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TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 286

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By L. Dürr.

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This airship was built by the Zeppelin Airship Company at Friedrichshafen in 1923-4, for the United States Navy, as the reparations service of the German Government in fulfillment of the treaty of peace. It has a larger gas capacity than any previously built airship. Its principal dimensions are as follows:

Gas capacity,	70,000 m	(2,472,000 cu.ft.)
Length, without mooring-mast attachment,	200 "	(656.2 ft.)
Greatest diameter,	27.64 m	(90.68 ft.)
Greatest width,	27.64 "	(90.68 ")
Greatest height, including pneumatic bumper,	31.00 "	(101.71 ")

This airship bears the factory number LZ126, but will be known in the American service as the ZR-3. It was built as a commercial airship and is furnished for carrying from 20 to 30 passengers. It has a streamlined hull consisting of a rigid, light-metal, fabric-covered frame with attached tail planes and 13 separate cells for the gas containers. Its central and rear portions carry the cars containing the engines, while the forward portion carries the control car and the adjoining passenger car. The rest of the apparatus

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* From "Zeitschrift des Vereines Deutscher Ingenieure," May 31, 1924, Vol. 68, No. 22, pp. 529-537.

and load are inside the hull. The design and construction of the whole airship accord with the latest stage of development. Special attention has been given to safety requirements, which are greater for a commercial airship than for a military airship. This has naturally reduced the carrying capacity, i.e., the weight of the crew, fuel, ballast, provisions, spare parts and "pay load," including passengers, which the airship can carry under so-called normal atmospheric conditions, namely, 760 mm (29.92 in.) barometric pressure, 0°C (32°F) air and gas temperature and 60% humidity. The carrying capacity of the ZR-3, inflated with hydrogen gas having a specific gravity of 0.1, as compared with the air, is about 46,000 kg (101,412 lb.). The ZR-3 can develop a speed of 127 km (79 mi.) per hour with its total power of 2000 HP, or 113 km (70 mi.) per hour with two-thirds of its power. On the latter basis, with a pay load of 5 metric tons (11,023 lb.) of passengers, baggage and freight and with the maximum amount of fuel, it is calculated to be able to make a continuous flight of 110 hours, corresponding to a distance of 12,500 km (7767 mi.) in still air.

Figs. 1-10 show the complete assembly and the principal details of the airship. Figs. 11-14 are views of one of the engine cars.

Hull.- The rigid frame, for maintaining the shape of the hull against the stresses produced by the lifting forces, loading and air forces, is built according to the well-known Zeppelin system of longitudinal girders and transverse frames. The latter are built on the basis of a regular polygon with 24 angles, with the straightening out of one angle on each side of the bottom meridian. The diameter of the circle circumscribed around this 24-sided polygon in the thickest part of the airship is called the greatest diameter of the airship. The transverse frames are located at certain, mostly uniform, distances from one another and their apexes are joined by the longitudinal girders of the hull.

The lower part of these transverse frames is constructed so as to provide for the triangular keel frame which extends throughout the whole length of the hull and contains all the apparatus, containers and rooms required for the operation of the airship.

The transverse frames and longitudinal girders consist of longitudinal members and connecting strips of sheet duralumin of special cross-sectional shapes riveted together. The resulting lattice girders are generally triangular cross-section. At a few points there are also square girders (Fig. 17) and, occasionally, stamped and crimped sheet-metal walls instead of lattice girders. The triangular girders of the transverse frames have their apexes inside, while the triangular longitudinal girders, which pass through the vertices of the transverse frames, have their apexes outside the frames, so as to form a continuous longitudinal contour.

The girders are fastened together at the joints by gussets and rivets. The assembly is further stiffened by brace wires in the planes of the main transverse frames and in the panels formed by the longitudinal girders and the perimeters of the transverse frames.

The transverse frames having brace-wires are called main transverse frames and those without brace-wires are called auxiliary or intermediate transverse frames. The main transverse frames, whose sides are braced in pairs by additional inside girders with king posts, divide the hull into a number of separate cells. The length of these cells is 10 m (32.8 ft.) in the rear, 15 m (49.2 ft.) in the central, and 12 m (39.4 ft.) in the front portion of the hull. The intermediate frames are generally about 5 m (16.4 ft.) apart. Thirteen of the 14 cells, as designated by the Roman numerals in Fig. 10, contain gas containers of so-called "skin-fabric" which is made by gluing the intestinal skins of large animals to a light cotton fabric. Each gas bag, when inflated, exactly fills one of the cells.

Aside from gas-tightness, no special demands are made on the skin-fabric, since the lifting stresses are transmitted to the frame of the airship by means of a special network of wires and string and since the fabric is still further protected by safety valves against excessive stresses from the expansion of the gas. From these safety valves (Figs. 1 and 4), which have a diameter of 50 cm (19.7 in.), the gas passes up through vertical shafts c, as shown in Fig. 1, and escapes into the air through hood-like openings, near which are located the valves for releasing gas for the purpose of descending. The gas bags are protected from sudden changes of temperature and the action of the sun by the hull covering and the layer of air between them and this covering.

