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AN INFLATED MOBILE LIFTING SYSTEM FOR AN 8 TON LOAD

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SUMMARY

A system comprising an inflatable load-lifting canopy of oval planform with buoyancy tube and separate trailer for inflation and towing over water has been proved feasible for loads of up to 8 tons over smooth ground and calm water. Limits of performance in more severe conditions have not been determined.

For future applications and in particular for loads of various sizes and load distribution a circular planform canopy should be considered, together with alternative methods of slinging, inflation and propulsion.

When used over porous surfaces and uneven ground, a blower with increased airflow would be of advantage to maintain air pressure and reduce friction and abrasion of the base of the structure.

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* Replaces R.A.E. Technical Report 67190 - A.R.C. 29789

CONTENTS

1 INTRODUCTION

During the early stages of development of hovercraft in 1959, R. & D.E., Cardington adapted a circular ten-men inflatable dinghy as a simple hovercraft by inverting it so that the floor formed a canopy. A secondary floor forming a plenum chamber was added, with peripheral slots and a conical skirt, inflated to a pressure of a few inches water gauge by a small blower powered by a petrol engine. A second engine drove a small airscrew for propulsion. Although this device hovered on a smooth surface it was seriously underpowered and deficient in control. However, this experience suggested that a buoyant ring with an inflated canopy would provide a cheap, light and portable means for lifting a load to cross, or for recovery from soft ground, bogs and water.

At the request of AD/AR a simple canopy or tent with an inflatable buoyancy ring was built, using a standard proofed cotton dinghy fabric (Fig.1). In tests over smooth ground and on calm water loads of approximately one ton could be lifted by wires secured to sixteeen strengthened patches attached inside the upper part of the canopy. Because the canopy was distorted by the application of the load there was difficulty in preventing the buoyancy ring from bending upwards in the middle of its straight portion. Escape of air from this cause was prevented by a curtain or carpet extending inwards from the bottom of the buoyancy ring. Above this carpet a fabric floor and wall provided a catwalk for movement of personnel when on water.

Towards the end of 1961 the War Office became interested in devices of this class mainly for the recovery of heavy vehicles but also as a means for vehicles to cross soft ground and rivers. This latter use was less promising because of the difficulty of entering and leaving the water where the bank was high and steep. Two theoretical papers on inflated lifting structures[1,2] were prepared by Mech. Eng. Dept., R.A.E. and a design study was requested by F.V.R.D.E. for a system to lift a 50 ton tank. It was considered that this was too large a step from the original one ton model and that a load of about five to ten tons should be investigated. F.V.R.D.E. offered to provide on loan a vehicle having an all up weight of eight tons and to assist with the development and provision of inflation and transport equipment. This report records the design, construction and trials of the resulting system.

2 DESIGN AND CONSTRUCTION OF LIFTING SYSTEM

2.1 Fabric structure

With regard to the inflated canopy or tent, a circular planform gives the simplest structure and allows the load to be lifted by a sling from a central point or a number of points evenly distributed about this point. If a load with a large length to width ratio is to be carried however, there is much wasted floor area, high weight and windage and increased difficulty in erecting the fabric canopy over the load. An oval planform was therefore chosen, to enclose the load as closely as possible and thus give the most compact and lightest system, as discussed in Ref.2. This is shown in Fig.2. A model of one tenth scale was first made to this design in light, proofed fabric without a buoyancy tube. When tested on water the model was stable until forcibly heeled to an angle sufficient to lift the lower lobe of fabric clear of the water on the side which was highest, when it sank owing to loss of inflation pressure. As the proposed load is relatively high in proportion to its width a buoyancy tube was considered necessary to counter this risk. Furthermore, the tube may be hinged in the middle to allow easy erection of the canopy over the load, thereby assisting the initial inflation of the tent and providing semi-rigid attachment surface for towing ropes and seating for the crew. A fabric catwalk attached to the buoyancy tube enables the crew to move about, make necessary rigging adjustments and control the air supply. A flexible curtain is fitted below the catwalk to prevent escape of air on rough surfaces.

For the canopy, two basic methods of construction were considered:

(1) In the form of a parachute in which generator cords[1] form the main strength members and in which a fairly light fabric is used to take the tensions normal to these cords,

(2) as a membrane similar to a tent or balloon, in which all the forces are contained by the fabric[2].

The latter form was chosen, not because of any foreseeable advantage in the completed system but because it could be most readily manufactured at Cardington.

Dimensions of the main structure are: length 41 feet, width 23 feet and height 15 feet. When supporting a load of eight tons the inflation pressure is approximately 8 in water gauge (40 lb/ft^2), which results in a tension in the upper lobe of approximately 17 lb/in. A three-ply cotton dinghy fabric to Spec. DTD 537 with a strength of 100 lb/in and weight of 8 oz/yd^2 was used, because it was already in stock at Cardington. This material was joined with adhesive K.B.63 self vulcanising solution.

The buoyancy chamber is 2 ft in diameter of cross-section and is divided into four compartments interconnected by a valve system as described in section 2.3. The fabric used is Neoprene-proofed nylon to Dunlop Spec.7987 joined with Multigrip L31 neoprene adhesive. Its strength is 400 lb/in width and weight 28 oz/yd^2. With this material it is necessary to apply tapes both internally and externally at the seams to prevent air leakage. When inflated to the designed pressure of 2 lb/in^2 the hoop loading is only 24 lb/in: the heavy material was used mainly to resist rough handling and abrasion.

Because the elastic moduli of the cotton and neoprene fabric are different some adjustment was necessary when seaming the buoyancy tube to the canopy. The total weight of the fabric structure is approximately 420 lb. With later developments in synthetic fabrics and further experience of this type of structure, a lighter weight could almost certainly be achieved.

