THE GERMAN MILITARY "ZEPPELIN I."*

DETAILED DESCRIPTION OF THE REMODELED THIRD AIRSHIP OF COUNT VON ZEPPELIN.

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THIS, the largest and most successful of the airships built by Zeppelin upon his so-called rigid system, is the remodeled third one he constructed.

The first, which made its premier ascent July 2nd, 1900, had various faults, the chief being that the stability, attained through a sliding weight hanging by ropes, was insufficient.

The second was destroyed in its first extended flight, being so badly pounded by the wind on the mountain top where Zeppelin landed to escape the fury of a sudden storm, that the framework was broken, and the inventor was obliged to take it to pieces to save the aluminium, at that time far dearer than now.

Undiscouraged by the warnings of scientists, engineers, and aeronauts, the Count succeeded in raising funds for the construction of a third airship on the same plan, which, when completed in 1907, immediately demonstrated its superiority to its predecessors.

In the period from September 26th to October 8th, 1907, this airship made various long and successful trips, showing the most admirable qualities of stability and dirigibility, and attaining a maximum speed of 14 meters (46 feet) per second, and an average speed of 10 meters (32.8 feet) per second.

After the accident in August, 1908, to the "Zeppelin IV," the "Zeppelin III" was reconstructed in the light of fresh experience.

The first step was to lengthen the frame and envelope from 128 meters (420 feet) to 136 meters (446 feet) as in the "Zeppelin IV." The diameter is 11.66 meters (38 feet) and the capacity about 12,000 cubic meters (423,768 cubic feet).

This quantity of gas is divided among 16 separate balloons, of which 12 are within the cylindrical part of the frame and 2 are found at each end. It must be observed that, strictly speaking, the form is not precisely cylindrical, since each of the rings over which the outer covering of the balloon is stretched has 16 corners, as each ring is composed of 16 straight rods.

The separate rings are fastened together by 16 longitudinal girders, which are united at each pointed end. They are further joined by 16 steel-wire cables which meet in the center, being fastened to a small ring like the spokes of a wheel.

Likewise, wire cables cross diagonally from one ring to the other in the plane of the longitudinal girders. From the inner ends of the longitudinal girders, ramie ropes are carried in the same way, so that a network is formed which holds the compartment balloons at a definite distance from the fabric stretched across the braces. Thus an air space is created between the balloons and the outer envelope. This air space is exceedingly important, and constitutes, indeed, one of the greatest advantages of Zeppelin's "rigid system."

Of especial value is the hindrance thus offered to the heating and expansion of the gas when exposed to the rays of the sun, and the consequent loss of gas.

Sudden cooling of the gas when sunshine is succeeded by clouds is also avoided. In free balloons, a rise in temperature to 50 deg. C. (122 deg. F.) has been noted. This change in temperature in both free balloons and dirigibles is the chief cause of loss of gas and ballast.

The loss of gas by diffusion, too, is less in rigid than in flexible dirigibles, because the gas is not under high pressure.

In order to compensate for this loss all non-rigid balloons must be provided with one or more air-bags known as "ballonets." When the gas diminishes in volume through cooling, air is driven into the ballonnet by a blower worked continuously by a motor, until

the ballonnet is full and the balloon envelope again fully distended.

But if the volume of gas has been lessened by more than the contents of the ballonnet, the balloon cannot be thus fully inflated.

If a motor balloon loses its inflated form, it becomes

Fig. 2.—REAR VIEW. *N*₂, rear car. *F*₁ to *F*₄, lateral stabilizing planes with vertical rudders *S*₁ and *S*₂ between. *F*₅, upper support of stability. *H*₃ and *H*₄, rear horizontal rudder. *T*₃ and *T*₄, propellers. *W*, shaft for driving propellers.

FIG. 2.—REAR VIEW.

more or less unsteerable and the motor must be stopped.

These faults are somewhat lessened by providing motor balloons with a keel framework according to the so-called semi-rigid system, but are avoided entirely only in the rigid frame as used by Zeppelin. This forms the chief advantage of the latter.

