particularly constructional stresses.

If the metal sheets were flat, buckling could occur accompanied by a sound very much resembling a breakage. We can imagine the effect that sound would have on an observer. He is bending down to his porthole and is admiring the submarine fauna. Suddenly he hears a crack. He jumps. The pilot only half reassures him when he says that that sound is heard every time a rapid descent is made. (According to newspaper accounts and remarks of one of the passengers of the *FNRS 3*, this cracking really occurs during the dives of this submarine. I attribute it to the fact that, contrary to my recommendations, flat partitions were used in it.)

If the partitions were rendered completely rigid by means of stiffeners the cracking would not occur: but the thermal stresses would not be done away with.

After having studied a whole series of constructions we adopted the following solution, suggested by Mr. Loser: it satisfies all the requirements set out here.

The partitions are made of metal having semicircular corrugations with a radius of curvature of 3·84 in. and with their axes vertical. Thus they provide sufficient resistance to variations in pressure (of which we have spoken). Calculations and tests with models completely reassured us on this point. If we consider a hull with a given circumference but which without too great an effort can become slightly oval, and if we allow the partitions to be rigid in the vertical direction and extensible or contractile in the horizontal direction, it can be seen that we satisfy all requirements. If the temperature of the partitions rises, the vertical diameter of the float will increase, while the horizontal diameter will decrease slightly in such a way as to allow the hull freely to assume a form which suits its circumference and which is determined by its own temperature.

The engineer will understand that our construction is in its main lines isostatic, while with flat partitions it would be very heterostatic.

At first sight it might be feared that our float might not be able to resist bending moments which would act on the horizontal plane. That is not the case, however. The circumference of the hull being given and its vertical diameter being fixed by the corrugated partitions, the horizontal diameter is determined by these two dimensions. Our partitions, although corrugated, prevent all deformation of the hull, as much in the lateral direction as in the vertical direction.

It can thus be seen that our partitions in corrugated sheeting do not offer any disadvantage, and perfectly answer all that we demand.

Appendix 5

Thickness of Metal Sheets of the Float

I fixed the thickness of the upper plates of the hull at $\frac{1}{5}$ in. The thicknesses suggested by the majority of specialists varied from $\frac{3}{25}$ in. to $\frac{4}{25}$ in., but some go as far as $\frac{2}{5}$ in. I think that $\frac{4}{25}$ in. would have been enough: but it must not be forgotten that if the tensile strength of two metal plates of $\frac{1}{5}$ in. and of $\frac{4}{25}$ in. are in the relation of 5 to 4, or 1·25, the deflective strengths are in the relation of 5^2 to 4^2, that is, 1·56, and those of buckling of 5^3 to 4^3, that is, 1·95; now the buckling of a part of the metal plate is one of the principal dangers for the float. The fact that resistance to buckling is practically doubled when we pass from $\frac{4}{25}$ in. to $\frac{1}{5}$ in. appears to justify the increase in weight of the hull (nearly a ton).

Appendix 6

The Keels

BILGE-KEELS

A conventional ship is provided on its underwater hull with a keel which makes it easier to maintain its direction and which, in particular in a sailing vessel, resists drifting, and which also damps rolling motions, that is to say, the oscillation of a boat about its longitudinal axis. In order not to increase its draught unduly, keels are also placed under the hull, laterally away from the centre. All these arrangements have a disadvantage: if a wave strikes the lateral keel, the resulting force applies a movement to the ship and thus a certain rolling is produced; if the swell displaces the ship laterally, the keel placed under the ship and supported by the motionless water also produces rocking. If these disadvantages could be avoided while keeping the favourable action of the keel, which in any case damps out the rocking after it is produced, it would be ideal. The cylindrical float of the bathyscaphe presents this possibility. In fact the petrol which is contained in it does not participate, so to speak, in the rolling: the hull turns round the petrol. If therefore we fix blades within the hull, these, to begin with, will necessarily damp out the rolling by their friction with the petrol and also, being removed from the action of the waves, will not be able to cause rolling.

Fig. 20 shows the arrangement of these interior anti-rolling keels, which, removed from the attack of the waves, can be made in relatively thin metal-sheeting and thus have the advantage over external keels of an appreciable economy in weight.

During our operations off Capri, the beneficial action of these keels was remarkable, the *Trieste* proving much more stable than another vessel of superior tonnage.

As our tests with models allowed us to anticipate, the *Trieste* during its trip to Capri exhibited poor course-holding qualities: instead of following its tug in a straight line, it zigzagged from left to right, making angles exceeding 45° with the tugboat's course. These variations produced altogether useless strains, which could even be harmful: it was necessary to avoid them. We managed this in a perfect way

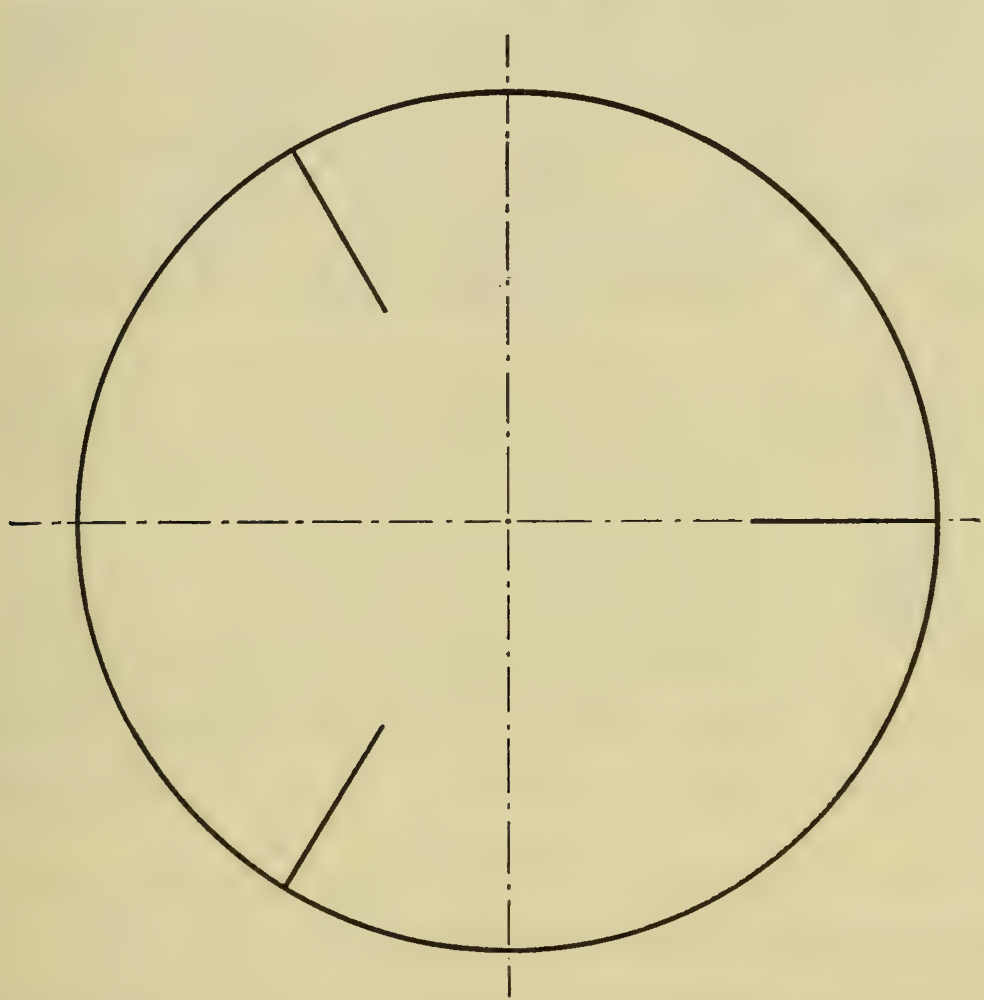


FIG. 20. Cross-section of the float, showing the anti-rolling keels immersed in petrol

by attaching a keel to the back of the bathyscaphe: that is to say, we attached a small vertical keel (see Plate XI). From this moment on, the *Trieste* yawed no more. However, I had the impression that this new keel tended to increase the rolling once more. If this observation is correct, this proves that the choice of position for the anti-rolling keels inside the hull was justified.

Appendix 7

Different Methods of Checking the Homogeneity of the Metal in the Cabin

Modern industry employs two methods of checking the internal structure of a casting: X-rays and gamma rays on the one hand and ultrasonic techniques on the other.

The first method produces an image of the object on the fluorescent screen or on the photographic film. Small airholes of $\frac{1}{25}$ in. in diameter or more, by the fact that they are more permeable than the metal, appear as light marks on the screen and as dark spots on the photographic plate. This method particularly lends itself to the study of castings. But the cabin of the *Trieste* was forged. A possible gas bubble or speck of slag by this operation would have been flattened into a flake or fault parallel to the surface of the sphere. The thickness of this would have been very slight. The difference of absorption of rays between the sound parts of the hull and the defective part would not have been perceptible. Nevertheless the management at Terni particularly wanted to make a complete radiograph of the cabin. A foreign body which had not been flattened by the forge would have shown up on it. The photographic films obtained were uniformly grey, without the slightest clouding. From this point of view, we were completely reassured.