2.2 Load and method of slinging

Fig.3 shows the Bedford cargo truck provided on loan by F.V.R.D.E. Alterations to the vehicle were not permitted, so that it was necessary to suspend it from existing strongpoints such as wheel hubs, small lift rings along the sides of the body, the rear tow hook and front bumper attachment points. The weight distribution varies according to the loading of the vehicle: when unladen the greatest weight is on the front axle and when laden the greatest weight is on the rear axle.

An even distribution of the load round the perimeter of the upper canopy lobe is important to the success of this design. In this region 38 suspension patches with a strength of half a ton were fitted to suspend the load. Because of the lack of matching attachment points on the vehicle, difficulty was expected in obtaining even distribution of the load and therefore in maintaining the designed shape. This problem could have been solved by increasing the height of the structure and taking the load on catenaries or by the use of a circular canopy with the load carried on a sling from a central point. It was, however, considered that an attempt should be made to produce a structure of the smallest packed bulk and lowest windage when inflated.

The variable C.G. position of the vehicle makes necessary some margin for fore and aft movement to keep the C.G. vertically in line with the centre of air pressure of the structure. The additional length which was provided for this purpose also simplifies erection by allowing the buoyancy tube to be hinged to fold over the vehicle.

In addition to the cords or wires to take the weight of the load, it is necessary to provide three further restraints: horizontal or nearly horizontal lashings to centralise the load with respect to the base, vertical cords to stabilise the load at the desired height and horizontal ties across the straight part of the buoyancy chamber to react the effect of inflation pressure. In practice it was found possible to use cords at about 45° to the horizontal to combine functions of the first two restraints.

2.3 Inflation and towing equipment

It was a requirement that the system should form a self-sufficient unit with the loaded vehicle. There was not enough room on the laden truck to mount the inflation unit or to carry the valise containing the fabric structure. The inflation unit might be mounted on the cab top but this was ruled out because the necessary modifications to the vehicle which was on loan, were not permitted. Provision would also be necessary for a hot exhaust pipe to pass through the canopy. It was therefore decided to carry the equipment on a trailer which could be buoyant and able to act as a tug for the system when crossing water, Fig.4. A standard Service fibreglass trailer was provided by F.V.R.D.E. and was given additional buoyancy in the form of an inflated ring fitted round the top of the body. Two 5 H.P. Seagull outboard motors with large diameter slow-running propellers to suit the towing conditions were clamped to the rear.

The blower unit comprised a 12 H.P. J.L.O. petrol engine and Shorrock supercharger driving a 15 inch Airscrew-Weyloc HEBA fan which delivered 2000 cubic feet of air per minute at $11\frac{1}{2}$ in water gauge, rising to 4000 cu ft/min at 4 in water gauge.

Fig.5 shows the arrangement of the inflation system for the buoyancy chambers. Procedure for inflation is as follows:-

(1) Air is fed from the blower to the front chamber of the buoyancy tube.

(2) When pressure reaches $1\frac{1}{2}$ lb/in^2 the pistons in the port and starboard automatic valves move to uncover ports which feed air into the rear chamber. At this stage the hinge is not inflated and the rear chamber can be hinged forward to allow entry of the vehicle, then hinged back to pull the canopy in place over the truck.

(3) Pumping is then continued to inflate the hinges. When pressure rises to 2 lb/in^2 further movement of the piston uncovers vents to prevent further pressure rise.

(4) If any compartment is damaged or intentionally deflated by opening release valves this reduces pressure so that the pistons in the automatic valves move back to seal off the air in the undamaged chambers.

3 TRIALS

3.1 Inflation with unladen vehicle

For this initial trial the unladen Bedford truck was used. Inflation was done on a smooth floor, using an electric blower, as the trailer blower was not ready. To speed up and simplify the operation of slinging the vehicle the half-ton patches were bridled together in pairs.

Lifting was attempted with no personnel inside the canopy because of possible danger of the load overturning or of injury from a breaking tie rope. It was therefore not possible to adjust the lengths and tensions of the ties under full inflation conditions. Pressure was raised until the vehicle was seen to rise on its springs. It did not leave the floor completely and one of the ropes to a lifting bridle parted. Some suspension patches were found to be strained, owing to unequal loading: some patches holding the horizontal ties were also strained.

3.2 Lift with 2 ton load

The vehicle was replaced by a trailer loaded to a total weight of two tons. This was raised from the floor with a pressure of 2 in water gauge, confirming that an 8 ton load should be lifted with the designed pressure of 8 in water gauge. With a pressure of $2\frac{3}{4}$ in water gauge a wheel clearance, from the floor, of four feet was obtained. The load was then increased to 5500 lb and again successfully lifted.

3.3 Patch replacement

An improved patch with a triangular link was developed and tested in sizes to support 2 tons, 1 ton and $\frac{3}{4}$ ton. Twelve 2 ton patches were fitted to the parallel sides of the canopy, fourteen 1 ton patches were fitted to the semi-circular ends and ten $\frac{3}{4}$ ton patches were fitted to the buoyancy tube: 36 patches in all.

3.4 Lift with 5000 lb vehicle

After fitting the improved patches, a smaller vehicle with a weight of 5000 lb was successfully lifted and it was proved that the system could then be moved by one man over the smooth floor. Inflation pressure at lift-off was $1\frac{1}{2}$ in water gauge and in the "hovering" condition for movement over the floor it was $2\frac{1}{2}$ in water gauge.

3.5 Measurement of rope loads with unladen Bedford truck

For tests with the Bedford truck it was decided to check the loads in the wires by dynamometers which had been calibrated on a tensile test machine. This entailed considerable time and effort as the empty vehicle had to be lifted approximately 50 times to obtain a set of readings and some of the loads obtained were beyond the range of the dynamometers. On a previous trial two wires connected to a wheel hub had broken due to compression of the vehicle springs; a cross beam was then fitted so that all wires came directly from the chassis.