But is this improvement gained at too dear a price? The chief disadvantage is the weight of the framework, which lessens the possible weight of the cargo. This is the reason, also, that rigid-frame airships must be built on a big scale. The cubic contents of the Par-

The rigid-frame airship, then, must carry more fuel to cover the same distance, but it needs less ballast because the loss of gas is less.

Another disadvantage is the far greater original cost of these airships, partly from their size, partly from the increased cost of the motors, and partly through the expense of the framework itself.

The third disadvantage is in the greater susceptibility to injury when not in the air, since the elasticity of non-rigid balloons protects them to some extent from the effects of pounding and dragging, to say nothing of the fact that injury to the envelope is far more easily and cheaply repaired than injury to the framework.

Besides, the rigid-frame balloons offer a larger surface to the pressure of the wind, and this surface cannot be lessened in time of need as is the case in the other balloons.

To sum up, the rigid-frame balloon is safer in the air, but less so on land. Also in time of storm it has difficulty in landing on large bodies of water, because of waves endangering it. On the other hand, it is commonly able to remain longer in the air than the others because of its smaller loss of gas.

Returning to the construction of the "Zeppelin I," we must observe that to give greater rigidity to the frame a keel-frame is fastened longitudinally under that of the balloon. This has a triangular cross-section, since it consists of two braces which proceed from the ends of the lower cross girders and unite underneath in a point, being each fastened by a longitudinal girder to the nearest cross girder.

At either end of this key-frame a space is left between the fourth and sixth balloons. Into these spaces are built boat-shaped cars, made of aluminium and steel tubing. When it descends upon water the balloon floats on these cars, which are attached by an aluminium framework to the balloon frame as well as the keel-frame.

Each car is 8 meters long, 1.3 wide, and 1.4 high (26¼ x 4¼ x 4½ feet). The position of each beneath the balloon corresponds to the center of pressure for that half of the balloon. The keel is covered with can-

K, keel frame. *L*, runway. *N*₂, rear car. *F*₂ to *F*₄, lateral stabilizing planes. *S*₁ and *S*₂, vertical rudders. *T*₃ and *T*₄, propellers.

FIG. 3.—VIEW FROM BENEATH.

seval balloon would hardly permit the Zeppelin balloon to carry its own weight, to say nothing of a cargo.

The smallest practical balloon yet built upon the Zeppelin system must have a capacity of about 6,000 cubic meters (211,884 cubic feet). From this it follows that a rigid-frame airship will need far more gas—probably twice as much—to carry a given amount of cargo, while to attain a given speed it will require more power and therefore more fuel. Furthermore, the resistance of the large balloon is correspondingly greater.

vas to lessen the resistance of the wind. The keel is floored between the cars, thus serving as a runway between them and adding to the passengers' sense of safety. Through the center rails are laid, on which a small car operated by wire ropes can be run back and forth at the will of the pilot. This serves to counterbalance any chance excess of weight in one of the cars of the airship, such, for instance, as might be caused by persons changing places. This small car serves as a tool-chest, being no longer used for a sliding weight for

1, 2, 3, 4, etc., divisions of the balloon frame. 1 to 3 in section, 4 and 5 seen from side without envelope. *K*, keel frame extended as runway. *L*, *N*₁, forward car. *N*₂, rear car. *P*₁, *P*₂, pneumatic buffers. *F*₁, *F*₂, lateral stabilizing planes with vertical rudder *S*₁ between them. *F*₅, upper stabilizing plane. *H*₃, one of the rear horizontal rudders; the forward ones (located between compartments 2 and 3) are not visible because of this part being shown in section. *T*₁ and *T*₃, propellers. *B*, board with cords for valves and ballast. *C*, steering wheel.

FIG. 1.—SIDE VIEW OF THE GERMAN MILITARY AIRSHIP "ZEPPELIN I," WITH PARTIAL LONGITUDINAL SECTION.

steering purposes, as was the case in the first Zeppelin model.