The second method, that of the ultrasonic technique, gave proof that there were no faults parallel to the surface.

This method has been in use in industry only for a few years. The principle is very simple. Let me explain it in a little digression. We are in a free balloon, the night is very dark, visibility nil. The pilot would like to know at what distance he is above the ground. Is he in danger of crashing into a mountain? Nothing is simpler than to make an approximate sounding of the distance from the ground. A strident cry or a trumpet blast: after a few seconds, the terrestrial echo will send him back the sound. Each second roughly is equal to 500 ft. (since the speed of sound in the air is of the order of 1100 ft. per second). If there is a discontinuity of temperature in the air, an intermediate echo is very distinctly perceived. This same method, it is true with certain modifications, is used to check materials. There is then employed a source of sound of very high frequency (a piezo-electric quartz, usually). These waves are sent through the cabin from outside: they traverse it, are reflected on the interior face and come back again. The time that this double journey lasts is checked. If it is $\frac{1}{30,000}$ second (sound goes through metals faster than through air), everything is in order. The transmitter and receiver are moved and in this way the whole cabin is probed. If there were a fault parallel to the surface, it would reflect the sound. Even if its thickness were only a very tiny fraction of a millimetre, one would see move on the screen of the cathode tube the luminous point which indicates the return of the rays: if the fault were only of small extent, there would be a double image. On the other hand, a small spherical air-hole, though very easily revealed by the gamma rays, could pass unobserved by the ultrasonic method.

It is clear that these two methods complement each other admirably.

It was by reason of this careful study of the cabin of the *Trieste* that I could without the slightest fear go down to 1700 fathoms with my son, and if I had had greater deeps within reach, I should have even gone down to 2½ miles without having the bathyscaphe first of all make a descent with the automatic pilot and 50% overload as I had suggested for the cabin of the *FNRS 3*.

Appendix 8

Graph of Hinge Moments on the Door

The hinge of the door is inclined 18° from the vertical. In a closed position the door will lean with about a third of its weight upon its seating since sine 18° equals 0·30902. The more open the door is, the less its weight tends to close the door. Open at 90°, it is in equilibrium (unstable). In Fig. 21 the curve represents the couple produced by the weight of the door as affected by the angle of opening. It is sinusoidal. To balance this varying couple, we placed a helical spring on the axis of the hinge. Its couple varies of course linearly with the angle of opening, so that it appears on the graph as a straight line. The compensation for the weight of the door cannot be perfect therefore throughout the whole of its movement. But that is not necessary, nor is it even desirable. One could select the characteristics of the spring as indicated by the dotted line. In this case the difference between the two couples would have a maximum value of 10% of the door's couple.

However, we preferred a characteristic corresponding to the solid line drawn on the graph. This latter offers the real advantage that the door when in a closed position has a tendency to remain closed and when in an open position to remain open. This advantage is offset by the fact that the maximum couple is now 17%, or $\frac{1}{6}$ of the couple of the door alone. But as the operating handle of the door is placed on the side opposite to the hinge, and the weight of the door has already

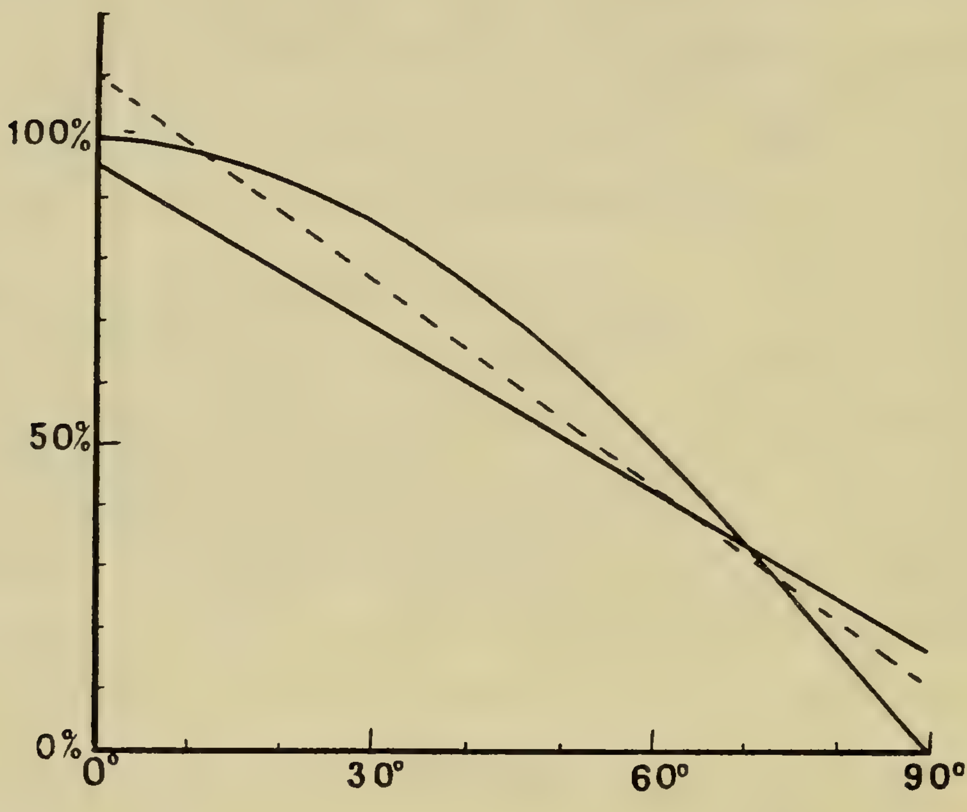


FIG. 21. Graph of variations of hinge moment with angle of opening of door

been reduced to $\frac{1}{3}$ by the inclination of the axis, one can easily operate the door with one hand.

The position of the door, open or closed, must be made secure, so that the oscillations of the bathyscaphe will not make it move. When the door is closed it must be held firmly in its seating for the first fathoms of the dive. Afterwards the pressure of the water will keep it in its conical seating. We have, in the *Trieste*, one single small screw that can be operated without difficulty with one hand, which serves to keep the door closed.

Appendix 9

Passage of the Electric Cables and Tubes through the Cabin Wall

The passages of a great number of electric cables, high-pressure tubes and two ventilation conduits (schnorkel) presented an interesting series of design problems. All these passages had to meet two conditions: to be watertight and strong.

Around the porthole, in the place where the thickness of the cabin wall is 5·9 in., we bored twelve holes of identical dimensions. On the external side each hole, for a length of 1·97 in., had a diameter of 1·97 in. Then came a cone of an angle of 45° for a length of ·55 in., which brought the diameter down to ·79 in. From a depth of 2·52 in. onwards the hole continued towards the interior of the cabin with a diameter of ·79 in.

Watertightness is achieved in all the holes in the conical part by means of a conical ferrule of plexiglas, forced into its seating by a steel plug. This construction is analogous to that of the portholes.

THE PASSAGE OF THE SCHNORKEL

To have effective ventilation, it is necessary to conserve as much as possible the free section that is offered in the hole of ·79 in. diameter. From the interior of the cabin one must be able easily and rapidly to open or close the passage.

Fig. 22 illustrates the design chosen by us. At the outside of the hole a thin metal box (visible at the top of Plate XIV), which will never have to resist high pressures, is screwed down on the orifice. The reliability of the joint between this box and the cabin *d* is ensured by means of a rubber washer. To this box is connected a long tube which traverses the float and ends on the deck. The tops of these tubes (folded back towards the base) are quite visible in Plates XI and XXI. A thin iron rod *j* passes through the entire length of the tube *e*. From the outside, it is fixed to an iron plug *g*. If, by means of screws placed inside the cabin, one pulls upon the rod, the plug forces the plexiglas ferrule into its seating. The watertightness thus effected is sufficient for low water pressures. As soon as the bathyscaphe dives, the external pressure of the water is added to the pull of the rod. The plexiglas is then compressed more and more between its seating and the plug and the watertightness is perfect for all pressures; it is an autoclave closing. The rubber ring which surrounds the upper rim of the