To obtain more accurate readings it would be necessary to fit strain gauges in all the wires, connected to a recording instrument in the vehicle. This could give a record of the dynamic, in addition to the static loading.

In view of the high cost of this full instrumentation a single strain gauge was used to take those readings beyond the range of the dynamometers, but it was only possible to measure static loads by this method. A complete set of readings, giving the loads in the wires when raising the unladen vehicle, is shown in Figs.6 and 7. The highest reading recorded was 820 lbf.

3.6 Trial on water pool

In view of the forces recorded in the foregoing test it was considered safe to launch the vessel with the unladen vehicle on the pool at Cardington. There was some difficulty in launching down the slope into the pool as both trailer and vessel have to be launched together, with the pump unit in operation. However, the vessel floated with the load and was brought ashore without damage, although it was difficult to haul it out of the water up the ramp.

3.7 Full load lift

A full load of sandbags and concrete blocks was then added to the vehicle, making an all up weight of 16868 lb. The vessel was lifted satisfactorily on a smooth floor.

3.8 Test by F.V.R.D.E. at Hawley Lake

A demonstration was subsequently made at Hawley Lake in which the vessel was inflated over the vehicle, launched down a sloping beach and towed by the trailer at a speed of approximately three knots in calm water.

When beached at the end of the trial the vehicle was able to drive above the waterline for folding of the canopy.

3.9 Test on shingle at Browndown

The system was inflated with the unladen vehicle on coarse shingle at the 1966 Hovershow at Browndown. Unfortunately, the 12 H.P. pump unit was not available. Using a 3 H.P. electric blower, it was found that the loss of air through the coarse shingle was too great to enable the necessary pressure for lifting the vehicle to be obtained.

4 DISCUSSION OF TESTS

As regards erection of the inflatable canopy over the load, the hinged buoyancy tube was found almost essential and it is thought that larger canopies would require some additional lifting gear. It was sometimes possible to position the structure and the load so that the canopy was partly inflated by the wind as the hinged portion was unfolded. When this is not possible there is a risk of the canopy fouling the load.

Slinging the load to give the designed canopy shape and at the same time to avoid serious difference in tension in the rigging lines was difficult. This was partly due to the lack of suspension points around the vehicle resulting in some of the lines not being at the correct angles to give even stress distribution. A structure of circular planform with a central lifting point (or series of points symmetrically disposed about the centre) and carrying the load on slings or on a pallet, would avoid this trouble. It would be bulkier for a given payload but attractive for rapid movement of loads of the order of one ton. Some of the canopy fabric, which had deteriorated with age and unfair loading in the early tests, was replaced. In view, therefore of the mixture of fabrics it was not considered worthwhile to continue investigation of this problem with the full load.

Although this system has been successfully tested over smooth ground and calm water it has been considered inadvisable to make trials over rough surfaces or in high winds because of the danger of losing the vehicle or damaging it by overturning. On rough surfaces the worst problem appears to be the wear of the buoyancy tube by abrasion. Some help is given by the inner skirt in retaining the air and allowing the tube to ride almost clear of the ground but over porous surfaces, such as shingle, the air supply provided by the 12 H.P. blower may possibly be inadequate to achieve this. The trailer developed for this structure had only a few inches of freeboard and would be swamped in rough weather even when crossing rivers of moderate size.

5 APPLICATIONS

There are numerous possible applications for devices operating on the principles described in this report. Some of these are listed below:-

(1) Transporting heavy machinery over weak floors, heavy cargo over decks. Transporting heavy equipment over weak bridges.

(2) For launching boats into shallow water ferrying to deep water and lowering. Crossing reefs, sand bars, beaching etc.

(3) To lift and transport machines and office equipment such as computers over polished floors without scoring or damaging floor.

(4) To take pylons, and heavy gear over soft ground or farmland without causing deep ruts or churning up the ground.

(5) To recover stores and equipment from soft sand, marsh and beach locations without bogging down.

(6) To lift or raise objects on soft ground or embedded in the ground when a crane is not available, or would become bogged.

(7) To assist in raising buried, or submerged objects in mud, water, sand etc.

(8) Aircraft recovery.

6 CONCLUSIONS

A system comprising an inflatable load-lifting canopy with buoyancy tube and separate trailer for inflation and towing over water has been proved feasible for loads of up to eight tons over smooth ground and water. Limits of performance in more severe conditions have not been tested.

For future application and in particular for loads of various sizes and load distribution a circular planform canopy should be considered, together with alternative methods of slinging, inflation and propulsion.

When used over porous surfaces and uneven ground, a blower with increased airflow would be of advantage to maintain air pressure and reduce friction and abrasion of the base of the structure.