The upper edge of the cars is only about $6\frac{1}{2}$ feet distant from the outer envelope of the balloon. This closeness is not dangerous, as might be supposed, since the air-space above described so dilutes any escaping gas as to make it neither injurious nor explosive. On the other hand, this nearness of the cars and motors to the balloon is highly advantageous, because the lateral stability obtained tends to prevent completely rolling motion. This feature was much condemned by scientists and professional men beforehand, since they believed it would cause the machine to cant, but Zeppelin stuck to his idea, with the result that the event proved his wisdom, since no other airship is so stable as his. Besides the stability given by the way in which the cars are hung, the stabilizing surfaces attached on each side at the rear also add stability, especially longitudinally, and prevent pitching.

These surfaces are double in the Zeppelin system, differing in this from all others. Though the extra weight is disadvantageous, this arrangement seems to be most favorable for the attachment of the vertical rudder. Zeppelin in his trials of "Zeppelin IV" first had vertical rudders at bow and stern, but later only at the stern. He determined that a large vertical rudder at the rear was much less effective than small multiple rudders at the sides. The bow-rudder scarcely worked at all.

These phenomena may be ascribed to the fact that in front of the balloon the air is somewhat compressed. At a considerable distance from the balloon, however, a vertical rudder would work.

These experiments with vertical rudders proved, too, that the planes fastened in front of the rudders in other airships, as those of Parseval, Gross and Lebaudy, are unnecessary. In all Zeppelin's flights the vertical rudders fastened between the stabilizing surfaces worked admirably. Each vertical rudder consists of three parallel surfaces, each of about 43 square feet area. Both can be operated, together or separately, from the forward car. At first the rudders were about in the middle of the stabilizing surfaces; later they were found to work better when attached at the rear.

For the same reason apparently in "Zeppelin IV" the stabilizing surfaces were prolonged so as to almost reach the end of the balloon. In "Zeppelin I" they terminate at about the middle of the point. Another stabilizing surface is placed vertically above the balloon, and "Zeppelin IV" also had one beneath.

The size of each of these surfaces is about 30 square meters (323 square feet) with a length of about 13 meters (42.6 feet). The upper surface cannot prevent pounding like the side surface, but it does prevent rolling and pitching. The framework of these surfaces and rudders is of aluminium covered with fabric. They are held in position by stretched wires.

The triple vertical rudders on each side of the balloon are operated by a curved rack attached to the innermost rudder and moved by a bevel gear meshing with it. Over a sprocket mounted on the same shaft with the bevel gear passes a chain which in turn is connected to a wire cable running to the steering wheel in the forward car.

The vertical steering is also much improved in this model. No other airship is so capable as "Zeppelin I" of altering its altitude by purely dynamic means; i. e., without the loss of gas or ballast.

The airship also follows the setting of the rudders very promptly—much more so than does the much smaller "Parseval II," which accomplishes vertical steering by means of ballonets attached to the ends of the balloon instead of by movable surfaces like all other modern balloons. But ballonets cannot be inflated as quickly as a lever can be pushed or a wheel turned.

Zeppelin has now accomplished in his last two models vertical steering entirely by means of movable surfaces and has dispensed with the sliding weight he formerly made use of, though he retains this method as a possibility by the situation of his tool chest.

This contingency is not apt to arise, since the horizontal rudders are double, a couple forward and a couple at the rear. Each pair can be worked separately, or both can be operated at once.

In the latter case, i. e., were the rear and forward rudders moved parallel, for example, with the forward edge toward the top, then the airship, without tilting, would be raised by the reaction of the air in the same way that an aeroplane is lifted.

If the forward rudder alone be tilted upward, then the balloon will instantly lift at the forward end and rise obliquely.

If the airship is to be made to ascend through the action of the rear rudder alone, this must be tilted with the front edge downward. The rear end of the airship will at once sink and the ship will then rise obliquely.

Each horizontal rudder consists of four parallel surfaces, attached to the first ring system of the cylindrical part of the balloon, underneath, fore and aft, at the sides.

Since the steering surfaces must lie horizontally with their axes, the form of the balloon necessitates that the upper surfaces shall be smaller than the lower.