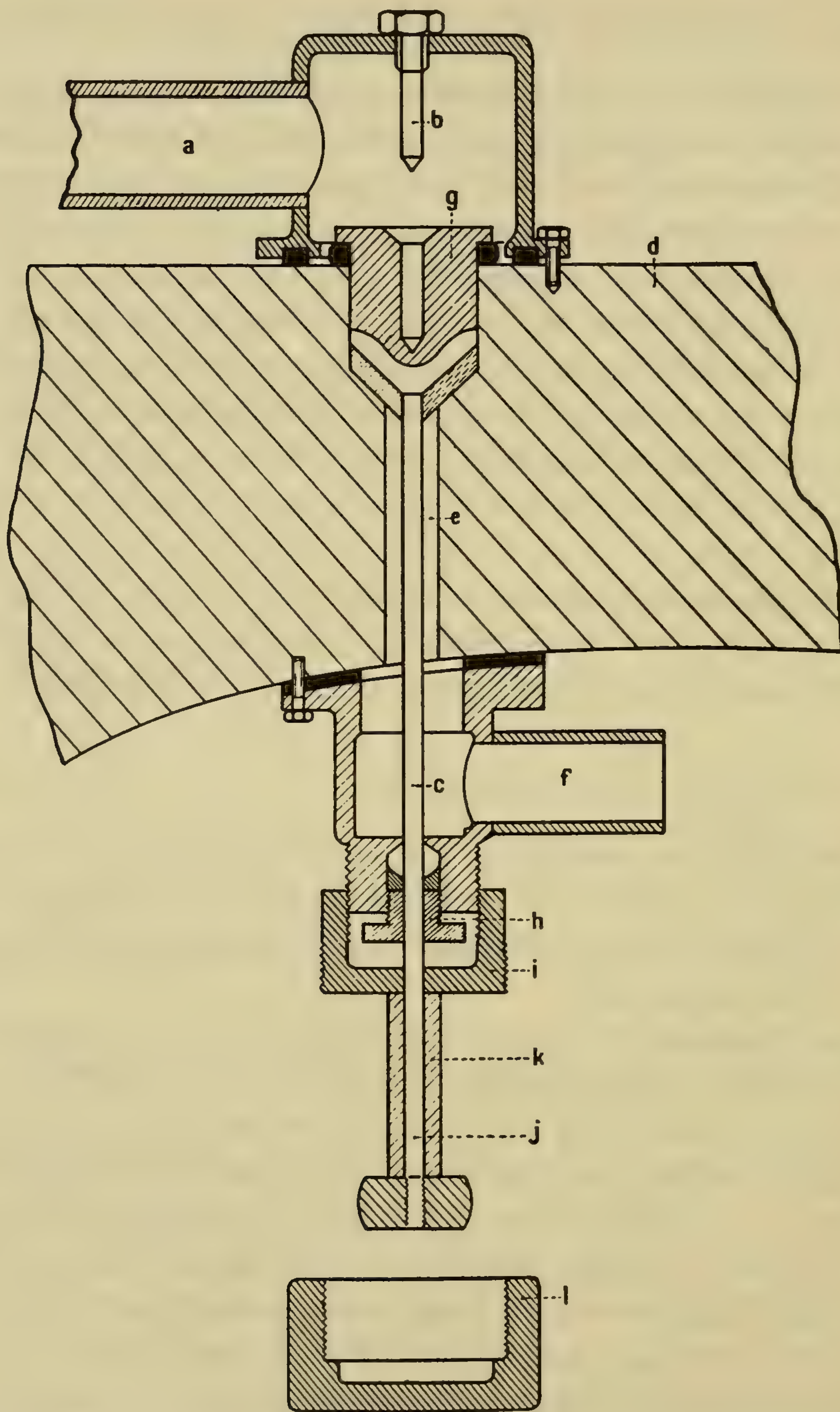


FIG. 22. Passage of the schnorkel tube through the cabin wall

plug (drawn in solid black) would, by itself, effect an autoclave closing. It is there to make the safety doubly sure.

After the bathyscaphe has risen again to the surface, the crew normally can reach the deck very quickly. But if, as a result of some mishap in the antechamber, the crew were obliged to remain shut up for many hours in the cabin and their supplies of oxygen and soda of lime were exhausted, it would be necessary to open the schnorkel to replace the vitiated air by fresh air, either by means of a ventilator placed in the cabin, or by means of compressed air furnished by a ship on the surface. In this case the pilot would have only to push the rod. Then the plug would go out with the plexiglas into the outside box, where it is held in a central position by means of a centring screw *b*. All the water contained in the external tubes will then enter the cabin where a tube *f* (on the right in the diagram) will lead it away to a suitable receptacle. Then, by means of the same tube, one could establish the required circulation of air.

The part played by the different pieces shown at the base of the design (stuffing-box, maintenance of the plug in open and closed positions) will be readily understood.

THE 'PYROTENAX' CABLES

For all external electric cables of the bathyscaphe and for the passages in towards the cabin, we made a very large use of 'Pyrotenax' cables. These cables, made by Pirelli of Milan, are composed of a copper tube through which pass one or several copper wires insulated by dehydrated and compressed asbestos. These cables are extraordinarily robust. They can be folded, even at a right angle, and, which is important for us, they can be heated red-hot and have rings brazed on to them with silver solder without imperilling the insulation.

ARALDITE D

The Ciba Company of Basle makes a synthetic resin, Araldite D, which rendered us great service. Unlike most synthetic resins, this can be polymerized without any need to heat it. By simply mixing two liquids there is obtained a fluid substance which, at the end of an hour, solidifies and which, after one or two days, becomes as hard and insulating as amber, and all this without showing any diminution of volume, which is not the case with many other synthetic resins.

THE PASSAGE OF THE THICK 'PYROTENAX' CABLES

In order to connect the large battery, originally placed on deck to the inside of the cabin, and to work the propellers and the floodlamps, it was necessary to utilize 'Pyrotenax' cables of an external diameter of ·59 to ·63 in. and containing one to three copper cores. Fig. 23 shows the construction of these passages. As it would have been difficult to