The hull covering consists of strips of cotton cloth firmly laced to the framework. The thickness of the cloth differs according to the amount of stress to be withstood. Special reinforcing strips are added in the vicinity of the propellers, for protection against pieces of ice or other substances thrown off from the propellers. Cellulose dope, with an admixture of aluminum powder, protects the hull against moisture and the rays of the sun. This also gives a smooth surface which, together with the streamlined shape, reduces the drag to the minimum.

Such a body of minimum drag, if it is to move in a definite desired direction, must have a certain stability, which is not innate and which must be imparted to it by certain devices. This stability is obtained by means of horizontal and vertical tail surfaces, comprising a pair of fixed horizontal fins with movable hinged extensions called "elevators" and a pair of fixed vertical fins with movable hinged extensions called "rudders." Any moment of lability which would tend to increase any undesired departure from the course of an airship without tail planes, is automatically counteracted, to a certain degree, by the moment of stability of the fins and can be completed by means of the elevators or rudders, which, of course, are also employed in changing the course. In order to operate the elevators and rudders readily from the control car, they are balanced as shown by the outline of the elevators in Fig. 10. The entire tail unit is constructed, like the framework of the hull, of duralumin girders and covered with fabric. The thick rigid fins are accessible and have very little external bracing, so as to keep the drag as small as possible.

The control and passenger cars constitute a structural unit built close against the hull under the forward part of the airship. This unit is streamlined and constructed of girders covered with fabric (Figs. 1 and 2).

While we can speak of a comprehensive arrangement of the load in the passenger car alone, all the other loads and equipment are distributed throughout the length of the airship according to the distribution of the lifting forces. When there are no special reasons for placing any of the equipment outside the hull, it is placed in the keel corridor within the hull, the heavier objects being located in the vicinity of the main transverse frames, which can best transmit the resulting stresses to the upper part of the hull. Aside from the control and passenger car, the only portion of the load carried outside the hull is the power plant, consisting of the engines and accessories in special cars located in the unobstructed air current.

Power Plant.- This consists of five independent power units in five separate engine cars (Figs. 11-14). Of these engine cars, which are constructed of duralumin girders strengthened and protected by sheet duralumin on the under side, one is located under the rear portion of the hull, while the other four are suspended in pairs by struts and cables on both sides of the middle portion of the hull. These cars afford sufficient room for the care of the engines and for making such repairs as may be necessary and practicable during flight. They are accessible from the hull by means of ladders and slide doors which are closed when not in use, in order to reduce the drag.

The engines of the ZR-3 were made by the Maybach Engine Company of Friedrichshafen and have 12 water-cooled cylinders arranged in the form of a V in two rows of 6 cylinders each (Figs. 11-14). They were designed with special reference to sureness of functioning for long periods of time. Each engine develops 400 HP at 1400 R.P.M., thus enabling direct propeller drive with satisfactory efficiency and rendering reduction gears unnecessary.

These Maybach engines are designed for using gasoline, the noteworthy innovations being the roller bearings of the crankshaft and connecting rods, as also the reversing device with the aid of compressed air, which is also used for starting The camshaft, as likewise the auxiliary apparatus, is driven by the vibrationless free end of the crankshaft, where there is a flywheel from which the power is transmitted to the propeller through a disconnectible coupling and an intervening shaft. On the operating side there is only the disconnectible air compressor. All operating devices lock automatically, so that a false move is impossible.

Propellers.- Two-bladed wooden pusher propellers are employed and the cars are so located that the projections of the propellers do not come in contact with one another (Figs. 1 and 10). Their tips and leading edges are covered with sheet aluminum for protection against injury from water or other sources.

Radiators.- The water for cooling the engine is re-cooled by a gilled radiator installed in the bow of the engine car, to which the air is admitted through an adjustable shield. The exhaust gases from each row of cylinders pass out through a special air-cooled exhaust pipe into the open air under the car.

In addition to the auxiliary apparatus and instruments required for the operation of the engines, each car has an extra oil tank, cooling-water tank, and two compressed-air tanks for supplementing the compressed air employed in starting and reversing the engines.

Figs. 1-10 show the arrangement and location of the engine cars. Figs. 11-14 show one of the rear pair of lateral engine cars. These figures show, in addition to the arrangement of the engine with the driving gear and propeller, the arrangement of the radiator with adjustable shield, the location of the fuel delivery pipe and the entrance from the keel corridor.

Fuel Storage.- The fuel is stored in the keel corridor, the normal number of tanks being 70, which can be increased to 100 for exceptionally long trips, such as, for example, across the Atlantic Ocean. The fuel tanks are cylindrical aluminum casks with rounded ends, suspended by wires (some rigidly and others so they can be shifted by sliding), usually in groups of three, from the top girders of the keel on both sides of the walkway. In the vicinity of each engine car, there is a group of such tanks for the immediate supply of that engine. These tanks are so placed that the fuel can flow to the engines by gravity, They are replenished from the reserve tanks by means of wind-driven pumps.

The requisite supply of lubricating oil is likewise stored in five aluminum tanks of 420 liters (111 gallons) each.