Each pair of horizontal rudders has about 22 square meters (237 square feet) surface. Together they give a pressure of almost 600 kilogrammes at full speed, and the airship can thus be made to rise dynamically about 1,640 feet.

The Zeppelin airship can rise from the surface of water by its dynamic power alone; i. e., even when somewhat heavier than air. In fact Zeppelin has already risen with an excess weight of over 100 kilogrammes (220 lbs.).

Each car contains an 85-horse-power motor, which power enables the ship to attain a velocity of 15 meters per second, about 33.5 miles per hour. The reservoirs and casks hold together over 5,512 pounds of gasoline. Since each motor at full speed uses about 66 pounds per hour, the fuel will last 41 hours with both motors at full speed. In favorable weather the gas leakage should not be more than equal to the loss of weight from use of fuel, so that the airship should really be able to make a 40-hour trip.

All steering apparatus, such as steering wheels for the rudders, and instruments of navigation and for finding the altitude, are placed in the forward car. Here, too, the cords governing valves and sacks of water ballast are brought together on a board. The ballast sacks are divided on either side of the keel.

The cars are united by a speaking tube and provided with buffers to break the shock of landing.

As in all the Zeppelin airships, the "Zeppelin I" has four propellers, two over each car.

The screws are geared to make the same number of revolutions as do the motors in order to keep the diameter as small as possible.

One great advantage of this arrangement is that the supporting brackets for the screws do not extend so far from the balloon, so that the balloon shed is correspondingly narrower than in the case of big screws. Secondly, the weight of smaller screws and small brackets is naturally much less. The diameter of the screws is not quite 3 meters (about $9\frac{3}{4}$ feet).

The transmission of power is by inclined shafts and bevel gears. Each motor is provided with a friction clutch, so that the propellers can be stopped while the motors are kept running.

Besides water anchors, earth anchors are provided which are furnished with points like harrows. The water anchors consist of funnel-shaped frames covered with cloth.

THE YIELDING OF THE EARTH TO DISTURBING FORCES.*

THE problem of determining how much the earth as a whole actually yields to the tidal disturbing forces of the sun and moon was definitely brought before scientific men by Lord Kelvin. He pointed out that, from observations of the tides of long period, it ought to be possible to obtain some definite information, and he urged the establishment of gravitational observatories fitted with instruments for detecting the lunar disturbance of gravity. However rigid the body of the earth may be, it necessarily yields a little to the deforming action of the sun and moon. This action produces two kinds of effect. In the first place, it alters the shape of the earth. If the earth were a perfect sphere, it would be drawn out by the attraction of the moon, for instance, into a prolate ellipsoid of revolution. The actual earth, of a shape that is nearly spherical but presents certain inequalities, acquires under the action of the moon a slight additional inequality of figure, of the same type as that which answers to elongation in the direction of the long axis of the ellipsoid and flattening round the parts remote from that axis. As the moon moves relatively to the earth, the long axis of the ellipsoid moves about in the earth, so that a corporeal tide is raised in the earth. Besides raising a corporeal tide, the action of the moon alters the attraction of the earth. If the change of external shape only is taken into account, the alteration of the attraction consists of the added attraction, due to the protuberances at the ends of the long axis of the ellipsoid, coupled with the loss of attraction, due to the flattening round the parts remote from these ends. But, since the material of which the earth is made up is not homogeneous, a similar effect is produced by the elongation and flattening of the surfaces of equal density, and, since the material is not absolutely incompressible, the density must be in some parts increased and in others diminished, owing to the attraction of the moon being different in different parts. The alteration of the earth's attraction by the action of the moon is therefore of a somewhat complex character. The effects produced by the action of the sun are similar to those produced by the action of the moon.

