LIGHTER THAN AIR CRAFT USING VACUUM

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Ever since his earliest times, man must have dreamed of copying the birds; of flying, of gaining mastery over the third dimension of space.

The earliest practicable route to achieve the aim of flying was in the use of balloons. The first balloons were hot-air balloons; they relied on the lower density of hot air, compared to that of the surrounding air, to obtain the lift they needed.

Balloons are, of course, an application of Archimedes Principle, which states that the upthrust exerted on a body by its surrounding medium is equal to the weight of the medium displaced. With a balloon, this upthrust must be greater than the weight of the balloon structure plus whatever the balloon contains, if the balloon is to rise.

In the search for greater lift, the obvious method was to use a light gas. The lightest natural gases are hydrogen and helium. Hydrogen exists as a two-atom molecule with each atom having an atomic weight of 1, giving a molecular weight of 2, and helium as one-atom "molecules", each with an atomic and molecular weight of 4. As the molecular weight of a gas mostly determines its density, hydrogen has half the density of helium.

Although hydrogen is lighter, the commercial choice between hydrogen and helium as a balloon lifting gas has been made on other considerations. Helium is non-inflammable, hence safe, but rarer than hydrogen and much more expensive. The airship Hindenburg used hydrogen partly because the Germans found it difficult to buy enough helium.

The only lighter possibility in a gas would be monatomic hydrogen, with each hydrogen atom separate, rather than combined in a molecule; such a substance would have twice the lifting power of ordinary hydrogen. Unfortunately, hydrogen is so reactive that no way is known at present to keep it in a monatomic state. So, nothing gives more lift than hydrogen or helium.

And in this last sentence is the clue to a possibility which could revolutionise many fields of human activity. This possibility is called the vacuum balloon.

Suppose your balloon were filled, not with a light gas, but with a vacuum? In this case, the upthrust is equal to the entire weight of the displaced air, instead of the difference in weights of air and the light gas. This immediately gives a major advantage, in a lifting power greater than any other possible material (or, strictly, nonmaterial!).

However, the greatest advantage of the vacuum balloon lies in the way it avoids one of the major limitations of conventional balloons. They leak. The

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leaks may be kept small, and reserves of the lifting gas can be kept in some form on board, but the fact remains that sooner or later a conventional balloon must run out of gas, and come to ground.

A vacuum balloon, however, does not have this limitation. Leaks in the structure containing the vacuum may exist, but they can be neutralized just by pumping out the air which has leaked in. For this reason, the vacuum balloon has the potential to remain permanently aloft. In fact, it is the nearest thing yet to the "Skyhook" which figures on the humorous wishlist of every civil engineer.

Not only can the vacuum balloon stay aloft indefinitely, it can also rise and fall as desired, simply by leaking or improving some of its vacuum. Conventional balloons can achieve this sort of control by liquefying or evaporating some of their lifting gas, but this is by no means as simple as just pumping air in or out.

Of course, the structure of a vacuum balloon cannot be the same as that of a simple weather balloon, which is essentially just a thin skin separating the lifting gas from the atmosphere; with a vacuum instead, the balloon would just collapse. Instead, the vacuum balloon needs a structure rigid enough to maintain its vacuum against the pressure of the surrounding atmosphere.

There is no real limitation in this. Airships like the Hindenburg, for example, had rigid structures, as did the early French hot air balloons. Of course, the structure must be rigid enough to withstand a pressure differential of up to one atmosphere, but a simple analysis shows that this does not present any real barrier.

Suppose the vacuum balloon has the shape of a sphere. The volume of a sphere, and hence the lift obtained, increases as the cube of its radius. The surface area of a sphere, and hence its mass, increases as the square of its radius. For example, if the radius is doubled, the mass is four times as much, but the lift is eight times as much. So a working vacuum balloon can be built of any reasonably rigid material, even cast-iron, provided that it is made large enough.

In practice, of course, materials are available today which enable very light and very rigid structures to be built. A "geodesic sphere", made on Buckminster Fuller's geodesic dome principle, but as a complete sphere, and covered with a plastic film, would be an example. Cross-braces on the "tube-in-tube" principle found in some pterodactyl bones would be permissible. It might even be possible to use the double-skin principle of the Quonset Hut, with a double balloon containing pressurized air between the skins, and a vacuum in the centre.

How big would such a balloon have to be in practice? Take the simplest case, of a sphere with a rigid skin. When evacuated, it would have to withstand a pressure of one atmosphere. This is not very much in everyday terms; those who have seen the school physics experiment in which a metal can is crushed by atmospheric pressure as the air is sucked out of it will remember that such cans had to be specially made out of a thick metal foil; an ordinary beer can could withstand evacuation quite easily. Other everyday examples include the vacuum tubes once used in radios, and the thin glass chemical apparatus used in vacuum distillation. Many parts of such equipment were less than

1mm thick, and some had concave surfaces (such as in light globes), and did not depend on any stressed sphere effect for strength.