Ballast.- The keel corridor also contains the ballast and store rooms for spare engine parts, baggage, freight and mail, as shown in Fig. 10. There are two kinds of ballast bags, one for landing-ballast and the other for flight-ballast. The difference is due to the fact that it must be possible to empty the former suddenly, while the latter can be emptied slowly. The former are located near the bow and stern, while the latter are distributed throughout the keel corridor on both sides of the walkway. The former are pants-shaped with the legs downward and can be completely emptied in a very short time by letting the top part fall, thus inverting them. Both kinds of ballast bags are made of three-ply rubberized fabric. There are twelve landing-ballast bags, each having a capacity of 250 liters (66 gallons). The flight-ballast bags have a capacity of 1000 liters (264 gallons) each and are emptied by means of valves, the water flowing out through cloth tubes with aluminum nozzles, so arranged as not to shower any of the cars. For this reason, the forward landing-ballast bags are hung at a considerable distance laterally from the center of the airship.

All the ballast bags can be emptied from the control car.

Control Car.- This contains all the necessary apparatus for navigating the ship, as shown in Fig. 15. Many windows, some of them removable, afford a good view in all directions. A ladder leads to the keel corridor and a door opens into the adjoining passenger car. The apparatus for directional navigation is separate from that for altitude navigation and requires separate attendance. The steering wheel and compass are in the bow of the control car. The elevator wheel and gas and ballast controls, with the instruments showing the altitude, the vertical velocity, the pitch of the airship and the gas and air temperatures are on the port side of the control car, while the telegraph instruments for giving orders to the engine cars, as likewise the telephone to the keel corridor, are on the starboard side, where the map table is also located.

A special coupling device enables the separate or combined operation of the two rudders. For use in case of emergency, rudder controls are also installed in the lower vertical fin, to which post orders can be telegraphed from either the control car or the rear engine car. Dials placed near the steering wheels show the amount of deflection of the rudders and elevators. The most essential aid to navigation is the compass. It is, however, subjected to greater demands on an airship than on a seaship, owing to the greater freedom of motion of the former. The ZR-3 is the first airship to have a triple-gyroscope Anschütz compass. The "mothercompass" is enclosed in a light helium-filled aluminum case on the starboard side near the rudder control, while the "daughter-compass" containing a "rose," is installed directly in front of the steering wheel. This compass immediately shows deviations as small as 0.1°, thus rendering it possible to keep the airship on her course without the application of much force to the rudder.

In altitude navigation, both static and dynamic forces are available for attaining and maintaining a given flight altitude. Since the static lift depends on the weight of the airship and also on the pressure, temperature and humidity of the air and of the gas, as well as on the quantity and character of the latter, it can be changed by releasing either gas or ballast. Gas can be released either by purposely ascending till the safety valves open automatically, or by pulling open the maneuvering valves provided especially for landing. The cords for releasing ballast and gas terminate on convenient ballast and gas boards above the elevator control wheel where they can be operated by handles arranged under a diagram of the airship. The gas cords are arranged so they can be pulled either singly or in groups. The dynamic lift is varied by changing the longitudinal position (trim) of the airship, either by releasing ballast or gas or operating the elevators. The airship can thus be held either below or above its altitude of static equilibrium and can even ascend above its static height limit (ceiling).

The principal instruments required by the altitude pilot are the aneroid barometer and barograph for showing and recording the altitude, the variometer for indicating change in altitude per unit of time, a leveling instrument, for showing the inclination of the airship, and thermometers for showing the temperature of the gas and of the atmosphere. Arrival at the altitude where the airship begins to lose gas is shown optically, through the medium of electricity, and also acoustically. The cup anemometer and the Pitot tube serve to determine the airspeed. For taking the airship's bearings, provision is made in the control car and in the rear end of the passenger car. For astronomical observations, the top of the airship can be reached from the passenger car through a shaft in the main transverse frame.

Orders are transmitted to the engine cars by mechanical signals. Provision is made for communicating with the crew quarters and with the anchor and mast-mooring points by telephone, with a switchboard in the control car. All cables and pipes pass through the keel corridor and are readily accessible.

Radio Room.- The radio outfit is installed in a sound-insulated cabin with pressure ventilation on the port side of the control car (Fig. 1). It consists of a 200 watt radiotelegraphic sender for wave lengths of 500 to 3000 meters (1640 to 9842 feet). It is also selective, with three stages of energy, and has a maximum range of 2500 km (1553 miles). For radiotelephony it has a range of 500 km (310 miles). The receiving apparatus consists of two audion tubes in the secondary circuit and a two-tube low-frequency amplifier for waves of 300 to 20,000 meters. The antenna is a three-part fanshaped antenna, all the wires being weighted and capable of being let down separately or together. For navigation purposes there is also a radiotelegraphic bearing-finder with rotatable loop antenna and wires passing transversely around the hull of the airship. The electric current is generated outside of the radio cabin by an Eisenman combined continuous-current and single-phase alternating-current, wind-driven generator with a capacity of 1200 watts continuous and 1500 watts alternating current. Another generator of the same kind is held in reserve in the airship and both can be used in an emergency with the twelve-celled 60 ampere-hour storage battery joined in parallel with the continuous-current generator.