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No.	Author	Title, etc.
1	W.G.S. Lester	Inflated mobile lifting structures: Analysis of generator-cord construction for circular planform. A.R.C. R. & M. 3377, 1962
2	I.S.H. Brown	Inflated mobile lifting structures: Analysis of membrane construction and design optimisation for oval planforms. A.R.C. R. & M. 3378, 1962

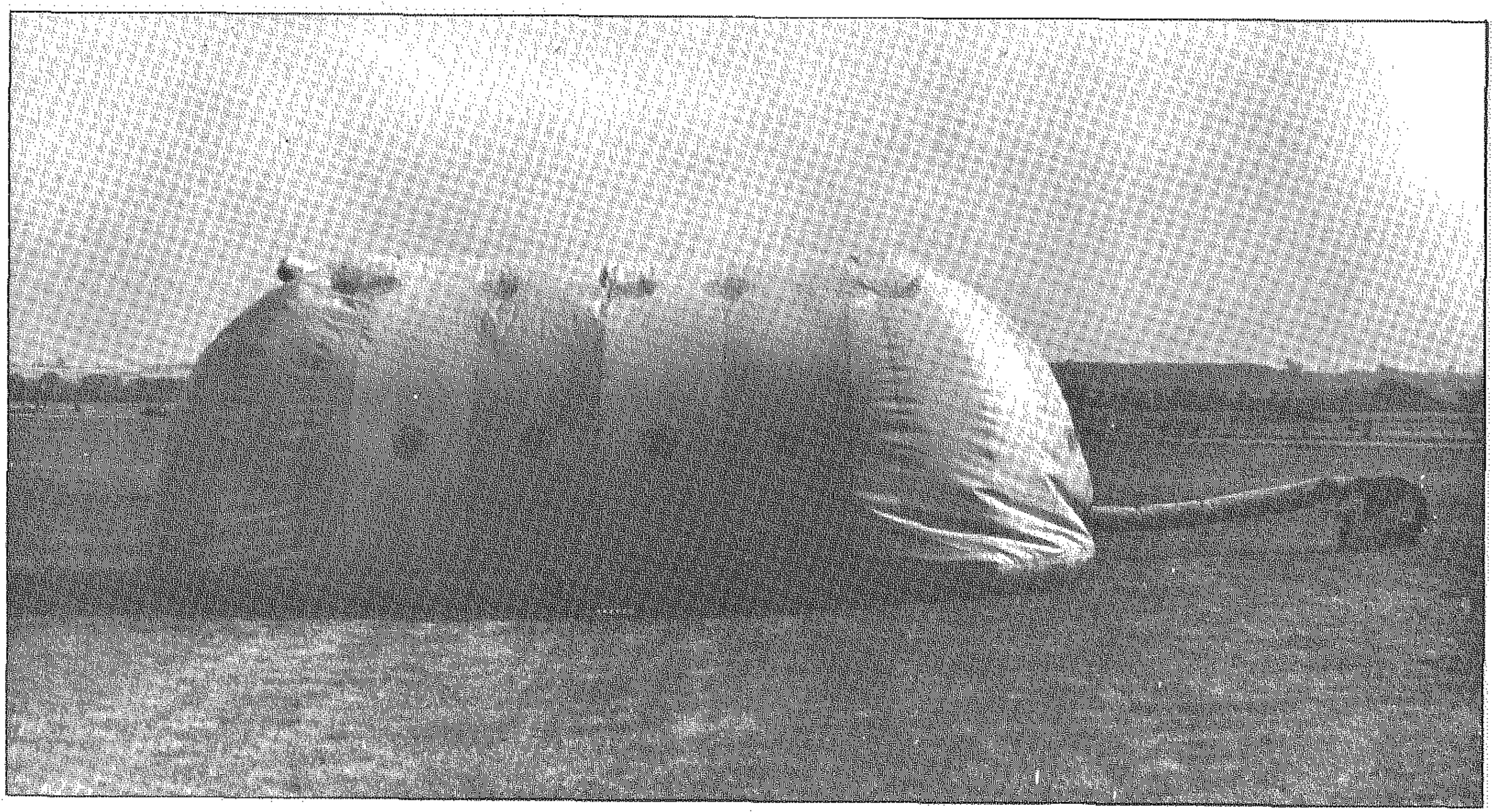