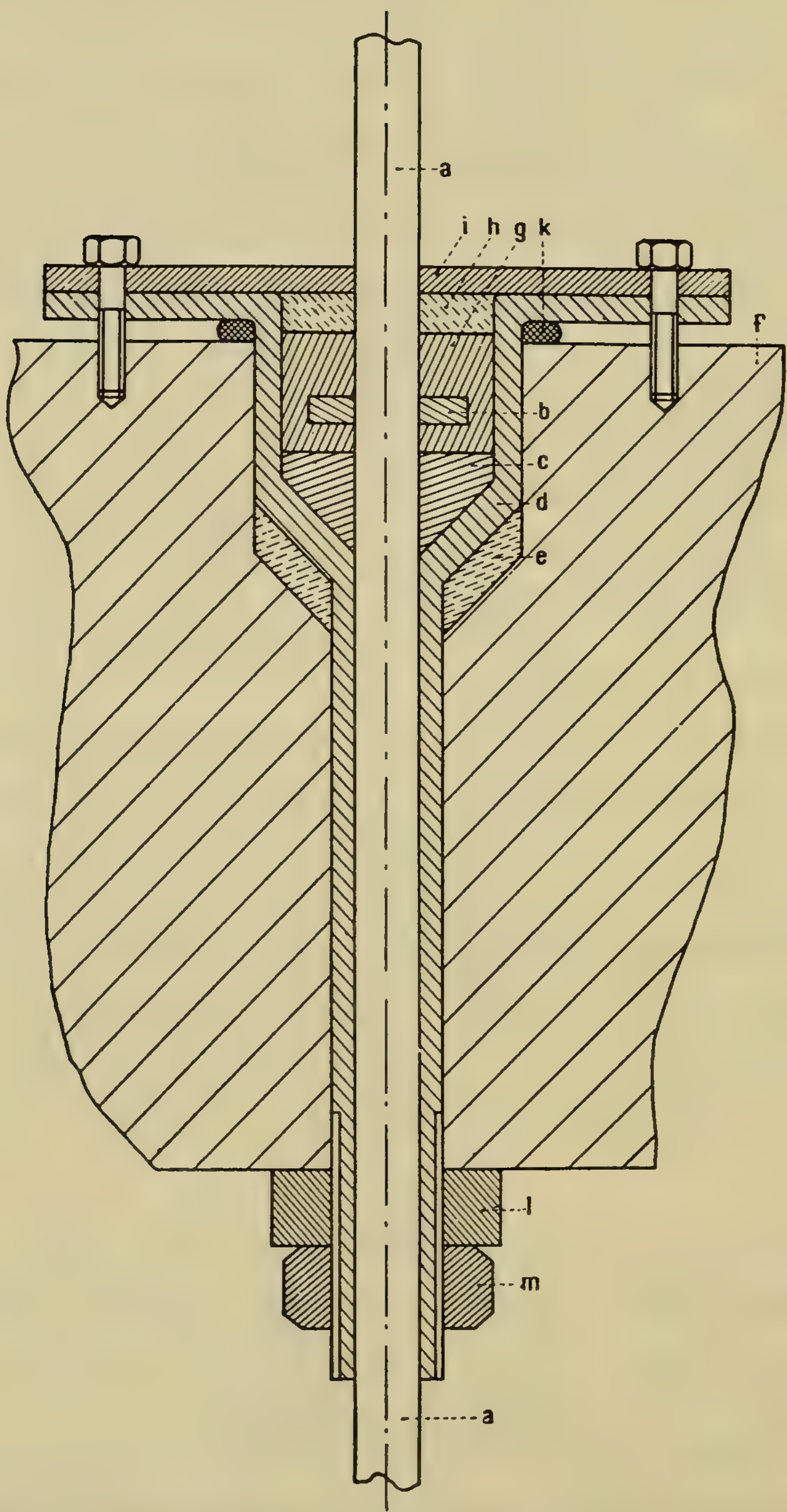


FIG. 23. Passage of a large electric cable through the cabin wall

seal them directly into the cabin, we sealed them in tubular plugs placed in the holes in the cabin *f*. Between the plugs and the cabin the watertightness was achieved by means of a plexiglas ferrule *e* against which the plug is forced by a nut *m* and, on the outside, by six screws. The rubber ring *k* doubles the security. The essential thing is that the cable should not be driven into the cabin by outside pressure. With this in view, it is brazed to the conical ring *c* which rests on the inside of the plug *d*. At a depth of $3\frac{3}{4}$ miles the longitudinal force that the water exerts upon the cable is 2640 lb. If the cone *c* has a height of ·4 in. the brazing is extended over a surface of 0·77 sq. in., and it is then subject to a shearing stress of 3410 lb. per sq. in. If the brazing is well done there is no danger whatever there. My son himself superintended the carrying out of the brazing. He ascertained that in every case the silver ran well into the joint. For additional security, another ring *b* was brazed to the cable: furthermore, the cable was held tight on the outside by a steel clamp. The jaws of this clamp had had small grooves machined in their faces to prevent the cable from sliding between them. In the laboratory we attempted to force a 'Pyrotenax' cable through a clamp of the same construction. A force of 13,200 lb. was not enough to displace it. After this test we observed that the machined jaws of the clamp had become embedded in the copper of the cable. No sliding was therefore possible. I think that in this construction we carried security farther than was necessary. But the practical result is that during the dives, seated before the porthole, the idea didn't even occur to us that the cables could be transformed into a deadly projectile.

It was not only necessary to see that the entire cable was not dislodged. We also had to be sure that the core of the cable would not slide in its sheath. This danger is avoided by the friction that the compressed insulating asbestos produced all along the cable. Besides, a certain number of bends in the cable would alone have prevented any displacement of the core and finally the extremity of the core was made safe.

We are therefore certain that the passage of our cable offers all the necessary strength. But we must also prevent all infiltration of water. It is here that we made use of Araldite D, poured into the plug *g*. As this resin is very hard, it is necessary to anticipate the possibility of its cracking as a result of a deformation of the metal. That is why we poured in upon the Araldite a soft wax *h* that the engineers of the Pirelli Company made specially for us and which has been given the name of 'bathycire'. This wax, liquid at high temperatures, is soft at an ordinary temperature. It offers an extraordinary adhesiveness to solid bodies. If one places a small piece of this wax in a glass filled with water at ordinary temperature, at the end of a few hours it sticks by itself to the bottom of the glass. In fact we never observed any cracks in the Araldite. But if any had occurred, the wax would have completely blocked them.

This sort of passage for conduits has a great advantage: we were able to put through the wall conductors with a core having a diameter of ·394 in. The current of the large battery could therefore be brought directly to the cabin: and the current operating engines and flood-lamps could also, by means of cables containing three large cores, pass through the wall. Thus we could completely give up all the relays, used in the *FNRS 2* and also the *FNRS 3*. The elimination of these relays, which must be protected by oil against the sea water, constitutes an enormous simplification.

THE PASSAGE OF HIGH-PRESSURE TUBES AND OF THE RADIO AERIAL

We have already mentioned the two steel tubes, by means of one of which the pressure gauges are connected to the external pressure, while the other serves to conduct compressed air into the antechamber to expel the water. These tubes have an external diameter of ·25 in. The aerial of our radio is connected with our radio by a 'Pyrotenax' cable of ·197 in. external diameter. These three cables pass through the same hole in the cabin. The construction is analogous to the preceding one, except in two points: we have been able to do without the plate *b*; and the cone *c* is pierced with three holes.

THE PASSAGE OF 36 THIN ELECTRIC CABLES

A large number of cables of small section must be provided for to be connected with various instruments placed outside the cabin. From the beginning we had to have six wires for the three electro-magnets (two to carry the ballast tubs and one to hold the trail-rope), four for the two magnetic ballast valves, three for the telephone (only used on the surface), two for the small lights and one for the tachometer. That is sixteen wires. But we also wanted to reserve for ourselves the possibility of connecting up other instruments later on. In the end, not to be caught napping, we had thirty-six copper wires of $\frac{1}{25}$ in. diameter passed through a single hole in the cabin. Fig. 24 shows the construction adopted. We see again the same steel plug *c* with its screws *d*, its rubber *g* and its nut *e* and the small round piece of plexiglas *h*, but it forms outside the wall of the cabin *f* a rather bulky head. In this head are the ends of thirty-six 'Pyrotenax' cables of $\frac{1}{5}$ in. external diameter. Their cores *k* are soldered to thirty-six copper wires which, together

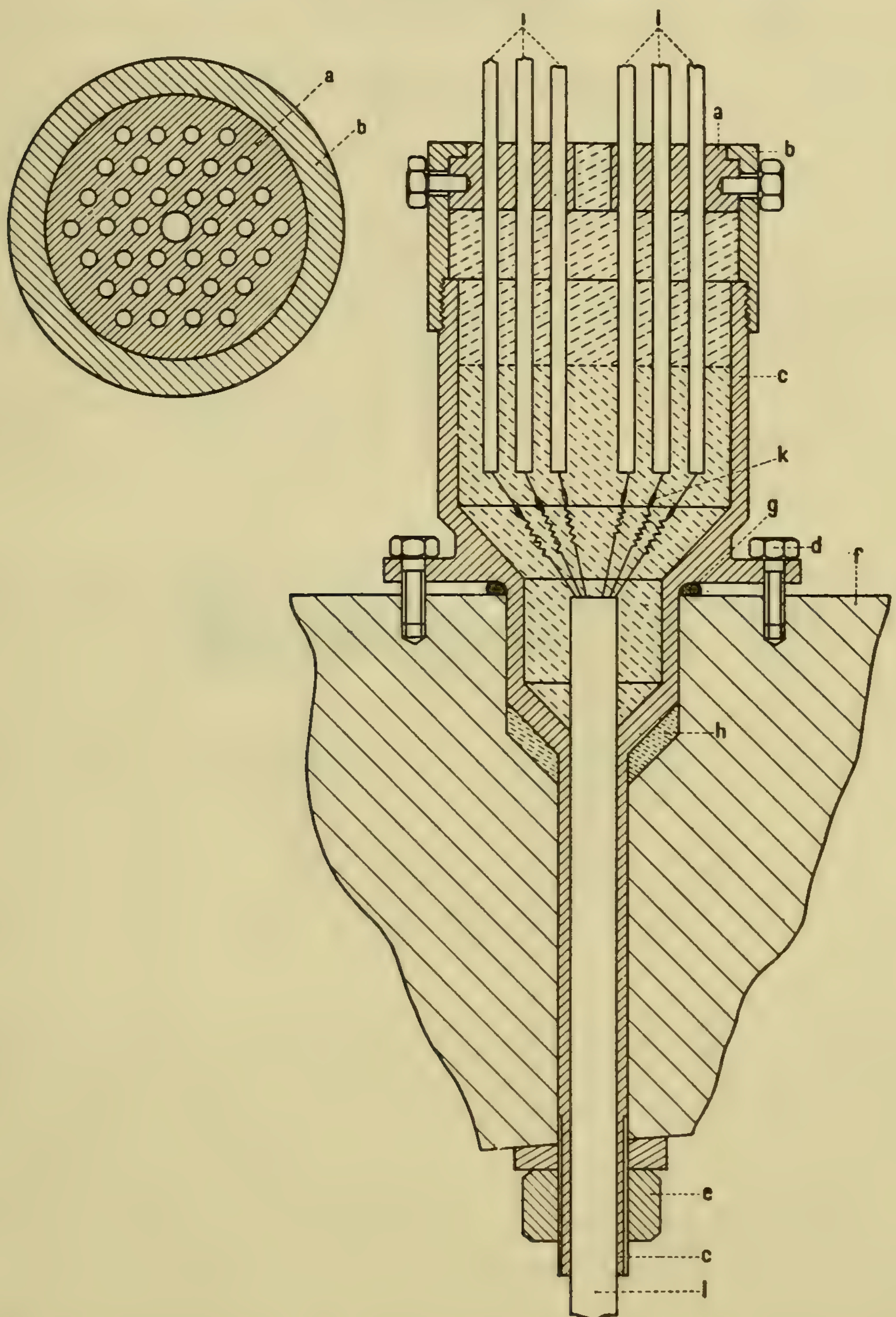


FIG. 24. Passage of thirty-six thin electric cables through the cabin wall

forming the cable *l*, pass through the plug to enter the cabin. The thirty-six wires of this cable are insulated one from the other by cotton and the whole cable is carefully coated with paraffin. The plug is prolonged by a tube *b* closed by a plate *a* pierced with thirty-seven holes. The base of the head is filled with Araldite D: above this is once more the 'bathycire' wax. Below *k* the copper wires are bent in a zigzag to prevent them from being pulled through the Araldite.

Appendix 10

The Reciprocating Valves

The hull must be able to 'breathe' if the volume of the petrol changes as a result of variations of pressure and temperature. We have seen (page 77) why we only allow water (which ought to be in the lower part of the float) to enter and leave the central compartment, compartment No. 7 (Fig. 8, page 76).