The continuous-current end of this generator gives a 24-volt current for the electric light plant of the airship. The main switchboard, which is located in the radio cabin, contains a voltmeter, an ammeter, starter for the transformer, insulation tester, switches and safety fuses for the seven circuits and the automatic regulating devices, consisting of automatic switches and current and voltage regulators for limiting the charging current, for the protection of the batteries against overcharging and for regulating the lighting current taken directly from the generator. The 64 lighting points of the whole airship, with lamps of one to fifty Hefner candle power each, are protected by gas and water-tight covers. Special rubber tubes serve as conduits. In the control car there is a connection for a 1000 candle power searchlight with Morse shutters. The 110-volt heating current for the kitchen is furnished by a special 4.5 kilowatt generator with special winding for constant voltage. The gyroscopic compass, likewise, has its own generator. All the electric generators are wind-driven by means of two-bladed and six-bladed propeller-like windmills. Though this method entails some loss of energy, it is more than counterbalanced by the convenient oversight of the sources of power, located in immediate proximity to the points of consumption, and the elimination of long-conducting wires. All the windmills are adjusted for slow flight. During swift flight they can be partially swung in and, when not needed, they can be entirely swung in, so as to diminish the drag.

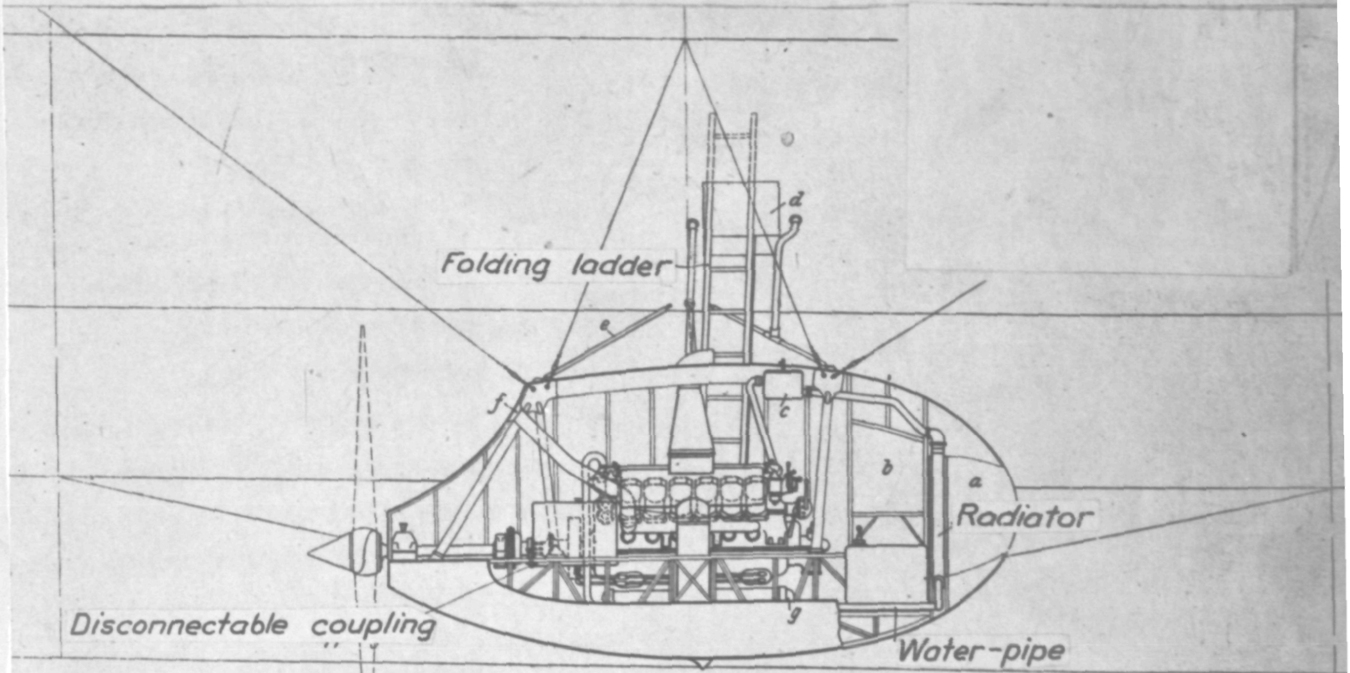
Landing Devices.- By means of trap-doors operated from the control car, two long ropes can be dropped from the bow and a shorter one from the stern of the airship, together with bundles of handling-lines from both these points. The control car and the rear engine car serve as feet for the airship in landing and are provided with shell-shaped shock-absorbers or pneumatic bumpers. For mooring to a mooring-mast, there is a special nose-piece with a mooring cone outrigger and the necessary winch for the mooring cable (Fig. 1).

The rest rooms for the unemployed members of the crew are in the keel corridor, for the navigating personnel near the control car and for the engineers in the middle portion, as shown in Fig. 10. There is a room for the captain, two double bedrooms and a sitting-room for the officers and six double bedrooms, together with two sitting-rooms and a wash-room, for the men. The rooms for provisions, mail, baggage and freight are likewise in the keel corridor and are distributed at many points throughout the length of the airship, as shown in Figs. 1 and 10.