Fig.1. One-ton lifting system

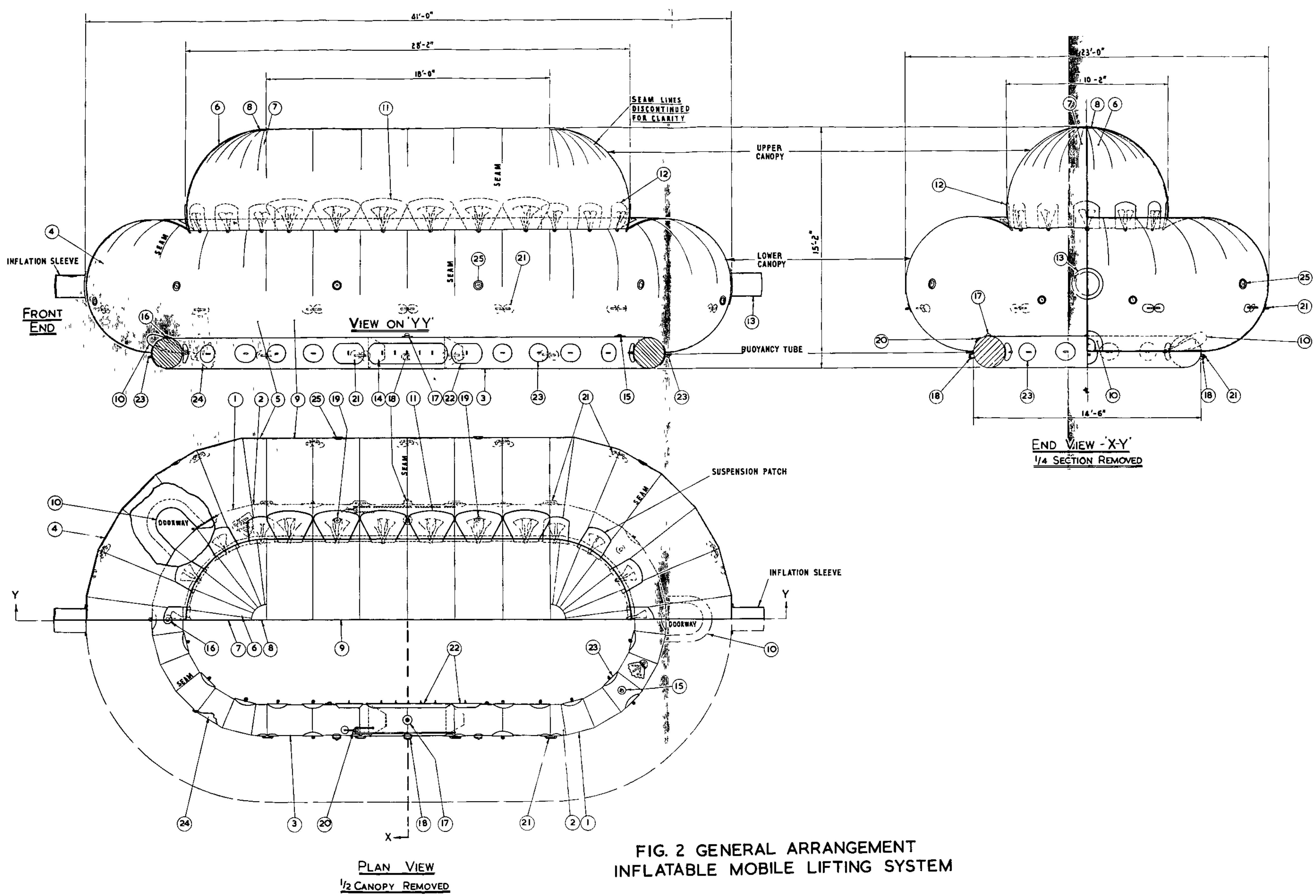
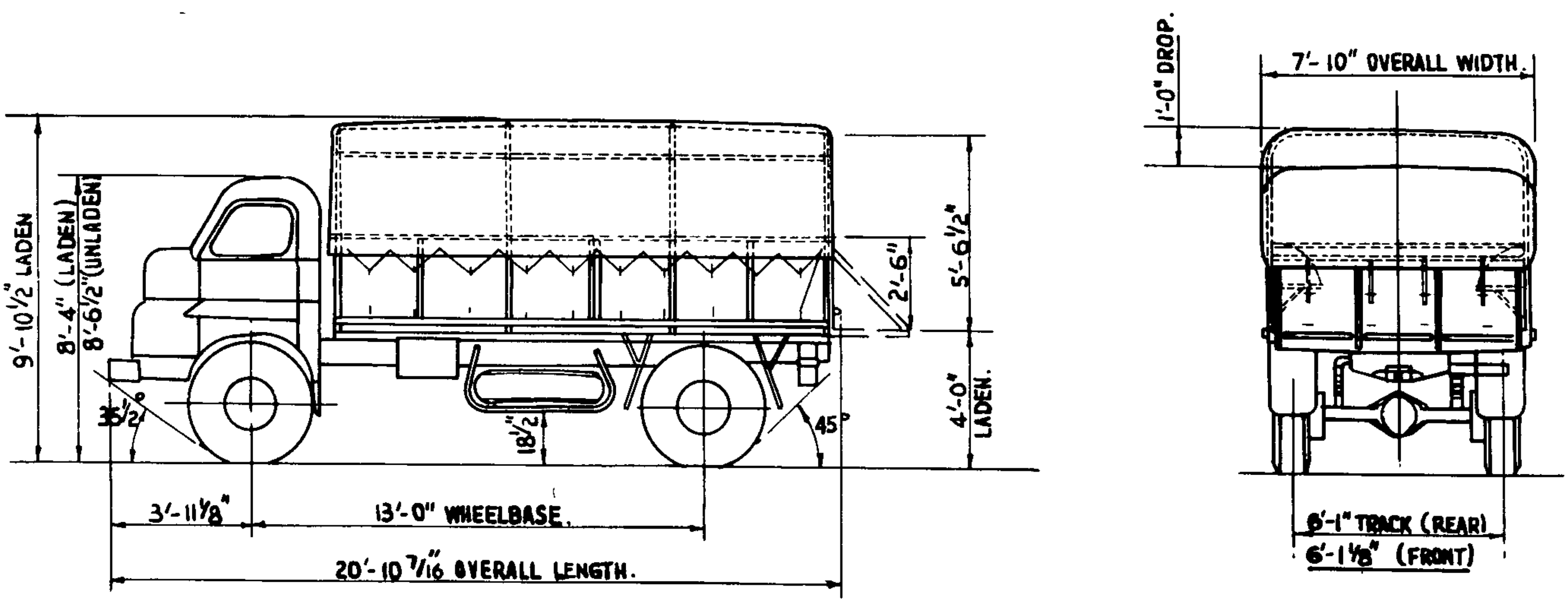


FIG. 2 GENERAL ARRANGEMENT
INFLATABLE MOBILE LIFTING SYSTEM

INTERNAL BODY DIMS. { LENGTH 168" / WIDTH 84" / HEIGHT 30" }



	FRONT AXLE	REAR AXLE	TOTAL
UNLADEN	2 TONS 6 CWTS.	1 TON 13 CWTS. 2 QRS.	3 TON 19 CWTS 2 QRS
LADEN	3 " 8 "	4 " 8 " 2 "	7 " 16 " 2 ".

TYRES 11.00 x 20.

SCALE:- ¼" = 1 FT.

