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A PRACTICAL CONCEPT FOR POWERED OR TETHERED WEIGHT-LIFTING LTA VEHICLES

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ABSTRACT: This paper will deal with a concept for a multi-hull weight-lifting airship, based upon the author's experience in the design and handling of gas-filled balloons for commercial purposes. The concept was first tested in April, 1972. In the flight test, two barrage balloons were joined side-by-side, with an intermediate frame, and launched in captive flight. The success of this flight test led to plans for a development program calling for a powered, piloted prototype, a follow-on 40-ton model, and a 400-ton transport model. All of these airships utilize a tetrehedric three-line tethering method for loading and unloading phases of flight, which bypasses many of the difficulties inherent in the handling of a conventional airship near the ground. Both initial and operating costs per ton of lift capability are significantly less for the subject design than for either helicopters or airships of conventional mono-hull design.

The French company LA GRUE VOLANTE (hereinafter referred to as LGV) was founded to exploit the potential of a design configuration for a weight-lifting LTA vehicle offering greater economy and ease of handling than airships of the Zeppelin type.

PART I: PRESENTATION OF THE LGV CONCEPT RESEARCH PRINCIPLES

Because the static lift of a Lighter Than Air gas such as helium has a maximum figure of 1.1 ounces per cubic foot at sea level, and a portion of this lift must be converted into useful load, an airship has necessarily a very light structure. This fact limits its resistance to weather factors, particularly the force and turbulence of wind, and imposes limitations on the control surfaces, increasing the difficulty of piloting large volumes in buoyant equilibrium while accommodating different variables such as the pressure and temperature of both ambient air and internal gas (on which sunlight or the absence thereof, clouds, rain,

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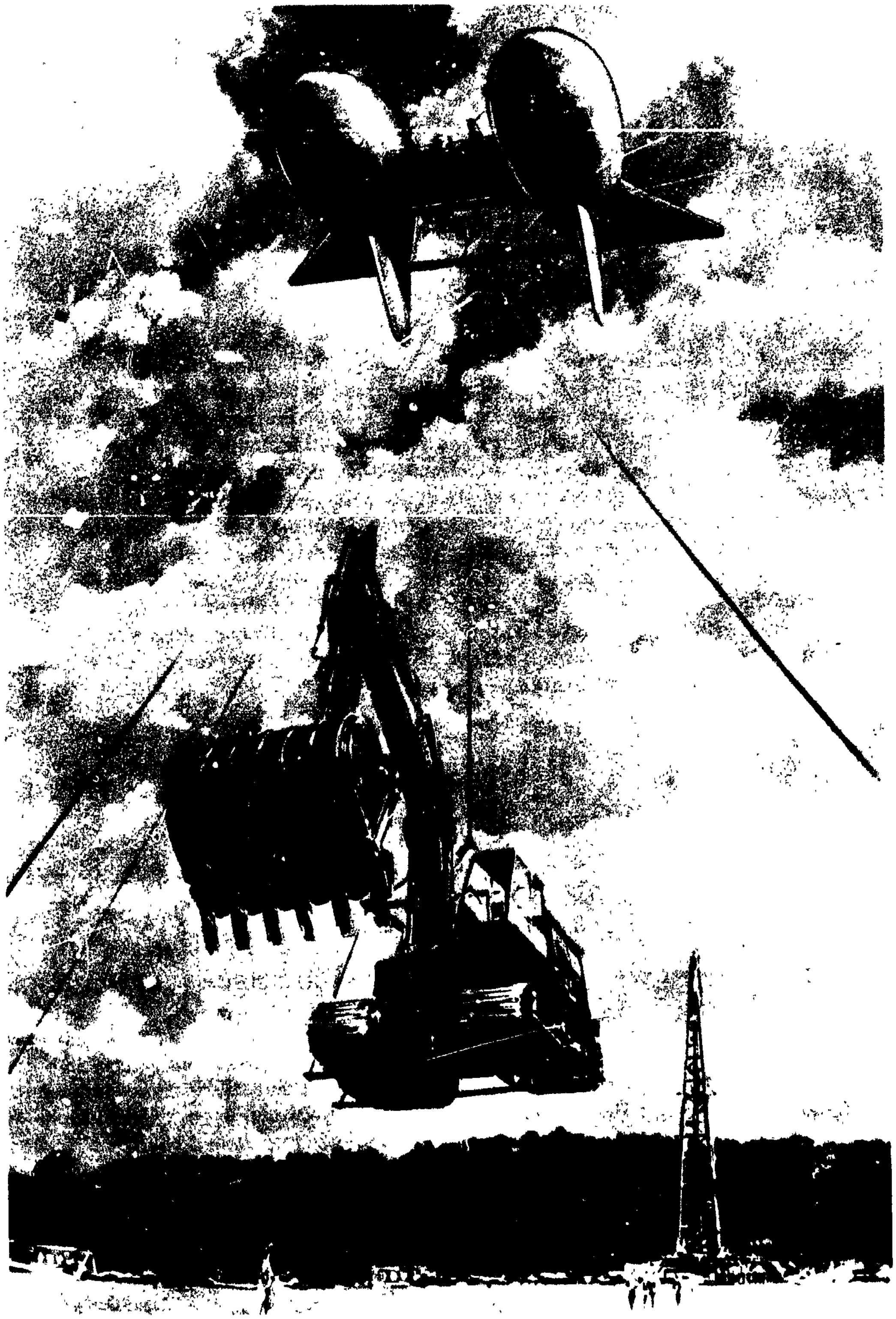