Many attempts have been made to measure the changes of level that are due to the tidal disturbing forces of the sun and moon. In the majority of such

attempts, instruments of the horizontal pendulum type have been used. The displacement of a horizontal pendulum that would be produced by the attraction of the moon, or the sun, if the earth were absolutely rigid, is known, for the attractions of the moon and sun are known. In the actual case, owing to the yielding of the earth, all we can hope to determine by observations of the tides or of the displacement of horizontal pendulums is a relative change of level, and to measure this is far from easy. The effect to be measured is extremely minute, and it is liable to be obscured, or even disguised altogether by the effects of air currents and of changes of temperature. Recently Dr. O. Hecker, of Potsdam, has succeeded in overcoming the experimental difficulties. By setting up two horizontal pendulums in an underground chamber, and observing their behavior during a protracted period, he was able to show that the effect of the moon, in particular, is perfectly definite, that in phase it follows very closely the motion of the moon, and that in amount it is almost exactly two-thirds of what it would be if the earth were absolutely rigid.

Hecker's result confirms decisively the results which had been found with much less perfect experimental means by previous observers. It leaves no shadow of doubt of the actuality of a corporeal tide produced by the moon. It accords also with those results, deduced from observations of fortnightly tides, which were used by Lord Kelvin in his famous estimate of the rigidity of the earth. This estimate was obtained by working out mathematically the change of shape that would be produced by the attraction of an external body, such as the moon, in a solid elastic globe, of the same size and mass as the earth, if the material of which it is made were homogeneous and absolutely incompressible. When these simplifying assumptions are made, the change of attraction is calculable in terms of the change of shape, and the measurement of the relative change of level leads easily to the determination of the absolute change of level. If with these simplifying assumptions there is combined the observed fact that the relative change of level is two-thirds of what it would be if the earth were absolutely rigid, it is found, as Lord Kelvin did in effect find, that the calculated rise and fall of the surface is one-third of what it would be if the earth were made of homogeneous incompressible fluid, and the calculated change of its attraction due to the sun, or moon, is one-half of the tide-generating force of the sun, or moon. The rigidity which the material, supposed homogeneous and incompressible, would need to have in order that the two numbers may have the calculated values, $1/3$ and $1/2$, is about the same as the rigidity of steel. Both the numbers $1/3$ and $1/2$, which are thus calculated, are inferred partly from a result of observation, and partly from the subsidiary hypotheses of homogeneity and incompressibility. If these hypotheses are discarded, all that can be inferred from observations of fortnightly tides and horizontal pendulums is a single equation connecting two numbers. The number which in the special case is $1/3$ is in general conveniently written as $2/5h$, and the number which in the special case is $1/2$ may be called k . The observations in question concur in leading to the equation $h - k = 1/3$. (In the special case $5/6 - 1/2 = 1/3$.)

It was first suggested by Prof. Simon Newcomb that the length of the earth's free period of nutation usually called the "Chandler period" may be an independent index of the yielding of the earth to small forces. It has long been known that if the earth were absolutely rigid this period would be about 306 days. A free nutation of the earth would be manifested by periodic changes of latitude of places on its surface. Small variations of latitude have long been known to exist, but all efforts of astronomers to detect a period of 306 days in these variations failed. It was announced by Dr. S. C. Chandler, in 1891, that the variations are roughly periodic, but that the period is really 427 days instead of 306. Newcomb pointed out that the lengthening of the period must be due to a yielding of the earth. At any instant the earth is rotating about an axis which does not quite coincide with a principal axis. A solid globe would be deformed by rotation into an oblate spheroid in the same way as a fluid one, but not so much. The inequality of the so-called "centrifugal force," due to the deviation of the instantaneous axis from a principal axis, produces a slight deformation of the surface, accompanied by a slight alteration of the attraction, and these effects can be specified by means of the same two numbers h and k as are required to express the effects of tidal disturbing forces. Mr. S. S. Hough, H. M.'s astronomer at the Cape of Good Hope, calculated, in 1896, the lengthening of the period in the case of a solid elastic globe of homogeneous incompressible material. The problem has recently been discussed in a more general way by Prof. G. Herglotz, who was able to dispense with the hypothesis of homogeneity. A review of the theory, as presented by Herglotz, shows that it is possible to dispense with the hypothesis of incompressibility also, and that the lengthening of the period depends upon the number k , and not upon the number h . The number k is found to be expressible in terms

* Based on a paper by Prof. A. E. H. Love, F.R.S., read before the Royal Society on January 14th.