This being so, we could have been satisfied with a simple opening L placed at the bottom of this compartment. I added above this opening

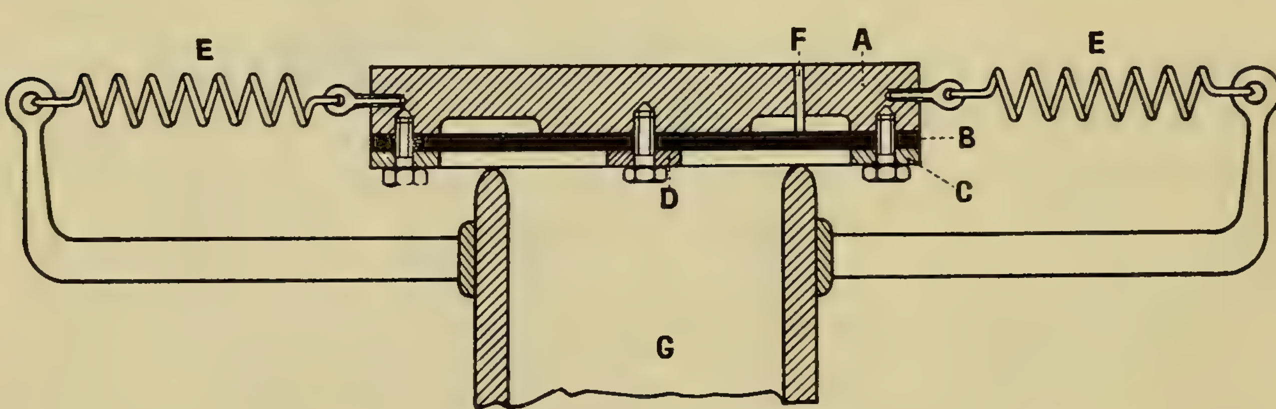


FIG. 25. Reciprocating valve

the piping and the double valve F (represented diagrammatically in Fig. 8) to avoid, if possible, and anyway to lessen the consequences of, a leak in the upper part of any of our compartments. Let us imagine a small accidental opening in the top of the float in compartment No. 9, for example. If the float were simply open at the bottom towards L, the petrol pushed by the pressure of the water would gush out in floods and, what is worse, the petrol in the central compartment, No. 7, might follow it as a result of siphoning action. A glance at our sketch will make the role of the double valve clear. Normally, if there is no leak anywhere, the hull will breathe by this valve. When (at the moment of a dive or at the moment of a lowering of temperature) the water must enter the float, it will enter by L, will raise the lower flap-valve and will reach the base of the float. This flap-valve, however, is loaded in such a manner that it will only open if the pressure exceeds

0·11 atmospheres. This pressure is insignificant from the viewpoint of the strength of the hull, but it exceeds the hydrostatic pressure which may be induced by the difference between the density of water and of petrol over a height of 11·55 feet (the height of the compartments). It is therefore impossible that as a result of a hole being made in the upper part of a compartment the petrol escaping will suck up the water through L. The petrol will not be able to leave the float unless the water comes in by the same opening. This is of first importance, for two reasons. First of all, there is no difference of pressure which will induce the petrol to gush out by a large vent. The outflow will then take place more slowly (the water and the petrol having to pass each other in the same opening) than if the water, entering at the bottom of the float, produced a hydrostatic pressure in the upper level of the float. If the damage to the upper part is produced at the surface—for example by collision (always to be feared)—the time thus gained could be very valuable. It could even, in certain circumstances, avoid catastrophe. On the other hand, if it is only a question of a slight leak, a local fissure in the welding for example, the petrol, pushed by the water entering directly at the base of the float, at the expiry of a certain time, would escape in considerable quantities. But if the water can only enter by the same fissure, it must meet and pass the petrol. In a fissure of small dimensions, this passing would not take place and the loss of petrol would be avoided.

Let us now see the role of the upper flap-valve in our double valve. If the petrol expands, it acts upon the water which is in the bottom of compartment No. 7. This water then rises into the annular space between the two tubes (see Fig. 8), lifts the upper flap-valve, then through the central tube escapes to the sea. The object of the flap-valve is solely to prevent the water coming in by this same route due to suction caused by a leak.

The double valve is placed on deck so that it will be easy at any time to check or repair it. It is covered by a large dome hermetically closed which protects it mechanically and removes all possibility of air entering in case of loss from the upper valve.

Let us now look at a few constructional details of our valve.

To begin with, the flap-valves must be made to move vertically so as to avoid all danger of seizing. If any rod slides in a bearing it is always to be feared that it may be blocked by a foreign body—a little grain of sand for example. To avoid an accident of this sort, I deviated from conventional construction. I suspended the valve between four spiral springs (see Fig. 25). Thus it can move vertically without any friction. The rubber ring itself is large enough for the small lateral displacements which these springs allow to take place without inconvenience.

The weight of the flap is such that it will lift itself as soon as the difference of pressure provided for is reached.

We could have contemplated the construction of metallic flaps. At first sight, such a valve appeared to be perfect. But just then there came into our memory the phantom of the very learned Mayor Otto von Guericke of Magdeburg, with his hemispheres, or, an example less distant in time, the terrible suckers of the giant squid which dragged to his death one of the brave sailors of the *Nautilus*.

If two metallic surfaces which are very flat, touch, and if one tries to separate them, it may occur that a vacuum is formed between them and opposes their separation. In the circumstances called 'ordinary' this adhesive force can naturally not exceed the pressure of the atmosphere, that is, 14·2 lb. per square inch. (This force must not be confused with the adhesion which occurs between two pieces machined with an extreme precision.) But, once again, a bathyscaphe is not always in 'ordinary' circumstances. At a great depth the 'sucking effect' can assume tremendous proportions—at $3\frac{3}{4}$ miles, for example, 600 atmospheres. This is not pure theory. The poor sperm-whales could say something about the wounds they receive at great depths from the suckers of the squids and which would be impossible if the effect of suction were limited to one atmosphere, which Otto von Guericke noted.

It may be imagined what would be the consequences if suction effect occurred between our flaps and their seatings, even if it were over a small area of their surface of contact. It must be rendered completely impossible. Fig. 25 shows the construction chosen. It is a supple rubber membrane which rests on the seating. If the flap tends to rise, the membrane is lifted first from its periphery. It can be seen at once that in these conditions no suction effect is to be feared.

It is true that in the beginning I was told that a valve with a flexible membrane was far too unorthodox and that it was dangerous thus to plunge into a new type of construction. I replied that I had inherited from my parents a pump of which the flaps were composed of supple membranes, that this pump had been working for nearly seventy years and that its valves had functioned at least 2500 million times without ever breaking down. Indeed, the human heart has no metal in any part of its construction; it is entirely made of flexible membranes: why not take them for a model?

The membranes are in synthetic rubber impervious to the action of petrol, and the seatings are of stainless steel. Thus there is no fear of the membranes and seatings adhering.

To make it even safer, I placed on the upper part of the tower a U-shaped iron tube containing mercury, connected with the central compartment of the float (see page 77 and Fig. 8). The fact that it lost no mercury proves that our valve has never been blocked.

Appendix 11

The Control Valve

In the top of the vessel containing the stabilizing petrol is an opening of 3·1 sq. in. section, closed by the valve flap, in the centre of which is fixed a vertical iron rod; this latter penetrates into a coil: if an electric current is passed through the coil the rod is attracted and the valve opens. When the current is cut off, it falls back and closes the opening. To decrease the number of ampere-turns necessary for the operation of this valve the magnetic circuit is closed by soft iron, except in the part which is situated between the rod described, and an iron core placed in the upper part of the coil. To lift the valve a rather strong current is necessary, but when the rod has reached the immediate neighbourhood of the core, the magnetic flux circulating almost entirely in iron requires for its maintenance only a small current. One takes advantage of this by arranging the switch so that a heavy current is maintained for only two seconds. This detail has its importance because the reserve of energy that our battery can furnish is limited and, above all, because a heavy current would at length generate too much heat in the coil and in the plugs of the passages through the cabin wall.

The pressure that the petrol exercises upon the base of the valve flap is variable. When the vessel containing the petrol is still full, it produces upon the 3·1 sq. in. of the section a force of 4·4 lb., but this force moves towards zero progressively as the petrol in the reservoir is replaced by water. To compensate this variation in force, the valve is loaded by a rod whose cross-sectional area is equal to that of the valve and whose density is equal to that of water. This rod consists of an aluminium tube filled with petrol. Its length is equal to the height of the vessel containing stabilizing petrol, i.e. 11·55 feet. Thus its apparent weight will always exactly compensate the variable thrust of the petrol upon the valve. This design, at first sight, seems perfect. It has, however, a defect: when the valve opens, the petrol flows out and necessarily the pressure of the liquid decreases at this moment. (The kinetic energy is acquired at the expense of the potential energy, which is represented by the pressure, according to a fundamental law of hydrodynamics.) It follows that the force that must be exerted to lift the valve must be increased progressively as this rises. The compensation is thus no longer perfect.