Artist's perspective of LGV weight-lifting LTA vehicle, illustrating tetrahedric tethering principle.

and snow can play a role) and the aerodynamic strength and shape of the balloon. All of these factors can vary simultaneously or at different times; some are very difficult to forecast accurately. The effect of slight differences on such a system is often magnified, and the net result is that the system is always in precarious equilibrium.

The pilotage of a conventional airship in approach and landing phases is difficult under any but the most ideal conditions. Conventional mooring at a mast does not facilitate loading and unloading, as the craft must be allowed to continuously weather-cock; and a relatively large surface area is required with the mast at center. Landing and mooring facilities must be duplicated at every location where it is desired to load or unload heavy undivisible industrial loads.

In the LGV concept, the airship is "moored" like a captive balloon, with three tether lines in a tetrehedric system. By utilizing this technique, the approach is simplified, requires less precision because it is farther away from the ground and other obstacles. As soon as the mooring system is attached, and tension is applied by a positive vertical lift, the summit of the tetrehedron is relatively fixed in space, and an undivisible load can be loaded or unloaded with nearly as much precision as with a crane. The LGV objective was to design such a vehicle with enough stability and resistance to weather variations to permit mooring in this manner -- without requiring hangar or landing facilities -- under all conditions of weather.

Above the summit of the tetrehedric mooring system, the vehicle can move freely in a horizontal plane, like a weather-cock. The three lines are continuously stretched if the system's L/D ratio is high enough to maintain the general resultant of forces within the volume of the tetrehedron. Observation and tests indicate that there are serious defects and limitations in the usual methods of obtaining an adequate L/D ratio for a captive balloon. Usually, in windy conditions, a streamlined balloon receives an aerodynamic lift dependent upon its general air foil shape, at a given incidence. For this reason, it is called a "kite balloon." But this kind of balloon presents two performance-limiting disadvantages. First, the aerodynamic lift of the balloon comes from the fact that its body is used as a wing, one with a very low span-to-chord ratio. The tip end vortex, or induced vortex, is relatively high, giving poor aerodynamic performance due to the low L/D ratio, resulting in significant instability. In a non-rigid balloon, the envelope material is required to provide large aerodynamic strengths. Also, the tail surfaces must themselves provide high aerodynamic strength to compensate for the above-noted instability and to compensate for the aerodynamic pitch couple due to the fact that aerodynamic lift is situated between 30% and 40% of the chord instead of at 40% to 50% for the static lift, requiring a positive incidence on the horizontal tail surfaces, and the resultant forces being transmitted by the envelope material.