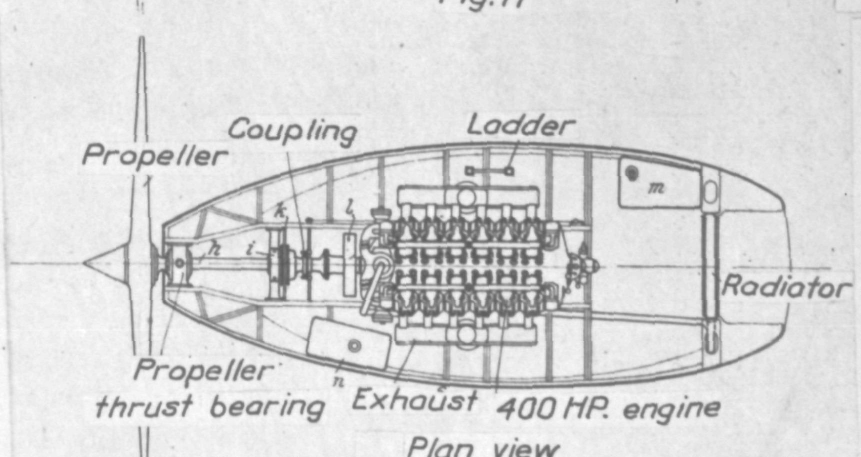
All the rooms for the passengers are in the passenger car. In the front portion, immediately behind the control car, and the radio cabin, there are five compartments with accommodations for sitting and sleeping (Fig. 16), after the manner of a Pullman car. For day and night trips, there are comfortable accommodations for 20 passengers, while 30 passengers can be provided for on shorter trips. Large windows afford a good outlook. Behind the living rooms there are wash-rooms and water-closets on the port side and the food counter, kitchen and pantry on the starboard side. The necessary water supply for use on the airship is stored in aluminum tanks directly overhead in the keel corridor. The kitchen is equipped with an electric range with two cooking plates and temperature regulator, with baking and roasting oven and warm compartment, as likewise a hot-water tank, the walls, floor and ceiling in their vicinity being protected by sheet aluminum.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

a - Air inlet, with adjustable screen
b - Window
c - Water tank
d - Slide door
e - Strut
f - Ventilating pipe
g - Cylinder of compressed air to start engine
h - Propeller shaft
i - Bushing
k - Propeller brake
l - Flexible coupling and flywheel
m - Water tank and seat
n - Oil tank