FIG. 3. 3 TON 4 x 4 G.S. (BEDFORD) CARGO TRUCK

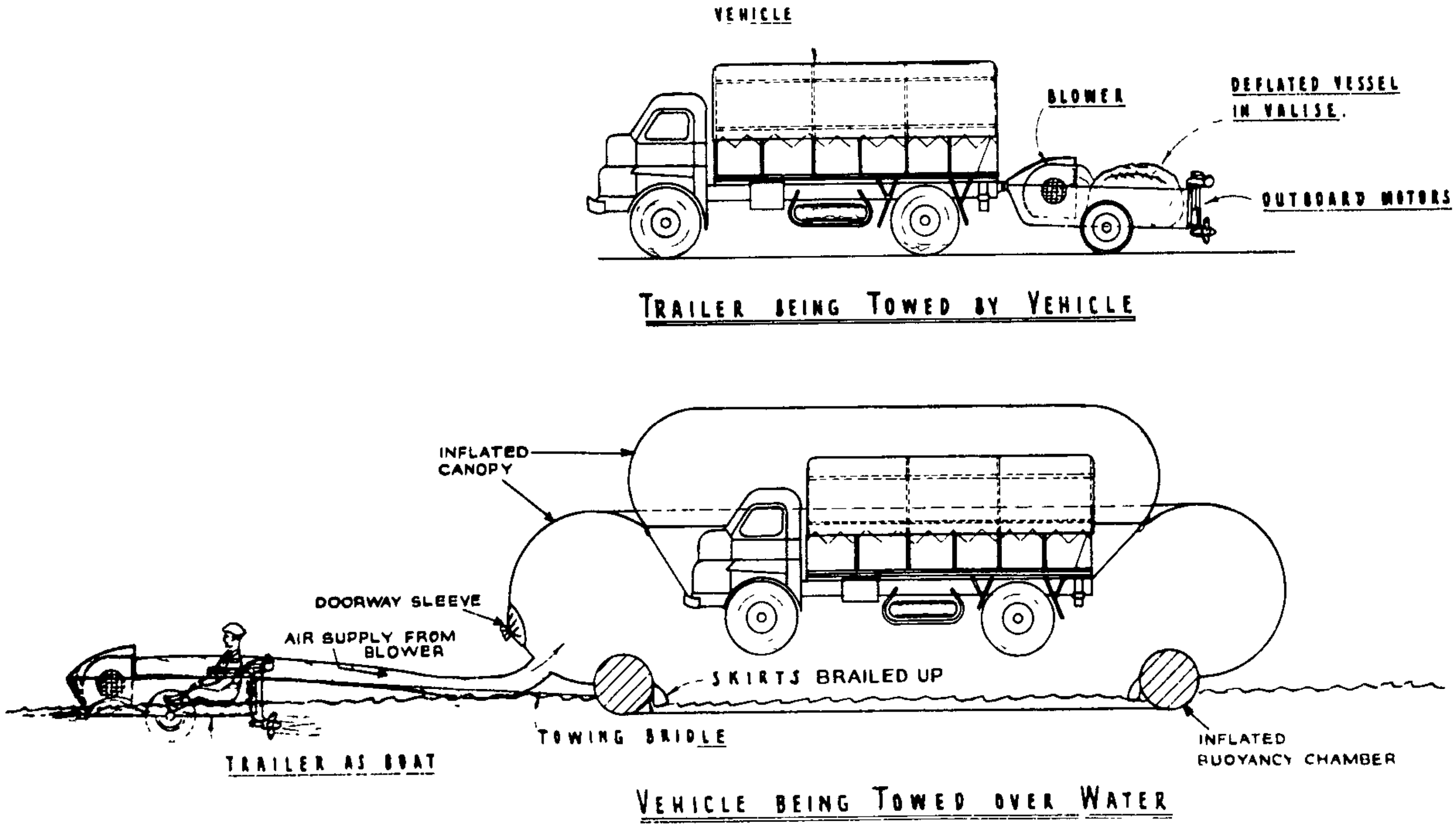