In formulating the LGV concept, it was desired to avoid, as much as possible, any aerodynamic lift from the balloon when at zero incidence. But it was necessary to provide for aerodynamic lift in windy conditions. A solution was to provide the balloon with a wing offering a good L/D ratio, coming from a sizable span-to-chord ratio. This would be difficult for a single balloon; the heart of the LGV concept was to mount the wing between two balloons. The wing, with the balloons at either end, presents an increased L/D ratio, the balloons acting like huge wing-tip tanks. The tail surfaces are ideally placed outside the passage between the two hulls, and being only stabilators, are used at zero incidence, minimizing the aerodynamic forces to be transmitted by the fabric of the envelopes, as well as minimizing the requirement for aerodynamic strength of the balloons themselves. The patent for the concept is pending, covering captive balloons and airships moored like captive balloons.

Another improvement increasing the performance of such a balloon, in particular its resistance to wind and weather effects, is from the use of new cables and envelope materials, specifically two to three times better than conventional ones such as polyester or fiberglass. The new French products, named CEF (Chord Europe France), are made of duPont Kevlar 49 fibers, for the first time satisfactorily configured to produce a tensile strength in the range of 240,000 psi for a density of only 1.05, with a weak elongation of only 2%, good resilience, excellent resistance to UV rays, full compatibility with all usual resins or pigmentation treatments, and a cost (slightly below that of carbon fibers) actually between $270 and $360 a pound, depending upon the quality and performance required. The French company LA CELLOPHANE is already studying the use of the CEF products for new envelope fabrics and laminated materials, at the request of the Balloon Division of the CNES and also at the request of LGV. Such products will allow the manufacture of non-rigid balloons with higher pressures than usual, with lighter than usual envelopes and inflated tail surfaces -- and even in the LGV concept, the median wing. When the cost has been brought sufficiently low, non-rigid airships will probably be less expensive and provide better structural performance than rigid designs, even for the largest sizes.

The LGV concept encompasses two slightly different designs, depending upon the two main applications:

a. Tethered or Captive Balloons. The balloons and tail surfaces have symmetrical profiles and zero angle of attack. The wing is fixed between the two hulls with a positive angle of attack, and its profile can be asymmetrical. There are no moving parts. The actual calculated L/D ratio of such captive balloons is about 6 to 1, higher than a conventional captive balloon, and LGV anticipates increasing the figure significantly after wind tunnel research. This is necessary to analyze aerodynamic interferences between different elements of the design, where calculations are insufficient for accurate prediction of performance, and to study different scales of wing span and thickness with relation to size of the hulls and to determine appropriate tail surface area required for a given stability.

b. Powered Balloons or Airships. Here the design is dependent mainly upon the requirements of mooring and loading operations. During powered flight, the overall system is supposed to have zero aerodynamic lift. Thus the wing has no incidence, nor has the hull axis or the horizontal tail surfaces; a symmetrical profile is presented. To operate as a captive balloon, the pilot lowers wing flaps, with the help of conventional gear. During the transition from one type of flight to the other, the pilot must hover about the destination point, and has a relatively wide margin of space precision. To facilitate this, vertical axis power units are scheduled on all the powered craft designed; these help the pilot stretch the tether lines, once anchored to the ground, before actuating the wing flap, and help him to remove tension from and detach the tether lines prior to undertaking normal flight.

PART II: TETHERED BALLOONS

Subsequent to the wind tunnel research, the LGV program begins with flight tests for two different captive balloons, to study the structure in various weather conditions. These will have volume, respectively, of 1,400 and 10,000 cubic feet.

Subsequently, the company will make captive balloons of varying sizes for various applications. The high level of performance scheduled will open the market to new applications, in addition to the traditional scientific ones. For load-moving applications, LGV will develop a system to vary the tether cable length to move the loading and unloading point within a given perimeter, and to make an on-board winch unnecessary. For conveyors, such balloons can be used like aerial poles. They can be used in off-shore operations, moored to anchored buoys. Such systems can obviate the need of a harbor for ship loading and unloading operations. In the same way, they can be used like "airborne buoys," to support the tether lines for a larger powered balloon of the same configuration, in locations where frequent loading and unloading operations can benefit from shortening the time interval required for mooring.

The efficiency of the tethered balloon concept is not affected by the size of the balloon. On the three types of forces applied (bursting, aerodynamic, and catenary), only the catenary forces increase more rapidly that the volume to limit the size of the balloon. The planned construction methods, which are proprietary, will void the need for hangars, permitting relatively low length to diameter ratios and permit large volumes with all-weather resistance and high useful load/total weight ratios. Unitary load capacities of up to 500 and even 1,000 tons are possible.