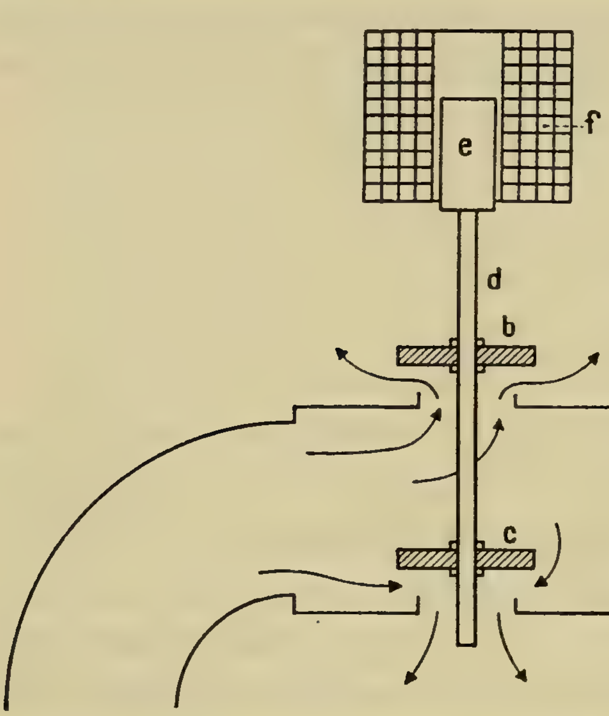


Fig. 26. Diagram of the electrically-compensated control valve

Technical problems often appear thus: you search up to the moment when you find *one* solution, then you go on to other problems; and it is only later that you see you have indeed found *a* solution, but not *the* solution, the only one, generally, which was perfect. That is what happened with my valve. I was satisfied to see it functioning, although the valve flap could not be raised as much as we should have liked.

It was only a little while before our leaving for Ponza that I found *the* solution: its simplicity is such that I should have found it at the first attempt. It is derived directly from the compensated valve of a steam engine that Professor Stodola explained to us when I was a student at Zurich. I am sure that I should have thought of it earlier, if I had not been fascinated by the invention of my compensating rod. The principle of this compensated control valve will be understood at once by a glance at Figs. 26 and 27. The first is diagrammatic. Coming from the reservoir *a*, the petrol enters the distributing chamber. This has two openings, one at the top, the other at the bottom. Each of these openings is closed on the upper side by a flap: the two flaps *b* and *c* are fixed to a common rod *d*. Thus the pressures of the liquid, acting upon one of the flaps from the bottom upwards and upon the other from the top downwards, always compensate each other exactly. At the top of the rod is fixed the soft iron core *e* which will be attracted by the magnetic field at the moment when the coil *f* is energized.

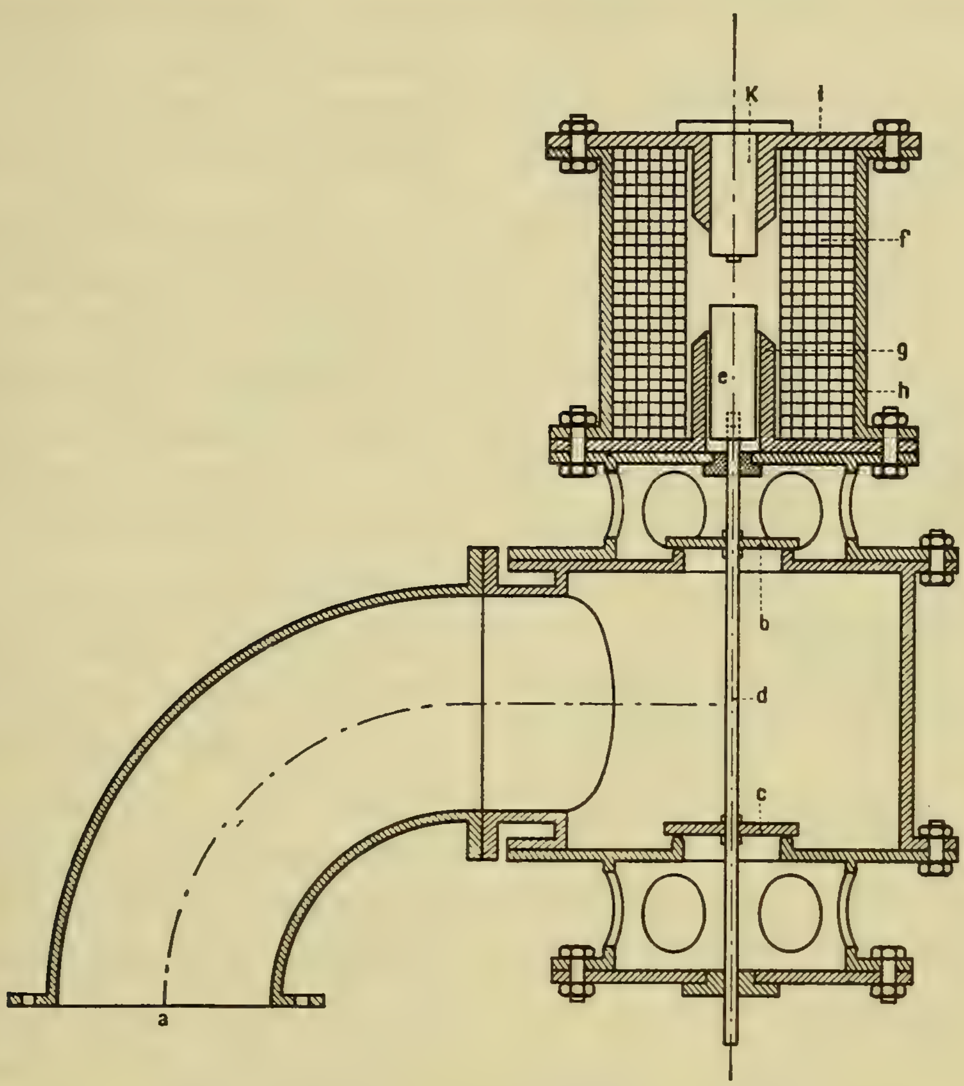


FIG. 27. Compensated control valve

Fig. 27 shows better than Fig. 26 some constructional details, especially the soft iron armature, *h*, *i*, *k*, which will conduct the magnetic flux.

Before our departure for Ponza, we lacked time to work out this valve. But I have now constructed it and it works perfectly.

Appendix 12

Low-pressure Gauge

We have seen that the *Trieste* is provided with four Haenni pressure gauges which measure pressures up to 600 atmospheres, corresponding approximately to depths of $3\frac{3}{4}$ miles. As these pressure gauges cannot have a high sensitivity, it would have been interesting to have at one's disposal a pressure gauge with range, for example, corresponding to 0 to 55 fathoms of depth only.