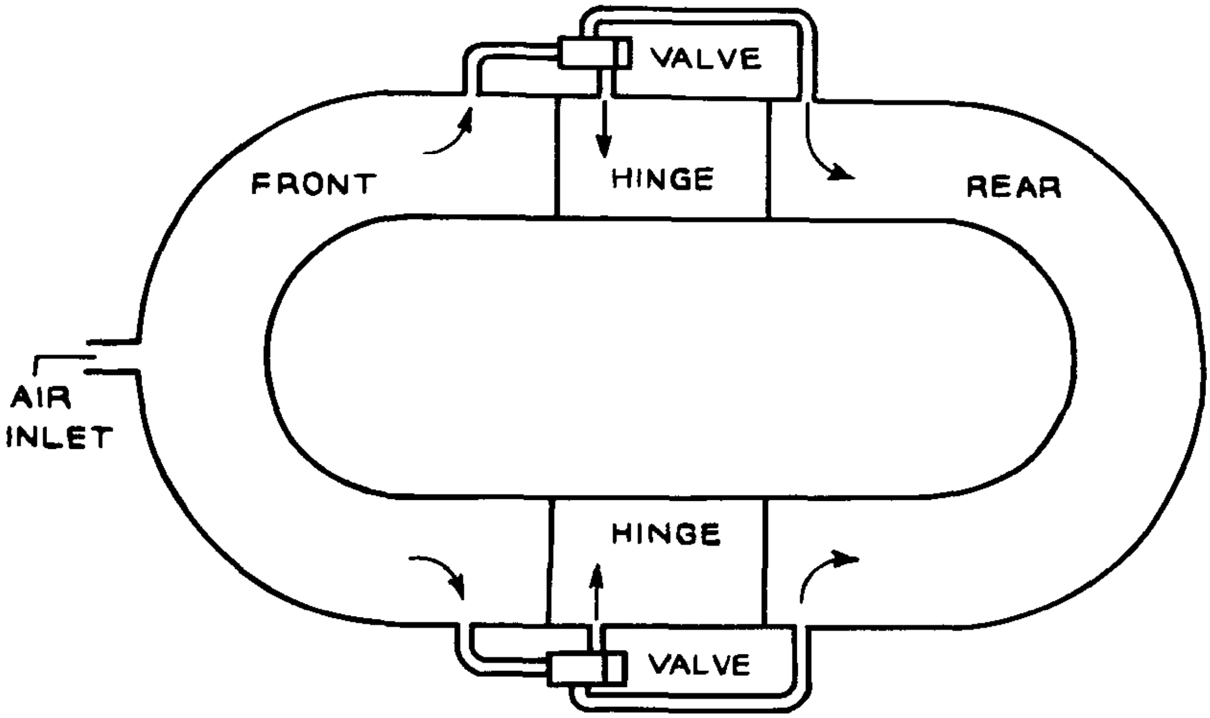
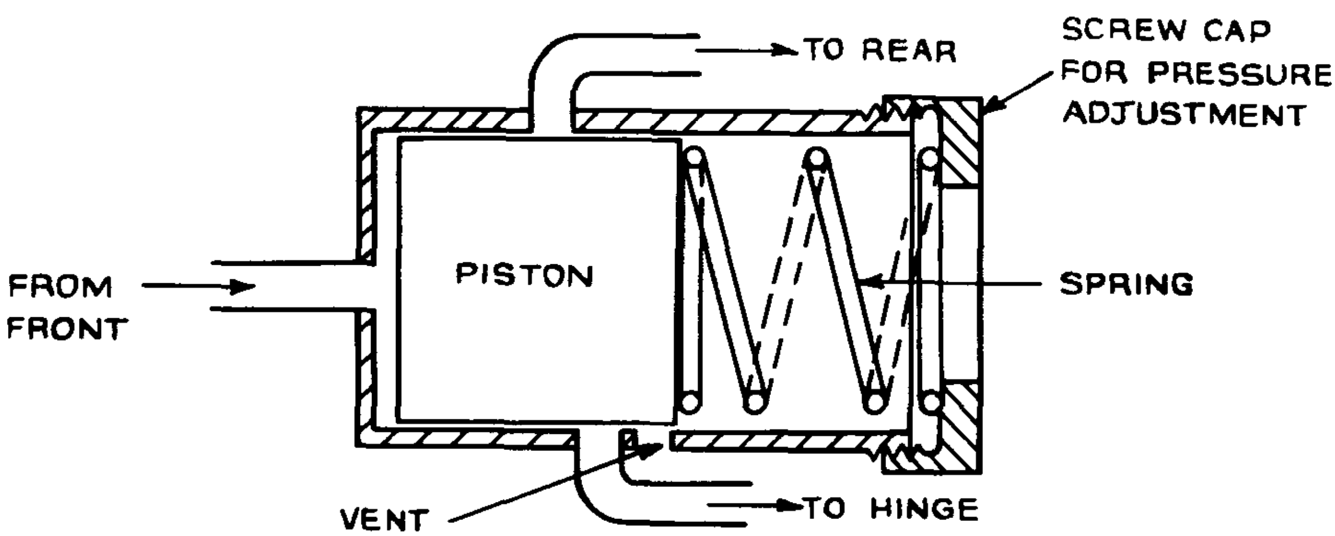