The mathematics involved is trivial. The volume of a sphere of radius R is $4\pi R^3/3$, and its surface area is $4\pi R^2$. If the sphere has a skin of thickness T, the skin volume is very close to $4\pi R^2 T$, and if the skin density is D, we have:

$$\text{Mass of sphere} = 4\pi R^2 TD \qquad (1)$$

The upthrust on the sphere from the surrounding air is the same as the weight of the displaced air. If the air density is A, multiplying this by the sphere volume, $4\pi R^3/3$, gives the upthrust:

$$\text{Upthrust} = 4\pi R^3 A/3 \qquad (2)$$

The vacuum balloon is at the point of rising when its skin weight and the upthrust match, which is when

$$4\pi R^2 TD = 4\pi R^3 A/3$$

or when

$$TD = RA/3$$

or

$$R = 3TD/A \qquad (3)$$

Suppose the sphere is made of any common rigid plastic, such as perspex, with a skin thickness T of 0.1cm; this should be more than adequate. Most organic plastics have a density D of around 1.0 g/cm^3 ; the density of dry air at 20°C and standard pressure, which we can take for A, is about 1.2×10^{-3} g/cm^3 . This gives our value for R:

$$R = 3 \times 0.1 \times 1.0 / 1.2 \times 10^{-3} = 250 \text{ cm} \qquad (4)$$

So a vacuum balloon with a 1mm rigid skin, to float when completely evacuated, would need to be about 5m across, not an especially difficult fabrication project. Its weight, the same as the weight of displaced air (the upthrust) would be about 80kg. With any skin of a given material, the radius is directly proportional to the skin thickness T; if T could be halved through selection of advanced materials (possibly carbon-fibre reinforced plastic), then R would also be halved.

Now consider a sphere made up of two concentric film skins, with the inner film linked to the outer one by thin threads 1cm long, placed roughly 1cm apart over the whole surface. The space between the films can be inflated to form a rigid skin which will behave like a solid skin in most respects, and will allow the centre of the sphere to be evacuated. The pressure needed in the skin should be just over 2 atmospheres (1 atmosphere above ambient), which again is not very large; bicycle tyres may be inflated to 5 atmospheres (4 above ambient).

Suppose that the combined thickness of the two skins was 0.01cm. This is about four-thousandths of an inch, in the range of conventional plastic packaging films, which can be made very tough. For example, the pressure exerted by the rim of a can of baked beans, at the bottom of a loaded plastic shopping bag, is well over two atmospheres equivalent.

In making the calculations, the weight of the air within the skin can be neglected as a first approximation; one atmosphere of the pressure supplies its own upthrust, and the other half has a total mass an order of magnitude less than the mass of 0.01cm of film. A value of 0.01cm for T leads to a value for R of 25cm, a radius of less than a foot:

$$R = 25\text{cm} \tag{5}$$

Even this inflated structure could be improved upon, by replacing the concentric film surfaces by a network of inflated ribs with a single film stretched between them; an inflated geodesic sphere. Not only would most of the sphere surface consist of only one film instead of two, but that single film would need to withstand a pressure differential of only one atmosphere instead of two.

Going to the other extreme, suppose a vacuum balloon was actually proposed with a skin of cast iron, half a centimetre thick. This would withstand a range of ballistic missiles, let alone one atmosphere of pressure. It would need to have a radius of around l00 m to float — a large, but not impossible, value.

Is the vacuum balloon only an interesting possibility, without practical applications? The answer must be no, for two reasons. Firstly, there are many possible applications which require little more than the ability to float, without the application for massive lift. Secondly, if massive lift is required, it can be provided, within conventional engineering capabilities.

The maximum lift attainable from a vacuum balloon is equal to the weight of the displaced air. This is the maximum theoretical lift (MTL); in real cases, the lift will be reduced by the weight of the structure and that of any residual air (no real "vacuum" is perfect), and actual calculations will need to allow for non-spherical structures, variations in atmospheric pressure with the weather, altitude and so on. Nevertheless, it is clear that it is feasible to build vacuum balloons in which a large fraction of the maximum theoretical lift (MTL) can be obtained.

Above I have shown that the MTL for a sphere of radius 2.5m would be around 80kg. Doubling the radius to 5m multiplies the MTL by 8, to a value of 640kg. With a radius of l0m, the MTL is already over 5 tonnes.

Finally, consider the Graf Zeppelin II, the largest airship built. This ship had a rigid metal framework and was 803 ft. long, about 250m. A vacuum balloon with a diameter of 250m would have a MTL of over 8000 tonnes, comparable to an ocean freighter, and certainly well above the toy range.

SOME POSSIBLE USES FOR THE VACUUM BALLOON

The most obvious application of the vacuum balloon is for transport. Manned or unmanned balloons, equipped with wind-sensing and intercommunications equipment, could rise and fall to take advantage of winds travelling in various directions at various heights, carrying people or freight. Tethered rows of vacuum balloons could support cable-car systems. They could also support a long electromagnetic launching frame to accelerate capsules into space.

Vacuum balloons could be positioned in clouds to collect water and tap the electrical energy they contain. The collected water would have considerable potential energy available for power generation, and could be piped long distances using gravity.

Large balloons positioned above the clouds would be ideal for collecting solar energy, as would collection surfaces suspended between networks of balloons. These could also be used to shade desert areas, giving some climate control. With plenty of water and sunlight available, it might be possible to shift some agriculture above ground, releasing the natural surface for restoration to wildlife conditions.

It should also be possible to locate communications equipment in vacuum balloons, providing transmission sites to bridge the gap between tall towers and communications satellites. The balloons could also replace helicopters and cranes to some extent, in moving things over difficult terrain or at great heights.

CONCLUSIONS

The vacuum balloon concept opens the way to a whole new era of man's control over his environment. For the first time, it could make true mastery of the third dimension of space possible.

It may be that our future civilization will change radically, from a groundbased one to an air-based one, with the bulk of the population living above the land, or the sea. Expansion into the third dimension would make elbowroom for everyone.

Through a vast network of Skyducts, producing energy, water and food, and providing easy transport and communications from essentially automatic equipment, most of man's needs would be met, giving him the room and the leisure to suit himself.