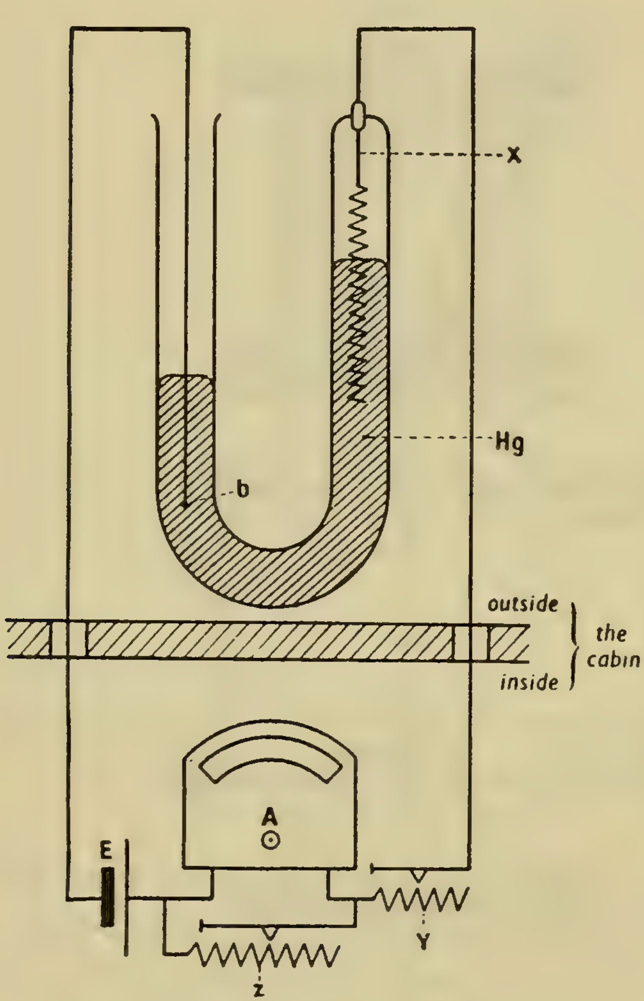


Fig. 28. Pressure gauge for use in the shallows

Nothing is simpler than to utilize a normal pressure gauge constructed for these pressures. But such an instrument naturally would not bear high pressures. It would be necessary therefore to provide it with a cock that the pilot would have to close as soon as the pressure approached the maximum for which the instrument was designed. This solution, however, is not suitable in practice, for if the pilot, who has many things to think about, forgets this detail, the gauge explodes. Naturally the use of an automatic cock could have been envisaged, but it would be better to find a pressure gauge which, while still being fairly sensitive to low pressures, could without danger bear the highest also. Although it has not yet been designed in detail, I should here like to describe an idea for an instrument which seems to me rather interesting. Fig. 28 gives the principle of it. It is a compressed-air gauge intended to be placed in the antechamber, therefore subjected to sea pressure. It is formed by a U-shaped tube in thin glass, of which the base contains mercury (Hg). One arm is open. The other is closed. It contains a resistance formed by a regular helical coil of thin constantan wire, one end of which is short-circuited by dipping in the mercury. This coil does not extend up to the top of the tube, but it is prolonged by a straight wire, of which the resistance must be insignificant. Let R be the additional resistance that the spiral would have if it were prolonged up to the top of the tube. Let us now close our electric circuit by a resistance Y, a milliammeter A with shunt Z and a small dry battery E, so that all the external resistance is precisely equal to R. Then, as long as the mercury does not go beyond the top of the coil, the total resistance of the circuit will be proportional to the volume of air enclosed above the mercury. But this volume of air is (if we ignore the effects of temperature) inversely proportional to the pressure: and since the current is inversely proportional to the resistance, it follows that the current is proportional to the pressure. The adjustable resistances Y and Z allow us to adjust the external resistances to the desired value and to regulate the sensitivity of the milliammeter in such a way that its scale gives the depths directly in metres, for example, but always increased by the constant of 33 ft. representing the pressure prevailing at the surface of the water. As soon as the resistance in the spiral is entirely short-circuited by the mercury, the current no longer increases and the ammeter does not risk being overloaded.

One could naturally leave out all the electric parts and place the pressure gauge near the porthole in such a way as to permit direct observation of the position of the mercury. But reading it would not be easy and I think it would be preferable to read the depths on the instrument panel inside the cabin.

AN ATTEMPT AT A RESTATEMENT

When the French edition of this work was already in the printer's hands, I became acquainted with the book which Commander Georges Houot and Naval Engineer Pierre Willm have just published under the title: Le Bathyscaphe à 4,050 mètres au fond de l'océan[1] *and in which the authors give a fine description of the bathyscaphe and its performances and a great deal of most interesting information.*

However, certain of their statements call for comment. I venture to analyse some of these statements.

[1] Published in England as 'Two Thousand Fathoms Down' (Hamish Hamilton and Rupert Hart-Davis, 1955).

This first bathyscaphe did not realize all the hopes that had been founded on it. That is agreed upon. But, just the same, it proved that the fundamental principle of the bathyscaphe was good. It went down deeper than a habitable cabin had ever gone before.

There was damage. Through a poorly-tightened joint a little water penetrated the insulators (oil-filled) of the electric circuits, which gradually put some of the electro-magnets out of service. However, during the last dive, the automatic pilot functioned so well that the bathyscaphe rose again perfectly after having reached almost exactly the depth prescribed. Yet Engineer Willm declares (page 36, English edition): 'Experience had shown that all its gear was unserviceable.' I find it difficult to imagine that a bathyscaphe of which 'all the gear was unserviceable' could have carried out this trip without a crew.

But there is a much more curious remark still (Houot, page 21): 'When she reached port there was nothing left of the float.' Really, there was nothing left of the float? Then how did we recover the 10-ton cabin? It ought to have gone straight to the bottom. What really happened? After the ascent, the swell had prevented the attachment of the lifting tackle of the derrick to the rings on the bathyscaphe; and instead of, as anticipated, taking the *FNRS 2* on board the *Scaldis*, after having emptied out the petrol, we were obliged to tow it for a whole night in bad conditions. The principal part of the float, that is to say, the seven aluminium drums constituting the petrol tanks braced to the steel frame, did not suffer at all. But these drums were surrounded by an envelope of thin iron sheeting of only $\frac{1}{25}$ in. thickness which formed the fairing. This metal was very much damaged in places. As it had no vital function whatever (it served above all to diminish resistance to the progress of the float), this accident alone would not have hindered the carrying out of experiments. Improvised repairs would even have been possible with materials at hand on board. But other reasons obliged us to hold up the experiments, for instance, the fact that the time during which the *Scaldis* was at our disposal had expired.

Later, the bathyscaphe was dismantled in the port of Dakar and the cabin, separately, was transported by cargo-ship from Dakar to Toulon. Is it possible that, seeing a photograph of the cabin taken after the dismantling, Commander Houot thought that the *FNRS 2* had arrived at Dakar in such a state?

On page 34 Engineer Willm declares: 'The principle of the float and of using steel-shot as ballast were the only survivals from Piccard's *FNRS 2*.' This is simply untrue. Engineer Willm momentarily forgets that the cabin of the *FNRS 2*, in short the main part of the bathyscaphe, was used, without any change, for the *FNRS 3*. Moreover, a whole series of features in the first bathyscaphe which were new for submarines were taken over at Toulon: the trail-rope, which can be jettisoned by electro-magnet; unballasting by breaking the current; two propellers steering the bathyscaphe without a rudder; the control valve; the lateral lighting with bulbs immersed in distilled water; the empty dive with automatic pilot (controlled by pressure gauge, clockwork, bottom detector and detector for leaks in the cabin) and many other details; finally, the plexiglas portholes. Do all the theoretical and experimental researches that I had devoted to these windows since before the war count for nothing? (See page 150.) Nevertheless it is to these same portholes, able to resist pressures of tens of miles, and not only of 9000 metres (5·6 miles), as Commander Houot says (page 212), that the French naval officers and Professor Monod, without hesitation, trusted their lives. Were these a mere detail?[1] I invite Engineer Willm to refer to Beebe's book, where the difficulties encountered by engineers before the use of my plexiglas portholes are described.

Next, to belittle even more the importance of what had been taken over from the *FNRS 2*, Engineer Willm continues (page 34): 'But on the prototype most of the ballast had consisted of cast-iron blocks that were cumbersome and unwieldy. Bird-shot played only a secondary part . . . Gempp[2] had been led to abandon mixed ballast. . . .' Here confusion is so great that I wonder if it was really Engineer Willm who wrote this passage. In fact the principle of releasable

[1] I suppose that this depth of 5·6 miles was reached as a result of a faulty calculation. We obtain, in fact, this order of magnitude by neglecting the radial components of forces operating at the conical surface. However, these components are in no way negligible for they combine in the plexiglas with the axial forces in such a way as to produce quasi-hydrostatic pressures in three dimensions. But the elementary theory of the strength of materials teaches us that such a uniform pressure is not prejudicial to the solidity of the piece. For the rest, a glance at our diagram on page 150 shows that the pressure at breaking point must be several times 5·6 miles of water.

[2] Gempp is the engineer who preceded Engineer Willm at the time of the construction of the *FNRS 3*. (Ed.)

batteries of the *FNRS 2* was taken over for the construction of the *FNRS 3*. (This is proved by the fact that the *FNRS 3* lost its batteries several times!) The tanks of the *FNRS 2*, filled as an economy measure with gravel and scrap iron, were provided, at their base, with a hatch which could be opened in the middle of a dive, but since they could only be closed on the surface, they were simply replaced by a large vessel filled with lead pellets, the bottom of the vessel operating exactly as with my reservoir tanks. In spite of its inconveniences, the principle of my mixed system without the 'blocks of cast-iron' (which, for that matter, were boxes filled with scrap iron) was thus retained for the *FNRS 3*. It was for the *Trieste* and not for the *FNRS 3* that my son Jacques suggested giving up the mixed system and employing only magnetic pellets. It is a great simplification. The iron pellets can thus be allowed to flow out in small doses, while, in case of emergency, the two tubs containing this ballast can be released.

EMPTY TESTS WITH OVERLOAD

I must first of all explain to the uninitiated the reason for the empty tests.

Each piece in a construction must be calculated with a certain margin of safety to resist the stress that it should normally bear. If there is no error in the calculations and if the material itself is in exact conformity with the premises of the calculations, the piece will certainly resist. Experience proves, however, that there can be defects in the materials. This is particularly true of a piece of metal which is not forged but cast (such as the cabin of the *FNRS 2–3*). To make sure of the strength of the piece one makes an 'empty trial'.