FIG 4 8 TON MOBILE LIFTING SYSTEM

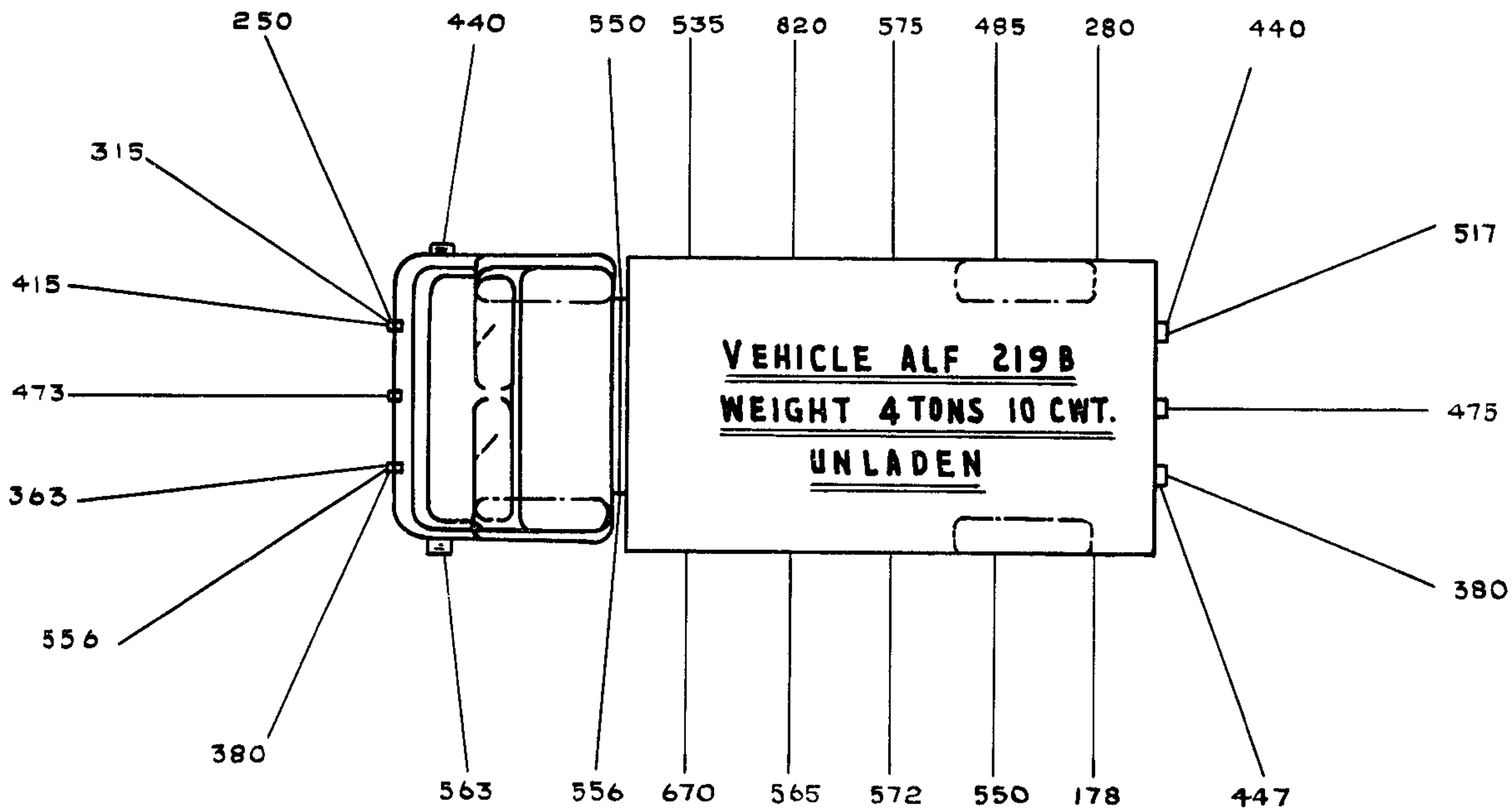


COMPARTMENT ARRANGEMENT



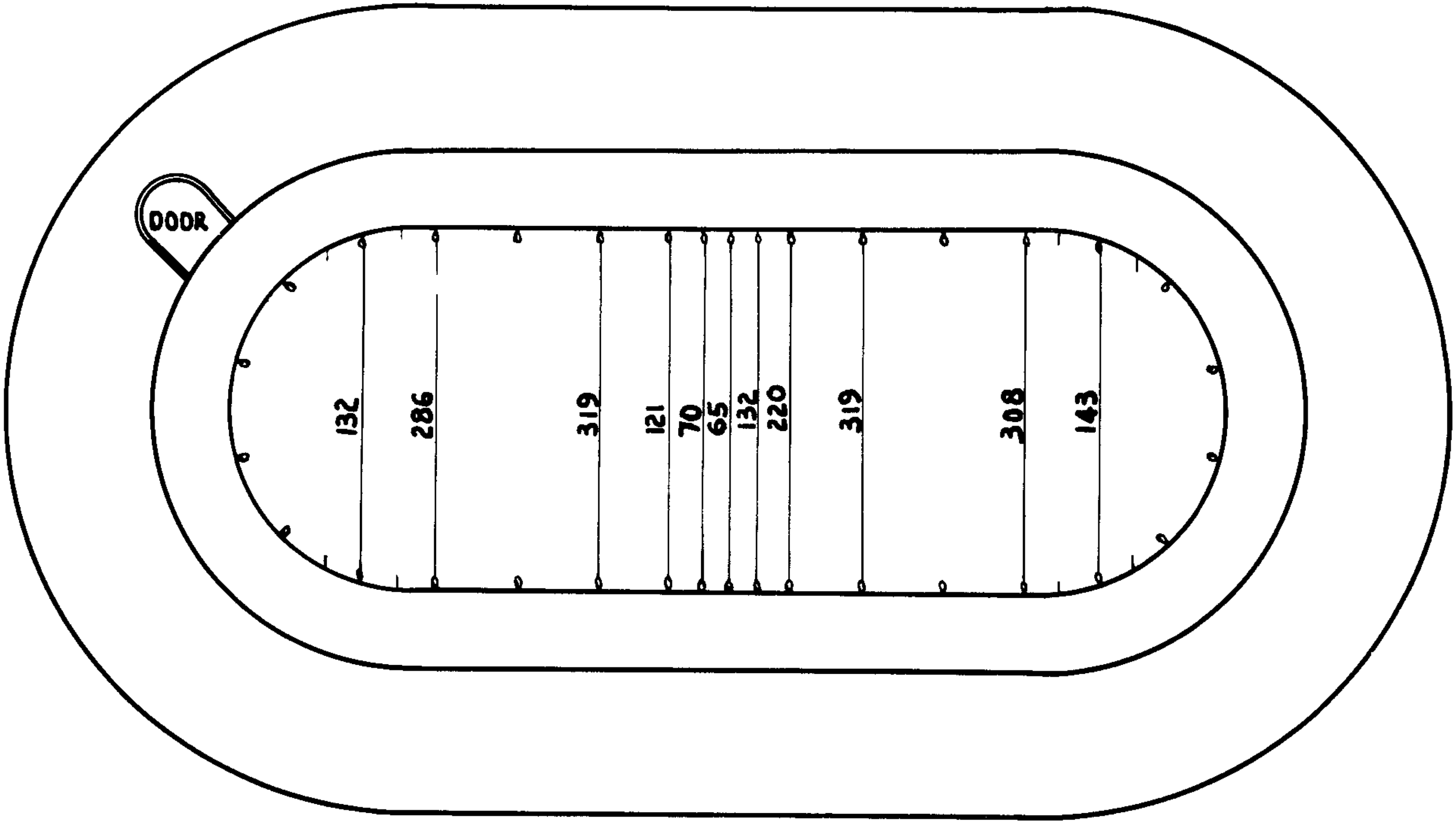
AUTOMATIC VALVE

FIG. 5 BUOYANCY TUBE INFLATION SYSTEM



LOADS IN LbF

FIG. 6 LOADS IN RIGGING LEGS OF LIFTING VESSEL



LOADS IN LbF

FIG. 7 LOADS IN BUOYANCY TUBE CROSS TIES

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DETACHABLE ABSTRACT CARDS

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