PART III: POWERED BALLOONS

Actually, the primary requirement for LTA devices in France is to lift and transport heavy, bulky undivisible loads, particularly such as nuclear vessels. At the same time, there is a potential world-wide demand for large airships to transport freight at speeds and rates less than those now required by commercial air transport. The load-carrying efficiency of an airship varies approximately linearly with her size, and therefore the larger the airship, the lower the ton/mile cost. But the risks involved in building airships of extreme size are such that no company (and for the moment, no government) would be well advised to start on too large a scale, even in spite of the numerous applicable improvements available since the time of the Zeppelins. Therefore, LGV recommends the development of new LTA systems systematically, with specific applications at each step, to attain the large sizes with optimum speed and safety.

After wind tunnel research and tests of the first two research captive balloons, the LGV program will divide into three main steps:

a. A Powered, Piloted Model. This will be a four-seater configuration. The two balloons (hulls) will have a total volume of 81,000 cubic feet and a length of 115 feet. A special feature of this model will be that the complete gondola, weighing about 2,900 pounds, including engines, will be separable from the balloon section and can be lowered to the ground to simulate load transfer and facilitate engine maintenance. Therefore, it will be necessary to control the moving parts of the balloon with the system operable both from the air and from the ground. The wing flap and tail surface tabs will be operated by electric means; the pressure fans and control unit of the balloons will also be electrical and provided with a battery for redundancy.

   To conserve time and money, the gondola will be the rebuilt fuselage of the prototype of an abandoned four-seat French push-pull aircraft, the "Jupiter" Matra-Moynet, fitted with two 200 horsepower Lycoming engines. The rear propeller will incorporate reversible pitch. Two lateral pods will support the vertical axis power units, fitted with a pair of two-stroke Hirth engines of 55 or 70 horsepower, similar to that used on the BD 5 sport aircraft. The vertical thrust will be reversible, up or down. Calculated top speed will be 60 miles per hour, and cruise speed with 50% power, 50 miles per hour.

The first flight is scheduled one year subsequent to completion of the wind tunnel research. Special authorization of flight will be delivered, under appropriate restrictions, by French authorities; they are presently preparing new rules for future airship certification, and wish to be involved with the specific problems of such prototype models as our own.

As soon as test flights of this model produce satisfactory results, the limitations of use determined with good levels of safety and viability, the original gondola will be replaced by a more elaborate one, involving type certification and acceptability for on-line production.

LGV has already received requests from potential users for production models of this size, for schedule prices between $400,000 and $600,000, depending upon user specifications. Aerial surveying and advertising are among the more frequent requests. One request, from a utility company, is to use such airships both for advertising and to provide illumination for night public events (in captive configuration) in locations where the erection of poles is forbidden or too costly.

The cost for the first powered model is scheduled for $300,000, including preliminary research; its development in the next configuration will cost about the same and require one more year.

b. A 40-Ton Useful Load Model. This model was inspired by potential user requests from oil companies for drilling needs in difficult locations, some now served by helicopter. But such airships should be far less expensive to operate, with higher levels of safety and viability, because a load under sling disequilibrates a helicopter but not an LTA system. Heavier transported loads will also decrease drilling costs, by the use of standard systems, because the use of custom helicopters necessitates special and costly drilling systems, divisible in transportable elements of usually two and one half tons maximum. Mounting and dismounting of such elements would be reduced, and the transport logistics of a drilling operation would be greatly enhanced by the extension of the airborne phase, avoiding intermediate costs and delays such as river barge operations in some situations and the use of cargo planes in others.

Foresters also are interested in such weight-lifting airships for logging operations in difficult locations throughout the world. LGV is also in close contact with a world charity organization, the Order of Malta, to provide such airships for health and rescue. In the event of natural disasters, such as earthquakes, particularly where ground transport activities are disorganized or non existent, these airships would be invaluable for such use as food transport and airborne hospitals.

Economic studies indicate that, after the first few units, serial production of such airships could be effected at costs low enough to make ton/mile costs competitive with surface transport in underdeveloped countries. At relatively low speeds, for example between 60 and 85 miles per hour, they are very economical of fuel, significantly more so than with conventional airships.