Elevation
Fig. 11



Plan view
Fig. 12

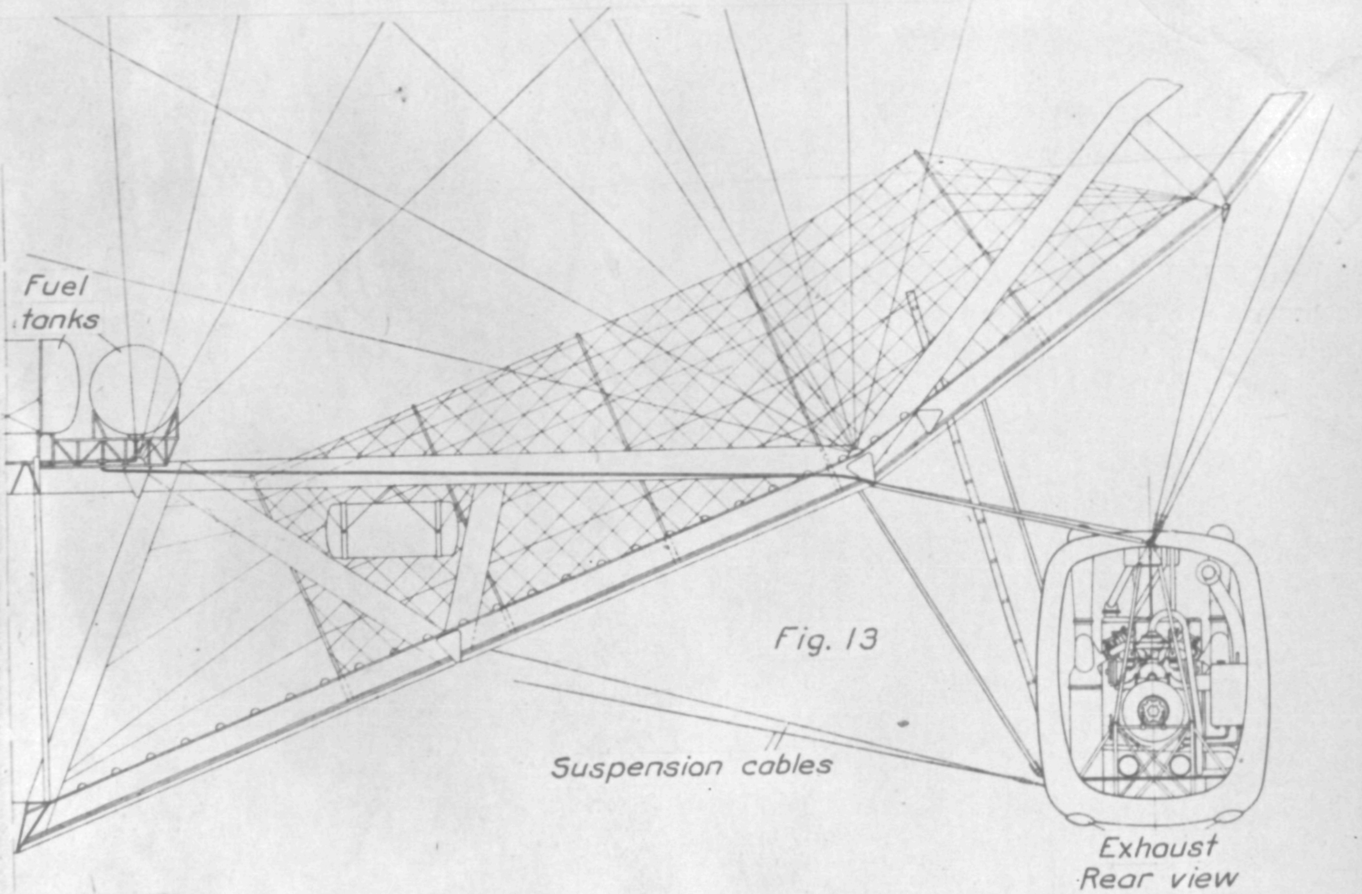

Fuel
tanks
Suspension cables
Exhaust
Rear view
Scale 1:60

Fig. 13

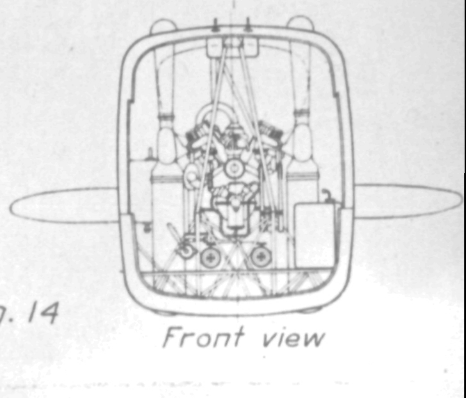

Front view

Fig. 14

a - Barograph
b - Mooring-force indicator
c - Air thermometer
d - Variometer
e - Instrument case for aneriod barometer, stop watch and two inclinometers
f - Lamp to illuminate barometer, etc.
g - Gas-pressure indicator
h - Elevator-deflection indicator
i - Elevator wheel
k - Gyroscopic inclinometer
l - Ballast board
m - Gas board
n - Hand lamp
o - Gas distance-thermometer
p - Magnetic compass
q - Gyroscopic compass dial ("daughter-compass")
r - Light
s - Rudder-deflection indicator
t - Rudder wheel
u - Resultant rudder-deflection indicator
v - Map-table lamp
w - Release for mooring-mast rope
x - Release for landing ropes
y - Searchlight with Morse shutters
z - Signal bell
a_1 - Device for signalling to engineers
b_1 - Telephone with switch-board
c_1 - Telephone junction box
d_1 - Airspeed meter
e_1 - Searchlight switch
f_1 - Control-car light