However, we know that if a part is loaded several times almost up to its initial breaking limit it will become 'fatigued' and will end by giving way even with loads somewhat inferior to the first. That is why one must make an empty trial with a certain overload. In the greater number of cases, an overload of the order of 50% is chosen, this being often even imposed by legal regulations. It is for this reason that, from the beginning of the building of the *FNRS 2*, I had declared that it should never be used by men at depths exceeding two-thirds of the trial pressure of the cabin, and I had provided for first sending it down empty to $3\frac{3}{4}$ miles, if we ourselves had to go down to $2\frac{1}{2}$ miles. This cabin is made of cast-steel. It contains, like many castings, small air-holes, with diameters reaching $\frac{1}{5}$ in. visible upon the radiographs, which probably are not prejudicial to its strength to any serious extent. (This depends upon the disposition of these air-holes in the wall of the hull.) We know that a small part of these defects were removed by boring and replacement by a plug of sound material. The cabin would perhaps resist pressures of 9 miles. But a possibility is not a certainty. That is why I gave the alarm when I learned through the newspapers that the observers were going to go down to $2\frac{1}{2}$ miles without a previous empty test down to $3\frac{3}{4}$ miles.[1] We know that the *FNRS 3*, before going down with Houot and Willm to 2 miles 2790 ft., made an empty dive to a depth of 2 miles 2880 ft., that is, with an insignificant overload of only 1·25%. Fortunately no accident occurred. But if the cabin had given way, is it not I who would have been blamed, being the designer responsible for the cabin? This does not prevent Engineer Willm from criticizing my attitude and saying (page 164): '. . . it was hardly necessary for him to conclude his statement to the Press by advising the authorities responsible for the *FNRS 3* to carry out an unmanned dive to 6000 metres before sending two men down to 4000. Thus to sow doubt as to the qualities of a sphere that he had himself designed to withstand the pressure at this depth might have had the gravest consequences for us. It was, in fact, casting doubt on the professional capacity of the engineers of the French Navy. Pessimism was in the air, but fortunately neither the responsible officers nor the Ministry were deflected from their decision: the bathyscaphe's trials would take place as scheduled.' This statement astonished me. Any civil engineer who put into operation a railway bridge designed by himself without making the prescribed overload trials would be at fault from the point of view of the law and, if he made the trial prescribed by the regulations, would he be calling into question the professional capacity of civil engineers?

This must be set beside Commander Houot's question (page 116): 'If this precaution is always to be taken, how would the passengers of the future bathyscaphe ever visit the deepest trough on the globe?' Therefore, because in ten years, perhaps, a brave explorer, yet unknown, will desire, on the other side of the globe, to make a dangerous experiment, must we today neglect the rules of safety which are perfectly applicable and were laid down from the beginning by the builders of the cabin of the *FNRS 3*? I cannot understand their argument. For the rest, before going down to 6 miles, because it would be

[1] I sent a registered letter on this subject to the authorities in Paris.

impossible to make an empty test to 9 miles, one could take a number of other precautionary measures. For example, one could make a cabin in forged steel designed with very high safety factors, well checked by ultrasonic methods, and several empty trials of long duration down to 6 miles, since it is important to make sure of the strength of the plexiglas. It seems to me that we could reply with an analogous logic: in wartime it is impossible to avoid completely the dangers of enemy fire; is it therefore useless to take precautions in peacetime on a rifle range?

Would it not have been more graceful and fairer to say simply that: four countries, Belgium, France, Italy and Switzerland, participated in a common effort to make headway in the sciences of peace and to open up to oceanography a new world, thanks to the submarine free balloon, the bathyscaphe.

Without labouring the point, I am happy to note that my work was viewed in another light at the Ministry, at Paris, the Head of the Technical Service of Naval Construction and Armament (Service Technique des Constructions et Armes Navales) having again written to me on the 26th August 1954 in connection with the defects in the casting of the cabin: '. . . You have my very warm thanks for the assistance that you have given the Navy in this new project.'

Brussels, 25th September 1954.

Acknowledgments

THE building of the *Trieste* and the carrying out of its dives was only possible because of the intelligent and generous support that we found in Switzerland and Italy.

I particularly wish here to express my warmest gratitude to the Italian Government and to the Italian Navy, as well as to the Swiss Federal Council and its Minister in Rome, M. Celio.

We received particularly large subsidies[1]:

from the Canton Governments of Basle; Geneva; Neuchatel; and Vaud.

from the F.I.A.T. (Turin);

from the Foundation for the Development of Swiss National Economy through Scientific Research (*Fondation pour le Développement de l'Économie nationale Suisse par la Recherche Scientifique*) (Zurich);

from the Swiss National Fund for Scientific Research (*Fonds National Suisse pour la Recherche Scientifique*) (Berne);

The principal parts of the bathyscaphe were furnished by:

the *Chantiers Réunis de l'Adriatique* (Trieste-Monfalcone), the float;

the Italian Esso Standard, petrol;

the 'Navalmeccanica' (Castellammare di Stabia), rigging up and fitting;

the *Société Terni*, cabin.

To them, and particularly to the late Mr. Aurelli, and to Messrs. Carmagnini, Ferrentino, Flagiello, Loser, de Lucca, Mandrelli, Perrotta, Rossi, Salvio, Traetta and Trevisan, and to all the personnel of these companies, I should like to express all my gratitude for the disinterestedness with which they participated in our work.

And finally, the following authorities, institutions, companies, manufacturers and private persons are entitled to our warmest thanks, either for their collaboration or for the subsidies which they granted us:

To begin with at Trieste:

S. S. Aquila's

E. Canz

[1] In alphabetical order.

Professor Giacomini, of the Institute of Physics of the University
Professor de Henriquez, Director of the Museum of History
S. A. Ilva
The Syndic of Trieste, Engineer Bartoli
The University
The Volta Institute

Then, in alphabetical order:

Abrasivi Metallici (Milan)
Aéro-Club Suisse (Zurich)
Aluminium-Industrie (Chippis-Suisse)
J. André (Lausanne)
Armco (Genoa)
Arthaud (Paris-Grenoble)
Assurance Mutuelle Vaudoise (Lausanne)
Bankverein (Basle)
Banque Bugnion (Lausanne)
Banque Cantonale de Thurgovie (Weinfelden)
Banque Cantonale Vaudoise (Lausanne)
Banque Hentsch et Cie (Geneva)
Banque Pictet (Geneva)
Baslini (Milan)
Brovins (Boncourt)
Chemische Fabrik (Uetikon, Switzerland)
Ciba S.A. (Basle)
Pasteur A. Clerc (Brussels)
Condensateurs S.A. (Fribourg)
Corradini & Primavesi (Milan)
Danzas (Basle)
De Backer (Brussels)
J. Destappes (Brussels)
H. Détraz (Vevey)
Draegerwerk S.A. (Luebeck)
Durand & Huguenin (Basle)
Eisfabrik Bürgin (Basle)
M. Erismann (Zurich)
Escher-Wyss S.A. (Zurich)
F. A. C. E. (Milan)

Falck S.A. (Milan)
Ferrania S.A. (Milan)
Ferronnerie Genevoise S.A. (Geneva)
Georg Fischer A. G. (Schaffhausen)
Dr. F. Forel (Chigny, Switzerland)
France-Soir (Paris)
Galileo S.A. (Florence)
Glacières de Bruxelles (Brussels)
Globus (Zurich)
Henri Groot (Brussels)
Grands Moulins de Cossonay
E. Guegi (Zuben, Switzerland)
Guzzi S.A. (Mandello del Lario, Italy)
Haenni (Jegenstorf, Switzerland)
Hensemberger S.A. (Monza, Italy)
Heuer (Bienne)
Hoffman-La Roche (Basle)
Huber (Pfäffikon-Zurich)
Ihagee Exakta (Dresden)
Incom (Rome)
Innocenti (Milan)
Instruments de Physique S.A. (Geneva)
Koudelsky (Lausanne)
P. Lancieri (Milan)
Lavorazione Leghe Leggere S.A. (Porto-Marghera)
Leutert (Zurich)
Dr. Limentani (Milan)
Longines S.A. (Saint-Imier)
J. Lüthi et Cie (Burgdorf)
Mahler (Zurich)
M. Maréchal (Brussels)
E. Marelli (Milan)
Matex (Milan)
Mess-Union (Zurich)
Microtechnique S.A. (Turin)
Minifon
Montecatini S.A. (Milan)
Movado (La Chaux de Fonds)
Nestlé S.A. (Vevey)

Notz et Cie (Bienne)
Ofinco S.A. (Geneva)
G. Pagano (Quisisana-Castellammare)
Paillard S.A. (Sainte-Croix, Switzerland)
Papierfabrik (Cham, Switzerland)
Pejrani (Turin)
Philips S.A. (Milan)
Mirelli S.A. (Milan)
Plus A.C. (Basle)
A. de Ridder (Prégny, Geneva)
Rinaldi S.A. (Milan)
Rolex S.A. (Geneva)
Baron de Rothschild (Prégny, Geneva)
M. Rubel (Zurich)
Salvas S.A. (Rome)
Sandoz S.A. (Basle)
Sauter S.A. (Basle)
Schaublin S.A. (Bévilard)
Schneider & Cie (Winterthur)
J. Schoch & Cie (Zurich)
Schott und Genossen (Mainz)
Sécheron S.A. (Geneva)
Siemans S.A. (Milan)
Siva (Turin)
Société Italienne pour l'Oxygène (Milan)
Dr. J. Somerhausen (Brussels)
Spoerry & Cie (Flums)
Sprecher & Schuh (Aarau)
Mme. Tissot (Basle)
Union Suisse (Geneva)
University of Naples
Uraca S.A. (Urach)
Vassena (Lecco)
Ch. Veillon (Lausanne)
M. Veillon (Meyrin, Switzerland)
Vetrocoke S.A. (Porto-Marghera)
'Vevey' S.A.
C. Zellweger (Prégny, Switzerland)