LGV is already in touch with an African government for the development of short-haul transports in their country, requiring initially ten 40-ton model units, only a part of the potential market envisioned.

Specifications of the 40-ton prototype include the following: Total volume of the two hulls will displace 3,150,000 cubic feet; length is 365 feet; maximum diameter 97 feet for each hull; overall width will be 550 feet; overall height 180 feet; installed power 2,300 horsepower, providing a top speed of 80 miles per hour and a cruise speed of 65 miles per hour at 50% power. Scheduled cost of the prototype, developed and built in France, is $2,520,000 (at a rate of exchange of five French francs per U. S. dollar), and serial production models are scheduled to sell between $1.6 million and $1.8 million, or less, depending upon the number to be produced. For comparison purposes, the cost of a helicopter like the S-64 "Skycrane," able to lift and transport only 12 tons under sling, costs more than $2 million, and involves higher operating costs.

LGV estimates that the first 40-ton production model could probably be operational and available three years after the start of the initial program.

One very interesting advantage of the concept will be that it requires only very short delays for mooring, unloading, reloading, and unmooring operations. The total sequence will take only two minutes during no-wind conditions, if mooring is not necessary, and five minutes if conventional mooring is necessary.

In mooring, the three tether cables are first properly anchored; and as with any airship, the mooring is never unfastened until the airship is reloaded with an equivalent weight of the one unloaded. The vertical axis power units are available to correct possible inaccuracies in the weight equilibrium, within a range of ±5-10% of the total weight. Thus for the hovering and transition flight sequences, the pilot can equilibrate within this margin during normal cruise flight, with the help of the tail surface control tabs.

The tether line anchorages are located at a distance from the center equivalent to about half of the mooring altitude, where loads have to be manipulated. As often as possible, the loads will be containerized or placed in nets, to shorten loading operation delays. When return freight is not available, even for a part of the total load, ballast is necessary, as often as possible with water in tanks or bags (or other ballast like sand, gravel, dust, suitably containerized by a ground crew), the total load for a powered flight always being the same, including fuel reserves.

c. A 400-Ton Useful Load Model. Specifications -- Total volume of the two hulls: 23,000,000 cubic feet. Length: 750 feet. Maximum diameter of each hull: 200 feet. Overall width at horizontal fin tips: 1,000 feet. Overall height at vertical fin tips: 370 feet. Performance: top speed 80 miles per hour at full power (with 40,000 horsepower). Cruise speed: 65 miles per hour at 50% power. Normal range: 400 to 600 miles. Ceiling: 5,000 feet.

The range can be increased with a reduction of payload, at the rate of about five tons per 100 miles.

For special transport systems of industrial loads from and to industrial yards, such as nuclear power stations, a special system to accurately place the loads will be developed -- to stabilize the position of the load in space by an action at the summit of the tetrehedric tether, the ground terminus of the tether lines will be fitted with hydraulic jacks actuated by an automatic control system taking references from the space position of the load itself. In this way, all the possible (including cyclic) slight movements of the load due to the action of the wind on the balloon and tether lines can be compensated for. The natural precision of location is about 1% of the altitude of the balloon, and with the control system could be reduced to 1/1000th and even to 1/10,000th with very accurate references.

For general freight use, the 400-ton model will present a ton/mile cost between 7.3¢ and 15¢ per mile, for 4,000 hours of flight per year and an average use of 80% of total capacity -- depending upon the cost of production of such models. It will provide excellent short and medium distance transport, for which the ease of mooring and loading operations offered by the LGV concept is more important than incremental ton/mile costs. However, it will not likely be as desirable for long distance transport, for which single hulled airships will present a lower drag and probably a lower ton/mile cost, even allowing for more difficult landing and loading operations requiring extensive ground facilities.

PART IV: FURTHER DEVELOPMENT OF THE CONCEPT

LGV has already studied such development in two directions: (1) Another configuration, covered by the same patents, providing possible improvements. (2) Development of fabrication technology, based primarily on an automatic machine for making the envelopes of the balloons, based on a completely new principle, more advanced than techniques already used in balloon manufacture (for example, the machines developed by the Balloon Division of the CNES in France and used by the Zodiac-Espace Company). The method of assembly of the different elements will also be completely new, and highly original. The main advantage will be to bypass the need of a costly hangar for the assemblage operation.