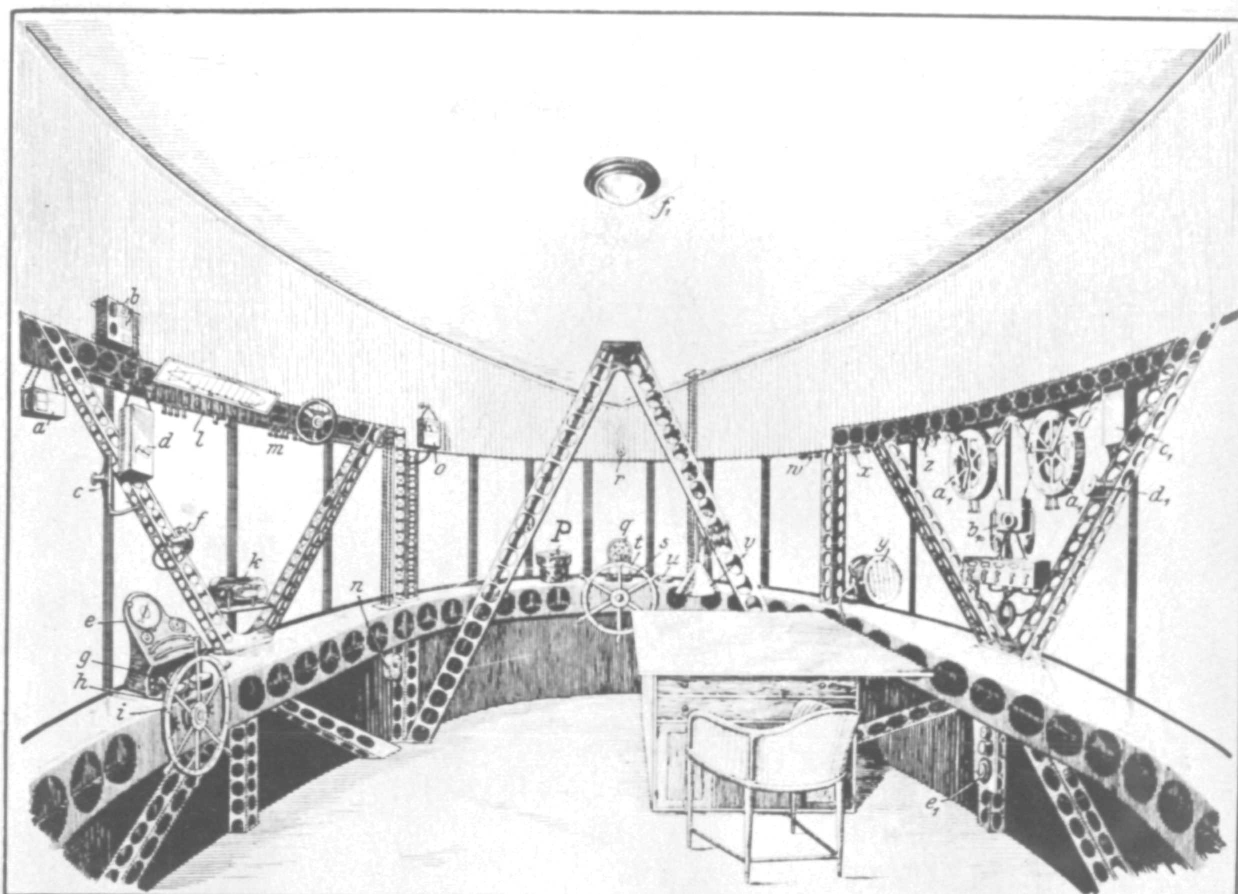


Fig. 15 Control car

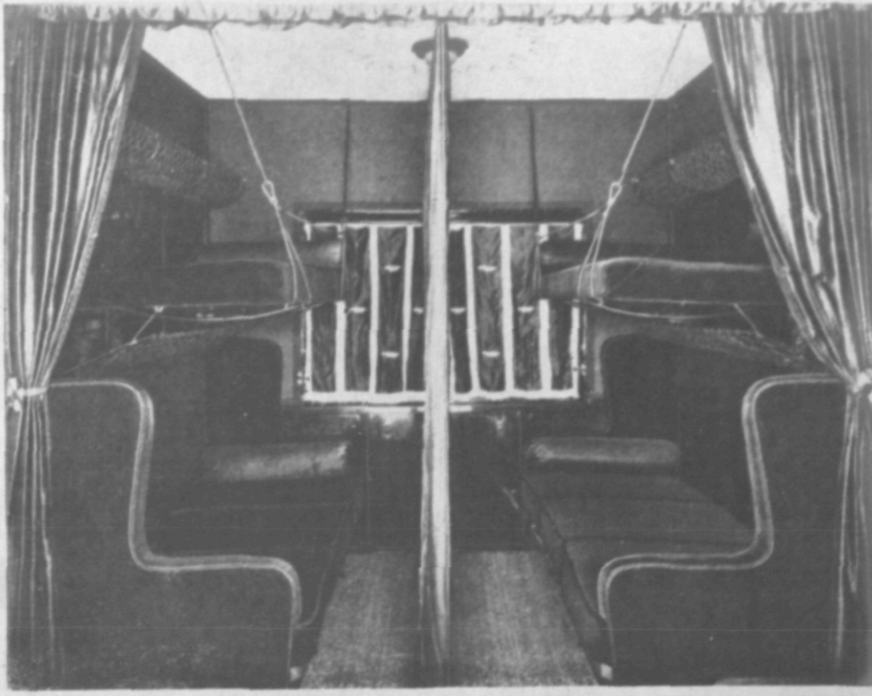


Fig. 16 Passenger cabin. Curtain partition in middle

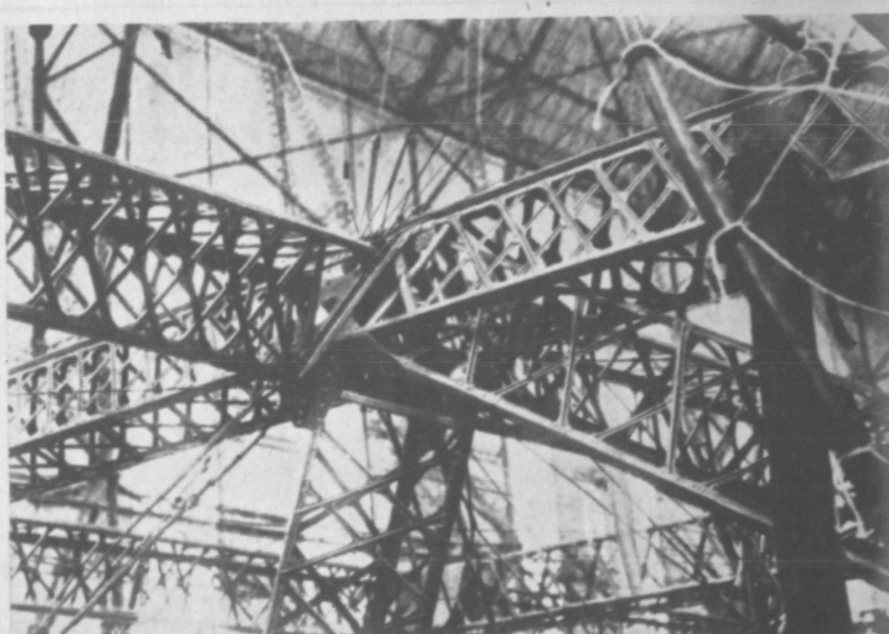
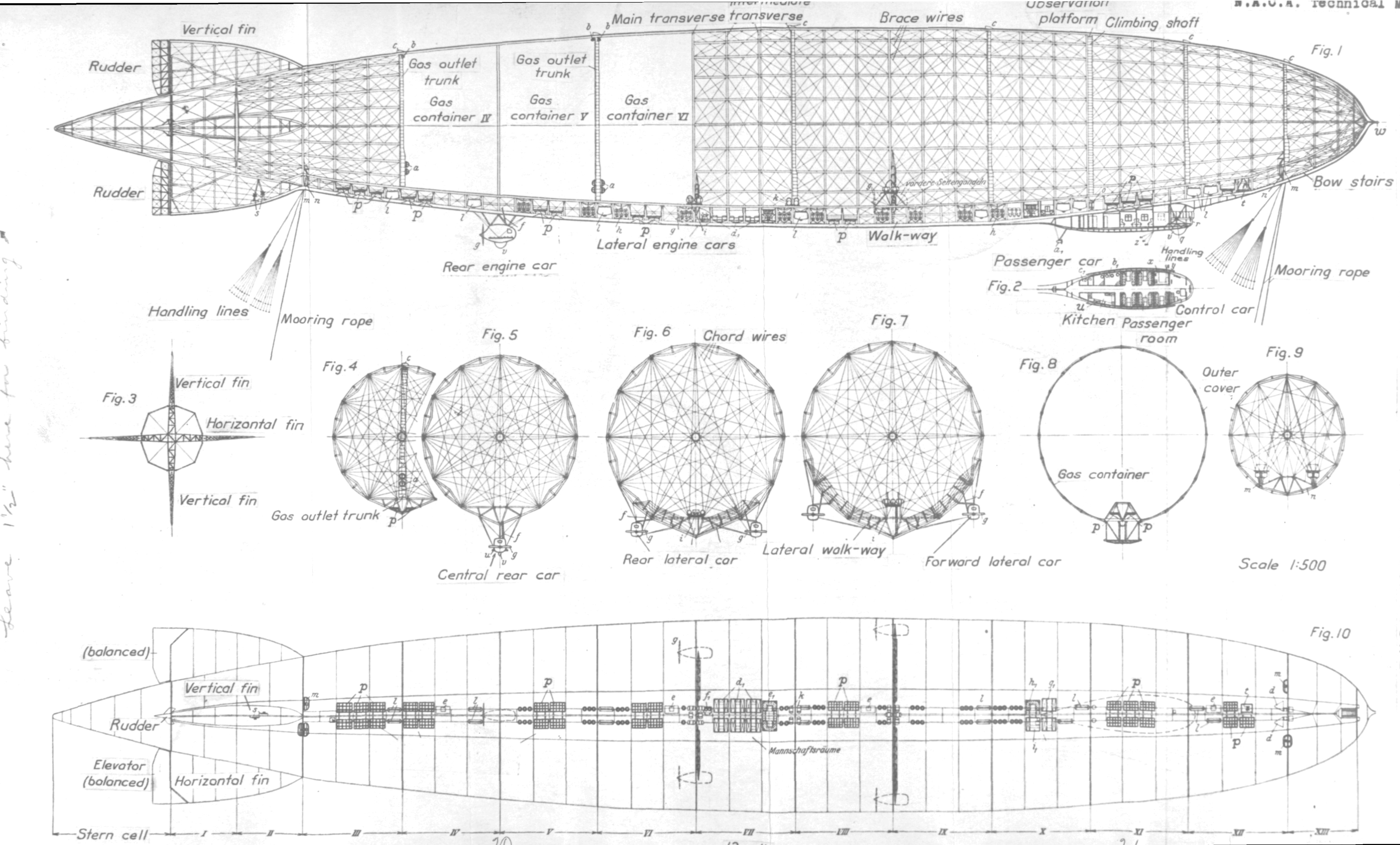


Fig. 17 Union assembly of longitudinal and transverse girders above keel



a - Automatic valve (gas)
b - Maneuvering valve (gas)
c - Bonnet over gas outlet trunk
d - Ventilating valve
e - Slide door
f - Entrance to engine car
g - Propeller
h - Reserve fuel tank
i - Feed tank
k - Oil tank
l - Ballast bags (flight ballast)
m - Ballast "pants" (landing ballast)
n - Entrance to the landing-ballast bags
o - Fresh-water tank
p - Storerooms for spare parts, provisions, baggage, freight and mail.
q - Elevator control wheel
r - Rudder control wheel
s - Auxiliary rudder control
t - Winch for tow-line
u - Hand-rail
v - Pneumatic bumper
w - Mooring cone outrigger
x - Radio room
y - Generator for light and radio
z - Radio antenna
a_1 - Generator for heating
b_1 - Wash-room
c_1 - Water-closet
d_1 - Bedrooms for crew
e_1 - Sitting-rooms for crew
f_1 - Wash-room
g_1 - Bedrooms for officers
h_1 - Sitting-rooms for officers
i_1 - Captains room